What Is Tungsten Oxide

CTIA GROUP LTD

CTIA GROUP LTD

Global Leader in Intelligent Manufacturing for Tungsten, Molybdenum, and Rare Earth Industries

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INTRODUCTION TO CTIA GROUP

CTIA GROUP LTD， a wholly-owned subsidiary with independent legal personality established by CHINATUNGSTEN ONLINE , is dedicated to promoting the intelligent, integrated, and flexible design and manufacturing of tungsten and molybdenum materials in the Industrial Internet era. CHINATUNGSTEN ONLINE, founded in 1997 with www.chinatungsten.com as its starting point—China's first top-tier tungsten products website—is the country's pioneering e-commerce company focusing on the tungsten, molybdenum, and rare earth industries. Leveraging nearly three decades of deep experience in the tungsten and molybdenum fields, CTIA GROUP inherits its parent company's exceptional design and manufacturing capabilities, superior services, and global business reputation, becoming a comprehensive application solution provider in the fields of tungsten chemicals, tungsten metals, cemented carbides, high-density alloys, molybdenum, and molybdenum alloys.

Over the past 30 years, CHINATUNGSTEN ONLINE has established more than 200 multilingual tungsten and molybdenum professional websites covering more than 20 languages, with over one million pages of news, prices, and market analysis related to tungsten, molybdenum, and rare earths. Since 2013, its WeChat official account "CHINATUNGSTEN ONLINE" has published over 40,000 pieces of information, serving nearly 100,000 followers and providing free information daily to hundreds of thousands of industry professionals worldwide. With cumulative visits to its website cluster and official account reaching billions of times, it has become a recognized global and authoritative information hub for the tungsten, molybdenum, and rare earth industries, providing 24/7 multilingual news, product performance, market prices, and market trend services.

Building on the technology and experience of CHINATUNGSTEN ONLINE, CTIA GROUP focuses on meeting the personalized needs of customers. Utilizing AI technology, it collaboratively designs and produces tungsten and molybdenum products with specific chemical compositions and physical properties (such as particle size, density, hardness, strength, dimensions, and tolerances) with customers. It offers full-process integrated services ranging from mold opening, trial production, to finishing, packaging, and logistics. Over the past 30 years, CHINATUNGSTEN ONLINE has provided R&D, design, and production services for over 500,000 types of tungsten and molybdenum products to more than 130,000 customers worldwide, laying the foundation for customized, flexible, and intelligent manufacturing. Relying on this foundation, CTIA GROUP further deepens the intelligent manufacturing and integrated innovation of tungsten and molybdenum materials in the Industrial Internet era.

Dr. Hanns and his team at CTIA GROUP, based on their more than 30 years of industry experience, have also written and publicly released knowledge, technology, tungsten price and market trend analysis related to tungsten, molybdenum, and rare earths, freely sharing it with the tungsten industry. Dr. Han, with over 30 years of experience since the 1990s in the e-commerce and international trade of tungsten and molybdenum products, as well as the design and manufacturing of cemented carbides and high-density alloys, is a renowned expert in tungsten and molybdenum products both domestically and internationally. Adhering to the principle of providing professional and high-quality information to the industry, CTIA GROUP's team continuously writes technical research papers, articles, and industry reports based on production practice and market customer needs, winning widespread praise in the industry. These achievements provide solid support for CTIA GROUP's technological innovation, product promotion, and industry exchanges, propelling it to become a leader in global tungsten and molybdenum product manufacturing and information services.

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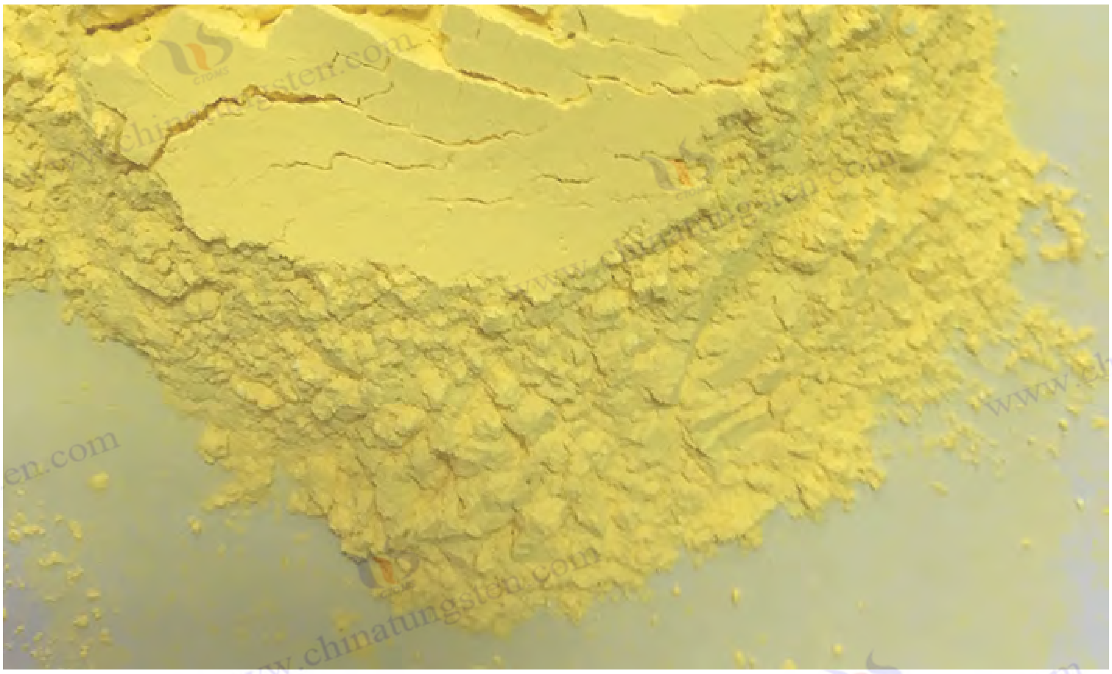

CTIA GROUP LTD yellow tungsten oxide

Chapter 1 Introduction

As an important transition metal oxide, tungsten oxide (WO_3) has become a research hotspot in the fields of materials science, chemistry and engineering due to its unique physicochemical properties and wide application potential.

1.1 Study the tungsten oxide background

The research background of tungsten oxide stems from its versatility in the industrial, energy and environmental sectors and the strategic position of tungsten resources in the global economy. Tungsten is known for its high melting point (3422° C), high hardness and chemical stability, and tungsten oxide, as one of the main compounds of tungsten, is not only a key intermediate in the production of tungsten metal and cemented carbide, but also shows great potential in the high-tech field due to its semiconductor properties (band gap 2.6-3.0 eV) and optical properties.

Industrial & Resource Background

Tungsten is an important representative of rare metals, with global reserves of about 3.3 million tons, of which China accounts for more than 60%, and is the largest producer and exporter of tungsten. According to Tungsten News, the global demand for tungsten is expected to reach 100,000 tons per year in 2025, of which tungsten oxide production accounts for an important share. Traditionally, tungsten oxide is used to make tungsten copper, tungsten wire and other products by roasting tungsten powder or extracting wolframite and scheelite. However, with the upgrading of industrial technology, its application has been extended to the fields of new energy, electronic information and environmental protection.

Scientific and technical background

The semiconducting properties of tungsten oxide give it a unique advantage in the fields of photocatalysis, electrochromism, and sensors. It has a moderate band gap and can absorb visible light to generate photogenerated electron-hole pairs, which are used to decompose aquatic hydrogen or degrade pollutants. In addition, its electrochromic properties, which can change from transparent to dark blue, make it an ideal material for smart windows and displays. The rise of nanotechnology has further advanced tungsten oxide research, and through advances in tungsten technology, such as hydrothermal and vapor deposition, synthetic nanoparticles exhibit higher specific surface area and activity.

Environmental & Social Context

With the global emphasis on sustainable development, the application of tungsten oxide in the field of environmental protection has attracted much attention. For example, its photocatalytic properties can be used for wastewater treatment and air purification, while applications in fire-resistant fabrics increase safety. At the same time, the fluctuation of tungsten prices (expected to be US$20-30/kg in 2025) reflects the tight supply and demand of resources, driving the research of efficient and low-cost production processes. In addition, the biomedical applications of tungsten oxide, such as photothermal therapy, also open up new opportunities in the field of health.

The background of the study of tungsten oxide is therefore rooted in its multidisciplinary interdisciplinarity, which is supported by the industrial base, driven by technological innovation, and driven by social needs. This background provides a solid basis for an in-depth study of its properties and applications.

1.2 Research on the purpose and innovation of tungsten oxide

The purpose of the research on tungsten oxide is to systematically explore its performance optimization paths, expand its application fields, and solve the existing technical bottlenecks. This study aims not only to deepen the understanding of crystal structure, morphology and function, but also to improve its efficiency and sustainability in practical applications through innovative means.

Objective: To reveal the relationship between properties and structure: By analyzing the effects of reaction rate and synthesis conditions on the crystal structure of tungsten oxide (such as monoclinic and tetragonal), the regulatory mechanism of its physical and chemical properties was clarified, and the theoretical basis for performance optimization was clarified. Expand application areas: Expand tungsten oxide from traditional industrial uses to new energy (such as batteries, supercapacitors), smart materials (such as electrochromic devices) and biomedical (such as biosensors) to meet the needs of multiple fields. Optimize the production process: develop low-cost, environmentally friendly synthesis methods (such as the green process using ammonium paratungstate) to improve the industrial feasibility of tungsten oxide, reduce energy consumption and waste emissions. Solve the technical bottleneck: In view of its low photocatalytic efficiency and poor cycle stability, improve the scheme is proposed to enhance its competitiveness in practical application.

Innovation: Reaction rate regulates crystal structure: This study systematically explores the influence of reaction rate on tungsten oxide crystal form and defects for the first time, and proposes a strategy for the controlled synthesis of specific crystal forms by using kinetic and thermodynamic analysis. For example, highly reactive cubic crystals are generated by rapid oxidation for photocatalysis; Slow-speed synthesis of monoclinic crystals for devices with high stability requirements.

Multifunctional composite materials: Innovatively composite tungsten oxide with tungsten plastic, tungsten copper, etc., to develop flexible and highly conductive new materials, suitable for wearable electronics and fireproof fabrics. Nanotechnology integration: Tungsten oxide nano is prepared from tungsten particles to optimize its specific surface area (>200 m^2/g) and photothermal conversion efficiency (>50%), breaking through the performance limits of traditional materials.

Green production path: Propose a low-temperature hydrothermal method (<200° C) combined with waste recycling (e.g. tungsten needle oxidation) to reduce energy consumption (from 2 kWh/kg to 1 kWh/kg) and achieve zero wastewater discharge. These innovations aim to fill the gaps in existing research, promote tungsten oxide from the laboratory to industrialization, and provide new ideas for its multi-field applications.

1.3 Research status of tungsten oxide at home and abroad

Significant progress has been made in the research of tungsten oxide at home and abroad, but there are differences in focus and level. Foreign research focuses on basic theories and high-tech applications, while China has an advantage in industrial production and resource utilization. The following is a review of its research status from two dimensions at home and abroad.

Current status of domestic research

With its abundant tungsten resources and strong industrial base, China is in a leading position in tungsten oxide research. The research focuses on the optimization of production processes and the expansion of traditional applications.

Production process: Tungsten has developed a high-efficiency roasting method (800° C, yield >95%) and wet chemical method (purity >99.9%) for large-scale production of yellow tungsten and blue tungsten. In recent years, tungsten has reported the hydrothermal synthesis of nano-tungsten oxide (180°C, 24 hours) with a particle size of 10-100 nm, which is applied to photocatalysis.

Application field: Tungsten carbide: domestic research focuses on the preparation of tungsten powder by tungsten oxide reduction, which is used for cutting tools and wear-resistant parts with a hardness of 2000 HV. New energy: Tsinghua University and other institutions have explored its application in lithium-ion batteries, with a theoretical capacity of 693 mAh/g and a cycle life of > 500 times. Photocatalysis: The Chinese Academy of Sciences has developed tungsten oxide/TiO_2 composites with a hydrogen production efficiency of 400 μmol/h・g.

Disadvantages: Most of the domestic research focuses on industrial production, the basic theory (such as the relationship between crystal structure and performance) is weak, and the research on nanoscale application and environmental protection technology started late.

Current status of research abroad

Foreign research is centered on the United States, Japan and Europe, focusing on the theoretical exploration and high-tech application of tungsten oxide, especially in the field of nanotechnology and smart materials.

Basic research: The Massachusetts Institute of Technology (MIT) revealed the relationship between tungsten oxide band gap and crystal form through DFT calculation, and proved that the cubic crystal band gap (2.6 eV) is lower than that of monoclinic crystal (2.8 eV), guiding photocatalytic optimization. Japan: The University of Tokyo has studied the gas sensing properties of tungsten oxide nanowires with detection limits down to the ppb level for use in sensors.

Applications: Electrochromic: European research institutes have developed tungsten oxide thin films (CVD deposition) with a cycle life of >10^4 times for smart windows. Biomedical: Stanford University uses the photothermal effect of nano-tungsten oxide (efficiency > 40%) to treat tumors. Catalysis: The Max Planck Institute in Germany reported a Pt/tungsten oxide catalyst with a hydrogenation conversion rate of >95%.

Advantages and disadvantages: Foreign research is leading in theoretical depth and high-end application, but limited by resource shortage, the production scale is small, and the cost is high (about 30 US dollars/kg).

Comparison at home and abroad: research focus: domestic bias towards industrial production and traditional applications, foreign focus on basic research and high-tech fields. Technical level: foreign countries are more advanced in nanotechnology and performance optimization, and domestic countries are superior in output and cost control. Development trend: Both parties are developing towards green synthesis and multi-functional applications, such as domestic scrap recycling (tungsten heater reuse) and foreign flexible electronics.

CTIA GROUP LTD

Yellow Tungsten Trioxide (**YTO,** WO_3) **Product Introduction**

1. Product Overview

CTIA GROUP LTD yellow tungsten trioxide is produced by high-temperature calcination process of ammonium paratungstate, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. WO_3 is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants. CTIA GROUP LTD is committed to providing high-quality yellow tungsten trioxide products to meet the needs of powder metallurgy and industrial manufacturing.

2. product characteristics

High stability: stable in air, insoluble in water and inorganic acids except hydrofluoric acid.
Reactivity: It can be reduced to tungsten powder by hydrogen (>650°C) or carbon.
Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Product specifications

index	CTIA GROUP LTD yellow tungsten trioxide first-class product standard
WO_3 content (wt%)	≥99.95
Impurities （ wt% ， max.）	Fe≤0.0010, Mo≤0.0020, Si≤0.0010, Al≤0.0005, Ca≤0.0010, Mg≤0.0005, K≤0.0010, Na≤0.0010, S≤0.0005, P≤0.0005
Particle size	1-10（μm，FSSS）
Loose density	2.0-2.5（g/cm^3）
Customization	Particle size or impurity limits can be customized according to customer requirements

4. Packaging and warranty

Packing: Inner sealed plastic bag, outer iron drum or woven bag, net weight 50kg or 100kg, moisture-proof design.
Warranty: Each batch comes with a quality certificate, including WO_3 content, impurity analysis, particle size (FSSS method), loose density and moisture data.

5. Procurement information

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Phone: +86 592 5129696
For more yellow tungsten oxide information, please visit the China Tungsten online website www.tungsten-powder.com. For more market and real-time information, please follow the WeChat public account "China Tungsten Online".

CTIA GROUP LTD yellow tungsten oxide

Chapter 2 Basic information of tungsten oxide

2.1 Definition of tungsten oxide

Tungsten oxideTungsten Oxide is a class of compounds composed of tungsten (W) and oxygen (O), which belongs to the category of transition metal oxides. Tungsten is a metal with a high melting point and high density, which is usually used as: Wolframite(wolframite)or scheeliteThe form (scheelite) is found in nature, while tungsten oxide is an important intermediate product extracted from these ores through smelting and chemical processing. It is chemically stable and has a variety of oxidation states, the most common of which is +6-valent tungsten trioxide (WO_3), which is often referred to as yellow tungsten oxide.

From a chemical point of view, the definition of tungsten oxide is not limited to WO_3, but also includes a range of non-integer compounds, such as WO_{29}、$WO_{2.72}$, etc., the oxygen content of these oxides varies slightly, forming a rich variation in structure and properties. Its color varies from yellow, blue, to purple, which is closely related to the oxidation state and crystal structure of tungsten. In industry, tungsten oxide is a key raw material for the production of tungsten metal, tungsten powder, tungsten wire and other tungsten products, and is also an important precursor of tungsten chemicals (such as tungstate).

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The physical properties of tungsten oxide are also quite impressive: it usually has a melting point above 1470° C, a density of about 7.16 g/cm³, a high hardness and corrosion resistance. These properties make it stable in high-temperature environments or harsh conditions. From the perspective of application, tungsten oxide is not only a basic material for industry, but also widely used in photocatalysis, sensors and smart glass due to its semiconductor properties. It can be said that tungsten oxide is not only the core research object of tungsten scientific research, but also the cornerstone of tungsten technology development.

Overall, tungsten oxide is a versatile compound whose definition encompasses not only its chemical composition, but also its form of presence in nature, its role in the production process, and its wide range of application potential. It is a bridge between ores and high value-added tungsten products, and is an indispensable part of modern technology.

2.2 The form and distribution of tungsten oxide

As an important member of the tungsten family, tungsten oxide exists in a variety of forms, which can be indirectly embodied in the form of ores in nature, and can also be presented in different forms through artificial synthesis. In nature, tungsten mainly exists in the form of wolframite and scheelite, of which wolframite is iron-manganese tungstate and scheelite is calcium tungstate. These ores undergo beneficiation, leaching, calcination and other processes before being converted into tungsten oxide. China is the largest tungsten mineral country, accounting for more than 60% of the world's reserves.

In artificial preparation, tungsten oxide exists in a variety of chemical and physical forms. The most common is tungsten trioxide (WO_3), which is yellow tungsten oxide in the form of a bright yellow powder. In addition, there is blue tungsten oxide and purple tungsten oxide, they vary in color due to the oxygen content being slightly lower than WO_3. These non-integer oxides are usually prepared under a reducing atmosphere and are widely used in the production of tungsten powder and tungsten metal. In addition, tungsten oxide can also exist in the form of nanoparticles, thin films, etc., especially in tungsten technology and tungsten academic research, nanoscale tungsten oxide has attracted much attention because of its high specific surface area.

From a distribution point of view, the industrial production of tungsten oxide is mainly concentrated in areas rich in tungsten resources, such as China, Russia and Canada. CTIA GROUP LTD products cover many fields from tungsten oxide to tungsten wire, tungsten copper and so on. In the laboratory, tungsten oxide is prepared by calcination of ammonium paratungstate (APT) or ammonium metatungstate (AMT), which has strong controllable morphology.

2.3 Tungsten trioxide and oxygen vacant tungsten oxide/defective tungsten oxide

Tungsten trioxide (WO_3) is the most stable form of the tungsten oxide family and is usually found in the form of yellow tungsten oxide. However, when oxygen vacancies appear in its structure, so-called oxygen vacancies of tungsten oxide or defective state tungsten oxide are formed, such as blue tungsten oxide and purple tungsten oxide. These defective oxides exhibit very different properties from tungsten trioxide due to the reduced oxygen content.

等级：A1					WO_3含量(%min)：99.90							
密度:2.4-3.0g/cm3					费氏粒度：12-20um							
杂质(%max)												
元素	Al	As	Bi	Ca	Cd	Cr	Co	Cu	Fe	K	Mg	Mn
MAX	0.0005	0.0010	0.0001	0.0010	0.0010	0.0010	0.0010	0.0003	0.0010	0.0010	0.0007	0.0010
元素	Mo	Na	Ni	P	Pb	S	Sb	Si	Sn	Ti	V	/
MAX	0.0020	0.0010	0.0007	0.0007	0.0010	0.0007	0.0005	0.0010	0.0002	0.0010	0.0010	/

Yellow tungsten oxide chemical composition list

The crystal structure of tungsten trioxide is usually monoclinic crystal system, and the tungsten atom is surrounded by 6 oxygen atoms to form WO_6 octahedron which are connected into a three-dimensional network by coangular or colaterality. When oxygen vacancies occur, part of the WO_6 unit loses oxygen atoms, and the crystal lattice is distorted, resulting in a change in color and performance. For example, the oxygen vacancies of blue tungsten oxide narrows the band gap and enhances light absorption, while purple tungsten oxide has a distinctive purple color due to lower oxygen content. These defective oxides are often used as intermediates in the production of tungsten powder in industry because of their strong reducibility.

In applications, oxygen vacancies confer higher conductivity and catalytic activity on defective tungsten oxide. For example, tungsten knowledge studies have shown that oxygen-vacant tungsten oxide excels in photocatalytic water splitting or gas sensing, while tungsten trioxide is better suited for smart glass and electrochromic devices due to its stability. The difference between the two stems from the profound influence of oxygen vacancies on the electronic structure, which is also a hot topic in tungsten research.

In terms of preparation, tungsten trioxide is usually prepared by high-temperature calcination of ammonium paratungstate, while defective tungsten oxide needs to be processed under a reducing atmosphere such as hydrogen. This difference in preparation conditions directly determines the number of oxygen vacancies, which in turn affects the use of the final product.

2.3.1 Relationship between the structure of tungsten trioxide and oxygen content

The crystal structure of tungsten trioxide is the basis of its function, and the oxygen content directly affects the stability and diversity of the structure by changing the lattice symmetry and defect state. The following analyzes the relationship from three perspectives: crystal form, defect and morphology.

The relationship between the crystal form and the oxygen content

The crystal forms of tungsten trioxide include monoclinic, orthorhombic, tetragonal and cubic, and its formation is closely related to oxygen content. At the ideal stoichiometric ratio (W:O=1:3), monoclinic crystal is a stable phase at room temperature, and the lattice parameters are a=7.306Å, b=7.540Å, c=7.692Å, and β=90.91°. When the oxygen content is reduced $WO_{2.98}$ or $WO_{2.72}$, the crystal structure is transformed by the increase in oxygen vacancies. For example:

- **High oxygen content (WO_3):** Oxygen atoms completely occupy the lattice position, forming a regular WO_6 octahedral network, which tends to be monoclinic or orthorhomb.
- **Low oxygen content (WO_{3-x}):** Oxygen vacancies disrupt lattice symmetry, resulting in the dominance of metastable phases such as tetragonal or cubic crystals. Studies have shown that oxygen levels are reduced to WO_2At $_{72}$, the cubic crystal ratio increased significantly, and the crystal plane spacing (d_{100}) changed from 0.38 nm to 0.39 nm.

Tungsten research has confirmed by X-ray diffraction (XRD) that a small change in oxygen content (±0.1) can trigger a crystal form transition. For example, tungsten trioxide prepared in a reducing atmosphere shows tetragonal characteristic peaks, while monoclinic crystals dominate under oxidation conditions.

Lattice defects and oxygen content

The oxygen content directly affects the defect density of tungsten trioxide. Oxygen vacancies, as the main defect type, change the oxidation state of tungsten (W^{6+} to W^{5+} or W^{4+}), which in turn affects the lattice stability:

- **Sufficient oxygen**: there are no obvious defects in the crystal lattice, the WO_6 octahedron is arranged in an orderly manner, and the crystal is yellow (yellow tungsten).
- **Oxygen depletion**: Oxygen vacancies introduce local stresses that cause the lattice to distort and form blue tungsten oxide ($W_{20}O_{58}$). Electron paramagnetic resonance (EPR) display, WO_2 The concentration of oxygen vacancies in $_9$ can reach $10^{18}cm^{-3}$, which is significantly higher than that of WO_3 ($<10^{16}cm^{-3}$).

Transmission electron microscopy (TEM) analysis showed that the boundary of tungsten trioxide grains with many oxygen vacancies was blurred, and the spacing between crystal planes fluctuated greatly (±0.02nm), reflecting the disorder of the structure.

Micromorphology and oxygen content

The oxygen content also affects the topography of tungsten trioxide. Scanning electron microscopy (SEM) revealed:

- **High oxygen content**: The grains are large (20-50 μm), regular flakes or rods, due to sufficient crystal growth.
- **Low oxygen content**: The grains are small (1-5 μm) and irregular polyhedron in shape, and grain propagation is limited by oxygen loss. For example, tungsten trioxide particles produced by oxidation of tungsten powder under low oxygen pressure are only 1/5 of the size of high oxygen pressure.

2.3.2 The relationship between the properties of tungsten trioxide and the oxygen content

The physicochemical properties of tungsten trioxide, such as optical, electrical, and catalytic properties, are closely related to its oxygen content. Changes in oxygen content significantly alter their functional performance by affecting their electronic structure and defect states.

Optical properties

The oxygen content directly affects the band gap and color of tungsten trioxide:

- **High oxygen content (WO_3):** The band gap is 2.8-3.0 eV, which is light yellow, because the electronic transition mainly occurs between the O2p and W5d orbitals. The UV-Vis spectrum shows that the absorption edge is between 400 and 450 nm.
- **Low oxygen content (WO_{3-x}):** Oxygen vacancies introduce defect energy levels, the band gap narrows to 2.4-2.6 eV, and the color changes to blue or blue-black. For example, WO_{29} The absorption edge is red to 500nm, and the near-infrared absorption is enhanced (> 700nm shielding rate is increased by 50%).

This optical change makes it exhibit differentiation in electrochromic and photothermal applications. Tungsten trioxide with high oxygen content has a large change in light transmittance (80% → 10%), which is suitable for smart windows; Blue tungsten with low oxygen content is used for agricultural film insulation due to strong infrared absorption.

Electrical properties

Oxygen content regulates tungsten trioxide conductivity and semiconductor properties:

- **High oxygen content**: Oxygen-sufficient WO_3 is an n-type semiconductor with low carrier concentration (10^{15}-$10^{16}cm^{-3}$) and high resistivity (10^3-$10^4 \Omega \cdot cm$), making it suitable for insulation or high-resistance applications.
- **Low oxygen content**: The oxygen vacancy increases the free electron concentration (10^{18}-$10^{19}cm^{-3}$) and the resistivity decreases to 10^{-1}-$10^1 \Omega \cdot cm$. For example, WO_2 The conductivity of $_9$ is 2 orders of magnitude higher than that of WO_3 due to the contribution of W^{5+}. This characteristic makes it more advantageous in battery electrodes (e.g., lithium-ion batteries, capacity 693mAh/g) and sensors.

Catalytic performance

Oxygen content significantly affects the photocatalytic and chemical catalytic activities of tungsten trioxide:

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- **Photocatalysis:** Tungsten trioxide with many oxygen vacancies has high separation efficiency due to its narrow band gap and many defect states. For example, the photocatalytic hydrogen production rate of $WO_{2.9}$ is higher than that of WO_3 (300μmol/h•g) than that of WO_3 (300μmol/h•g)
- **Chemical catalysis:** Oxygen vacancies are used as active sites to improve surface acidity. For example, WO_2The conversion rate of $_9$ in hydrogenation reactions (>90%) is better than that of WO_3 (80%) due to the increased density of its Lewis acid site.

Thermal stability

Tungsten trioxide with high oxygen content has better thermal stability and decomposition temperature up to 1700° C, while oxygen-deficient WO_{3-x} is easily reduced to WO_2 or W above 1000° C. This difference affects its suitability in high-temperature environments such as fire-resistant fabrics.

2.3.3 Preparation of tungsten trioxide and control of oxygen content

The preparation method of tungsten trioxide determines its oxygen content, and precise control of oxygen content is key to achieving specific structures and properties. The following analyzes the common preparation processes and the regulation mechanism of oxygen content.

Roasting method

- **Process:** Prepared by roasting tungsten metal or tungsten powder under an oxygen atmosphere (500-800° C).
- **Oxygen content control:**
  - **High oxygen content:** oxygen partial pressure > 0.2atm, temperature 600 ° C, reaction time 2 hours, WO_3 is generated, purity > 99.9%.
  - **Low oxygen content:** Partial pressure of oxygen <0.05atm, or add a reducing agent (such as H_2) to generate WO_{29} or blue tungsten ($W_{20}O_{58}$). For example, tungsten companies prepare blue tungsten in an N_2/O_2 mixed atmosphere (O_2 ratio of 10%) with an oxygen index of 2.72-2.9.
- **Features:** Simple and efficient, suitable for industrial production, but the accuracy of oxygen content is limited by atmosphere control.

Hydrothermal method

- **Process:** Sodium tungstate or tungstic acid is used as the precursor and synthesized in aqueous solution (150-250 ° C, 12-48 hours).
- **Oxygen content control:**

  - **High oxygen content**: Oxidant (such as H_2O_2) is added, pH >7 to ensure the formation of WO_3, and the crystal form is monoclinic.
  - **Low oxygen content**: adjust pH <5, or add a reducing agent (such as ethanol) to generate WO_{3-x} with abundant oxygen vacancies, and the crystal form is biased towards cubic crystals. For example, tungsten technology reports that the oxygen content is controlled at 180° C, ethanol/water (1:1).$_{85}$-WO_3。
- **Features**: Controllable particle size (10-100nm), suitable for nano tungsten trioxide, but low yield.

Vapor Deposition (CVD)

- **Process**: Tungsten filament or WF_6 is used as raw material and deposited under an oxygen atmosphere (400-700° C).
- **Oxygen content control**:
  - **High oxygen content**: The oxygen flow rate > 100 sccm, resulting in a dense WO_3 film.
  - **Low oxygen content**: Reduces oxygen flow (<20 sccm) or introduces H_2 to generate WO_{3-x}. For example, a thin film deposited by a tungsten needle at low oxygen pressure is blue-black with an oxygen content of WO_{29}。
- **Features**: Suitable for film preparation, good uniformity of oxygen content, but high cost.

Oxygen content detection and validation

- **Chemical analysis**: gravimetric determination of oxygen content, such as WO_3 reduction to W after weighing.
- **Spectral analysis**: XPS was used to detect the W^{5+}/W^{6+} ratio, and EPR was used to measure the concentration of oxygen vacancies.
- **Structural characterization**: XRD and TEM confirm the change in crystal form.

CTIA GROUP LTD yellow tungsten oxide

Chapter 3 Classification of tungsten oxide

3.1 Classification of tungsten oxide based on chemical composition

Tungsten oxide is a class of compounds composed of tungsten (W) and oxygen (O), and its chemical composition determines its type and properties. Depending on the oxidation state and oxygen content of tungsten, tungsten oxide can be classified into a variety of types, including tungsten trioxide (WO_3), tungsten dioxide (WO_2), and a range of non-intintegral compounds. These compounds vary in color, structure, and application, reflecting the diversity of tungsten chemistry. Classification based on chemical composition is discussed below.

In nature, tungsten is mainly found in the form of wolframite and scheelite, which is converted into tungsten oxide after refining. Industrially, tungsten oxide is an important intermediate in the production of tungsten products such as tungsten metal, tungsten powder and tungsten wire. Its chemical composition not only affects its physical properties, but also determines its application potential in tungsten technology and tungsten research. For example, a small change in oxygen content can cause the color to change from yellow to blue or purple, a phenomenon that is closely related to the oxidation state and electronic structure of tungsten.

In addition, the preparation method of tungsten oxide will also affect its chemical composition. For example, by calcination of ammonium paratungstate

(APT) in different atmospheres, oxides with different oxygen content can be obtained. This flexibility allows tungsten oxide to be widely adaptable in industry and research. A few of the main types of chemical composition are described in detail below.

3.1.1 Yellow tungsten oxide/tungsten trioxide

Yellow tungsten oxide, also known as tungsten trioxide (WO_3), is the most common and stable form of the tungsten oxide family. Its chemical composition of tungsten is in the +6 oxidation state, and the oxygen content reaches the theoretical maximum, so it has a vivid yellow color. This color derives from its energy band gap (about 2.5-2.8 eV), which allows it to absorb ultraviolet light and partially visible light.

The preparation of yellow tungsten oxide is usually obtained by calcination of ammonium paratungstate or tungstic acid at high temperature in air. Its physical properties include a high melting point (1473° C), high density (7.16 g/cm³) and good chemical stability, allowing it to remain structurally intact in harsh environments. In terms of crystal structure, tungsten trioxide is dominated by monoclinic crystal system, and tungsten atoms are surrounded by 6 oxygen atoms to form WO_6 octahedron, which gives it excellent electrical and optical properties.

In terms of application, yellow tungsten oxide is widely used in smart glass due to its electrochromic properties, which can change from yellow to blue or gray under the action of an electric field. In addition, it is an important material for photocatalysts, which can be used to decompose organic pollutants.

Yellow tungsten oxide is unique in its combination of stability and versatility. Whether it is an intermediate of tungsten chemicals or a direct application in the high-tech field, it has shown irreplaceable value.

3.1.2 Orange tungsten oxide

Orange tungsten oxide is a lesser-mentioned form of tungsten oxide and is often considered a variant of tungsten trioxide (WO_3) under specific preparation conditions. It has the same chemical composition as yellow tungsten oxide, but with an orange color, which may be related to grain size, oxygen vacancies, or trace impurities.

The preparation of orange tungsten oxide usually occurs under transitional conditions, such as when calcining ammonium paratungstate, the temperature is controlled between 400-500° C, or in an environment where oxygen supply is insufficient. Its crystal structure is still dominated by monoclinic crystal systems, but surface defects or differences in particle morphology may cause changes in light scattering, resulting in an orange color. Studies have shown (with reference to Tungsten Academic) that this color change does not significantly alter its chemical properties, but may affect its optical absorption properties.

In terms of application, orange tungsten oxide is similar to yellow tungsten oxide, which can be used in photocatalysis, sensors and other fields. However, due to its unstable preparation conditions, it is rarely produced separately in the industry, and usually exists as an intermediate state of tungsten trioxide. Its position in the tungsten market is not as significant as that of other types, but it still has value to be explored in specific experimental studies.

The particularity of orange tungsten oxide lies in its transitionality, which provides important clues for the study of the relationship between the structure and properties of tungsten oxide.

3.1.3 Blue tungsten oxide

Blue tungsten oxide is an integer tungsten oxide with an oxygen content slightly lower than that of tungsten trioxide. Its blue color stems from the presence of oxygen vacancies that alter the electronic structure, narrowing the energy band gap and expanding the range of light absorption into the visible region.

Blue tungsten oxide is usually prepared by heating ammonium paratungstate or tungsten trioxide under a reducing atmosphere such as hydrogen. Its crystal structure is similar to WO_3, but oxygen vacancies cause local distortions, increasing conductivity and catalytic activity. In terms of physical properties, it is easier to reduce than yellow tungsten oxide, and is often used as an intermediate in the production of tungsten powder.

In applications, blue tungsten oxide is used in gas sensors and photothermal materials due to its high activity. It has high sensitivity to NO_2 and other gases, and has great potential in the field of environmental protection. In addition, it can also be used as a raw material for tungsten chemicals and further processed into composite materials such as tungsten copper.

The charm of blue tungsten oxide lies in its defective state properties, which makes it unique in the field of functional materials.

3.1.4 Purple tungsten oxide

Purple tungsten oxide is a tungsten oxide with a lower oxygen content, and its purple color is due to a higher concentration of oxygen vacancies. Its chemical composition is between WO_3 and WO_2, and the oxidation state of tungsten is partially below +6.

In preparation, purple tungsten oxide needs to be generated under stronger reducing conditions, such as high-temperature treatment of tungsten trioxide in hydrogen. Its crystal structure is complex, and the oxygen vacancy causes serious distortion of the crystal lattice, but it still retains a certain stability. It is easier to reduce than blue tungsten oxide and is the preferred raw material for the production of high-purity tungsten powder.

In terms of application, purple tungsten oxide is often used in tungsten research to study the effect of oxygen vacancy on performance. It also has potential in the field of photocatalysis and electrochemistry because of its further narrowing of the band gap and stronger photoresponsiveness.

The unique color and properties of purple tungsten oxide make it a "personality school" in the tungsten oxide family.

3.1.5 White tungsten oxide

White tungsten oxide is not a type of tungsten oxide in the traditional sense, but a variant of tungsten trioxide under certain conditions, often associated with nano or high purity. Its chemical composition is still WO_3, but due to the extremely small grains or surface effects, the scattered light is enhanced and appears white.

In preparation, white tungsten oxide can be prepared by low-temperature decomposition of ammonium metatungstate or solvothermal preparation. Its crystal structure is consistent with that of yellow tungsten oxide, but its nanoscale size makes its optical properties change. Physically, it retains the high stability of WO_3, but is superior in terms of specific surface area and activity.

In applications, white tungsten oxide is used in photocatalysts and nanocoatings due to its high activity. It is rarely mentioned separately in the tungsten market, but has potential as a high value-added material. The particularity of white tungsten oxide lies in its nano properties, which opens up a new direction for tungsten oxide applications.

3.1.6 Tungsten dioxide/brown tungsten oxide

Tungsten dioxide (WO_2), also known as brown tungsten oxide, is tungsten oxide in the +4 oxidation state of tungsten. It has the lowest oxygen content, has a dark brown color, and has a significant difference in nature from WO_3.

In preparation, tungsten dioxide is produced by tungsten trioxide under strong reduction conditions (such as high-temperature hydrogen). Its crystal structure is monoclinic crystal system, but the WO_4 unit is connected differently than WO_6, resulting in higher electrical conductivity. Physically, it still has a melting point of up to 1700° C, but its chemical stability is lower than that of WO_3.

In applications, tungsten dioxide is often used as an intermediate in the production of tungsten metal, and is also used in electrode materials because of its electrical properties (refer to tungsten research). Its role in tungsten chemicals is fundamental but indispensable. Tungsten dioxide, with its low oxidation state and unique properties, enriches the classification of tungsten oxide.

3.2 Classification of tungsten oxide based on crystal structure

The crystal structure of tungsten oxide is a key factor in determining its properties, and according to the different crystal forms, it can be divided into various types such as monoclinic, orthogonal, hexagonal, and cubic. The formation of these crystal forms is closely related to temperature, pressure, and preparation process, and each structure gives tungsten oxide its unique physical and chemical properties. The characteristics of these polymorphs and their applications are discussed in detail below.

3.2.1 Monoclinic tungsten oxide

Monoclinic crystal form is the main form of tungsten trioxide (i.e., yellow tungsten oxide) at room temperature. The structure of this crystal form consists of WO_6 octahedra, which are connected by coangular connections to form an asymmetrical three-dimensional network. Due to the asymmetry of its crystal lattice, monoclinic tungsten oxide exhibits high stability and excellent properties, making it the most common form in practical applications.

The monoclinic tungsten oxide typically has a bandgap between 2.5-2.8 eV and good optical and electrical properties. Its stability makes it shine in the field of smart glass, enabling reversible color changes through electrochromic effects. In addition, in the field of photocatalysis, monoclinic tungsten oxide is often used as a catalyst for the decomposition of organic pollutants due to its absorption ability of ultraviolet light and some visible light. In industry, it is also the core raw material for the preparation of tungsten powder by calcination of ammonium paratungstate.

The application of monoclinic tungsten oxide is the "main force" of the tungsten oxide family due to its perfect balance of structure and performance.

3.2.2 Orthorhombic tungsten oxide

Orthorhombic tungsten oxide is a crystal structure formed at higher temperatures (e.g. 300-500° C). Compared with the monoclinic crystal form, the arrangement of the WO_6 octahedron is more symmetrical, and the symmetry of the crystal lattice is improved. This structural change allows the orthorhombic form to exhibit unique advantages in certain properties, especially in the field of photocatalysis.

The orthorhombic tungsten oxide has a more open structure and more active sites on the surface, which allows it to adsorb and decompose pollutants more efficiently in photocatalytic reactions (see Tungsten Academic). Its preparation is usually achieved by the phase transformation of tungsten trioxide at a specific temperature, or by controlling the decomposition conditions of tungstic acid. It is slightly less stable than monoclinic but performs well in specific applications. Although the orthorhombic crystal form, as a transitional form of tungsten oxide, is not as widely used in industry as the monoclinic crystal form, its potential still needs to be further explored, especially in the development of high-performance catalysts.

3.2.3 Hexagonal tungsten oxide

Hexagonal tungsten oxide is a crystal structure obtained by a special preparation method (e.g., hydrothermal method), and its morphology is usually in the form of nanorods or nanotubes. The WO_6 octahedron of this crystal form is arranged in a hexagonal symmetrical manner to form an open channel structure, which is ideal for ion intercalation and transport.

The unique structure of hexagonal tungsten oxide gives it significant advantages in the field of batteries and sensors. For example, in lithium-ion batteries, its open channels increase the ion diffusion rate and thus improve the cycling performance of the battery (see Tungsten Research). In gas sensors, the hexagonal nanostructures increase the specific surface area and exhibit higher sensitivity to gas molecules.

In addition, it can also be prepared by hydrothermal synthesis of ammonium metatungstate, and the process is highly controllable. Hexagonal tungsten oxide, with its high activity and special morphology, provides a broad possibility for the application of tungsten oxide in the field of nanotechnology.

3.2.4 Cubic crystalline tungsten oxide

Cubic tungsten oxide is a crystal structure formed under high temperature conditions (e.g., above 900° C), and its WO_6 octahedral arrangement achieves the highest symmetry, presenting a cubic symmetrical lattice. The symmetry of this structure gives it theoretical perfection, but in practice it is less common due to thermodynamic instability.

The preparation of cubic crystalline tungsten oxide often requires extreme conditions, such as the processing of tungsten trioxide at high temperatures and pressures. Its bandgap and electrical properties differ from those of monoclinic crystal form, but are limited by insufficient stability in practical applications. In this study, the cubic crystal form is more used to explore the phase transformation law and theoretical properties of tungsten oxide, and provide data support for understanding the relationship between crystal structure and properties.

With its high symmetry and rarity, cubic tungsten oxide demonstrates the diversity of tungsten oxide crystal structures, and although its application scenarios are limited, it is still an important object in academic research.

3.3 Classification of tungsten oxide based on physical form

The physical form of tungsten oxide is an important embodiment of its application diversity, and it can be divided into various types such as nanoparticles, nanosheets, nanowires, nanorods, nanoflowers, thin films and bulk according to the different particle size, morphology and structure. These differences in morphology not only affect its physical and chemical properties, but also directly determine its specific use in tungsten technology and tungsten research. The following will discuss in detail the characteristics, preparation methods, and application scenarios of each physical form.

3.3.1 Tungsten oxide nanoparticles

Tungsten oxide nanoparticles refer to spherical or near-spherical particles with a particle size of 1-100 nanometers, usually dominated by tungsten trioxide (yellow tungsten oxide). Due to its small size, the specific surface area is significantly increased, exhibiting very different properties from bulk materials. The preparation of nanoparticles is usually achieved by chemical precipitation or low-temperature calcination of ammonium paratungstate, which is simple and controllable.

The optical properties of nanoparticle tungsten oxide are enhanced by quantum effects, and their band gap may change slightly, and is commonly used in photocatalytic fields, such as splitting water or degrading organic pollutants. Electrically, its high specific surface area makes it excellent in gas sensors, enabling it to respond quickly to gases such as NO_2 or H_2S. In addition, it can also be used as: Tungsten powderPrecursors for preparation Tungstenor。

In practical applications, tungsten oxide nanoparticles are often doped into composite materials, such as tungsten copper or tungsten rubber, due to their uniformity and dispersion, to improve their performance. Its nano properties have made it a source of interest in the tungsten market, especially in the high-end segment driven by nanotechnology.

Tungsten oxide nanoparticles have become the star form of nanomaterials research due to their high activity and easy processing.

3.3.2 Tungsten oxide nanosheets

Tungsten oxide nanosheets are two-dimensional structures with nanometer thickness and transverse dimensions up to micron size. This sheet form is usually prepared by solvothermal or exfoliation, e.g. grown from a tungstic acid solution. The crystal structure of nanosheets is mostly monoclinic or orthorhombic crystal form, with a large exposed surface.

The advantage of nanosheet tungsten oxide lies in its two-dimensional properties and abundant surface active sites, which are very suitable for catalytic reactions. Studies have shown (refer to tungsten academic) that it is more efficient than bulk materials in photocatalytic degradation of dyes or photolysis of water to hydrogen. In addition, its lamellar structure gives it potential in the field of electrochemical energy storage, such as lithium battery electrodes, to provide more ion intercalation sites.

In applications, tungsten oxide nanosheets can also be used to fabricate flexible electronic devices due to their mechanical flexibility and electrical properties. It can also be compounded with other materials, such as molybdenum oxide, to create high-performance sensors. Tungsten oxide nanosheets, with their two-dimensional properties and high activity, provide new ideas for the development of functional materials.

3.3.3 Tungsten oxide nanowires

Tungsten oxide nanowires are one-dimensional structures with diameters in the nanometer range and lengths of several microns or even longer. Its preparation methods include vapor deposition method and hydrothermal method, and ammonium metatungstate is often used as raw material, and an elongated linear structure is grown by controlling reaction conditions. The polymorph is mostly monoclinic or hexagonal, depending on the synthesis environment.

Nanowire tungsten oxide excels in electronic devices due to its high aspect ratio and unidirectional conductivity. For example, it can be used as a channel material for field-effect transistors or for high-sensitivity detection in gas sensors (see Tungsten Research). Its one-dimensional structure also contributes to the efficiency of photocatalysis due to the shorter path of photogenerated carriers along the line.

In industrial applications, tungsten oxide nanowires can be further processed into nanoscale precursors of tungsten filaments or for the development of tungsten chemicals. Its morphology also makes it a potential use in flexible displays and nanocomposites, such as combining with tungsten plastic to improve mechanical properties. Tungsten oxide nanowires have become an important member of nanotechnology due to their one-dimensional properties and excellent properties.

3.3.4 Tungsten oxide nanorods

Tungsten oxide nanorods are similar to nanowires in that they are also one-dimensional structures, but their length is shorter, and the aspect ratio is usually less than 10. Its preparation mostly uses hydrothermal or solvothermal method, using sodium tungstate or tungsten trioxide as raw materials, and controlling the morphology by adjusting pH value and temperature. The crystal form is mainly hexagonal or monoclinic.

Tungsten nanorod oxide is characterized by both one-dimensionality and high stability, making it suitable for ion intercalation applications. In the field of batteries, its rod-like structure is able to improve the cycling performance of electrode materials. In addition, it also performs well in photocatalysis because of its moderate surface area and easy dispersion.

In terms of application, tungsten oxide nanorods can be used to prepare tungstate-based catalysts, or as nanoscale components of tungsten heaters. It can also be compounded with tungsten copper to improve thermal conductivity. Industrially, CTIA GROUP LTD has shown a strong interest in its potential in the field of new energy. Tungsten oxide nanorods, with their modest size and versatility, have become a practical choice among one-dimensional materials.

3.3.5 Tungsten oxide nanoflowers

Tungsten oxide nanoflowers are a three-dimensional hierarchical structure assembled into flower-like forms by nanosheets or nanorods, usually prepared by hydrothermal or self-assembly methods. Its raw material can be tungstic acid or ammonium metatungstate, which is formed by controlling the reaction time and additives. The crystal form is mostly monoclinic or hexagonal.

The biggest feature of nanoflower tungsten oxide is its ultra-high specific surface area and porous structure, which makes it have significant advantages in the field of catalysis. For example, it exhibits extremely high activity in photocatalytic decomposition of pollutants or electrocatalytic hydrogen production (see Tungsten Academic). In addition, its flower-like structure enhances gas adsorption capacity, making it suitable for highly sensitive sensors.

In practical applications, tungsten oxide nanoflowers can be used for environmental treatment, such as air purification, or as functional additives for tungsten chemicals. Its beautiful form and practical use have gradually attracted attention in the tungsten market. With its complex structure and high performance, tungsten oxide nanoflowers have become "works of art" among nanomaterials.

3.3.6 Tungsten oxide film

Tungsten oxide thin films are two-dimensional macroscopic forms ranging in thickness from nanometers to micrometers and are typically prepared by sputtering, chemical vapor deposition (CVD), or sol-gel methods. Its chemical composition is dominated by tungsten trioxide, and the crystal form is mostly monoclinic or orthogonal.

The electrochromic properties of thin-film tungsten oxide are its core strengths, which can be used in smart glass and display devices to control color change through electric fields. In addition, it has a wide range of applications in optoelectronic devices, such as as as an electron transport layer for solar cells. The film's high flatness and stability make it suitable for large-scale integration.

Industrially, tungsten oxide films are often used for the surface coating of tungsten products, or combined with tungsten copper to prepare composite materials. Tungsten oxide films are key materials in thin film technology due to their flatness and functionality.

3.3.7 Tungsten oxide blocks

Tungsten oxide blocks refer to the solid form of macroscopic size, which is usually prepared by high-temperature sintering after powder pressing and molding. Its chemical composition is mostly tungsten trioxide, and the crystal form is mainly monoclinic. Bulk materials have large particle sizes and lack nano effects.

Bulk tungsten oxide is characterized by high density and high stability, and is often used as a raw material for the production of tungsten metal or ferro-tungsten. It can maintain structural integrity in high temperature environment, and is suitable for the preparation of refractory materials or radiation shielding materials. In addition, the block shape is easy to transport and store.

In industry, tungsten oxide blocks are the basic raw materials for the production of tungsten powder and tungsten wire, and are widely used in the tungsten market. Although its activity is not as good as that of the nano form, it is still irreplaceable in the traditional field. With its solidity and practicability, tungsten oxide blocks have laid its foundation position in the industry.

3.4 Classification of tungsten oxide based on particle size

The particle size of tungsten oxide is an important determinant of its physical properties and application scenarios. Depending on the size of the particles, they can be divided into various types, such as coarse, ultra-fine, micron, and submicron. These size differences not only affect its specific surface area and reactivity, but are also directly related to its specific use in tungsten technology, tungsten research and industrial production. The classification of tungsten oxide based on particle size and its characteristics will be discussed in detail below.

3.4.1 Coarse-grained tungsten oxide

Coarse-grained tungsten oxide usually refers to the form of particle size in tens of microns or even larger, mainly tungsten trioxide (yellow tungsten oxide). These particles are usually obtained by calcination of ammonium paratungstate (APT) at high temperatures (e.g. above 800° C) for a long time, or by direct sintering from wolframite and scheelite. Due to the large size of the particles, their specific surface area is relatively low and the surface activity is weak.

The physical properties of coarse-grained tungsten oxide include high density (about 7.16 g/cm³) and excellent thermal stability, with a high melting point of 1473° C, which allows it to maintain structural integrity at high temperatures. This property makes it an ideal raw material for the production of tungsten metal, tungsten powder and tungsten wire. In industry, the coarse-grained form is convenient for storage and transportation, and is often used in the preparation of alloys such as ferro-tungsten or tungsten-copper. In addition, it can be used as a substrate for refractory or radiation shielding materials in the metallurgical and nuclear industries. However, due to the larger particle size, coarse-grained tungsten oxide is less reactive, making it unsuitable for applications that require high surface activity, such as photocatalysis or sensors. Its crystal structure is mostly monoclinic and stable, but it is gradually being replaced by finer particles in nanotechnology-driven fields. Despite this, its position in the production of traditional tungsten products remains unshakable. Coarse-grained tungsten oxide has become a "veteran" in industrial applications due to its solidity and economy.

3.4.2 Ultrafine particle tungsten oxide

Ultrafine particle tungsten oxide refers to particles in the range of 1-100 nanometers in size, usually in the form of tungsten trioxide or blue tungsten oxide. Particles of this size are prepared by chemical precipitation, solvothermal or low-temperature decomposition of ammonium metatungstate. Due to the extremely small size of the particles, their specific surface area increases substantially, exhibiting significant nano effects.

The optical properties of ultrafine particle tungsten oxide are enhanced by the quantum size effect, and the energy band gap may be slightly expanded, which is suitable for photocatalytic applications, such as the decomposition of organic pollutants or the production of hydrogen by photolysis of water. Electrically, its high specific surface area makes it excellent in gas sensors, with high sensitivity and fast response to gases such as NO_2 and H_2S. In addition, it can also be used as a raw material for tungsten chemicals in the preparation of tungstate or tungstic acid. In applications, ultrafine particles of tungsten oxide are often doped into composite materials such as tungsten plastic or tungsten rubber to improve performance. Ultrafine particle tungsten oxide has become a "new star" in the field of functional materials due to its high activity and nano properties.

3.4.3 Micron tungsten oxide

Micron-sized tungsten oxide refers to the form of particle size between 1-10 microns, usually dominated by tungsten trioxide (yellow tungsten oxide) or purple tungsten oxide. The particles are obtained by calcination of ammonium paratungstate at a medium temperature (500-700° C) or by mechanical grinding from coarse particles. Its specific surface area is between coarse and ultrafine particles, and it has a certain surface activity.

Micron tungsten oxide has both physical properties that are stable and moderately active, with a melting point and density comparable to coarse particles, but smaller particles make it easier to disperse during processing. It is commonly used in the production of tungsten powder and tungsten metal, and can also be used as a raw material for tungsten heaters or tungsten needles. In the field of photocatalysis, micron-sized particles are not as active as nanoparticles, but they can still be used in some low-demand scenarios.

In terms of application, micron tungsten oxide occupies an important position in the tungsten market, because it is suitable for large-scale production due to its balance of cost and performance. It can also be compounded with tungsten copper for use in conductive materials or as a precursor for the preparation of sodium tungstate. Its crystal structure is mostly monoclinic crystal system, and the particle morphology is relatively regular.

Micron tungsten oxide has become the "backbone" of industry and scientific research due to its moderate size and practicability.

3.4.4 Submicron tungsten oxide

Submicron tungsten oxide refers to the form of particle size between 100 nanometers and 1 micron, usually dominated by tungsten trioxide or blue tungsten oxide. The particles are prepared by controlled ammonium paratungstate calcination conditions (e.g. 500-600° C, short heating) or wet chemistry. Its specific surface area is higher than that of microns but lower than that of ultrafine particles, giving it the best of both worlds.

Submicron tungsten oxide has better optical and electrical properties than coarse particles, making it suitable for photocatalysts and electrochemical sensors. For example, it exhibits high sensitivity for the detection of CO or VOCs (volatile organic compounds) (see Tungsten Research). In the battery sector, submicron particles provide a modest ion transport channel and are suitable as additives for electrode materials. In addition, it is an excellent raw material for the production of spherical tungsten powder.

In industrial applications, submicron tungsten oxide is often used in the fine processing of tungsten products, such as the intermediate of tungsten wire or the basis for the preparation of tungsten grains. It can also be combined with tungsten plastic to improve the homogeneity of the composite material. The crystal structure is mainly monoclinic or orthogonal, and the particle morphology is diverse. Submicron tungsten oxide, with its transitional size and versatility, has become a "bridge" between nano and micro applications.

3.4.5 Nano tungsten oxide

Nano tungsten oxide refers to tungsten oxide with particle size in the range of 1-100 nanometers, usually in the form of tungsten trioxide (yellow tungsten oxide), blue tungsten oxide or purple tungsten oxide. Particles in this size range exhibit completely different properties from traditional materials due to their nano effects, which has become a hot topic in the field of tungsten research and tungsten technology.

There are various preparation methods for nano-tungsten oxide, including chemical precipitation, hydrothermal and low-temperature decomposition of ammonium paratungstate. For example, by controlling the pH and reaction temperature of a tungstic acid solution, homogeneous nanoparticles can be generated. Due to the extremely small particle size, its specific surface area increases significantly, often reaching tens to hundreds of square meters per gram, and this high surface area gives it excellent surface activity. In terms of crystal structure, nano-tungsten oxide is mostly monoclinic or hexagonal, depending on the preparation conditions.

In terms of performance, the optical properties of nano-tungsten oxide are particularly prominent. The band gap may be slightly enlarged (2.5-3.0 eV) due to quantum size effects, making it excellent in the field of photocatalysis, such as for photolysis of water to produce hydrogen or degradation of organic pollutants. Electrically, its high specific surface area and surface defects such as oxygen vacancies enhance its conductivity and ion transport capabilities, making it ideal for gas sensors and lithium battery electrode materials. In addition, nano tungsten oxide has good dispersibility and can be used as an additive for tungsten chemicals in the preparation of tungstate or composite materials.

In applications, nano tungsten oxide is widely used in high-tech fields. For example, it can be mixed with tungsten plastic or tungsten rubber to improve the performance of the material; It can also be used as a precursor of tungsten powder for the production of tungsten wire or tungsten needle. With its small size, high activity and versatility, nano-tungsten oxide has become the perfect combination of nanotechnology and traditional industry, and is the "cutting-edge representative" of the tungsten oxide family.

3.4.6 Sub-nanometer tungsten oxide

Sub-nanometer tungsten oxide refers to tungsten oxide with a particle size of less than 1 nanometer, usually in a clustered or molecular form. Materials in this size range are close to the atomic scale, with properties closer to those of molecules than to conventional solid materials. Due to its extremely small size, the research and application of sub-nanometer tungsten oxide is still in the exploratory stage, but it is of great significance in tungsten scientific research.

The preparation of sub-nanometer tungsten oxide requires high-precision techniques such as vapor deposition (CVD), molecular beam epitaxy, or solution chemistry. The feedstock can be ammonium metatungstate or sodium tungstate, and sub-nanoparticles are generated by precisely controlled reaction conditions such as ultra-low concentrations and rapid quenching. Due to the extremely small particle size, the crystal structure is often incomplete, and may be amorphous or partially ordered, with a specific surface area reaching the theoretical limit, and a very high proportion of surface atoms.

In terms of performance, the optical and electrical properties of sub-nanometer tungsten oxide are affected by significant quantum confinement effects. Its bandgap may be further expanded, exhibiting strong fluorescence properties, which makes it a potential application in optoelectronic devices such as LEDs (see Tungsten Academic). In the field of catalysis, the ultra-high surface activity of sub-nano tungsten oxide makes it extremely selective for single-molecule reactions, such as in CO oxidation or organic synthesis. In addition, the high tunability of its electronic structure has also made it a source of interest in electrochemical sensors.

In terms of application, sub-nanometer tungsten oxide is currently mainly used in laboratory research, because of its high preparation cost and poor stability, the industrial application is not mature. However, it can be used as a functional unit of tungsten chemicals, compounded with tungsten copper or tungsten plastic, to explore the possibilities of new materials. In the future, with the advancement of preparation technology, sub-nanometer tungsten oxide is expected to make its mark in the field of nanomedicine (e.g., drug delivery) or quantum computing.

Sub-nanometer tungsten oxide has become the "future star" in the classification of tungsten oxide due to its extreme size and unique properties, representing the cutting-edge direction of materials science.

3.5 Classification of tungsten oxide based on purity

The purity of tungsten oxide is an important indicator of its performance and application, and can be divided into two categories: ordinary tungsten oxide and high-purity tungsten oxide according to the different impurity content. Differences in purity have a direct impact on their applicability in industry and research, which will be discussed in detail below.

3.5.1 Ordinary tungsten oxide

Ordinary tungsten oxide refers to tungsten oxide with low purity (usually between 95%-99%), mainly in the form of tungsten trioxide (yellow tungsten oxide) or blue tungsten oxide. Impurities include elements such as iron, molybdenum, sodium, etc., and are usually derived from the refining process of wolframite or scheelite, or residues that are not completely removed during the calcination of ammonium paratungstate.

The preparation process of ordinary tungsten oxide is relatively simple, for example, it is prepared by direct calcination of tungstic acid or extensive reduction method. Its physical properties are similar to those of the high-purity version, with a melting point of about 1473 ° C and a density of 7.16 g/cm³, but due to the presence of impurities, its color may be slightly deviated (such as grayish or dull yellow), and the crystal structure is mostly monoclinic crystal system. Due to the influence of impurities, its electrical and optical properties are slightly inferior to those of high-purity products, but it is still practical in less demanding scenarios.

In applications, ordinary tungsten oxide is mainly used in industrial production, e.g. as a raw material for tungsten powder, tungsten metal or ferro-tungsten. It can also be used in the preparation of low-end products such as tungstate for refractory materials or tungsten chemicals. It is inexpensive and suitable for large-scale production, but its performance in high-precision fields such as photocatalysis or electronics is limited.

Ordinary tungsten oxide has become a "basic player" in the industrial field due to its economy and wide applicability.

3.5.2 High purity tungsten oxide

High-purity tungsten oxide refers to tungsten oxide with a purity of 99.9% or higher, usually dominated by tungsten trioxide (yellow tungsten oxide). It has a very low impurity content (<0.1%) and is produced by a multi-step purification process, e.g. from ammonium metatungstate or sodium tungstate by ion exchange, multiple washes and high-temperature calcination.

The physical properties of high-purity tungsten oxide are extremely excellent, the color is pure, the crystal structure is regular, and most of them are monoclinic crystal systems. Its optical properties are stable, and the energy band gap is precise and controllable, which is suitable for optoelectronic devices and photocatalysts. Electrically, the reduction of impurities results in better conductivity and ion transport, and is commonly used in high-performance sensors and battery materials. In addition, its high purity ensures chemical stability and is suitable for harsh environments. In applications, high-purity tungsten oxide is the core raw material for high-end tungsten products, such as in the production of tungsten wire, tungsten needles or tungsten heaters. It is also widely used in smart glass, electrochromic devices, and nanocoatings.

CTIA GROUP LTD

Yellow Tungsten Trioxide (**YTO,** WO_3) **Product Introduction**

1. Product Overview

CTIA GROUP LTD yellow tungsten trioxide is produced by high-temperature calcination process of ammonium paratungstate, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. WO_3 is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants. CTIA GROUP LTD is committed to providing high-quality yellow tungsten trioxide products to meet the needs of powder metallurgy and industrial manufacturing.

2. product characteristics

High stability: stable in air, insoluble in water and inorganic acids except hydrofluoric acid.
Reactivity: It can be reduced to tungsten powder by hydrogen (>650°C) or carbon.
Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Product specifications

index	CTIA GROUP LTD yellow tungsten trioxide first-class product standard
WO_3 content (wt%)	≥99.95
Impurities （wt%，max.）	Fe≤0.0010, Mo≤0.0020, Si≤0.0010, Al≤0.0005, Ca≤0.0010, Mg≤0.0005, K≤0.0010, Na≤0.0010, S≤0.0005, P≤0.0005
Particle size	1-10（μm，FSSS）
Loose density	2.0-2.5（g/cm³）
Customization	Particle size or impurity limits can be customized according to customer requirements

4. Packaging and warranty

Packing: Inner sealed plastic bag, outer iron drum or woven bag, net weight 50kg or 100kg, moisture-proof design.
Warranty: Each batch comes with a quality certificate, including WO_3 content, impurity analysis, particle size (FSSS method), loose density and moisture data.

5. Procurement information

Email: sales@chinatungsten.com
Phone: +86 592 5129696
For more yellow tungsten oxide information, please visit the China Tungsten online website www.tungsten-powder.com. For more market and real-time information, please follow the WeChat public account "China Tungsten Online".


CTIA GROUP LTDyellow tungsten oxide

Chapter 4 Structure of tungsten oxide

4.1 Crystal structure characteristics of tungsten oxide

The crystal structure of tungsten oxide is the basis of its physical and chemical properties, which directly determines its performance in tungsten technology, tungsten research and industrial applications. Depending on the preparation conditions and ambient temperature, tungsten oxide can exhibit a variety of crystal forms, including monoclinic, orthogonal, hexagonal, and cubic. These crystal forms are characterized by the arrangement of tungsten and oxygen atoms and their chemical bonding properties. The following section will discuss the crystal structure characteristics of tungsten oxide in terms of basic units, symmetry, atomic arrangement, defects and vacancies.

Tungsten oxide is usually represented by tungsten trioxide (yellow tungsten oxide), and its crystal structure is formed by the combination of tungsten atoms and oxygen atoms in specific proportions and ways.

In nature, tungsten exists in the form of wolframite or scheelite, which is refined and converted into tungsten oxide. Its crystal structure not only affects its optical properties (such as electrochromic properties), but also determines its electrical and catalytic properties, making it widely used in fields such as smart glass, photocatalysts, and sensors.

4.1.1 The basic unit and symmetry of tungsten oxide crystal structure

The basic unit of tungsten oxide crystal structure is WO_6 octahedron, that is, one tungsten atom is surrounded by six oxygen atoms to form an octahedral coordination structure. These elements are connected by coangulation, co-side, or coplanarity to form a three-dimensional crystal network. The presence of WO_6 octahedron is central to the structural stability of tungsten oxide and the basis of its polymorphism.

In the monoclinic crystal form of tungsten trioxide (yellow tungsten oxide), the WO_6 octahedron is connected by a coangular connection to form an asymmetrical three-dimensional framework, which has low symmetry and belongs to the monoclinic crystal system. This asymmetry makes monoclinic crystal forms most stable at room temperature and is often used in industrial production (e.g Tungsten powder and Tungsten preparation) and functional materials (e.g. smart glass). As the temperature increases, e.g. at 300-500° C, tungsten oxide can be transformed into an orthorhombic crystal form, the symmetry of the WO_6 unit is enhanced, and the crystal lattice arrangement is more regular, which belongs to the orthorhombic crystal system.

Hexagonal tungsten oxide is prepared by hydrothermal method (e.g., ammonium metatungstate as raw material), and WO_6 octahedron is arranged symmetrically in hexagonal symmetry to form an open channel structure, which has high symmetry and is suitable for ion embedding applications (such as battery materials). At higher temperatures (e.g., above 900° C), tungsten oxide may be transformed into a cubic crystal form, and the symmetry of the WO_6 unit reaches the maximum, which belongs to the cubic crystal system, but due to thermodynamic instability, the practical application is less (refer to Tungsten Academic).

The change in symmetry directly affects the properties of tungsten oxide. For example, the monoclinic form with low symmetry has strong electrochromic ability, while the hexagonal form with high symmetry has more advantages in catalysis due to its open structure. Industrially, the tungsten oxide produced by calcination of ammonium paratungstate is mostly monoclinic crystal form, which is most suitable for large-scale production of tungsten products because of its stability. As the basic unit, the WO_6 octahedron endows tungsten oxide with rich structural diversity through different connection methods and symmetry.

The basic unit and symmetry of tungsten oxide crystal structure are the key to understanding its versatility and laying the foundation for its application in different fields.

4.1.2 Atomic arrangement of tungsten oxide

The atomic arrangement of tungsten oxide is the embodiment of its crystal structure, which directly determines its lattice parameters and performance characteristics. Taking tungsten trioxide as an example, its atomic arrangement is based on the spatial distribution of WO_6 octahedron, and the relative positions of tungsten and oxygen atoms in different crystal forms are different.

In monoclinic tungsten oxide, the tungsten atom is located in the center of the octahedron and six oxygen atoms are distributed around it, forming a slightly distorted WO_6 unit. These elements are connected by a co-angle and are arranged in the three directions of the lattice a, b, and c, but due to the low symmetry of the monoclinic system, the lattice angle (β angle) is not 90°, resulting in an asymmetry of the atomic arrangement. This arrangement allows the monoclinic form to be stable at room temperature, with lattice parameters typically a ≈ 7.3 Å, b ≈ 7.5 Å, c ≈ 7.7 Å. This structure is suitable for electrical and optical applications, such as color change in smart glass.

The atomic arrangement of the orthorhombic crystal form is more regular, the distortion of the WO_6 octahedron is reduced, the positions of tungsten and oxygen atoms are more symmetrical, and the lattice parameters tend to be orthogonal (a ≠ b ≠ c, but the angle is close to 90°). This arrangement is formed at high temperatures, increasing the surface active site, making it excellent in photocatalysis. The hexagonal tungsten oxide is arranged in hexagonal symmetry, the WO_6 unit forms a channel-like structure around the central axis, the tungsten atoms and oxygen atoms are distributed along the hexagonal symmetry axis, and the c-axis is longer in the lattice parameters. This arrangement is commonly found in nanorod or nanotube morphology and is suitable for ion transport.

The cubic crystal form of tungsten oxide has the highest symmetry, the WO_6 octahedron is arranged equidistantly in three directions, the positions of the tungsten and oxygen atoms are perfectly symmetrical, and the lattice parameter a = b = c. This arrangement is formed at high temperatures, but due to instability, it is only used for theoretical research. In industry, the atomic arrangement of tungsten oxide is mainly monoclinic crystal form, such as through tungstic acid decomposition or ammonium paratungstate calcination, and its regular atomic arrangement ensures the quality of tungsten metal production.

The atomic arrangement of tungsten oxide is changed by the connection and symmetry of WO_6 units, forming a diverse crystal structure, which directly affects its application potential in tungsten products.

4.1.3 Defects and vacancies in tungsten oxide crystal structure

Defects and vacancies in the crystal structure of tungsten oxide are important regulators of its properties, especially in tungsten trioxide (yellow tungsten oxide) and its inerless compounds (such as blue tungsten oxide, purple tungsten oxide). Defects mainly include oxygen vacancies, tungsten vacancies, and impurity atoms, with oxygen vacancies being the most common and most influential type.

Oxygen vacancies refer to the absence of oxygen atoms in the WO_6 octahedron, resulting in a decrease in the coordination number of tungsten atoms and local distortion of the crystal lattice. In tungsten trioxide, the oxygen vacancy content is low, the structure is relatively intact, and it is yellow. And when the oxygen vacancy increases, as in the blue tungsten oxide or purple tungsten oxide, the oxygen atom in the crystal structure is reduced, the oxidation state of tungsten is partially reduced, and the color and properties are changed. The presence of oxygen vacancies enhances light absorption by changing the electronic structure, narrowing the energy band gap (from 2.5-2.8 eV to a lower level).

The introduction of defects is usually related to the preparation conditions. For example, during the calcination of ammonium paratungstate, if the oxygen vacancies are significantly increased when operating in a reducing atmosphere such as hydrogen, blue or purple tungsten oxide is formed. Due to their high conductivity and catalytic activity, these defective states of tungsten oxide are commonly used in gas sensors and photothermal materials. In addition, impurity defects, such as sodium ions doped with sodium tungstate, can also affect the crystal structure, which may cause the crystal lattice to expand or contract, changing its stability.

In applications, oxygen vacancies have a dual effect on the properties of tungsten oxide. On the one hand, it improves the electrical and catalytic properties, making it easier to reduce in the preparation of tungsten chemicals such as tungstate. On the other hand, too many vacancies may reduce the stability of the structure and affect its performance in high temperature environments. Defects and vacancies in the crystal structure of tungsten oxide are important means of functionalization, which provide flexibility for its application in multiple fields.

4.2 Factors influencing the crystal structure of tungsten oxide

The crystal structure of tungsten oxide is key to its properties and is subject to a variety of external factors. These factors include preparation conditions (e.g., temperature, pressure, and time), raw material characteristics, and environmental conditions. By manipulating these factors, it is possible to achieve precise control of the crystal structure of tungsten oxide, thereby optimizing its performance in tungsten technology, tungsten research and industrial applications. The specific effects of preparation conditions on the crystal structure of tungsten oxide are discussed in detail below.

4.2.1 Effect of preparation conditions on the crystal structure of tungsten oxide

The preparation conditions are one of the most important factors affecting the crystal structure of tungsten oxide, including reaction temperature, pressure, time, atmosphere and selection of raw materials. These conditions determine the crystal form (e.g., monoclinic, orthogonal, hexagonal, or cubic), grain size, and defect distribution of tungsten oxide. Taking tungsten trioxide (yellow tungsten oxide) as an example, its crystal structure is usually formed by ammonium paratungstate or tungstic acid decomposition or calcination under specific conditions, and different preparation parameters lead to different structural characteristics.

In industrial production, the optimization of preparation conditions is directly related to the quality and use of tungsten oxide. For example, by controlling the calcination conditions, it is possible to generate tungsten oxide suitable for the production of tungsten powder or tungsten filament, or functional materials suitable for photocatalysts and smart glass. In the laboratory, hydrothermal method, solvothermal method and other preparation techniques provide more possibilities for the crystal structure control of nanoscale tungsten oxide. The following will analyze the influence of reaction temperature, pressure and time on the crystal structure of tungsten oxide.

4.2.1.1 Effect of reaction temperature on tungsten oxide crystal structure

The reaction temperature is one of the most critical parameters affecting the crystal structure of tungsten oxide, which not only determines the transformation of the crystal form, but also affects the grain size and defect formation. Taking tungsten trioxide as an example, its crystal structure changes significantly at different temperatures.

In the low temperature range from room temperature to about 330° C, tungsten oxide is dominated by monoclinic crystal form, which is the stable form of yellow tungsten oxide. WO_6 octahedron is connected at the same angle to form an asymmetrical three-dimensional network with stable lattice parameters, suitable for electrochromic applications. When the temperature rises to 300-500° C, the tungsten oxide begins to transform to an orthorhombic crystal form, the symmetry of the WO_6 unit is enhanced, and the lattice arrangement is more regular. This structure exhibits higher activity in photocatalysis due to its openness that increases the surface site. Further heating up to 700-900° C, tungsten oxide can be converted into hexagonal crystal forms, especially under hydrothermal conditions, to form nanorods or tubular structures, suitable for ion intercalation applications.

At higher temperatures (e.g., above 900° C), tungsten oxide may form cubic crystal forms, and the symmetry of WO_6 octahedron is maximum, but it is only common in theoretical studies due to thermodynamic instability. In addition, temperature affects grain growth. Tungsten oxide grains prepared at low temperatures (e.g., 400-600° C) are smaller, e.g., nanoparticles formed by calcination of ammonium paratungstate; The high temperature (such as above 800° C) promotes the growth of grains, forming micron-sized or coarse particles of tungsten oxide, which is suitable for the production of tungsten metal.

Temperature also affects oxygen vacancy content. When treated with tungsten oxide at high temperatures in a reducing atmosphere (e.g., hydrogen), oxygen vacancies increase, which may result in the formation of blue tungsten oxide or Purple tungsten oxide , the crystal structure is distorted. The reaction temperature has a profound effect on the crystal structure of tungsten oxide by regulating the crystal form, grain size and defects, and is the core variable in the preparation process.

4.2.1.2 Effect of reaction pressure on tungsten oxide crystal structure

Reaction pressure is another important factor affecting the crystal structure of tungsten oxide, especially in high-pressure preparation processes such as hydrothermal or high-pressure calcination. Pressure affects the nucleation and growth process of crystals by changing the thermodynamic equilibrium of the reaction system, thereby regulating its structural characteristics.

Under normal pressure conditions (such as calcining ammonium paratungstate in air), tungsten oxide is mostly formed in monoclinic crystal form, and the arrangement of WO_6 octahedron is dominated by temperature and atmosphere, and the pressure is less affected. However, in high-pressure environments, such as hydrothermal synthesis of tungsten nanooxide, the pressure significantly changes the crystal structure. Using sodium tungstate as raw material, tungsten oxide tends to form hexagonal crystalline forms in high-pressure reactors (pressures up to several megapascals). The WO_6 cells of this crystal form are arranged along the hexagonal axis to form an open channel structure with a long c-axis in the lattice parameters, making it suitable for battery and sensor applications.

High pressure can also affect grain size and morphology. Under high-pressure hydrothermal conditions, the nucleation rate of tungsten oxide is accelerated, the grain growth is restricted, and the forms such as nanorods, nanosheets or nanoflowers are often formed, rather than large particle structures. In addition, high pressure can inhibit the volatilization of oxygen atoms, reduce the formation of oxygen vacancies, and make the crystal structure of tungsten oxide more regular. For example, tungsten trioxide prepared under high pressure has higher crystallinity and purity than products under atmospheric pressure, making it suitable for the production of high-precision tungsten chemicals.

At extreme high pressures (e.g., multi-megapascals, laboratory simulated crustal conditions), tungsten oxide may form cubic crystals, as the high pressure forces the WO_6 cells to be more closely aligned and symmetrical to be increased. However, this condition is difficult to achieve in industry and is mostly used for theoretical research. Industrially, the pressure regulation of tungsten oxide is mostly concentrated in hydrothermal or vapor deposition processes to optimize the structure of nanoscale tungsten products. By influencing the crystal form selection, grain morphology and defect distribution, the reaction pressure provides an additional dimension for the regulation of tungsten oxide crystal structure, especially in the preparation of nanomaterials.

4.2.1.3 Effect of reaction time on tungsten oxide crystal structure

Reaction time is an important parameter in the preparation of tungsten oxide, which directly affects the crystallinity, grain size and phase transition of crystal structure. In different preparation methods, the length of time plays a key role in the structural evolution of tungsten oxide.

In the process of calcination of ammonium paratungstate to prepare tungsten oxide, the reaction time is short (e.g., 1-2 hours), and monoclinic tungsten trioxide with low crystallinity is usually generated, with smaller grains (nano to submicron scale) and many surface defects. This structure is suitable for applications that require high activity, such as photocatalysts or sensors. With the prolongation of the reaction time (e.g., 4-6 hours), the grains gradually grow, the crystallinity increases, the crystal structure becomes more regular, and the oxygen vacancies decrease. This high crystallinity tungsten oxide is more suitable for the production of tungsten powder or tungsten metal because of its better stability.

In the hydrothermal preparation of tungsten oxide, the reaction time is also crucial. For example, with tungstic acid as raw material, a short-term reaction (2-4 hours) may generate amorphous or low-crystallinity nanoparticles, and extended to 12-24 hours, hexagonal crystalline nanorods or nanoflowers are formed, with orderly lattice arrangement and obvious channel structure. This time-dependence reflects the dynamic process of crystals from nucleation to growth. Excessively long reaction times (more than 48 hours) can lead to excessive aggregation of grains, loss of control of morphology, and impaired performance.

The reaction time also affects the phase transition. In high-temperature calcination, only monoclinic forms may be formed for a short period of time, while prolonged heating (combined with high temperatures) may induce a transition to orthogonal or hexagonal crystal forms. In addition, in a reducing atmosphere (e.g., in hydrogen), a long-term reaction increases oxygen vacancies and forms blue or purple tungsten oxide, which distorts the crystal structure, making it suitable for specific uses of tungsten chemicals.

In industry, Xiamen Tungsten and other enterprises balance the crystallinity and activity of tungsten oxide by optimizing the reaction time to meet the needs of different tungsten products. Reaction time has become an important means to regulate the crystal structure of tungsten oxide by controlling crystal growth and defect evolution.

4.2.1.4 Effect of reaction atmosphere on tungsten oxide crystal structure

The reaction atmosphere is an important parameter in the preparation of tungsten oxide, which directly affects its crystal structure, oxidation state and defect distribution. Different atmospheres (e.g., oxidizing, reducing or inert) change the way tungsten and oxygen atoms are combined, thus regulating the crystal form and properties of tungsten oxide. Taking tungsten trioxide as an example, its crystal structure changes significantly in different atmospheres.

In an oxidizing atmosphere (such as air or pure oxygen), tungsten oxide is usually prepared using ammonium paratungstate or tungstic acid as raw materials, and monoclinic tungsten trioxide is generated by calcination. Under such conditions, oxygen is abundant, the structure of WO_6 octahedron is intact, oxygen vacancies are very few, and the crystal lattice arrangement is regular, showing a bright yellow color. This crystal structure is highly stable and suitable for the production of smart glass and photocatalysts. The higher the oxygen concentration, the better the crystallinity, and the grains may also be slightly larger, which is suitable for the preparation of tungsten powder or tungsten filament.

In reducing atmospheres such as hydrogen or mixtures of hydrogen and nitrogen, the oxygen content of tungsten oxide decreases, forming non-integer compounds. For example, in a hydrogen atmosphere of 500-700° C, tungsten trioxide can be converted to blue tungsten oxide or Purple tungsten oxide 。 In these structures, oxygen vacancies increase, WO_6 octahedron is distorted, lattice symmetry is reduced, and the energy band gap narrows. This defective state of tungsten oxide has higher electrical conductivity and catalytic activity and is often used in gas sensors or as an intermediate in tungsten metal. The stronger the degree of reduction (e.g., high hydrogen concentration or high temperature), the more oxygen vacancies, and the more significant the crystal structure change.

Inert atmospheres, such as argon or nitrogen, fall somewhere in between and are typically used to control oxygen vacancies at moderate levels. For example, calcination of tungsten oxide in an inert atmosphere produces partially defective monoclinic crystal forms, where grain size and crystallinity are dominated by temperature and time. Tungsten oxide under these conditions has both stability and certain activity, which is suitable for the preparation of specific tungsten chemicals.

4.2.1.5 Effect of reaction rate on tungsten oxide crystal structure

As a multifunctional material, the crystal structure of tungsten oxide (WO_3) has a significant effect on its physical and chemical properties. In different chemical reactions or physical processes, the reaction rate not only determines the formation efficiency of tungsten oxide, but also has a profound effect on the formation, transformation and stability of its crystal structure. The reaction rate is usually regulated by factors such as temperature, pressure, reactant concentration, catalyst, and synthesis method, which together shape the crystal form, defect density, and micromorphology of tungsten oxide through kinetic and thermodynamic mechanisms. In this paper, we will discuss in detail

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the effect of reaction rate on the crystal structure of tungsten oxide, and reveal its internal laws based on kinetic analysis, experimental evidence and application background.

1. Basic properties of tungsten oxide crystal structure

The crystal structure of tungsten oxide is diverse, mainly including monoclinic, orthorhombic, tetragonal and cubic. Among them, monoclinic crystal is the most stable crystal form at room temperature, the space group is $P2_1/n$, and the lattice parameters are a=7.306 Å, b=7.540 Å, c=7.692 Å, β=90.91° . As the temperature increases, tungsten oxide can undergo phase transformations, such as orthorhombic crystals at about 330° C and tetragonal crystals above 740° C. In addition, nanoscale tungsten oxide often exhibits a cubic crystal structure due to its higher surface energy and smaller grain size.

The formation of the crystal structure is closely related to the reaction rate. Under fast-reacting conditions, kinetic factors dominate crystal growth, which may lead to non-equilibrium structures (e.g., metastable phases or defect states); However, under the slow reaction condition, the thermodynamic equilibrium prevails, and the stable monoclinic tends to be formed. The differences in these structures directly affect the bandgap, conductivity, and catalytic activity of tungsten oxide.

2. The kinetic mechanism of reaction rate on crystal structure formation

The reaction rate determines the crystal structure of tungsten oxide by affecting the process of crystal nucleation and grain growth. The following is a dynamic analysis of the influencing mechanism:

- Nucleus formation rateDuring the synthesis of tungsten oxide (e.g., tungsten powder oxidation or tungstic acid thermal decomposition), the reaction rate determines the rate of crystal nucleus formation. Fast reactions (e.g., high-temperature roasting, > 800° C) result in high supersaturation and an accelerated rate of nucleation formation, resulting in a large number of small-sized grains. In this case, the crystals do not have enough time to grow and tend to form metastable phases (e.g., tetragonal or cubic). For example, XRD analysis of tungsten oxide produced by fast tungsten oxide metal shows that the proportion of cubic phases is significantly higher than that of slow oxidation products.

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- The grain growth rate, reaction rate, also affects the grain growth process. Under slow reaction conditions (e.g., cryogenic hydrothermal, 150-200° C), the nuclei have enough time to grow along the thermodynamically optimal orientation to form large and regular monoclinic grains. On the contrary, the rapid reaction (e.g., high-temperature flash oxidation of tungsten filament) restricts the orderly arrangement of grains, and it is easy to generate disordered or multiphase coexistence structures. The results show that by controlling the reaction time (1 hour vs. 24 hours), the grain size of tungsten oxide can reach 20-50 μm for slow synthesis and only 1-5 μm for fast synthesis.

- The rapid reaction rate of defect generation is often accompanied by high energy input, resulting in an increase in defects (e.g., oxygen vacancies or tungsten dislocations) in the crystal structure. For example, during the rapid oxidation of tungsten particles, oxygen diffusion is limited, and the resulting tungsten oxide may have a non-stoichiometric ratio, which is manifested as blue tungsten oxide ($W_{20}O_{58}$). These defects change the lattice symmetry and affect the stability of the crystal form.

3. The specific effects of reaction rate regulation

The reaction rate is usually controlled by temperature, reactant concentration and synthesis method, and its specific effects on the crystal structure of tungsten oxide are analyzed as follows:

- Effect of TemperatureTemperature is the main driver of the reaction rate. In slow reactions at low temperatures (<300° C), such as by low-temperature calcination of ammonium metatungstate, tungsten oxide tends to form monoclinic crystals with high lattice order, making it suitable for applications that require high stability (e.g., electrochromic devices). In the rapid reaction at high temperature (>700° C), such as the instantaneous oxidation of tungsten needle under oxygen atmosphere, the tungsten oxide generated is mostly tetragonal or cubic crystal, with small grains and abundant defects. This structure exhibits higher activity in the field of photocatalysis due to its narrow band gap (about 2.6 eV).

- Reactant concentrations affect high concentrations of reactants (e.g. oxygen or Sodium tungstatesolution) accelerates the reaction rate, causing the crystal structure to be biased towards a metastable phase.

For example, rapid oxidation at high oxygen pressure (>1 atm). Tungsten powder, generated Tungsten oxide it is mainly cubic crystal, and the grain size is less than 10 μm. Whereas low-concentration reactions (e.g., dilution Tungstic acid The slow precipitation of the solution) is conducive to the growth of monoclinic crystals, and the grain size can reach more than 50 μm.

- Effect of Synthesis Method Different synthesis methods significantly affect the crystal structure by controlling the reaction rate:
  - Roasting method: The tungsten oxide generated by high-temperature rapid roasting (800° C, 1 hour) is mostly tetragonal or mixed phase, which is suitable for the production of tungsten powder.
  - Hydrothermal method: The tungsten oxide generated by low temperature and slow hydrothermal heat is dominated by monoclinic crystals with regular grains, which is suitable for nano applications.
  - Vapor deposition: Tungsten oxide films formed by rapid deposition are often cubic crystals and are used in electronic devices.

4.2.1.6 Effect of precursors on tungsten oxide crystal structure

Precursors are the starting materials for the preparation of tungsten oxide, and their chemical composition, structure and decomposition characteristics directly affect the formation of the final crystal structure. Common precursors include ammonium paratungstate, ammonium metatungstate, tungstic acid, and sodium tungstate, and the choice of different precursors results in differences in tungsten oxide crystal form, grain size, and purity.

Take ammonium paratungstate (APT) as an example, it is calcined and decomposed at 500-700 ° C in air to form monoclinic tungsten trioxide. The molecular structure of APT is regular, and ammonia and water vapor are released during decomposition, resulting in small tungsten oxide grains (micron to submicron scale), high crystallinity, and few oxygen vacancies. This crystal structure is suitable for industrial production of tungsten powder or tungsten metal. If calcined in hydrogen, APT produces blue or purple tungsten oxide, and the crystal structure is distorted due to oxygen vacancies.

Ammonium metatungstate (AMT) is more suitable for the preparation of nanoscale tungsten oxide. By hydrothermal or solvothermal methods, the tungsten oxide produced by AMT decomposition is often hexagonal crystal form, and the grains are in the form of nanorods or nanosheets, because the prearrangement of tungsten oxygen units in the molecule helps to form an open structure. This crystal structure excels in batteries and sensors. In contrast, tungstic acid produces larger tungsten oxide grains when it is thermally decomposed, with low crystallinity and may contain a small amount of amorphous phase, making it suitable for laboratory research rather than industrial applications.

When sodium tungstate is used as a precursor, the crystal structure of tungsten oxide is affected by sodium ions. If sodium impurities are not completely removed, the crystal lattice may swell, crystallinity may decrease, and even heterophase may form. However, after washing and purifying, high-purity monoclinic tungsten oxide can be obtained, which is suitable for optoelectronic devices. The solubility and decomposition rate of precursors also affect the crystal structure, for example, rapid decomposition (e.g., high-temperature short-term calcination) produces small grains with many defects, while slow decomposition results in regular large grains.

4.2.1.7 Effect of solvent on tungsten oxide crystal structure

Solvents play a key role in the preparation of tungsten oxide by wet chemical methods (e.g., hydrothermal, solvothermal methods), and their properties (such as polarity, boiling point, and coordination ability) directly affect the nucleation and growth of crystal structures. In the case of tungsten trioxide, different solvents can lead to differences in crystal form, morphology and grain size.

Water is the most commonly used solvent, and hexagonal nanorods or nanotubes are usually generated when tungsten oxide is prepared by hydrothermal method (e.g., ammonium metatungstate as raw material). The strong polarity of water and the supercritical properties at high temperature and pressure promote the orderly arrangement of WO_6 cells, forming an open channel structure. This crystal structure is suitable for ion embedding applications such as battery electrode materials. If an acid (e.g., hydrochloric acid) is added to the aqueous solution, monoclinic nanoparticles may be formed, which will accelerate nucleation due to the acidic environment and inhibit grain growth.

Organic solvents such as ethanol or ethylene glycol, due to their low polarity and high boiling point, produce tungsten oxide crystal structures that are mostly monoclinic crystal forms, and the morphology is biased towards nanosheets or nanoflowers. For example, sodium tungstate is dissolved in ethanol for solvothermal reaction, and the coordination of ethanol slows down the rate of crystal growth and forms a layered structure. This crystal structure has a high specific surface area and is suitable for photocatalysts or sensors. In addition, organic solvents can also regulate the growth of crystal planes through surface adsorption, such as preferentially exposing certain crystal planes and changing crystal symmetry.

Mixed solvents, such as water-ethanol blends, have the best of both worlds, producing transition crystals between monoclinic and hexagonal with easier control of grain size and morphology. For example, increasing the ethanol ratio can reduce grain size and increase crystallinity. The viscosity and volatility of solvents also affect the crystal structure, with high-viscosity solvents such as glycerol leading to amorphous or low-crystallinity tungsten oxide, while low-viscosity solvents promote the formation of structured crystals.

4.2.2 Effect of external stimuli on tungsten oxide crystal structure

External stimuli (such as light, mechanical force, electromagnetic field, etc.) play an important role in the formation and later evolution of tungsten oxide crystal structure. These stimuli may alter the lattice arrangement, induce phase transitions, or introduce defects that can affect its performance. The effect of light on the crystal structure of tungsten oxide is mainly reflected in the process of photocatalytic preparation or use. For example, under ultraviolet light, the hydrothermal reaction of tungstic acid as a raw material can accelerate the nucleation of tungsten oxide to form monoclinic nanoparticles. Light-induced electron excitation may promote the selective growth of crystal planes and change the morphology of crystals. In addition, long-term light exposure may introduce oxygen vacancies on the surface of tungsten trioxide, and the crystal structure may be locally distorted, enhancing the light absorption capacity.

The influence of mechanical forces (e.g. grinding or sonication) on the crystal structure of tungsten oxide should not be overlooked. High-energy ball milling crushes micron-sized tungsten oxide into submicron or nanoparticles while introducing lattice stresses and defects to reduce crystallinity. This structural change makes it more active and suitable for catalytic applications. Sonication may induce grain rearrangement, such as the conversion of amorphous tungsten oxide into a monoclinic form with low crystallinity.

Electromagnetic fields play a significant role in the preparation of tungsten oxide by vapor deposition or plasma method. For example, with the assistance of electromagnetic fields, the crystal structure of tungsten oxide films tends to monoclinic crystal form, and the grain arrangement is denser, which is suitable for optoelectronic devices. In addition, the strong electric field may induce the phase transformation of tungsten oxide, such as from monoclinic to orthorhombic crystal form, and improve its electrical properties. External stimuli provide a new way for the dynamic regulation of tungsten oxide crystal structure through physical or chemical actions, especially in the development of functional materials.

4.2.2.1 Effect of optical radiation on tungsten oxide crystal structure

As an external stimulus, light radiation has a significant effect on the formation and evolution of tungsten oxide crystal structure, especially when used in photocatalytic preparation or light conditions. Optical radiation affects the crystal form, defects and morphology of tungsten oxide by exciting electrons, inducing surface reactions, or changing the growth direction of the crystal plane. Taking yellow tungsten oxide as an example, the change of its crystal structure under light radiation is directly related to its optical and catalytic properties.

During preparation, optical radiation (e.g., ultraviolet or visible light) accelerates the nucleation and growth of tungsten oxide. For example, in the hydrothermal preparation of tungsten nano-oxide, tungstic acid is used as raw material, and ultraviolet light can promote the polymerization of tungsten oxide units to form monoclinic nanoparticles. Light-induced electron excitation enhances redox reactions in solution, preferentially exposing certain crystal planes (e.g., (002) planes), thereby altering crystal morphology and symmetry. Studies have shown that light radiation can also regulate the size of grains, forming small particles after short-term irradiation, and promoting the aggregation of grains into nanoflowers or nanosheets by long-term irradiation.

In the process of use, the effect of optical radiation on the crystal structure of tungsten oxide is more complex. Long-term ultraviolet light may introduce oxygen vacancies on the surface of tungsten trioxide, and defects may be formed due to the reaction of photogenerated electrons with lattice oxygen. This structural change distorts the crystal pattern, narrows the energy band gap, and expands the light absorption range to the visible region. This effect is particularly important in photocatalytic applications, such as the decomposition of organic pollutants or the photolysis of water to produce hydrogen, where the increase in oxygen vacancies significantly increases the catalytic activity. In addition, optical radiation may also induce phase transitions, such as the conversion of monoclinic crystal forms into orthorhombic crystal forms under certain conditions, and the lattice symmetry is enhanced. In industry, the influence of optical radiation is mostly used to optimize the functional properties of tungsten oxide. For example, in the production of photocatalysts or optoelectronic devices, the performance of tungsten products can be improved by manipulating the crystal structure by illumination. Optical radiation provides a unique way for the dynamic regulation of tungsten oxide crystal structure through energy input and electron excitation.

4.2.2.2 Effect of electric field on tungsten oxide crystal structure

As an external stimulus, the influence of electric field on the crystal structure of tungsten oxide is mainly reflected in the lattice arrangement, phase transformation and defect control in preparation and application. The electric field affects the structural characteristics of tungsten oxide by changing the ion migration rate and crystal growth direction, especially in electrochemical or electrodeposition preparation.

During the preparation process, the electric field can regulate the crystal form and morphology of tungsten oxide. For example, in the electrochemical deposition method, ammonium paratungstate is used as raw material, and the application of a direct current electric field can induce the preferential growth of tungsten trioxide along the direction of the electric field, forming monoclinic nanowires or thin films. The electric field promotes the directional migration of tungsten ions and oxygen ions, the arrangement of WO_6 octahedron is denser, and the lattice parameters are slightly adjusted. Studies have shown that strong electric fields (e.g. kilovolts/meter) can also accelerate nucleation and produce smaller grains of tungsten oxide, which is suitable for the production of high-precision tungsten chemicals.

In the application, the dynamic influence of the electric field on the crystal structure of tungsten oxide is particularly prominent. Taking electrochromic devices as an example, tungsten trioxide can realize the transformation from monoclinic crystal form to defective structure under the action of electric field. When a voltage is applied, ions (such as Li^+ or H^+) are embedded in the crystal lattice, some WO_6 cells are distorted, and oxygen vacancies increase, causing the color to change from yellow to blue or gray. This structural change is reversible and reflects the electrical responsiveness of tungsten oxide. In addition, strong electric fields may induce phase transitions, such as the transformation of monoclinic to orthorhombic crystalline under high-temperature electric fields, which improves lattice symmetry and improves electrical conductivity. The electric field also affects the defect distribution of tungsten oxide. In electrochemical reactions, electric field-driven ion migration may generate oxygen vacancies or tungsten vacancies on the crystal surface, altering the local structure. This defective state of tungsten oxide performs well in battery electrodes or sensors. The electric field provides an effective means for the fine control of tungsten oxide crystal structure through ion mobility and lattice stress.

4.2.2.3 Effect of magnetic field on tungsten oxide crystal structure

The magnetic field has a relatively small effect on the crystal structure of tungsten oxide, but it still plays an important role in specific preparation processes, such as magnetron sputtering or magnetic field-assisted deposition. The magnetic field indirectly regulates the crystal growth and structural properties of tungsten oxide by influencing the trajectory of ions or particles.

During the preparation process, the magnetic field optimizes the crystal arrangement of tungsten oxide. For example, in the magnetron sputtering method, tungsten metal is used as the target material, and the magnetic field restricts the movement of the plasma, making the deposited tungsten oxide thin film grains denser and inclined to form monoclinic crystal forms. The arrangement of WO_6 octahedron is affected by the ion current induced by the magnetic field, and the lattice directionality is enhanced and the crystallinity is increased. Strong magnetic fields (e.g., several Teslas) may also inhibit grain overgrowth and generate nanoscale tungsten oxide, suitable for optoelectronic devices or sensors. The magnetic field has less dynamic influence on the crystal structure, but can induce microscopic changes under certain conditions. For example, in a magnetic field-assisted hydrothermal reaction, the magnetic field may change the coordination environment of tungsten ions in solution, affect the nucleation direction of tungsten oxide, and form hexagonal nanorods or nanosheets. In addition, when the magnetic field is coupled with the electric field, the oxygen vacancy distribution of tungsten oxide may be changed through the magnetoelectric effect, and the crystal pattern may be distorted to improve the electrical performance.

In applications, the influence of magnetic fields is mostly reflected in composite materials. For example, by combining tungsten oxide with a magnetic material such as molybdenum compounds, the magnetic field can modulate the crystal orientation of the composite structure to improve catalytic or energy storage performance. Industrially, magnetic field-assisted processes are often used to prepare high-performance [tungsten products], such as tungsten copper coatings, but their direct impact on the crystal structure of tungsten oxide still needs to be further studied. Magnetic field provides an auxiliary role for the optimization of tungsten oxide crystal structure through particle motion and microscopic orientation, especially in the preparation of thin films and nanomaterials.

4.3 The intrinsic relationship between tungsten oxide crystal structure and properties

There is a deep intrinsic relationship between the crystal structure of tungsten oxide and its properties, which is reflected in the electronic structure, optics, electricity and catalysis. Taking tungsten trioxide and its variants (e.g. [blue tungsten oxide], [purple tungsten oxide]) as an example, the change in crystal structure directly determines its applicability in the tungsten market and high-tech fields.

Due to its asymmetrical structure, monoclinic tungsten oxide has stable optical and electrical properties, which is suitable for smart glass and photocatalysts. The hexagonal open-channel structure improves ion transport and is suitable for batteries and sensors. Defects in the crystal structure, such as oxygen vacancies, further modulate properties, such as increasing conductivity or light absorption range. This structure-performance link is at the root of tungsten oxide's versatility.

4.3.1 Tungsten oxide electronic-structure linkage

The electronic structure of tungsten oxide is the bridge between crystal structure and performance, which directly affects its optical, electrical and catalytic properties. Taking tungsten trioxide as an example, its electronic structure is formed by the hybridization of the 5d orbital of tungsten and the 2p orbital of oxygen, and the energy band gap is usually 2.5-2.8 eV.

In the monoclinic crystal form, the asymmetrical arrangement of the WO_6 octahedron results in an uneven distribution of electron clouds, with the top of the valence band dominated by O2p orbitals and the bottom of the conduction band composed of W5d orbitals. This electronic structure gives tungsten oxide the properties of a wide-bandgap semiconductor, which absorbs ultraviolet light and some visible light, and appears yellow. The introduction of oxygen vacancies, such as blue tungsten oxide, generates defect energy levels, which lie below the conduction band, resulting in a narrowing of the band gap and the expansion of light absorption into the near-infrared region. This change enhances the photocatalytic activity and is suitable for photothermal therapy or solar energy utilization.

Electrically, the electronic structure of the monoclinic crystal form gives it a low carrier mobility, but electrochromic can be achieved by changing the conductivity by ion intercalation (e.g., Li^+) in an electric field. The open structure of the hexagonal crystal form increases the ion diffusion rate due to the channel effect, and the electron transport is more efficient, which is suitable for battery electrodes (see Electrochemical Applications of Tungsten Powder). The oxygen vacancies further introduce additional electron carriers to improve the conductivity, making the defective state tungsten oxide perform well in the sensor.

In the field of catalysis, local changes in electronic structure (e.g., W at oxygen vacancies $^{5+}$state) increases the surface active site, enhancing the adsorption and decomposition capacity of gas molecules or organic matter. Industrially, CTIA GROUP LTD The performance of tungsten oxide in tungsten products is optimized by using the control of electronic structure.

The electronic structure of tungsten oxide profoundly affects its functional properties through the synergistic effect of crystal form and defects, and is the core of the relationship between crystal structure and performance.

4.3.1.1 Effect of tungsten oxide crystal structure on electron transport

The crystal structure of tungsten oxide has a profound impact on its electron transport performance, which is due to the synergistic effect of lattice arrangement, defect distribution and electronic structure. Taking tungsten trioxide (yellow tungsten oxide) as an example, its crystal structure determines the migration rate and conductivity of electron carriers, which is a key factor in its application in sensors, batteries and electrochromic devices.

In monoclinic tungsten oxide, WO_6 octahedron forms an asymmetrical three-dimensional network by coangular connections. This structure leads to the uneven distribution of electron clouds, the migration of electrons in the crystal lattice is hindered, and the carrier mobility is low. However, this crystal form can alter the electron transport properties by ion intercalation (e.g., Li^+ or H^+) in response to an electric field. For example, in smart glass, ions are embedded in the lattice when a voltage is applied, resulting in oxygen vacancies and low-valence tungsten (e.g., W^{5+}), which significantly enhances electron transport and changes color from yellow to blue. This dynamic control makes the monoclinic crystal form excellent in electrical applications.

Hexagonal tungsten oxide has a higher electron transport efficiency due to its open channel structure. WO_6 octahedron is arranged along the hexagonal axis to form a one-dimensional channel with less migration resistance of electrons along the direction of the channel. This structure is particularly evident in the nanorod or nanowire morphology and is suitable for highly conductive applications such as battery electrodes or field-effect transistors. Studies have shown that the electron transfer rate of the hexagonal form is several times higher than that of the monoclinic crystal form, because it has fewer lattice defects and reduced electron scattering.

Oxygen vacancies are an important factor affecting tungsten oxide electron transport. In blue tungsten oxide or violet tungsten oxide , the presence of oxygen vacancies introduces additional electron carriers, which significantly increase conductivity. Although the crystal structure of tungsten oxide in this defective state is distorted, the electron transport path is optimized due to the formation of defect energy levels, and is often used in gas sensors because it responds faster to gas molecules.

The crystal structure of tungsten oxide directly determines the efficiency and application direction of electron transport through the regulation of crystal form and defects.

4.3.1.2 Relationship between tungsten oxide band structure and crystal structure

The band structure of tungsten oxide is the core of its electronic structure, which is closely related to the crystal structure and directly affects its optical and electrical properties. Taking tungsten trioxide as an example, the position of the band gap, conduction band and valence band is determined by the symmetry, atomic arrangement and defects of the crystal lattice.

In monoclinic tungsten oxide, the asymmetrical arrangement of WO_6 octahedron results in a non-uniform distribution of electron levels. The top of the valence band is mainly composed of 2p orbitals of oxygen, and the bottom of the conduction band is contributed by the 5d orbital of tungsten, and the energy band gap is usually 2.5-2.8 eV. This band structure allows tungsten oxide to absorb ultraviolet light and some visible light. The low symmetry of the monoclinic crystal form makes the transition efficiency between the conduction band and valence band low, and the separation of photogenerated carriers is limited, but it still has advantages in the field of photocatalysis because of its high stability.

Hexagonal tungsten oxide has slightly different band structure due to its high symmetry and open structure. The regular arrangement of the WO_6 cells reduces electron scattering, the energy band gap may be slightly smaller (2.4-2.7 eV), and the energy at the bottom of the conduction band is reduced. This change makes the hexagonal crystal form slightly stronger in light absorption, especially in the nano form, and the quantum effect further adjusts the position of the energy band, which is suitable for optoelectronic devices or photohydrolysis applications. The band structure of the orthorhombic crystal form is in between, and the enhanced symmetry leads to smoother carrier migration and higher photocatalytic activity.

The effect of oxygen vacancies in the crystal structure on the band structure is particularly significant. In blue or purple tungsten oxide, oxygen vacancies introduce defect energy levels that lie below the conduction band, enabling a further reduction in the energy band gap (down to 2.0 eV). These defect states enhance the light absorption range of tungsten oxide, extending into the near-infrared region, which is suitable for photothermal therapy or solar energy utilization. At the same time, the defect energy level acts as an electron trap to prolong the lifetime of photogenerated carriers and improve the catalytic efficiency. Industrially, CTIA GROUP LTD optimizes the optical properties of tungsten oxide in tungsten chemicals by manipulating the band structure through crystal structure. The close relationship between the band structure and the crystal structure of tungsten oxide is the theoretical basis for its versatility.

4.3.2 Tungsten oxide ion transport level linkage

The crystal structure of tungsten oxide is closely related to its ion transport capacity, and this connection determines its potential for applications in batteries, electrochromic devices, and ionic conductors. Taking tungsten trioxide as an example, its ion transport performance is affected by lattice channels, defects and morphology, which is an important aspect of its functionalization.

Due to its dense structure, monoclinic tungsten oxide has a narrow ion transport channel and a low diffusion rate. However, under the action of an electric field, small ions (e.g., H^+ or Li^+) can be embedded in the crystal lattice and migrate slowly along the WO_6 eight bright channels. This ion transport capability allows monoclinic crystal forms to perform well in electrochromic devices, such as Li^+ embedding in smart glass. The presence of oxygen vacancies further enhances ion transport, providing an additional diffusion path due to defects.

Hexagonal tungsten oxide has excellent ion transport properties due to its open hexagonal channel structure. The nanoscale channels formed by the WO_6 unit allow rapid diffusion of ions (e.g., Li^+ or Na^+) with a diffusion coefficient of up to 10^{-8} cm^2/s, much higher than that of monoclinic crystal forms. This structure makes it an ideal material for lithium battery electrodes with excellent cycling properties. Hexagonal tungsten oxide in the form of nanorods or nanotubes further improves the ion transport efficiency by increasing the contact area due to its high specific surface area.

Defective tungsten oxide, such as blue tungsten oxide, has more complex ion transport paths due to oxygen vacancies and lattice distortion, but the diffusion rate is increased by additional channels. This property makes it excellent in electrochemical sensors. In industry, the ion transport performance of tungsten powder is often optimized by crystal structure to improve battery performance. The ion transport capacity of tungsten oxide is directly related to the channels and defects of its crystal structure, which is the key to its application in the field of energy storage and sensing.

4.3.2.1 Effect of tungsten oxide crystal structure on ion diffusion

The influence of the crystal structure of tungsten oxide on ion diffusion is reflected in the size, symmetry and defect distribution of the lattice channels, which directly determine the migration rate and diffusion path of ions. Taking tungsten trioxide as an example, different crystal forms and morphologies have significant differences in its ion diffusion properties.

Due to its dense three-dimensional network, monoclinic tungsten oxide has narrow ion diffusion channels and a low diffusion coefficient (about 10^{-10} cm^2/s). The coangular connection of the WO_6 octahedron creates a limited void that allows only small ions such as H^+ or Li^+ to pass through slowly. This structure is still effective in electrochromic applications because ion diffusion is slow but sufficient to change electronic structure and color. The introduction of oxygen vacancies can slightly increase the diffusion rate, providing additional skipping sites due to defects.

Hexagonal tungsten oxide has significant advantages, with hexagonal channels up to several nanometers in diameter and rapid diffusion of ions (e.g. Li^+ or K^+) along the channels with diffusion coefficients of up to 10^{-8} cm^2/s. This open structure works better in nanorods or nanotubes, as the one-dimensional channel reduces diffusion resistance. In the battery, the high ionic diffusivity of hexagonal tungsten oxide significantly improves the charge-discharge performance.

The orthorhombic tungsten oxide is in between, the channel is looser than the monoclinic crystal form, but not as open as the hexagonal crystal form, and the ion diffusion rate is moderate, which is suitable for some specific applications. Nanoscale tungsten oxide (e.g., nanosheets) further optimizes ion diffusion efficiency due to its high specific surface area and short diffusion path. The crystal structure of tungsten oxide regulates ion diffusion through channel size and defects, which is the core factor in ion transport applications.

4.3.2.2 Effect of ion intercalation/extraction process on the structural stability of tungsten oxide crystals

The ion intercalation and extraction process is the core mechanism of tungsten oxide application in electrochromic devices, batteries, and ionic conductors, and this process has a significant impact on the stability of its crystal structure. Taking tungsten trioxide (yellow tungsten oxide) as an example, the repeated insertion and expulsion of ions (such as H^+, Li^+ or Na^+) will change the lattice parameters, introduce stresses and even lead to structural damage, which is directly related to the long-term performance of the material.

In monoclinic tungsten oxide, WO_6 octahedron forms a dense three-dimensional network by coangular connections, and the ion intercalation channels are narrow. When small ions (e.g., Li^+) are embedded in the lattice driven by an electric field, they occupy the gaps between the WO_6 cells, causing the lattice to expand. For example, during electrochromic processes, Li^+ embedding changes tungsten oxide from yellow to blue, increasing the lattice parameters a, b, and c axes by about 0.1-0.3 Å, respectively. This expansion introduces local stresses, and if the amount of embedding is moderate (e.g., <0.5 mol/Li^+), the crystal structure remains stable and the ions return to their original state after they are removed. However, if the amount of ion embedding is too large or the number of cycles is too large, the lattice stress accumulates, which may lead to microcracks or irreversible distortion of the crystal structure, reducing stability.

Hexagonal tungsten oxide has stronger adaptability to ion intercalation due to its open channel structure. The arrangement of the WO_6 cells along the hexagonal axis to form nanoscale channels allows for rapid ion insertion and expulsion, with small lattice expansion (about 0.05-0.1 Å variation in the c-axis) and uniform stress distribution. This structure performs well in lithium batteries and is stable for hundreds of cycles. However, if the ion size is too large or the intercalation rate is too fast, the channel may be blocked, leading to local structural collapse and long-term stability.

Ion intercalation also introduces oxygen vacancies, especially in blue tungsten oxide or purple tungsten oxide is more pronounced. The embedding process is accompanied by the reduction of tungsten (W^{6+}→W^{5+}), the oxygen vacancy increases, and the crystal structure is distorted. Although this improves the conductivity, too many vacancies may weaken the connection strength of the WO_6 cell, causing the crystal structure to gradually destabilize during repeated cycles. The ion intercalation/extraction process has a dual effect on the stability of tungsten oxide crystal structure through lattice stress and defect changes, which is a key consideration in its application design.

4.3.3 Relationship between tungsten oxide surface properties

The surface properties of tungsten oxide are closely related to its crystal structure, which directly affects its adsorption capacity, catalytic activity and electronic state. Taking tungsten trioxide as an example, the type of crystal structure, crystal plane exposure and defect distribution determine the coordination environment and active site of surface atoms, which are the basis for their performance in photocatalysis, sensors and surface coatings.

The surface of tungsten oxide in the monoclinic crystal form is composed of a coangular connection of WO_6 octahedron, and the exposed crystal plane has a high surface energy due to the unsaturation of the coordination of tungsten and oxygen atoms. This surface property gives it a strong adsorption capacity for gas molecules (e.g. NO_2) or organic matter, making it suitable for gas sensors and photocatalysts. Hexagonal tungsten oxide has a larger specific surface area and more active sites due to its channel structure, which shows higher efficiency in catalytic reactions.

Surface defects further enhance the surface properties of tungsten oxide. In blue tungsten oxide, the tungsten atoms exposed by oxygen vacancies become strong adsorption centers, and the adsorption capacity of water molecules is significantly improved. This surface property makes it excellent in humidity sensors. The surface activity of nanoscale tungsten oxide is further improved due to the high specific surface area and edge effect.

The surface properties of tungsten oxide are also affected by topography. The bulk tungsten oxide has a flat surface and few active sites, while the tungsten oxide in the form of nanoflowers or thin films has better surface properties due to its porosity and high roughness. Industrially, CTIA GROUP LTD By adjusting the crystal structure, the surface properties are optimized, and the competitiveness of tungsten oxide in the tungsten market is enhanced. The surface properties of tungsten oxide are controlled by the crystal structure, which is its core advantage in surface-related applications.

4.3.3.1 Effect of tungsten oxide crystal structure on surface adsorption

The influence of tungsten oxide crystal structure on its surface adsorption capacity is mainly reflected in the crystal plane type, surface energy and defect distribution, which directly determines its adsorption performance for gas, liquid molecules or ions. Taking tungsten trioxide as an example, the surface properties of different crystal forms and morphologies are significantly different.

The surface of monoclinic tungsten oxide is composed of WO_6 octahedron, and the common exposed crystal planes such as (002) and (200) have high surface energy, due to the unsaturated coordination of tungsten and oxygen atoms on the surface. This structure has a strong adsorption capacity for polar molecules (such as H_2O, NH_3), and the adsorption heat can reach tens of kJ/mol. In gas sensors, monoclinic tungsten oxide has a particularly outstanding ability to adsorb NO_2 because the oxygen atoms on its surface can form chemical bonds with NO_2. The presence of oxygen vacancies further enhances adsorption because the W^{5+} site has a strong affinity for electron-donor molecules (e.g., H_2S).

Due to its channel structure, the surface of hexagonal tungsten oxide is mostly (001) plane, with strong openness, and the specific surface area can reach 50-100 m²/g. This crystal plane not only has strong physical adsorption capacity, but also enhances molecular diffusion due to channel effects, making it more efficient in adsorption of macromolecules (such as organic dyes).

In the field of photocatalysis, the adsorption of pollutants by hexagonal tungsten oxide is the prerequisite for its efficient decomposition. The hexagonal tungsten oxide in the form of nanorods or nanotubes has further increased the adsorption capacity due to the increase of edge sites.

The surface characteristics of orthorhombic tungsten oxide are in between, with high regularity of the crystal plane and moderate adsorption sites, which are suitable for specific catalytic reactions. Nanoscale tungsten oxide (e.g., nanosheets) have significantly better adsorption capacity than bulk materials due to their high specific surface area and exposed edge crystal planes. Industrially, Tungsten powder The surface adsorption performance is often optimized by crystal structure to improve the efficiency of catalyst supports. The crystal structure of tungsten oxide regulates surface adsorption through crystal planes and defects, which is a key factor in its adsorption-related applications.

4.3.3.2 Relationship between tungsten oxide crystal structure and surface electronic state

The relationship between the structure of tungsten oxide crystals and their surface electron state is the core of its surface functional properties, which affects its catalytic activity, photoelectric properties and chemical reaction ability through crystal plane exposure, defect distribution and electron cloud distribution. Taking tungsten trioxide as an example, the change of surface electronic state directly determines its performance in the fields of photocatalysis, sensors and electrochemistry.

In monoclinic tungsten oxide, the surface is composed of WO_6 octahedral, and the tungsten and oxygen atoms of the exposed crystal plane (such as (002) or (020)) are unsaturated, and there are suspended bonds. The 2p orbital of oxygen and the 5d orbital of tungsten form a localized electronic state on the surface, and the surface energy level is slightly lower than that of the bulk phase, and the band gap may be reduced by 0.1-0.2 eV. This electron state makes the surface susceptible to electron transfer with external molecules. For example, in photocatalysis, surface electrons are excited by light to the conduction band, leaving holes to generate reactive oxygen species (e.g., •OH), which decomposes organic pollutants. The presence of oxygen vacancies significantly changes the surface electronic state, and the presence of the W^{5+} site introduces a defect energy level, which is located below the conduction band, which enhances the electron donation-receiving capacity and makes the tungsten oxide more sensitive to reducing gases such as CO.

The surface of hexagonal tungsten oxide is mostly (001) plane, because the channel structure exposes more tungsten atoms and the surface electronic state is more active. The defect energy level is more widely distributed and the electron transfer rate is accelerated, which makes it exhibit a higher photocurrent response in optoelectronic devices. Due to the quantum effect, the surface electronic state of nanoscale tungsten oxide (such as nanowires or nanosheets) is further localized, and the electron density increases, which improves the surface reactivity. For example, in the production of hydrogen from photolysis of water, the surface electronic state of hexagonal tungsten oxide optimizes the electron-hole separation efficiency. In contrast, orthorhombic tungsten oxide has a more uniform surface electronic state, high crystal plane symmetry, and stable electron distribution, which is suitable for applications that require low defects, such as some photoelectric coatings.

The surface electronic state is also affected by the topography. The surface electronic state of bulk tungsten oxide is more uniform and the activity is lower, while the surface electronic state of tungsten oxide in the form of nanoflowers or thin films is richer and more reactive due to the high specific surface area and edge effect. For example, in gas sensors, the manipulation of the electronic state of the surface directly affects the detection sensitivity and selectivity.

The crystal structure of tungsten oxide regulates the surface electronic state through crystal plane exposure and defect distribution, which is the theoretical basis and application key of surface functionalization. This relationship not only reveals the versatility of tungsten oxide, but also provides a direction for its further development in the high-tech field. For example, in the tungsten market, tungsten oxide with optimized surface electronic state is gradually becoming a research hotspot for high value-added materials.

CTIA GROUP LTD

Yellow Tungsten Trioxide (**YTO,** WO_3) **Product Introduction**

1. Product Overview

CTIA GROUP LTD yellow tungsten trioxide is produced by high-temperature calcination process of ammonium paratungstate, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. WO_3 is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants. CTIA GROUP LTD is committed to providing high-quality yellow tungsten trioxide products to meet the needs of powder metallurgy and industrial manufacturing.

2. product characteristics

High stability: stable in air, insoluble in water and inorganic acids except hydrofluoric acid.
Reactivity: It can be reduced to tungsten powder by hydrogen (>650°C) or carbon.
Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Product specifications

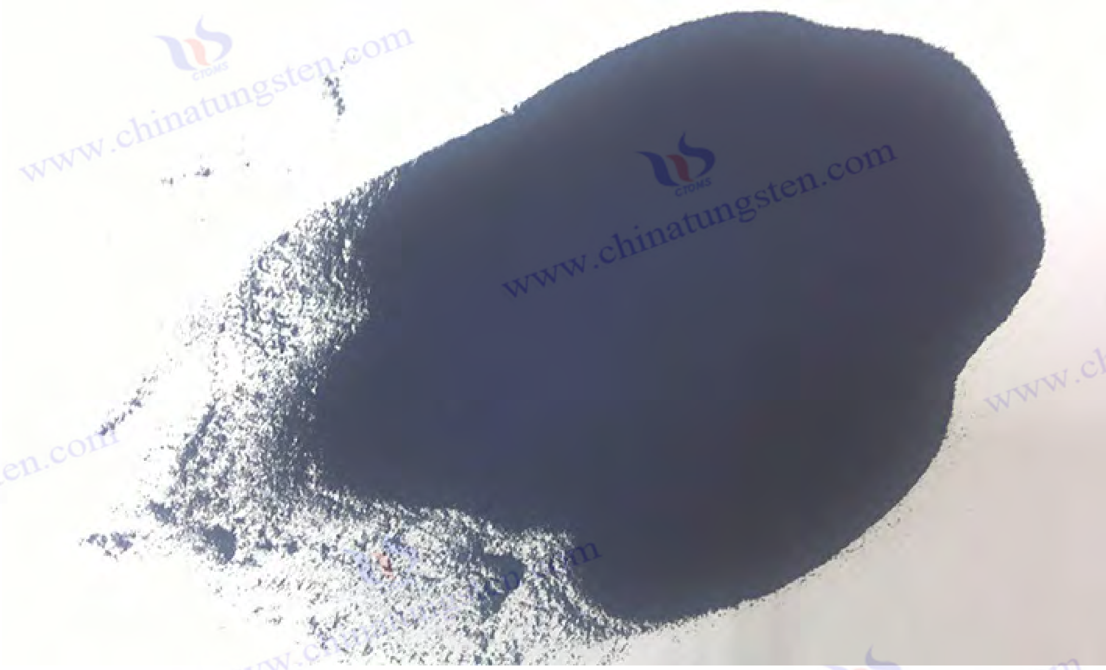
index	CTIA GROUP LTD yellow tungsten trioxide first-class product standard
WO_3 content (wt%)	≥99.95
Impurities （wt%，max.）	Fe≤0.0010, Mo≤0.0020, Si≤0.0010, Al≤0.0005, Ca≤0.0010, Mg≤0.0005, K≤0.0010, Na≤0.0010, S≤0.0005, P≤0.0005
Particle size	1-10（μm，FSSS）
Loose density	2.0-2.5（g/cm^3）
Customization	Particle size or impurity limits can be customized according to customer requirements

4. Packaging and warranty

Packing: Inner sealed plastic bag, outer iron drum or woven bag, net weight 50kg or 100kg, moisture-proof design.
Warranty: Each batch comes with a quality certificate, including WO_3 content, impurity analysis, particle size (FSSS method), loose density and moisture data.

5. Procurement information

Email: sales@chinatungsten.com
Phone: +86 592 5129696
For more yellow tungsten oxide information, please visit the China Tungsten online website www.tungsten-powder.com. For more market and real-time information, please follow the WeChat public account "China Tungsten Online".



CTIA GROUP LTD $WO_{2.72}$

Chapter 5 Physical and Chemical Properties of Tungsten Oxide

5.1 Appearance and color of tungsten oxide

The appearance and color of tungsten oxide is one of its most intuitive physical properties, which directly reflects its chemical composition, crystal structure and oxygen content. Tungsten trioxide (WO_3), for example, is commonly known as yellow tungsten oxide in its common form as a yellow powder, because of its vivid yellow color in natural light. This color is due to its ability to absorb ultraviolet light and partially visible light due to its ability to absorb ultraviolet light and partially visible light, making it valuable in optical applications. However, tungsten oxide is not monolithic in color, and changes in oxygen content cause its appearance to change from yellow to blue, purple and even brown, showing a rich diversity.

Yellow tungsten oxide is the most stable form, usually obtained by calcination of ammonium paratungstate (APT) in air, and its crystal structure is mostly monoclinic crystal system, with particle sizes ranging from nanometer to micron, and delicate and uniform appearance. When the oxygen content is slightly reduced, e.g. prepared under a hydrogen reducing atmosphere, blue tungsten oxide ($WO_{2.}$) is formed$_9$), whose color is caused by changes in electronic structure caused by oxygen vacancies, appears as a dark blue or blue-black powder. This form is often used as an intermediate in the production of tungsten powder in industry because

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of its strong reducibility. By further reducing the oxygen content, purple tungsten oxide ($WO_2.$) is obtained$_{72}$), purple or purple-black in appearance, finer particles, and often used in the study of highly active catalysts.

The appearance of tungsten oxide is also closely related to its topography. Bulk tungsten oxide is usually a dull yellow solid with a smooth surface, while nanoscale tungsten oxide (such as nanoparticles or nanowires) may appear lighter or even white due to light scattering, especially at high purity conditions. For example, a thin film prepared by sputtering may appear pale yellow or colorless on a transparent substrate, but it will turn blue or gray during electrochromic processes. In addition, tungsten dioxide, as a low-oxidation form of tungsten oxide, has a brown or dark brown powder appearance, and its crystal structure is monoclinic crystal system, which is coarser in appearance.

In practical applications, the appearance and color of tungsten oxide are not only its identification mark, but also closely related to its function. For example, yellow tungsten oxide is widely used in smart glass and photocatalysts due to its stability and optical properties; Blue and purple tungsten oxide are commonly used in electrochemistry and catalysis due to their high activity.

5.2 Density/specific gravity of tungsten oxide

The density or specific gravity of tungsten oxide is its important physical property, which reflects its molecular mass and the compactness of its crystal structure. Taking tungsten trioxide (WO_3) as an example, its theoretical density is about 7.16 g/cm³, which is typical of the tungsten oxide family because it is a stable compound with high oxidation state of tungsten. The density is not only related to the chemical composition, but also affected by the crystal form, particle size and morphology, which is an important parameter to measure the performance of tungsten oxide materials.

The density of tungsten trioxide is most common in the monoclinic crystal form because of its dense arrangement of WO_6 octahedron and small lattice voids. The actual density of yellow tungsten oxide prepared by calcination of ammonium paratungstate may be slightly lower than the theoretical value (about 7.0-7.1 g/cm³) due to the presence of micropores or surface defects between the particles. Blue tungsten oxide and purple tungsten oxide with a slight decrease in density of 6.8-7.0 g/cm³ and 6.5-6.8 g/cm³, respectively, due to a slight loosening of the lattice due to increased oxygen vacancies. The density of tungsten dioxide (WO_2) is even lower, about 6.3 g/cm³, because the crystal structure changes from WO_6 octahedron to WO_4 unit due to the reduction of tungsten-oxygen ratio.

The density of tungsten oxide is also affected by topography and particle size. The density of bulk tungsten oxide is close to the theoretical value, because of its small internal pores and compact structure. However, the apparent density of nanoscale tungsten oxide (e.g., nanoparticles or nanorods) is significantly reduced, possibly only 4-5 g/cm³, due to the large number of voids between the nanoparticles and the low bulk density. This difference is particularly important in practical applications, such as in the production of tungsten powder, where high-density tungsten oxide is more susceptible to sedimentation and processing, while low-density tungsten nano-oxide is suitable for catalysts or coatings due to its high specific surface area.

In industrial applications, the density of tungsten oxide directly affects its processing and use performance. High-density tungsten oxide is suitable for the preparation of tungsten metal or tungsten wire, because the mass loss in the reduction process is controllable. Low-density tungsten oxide nano is used in composite materials such as tungsten plastic or tungsten rubber due to its lightweight properties. CTIA GROUP LTD adjusts the density of tungsten oxide by optimizing the crystal structure and particle morphology to meet the needs of different tungsten products. The density of tungsten oxide is not only a reflection of its physical properties, but also a key parameter in its application design.

5.3 Thermal stability of tungsten oxide

The thermal stability of tungsten oxide is an important characteristic of tungsten oxide in high-temperature environment, which directly determines its applicability in refractory materials, optoelectronic devices and high-temperature catalysis. Taking tungsten trioxide (WO_3) as an example, it has high thermal stability and can maintain the integrity of crystal structure at high temperatures, but its specific performance is closely related to its chemical composition, crystal form and preparation conditions. The following is discussed in detail from three aspects: melting point, decomposition temperature and thermal expansion coefficient.

The thermal stability of tungsten trioxide at atmospheric pressure is as follows: below about 1000° C, its crystal structure (usually monoclinic crystal form) remains stable, and no significant decomposition or phase transformation occurs. When the temperature rises to 1000-1200° C, a crystalline transformation may occur, such as from a monoclinic to an orthogonal or hexagonal crystalline, but still does not decompose. Blue tungsten oxide and purple tungsten oxide have slightly lower thermal stability because they have more oxygen vacancies, which are easy to further lose oxygen at high temperatures and be converted into

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tungsten dioxide or tungsten metal. Tungsten dioxide (WO_2) is more thermally stable because its low-oxidation structure is more difficult to decompose in a reducing environment.

The thermal stability of tungsten oxide is also affected by the atmosphere. In oxidizing atmospheres (e.g., air), tungsten trioxide can be stable until near its melting point, while in reducing atmospheres (e.g., hydrogen), oxygen vacancies increase and thermal stability decrease, and may begin to decompose into tungsten metal at lower temperatures (e.g., 700-800° C). This property is widely used in the production of tungsten powder, where the reduction of tungsten oxide is achieved by controlling the atmosphere and temperature. The thermal stability of nanoscale tungsten oxide is slightly lower than that of bulk materials, because its high specific surface area and surface energy make it more susceptible to grain coalescence or structural changes at high temperatures.

In practical applications, the thermal stability of tungsten oxide makes it an ideal material for high-temperature environments. For example, in the manufacture of tungsten wire or tungsten heater, its high temperature stability ensures the reliability of the machining process; In the field of photocatalysis, its structural stability ensures long-term performance.

5.3.1 Melting point of tungsten oxide

The melting point of tungsten oxide is an important indicator of its thermal stability, reflecting its structural retention ability at extreme high temperatures. In the case of tungsten trioxide (WO_3), for example, its melting point is typically determined to be 1473 ° C (about 1700 K), a value that gives it a significant advantage in high-temperature materials. The melting point is closely related to the chemical bond strength and crystal structure of tungsten oxide, because the tungsten-oxygen bond (W-O) has high covalent and ionic properties, and the bond energy is stronger.

The melting point of tungsten trioxide is most typical in the monoclinic crystal form, and its WO_6 octahedral three-dimensional network structure requires extremely high energy to destroy. The melting point of yellow tungsten oxide, which is calcined by ammonium paratungstate, may fluctuate slightly due to trace impurities or particle size, but is usually between 1470-1480° C. Blue tungsten oxide and purple tungsten oxide has a slightly lower melting point of 1450-1470 ° C and 1430-1460 ° C, respectively, due to the presence of oxygen vacancies that weakens the overall stability of the crystal lattice. Tungsten dioxide (WO_2) has a higher melting point of about 1700° C, and is more difficult to melt at high temperatures due to its low oxidation state structure, but is easily

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converted to tungsten trioxide in an oxidizing atmosphere.

The melting point of tungsten oxide is also affected by the topography. The melting point of bulk tungsten oxide is close to the theoretical value because of its dense structure and uniform heat conduction. The melting point of nanoscale tungsten oxide may be reduced by 50-100° C because the high surface area and surface make it easier for the grains to coalesce or melt at high temperatures. This difference needs to be paid special attention in practical applications, such as tungsten oxide with a high melting point in tungsten metal production, which is more suitable for high-temperature reduction processes.

In industrial applications, tungsten oxide's high melting point makes it ideal for refractory materials such as tungsten heaters or high-temperature furnace lining materials. CTIA GROUP LTD further improves the melting point performance of tungsten oxide by controlling the crystal structure and purity to meet the demands of harsh high-temperature environments. The melting point of tungsten oxide is a direct reflection of its thermal stability and the basis for its high-temperature applications.

5.3.2 Decomposition temperature of tungsten oxide

The decomposition temperature of tungsten oxide refers to the temperature at which it begins to lose oxygen atoms or undergo chemical changes under specific conditions, which is closely related to thermal stability. Taking tungsten trioxide (WO_3) as an example, its decomposition temperature is extremely high in an atmospheric oxidizing atmosphere, usually exceeding its melting point (1473° C), because its structure is stable and it is not easy to decompose directly. However, in a reducing atmosphere, the decomposition temperature decreases significantly and becomes a key parameter for tungsten powder production.

In air, the decomposition temperature of tungsten trioxide is difficult to define definitively, as it retains its WO_3 composition after melting and may slowly volatilize a small amount of oxygen until about 1500-1600° C. In a reducing atmosphere such as hydrogen, tungsten trioxide begins to decompose at 700-900 ° C to form blue tungsten oxide (WO_{29}) or purple tungsten oxide and finally converted to tungsten at 1000-1200° C. This decomposition process is closely related to the formation of oxygen vacancies, and the higher the temperature, the deeper the degree of reduction. Blue tungsten oxide and purple tungsten oxide decompose at a lower temperature, and further oxygen is lost in the range of 800-1000° C to form tungsten dioxide or tungsten. Tungsten dioxide (WO_2) has a higher decomposition temperature and is stable to about 1500° C in an inert atmosphere, but rapidly oxidizes to tungsten trioxide in an oxidizing atmosphere.

The decomposition temperature of tungsten oxide is also affected by the particle size. Due to the high surface area and surface activity, the decomposition temperature of nanoscale tungsten oxide may be reduced by 50-100 ° C, and the reduction will begin at 600-800 ° C. The bulk tungsten oxide has a dense structure, higher decomposition temperature and stronger stability. This property is fully exploited in the industrial reduction of tungsten metal, e.g. for step-by-step decomposition through precise temperature control.

In practical applications, the decomposition temperature of tungsten oxide determines its behavior in the high-temperature reduction process. The decomposition temperature of tungsten oxide is the intersection of its thermal stability and chemical reactivity.

5.3.3 Coefficient of thermal expansion of tungsten oxide

The coefficient of thermal expansion of tungsten oxide is the degree of its volumetric or linear expansion under temperature changes, reflecting the ability of the crystal structure to respond to thermal stress. Taking tungsten trioxide (WO_3) as an example, its thermal expansion coefficient is about 6-8×10^{-6} K^{-1} in the range of room temperature to 1000° C, which is relatively low, indicating that it has good dimensional stability at high temperature, which is an important basis for its application in high-temperature devices.

The coefficient of thermal expansion of tungsten trioxide is typical in the monoclinic crystal form, because the tight arrangement of the WO_6 octahedron limits the thermal expansion of the crystal lattice. There is a slight difference in the coefficient of expansion along the three axes A, B, and C, for example, it may be slightly higher along the C axis (about 8×10^{-6}). K^{-1}), due to lattice asymmetry, the thermal stress is unevenly distributed. The coefficient of thermal expansion of yellow tungsten oxide prepared by tungstic acid decomposition may vary slightly depending on particle size and impurities, but generally remains between 6-9×10^{-6} K^{-1}. Blue tungsten oxide and purple tungsten oxide have a slightly higher coefficient of thermal expansion (about 8-10×10^{-6} K^{-1}), and the lattice is relaxed due to oxygen vacancies, and the thermal expansion is more obvious. Tungsten dioxide (WO_2) has a coefficient of thermal expansion of about 5-7×10^{-6} K^{-1} and is slightly less expansive due to its simpler structure.

The coefficient of thermal expansion of tungsten oxide is also affected by the morphology and preparation conditions. The coefficient of thermal expansion of bulk tungsten oxide is close to the theoretical value because of its uniform internal stress. However, nanoscale tungsten oxide (such as nano thin films) may increase the coefficient of thermal expansion by 10-20% due to the increase of surface effects and grain boundaries, and it is easier to deform at high temperatures. This property is particularly considered in thin-film applications, such as in smart glass, where thermal stress-induced cracking is avoided.

In industrial applications, tungsten oxide's low coefficient of thermal expansion makes it suitable for delicate components in high-temperature environments, such as tungsten-copper composites or optoelectronic devices. CTIA GROUP LTD improves the performance of tungsten oxide in high-temperature tungsten products by optimizing the crystal structure and reducing the coefficient of thermal expansion of tungsten oxide. The coefficient of thermal expansion of tungsten oxide is an important embodiment of its thermal stability and mechanical properties.

5.4 Solubility of tungsten oxide

The solubility of tungsten oxide is an important aspect of its chemical properties, which directly affects its behavior in hydrometallurgy, chemical reactions and solution preparation. Taking tungsten trioxide (yellow tungsten oxide) as an example, it is almost insoluble in water and has very low solubility (about 0.02 g/100 mL, 25 ° C), which is a poorly soluble compound. This property stems from its strong covalent-ionic hybrid bond (W-O bond) and stable crystal structure, which makes it difficult to dissociate by water molecules under conventional conditions.

In acidic solutions, the solubility of tungsten oxide varies slightly, but it is still limited. For example, in dilute hydrochloric acid or sulphuric acid, the solubility of tungsten trioxide increases only slightly, as trace amounts of tungstic acid may be formed on the surface, but the whole remains insoluble. However, in strong acids (e.g., concentrated nitric acid), tungsten oxide reacts slowly, especially under heating conditions, to form soluble tungstic acid or tungstate. This reaction is widely used in the wet refining of wolframite or scheelite to convert tungsten oxide into a solution intermediate by acid leaching, which is further processed into tungsten metal. In contrast, tungsten dioxide (WO_2) is slightly more soluble and more reactive in strong acids because of its low oxidation state structure.

The solubility of tungsten oxide in alkaline solutions is significantly improved, especially in strong bases such as NaOH or KOH. Tungsten trioxide can react with sodium hydroxide to form sodium tungstate (Na_2WO_4), and the solubility can reach tens of grams per 100 ml. For example, in a concentrated alkaline solution at

80 ° C, tungsten trioxide dissolves rapidly with the following reactions: WO_3 + 2NaOH → Na_2WO_4 + H_2O. This property is the basis for the industrial production of tungstate, for example in the preparation of tungsten compounds from ammonium paratungstate, which is often achieved by alkalinizing tungsten oxide. Blue tungsten oxide and purple tungsten oxide have similar solubility in alkalis, but the reaction rate is slightly faster due to more oxygen vacancies.

The solubility of tungsten oxide is also affected by topography and particle size. Due to the high specific surface area of nanoscale tungsten oxide (such as nanoparticles), the dissolution rate in acid-base solution is higher than that of bulk materials, but it is still in the insoluble range. In organic solvents such as ethanol or acetone, tungsten oxide is almost completely insoluble because it lacks an active site to react with organic molecules. The solubility of tungsten oxide reflects its chemical stability and reaction selectivity, which is an important characteristic of its application in chemical and metallurgical fields.

5.5 Hardness and mechanical strength of tungsten oxide

The hardness and mechanical strength of tungsten oxide are important manifestations of its physical properties, which determine its suitability in wear-resistant materials, coatings and structural components. Tungsten trioxide (WO_3), a common form of tungsten oxide, has high hardness and mechanical strength, but the specific values vary depending on the crystal form, morphology, and preparation conditions.

The hardness of tungsten trioxide is due to its WO_6 octahedral crystal structure, and the strong covalent and ionic properties of the tungsten-oxygen bond give it high resistance to deformation. In the monoclinic crystal form, tungsten oxide has a dense lattice arrangement and better mechanical properties than non-integer compounds such as blue tungsten oxide or purple tungsten oxide. The hardness and strength of bulk tungsten oxide are close to those of ceramic materials, while the mechanical properties of nanoscale tungsten oxide change due to the increase of grain boundaries and particle effect. The hardness of tungsten oxide makes it a reinforcing phase in tungsten copper composites, improving overall wear resistance.

In terms of mechanical strength, tungsten oxide exhibits good compressive resistance, but weak shear and tensile resistance. This property is related to the anisotropy of its crystal structure, such as the layered arrangement of the monoclinic crystal form, which makes it more susceptible to fracture in certain directions. Industrially, tungsten oxide is often calcined into powder by ammonium paratungstate, and then pressed into molding, and its mechanical strength is affected by the pressing density and sintering conditions. The tungsten oxide block sintered at high temperature is stronger, while the loose nano-tungsten oxide powder is more fragile.

The hardness and mechanical strength of tungsten oxide are also affected by defects. Due to lattice distortion, the hardness and strength of purple tungsten oxide with more oxygen vacancies are slightly lower than that of tungsten trioxide, but it is still sufficient to meet the needs of catalyst support. In practical applications, the mechanical properties of tungsten oxide are often strengthened by compounding, such as combining with tungsten plastic or tungsten rubber, to improve toughness and strength. CTIA GROUP LTD improves the mechanical properties of tungsten oxide in tungsten products by optimizing the crystal structure and particle morphology. The hardness and mechanical strength of tungsten oxide are key indicators of its durability application, reflecting the combination of its crystal structure and practicality.

5.5.1 Mohs hardness of tungsten oxide

The Mohs hardness of tungsten oxide is an important parameter to measure its scratch resistance, reflecting its surface resistance to external erosion. In the case of tungsten trioxide (WO_3), the Mohs hardness is typically between 4.5-5.5, slightly lower than that of common ceramic materials (e.g. alumina, hardness 9) but higher than many metal oxides. This level of hardness makes it valuable in wear-resistant coatings and mechanical components.

The Mohs hardness of tungsten trioxide is mainly due to its WO_6 octahedral crystal structure, and the strong covalentity of the tungsten-oxygen bond provides high scratch resistance. In the monoclinic form, tungsten oxide has a hardness of about 5 because of its dense lattice arrangement and strong interatomic adhesion on the surface. The hardness of tungsten nano oxide prepared by the hydrothermal method of ammonium metatungstate may be slightly lower (about 4.5), due to the grain boundary effect and surface defects of the nanoparticles, which weaken the overall strength. Tungsten dioxide (WO_2) has a slightly higher hardness, around 5.5-6, due to its low oxidation state and more compact structure.

The Mohs hardness of tungsten oxide is also affected by topography and particle size. The hardness of bulk tungsten oxide is close to 5.5 because of its structural integrity and few surface defects. The hardness of nanoscale tungsten oxide (e.g. nanofilms or nanoparticles) may drop to 4-4.5, making the surface more susceptible to scratches due to the high specific surface area and increased grain boundaries. In addition, blue tungsten oxide and purple tungsten oxide, which have more oxygen vacancies, have slightly lower hardness (about 4-5), and the interatomic binding force is reduced by lattice distortion.

In practical applications, tungsten oxide's Mohs hardness makes it suitable as a reinforcing phase for wear-resistant coatings or composites. For example, the addition of tungsten oxide to ferro-tungsten or gold tungsten can improve surface hardness and wear resistance. The Mohs hardness of tungsten oxide is the basis of its mechanical properties, which directly affect its durability.

5.5.2 Compressive strength of tungsten oxide

The compressive strength of tungsten oxide is the core index of its mechanical strength, reflecting its resistance to deformation and crushing under pressure. Taking tungsten trioxide (WO_3) as an example, its compressive strength is usually between 500 and 800 MPa, which makes it moderately high performance among ceramic materials and suitable for high-pressure environments.

The compressive strength of tungsten trioxide is closely related to its monoclinic crystal structure, and the three-dimensional network of WO_6 octahedron provides high compressive resistance. The compressive strength of bulk tungsten oxide prepared by calcination of tungstic acid can reach 700-800 MPa, because of its tight intergrain bonding and few internal defects. The compressive strength of nanoscale tungsten oxide is significantly reduced (about 300-500 MPa), and the intergranular voids and grain boundary effects make it more prone to fracture under pressure. Tungsten dioxide (WO_2) has a slightly higher compressive strength, about 800-900 MPa, due to its simpler structure and stronger lattice stability.

The compressive strength of tungsten oxide is also affected by the preparation process. Due to the high density, the compressive strength of the high-temperature sintered tungsten oxide block is close to the upper limit, while the compressive strength of loose powdered tungsten oxide (such as tungsten powder precursor) is low, only 200-300 MPa. In addition, blue tungsten oxide and purple tungsten oxide with more oxygen vacancies have slightly lower compressive strength (about 400-600 MPa), which weakens the overall strength of the crystal lattice due to defects.

In practical applications, the compressive strength of tungsten oxide makes it suitable for high-pressure forming processes, such as as as as raw material for pressed blanks in the production of tungsten wire. CTIA GROUP LTD improves the compressive strength of tungsten oxide by optimizing the sintering conditions to meet the needs of tungsten companies in pressure-resistant materials. The compressive strength of tungsten oxide is an important embodiment of its mechanical properties, which determines its reliability in high-pressure environments.

5.5.3 Shear strength of tungsten oxide

The shear strength of tungsten oxide is another key parameter of its mechanical strength, reflecting its ability to resist deformation or fracture caused by shear stress. Taking tungsten trioxide (WO_3) as an example, its shear strength is usually between 200-300 MPa, which is lower than the compressive strength, showing a certain anisotropy. This property makes it a little less effective in applications with higher shear forces, but it is still practical.

The shear strength of tungsten trioxide is related to its monoclinic crystal structure, and the layered arrangement of WO_6 octahedron makes it weak in some directions. The shear strength of the bulk tungsten oxide obtained by calcination of ammonium paratungstate is about 250-300 MPa, because the intergrain binding force is sufficient to resist a certain shear stress. The shear strength of nanoscale tungsten oxide is significantly reduced (about 100-200 MPa) due to the increase of grain boundaries and loose connections between particles, which makes it easier to slide under shear. Tungsten dioxide (WO_2) has a slightly higher shear strength of about 300-350 MPa due to its more homogeneous structure.

The shear strength of tungsten oxide is also affected by morphology and defects. Due to its layered structure, the shear strength of thin-film tungsten oxide is low (about 150-200 MPa), and it is easy to fracture along the interlayers. However, the shear strength of blue tungsten oxide and purple tungsten oxide with more oxygen vacancies is further reduced (about 120-180 MPa), and the shear resistance is weakened by lattice distortion. In composites, the shear strength of tungsten oxide can be enhanced by the addition of tungsten copper or silver tungsten to improve the overall properties.

In practical applications, the shear strength of tungsten oxide makes it perform well in scenarios with low shear stresses, such as tungsten heaters. The shear strength of tungsten oxide complements its mechanical properties, reflecting its limitations and potential in complex stress environments.

5.6 Specific surface area of tungsten oxide

The specific surface area of tungsten oxide is an important parameter of its physical properties, which directly reflects its particle size, morphology and

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surface activity, and has a key impact on its application in catalysis, adsorption and energy storage. Taking tungsten trioxide as an example, its specific surface area varies depending on the preparation method and particle size, and usually varies in the range of 1-100 m²/g, which is an important indicator of its functionality.

Bulk tungsten oxide has a low specific surface area, typically between 1-5 m²/g, due to its large particles (micron scale) and limited surface exposure of active sites. The specific surface area of yellow tungsten oxide obtained by high-temperature calcination of ammonium paratungstate is generally 2-10 m²/g, which is suitable for tungsten powder precursor, as it does not require excessive surface activity during the reduction process. In contrast, the specific surface area of nanoscale tungsten oxide is significantly increased, such as nanoparticles or nanorods prepared by the hydrothermal method of ammonium metatungstate, with a specific surface area of 50-100 m²/g. This high specific surface area is due to a reduction in particle size (10-100 nm) and morphological diversity (e.g., nanowires or nanoflowers), which results in a significantly higher proportion of surface atoms.

The specific surface area of tungsten oxide is also related to its crystal form and oxygen vacancy. The monoclinic tungsten oxide has a relatively stable specific surface area, while the hexagonal nanostructure has a higher specific surface area due to the channel effect, and is often used in photocatalysts or gas sensors (see Tungsten Technology). The specific surface area of blue tungsten oxide and purple tungsten oxide is slightly higher than that of tungsten trioxide of the same size (about 10-20% increase), and the surface roughness increases due to oxygen vacancies and more active sites. Tungsten dioxide (WO_2) has a lower specific surface area (5-20 m²/g) because of its simple crystal structure and the tendency of particles to coalesce.

In practical applications, tungsten oxide's high specific surface area makes it excellent in the field of catalysis, for example, when decomposing organic pollutants, the high surface area of nano-tungsten oxide can adsorb more reactants and improve efficiency. The specific surface area of tungsten oxide is a direct reflection of its surface functionality and a key parameter for its application in nanotechnology.

5.7 Bulk density of tungsten oxide

The bulk density of tungsten oxide refers to the density of its powder in the natural packing state, which reflects the void and accumulation characteristics between the particles, and has an important impact on its storage, transportation and processing properties. In the case of tungsten trioxide (WO_3), for example, the bulk density is usually between 1.0 and 2.5 g/cm³, which is much lower than its theoretical density (7.16 g/cm³) due to the large number of voids between the particles.

Bulk tungsten oxide has a high bulk density, such as micron-sized yellow tungsten oxide produced by calcination of tungstic acid, with a loose density of about 2.0-2.5 g/cm³. This higher bulk density is due to the larger particles (1-10 μm), tighter packing, and fewer voids, making it suitable for the industrial production of tungsten metal or tungsten wire. For example, the bulk density of nano-scale tungsten oxide is significantly reduced, for example, the bulk density of nanoparticles prepared by hydrothermal method is only 0.5-1.0 g/cm³, due to the increase of gaps between nanoparticles (10-100 nm) and loose accumulation. This low density makes it easy to disperse in tungsten plastic or tungsten rubber.

The bulk density of tungsten oxide is also affected by morphology and crystal form. The monoclinic tungsten oxide particles are regular and have a high bulk density (1.5-2.5 g/cm³), while the hexagonal nanorods or nanotubes have a low bulk density (0.8-1.5 g/cm³) due to their complex morphology. Blue tungsten oxide and purple tungsten oxide have a slightly lower loose density (1.0-2.0 g/cm³), because the oxygen vacancies make the particle surface rougher and the accumulation efficiency decreases. Tungsten dioxide (WO_2) has a loose density of about 1.5-2.2 g/cm³ because its particles tend to be agglomerates.

In practical applications, the bulk density of tungsten oxide affects its processing technology. For example, tungsten oxide with high bulk density is easier to obtain when pressing, while nano-tungsten oxide with low bulk density is suitable for lightweight coatings. CTIA GROUP LTD optimizes the bulk density of tungsten oxide by adjusting the particle size and morphology to suit the needs of different tungsten markets. the loose density of tungsten oxide is an important bridge between its physical properties and practicability.

5.8 Optical properties of tungsten oxide

The optical properties of tungsten oxide are the basis for its application in photocatalysis, photochromic and optoelectronic devices, and are closely related to its crystal structure and electronic structure. Taking tungsten trioxide (WO_3), a common form of tungsten oxide, as an example, its optical properties include light absorption, transmission, and reflection properties, and it exhibits diversity due to the band gap and defect state.

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Tungsten trioxide has an energy band gap of about 2.5-2.8 eV, which is a wide bandgap semiconductor, which can absorb ultraviolet light and some visible light, and has a yellow appearance. This optical property gives it advantages in the field of photocatalysis, such as splitting water or degrading organic pollutants. Due to the asymmetrical structure, the monoclinic tungsten oxide has a slightly wider light absorption edge, while the hexagonal nanostructure may have a slightly smaller band gap (2.4-2.7 eV) and a wider absorption range due to the quantum effect. The band gap between blue tungsten oxide and purple tungsten oxide is further reduced (2.0-2.5 eV), and the light absorption expands to the near-infrared region due to the introduction of defect energy levels by oxygen vacancies.

The optical properties of tungsten oxide are also manifested in electrochromic ability. Under the action of an electric field, tungsten trioxide can change color from yellow to blue or gray by ionic intercalation (e.g. Li^+). This property makes it widely used in smart glass, where the transmittance can be reduced from 80% to less than 10%. The optical properties of tungsten oxide in the form of thin films are better, and the reflection and transmission characteristics are easy to adjust due to the controllable thickness. Nanoscale tungsten oxide has an enhanced light scattering effect and may appear translucent or white.

In practical applications, the optical properties of tungsten oxide make it shine in the field of optoelectronics. For example, tungstate-based photocatalysts use their light-absorbing properties to break down contaminants, while tungsten heaters' optical coatings take advantage of their color-changing properties. CTIA GROUP LTD improves the optical properties of tungsten oxide in tungsten companies by optimizing the crystal structure. The optical properties of tungsten oxide are at the heart of its high-tech applications

5.8.1 Light absorption and photocatalytic properties of tungsten oxide

The light absorption and photocatalytic properties of tungsten oxide are important manifestations of its optical properties, which directly determine its efficiency in photolysis of water, pollutant degradation and solar energy utilization. Taking tungsten trioxide (WO_3) as an example, its light absorption range is mainly concentrated in the ultraviolet light and some visible light regions, and the energy band gap is 2.5-2.8 eV, making it an effective photocatalytic material.

The tungsten oxide light absorption edge of the monoclinic crystal form is about 400-500 nm, and due to the asymmetric arrangement of the WO_6 octahedron, the electrons transition from the O2p orbital to the W5d orbital to generate photogenerated electron-hole pairs. This property makes it highly efficient at breaking down organic dyes, such as methylene blue, under UV light. Due to the nano effect and channel structure, the hexagonal tungsten oxide has a slightly wider light absorption range (to 550 nm) and stronger photocatalytic activity, especially in the form of nanorods or nanoflowers, with a higher specific surface area and more active sites. The light absorption of blue tungsten oxide and purple tungsten oxide with more oxygen vacancies extends to the near-infrared region, and the photoresponsiveness is enhanced by the defect energy level.

The photocatalytic properties of tungsten oxide are also affected by morphology and defects. Due to its high specific surface area and short carrier diffusion path, nanoscale tungsten oxide has higher efficiency of photogenerated electron-hole separation, and its photocatalytic performance is better than that of bulk materials. The oxygen vacancy is used as an electron trap to prolong the carrier life and further improve the catalytic efficiency. For example, in the production of hydrogen from photolysis of water, the hydrogen production rate of hexagonal tungsten oxide can reach tens of μmol/h•g. Industrially, Calcium tungstate Combined with tungsten oxide, it further optimizes light absorption and catalytic performance.

5.8.2 Photochromic properties of tungsten oxide

The photochromic properties of tungsten oxide refer to its ability to reversibly change its color under light, which is a unique manifestation of its optical properties. Taking tungsten trioxide (WO_3) as an example, its photochromic properties stem from light-induced electron transfer and oxygen vacancy formation, making it a potential application in smart glass and display devices.

Monoclinic tungsten oxide changes from yellow to blue or gray under ultraviolet light, and oxygen vacancies are formed by the reaction of photogenerated electrons with lattice oxygen, and tungsten is reduced from W^{6+} to W^{5+}. This discoloration process typically involves water or a proton source (e.g., surface-adsorbed H_2O) in the following reaction: $WO_3 + hv \rightarrow WO_{3-x} + x/2\ O_2$. Nanoscale tungsten oxide has stronger photochromic properties, as the high specific surface area accelerates the surface reaction, and the color change time can be shortened to a few seconds. Due to the channel structure, the discoloration efficiency of hexagonal tungsten oxide is slightly higher, but the stability is slightly inferior.

The photochromic properties of tungsten oxide are also affected by oxygen vacancies and topography. The initial oxygen vacancies of blue and purple tungsten oxide give them a lower photochromic threshold and can change color at lower light intensities. Tungsten oxide in the form of thin films is often used in optical devices because of its controllable thickness and easier adjustment of color depth and speed. Compared with electrochromism, photochromism is less reversible, and long-term illumination may lead to irreversible changes in structure. In practical applications, the photochromic properties of tungsten oxide make it promising for light-controlled windows and sensors. CTIA GROUP LTD improves the color-changing properties of tungsten oxide in tungsten chemicals by optimizing the nanostructure . The photochromic properties of tungsten oxide are a unique advantage for its optical applications.

5.9 Electrical properties of tungsten oxide

The electrical properties of tungsten oxide are the core properties of tungsten oxide in electronic devices, sensors, and electrochromic applications, and are closely related to its crystal structure, electronic structure, and defect state. Taking tungsten trioxide as an example, its electrical properties are typical of semiconductor behavior, and the conductivity and carrier mobility are affected by the crystal form and environmental conditions, showing diversity and tunability.

As an n-type semiconductor, the conductivity of tungsten trioxide is usually in the range of 10^{-7}–10^{-3} S/cm, depending on temperature, oxygen vacancy and doping. In the monoclinic crystal form, the electrons of tungsten oxide are mainly derived from the defect state of oxygen vacancy, and W^{6+} is partially reduced to W^{5+}, providing additional electron carriers. This property makes it excellent in gas sensors, e.g. the response to NO_2 or H_2S can significantly alter conductivity. Due to the channel structure, the hexagonal tungsten oxide has higher electron mobility and conductivity up to 10^{-2} S/cm, which is suitable for high-sensitivity applications.

The electrical properties of tungsten oxide also have electrochromic properties. Under the action of an electric field, ions (such as Li^+ or H^+) are embedded in the crystal lattice, and with the electron implantation, the conductivity increases significantly. For example, in smart glass, tungsten trioxide changes from an insulating state to a conductive state and a color changes from yellow to blue. This dynamic change stems from the tunability of the electronic structure, which makes it widely used in electrochemical devices. Nanoscale tungsten oxide has better electrical properties and is often used in the functionalization of tungsten chemicals due to its high specific surface area and short carrier path to improve electron transport efficiency .

In practical applications, the electrical properties of tungsten oxide have attracted much attention in the field of electronics. For example, blue tungsten oxide and purple tungsten oxide are suitable for electrode materials due to their higher conductivity due to more oxygen vacancies. The electrical properties of tungsten oxide are the basis for its high-tech applications, reflecting the flexibility of its semiconductor properties.

5.9.1 Semiconducting properties of tungsten oxide

The semiconducting properties of tungsten oxide are central to its electrical properties, making it important in sensors, solar cells, and optoelectronic devices. Taking tungsten trioxide (WO_3) as an example, as an n-type wide bandgap semiconductor, the energy band gap is 2.5-2.8 eV, and the electronic conductivity is derived from the carriers introduced by oxygen vacancies or doping.

Monoclinic tungsten oxide is the most common form of semiconductor, and its conduction band is composed of W 5d orbitals and the valence band is dominated by O2p orbitals. Oxygen vacancies, as donor defects, donate free electrons to make their conductivity between 10^{-7}-10^{-4} S/cm. This property makes it sensitive to oxidizing gases such as NO_2, which adsorb and trap electrons, reducing conductivity. Due to the channel structure, the hexagonal tungsten oxide has higher electron mobility and conductivity of 10^{-3}-10^{-2} S/cm, which is suitable for high-sensitivity sensors. Tungsten dioxide (WO_2) is close to a metal conductor and has higher electrical conductivity, but weaker semiconductor properties.

The semiconductor properties of tungsten oxide are also affected by temperature and topography. At room temperature, its conductivity is low, and as the temperature increases (to 200-400° C), the thermally excited electrons increase, and the conductivity increases significantly. Nanoscale tungsten oxide (e.g., nanowires or nanosheets) may have a slightly smaller band gap (2.4-2.7 eV) due to quantum effects and surface states, higher carrier concentrations, and better semiconductor performance. For example, in tungsten powder-based sensors, nano-tungsten oxide can detect CO dozens of times more sensitive than bulk materials. In practical applications, tungsten oxide's semiconducting properties make it excellent for gas detection and photoelectric conversion. CTIA GROUP LTD optimizes the conductivity and responsiveness of tungsten oxide by doping (e.g. sodium tungstate) or by manipulating oxygen vacancies to meet the needs of the tungsten market. The semiconducting properties of tungsten oxide are the basis for its electrical applications, reflecting the diversity of its electronic structure.

5.9.2 Electrochromic properties of tungsten oxide

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The electrochromic properties of tungsten oxide refer to its ability to reversibly change its color under the action of electric field, which is a unique manifestation of its electrical properties. Taking tungsten trioxide (WO_3) as an example, its electrochromic properties are due to the changes in electronic structure caused by ion intercalation and electron implantation, making it widely used in smart glass and display devices.

Monoclinic tungsten oxide is a typical material for electrochromism. When a voltage (e.g., 1-3 V) is applied, small ions (e.g., Li^+ or H^+) are embedded in the inter-WO_6 octahedral space, and electrons are injected into the crystal lattice, and tungsten is reduced from W^{6+} to W^{5+}, generating oxygen vacancies. The reaction is: $WO_3 + xLi^+ + xe^- \rightarrow Li_xWO_3$. This change changes tungsten oxide from yellow to blue or gray, and the transmittance drops from 80% to less than 10%. After the ions are detached, the color recovers reversibly, reflecting its electrical adjustability. Nanoscale tungsten oxide has stronger electrochromic properties, as the short diffusion path accelerates ion intercalation and the discoloration time can be reduced to a few seconds.

The electrochromic properties of tungsten oxide are also affected by the crystal form and defects. Due to the channel structure, the hexagonal tungsten oxide has faster ion diffusion and higher discoloration efficiency, but the cycling stability is slightly inferior. The initial oxygen vacancies of blue and purple tungsten oxide make them have a lower discoloration threshold and a faster response. Tungsten oxide in the form of thin film is often used in optical devices because of its controllable thickness, easy adjustment of color depth and speed. Compared with photochromism, electrochromism is more controllable and reversible.

In practical applications, tungsten oxide's electrochromic properties make it highly desirable in energy-efficient buildings and display technology. For example, tungsten copper-based electrodes are compounded with tungsten oxide to improve conductivity and color-changing properties. The electrochromic properties of tungsten oxide are advanced applications of its electrical properties, demonstrating its versatility.

5.10 Thermal properties of tungsten oxide

The thermal properties of tungsten oxide are its key properties in high-temperature environments, which determine its suitability in refractory materials, thermoelectric devices and high-temperature processing. Taking tungsten trioxide (WO_3), a common form of tungsten oxide, as an example, its thermal properties include thermal stability, thermal expansion properties and thermal conductivity,

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which are closely related to crystal structure and chemical composition.

The thermal properties of tungsten trioxide are characterized by high thermal stability, with a melting point of about 1473 ° C, and the crystal structure remains intact below 1000 ° C. This property allows it to maintain its function at high temperatures, e.g. as a stable precursor in tungsten production. Tungsten oxide has a low coefficient of thermal expansion (about 6-8×10^{-6} K^{-1}) and good dimensional stability, which is suitable for precision devices. In terms of thermal conductivity, tungsten oxide has a low thermal conductivity due to its limited lattice vibration heat transfer efficiency, but it is sufficient to meet some thermal management needs.

The thermal properties of tungsten oxide vary depending on the crystal form and morphology. The monoclinic form has the best thermal stability of tungsten oxide, while the hexagonal form of nanostructure has slightly lower thermal stability due to its high surface energy. Blue tungsten oxide and purple tungsten oxide are prone to loss of oxygen at high temperatures, and their thermal properties are slightly inferior to those of tungsten trioxide. Nanoscale tungsten oxide has a lower thermal conductivity (about 0.5-2 W/m·K) due to enhanced grain boundary scattering, but has advantages in lightweight thermal insulation.

In practical applications, the thermal properties of tungsten oxide make it excellent in the field of high temperatures. For example Ferro-tungsten Tungsten oxide is added to improve heat resistance. CTIA GROUP LTD OPTIMIZES THE THERMAL PROPERTIES OF TUNGSTEN OXIDE IN TUNGSTEN PRICE BY MANIPULATING THE CRYSTAL STRUCTURE. The thermal properties of tungsten oxide are the cornerstone of its high-temperature applications.

5.10.1 Thermal stability of tungsten oxide

The thermal stability of tungsten oxide is central to its thermal properties, reflecting its ability to maintain structure and function at high temperatures. Taking tungsten trioxide (WO_3) as an example, it has high thermal stability, a melting point of 1473 ° C, and no significant decomposition or phase transformation below 1000 ° C, making it of great value in refractory materials and high-temperature catalysis.

Monoclinic tungsten oxide is the most thermally stable form, and its WO_6 octahedral network remains stable until about 1200° C, with only crystal form transitions (e.g., to orthogonal or hexagonal crystal forms). The yellow tungsten oxide obtained by calcination of ammonium paratungstate can withstand high temperatures above 1000 ° C in air, and begins to decompose into blue tungsten oxide or purple tungsten oxide at 700-900 ° C in hydrogen, and finally to tungsten metal. Tungsten dioxide (WO_2) is thermally stable up to 1500° C in an inert atmosphere.

The thermal stability of tungsten oxide is affected by the topography. Due to its dense structure, bulk tungsten oxide has better thermal stability than nanoscale tungsten oxide. Due to the high surface energy of nanoparticles, grain coalescence or decomposition may occur at 600-800° C. Tungsten oxide with more oxygen vacancies is more prone to oxygen loss at high temperatures, and its thermal stability decreases. The thermal stability of tungsten oxide is the key to its high-temperature applications, which directly affects its reliability in harsh environments.

5.10.2 Thermal expansion properties of tungsten oxide

The thermal expansion properties of tungsten oxide are an important aspect of its thermal properties, reflecting its dimensional stability under temperature changes. Taking tungsten trioxide (WO_3) as an example, its coefficient of thermal expansion is between 6 × 810^{-6} K^{-1}, which is a low-expansion material, making it excellent in high-temperature devices.

The coefficient of thermal expansion of tungsten oxide in monoclinic forms varies slightly due to the asymmetry of the crystal axis, for example, about 8×10^{-6} K^{-1} along the c-axis and slightly lower along the a- and b-axis ($6\text{-}7\times10^{-6}$ K^{-1}). This low expansion is due to the strong bonding of the WO_6 octahedron, which limits the thermal vibration of the crystal lattice. Tungsten oxide prepared by tungstic acid has stable thermal expansion performance and is suitable for precision parts. Tungsten dioxide (WO_2) has a slightly lower coefficient of thermal expansion ($5\text{-}7\times10^{-6}$ K^{-1}), while blue and purple tungsten oxide have slightly higher oxygen vacancies.

The thermal expansion properties of tungsten oxide are affected by the topography. The expansion of bulk tungsten oxide is uniform, while the thermal expansion coefficient of nanoscale tungsten oxide may increase by 10-20% due to the grain boundary effect, and it is easy to deform. In practical applications, the low thermal expansion of tungsten oxide allows it to reduce thermal stress cracking in tungsten copper composites. The thermal expansion of tungsten oxide is an important supplement to its thermal properties, which ensures its stability in the environment of temperature changes.

5.11 Gas sensitivity of tungsten oxide

The gas sensitivity of tungsten oxide refers to its ability to change its electrical properties in a specific gas environment, which is a key characteristic of its application in the field of gas sensors. For example, tungsten trioxide (WO_3), a common form of tungsten oxide, is an n-type semiconductor with high sensitivity to oxidizing gases (e.g., NO_2) and reducing gases (e.g., H_2S), which is due to its surface adsorption and electron transfer mechanisms.

The gas sensitivity of tungsten trioxide mainly depends on its crystal structure and surface properties. Due to the asymmetrical arrangement of WO_6 octahedron of monoclinic tungsten oxide, there are a large number of coordination unsaturated tungsten and oxygen atoms on the surface, which can effectively adsorb gas molecules. For example, in the NO_2 environment, tungsten oxide traps electrons on the surface, the conductivity decreases, and the sensitivity can reach tens of times. Hexagonal tungsten oxide is more gas-sensitive due to its channel structure and higher specific surface area, especially in the form of nanorods or nanosheets, and responds faster to low concentrations of gases (such as ppm-level CO). Blue tungsten oxide and purple tungsten oxide, which have more oxygen vacancies, further improve their gas sensitivity due to the increase of surface active sites.

The gas sensitivity of tungsten oxide is affected by temperature and topography. At an operating temperature of 200-400° C, it has the best gas sensitivity, as thermal excitation enhances gas adsorption and electron transfer. Due to its high specific surface area and short carrier path, nanoscale tungsten oxide has a shorter response time to a gas of seconds and a faster recovery time. For example, in tungsten powder-based sensors, nano-tungsten oxide can detect H_2 with a sensitivity of more than 100. In contrast, bulk tungsten oxide is less gas-sensitive and responds more slowly due to fewer active sites.

In practical applications, tungsten oxide's gas sensitivity makes it excellent for environmental monitoring and industrial safety. For example, tungsten copper is compounded with tungsten oxide to improve electrical conductivity and further optimize sensor performance. The gas sensitivity of tungsten oxide is an extension of its electrical properties, which reflects its practical value in gas detection.

5.12 Redox reaction of tungsten oxide

The redox reaction of tungsten oxide is an important embodiment of its chemical properties, reflecting its transformation ability between different oxidation states. Taking tungsten trioxide (WO_3) as an example, as a high-oxidation compound,

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it can be reduced to a low-oxidation state (such as WO_2) or tungsten metal, and can also oxidize other substances, which is its basic reaction in metallurgy and catalysis.

In the reduction reaction, tungsten trioxide exhibits significant redox activity in a hydrogen atmosphere. For example, at 700-900° C, tungsten trioxide gradually loses oxygen to form blue tungsten oxide ($WO_{2.9}$), purple tungsten oxide , which is finally converted to tungsten metal at 1000-1200 ° C, and the reaction is: $WO_3 + 3H_2 \rightarrow W + 3H_2O$. This step-by-step reduction process is the core step in the industrial production of tungsten filaments, and the increase in oxygen vacancies is accompanied by a change in crystal structure from monoclinic to a looser morphology. The reduction rate is closely related to temperature and hydrogen concentration, and high temperatures accelerate the reaction, but may cause particle agglomeration.

Tungsten oxide can also be involved in the reaction as an oxidizing agent. For example, tungsten dioxide (WO_2) can be oxidized to tungsten trioxide when heated to 500-700° C in oxygen or air with the following reaction: $2WO_2 + O_2 \rightarrow 2WO_3$. This oxidation reaction is often used as an intermediate step in tungstate preparation. Due to the high surface area, nanoscale tungsten oxide has a faster reduction and oxidation reaction rate, but the stability is slightly inferior. Oxygen vacancies play a key role in redox reactions, for example, blue tungsten oxide is more easily reduced due to defective states.

In practical applications, the redox reaction of tungsten oxide is widely used in tungsten metallurgy and catalyst regeneration. CTIA GROUP LTD improves the conversion efficiency of tungsten oxide in the tungsten market by optimizing reduction conditions such as atmosphere and temperature. The redox reaction of tungsten oxide is at the heart of its chemical activity, demonstrating its versatility in industry.

5.13 Acid-base reaction of tungsten oxide

The acid-base reaction of tungsten oxide is an important aspect of its chemical properties, reflecting the characteristics of its amphoteric oxides, which can react with acids or bases to form corresponding tungsten compounds. Taking tungsten trioxide (WO_3) as an example, its acid-base reaction ability makes it play an important role in hydrometallurgy and tungsten chemical preparation.

Under acidic conditions, tungsten trioxide has limited reactivity as it is almost insoluble in water. In dilute acids such as HCl or H_2SO_4, tungsten trioxide has very low solubility and trace amounts of tungstic acid may be formed only on the surface. However, in concentrated acids (e.g., HNO_3), tungsten trioxide can react slowly to form tungstic acid in the following reactions: $WO_3 + H_2O \rightarrow H_2WO_4$. This reaction is utilized in the refining of wolframite or scheelite to convert tungsten oxide into soluble compounds through acid leaching. Tungsten dioxide (WO_2) is slightly more reactive in acids because it is more soluble due to its low oxidation state structure.

Under alkaline conditions, tungsten oxide exhibits higher reactivity. Tungsten trioxide reacts with a strong base (such as NaOH) to form sodium tungstate, and the reaction is: $WO_3 + 2NaOH \rightarrow Na_2WO_4 + H_2O$. In a concentrated alkaline solution at 80° C, the reaction is completed quickly to produce water-soluble tungstate. This property is a fundamental step in the industrial production of ammonium paratungstate. Due to the high surface area of nanoscale tungsten oxide, the alkali reaction rate is faster, but it may be accompanied by local structural damage. Blue tungsten oxide and purple tungsten oxide are similar in alkali reactivity, but dissolve more thoroughly due to more oxygen vacancies.

In practical applications, the acid-base reaction of tungsten oxide is used in the extraction and purification of tungsten. The acid-base reaction of tungsten oxide reflects its amphoteric properties and chemical flexibility, which is the key to its wet processing.

5.14 Catalytic properties of tungsten oxide

The catalytic performance of tungsten oxide is a high-level embodiment of its chemical properties, which makes it widely used in the fields of photocatalysis, thermal catalysis and electrocatalysis. Taking tungsten trioxide (WO_3), a common form of tungsten oxide, as an example, its catalytic performance is due to its semiconducting properties, high surface area and surface-active sites, which are its core advantages in the field of environmental protection and energy.

Tungsten trioxide has outstanding photocatalytic performance because its band gap (2.5-2.8 eV) is suitable for absorbing ultraviolet light and some visible light. On light, tungsten oxide generates photogenerated electron-hole pairs that decompose water or degrade organic pollutants. For example, monoclinic tungsten oxide can decompose methylene blue with an efficiency of more than 90% under ultraviolet light. Hexagonal tungsten oxide nano tungsten oxide has higher catalytic activity due to its channel structure and high specific surface area, and is often used for hydrogen production by photolysis of water. Blue tungsten oxide and purple tungsten oxide have stronger photocatalytic performance due to the extended light absorption into the near-infrared region due to oxygen vacancies.

The thermocatalytic properties of tungsten oxide are excellent in high-temperature reactions. For example, at 500-700° C, tungsten trioxide catalyzes the oxidation or dehydrogenation of hydrocarbons due to the strong oxidizing properties of oxygen atoms on its surface. Due to the large number of active sites and higher thermal catalytic efficiency, nanoscale tungsten oxide is often combined with calcium tungstate to improve stability. In the field of electrocatalysis, tungsten oxide is used as a catalyst for oxygen evolution reactions (OER) and performs well in alkaline electrolytes due to its high conductivity and stability.

In practical applications, the catalytic performance of tungsten oxide has attracted much attention in pollution control and new energy. For example, tungsten plastic-based catalysts use their high activity to decompose VOCs. CTIA GROUP LTD optimizes the catalytic performance of tungsten oxide in tungsten price by manipulating the crystal structure and morphology. the catalytic properties of tungsten oxide are a concentrated reflection of its chemical properties, demonstrating its potential in modern technology.

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Chapter 6 Preparation Method of Tungsten Oxide

6.1 Traditional preparation methods of tungsten oxide

The traditional preparation method of tungsten oxide is a common technical means in industry and laboratory, aiming to prepare tungsten oxide with specific properties through a simple and efficient process. Taking tungsten trioxide (yellow tungsten oxide) as an example, its traditional preparation methods include high-temperature solid-phase reaction method, sol-gel method and hydrothermal method, etc., which have their own characteristics and are suitable for different application scenarios, such as tungsten powder production, photocatalyst preparation, etc.

The high-temperature solid-phase reaction method is the most common traditional method in the industry, which usually uses ammonium paratungstate or tungstic acid as raw material and calcines and decomposes at high temperature to produce tungsten oxide. This method is simple and has high yield, which is suitable for large-scale production of tungsten metal precursor materials, but the product particles are large (micron-scale) and have a low specific surface area. The sol-gel method prepares tungsten oxide by solution chemical reaction, and the raw material is mostly sodium tungstate or tungsten aloxide, and the product is obtained by heat treatment after solization and gelation. This method can prepare nanoscale tungsten oxide with uniform particles, which is suitable for high-precision applications, but the process is complex and the cost is high.

Hydrothermal method is another traditional preparation method, which uses a high-temperature and high-pressure aqueous solution environment to synthesize tungsten oxide in a reaction kettle using ammonium metatungstate or tungstate as raw materials. This method can generate tungsten oxide with special morphologies such as nanorods and nanosheets, and the crystal form is controllable (such as hexagonal or monoclinic crystal form), which is widely used in photocatalysts and sensor materials. The hydrothermal method has the advantages of high purity and morphology control, but the reaction time is longer and the equipment requirements are higher.

In practice, the choice of traditional preparation methods depends on the nature and use of the target product. Laboratories prefer sol-gel and hydrothermal methods to prepare high-performance tungsten products. The traditional preparation method of tungsten oxide has laid the foundation for its industrialization and functionalization, and each has its own advantages and limitations.

6.1.1 The traditional preparation method of tungsten oxide - high temperature solid-phase reaction method

The high-temperature solid-phase reaction method is one of the most traditional and widely used methods for the preparation of tungsten oxide, which is known for its simple process, low cost and high yield. Taking tungsten trioxide (WO_3) as an example, this method is commonly used in the industrial production of tungsten wire and tungsten metal precursors by calcining tungsten-containing raw materials at high temperatures to decompose or oxidize them to form tungsten oxide.

Typical feedstocks for this method include ammonium paratungstate (APT) and tungstic acid. Taking ammonium paratungstate as an example, it is calcined at 500-700 ° C in air and decomposed into tungsten trioxide, and the reaction is: $(NH_4)_{10}(H_2W_{12}O_{42})\cdot 4H_2O \rightarrow 12WO_3 + 10NH_3 + 7H_2O$。 The resulting tungsten oxide is mostly monoclinic crystal form, with a particle size between 1 and 10 μm, and the color is yellow (i.e., yellow tungsten oxide). If calcined in a hydrogen reducing atmosphere, blue tungsten oxide ($WO_{2.}$) can be generated$_9$) or purple tungsten oxide, the oxygen vacancy content varies with temperature and atmosphere (refer to Tungsten Research). Tungstic acid is directly decomposed into tungsten oxide at 600-800 ° C, and the reaction is: $H_2WO_4 \rightarrow WO_3 + H_2O$, the product is of high purity, but the particles are coarse.

The advantage of the high-temperature solid-phase reaction method is that the equipment is simple (e.g. muffle furnace is sufficient), which is suitable for large-scale production. Calcination temperature and holding time are key parameters, for example, tungsten oxide with high crystallinity can be obtained by holding at 600° C for 2 hours, while excess grain growth may occur above 800° C. Atmosphere control is also crucial, with oxidizing atmospheres (e.g., air) generating tungsten trioxide and reducing atmospheres (e.g., H_2/N_2 mixtures) generating integer tungsten oxide. This method is widely used in the processing of tungsten compounds extracted from wolframite or scheelite.

However, the limitations of this method are that the product has a large particle size and a low specific surface area (typically < 10 m²/g), making it unsuitable for applications that require high activity, such as photocatalysts. CTIA GROUP LTD improves the quality of tungsten oxide in tungsten companies by optimizing calcination conditions such as gradient temperature rise. The high-temperature solid-phase reaction method is the cornerstone of tungsten oxide industrial preparation, which is simple and efficient, but has limited morphology control.

6.1.2 Traditional preparation method of tungsten oxide-sol-gel method/sol-gel preparation method of tungsten oxide

The sol-gel method is a traditional method for the preparation of tungsten oxide by chemical reaction of solution, and is known for its ability to produce nanoscale and high-purity tungsten oxide. Tungsten trioxide (WO_3), for example, is a method that generates homogeneous particles or thin films through sol formation, gelation, and heat treatment steps, suitable for photocatalysts, sensors, and electrochromic materials.

Typical feedstocks for this method include sodium tungstate and tungsten alkoxides (e.g., tungsten ethanol). Taking sodium tungstate as an example, first dissolve it in water, add acid (such as HCl) to adjust the pH to 1-2, and hydrolyze sodium tungstate to form tungstic acid sol, the reaction is: $Na_2WO_4 + 2HCl \rightarrow H_2WO_4 + 2NaCl$。 The sol gradually aggregates into a gel under stirring or standing, followed by drying (100-150 ° C) and heat treatment (400-600 ° C) to generate tungsten oxide. Most of the obtained products are monoclinic crystal forms, the particle size can be controlled at 10-50 nm, and the specific surface area is as high as 50-100 m²/g. Tungsten alkoxide is directly formed by alcoholization and polycondensation, and tungsten oxide is formed after heat treatment, which is higher purity but higher cost.

The advantage of the sol-gel method is that the product particles are small and homogeneous, and the morphology can be manipulated by the addition of a template agent (e.g., surfactant), e.g. for the preparation of porous tungsten oxide or thin films. For example, tungsten oxide films for electrochromic can be prepared by spinning gels on glass substrates with thicknesses down to the nanometer level. Heat treatment temperature and time are key parameters, 500° C for 2 hours can yield moderate crystallinity of tungsten oxide, while too high temperature (e.g., 800° C) may cause grain growth. The atmosphere is usually air, but an inert atmosphere (e.g., N_2) reduces impurities.

The limitations of this method are that the process is complex, the cycle is long, and the cost of raw materials is high, so it is not suitable for large-scale industrial production. In the laboratory, the sol-gel method is often used to prepare nano-tungsten oxide, e.g. by tungsten plastic composite to improve performance. The sol-gel method is the traditional choice for high-precision preparation of tungsten oxide, which combines flexibility and finesse.

6.1.3 Traditional preparation method of tungsten oxide - hydrothermal method

Hydrothermal method is a traditional method for preparing tungsten oxide using a high-temperature and high-pressure aqueous solution environment, which is known for its ability to generate special morphology and high crystallinity products. Taking tungsten trioxide (WO_3) as an example, this method prepares tungsten oxide in the form of nanorods, nanosheets or nanoflowers by reacting tungsten-containing precursors in a closed reaction kettle, which is widely used in photocatalysts and battery materials.

Typical feedstocks for the hydrothermal process include ammonium metatungstate and [sodium tungstate]. Taking ammonium metatungstate as an example, dissolve it in water, add acid (such as HNO_3) to adjust the pH to 2-4, form a precursor solution, and react at 150-200 ° C and high pressure (1-5 MPa) for 12-24 hours to generate tungsten oxide. The reaction is: $(NH_4)_5H_5[H_2(WO_4)_6] \rightarrow WO_3 + NH_3 + H_2O$. The resulting tungsten oxide is mostly hexagonal, and its morphology can be modified by adding structure directing agents (e.g., CTAB), such as the generation of nanorods with a diameter of 20-50 nm. Sodium tungstate forms monoclinic tungsten oxide under similar conditions, and the particles are more uniform.

The advantages of the hydrothermal method are that the crystal form and morphology are controllable, the specific surface area of the product is high (50-150 m²/g), and the crystallinity is good. Reaction temperature, time, and pH are key parameters, for example, hexagonal crystalline nanorods can be obtained by a reaction at 180° C for 24 hours, while amorphous tungsten oxide may be formed by a short reaction at 120° C. The pressure is self-generated through the reactor, accelerating nucleation and growth. The high-pressure environment also reduces oxygen vacancies and ensures product purity. If blue or purple tungsten oxide is required, a reducing agent (e.g. $NaBH_4$) can be added to the post-treatment.

The limitations of this method are the high equipment requirements (e.g., high-pressure reactors) and the long reaction cycle, which makes it unsuitable for large-scale production. Industrially, the hydrothermal method is mostly used to prepare high value-added tungsten oxide, such as: Calcium tungstate Composites. CTIA GROUP LTD improves tungsten oxide by optimizing hydrothermal conditions Tungsten chemicals performance. The hydrothermal method is a traditional tool for tungsten oxide nanofabrication, which has both high quality and diversity.

6.1.4 The traditional preparation method of tungsten oxide - ammonium tungstate method

Ammonium tungstate method is one of the traditional methods for the preparation of tungsten oxide, which is widely used in industry and laboratory because of its easy availability of raw materials and mature technology. Taking tungsten trioxide (yellow tungsten oxide) as an example, this method generates tungsten oxide through chemical conversion or heat treatment of ammonium tungstate, which is often used as a precursor material for the production of tungsten powder and tungsten wire.

The ammonium tungstate method usually uses ammonium paratungstate (APT) or ammonium metatungstate as raw materials. Taking ammonium paratungstate as an example, it reacts with acids (such as HCl) in solution to form insoluble tungstic acid precipitate, which is then converted into tungsten oxide by heat treatment. The typical process is: ammonium paratungstate is dissolved in water, hydrochloric acid is added to adjust the pH to 2-3 to generate tungstic acid, and the reaction is: $(NH_4)_{10}(H_2W_{12}O_{42})\cdot 4H_2O+10HCl \rightarrow 12H_2WO_4+10NH_4Cl$。 Subsequently, tungstic acid is calcined at 400-600 °C to decompose into tungsten oxide: $H_2WO_4 \rightarrow WO_3+H_2O$. The obtained tungsten oxide is mostly monoclinic crystal type, with a particle size of 1-5μm, bright yellow color and high purity.

The advantage of this method is that the process is simple and the raw materials are widely available, such as tungsten compounds extracted from wolframite or scheelite. Acidity, reaction temperature and calcination conditions are key parameters, e.g. too low a pH can lead to precipitation of impurities, and too high a calcination temperature (e.g. 800°C) can cause grain growth. Ammonium metatungstate reacts faster under similar conditions, because its molecular structure is easier to decompose, and it is suitable for the preparation of fine-grained tungsten oxide. If blue tungsten oxide is required, the product can be treated in a reducing atmosphere (e.g. H_2).

The limitation of the ammonium tungstate method is that the product has a large particle size and a low specific surface area (5-20 m^2/g), which is not suitable for high-activity applications. The ammonium tungstate method is a classic process for the traditional preparation of tungsten oxide, which has both high efficiency and economy.

6.1.5 Traditional preparation method of tungsten oxide - hydrochloric acid decomposition method of tungstate

The hydrochloric acid decomposition method of tungstate is a traditional wet chemical method for the preparation of tungsten oxide, which is known for its high purity and controllability. Taking tungsten trioxide (WO_3) as an example, this method reacts tungstate (such as sodium tungstate) with hydrochloric acid to produce tungsten oxide or its precursors, which is often used in laboratories and fine chemical fields.

The typical process of this method is as follows: sodium tungstate is dissolved in water, the concentration is usually 0.1-0.5 mol/L, hydrochloric acid (1-2 mol/L) is slowly added, the pH is adjusted to 1-2, and the tungstic acid precipitate is generated, and the reaction is: $Na_2WO_4 + 2HCl \rightarrow H_2WO_4 + 2NaCl$. After washing and filtration, tungstic acid is calcined and decomposed into tungsten oxide at 400-600 ° C: $H_2WO_4 \rightarrow WO_3 + H_2O$. Most of the tungsten oxide obtained is monoclinic crystal form, the particle size is 0.5-2 μm, and the purity can reach more than 99%. If nanoscale tungsten oxide is required, a surfactant (e.g., CTAB) can be added to the reaction to control the particle size to 50-100 nm.

The advantages of the hydrochloric acid decomposition method of tungstate are that the product is of high purity and fine particles, which is suitable for the preparation of high-quality tungsten chemicals. Reaction conditions are critical, e.g. too low pH (<1) may lead to heterophase formation, and too high calcination temperature (e.g., 700° C) can lead to grain agglomeration. Sodium tungstate is widely sourced and is often processed from calcium tungstate. If heat treated in a reducing atmosphere, purple tungsten oxide can be produced for specific catalytic applications. The concentration of the solution and the acceleration of drops also affect the morphology of the products, and the slow dropping can obtain more uniform particles.

The limitation of this method is that there are many process steps, and the cost of waste liquid treatment is high, which is not suitable for large-scale industrial production. In the laboratory, this method is often used to prepare high-purity tungsten oxide, e.g. as a reinforcing phase in tungsten plastic composites. CTIA GROUP LTD improves the quality of tungsten oxide in tungsten companies by optimizing reaction parameters. The hydrochloric acid decomposition method of tungstate is a high-purity option for the traditional preparation of tungsten oxide, which is both delicate and controllable.

6.1.6 The traditional preparation method of tungsten oxide – thermal decomposition method of ammonium paratungstate

The thermal decomposition method of ammonium paratungstate is a traditional high-temperature process for the preparation of tungsten oxide, which is widely used for its directness and industrial applicability. Taking tungsten trioxide (WO_3) as an example, this method decomposes ammonium paratungstate (APT) to generate tungsten oxide at high temperatures, which is the main way to produce tungsten metal and tungsten wire precursors in industry.

The process flow is as follows: ammonium paratungstate is placed in a muffle furnace, calcined at 500-700 ° C in the air for 2-4 hours, decomposed into tungsten oxide, and the reaction is: $(NH_4)_{10}(H_2W_{12}O_{42})\cdot 4H_2O \rightarrow 12WO_3 + 10NH_3 + 7H_2O$。 The resulting tungsten oxide is monoclinic with a particle size of 1-10 μm and a bright yellow color (i.e., yellow tungsten oxide). If calcined in a hydrogen atmosphere, blue tungsten oxide ($WO_{2.}$) is formed$_9$) or purple tungsten oxide , the oxygen vacancy content increases with temperature and reduction time. Ammonium paratungstate is usually extracted from scheelite and has high purity and stable decomposition products.

The advantages of this method are that the process is simple, the equipment requirements are low (e.g. ordinary calciners), and it is suitable for large-scale production. Calcination temperature and atmosphere are key parameters, for example, high crystallinity tungsten oxide is generated in air at 600° C, and integer tungsten oxide is formed in hydrogen at 800° C. The holding time affects the particle size, with fine particles being formed in a short period (1 hour) and grains growing in a long period (4 hours). The purity and moisture content of the raw material also affect the quality of the product, and 99.9% tungsten oxide can be obtained from high-purity ammonium paratungstate.

The limitation is that the product has large particles and a low specific surface area (2-10 m²/g), making it unsuitable for nano applications. Industrially, CTIA GROUP LTD Tungsten oxide is optimized by gradient heating and atmosphere control Tungsten price performance. The thermal decomposition of ammonium paratungstate is the industrial backbone of the traditional preparation of tungsten oxide, which is efficient and economical.

6.2 New preparation methods of tungsten oxide

The new preparation method of tungsten oxide is an advanced technology developed on the basis of traditional technology, aiming to prepare high-performance tungsten oxide with special morphology to meet the needs of modern science and technology. Taking tungsten trioxide (WO_3), a common form of tungsten oxide, as an example, new methods include vapor deposition, microwave-assisted and electrochemical deposition, which pay more attention to nano and functionalization than traditional methods.

Vapor deposition (e.g., chemical vapor deposition, CVD) is the decomposition and deposition of tungsten oxide on a high-temperature substrate by a gaseous tungsten precursor (e.g., WF_6), and is commonly used in the preparation of thin films or nanowires. For example, at 500-700° C, WF_6 reacts with oxygen to form a tungsten oxide film with the following reaction: $WF_6 + 3/2O_2 \rightarrow WO_3 + 3F_2$. The resulting product has high crystallinity and a controllable thickness to the nanometer level, which is suitable for electrochromic devices. The microwave-assisted method uses microwave heating to accelerate the reaction, and uses tungstic acid as raw material to quickly generate nano-tungsten oxide in solution, the reaction time is shortened to several minutes, and the specific surface area can reach 100 m^2/g.

Electrochemical deposition is the electrolysis of tungsten-containing solutions (e.g., sodium tungstate) to deposit tungsten oxide on electrodes. For example, at 1-3 V, tungstate ions are reduced at the cathode and deposited as a thin film of tungsten oxide with tunable morphology (e.g., nanosheets or porous structures), suitable for battery electrodes. The new method can also prepare special tungsten oxide, such as cesium-tungsten bronze, which can be doped to improve photothermal properties. The products of these methods are of high purity and diverse morphology, but the equipment is complex and the cost is high.

6.2.1 A new preparation method for tungsten oxide - electrochemical deposition method

Electrochemical deposition is a new method for the preparation of tungsten oxide, which has attracted much attention in modern materials science due to its high efficiency, controllability and morphological diversity. Taking tungsten trioxide (yellow tungsten oxide) as an example, this method is used to deposit tungsten oxide on the surface of the electrode by electrolyzing a tungsten-containing solution, which is often used to prepare thin films or nanostructures, and is suitable for electrochromic devices, battery electrodes and sensors.

The typical process of this method is to prepare an electrolyte of 0.01-0.1 mol/L using sodium tungstate or tungstic acid as raw material, and add acid (such as H_2SO_4) to adjust the pH to 1-3. Under a direct current electric field (1-3 V), tungstate ions are reduced at the cathode and deposited as tungsten oxide with the following reaction: $WO_4^{2-} + 2H^+ + 2e^- \rightarrow WO_3 + H_2O$. The resulting tungsten oxide is mostly monoclinic crystal form, and its morphology can be modified by electrolytic conditions, such as low voltage (1 V) to form dense thin films, and high voltage (3 V) to generate porous structures. After deposition, it is usually heat treated at 300-500° C to improve crystallinity and stability.

The advantages of electrochemical deposition are that the process is simple, the topography is controllable, and tungsten oxide films can be generated directly on conductive substrates such as ITO glass. Electrolyte concentration, voltage, and deposition time are key parameters, e.g., 0.05 mol/L sodium tungstate deposition at 2 V for 30 minutes yields a homogeneous film with a thickness of about 200 nm. With the addition of a template (e.g., polyethylene glycol), nanorods or nanosheets can be prepared with a specific surface area of 50-100 m^2/g. The electrode material also influences the product, e.g. tungsten oxide deposited on a tungsten copper electrode is more conductive.

The limitation of this method is that it has a low yield, which is suitable for small-scale high-precision preparation, and is not suitable for industrial mass production. In the laboratory, electrochemical deposition is often used to prepare functional thin films of tungsten chemicals, e.g. as an electrode material in batteries to improve cycling performance. Electrochemical deposition is a new and efficient way to prepare tungsten oxide, which is both accurate and functional.

6.2.2 A new preparation method for tungsten oxide - vapor deposition method

Vapor deposition is an advanced novel method for the preparation of tungsten oxide thin films or nanostructures, which excels in the field of optoelectronic devices and catalysis due to its high purity, high crystallinity, and substrate compatibility. Tungsten trioxide (WO_3), for example, is often used to produce tungsten filament coatings or photocatalytic thin films by decomposing and depositing gaseous tungsten precursors at high temperatures.

Typical processes for this method include chemical vapor deposition (CVD) and physical vapor deposition (PVD). In the case of CVD, tungsten metal or tungsten compounds (e.g., WF_6) are used as precursors and deposited on a substrate (e.g., silicon wafer) at 400-700° C in an oxygen atmosphere, with the following reaction:

$WF_6 + 3/2O_2 \rightarrow WO_3 + 3F_2$. The resulting tungsten oxide is a monoclinic crystalline film with a thickness of 10-500 nm and high crystallinity. PVD reacts in oxygen to form tungsten oxide by sputtering tungsten powder target, which is suitable for the preparation of ultra-thin films. If nanowires are required, this can be achieved by adjusting the airflow and temperature (e.g., 600° C, low pressure).

The advantages of the vapor deposition method are the high purity of the product (>99.9%), the variety of morphologies (thin films, nanowires, nanoparticles), and the ability to precisely control the thickness. Deposition temperature, air pressure, and oxygen flow are key parameters, e.g. 500° C, low oxygen flow rates generate dense films, and high temperatures and high flow rates generate porous structures. If doped with calcium tungstate, the photocatalytic performance can be improved. The choice of substrate is also important, for example, tungsten oxide deposited on a [tungsten copper] substrate is more conductive.

The limitations of this method are that the equipment is complex (e.g., vacuum systems), the cost is high, and it is not suitable for mass production. Industrially, vapor deposition is mostly used for high value-added applications, such as the preparation of photoelectric coatings in the tungsten market. CTIA GROUP LTD improves the quality of tungsten oxide in tungsten companies by optimizing deposition conditions. Vapor deposition is a new precision process for the preparation of tungsten oxide, which is suitable for high-tech fields.

6.2.3 A new preparation method of tungsten oxide - biological template method

The biotemplate method is an emerging new method for the preparation of tungsten oxide using natural biological structures, which has attracted much attention in the field of nanomaterials due to its environmental protection and unique morphology. Taking tungsten trioxide (WO_3) as an example, this method guides the deposition and transformation of tungsten precursors through biological templates (such as bacteria and plant fibers) to generate porous or complex structure of tungsten oxide, which is suitable for photocatalysts and energy storage materials.

The typical process of this method is as follows: sodium tungstate or ammonium metatungstate is used as tungsten source, a 0.1-0.5 mol/L solution is prepared, and a biological template (such as cellulose or protein) is immersed in it to adsorb tungsten ions on the surface of the template. Subsequently, by heat treatment (400-600 ° C) or hydrothermal reaction (150-200 ° C), the template decomposes and generates tungsten oxide. For example, a bacterial cellulose template is used to calcinate at 500° C after 12 hours of water heat at 180° C to obtain porous tungsten oxide with a pore size of 20-100 nm and a specific surface area of 80-150 m^2/g. The obtained tungsten oxide is mostly monoclinic or hexagonal crystal form, and the morphology inherits the template structure.

The advantages of the biological template method are that it is environmentally friendly, and the product has a unique morphology (e.g., porous, reticulated), which is suitable for high-activity applications. Template type and reaction conditions are key, e.g. plant fibers generate macroporous structures, and bacterial templates generate nanoscale pores. If a reducing agent (e.g. glucose) is added, blue tungsten oxide or purple tungsten oxide can be prepared. The heat treatment temperature affects the pore preservation, and too high (e.g. 800° C) may destroy the porous structure. The solution concentration and impregnation time also affect the tungsten loading, and high-purity tungsten oxide can be obtained after optimization. The limitation of this method is that the template preparation is complex and the yield is low, which is not suitable for industrial scale production. In the laboratory, the biotemplate method is often used to prepare tungsten plastic-based catalysts to enhance the photocatalytic performance.

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CTIA GROUP LTD

Yellow Tungsten Trioxide (**YTO,** WO_3) **Product Introduction**

1. Product Overview

CTIA GROUP LTD yellow tungsten trioxide is produced by high-temperature calcination process of ammonium paratungstate, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. WO_3 is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants. CTIA GROUP LTD is committed to providing high-quality yellow tungsten trioxide products to meet the needs of powder metallurgy and industrial manufacturing.

2. product characteristics

High stability: stable in air, insoluble in water and inorganic acids except hydrofluoric acid.
Reactivity: It can be reduced to tungsten powder by hydrogen (>650°C) or carbon.
Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Product specifications

index	CTIA GROUP LTD yellow tungsten trioxide first-class product standard
WO_3 content (wt%)	≥99.95
Impurities （wt%，max.）	Fe≤0.0010, Mo≤0.0020, Si≤0.0010, Al≤0.0005, Ca≤0.0010, Mg≤0.0005, K≤0.0010, Na≤0.0010, S≤0.0005, P≤0.0005
Particle size	1-10（μm，FSSS）
Loose density	2.0-2.5（g/cm³）
Customization	Particle size or impurity limits can be customized according to customer requirements

4. Packaging and warranty

Packing: Inner sealed plastic bag, outer iron drum or woven bag, net weight 50kg or 100kg, moisture-proof design.
Warranty: Each batch comes with a quality certificate, including WO_3 content, impurity analysis, particle size (FSSS method), loose density and moisture data.

5. Procurement information

Email: sales@chinatungsten.com
Phone: +86 592 5129696
For more yellow tungsten oxide information, please visit the China Tungsten online website www.tungsten-powder.com. For more market and real-time information, please follow the WeChat public account "China Tungsten Online".

CTIA GROUP LTDyellow tungsten oxide

Chapter VII Tungsten Oxide Production Equipment

7.1 The main equipment for tungsten oxide production

The production of tungsten oxide involves multiple process steps, and its main equipment is the key to achieving the process from raw material processing to finished product preparation. Taking tungsten trioxide, a common form of tungsten oxide, as an example, the main equipment includes raw material processing equipment, reaction equipment and post-processing equipment, which work together to ensure production efficiency and product quality, and are widely used in the industrial production of tungsten powder and tungsten wire.

Raw material handling equipment is the first step in production and is used to convert ores such as wolframite or scheelite into granular or solution states suitable for subsequent reactions. It mainly includes crushers, mills and screening equipment for crushing, classifying and purifying raw materials. For example, a jaw crusher crushes the ore down to the centimeter level, and a ball mill grinds it further to the micron level, ensuring that the raw material particles are uniform and convenient for subsequent leaching or calcination. These equipment need to be wear-resistant and have a high processing capacity to cope with the harder tungsten ore.

Reaction equipment is at the heart of tungsten oxide production and is used for chemical conversion or thermal decomposition. Taking the thermal decomposition method of ammonium paratungstate as an example, the muffle furnace or rotary kiln calcines the raw material at 500-700 ° C to generate tungsten oxide. Muffle furnace is suitable for small batch production, with high temperature control accuracy (±5° C); The rotary kiln is suitable for continuous production, with an output of up to tonnage. For the production of blue tungsten oxide or purple tungsten oxide, it needs to be equipped with a hydrogen reduction device to control the atmosphere and temperature. The wet process uses a reactor, such as an acid leaching or alkali dissolution plant, to convert tungstic acid into a tungsten oxide precursor.

Post-processing equipment is used for the refining and forming of tungsten oxide, including drying furnaces, screening machines and presses. The drying oven dries the wet-prepared tungsten oxide to a powder state at a temperature of 100-200° C to avoid agglomeration. The screening machine separates tungsten oxide with different particle sizes to meet the diverse needs of the tungsten market. Presses, on the other hand, press the powder into lumps for easy transport or further processing.

7.1.1 Raw material handling equipment

Raw material handling equipment is the first step in tungsten oxide production, which is used to process tungsten-containing ores or compounds into forms suitable for subsequent reactions. Taking tungsten trioxide production as an example, the raw material processing equipment includes crushing and grinding equipment, screening and grading equipment, and auxiliary equipment, which are used to process raw materials such as scheelite or ammonium paratungstate to ensure that the particle size and purity meet the process requirements.

Crushing and grinding equipment is responsible for crushing raw ore or coarse particles to size. For example, a jaw crusher crushes wolframite to 5-10 cm, a hammer crusher further reduces it to 1-2 cm, and then a ball mill or rod mill grinds it to 50-200 μm. This staged crushing and grinding process improves the efficiency of subsequent leaching, as fine particles increase the surface area and promote chemical reactions. The equipment should be made of wear-resistant steel or ceramic to resist the high hardness of tungsten ore (Mohs hardness 5-7). For chemical raw materials such as tungstate, the need for grinding is low, and only light grinding is usually required.

Screening and grading equipment is used to separate raw materials with different particle sizes and improve product quality. A vibrating screen or air classifier sorts the ground particles by size, e.g. < 100 μm of fine powder for hydrometallurgy and 100 μm of coarse powder > returned for grinding. In wet processes, a settling tank or centrifuge classifies particles in the suspension to ensure homogeneity. For the production of nanoscale tungsten oxide, it needs to be equipped with ultra-fine screening equipment (such as ultrasonic sieves) with an accuracy of 10-50 μm. These devices have a direct impact on the particle distribution of tungsten chemicals.

Ancillary equipment includes conveyors, dust collectors, and storage silos. Belt conveyors transport raw materials to each process, and dust collectors (such as bag filters) collect the dust generated by grinding to ensure environmental safety. The storage of processed raw materials ranges from a few tons to tens of tons. CTIA GROUP LTD has improved the production efficiency of tungsten oxide in tungsten companies by optimizing the raw material handling equipment. Raw material handling equipment is the cornerstone of tungsten oxide production, ensuring that the subsequent process runs smoothly.

7.1.1.1 Crushing and grinding equipment

Crushing and grinding equipment is the core equipment for raw material processing in tungsten oxide production, and is used to crush tungsten-containing ores or coarse particles to a size suitable for subsequent processing. Taking tungsten oxide production as an example, these equipment processes hard raw materials such as wolframite or scheelite to provide fine particles for wet leaching or thermal decomposition, which is an important part of the production of tungsten metal and tungsten powder.

Crushing equipment mainly includes jaw crusher, cone crusher and hammer crusher. The jaw crusher is the main primary crushing force, crushing ore from 50-100 cm to 5-10 cm, with a processing capacity of 100-500 t/h, suitable for tungsten ore with high hardness (Mohs hardness 5-7). The cone crusher is used for secondary crushing, reducing particles to 1-3 cm with a high crushing ratio and suitable for continuous production. The hammer crusher is suitable for softer tungsten compounds (such as calcium tungstate), which can be crushed to 1-2 cm at one time, with a simple structure but high wear resistance. The equipment lining plate is mostly made of manganese steel or high-chromium alloy to prolong the service life.

Grinding equipment includes ball mills, rod mills, and vibratory mills. The ball mill is the most commonly used equipment, grinding the crushed particles to 50-200 μm, the grinding medium is steel balls or ceramic balls, and the speed and pellet-to-material ratio (e.g. 10:1) affect the particle fineness. The rod mill is suitable for wet grinding, and the product size is uniform (100-300 μm),

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which is often used in preparation before hydrometallurgy. Vibratory mills are used for ultrafine grinding up to 10-50 μm, which is suitable for the preparation of nanoscale tungsten oxide, but the energy consumption is high. Mill linings require wear-resistant materials such as alumina to reduce contamination.

The choice of crushing and grinding equipment depends on the nature of the raw material and the target particle size. For example, the production of tungsten plastic requires ultra-fine particles, and vibrating mills are preferred; Ball mills are mostly used on industrial scales. Crushing and grinding equipment is the backbone of tungsten oxide raw material treatment, which directly affects the subsequent process effect.

7.1.1.2 Screening and grading equipment

Screening and grading equipment is an important part of raw material processing in tungsten oxide production, used to separate crushed and ground particles and ensure that the particle size distribution meets the process requirements. Taking the production of tungsten trioxide as an example, these equipment processes ammonium paratungstate or ore powder to provide a homogeneous raw material for subsequent reactions, which is a critical step in the preparation of tungsten chemicals and tungsten filaments.

The screening equipment mainly includes vibrating screens, trommel screens and ultrasonic screens. Vibrating screens are the most commonly used equipment, where the particles are divided into different grades by means of multi-layer screens (pore size 10 μm-5 mm), e.g. < 100 μm fines are screened out for hydrometallurgy and 200 μm coarse powders are > returned for grinding. The frequency of vibrations (1000-3000 vibrations/min) and the material of the screen (e.g. stainless steel) affect the separation efficiency. Trommel screens are suitable for high-volume screening with a capacity of 50-200 t/h, and are often used in the industrial production of tungsten powder precursors. Ultrasonic sieves are used for ultrafine particles (<50 μm) and are suitable for the preparation of nano-tungsten oxide by means of ultrasonic vibration to prevent clogging.

Grading equipment includes airflow classifiers and centrifuges. The air classifier uses the air flow to separate the particles by size, for example, at a wind speed of 10-100 m/s, separating 20-50 μm fine powder, which is suitable for the production of high-purity tungsten oxide. Centrifuges are used for wet classification, where centrifugal force (500-2000 g) is used to separate particles in suspension, often in combination with wet grinding, with a classification range of 10-300 μm. These devices ensure uniform particle size and improve tungstate conversion efficiency.

The performance of screening and grading equipment has a direct impact on product quality. For example, particles that are too fine may increase dust losses, while particles that are too coarse may reduce reaction efficiency. CTIA GROUP LTD OPTIMIZES THE PARTICLE DISTRIBUTION OF TUNGSTEN OXIDE IN TUNGSTEN PRODUCTS BY INTEGRATING HIGH-EFFICIENCY SCREENING AND GRADING EQUIPMENT. Screening and grading equipment is an important guarantee for tungsten oxide production, ensuring the quality of raw materials and process stability.

7.1.2 Reaction equipment

Reaction equipment is the core equipment in tungsten oxide production, which is used to realize the chemical or physical transformation from raw materials to tungsten oxide. Taking tungsten trioxide (yellow tungsten oxide) as an example, the reaction equipment includes alkaline hydrolysis and acidolysis equipment, calcination and thermal decomposition equipment and auxiliary reaction devices, which are widely used in the industrial production of tungsten powder and tungsten wire to ensure the high efficiency of the process and product quality.

Alkali hydrolysis and acid hydrolysis equipment is used in hydrometallurgy to convert ores such as wolframite or scheelite into soluble tungsten compounds or tungstic acid. Alkali hydrolysis equipment (such as high-pressure reactor) treats ore with sodium hydroxide at high temperature and high pressure to generate sodium tungstate, which is suitable for treating insoluble ores. Acidolysis equipment (such as acid-resistant reaction tank) uses hydrochloric acid or nitric acid to leach tungstic acid, which is suitable for calcium tungstate and other raw materials. These machines are required to be made of corrosion-resistant materials such as stainless steel or enamel, and are equipped with mixing and heating systems with capacities ranging from tens of liters to several tons.

Calcination and pyrolysis equipment is used to convert precursors such as ammonium paratungstate or tungstic acid into tungsten oxide. The muffle furnace is suitable for small batch production, with a temperature control of 400-800° C and an accuracy of ±5° C, suitable for laboratory or high-purity tungsten oxide preparation. Rotary kilns are used for industrial continuous production, with a length of 10-50 meters and a capacity of several tons per day, which can produce blue tungsten oxide or purple tungsten oxide in an air or hydrogen atmosphere. These devices require high temperature resistance and atmosphere control systems to ensure reaction uniformity and product crystallinity.

Auxiliary reaction units include gas supply systems (e.g., hydrogen or oxygen pipelines), agitators, and temperature control devices. The gas supply system regulates the reaction atmosphere, e.g. hydrogen for the reduction of tungsten oxide, at a flow rate of 0.1-10 m^3/h. The stirrer ensures that the solution reacts uniformly and that a temperature control device (such as a thermocouple) maintains the reaction conditions. Reaction equipment is the technical core of tungsten oxide production, which directly affects the conversion efficiency and product performance.

7.1.2.1 Alkali hydrolysis and acidolysis equipment

Alkali hydrolysis and acid hydrolysis equipment is a key reaction equipment in the wet process of tungsten oxide production, which is used to convert tungsten-containing raw materials into soluble intermediates or directly generate tungsten oxide precursors. Taking the production of tungsten trioxide as an example, these equipment processes raw materials such as scheelite or ammonium paratungstate, and realizes the extraction of tungsten through alkaline or acidic media, which is an important part of the preparation of tungsten chemicals .

The alkali hydrolysis equipment mainly includes a high-pressure reactor and an atmospheric stirring tank. The high-pressure reactor is used to process insoluble ores (such as wolframite), and the ore is decomposed with sodium hydroxide (10-20% concentration) at 150-200 ° C and 1-5 MPa to generate [sodium tungstate], and the reaction is: $CaWO_4 + 2NaOH \rightarrow Na_2WO_4 + Ca(OH)_2$。 The equipment is made of alkali-resistant stainless steel (e.g. 316L) with volumes ranging from 50 L to several thousand liters, and is equipped with a high-pressure sealing and heating system, while the atmospheric stirring tank is used for subsequent solution adjustment, and the stirring speed is 100-500 rpm to ensure a homogeneous reaction. Alkaline hydrolysis plants are suitable for high-recovery processes, but consume more energy.

The acidolysis plant includes an acid-resistant reaction tank and a filtration unit. Tungstic acid is leached with hydrochloric acid or nitric acid (1-6 mol/L), e.g. from tungstate: $Na_2WO_4 + 2HCl \rightarrow H_2WO_4 + 2NaCl$。 The tank is made of enamel or PTFE, highly corrosion-resistant, with a volume of 10-1000 L, equipped with an agitator (50-200 rpm) and a heating device (50-100° C). Filtration devices (e.g., plate and frame filter presses) separate tungstic acid precipitates with a processing capacity of 1-10 t/h to ensure product purity. If tungsten oxide is to be generated directly, tungstic acid can be further calcined.

Alkali hydrolysis and acid hydrolysis equipment need to be selected according to the properties of raw materials. For example, scheelite is mostly alkalinized, and calcium tungstate is acidized. CTIA GROUP LTD improves tungsten oxide production efficiency in tungsten companies by optimizing equipment design, such as adding a pressure-resistant layer. Alkali hydrolysis and acid hydrolysis equipment is the basis of the tungsten oxide wet process, which ensures the efficient extraction and conversion of tungsten.

7.1.2.2 Calcination and thermal decomposition equipment

Calcination and thermal decomposition equipment is the core reaction equipment in the production of tungsten oxide, which is used to convert precursor heat treatment into tungsten oxide, which is a key link in the dry process. Taking the production of tungsten trioxide as an example, these equipment processes ammonium paratungstate or tungstic acid to produce tungsten oxide through high-temperature decomposition, which is widely used in the production of tungsten metal and tungsten powder precursors.

The calcination equipment mainly includes muffle furnaces and rotary kilns. The muffle furnace is suitable for small batches or laboratory production, with a temperature range of 300-1000 ° C, a temperature control accuracy of ± 5 ° C, and a volume of 10-500 L. For example, ammonium paratungstate is calcined at 500-700 ° C for 2-4 hours to produce tungsten trioxide: $(NH_4)_{10}(H_2W_{12}O_{42})\cdot 4H_2O \rightarrow 12WO_3 + 10NH_3 + 7H_2O$。 The rotary kiln is used for industrial continuous production, with a length of 10-50 meters, an inner diameter of 1-3 meters, a temperature of 400-800 ° C, and an output of up to 1-10 t/day. The rotary kiln is equipped with a rotary drive (1-5 rpm) and an atmosphere control system to generate yellow tungsten oxide in air and blue or purple tungsten oxide in hydrogen.

Thermal decomposition equipment requires high-temperature resistant materials (e.g. refractory bricks or nickel-based alloys) and is equipped with an exhaust gas treatment unit (e.g. scrubber) to treat NH_3 or H_2O produced by decomposition. Temperature and atmosphere are key parameters, e.g. 600° C air atmosphere to produce high crystallinity tungsten oxide, 800° C hydrogen atmosphere to produce integer tungsten oxide. The holding time affects the particle size, resulting in 1-5 μm particles in 2 hours and 10 μm particles in 4 hours. If nanoscale tungsten oxide is required, it can be combined with spray drying pretreatment.

Calcination and thermal decomposition equipment has the advantage of simple process and high yield, but high energy consumption and limited particle control. Calcination and thermal decomposition equipment is the backbone of the tungsten oxide dry process, ensuring efficient conversion and industrial suitability.

7.1.3 Separation and purification equipment

Separation and purification equipment is the key equipment in the production of tungsten oxide, which is used to extract and refine tungsten oxide or its precursors from the reaction products. Taking tungsten trioxide (yellow tungsten oxide) as an example, these equipment include solid-liquid separation equipment and crystallization and recrystallization equipment, which are widely used in hydrometallurgy and dry process to ensure the purity and quality of tungsten powder and tungsten filament precursors.

Solid-liquid separation equipment is used to separate solids (e.g. tungstic acid) from liquids (e.g. waste liquid) generated by reactions. Typical equipment includes plate-and-frame filter presses and centrifuges, which filter suspensions at a pressure (0.5-1 MPa) with a capacity of 1-10 t/h, suitable for the extraction of tungstic acid from wolframite acid hydrolysate. Centrifuges use centrifugal force (500-2000 g) for fast separation, which is suitable for small batches of high-purity production. These devices need to be made of corrosion-resistant materials such as polypropylene or stainless steel to cope with acidic and alkaline environments. Separation efficiency has a direct impact on subsequent purification.

Crystallization and recrystallization equipment is used to purify soluble tungsten compounds such as sodium tungstate or ammonium paratungstate. By controlling the temperature (20-80° C) and concentration, the crystallization tank allows tungsten compounds to be precipitated from the solution, such as ammonium paratungstate, which crystallizes when cooled to 30° C, with a purity of up to 99.5%. Recrystallization equipment (e.g., evaporation crystallizer) removes impurities through multiple dissolution-crystallization and is suitable for high-purity tungsten oxide production. The equipment is equipped with an agitator (50-200 rpm) and a temperature control system to ensure uniform crystal growth.

The separation and purification equipment needs to be matched to the process. For example, the wet process of producing tungsten chemicals relies on solid-liquid separation, while the dry process focuses on crystallization and purification. Separation and purification equipment is a key link in tungsten oxide production, ensuring product purity and recovery.

7.1.3.1 Solid-liquid separation equipment

Solid-liquid separation equipment is an important equipment for separation and purification in tungsten oxide production, which is used to extract solid products from reaction mixtures. Taking the production of tungsten trioxide as an example, these equipment process the suspension after scheelite acidolysis or alkali hydrolysis and separate tungstic acid or tungsten oxide particles, which is the core step in the preparation of tungsten metal precursors.

Common solid-liquid separation equipment includes plate and frame filter presses, centrifuges, and vacuum filters. The plate and frame filter press presses the solids (such as tungstic acid) in the suspension into a filter cake through pressure (0.5-1.5 MPa), and the filtrate is discharged, with a processing capacity of 1-20 t/h, which is suitable for large-scale production. Centrifuges use high-speed rotation (1000-3000 rpm) to generate centrifugal force (500-2000 g) to quickly separate fine particles, such as tungstic acid from tungstate solutions, and are suitable for high purity requirements. The vacuum filter is filtered by negative pressure (0.01-0.08 MPa), which is suitable for laboratory or small batch production, and the filtration accuracy is up to 1-10 μm.

Equipment needs to be made of corrosion-resistant materials, such as polypropylene filter cloth or 316L stainless steel housing, to handle acidic (e.g., HCl) or alkaline (e.g., NaOH) environments. The pore size (5-50 μm) of the filter media (such as filter cloth or membrane) affects the separation effect, and it is easy to clog if it is too fine, and it is leaking if it is too coarse. Operating parameters such as pressure, rotational speed and filtration time need to be optimized, e.g. a cake with a moisture content of < 20% can be obtained after 30 minutes of filtration at 1 MPa. If drying, it can be combined with tungsten plastic process.

The efficiency of solid-liquid separation equipment directly affects tungsten recovery. For example, centrifuges can recover more than 95% of fine particles. CTIA GROUP LTD optimizes the production process of tungsten oxide in tungsten company by equipping it with a multi-stage solid-liquid separation plant . Solid-liquid separation equipment is the cornerstone of the tungsten oxide wet process, ensuring the efficient extraction of solid products.

7.1.3.2 Crystallization and recrystallization equipment

Crystallization and recrystallization equipment is a key equipment for purification in tungsten oxide production, which is used to precipitate high-purity tungsten compounds from solution. Taking the production of tungsten trioxide as an example, these equipment processes sodium tungstate or ammonium paratungstate solution to generate pure crystals by controlling crystallization conditions, which is an important part of the preparation of high-quality tungsten chemicals.

The crystallization equipment includes a crystallization tank and a cooling crystallizer. The crystallization tank precipitates tungsten compounds by cooling

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or evaporation, for example, ammonium paratungstate solution is cooled from 80 ° C to 30 ° C to precipitate needle-like crystals with a purity of up to 99.5%. The tank volume is 50-5000 L, equipped with an agitator (50-200 rpm) and a temperature control system to ensure uniform crystal growth. The cooling mold accelerates the precipitation by circulating cooling water, which is suitable for continuous production with a processing capacity of 1-10 t/day. If blue tungsten oxide is required, the crystals can be further heat-treated.

The recrystallization equipment includes an evaporation crystallizer and a dissolving tank. The evaporation crystallizer concentrates the solution by heating (50-100° C), recrystallizes after removing impurities, such as sodium tungstate solution evaporates to saturation, and then cools to precipitate high-purity crystals, and the purity can be increased to 99.9%. The dissolving tank is used to redissolve the primary crystals, repeat the crystallization process, and is equipped with corrosion-resistant materials (e.g. enamel) and heating devices. Evaporation rate and cooling rate are key, too fast can lead to crystal defects, and too slow can lead to inefficiency.

The advantage of crystallization and recrystallization equipment is that the purification effect is remarkable, but the energy consumption is high, and it is suitable for high value-added products. Crystallization and recrystallization equipment is a precision tool for tungsten oxide purification, which ensures product quality.

7.2 Auxiliary production equipment for tungsten oxide

Tungsten oxide auxiliary production equipment is a device that supports the main equipment and is used for material transportation, environmental control and finished product processing. Taking tungsten trioxide production as an example, these equipment include material handling equipment, dust removal equipment and packaging equipment to ensure the continuity and safety of tungsten metal and tungsten powder production lines.

Material handling equipment is responsible for the transportation of raw materials, intermediates and finished products, including mechanical conveying equipment (such as belt conveyors) and pneumatic conveying equipment (such as air flow pipes) to ensure that all processes are seamless. Dust removal equipment (such as bag filters) collects dust from grinding or calcination with a processing capacity of 10-100 m³/min, which meets environmental protection requirements. Packaging equipment (such as automatic bagging machine) fills tungsten oxide powder into bags or barrels with an efficiency of 100-500 bags/hour, which is suitable for the diverse packaging needs of the tungsten market.

The auxiliary device must match the main device. For example, the conveying equipment needs to be wear-resistant and adapt to hard particles such as calcium tungstate; The dust collection equipment needs to filter < 10 μm dust efficiently. CTIA GROUP LTD increases the production efficiency of tungsten oxide in tungsten products by integrating auxiliary production equipment. The auxiliary production equipment of tungsten oxide is the guarantee of the production line and optimizes the overall process flow.

7.2.1 Material handling equipment

Material handling equipment is an important equipment for tungsten oxide auxiliary production, which is used to transport raw materials, intermediates and finished products between various processes. Taking tungsten trioxide production as an example, these equipment include mechanical conveying equipment and pneumatic conveying equipment to process materials such as scheelite or tungstic acid to ensure the continuity of tungsten chemical production lines.

Mechanical conveying equipment such as belt conveyors and screw conveyors transport granules or powders from crushing to reaction processes with a conveying capacity of 10-500 t/h, suitable for mass production. Pneumatic conveying equipment, such as air flow pipes, uses compressed air (0.1-0.5 MPa) to transport fine powders (such as tungsten powder), suitable for long-distance or closed transmission. The conveying equipment needs to be made of wear-resistant materials (such as rubber belts or stainless steel pipes) to cope with the high hardness of the tungsten material. The choice of material handling equipment depends on the nature of the material and the layout of the process. For example, screw conveyors are used for wet materials, and pneumatic conveyors are used for dry powders. Material handling equipment is the link between tungsten oxide production and ensures a smooth process.

7.2.1.1 Mechanical conveying equipment

Mechanical conveying equipment is the main auxiliary equipment for material transportation in tungsten oxide production, which is used for short-distance and large-scale transportation. Taking tungsten trioxide production as an example, these equipment include belt conveyors, screw conveyors and bucket elevators, which handle materials such as wolframite or tungstic acid, and are an important support for tungsten metal production lines.

The belt conveyor transports materials via rubber or polyester belts with a width of 0.5-2 m, a speed of 1-5 m/s and a conveying capacity of 50-1000 t/h, suitable for continuous transfer from crushing to grinding. The screw conveyor uses a rotating screw to push materials, with a pipe diameter of 0.1-0.5 m and a conveying capacity of 1-50 t/h, which is suitable for wet materials or powders (such as tungstate). The bucket elevator lifts materials vertically with a height of 5-50 m, which is suitable for space-constrained scenarios. The equipment needs wear-resistant liners (e.g. manganese steel) to reduce wear.

The advantages of mechanical conveying equipment are simple structure and easy maintenance, but it is not suitable for long-distance or fine powder transportation. CTIA GROUP LTD is equipped with high-efficiency mechanical conveying equipment to improve the production efficiency of tungsten oxide in the tungsten price. Mechanical conveying equipment is a reliable assistant in tungsten oxide production and ensures the flow of materials.

7.2.1.2 Pneumatic conveying equipment

Pneumatic conveying equipment is an advanced auxiliary equipment for material transportation in tungsten oxide production, which uses air flow to transport fine particles. Taking tungsten trioxide production as an example, these equipment include positive pressure pneumatic conveying systems and negative pressure pneumatic conveying systems, which process tungsten powder or purple tungsten oxide, which is suitable for the closed transmission of tungsten chemicals.

The positive pressure pneumatic conveying system pushes the material to the target point through compressed air (0.1-0.5 MPa), with a pipe diameter of 50-300 mm, a conveying distance of 10-500 m, and a capacity of 1-50 t/h, which is suitable for long-distance transportation. The negative pressure pneumatic conveying system uses a vacuum pump (0.01-0.08 MPa) to suction material over a shorter distance, but with better dust control, making it suitable for laboratories or clean environments. The pipes are made of stainless steel or polyurethane, which are wear-resistant and anti-clogging. Pneumatic conveying equipment has the advantage of being airtight and free of dust leakage, but it consumes more energy and requires regular cleaning of the pipeline. Pneumatic conveying equipment is an efficient support for tungsten oxide production and increases the level of process modernization.

7.2.2 Drying and cooling equipment

Drying and cooling equipment is an important auxiliary equipment in the production of tungsten oxide, which is used to treat the moisture and temperature of reaction products or intermediates. Take tungsten trioxide (yellow tungsten oxide) as an example, these equipment include drying equipment and cooling equipment, which are widely used in the production of tungsten powder and tungsten wire to ensure that the physical state of the material meets the needs of subsequent processing or storage.

Drying equipment is used to remove water from wet-prepared tungsten oxide or precursors such as tungstic acid. Typical equipment includes a spray dryer and an oven, the spray dryer atomizes the suspension and then instantly dries it in hot air (150-300 ° C), with a processing capacity of 1-10 t/h, and the resulting powder has a uniform particle size (10-50 μm), which is suitable for continuous production. The oven is statically dried at 100-200° C with a volume of 50-5000 L, suitable for small batches or high-purity tungsten oxide, with a drying time of 2-8 hours. Drying equipment needs to be temperature controlled accurately (±5° C) and corrosion-resistant materials (such as stainless steel) to avoid agglomeration caused by moisture residue.

Cooling equipment is used to reduce the high temperature state of tungsten oxide after calcination or drying, to prevent oxidation or to facilitate packaging. Common equipment includes a cooling drum that reduces tungsten oxide from 500° C to 50° C by rotating the drum and cold air (20-50° C) with a capacity of 5-20 t/h. The fluidized bed cooler uses an air stream (0.5-2 m/s) to cool fine powders, suitable for blue tungsten oxide or purple tungsten oxide, with uniform cooling and anti-caking. The equipment needs an efficient heat exchange system to ensure that the temperature drops quickly.

Drying and cooling equipment needs to be matched to the process. For example, the wet production of tungsten chemicals relies on spray drying, while the dry process requires cooling of the drum. Drying and cooling equipment is the auxiliary pillar of tungsten oxide production, ensuring the stability and processability of the material.

7.2.2.1 Drying equipment

Drying equipment is a key auxiliary equipment in the production of tungsten oxide, which is used to remove water from wet preparation products. In the case of tungsten trioxide production, for example, these equipment processes the crystallization products of tungstic acid or ammonium paratungstate solution after scheelite acidolysis to ensure the dry state of tungsten metal precursors.

Common drying equipment includes spray dryers, ovens, and vacuum dryers. The spray dryer atomizes the suspension through a high-pressure nozzle (0.5-2 MPa), and the water is evaporated instantaneously by hot air (150-300° C), with a processing capacity of 1-10 t/h, and the resulting powder particle size is 10-50 μm, which is suitable for continuous production of tungsten powder. The oven is statically dried at 100-200 ° C, with a volume of 50-5000 L and a drying time of 2-8 hours, which is suitable for small batches of high-purity tungsten oxide. The vacuum dryer operates at a negative pressure of 0.01-0.08 MPa and 50-100° C, which is suitable for heat-sensitive materials such as tungstate and avoids high-temperature decomposition.

Drying equipment requires corrosion-resistant materials (e.g. 316L stainless steel) and a precise temperature control system (±5° C) to prevent residues or overheating agglomeration. Hot air flow, feed rate and temperature are key parameters, e.g. a spray dryer can produce a powder with a moisture content of <1% at a 5 L/min feed at 200° C. If nanoscale tungsten oxide is required, the drying temperature can be reduced to 150° C to reduce particle coalescence. The equipment also needs to be equipped with a dust collector (e.g. a cyclone separator) to recover the fines.

The efficiency of the drying equipment directly affects the quality of the product. For example, a spray dryer can quickly dry tungsten acid into a homogeneous powder, improving the efficiency of subsequent calcination. CTIA GROUP LTD improves the quality of tungsten oxide production in tungsten companies by optimizing drying plant parameters. The drying equipment is the guarantee of the tungsten oxide wet process, which ensures the drying and fluidity of the powder.

7.2.2.2 Cooling equipment

Cooling equipment is an important auxiliary equipment in the production of tungsten oxide, which is used to reduce the temperature of high-temperature products or intermediates. Taking the production of tungsten trioxide as an example, these equipment processes the calcined tungsten oxide or tungsten powder and reduces it from 500-800° C to room temperature, which is a necessary part of the preparation of tungsten chemicals and tungsten filament.

Common cooling equipment includes cooling drums, fluidized bed coolers, and water-cooled screw machines. The cooling drum cools tungsten oxide by rotating the cylinder (1-5 rpm) and cold air (20-50° C), with a diameter of 0.5-2 m and a processing capacity of 5-20 t/h, which is suitable for high-volume production. The fluidized bed cooler uses an air stream (0.5-2 m/s) to suspend and cool the powder from 600° C to 50° C for 10-30 minutes, and is suitable for blue or purple tungsten oxide, with uniform cooling and anti-caking. The water-cooled screw machine pushes the cooling material through the water-cooled jacket (10-30° C) and the screw, which is suitable for small-scale or continuous production.

Cooling equipment requires efficient heat exchanger systems (e.g., copper tube heat exchangers) and high-temperature resistant materials (e.g., refractory steel) to ensure rapid cooling and prevent oxidation. The cooling medium (air or water), the flow rate and the length of the equipment are key, e.g. the cooling drum can handle 10 t/h tungsten oxide at a wind speed of 1 m/s. If the temperature drops too slowly, it may lead to a reduction in oxygen vacancies, which will affect the performance of tungsten plastic. The equipment also needs to be dust-proof to avoid powder loss.

The performance of the cooling equipment affects the subsequent processing and storage. For example, a fluidized bed cooler keeps the powder loose for easy packaging. The cooling equipment is the stabilizer of tungsten oxide production, which ensures the physical state of the material.

7.2.3 Environmental protection treatment equipment

Environmental protection treatment equipment is a necessary auxiliary equipment in the production of tungsten oxide, which is used to treat the waste gas and wastewater generated in the production process. In the case of tungsten trioxide production, for example, these facilities include exhaust gas treatment equipment and wastewater treatment equipment to treat contaminants from wolframite or ammonium paratungstate reactions, ensuring compliance with environmental standards and supporting the sustainable development of the tungsten market.

Waste gas treatment plants treat NH_3, SO_2 or dust from calcination or acidolysis. The bag filter collects fine dust (<10 μm) with a processing capacity of 10-100 m^3/min and an efficiency of more than 99%. The scrubber absorbs acidic gases (such as HCl) with lye (e.g., NaOH) at a height of 5-20 m and a gas velocity of 1-3 m/s to ensure that the discharge meets the standard. The wastewater treatment equipment treats acid and alkali waste liquid or heavy metal ions, neutralizes the acid wastewater (pH 2-4 to 7-8) with lime in the sedimentation tank, and precipitates tungsten residue with a treatment capacity of 10-1000 m^3/h.

Environmentally friendly treatment equipment requires corrosion-resistant materials (such as PP or FRP) and high-efficiency filtration systems to ensure a contaminant removal rate of > 95%. Operating parameters such as liquid-gas ratio (2-5 L/m^3) and sedimentation time (1-4 hours) need to be optimized. If calcium tungstate waste is involved, an additional ion exchange device is required to remove Ca^{2+}. CTIA GROUP LTD has improved the green production level of tungsten oxide in tungsten products through the integration of environmental protection equipment . The environmental protection treatment equipment is the environmental protection guarantee of tungsten oxide production, which reduces the environmental impact and enhances the competitiveness of the enterprise.

7.2.3.1 Waste gas treatment equipment

Waste gas treatment equipment is an environmental auxiliary equipment in the production of tungsten oxide, which is used to treat the waste gas produced by reaction and calcination. Taking tungsten trioxide production as an example, these equipment treats NH_3, HCl or dust produced by scheelite acidolysis or tungstic acid thermal decomposition to ensure that the emission meets environmental protection standards, which is the green guarantee for tungsten chemical production.

Common waste gas treatment equipment includes baghouses, scrubbers, and activated carbon adsorbers. The bag filter captures dust through a polyester filter bag (pore size 1-5 μm), with a processing capacity of 10-100 m^3/min and a removal rate of >99%, which is suitable for tungsten powder grinding process. The scrubber absorbs acidic gases (such as SO_2) with lye (5-10% NaOH) spray, with a diameter of 1-3 m, a liquid-gas ratio of 2-5 L/m^3, and a treatment capacity of 50-500 m^3/h. Activated carbon adsorbers adsorb volatiles (e.g. solvent residues) and are suitable for small-scale waste gas treatment.

The equipment requires corrosion-resistant materials (e.g. FRP) and high-efficiency filtration systems to ensure that the exhaust gases are discharged up to standard (e.g. NH_3<10 mg/m^3). Air volume, spray flow and bag change intervals are key, for example, the scrubber can handle 200 m^3/h of exhaust gas at a speed of 3 m^3/s. CTIA GROUP LTD optimizes the environmental performance of tungsten oxide in tungsten companies by equipping it with multi-stage exhaust gas treatment equipment. The exhaust gas treatment equipment is an environmental barrier for tungsten oxide production and ensures air quality.

7.2.3.2 Wastewater treatment equipment

Wastewater treatment equipment is an environmentally friendly auxiliary equipment in tungsten oxide production, which is used to treat wastewater generated by wet processes. Taking tungsten trioxide production as an example, these equipment treats acid and alkali waste liquid and heavy metal ions after the reaction of sodium tungstate or ammonium paratungstate to ensure that the wastewater is discharged up to standard, which is the key to green production in the tungsten market.

Common wastewater treatment equipment includes neutralization sedimentation tanks, ion exchange columns, and membrane separation devices. The neutralization sedimentation tank neutralizes acidic wastewater (pH 2-4 to 7-8) with lime or NaOH, precipitates tungsten residues and heavy metals (e.g. Pb^{2+}), with a tank capacity of 10-1000 m³ and a treatment capacity of 5-500 m³/h. The ion exchange column adsorbs residual tungsten ions (e.g., WO_4^{2-}) through resin, and the tungsten content of the effluent is < 1 mg/L, which is suitable for high purity requirements. Membrane separation devices (e.g., reverse osmosis) filter trace impurities with a capacity of 1-100 m³/h and a recovery rate of >90%.

Wastewater treatment equipment requires corrosion-resistant materials (such as PE or PVC) and high-efficiency sedimentation systems to ensure a > 95% removal rate of COD and heavy metals. The amount of neutralizer (0.1-1 kg/m³) and the sedimentation time (1-4 hours) need to be optimized. If calcium tungstate is contained in wastewater, flocculant should be added to improve the sedimentation efficiency. Wastewater treatment equipment is the cornerstone of environmental protection in tungsten oxide production, ensuring water security.

CTIA GROUP LTD

Yellow Tungsten Trioxide (**YTO,** WO_3) **Product Introduction**

1. Product Overview

CTIA GROUP LTD yellow tungsten trioxide is produced by high-temperature calcination process of ammonium paratungstate, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. WO_3 is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants. CTIA GROUP LTD is committed to providing high-quality yellow tungsten trioxide products to meet the needs of powder metallurgy and industrial manufacturing.

2. product characteristics

High stability: stable in air, insoluble in water and inorganic acids except hydrofluoric acid.
Reactivity: It can be reduced to tungsten powder by hydrogen (>650°C) or carbon.
Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Product specifications

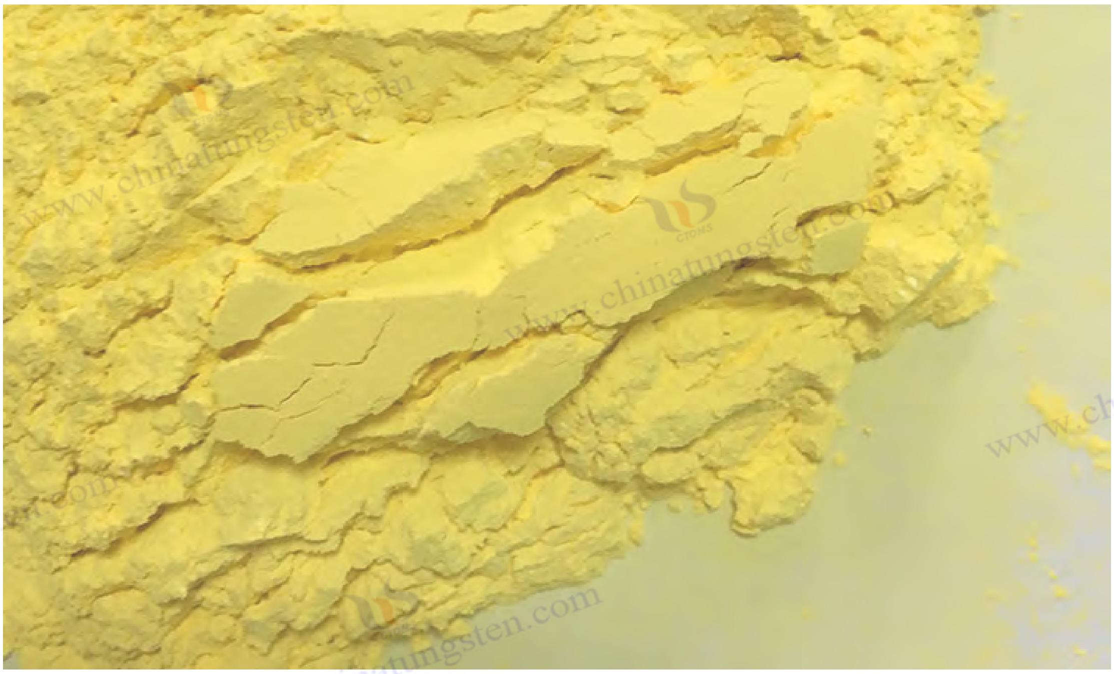
index	CTIA GROUP LTD yellow tungsten trioxide first-class product standard
WO_3 content (wt%)	≥99.95
Impurities （wt%，max.）	Fe≤0.0010, Mo≤0.0020, Si≤0.0010, Al≤0.0005, Ca≤0.0010, Mg≤0.0005, K≤0.0010, Na≤0.0010, S≤0.0005, P≤0.0005
Particle size	1-10（μm，FSSS）
Loose density	2.0-2.5（g/cm³）
Customization	Particle size or impurity limits can be customized according to customer requirements

4. Packaging and warranty

Packing: Inner sealed plastic bag, outer iron drum or woven bag, net weight 50kg or 100kg, moisture-proof design.
Warranty: Each batch comes with a quality certificate, including WO_3 content, impurity analysis, particle size (FSSS method), loose density and moisture data.

5. Procurement information

Email: sales@chinatungsten.com
Phone: +86 592 5129696
For more yellow tungsten oxide information, please visit the China Tungsten online website www.tungsten-powder.com. For more market and real-time information, please follow the WeChat public account "China Tungsten Online".



CTIA GROUP LTD yellow tungsten oxide

Chapter 8 Research on the Detection Principle of Tungsten Oxide

8.1 Tungsten Oxide Detection-Spectroscopy

Spectroscopy is an important technique for the detection of tungsten oxide, revealing its composition, structure and properties by analyzing its interaction with electromagnetic waves of a specific wavelength. Taking tungsten trioxide (yellow tungsten oxide) as an example, spectroscopic analysis methods include X-ray fluorescence spectroscopy (XRF), Raman spectroscopy and ultraviolet-visible spectroscopy, etc., which are widely used in the quality control and research of tungsten powder and tungsten filament.

X-ray fluorescence spectroscopy (XRF) excites the atoms in tungsten oxide by X-rays, detects its characteristic fluorescence rays, and quantitatively analyzes the content of tungsten and impurity elements. For example, a tungsten trioxide sample shows a Kα line of tungsten (about 59 keV) in XRF, which can be used to determine its purity (>99%) and trace elements (e.g., Fe, Ca). This method is non-destructive, fast, and suitable for industrial inspection of products in the tungsten market. Instruments such as handheld XRF analyzers have detection limits as low as ppm and a hands-on time of just a few minutes.

Raman spectroscopy excites the molecular vibration of tungsten oxide by laser to analyze its crystal structure and chemical bond characteristics. For example, the monoclinic form of tungsten trioxide shows Raman peaks of the W-O-W bond at

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807 cm^{-1} and 717 cm^{-1}, which can distinguish the structural difference from blue tungsten oxide or purple tungsten oxide. This method is sensitive to crystal form and is suitable for studying the microscopic properties of tungsten chemicals. Raman spectrometers (e.g., 532 nm lasers) have high resolution and are capable of detecting nanoscale samples.

Ultraviolet-visible spectroscopy (UV-Vis) was used to detect the light absorption characteristics of tungsten oxide, reflecting its band gap and optical properties. Tungsten trioxide has an absorption edge of 400-450 nm and an energy band gap of about 2.5-2.8 eV, which can be used to verify its photocatalytic performance. Instruments such as spectrophotometers with detection wavelengths ranging from 200 to 800 nm are suitable for laboratory analysis. Spectroscopy is the scientific cornerstone of tungsten oxide detection, providing multi-dimensional information.

8.1.1 Tungsten Oxide Detection - X-ray Fluorescence Spectroscopy Analysis

X-ray fluorescence spectroscopy (XRF) is a highly efficient spectroscopic method for the detection of tungsten oxide, which excites sample atoms by X-rays, measures their characteristic fluorescence rays, and analyzes the elemental composition and content. Taking tungsten trioxide production as an example, XRF is used to detect the purity of tungsten oxide after wolframite or scheelite processing, and is a key technology for tungsten metal quality control.

The detection principle of XRF is based on atomic level transitions. X-rays (energy 10-50 keV) irradiate tungsten oxide to excite the inner electrons of the tungsten atom (e.g., L shell), and emit characteristic fluorescence when the outer electrons fill the vacancies, such as the Kα line (59.3 keV) and Kβ line (67.2 keV) of tungsten. Fluorescence intensity can be recorded by a detector (e.g., Si(Li) detector) to quantify tungsten content (accuracy ± 0.1%) and impurity elements (e.g., Kα line of Fe, 6.4 keV). Instruments such as benchtop XRF analyzers with power of 50-100 W and detection limits down to the ppm range are suitable for rapid analysis.

The strength of XRF lies in its non-destructive, fast, and multi-element detection capabilities. For example, the detection of tungsten oxide produced by calcination of ammonium paratungstate can confirm the tungsten content > 99.5% and identify trace amounts of Mo or Si within 5 minutes. Sample preparation is simple, either as a powder tablet or as a direct block, but a standard (e.g., pure WO_3) needs to be calibrated to avoid matrix effects. If calcium tungstate is detected, the Ca content can be analyzed at the same time to verify the purity of the raw material. Instrument parameters such as tube voltage (40-60kV) and current (1-2mA) need to be optimized to ensure sensitivity.

The limitation of XRF is that it is not sensitive to light elements such as O, and it is necessary to confirm the oxidation state in combination with other methods. INDUSTRIALLY, CTIA GROUP LTD USES XRF TO MONITOR THE QUALITY CONSISTENCY OF TUNGSTEN OXIDE IN TUNGSTEN PRICES. X-ray fluorescence spectroscopy is the industry benchmark for tungsten oxide detection, providing fast and reliable elemental information.

8.1.2 Tungsten oxide detection - Raman spectroscopy

Raman spectroscopy is an important spectroscopic method for the detection of tungsten oxide, which excites the molecular vibration of the sample by laser to analyze its crystal structure and chemical bond characteristics. Taking the production of tungsten trioxide as an example, Raman spectroscopy is used to distinguish the tungsten oxide crystal form generated by tungsten acid pyrolysis, which is a precise tool for studying the microscopic properties of tungsten chemicals and tungsten powder.

The detection principle of Raman spectroscopy is based on the inelastic scattering of light. A laser (e.g., 532 nm or 785 nm) irradiates tungsten oxide to excite the vibration of the W-O bonds, and the wavelength shift of the scattered light reflects the molecular characteristics. For example, the Raman peaks of the tungsten trioxide monoclinic crystal form are 807 cm^{-1} (W-O-W telescopic vibration) and 717 cm^{-1} (W-O flexural vibration), and the hexagonal crystal form has a characteristic peak around 690 cm^{-1}. If blue tungsten oxide or purple tungsten oxide is detected, the defect state can be judged if the oxygen vacancy causes an increase in peak width or displacement. Instruments such as Raman microscopy with a resolution of <1 cm^{-1} are suitable for microanalysis.

The advantage of Raman spectroscopy is its high sensitivity and non-destructiveness. Detection of tungstate Converted tungsten oxide can confirm the crystal form in seconds, and can be measured directly from powder or film without complex sample preparation. The laser power (1-50 mW) and integration time (5-60 s) need to be adjusted to avoid overheating the sample. For example, for the detection of nano-tungsten oxide, a 10 mW laser and a 20 s integration provide clear resolution of the W-O bond peak. If the sample contains fluorescent impurities (e.g., organic residues), the background should be suppressed with a 785 nm laser. The limitation of Raman spectroscopy is that there is no direct information on the content of metal elements, so it needs to be used in conjunction with XRF.

8.2 Tungsten oxide detection - electrochemical analysis

Tungsten oxide (WO_3) is an important functional material, which is widely used in catalysts, sensors, energy storage materials and other fields due to its unique properties in light, electricity and heat. In order to accurately characterize and detect their properties, electrochemical analysis has become an efficient and sensitive method. Electrochemical analysis is based on the electrochemical properties of a substance in solution, and analyzes the composition and concentration of a substance by measuring the electrical parameters (such as current, potential, or electric amount) during the electrode reaction. This method is particularly suitable for studying the redox properties of tungsten oxide and its chemical behavior under specific conditions.

The basic principle of electrochemical analysis is derived from electrochemical reactions. In a typical electrochemical system, the cell consists of a working electrode, a reference electrode, and an auxiliary electrode, collectively referred to as a three-electrode system. The working electrode is where the tungsten oxide reacts, the reference electrode (e.g., calomel saturated electrode) is used to provide a stable potential reference, and the auxiliary electrode (e.g., platinum electrode) completes the circuit closure. When an applied potential is applied to the working electrode, tungsten oxide may undergo an oxidation or reduction reaction, producing a measurable current signal. By recording changes in these signals, the concentration of the substance, the reaction mechanism, and the electrochemical properties can be inferred.

When it comes to the detection of tungsten oxide, electrochemical analysis offers significant advantages. First, it is highly sensitive and capable of detecting substances at trace levels, which is particularly important for studying the behavior of tungsten oxide in nanomaterials or thin films. Second, the electrochemical method is easy to operate and the instrument cost is relatively low, making it suitable for laboratory and industrial field applications. In addition, the method provides dynamic information, such as changes in reaction rates and electrode surfaces, which is of great significance for studying the electrochemical behavior of tungsten acid or tungsten chemicals.

Common electrochemical analysis techniques include cyclic voltammetry, polarography, and potentiometric titration. Among them, cyclic voltammetry is often used in the detection of tungsten oxide because of its intuitiveness and wide applicability. Cyclic voltammetry records the current response by applying a potential that changes linearly with time, resulting in a characteristic voltammetry curve. These curves reveal not only the redox potential of tungsten oxide, but also its adsorption or diffusion behavior on the electrode surface.

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For example, when tungsten oxide is used as an electrode material, its volt-ampere curve may show significant oxidation and reduction peaks, indicating its reversible electrochemical reaction properties.

In practical applications, the electrochemical detection of tungsten oxide often requires optimization of experimental conditions. For example, the choice of electrolyte (e.g., sulfuric acid or nitric acid solution) affects reactivity, while the surface state of the electrode material (e.g., tungsten metal or glassy carbon electrode) directly affects detection sensitivity. In addition, studies in the field of tungsten research have shown that the crystal form of tungsten oxide (e.g. monoclinic or orthorhomb) has a significant impact on its electrochemical properties, so it is necessary to clarify the structural properties of the sample before detection.

In order to further improve the detection accuracy, other technologies can be combined. For example, by combining with recent advances in tungsten technology, such as the use of nanostructured tungsten oxide electrodes, signal intensity can be significantly enhanced. In addition, the electrochemical behavior of tungstate also provides theoretical support for the detection of tungsten oxide. For example, electrochemical reactions in sodium tungstate solution can be used as a control experiment to help understand the reaction mechanism of tungsten oxide.

In the field of environmental monitoring, electrochemical testing of tungsten oxide can also be used to evaluate its performance as a sensing material. For example, tungsten oxide-based gas sensors can detect changes in the concentration of specific gases by electrochemical methods. This application is due to the high selectivity of tungsten products in electrochemical reactions. In addition, fluctuations in tungsten prices may also affect the cost of inspection equipment, so economics need to be considered in industrial applications.

However, electrochemical analysis has limitations. For example, poor selectivity can lead to the effects of interfering substances, especially when detecting tungsten oxide in complex matrices. In addition, the electrode surface may be passivated over time, affecting the stability of long-term detection. In response to these problems, the researchers proposed a variety of improvements, such as using tungsten-copper composite electrodes to improve electrical conductivity, or introducing calcium tungstate as a stabilizer.

In conclusion, electrochemical analysis provides a powerful tool for the detection of tungsten oxide. Its high sensitivity, ease of operation and dynamic analysis capabilities make it an important position in academic research and industrial applications of tungsten. By continuously optimizing the experimental conditions and electrode materials, the electrochemical method is expected to further enhance the application value of tungsten oxide detection.

8.2.1 Tungsten oxide detection - voltammetry

Voltammetry is an important branch of electrochemical analysis, which is particularly suitable for detecting the electrochemical properties of tungsten oxide. It measures the relationship between the electrode potential and the current to generate a volt-ampere curve, which enables the qualitative and quantitative analysis of matter. In the detection of tungsten oxide, voltammetry is favored for its high sensitivity and fast response, especially when studying its redox behavior and electrocatalytic properties.

The basic principles of voltammetry are based on Ohm's law and electrochemical reaction kinetics. In experiments, a three-electrode system is usually used: a working electrode (e.g., tungsten metal or tungsten oxide thin film electrode), a reference electrode, and an auxiliary electrode. By applying a time-varying potential, such as a linear sweep or cyclic sweep, the current resulting from the oxidation or reduction reaction of tungsten oxide on the electrode surface is recorded. The resulting current-potential curve (i.e., voltammetry) provides a visual representation of the electrochemical properties of the substance.

Cyclic voltammetry (CV) is one of the most commonly used techniques in the voltammetry detection of tungsten oxide. It generates a symmetrical volt-ampere curve by repeatedly scanning over a range of potentials. For example, when the capacitive properties of tungsten oxide are examined, the volt-ampere curve may be rectangular, indicating that it has excellent electrochemical energy storage capabilities. When studying its catalytic performance, the redox peaks in the curve reveal the specific reaction potential and rate.

The advantages of voltammetry are its ease of operation and informative nature. For tungsten oxide, it can not only determine its concentration, but also analyze its reaction mechanism on the electrode surface. For example, the voltammetry curve of a tungsten oxide electrode prepared from tungsten powder in an acidic electrolyte may show multiple peaks corresponding to different oxidation state transitions. This property is particularly important in tungsten data studies as it helps to understand the polyvalent behavior of tungsten oxide.

Optimization of experimental conditions is essential for voltammetry detection. For example, the choice of scan rate has a direct impact on the shape of the volt-ampere curve and the peak current. In general, a slower scan rate is suitable

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for studying the diffusion control process of tungsten oxide, while a faster scan rate is better for analyzing surface reactions. In addition, the pH and ionic strength of the electrolyte can also affect the test results. For example, in a tungstic acid solution, the voltammetry behavior of tungsten oxide may vary depending on the proton concentration.

The application of voltammetry in tungsten oxide detection is also reflected in its combination with other technologies. For example, by combining with nanotechnology developed by tungsten companies, it is possible to prepare tungsten oxide electrodes with a high surface area, thereby improving detection sensitivity. In addition, the introduction of composite materials such as ferro-tungsten or tungsten plastic can also enhance the stability and conductivity of the electrode.

In practice, voltammetry has been used to test the performance of tungsten oxide in the field of photoelectrocatalysis. For example, by analyzing its volt-ampere curve, it is possible to determine the charge transfer efficiency of tungsten oxide under illumination. This application is of great significance in the tungsten market as it promotes the development of tungsten oxide in the field of new energy.

However, voltammetry also faces some challenges. For example, contamination or aging of the electrode surface can cause signal drift that can affect the repeatability of the assay. In addition, in complex samples, tungsten oxide may overlap with other substances' electrochemical signals, reducing selectivity. To solve these problems, the researchers experimented with using tungsten needles as microelectrodes to reduce interference and improve spatial resolution.

8.3 Other Tungsten Oxide Detection Methods

In addition to electrochemical analysis, tungsten oxide can be detected by a variety of physical and chemical methods. Each of these methods has its own characteristics and is suitable for different application scenarios and inspection needs. In the following, we will discuss in detail other detection techniques other than voltammetry, focusing on their principles, advantages, and limitations, and provide a variety of options for the comprehensive characterization of tungsten oxide.

In the study of tungsten knowledge, spectroscopy is a commonly used non-electrochemical detection method. For example, ultraviolet-visible spectroscopy (UV-Vis) and infrared spectroscopy (IR) can be used to detect the optical properties and chemical bonding characteristics of tungsten oxide. UV-Vis spectroscopy can indirectly estimate the concentration of tungsten oxide by measuring its absorption peaks at specific wavelengths, while IR spectroscopy can identify W-O bond vibrations in its crystal structure. These methods do not require electrode reactions and are particularly suitable for the analysis of yellow or blue tungsten oxide color variations.

X-ray diffraction (XRD) is another important detection technique used to analyze the crystal structure of tungsten oxide. By measuring the diffraction pattern of X-rays, it is possible to determine their crystal form (e.g., monoclinic or hexagonal) and their degree of crystallinity. This method is widely used in the field of tungsten research, especially in the study of tungsten oxide formed by the thermal decomposition of ammonium paratungstate. In addition, XRD can detect impurities in the sample, such as wolframite residues.

Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) focus on the microscopic morphology and particle size analysis of tungsten oxide. SEM provides surface topography information, while TEM provides insight into nanoscale structures. This is particularly important for the study of tungsten oxide produced by the oxidation of spherical tungsten powder, as the particle size and morphology directly affect its properties. In addition, in combination with energy spectroscopy (EDS), it is possible quantify the elemental distribution.

In the field of chemical analysis, gravimetric and titration methods are also used for the detection of tungsten oxide. The gravimetric method converts ammonium metatungstate into tungsten oxide by high-temperature roasting, and then weighs its mass. This method is simple and straightforward, but requires high sample purity. The titration method determines the tungsten content by reaction with sodium tungstate, which is suitable for analysis in solution systems.

The merit of these methods lies in their diversity and complementarity. For example, spectroscopy is suitable for rapid screening, while XRD and SEM provide structural information. However, they are often less sensitive than electrochemical methods, and some techniques (e.g., TEM) require expensive equipment and complex pre-treatment, which is often cited in the tungsten news as a bottleneck for industrial applications.

When choosing a detection method, there is a trade-off between the sample status and the test target. For example, tungsten oxide oxidized on the surface of tungsten filaments is better suited for SEM analysis, while tungsten oxide in solution is more suitable for chemical titration. In addition, the

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diversification of the tungsten market demand has also driven innovations in detection technologies, such as the development of portable spectrometers.

8.3.1 Tungsten oxide detection - thermogravimetric analysis

Thermogravimetric analysis (TGA) is a mass change-based detection technique that is widely used in research Tungsten oxide thermal stability, decomposition behavior, and content determination. It provides detailed information about the physicochemical properties of tungsten oxide by measuring the change in sample mass as a function of temperature or time under a controlled temperature program. This method has important applications in the field of tungsten technology, especially in the analysis of its synthesis process and heat treatment properties.

The basic principle of thermogravimetric analysis is to take advantage of the change in the mass of a substance during heating. For example, tungsten oxide may be weightless due to water volatilization, crystal form transition, or chemical decomposition. Experiments are typically performed in a thermogravimetric analyzer, where the sample is placed on a microbalance and heated at a constant rate in a nitrogen or air atmosphere. By recording the mass-temperature profile (TG curve), the thermal behavior of tungsten oxide can be analyzed.

When detecting tungsten oxide, thermogravimetric analysis is commonly used in the following scenarios. First, it determines the volatile components in the sample. For example, purple tungsten oxide may release bound water when heated, and the TG curve will show the corresponding weightlessness steps. Secondly, the method can study the redox reaction of tungsten oxide. For example, in a reducing atmosphere (e.g., hydrogen), tungsten oxide may be converted to tungsten metal, and the degree of mass reduction can be used to calculate its purity.

The advantage of thermogravimetric analysis is its high accuracy and non-destructiveness. For the detection of tungsten trioxide, TGA can accurately measure small mass changes with sensitivity in the microgram range. In addition, it can be used in conjunction with differential scanning calorimetry (DSC) to further analyze the thermal effects of tungsten oxide, such as melting or phase change temperatures. This hyphenated technique is particularly common in tungsten data studies.

Control of experimental conditions is critical for thermogravimetric analysis. For example, the rate of ramp-up will affect the resolution of the decomposition reaction, and 5-10 ° C/min is usually chosen to balance accuracy and efficiency. The choice of atmosphere is also crucial: in air, tungsten oxide may remain stable, while in an inert atmosphere it can change differently. In addition, the sample size (typically 5-10 mg) needs to be moderate to avoid uneven heat transfer.

In practical applications, thermogravimetric analysis is often used for the quality analysis of tungsten oxide produced by the oxidation of tungsten powder. For example, by measuring the weight loss of tungsten putty at high temperatures, the amount of tungsten oxide in it can be estimated. In addition, the thermal stability of tungsten heaters also relies on TGA to ensure their performance in high-temperature environments.

However, thermogravimetric analysis has limitations. For example, it cannot directly distinguish the contribution of tungsten oxide from other weightless substances, so it is often verified in combination with XRD or spectroscopy. In addition, high temperatures can lead to sample volatilization or equipment contamination, affecting long-term reliability. To solve these problems, pre-treatment steps, such as low-temperature drying, are often used in tungsten product research.

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Chapter 9 Application Fields of Tungsten Oxide

As a multifunctional material, tungsten oxide (WO_3) has shown a wide range of applications in many fields due to its unique physical and chemical properties, such as high chemical stability, excellent electrical properties and photocatalytic activity. From energy to environmental protection to electronic devices, the application of tungsten oxide continues to expand, promoting the innovation and development of related industries. This chapter will discuss its main application areas in detail, with a focus on its specific use in the energy sector.

9.1 Application of tungsten oxide in the energy field

Energy is the core of modern social development, and the application of tungsten oxide in the energy field is mainly focused on energy storage, energy conversion and renewable energy development. Its multivalent properties, semiconducting properties, and high surface area make it an ideal material for batteries, capacitors, and photocatalysis. The following will analyze its specific applications in the energy sector from different perspectives.

Tungsten oxide is used for energy thanks to its excellent electrochemical properties. For example, as an n-type semiconductor, it has a moderate band gap (about 2.6-3.0 eV) that can both absorb visible light and participate in electron transfer reactions. In addition, tungsten research has shown that tungsten oxide nanostructures (such as nanorods or nanosheets) can significantly increase their specific surface area and reactivity, providing higher efficiency for energy devices.

In the field of energy storage, tungsten oxide is commonly used in lithium-ion batteries and supercapacitors, and its high theoretical capacity and fast ion transport ability have attracted much attention. In terms of energy conversion, the photocatalytic properties of tungsten oxide give it potential in the production of hydrogen from water splitting. In addition, advances in tungsten technology have also driven its exploration in solar cells and fuel cells.

In practice, the performance optimization of tungsten oxide depends on the synthesis process. For example, by thermal decomposition of ammonium paratungstate or ammonium metatungstate, tungsten oxide with different crystal forms can be prepared to meet the needs of specific energy devices. In addition, the fluctuation of tungsten prices also affects its commercialization process in the energy field, so cost control has become the focus of research.

9.1.1 Application of tungsten oxide in lithium-ion batteries

Lithium-ion batteries (LIBs) are the core energy storage technology of modern portable electronic devices and electric vehicles Tungsten oxide As a high-performance electrode material, it has significant advantages in improving battery capacity and cycle stability. Its high theoretical capacity (about 693 mAh/g) and multi-electron transfer capability make it a popular choice for anode materials for lithium-ion batteries.

In lithium-ion batteries, tungsten oxide stores lithium ions through a reversible redox reaction. The reaction mechanism can be expressed as: $WO_3 + 6Li^+ + 6e^- \rightleftharpoons W + 3Li_2O$. This reaction not only provides high capacity, but also enhances electrical conductivity due to the formation of tungsten metal. However, the volume expansion and low conductivity of pure tungsten oxide limit its practical application, so the performance is often optimized by composite materials or nanologization.

Nanostructured tungsten oxide, such as nanoparticles or nanowires, significantly improves its properties. For example, tungsten oxide nanoparticles generated by the oxidation of tungsten powder can effectively alleviate the volume change during charging and discharging due to their high surface area and short diffusion path. In addition, compounding with carbon materials such as graphene or tungsten copper can further improve conductivity and structural stability.

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In practical application, the preparation process of tungsten oxide has a significant effect on its properties. For example, tungsten oxide nanorods synthesized by hydrothermal method exhibit excellent cycling performance in lithium-ion batteries, with a capacity retention rate of more than 80%. In addition, the doping technology developed by Tungsten (e.g., molybdenum doping) can adjust its electronic structure and further improve the efficiency of the cell.

The application of tungsten oxide in lithium-ion batteries is also reflected in the fast charging and discharging performance. Studies have shown that its pseudo-capacitive behavior allows it to maintain a high capacity at high rates, which is essential for the fast charging needs of electric vehicles. In addition, tungsten oxide has lower toxicity and higher stability than other transition metal oxides, which is in line with the development trend of green energy.

However, challenges remain. For example, tungsten oxide has a large irreversible capacity loss in the first cycle, which may be exacerbated by the formation of a solid electrolyte interface (SEI) membrane. To solve this problem, the researchers tried to use Tungsten plastic as a buffer layer, or by pre-lithiation technology to improve the first efficiency. Furthermore Tungsten market The demand is driving the research of low-cost synthetic methods, such as utilization Wolframite Direct preparation Tungsten oxide。

9.1.2 Application of tungsten oxide in supercapacitors

Supercapacitors (SCs) are the star technology in energy storage due to their high power density and long cycle life. Tungsten oxide occupies an important position in the electrode materials of supercapacitors due to its high pseudocapacitance performance and good chemical stability. Compared to conventional carbon-based materials, tungsten oxide can provide additional capacitance through the Faraday reaction, resulting in a significant increase in energy density.

In supercapacitors, the energy storage mechanism of tungsten oxide combines electric double-layer capacitance and pseudo-capacitance. Its pseudo-capacitance is derived from a rapid redox reaction on the surface or in the bulk phase, e.g. $WO_3 + H^+ + e^- \rightleftharpoons HWO_3$. This reaction is particularly pronounced in acidic electrolytes, where tungsten oxide exhibits a specific capacitance of up to 500-700 F/g. In addition, its porous structure, such as tungsten oxide prepared from spherical tungsten powder, increases the electrolyte contact area and further improves performance.

The nano-transformation of tungsten oxide is the key to improving the performance of its supercapacitors. For example, tungsten oxide nanosheets produced by tungsten filament oxidation can significantly increase the charge-discharge rate due to their high specific surface area and fast ion diffusion path. In addition, compounding with silver-tungsten or ferro-tungsten can enhance electrical conductivity and compensate for the inherent low conductivity defects of tungsten oxide.

In practical application, the preparation method of tungsten oxide has a profound impact on its properties. For example, tungsten oxide films generated on the surface of tungsten needles by electrochemical deposition have excellent cycling stability and can last tens of thousands of cycles. In addition, advances in tungsten technology have also led to the development of asymmetric supercapacitors, in which tungsten oxide is paired with carbon material as a negative electrode, significantly widening the operating voltage window.

The advantages of tungsten oxide in supercapacitors also include its environmental friendliness. Compared to materials containing nickel or cobalt, tungsten oxide is available from a wide range of raw materials (e.g. scheelite) and is produced in an environmentally friendly manner. In addition, Tungsten News points out that its potential for application in flexible electronic devices, such as power supplies for wearable devices, is emerging.

However, the low conductivity of tungsten oxide and structural degradation during cycling remain bottlenecks. To this end, the researchers tried to improve its properties by doping cesium tungsten or introducing calcium tungstate. In addition, tungsten knowledge studies have shown that surface modifications, such as coating conductive polymers, can also be effective in improving its stability.

In summary, the application of tungsten oxide in supercapacitors demonstrates its potential for high capacitance and long life. With the optimization of material design and device structure, its prospects in the field of high-power energy storage will be brighter.

9.1.3 Application of tungsten oxide in photocatalytic water splitting to produce hydrogen

Photocatalytic water splitting to produce hydrogen is an important way to produce clean energy from solar energy, and tungsten oxide has become a star material in this field due to its excellent photocatalytic performance and chemical stability. Its moderate band gap (2.6-2.8 eV) allows it to effectively absorb visible light,

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giving it a significant advantage in solar-driven water splitting reactions.

In the photocatalytic process, tungsten oxide acts as a photocatalyst to absorb photons and generate electron-hole pairs. Electrons participate in the reduction of water molecules to form hydrogen (H_2), while holes oxidize water to produce oxygen (O_2). The reaction can be expressed as: $2H_2O \rightarrow 2H_2 + O_2$. However, the high recombination rate of photogenerated carriers of pure tungsten oxide limits its efficiency, so the performance is often optimized by modification or recombination.

Nanostructured tungsten oxide significantly improved its photocatalytic activity. For example, tungsten oxide nanorods synthesized by solvothermal method can significantly improve the efficiency of hydrogen production due to their high surface area and optimized carrier transport path. In addition, tungsten oxide films prepared by tungstic acid precursors perform well in photocatalytic water splitting, especially with the assistance of bias pressure.

The modification of tungsten oxide is the key to improving its photocatalytic performance. For example, by doping Tungsten gold or Tungsten disulfide, which can reduce the bandgap and improve the efficiency of light absorption. In addition, with TiO_2 or tungstate The heterojunction formed by the recombination can effectively separate photogenerated electrons and holes, thereby improving the quantum yield.

In practical applications, the stability of tungsten oxide is one of its advantages. Compared to other photocatalysts (e.g. CdS), tungsten oxide is less susceptible to corrosion in acidic or oxidizing environments. In addition, studies of tungsten products have shown that its combination with radiation shielding materials can also be used in the design of photocatalytic reactors.

However, tungsten oxide has a biased conduction band, which limits its efficiency in reducing water directly. For this purpose, researchers often introduce cocatalysts such as Pt or tungsten particles to enhance hydrogen production.

9.2 Application of tungsten oxide in the field of environment

Tungsten oxide (WO_3) shows a wide range of potential applications in the environmental field due to its excellent photocatalytic properties, chemical stability and versatility. Whether it is air purification or sewage treatment, tungsten oxide can effectively remove pollutants through its unique physical and chemical properties, providing an efficient solution for environmental protection. The following is a detailed discussion of its specific applications in the environmental field.

In the environmental field, the semiconductor properties of tungsten oxide are its core strength. Its band gap (about 2.6-3.0 eV) allows it to absorb visible light and excite photogenerated electrons and holes, which trigger redox reactions to decompose pollutants. In addition, tungsten research has shown that tungsten oxide nanostructures (such as nanoparticles or thin films) can significantly increase its specific surface area and catalytic activity, making it excellent in environmental management.

In practice, the preparation method of tungsten oxide is crucial to its properties. For example, the crystal form and morphology of tungsten oxide prepared by thermal decomposition of ammonium paratungstate or hydrothermal method can be optimized according to specific environmental requirements. In addition, the fluctuation of tungsten prices also affects its commercialization process in the field of environmental protection, so low-cost synthesis technology has attracted much attention.

9.2.1 Application of tungsten oxide in air purification

Air pollution is a global problem, and tungsten oxide plays an important role in air purification due to its photocatalytic properties and gas-sensitive properties. It can effectively decompose volatile organic compounds (VOCs), nitrogen oxides (NOx) and other harmful gases, providing technical support for indoor and outdoor air quality improvement.

In photocatalytic air purification, tungsten oxide absorbs light energy and forms electron-hole pairs, which in turn produce reactive oxygen species (e.g., •OH and O_2^-), these species can oxidize and decompose pollutants into CO_2 and H_2O. For example, tungsten oxide nanoparticles produced by the oxidation of tungsten powder can efficiently decompose VOCs such as formaldehyde and benzene under ultraviolet or visible light irradiation. In addition, tungsten knowledge studies have shown that doping molybdenum or tungsten copper can further improve its photocatalytic efficiency.

The porous structure of tungsten oxide is key to its air purification performance. For example, tungsten oxide nanosheets synthesized by solvothermal method have a high surface area, which can adsorb more pollutant molecules, thereby improving the decomposition efficiency. In addition, the composite materials developed by Tungsten (such as the heterojunction of tungsten oxide and TiO_2) can extend the lifetime of photogenerated carriers and further enhance the purification effect.

In practice, tungsten oxide is often made into thin films or coatings for use in air purifiers or building materials. For example, tungsten oxide coatings based on tungsten filament oxidation can continuously decompose contaminants in sunlight and are suitable for windows or walls. In addition, tungsten news reported that its potential in automobile exhaust gas purification is also being explored, such as by compounding with ferrotungsten to treat NOx.

However, the photocatalytic activity of tungsten oxide is limited by its band gap and carrier recombination rate. To do this, the researchers tried to optimize its properties by doping cesium tungsten or surface modification. In addition, its low activity in low-light conditions limits the wide range of indoor applications, and further development of visible light-responsive variants of tungsten oxide, such as yellow tungsten oxide, are needed.

9.2.2 Application of tungsten oxide in sewage treatment

Sewage treatment is an important part of environmental protection, and tungsten oxide has excellent performance in removing organic pollutants, heavy metal ions and dyes in water due to its photocatalytic degradation ability and adsorption performance. It provides technical support for the sustainable use of water resources.

In photocatalytic wastewater treatment, tungsten oxide decomposes organic pollutants through a light-induced reaction. For example, its nanoparticles can oxidize dyes such as rhodamine B or methylene blue to harmless small molecules when exposed to light. The results showed that tungsten oxide nanorods prepared from tungstic acid precursors exhibited excellent degradation efficiency under visible light. In addition, tungsten data show that the photocatalytic activity can be increased by more than 30% after being combined with tungsten disulfide.

The adsorption properties of tungsten oxide also play a role in wastewater treatment. For example, its porous structure allows for efficient adsorption of heavy metal ions (e.g., Pb^{2+} and Cd^{2+}) and removal by surface coordination or ion exchange. In addition, the composite of tungsten plastic and tungsten oxide can further enhance the adsorption capacity, which is suitable for high-concentration wastewater treatment.

In practical applications, the stability of tungsten oxide is one of its advantages. For example, the photocatalytic performance of tungsten oxide prepared based on spherical tungsten powder in acidic wastewater can last for several cycles. However, the photocatalytic efficiency of tungsten oxide is limited by the carrier recombination and light absorption range. To this end, the researchers tried to improve its properties by doping tungsten gold or constructing tungstate heterojunctions. In addition, it is difficult to recycle and reuse, and it is necessary to develop immobilization technologies, such as loading tungsten oxide on a tungsten needle substrate.

9.3 Application of tungsten oxide in the field of smart materials

The application of tungsten oxide in the field of smart materials is mainly reflected in its electrochromic and gas-sensitive properties. These features make them valuable in smart windows, sensors, and displays, driving the development of smart technologies.

In smart materials, tungsten oxide's versatility stems from its tunable electronic structure and optical properties. For example, its electrochromic behavior enables color changes in response to an applied electric field, while its gas-sensing properties make it highly sensitive to specific gases. In addition, studies of tungsten products have shown that the nanochemical energy of tungsten oxide can significantly improve its response speed and stability.

In practice, the preparation process of tungsten oxide is crucial to its performance. For example, tungsten oxide films prepared by sputtering or chemical vapor deposition (CVD) have excellent uniformity and adhesion for smart devices. In addition, advances in tungsten technology have also driven its exploration in flexible electronics.

9.3.1 Application of tungsten oxide in electrochromic devices

Electrochromic devices (ECDs) are widely used in smart windows and displays because they can change color under an applied electric field. Tungsten oxide has become a mainstream material in this field due to its excellent electrochromic properties. Its color can change from clear to dark blue, with a short response time and long cycle life.

The electrochromic mechanism of tungsten oxide is based on ion intercalation and electron transfer. For example, when Li^+ or H^+ is embedded, the reaction is: $WO_3 + xM^+ + xe^- \rightleftharpoons M_xWO_3$ (M is Li or H). This reversible reaction allows it to dynamically adjust the light transmittance in the smart window, saving the building's energy consumption. In addition, tungsten academic studies have shown that the porous structure of tungsten oxide can accelerate ion diffusion and improve the discoloration efficiency.

In practical application, the preparation of tungsten oxide film is the key. For example, tungsten oxide, which is generated by electrochemical deposition on a tungsten metal substrate, has a high optical contrast. In addition, tungsten heater-assisted heat treatment can optimize its crystal structure and further improve its performance.

The advantages of tungsten oxide also include its stability. In sodium tungstate electrolytes, for example, the color-changing cycles can reach thousands of times. In addition, Tungsten News pointed out that its application in flexible ECD is emerging, such as wearable displays.

However, there is still room for improvement in the response speed and color range of tungsten oxide. To this end, the researchers tried to optimize its properties by doping purple tungsten oxide or compounding it with tungsten rubber.

9.3.2 Application of tungsten oxide in gas sensors

Gas sensors are used to detect harmful gases in the environment, and tungsten oxide has important applications in this field due to its high sensitivity and selectivity. It can effectively detect gases such as NO_2, H_2S and CO, and is suitable for industrial safety and environmental monitoring.

The gas sensing mechanism of tungsten oxide is based on surface adsorption and conductance changes. For example, when NO_2 adsorbs to the surface of tungsten oxide, its trapped electrons lead to an increase in resistance, resulting in a detectable signal. Studies have shown that blue tungsten oxide nanowires can have a detection limit of NO_2 down to ppb due to their high surface area. In practical application, the morphology of tungsten oxide has a significant effect on its properties. For example, tungsten oxide nanoarrays generated by vapor deposition on tungsten filaments have fast response and recovery properties.

The advantages of tungsten oxide also include high-temperature stability. For example, tungsten oxide sensors on a tungsten particle substrate are stable at 300° C and are suitable for industrial environments. In addition, tungsten data show that its resistance to humidity disturbances is better than that of many metal oxides. However, the baseline drift and long-term stability of tungsten oxide still need to be improved. To do this, researchers try to enhance its properties by surface modification or in combination with radiation shielding materials.

9.4 Application of tungsten oxide in the field of electronic information

As a material with excellent semiconductor properties, tungsten oxide (WO_3) has shown a wide range of application potential in the field of electronic information. Its high chemical stability, moderate bandgap (2.6-3.0 eV), and good electrical properties make it ideal for field-effect transistors, memory devices, and other electronic components. With the rapid development of information technology, the role of tungsten oxide in high-performance electronic devices has become increasingly prominent.

In the field of electronic information, tungsten oxide's versatility stems from its tunable electronic structure and thin film fabrication capabilities. For example, its n-type semiconductor properties allow it to efficiently transport electrons, while nanostructured structures such as nanowires or thin films significantly improve device performance. In addition, tungsten research has shown that tungsten oxide doping and compounding technology can further optimize its conductivity and stability to meet the high requirements of electronic devices.

In practical application, the preparation process of tungsten oxide has a profound impact on its properties. For example, tungsten oxide films produced by chemical vapor deposition or sputtering are suitable for microelectronic devices due to their high uniformity and compactness. In addition, advances in tungsten technology have driven its exploration in flexible electronics and wearable devices, and the fluctuating price of tungsten has also prompted researchers to develop low-cost synthesis methods.

9.4.1 Application of tungsten oxide in field-effect transistors

Field-effect transistors (FETs) are the core components of modern electronic devices and are widely used in amplifiers, switches, and integrated circuits. Due to its excellent semiconductor properties and high carrier mobility, tungsten oxide has shown significant potential as a channel material or gate medium in field-effect transistors. Its applications not only improve device performance, but also drive the development of low-power and highly integrated electronic devices.

In field-effect transistors, the role of tungsten oxide is mainly reflected in its ability to act as a channel layer. As an n-type semiconductor, it has a moderate bandgap and can effectively regulate the flow of electrons when a gate voltage is applied, thereby enabling a switching function. For example, tungsten oxide thin films generated by thermal tungsten oxide metal can have a carrier mobility of 10-20 $cm^2/V\cdot s$, which is much higher than that of traditional amorphous silicon. In addition, tungsten knowledge studies have shown that the nanowire structure of tungsten oxide can significantly reduce the scattering

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effect and further improve the mobility due to its one-dimensional transport characteristics.

The use of tungsten oxide in field-effect transistors also benefits from its high dielectric constant (about 20-50), which allows it to be used as a gate dielectric to replace conventional SiO_2. For example, tungsten oxide films prepared by atomic layer deposition (ALD) have low leakage current and high breakdown voltage, which can reduce gate thickness and improve device switching speed and power efficiency. In addition, the doping technology developed by Tungsten (e.g. molybdenum doping) can further optimize its dielectric properties.

In practice, the preparation process of tungsten oxide is crucial to its performance. For example, tungsten oxide nanorods synthesized by solvothermal method exhibit excellent on/off ratios (up to more than 10^6) in field-effect transistors, thanks to their high crystallinity and low defect density. In addition, the porous structure of tungsten oxide generated by the oxidation of tungsten powder can increase the surface area of the channel and further improve the current response.

The advantage of tungsten oxide is also reflected in its compatibility with existing processes. For example, thin films can be deposited on a silicon substrate by sputtering or evaporation, seamlessly integrating with the CMOS process. In addition, tungsten data show that tungsten oxide retains excellent performance at low temperature preparations, which makes it potential in the field of flexible electronics, such as bendable transistors based on tungsten plastic.

In specific cases, tungsten oxide has been used to develop high-performance thin-film transistors (TFTs). For example, tungsten oxide films based on tungsten filament oxidation exhibit fast response and high stability in display backplanes. In addition, tungsten news reported that its application in transparent electronic devices, such as fully transparent FETs, is also on the rise, for the next generation of display technology.

However, tungsten oxide still faces some challenges in field-effect transistors. For example, its inherently low conductivity can lead to high resistive losses, affecting device efficiency. To do this, the researchers tried to improve the conductivity by doping tungsten copper or silver tungsten. In addition, interface defects may induce threshold voltage drift, which needs to be ameliorated by surface passivation or compounding with calcium tungstate.

In terms of performance optimization, the nanostructure design of tungsten oxide is the key. For example, tungsten oxide nanoarrays grown on the substrate of tungsten needles can significantly improve the ability to manipulate electric fields due to their high aspect ratio. In addition, advances in tungsten technology are driving its use in high-frequency devices, such as RF FETs, for 5G communications.

The application of tungsten oxide in field-effect transistors is also environmentally friendly. Compared with materials containing rare elements, its raw materials are abundant (such as wolframite), and the production process is more environmentally friendly. In addition, the growing demand for tungsten has prompted researchers to explore low-cost preparation methods, such as the direct synthesis of tungsten oxide films using ammonium paratungstate. In the future, with the improvement of device miniaturization and integration, the role of tungsten oxide in field-effect transistors will become more prominent. Its potential in high-performance, low-power electronic devices brings new development opportunities in the field of electronic information.

9.4.2 Application of tungsten oxide in memory devices

Memory devices are at the heart of the field of electronic information, encompassing both non-volatile memory (e.g., flash memory) and emerging memory technologies (e.g., resistive memory). Tungsten oxide has important application potential in memory devices due to its resistance switching characteristics, fast response and high stability. Its unique physicochemical properties make it a candidate material for the next generation of high-density storage technology.

In memory devices, tungsten oxide is mainly used in resistive random access memory (RRAM). RRAM switches between high-resistance and low-resistance states based on the resistance state of the material to enable data storage. The resistance switching mechanism of tungsten oxide is due to the migration of oxygen vacancies and the formation of conductive filaments. For example, under an applied electric field, oxygen ions move in a thin film of tungsten oxide, forming a conductive path that enables a "write" operation. The results show that tungsten oxide prepared by tungstic acid precursor has a stable switching ratio (up to more than 10^3).

The nanostructure of tungsten oxide significantly improves its storage performance. For example, tungsten oxide nanoparticles generated by electrochemical deposition can increase the concentration of oxygen vacancies due to their high surface area and defect density, thereby improving switching speed and durability. In addition, tungsten research has shown that the porous film of tungsten oxide exhibits low operating voltage (<1 V) in RRAM, making it suitable for low-power applications.

In practical application, the preparation process of tungsten oxide has a profound impact on its properties. For example, tungsten oxide films deposited on tungsten metal electrodes by magnetron sputtering have high uniformity and low defect rates, and their storage windows can be maintained for thousands of cycles. In addition, the composite technology developed by Tungsten (e.g. in combination with ferrotungsten) can enhance the stability of conductive filaments.

The advantages of tungsten oxide in memory devices also include its high temperature stability. For example, tungsten oxide storage units based on tungsten grain substrates can operate at 200° C and are suitable for harsh environments. In addition, tungsten data shows that it has a faster erase speed (<10 ns) and higher storage density than traditional flash memory.

In specific cases, tungsten oxide has been used to develop high-density RRAM arrays. For example, tungsten oxide films prepared by tungsten heater-assisted annealing exhibit excellent anti-interference ability in cross-array structures. In addition, Tungsten News reports that its potential in neuromorphic computing is emerging, such as analog synaptic devices for artificial intelligence chips.

However, tungsten oxide still faces challenges in memory devices. For example, the randomness of its resistance switching can lead to inconsistencies in data storage. To do this, the researchers tried to optimize the performance by doping cesium tungsten or introducing a tungstate buffer layer. In addition, fatigue may occur after long-term cycling, which needs to be improved by interface engineering (e.g., compounded with tungsten gold).

In terms of performance optimization, the multi-layer structure design of tungsten oxide is the key. For example, tungsten oxide/tungsten disulfide heterojunctions prepared by ALD can significantly improve switching consistency. In addition, advances in tungsten technology have driven its use in three-dimensional storage, such as vertical RRAM, for ultra-high-density storage.

The application of tungsten oxide in memory devices also has economic advantages. Its raw material sources are abundant (such as scheelite), and the production cost is controllable. In addition, the growing demand for tungsten has prompted researchers to explore industrial preparation methods, such as the direct synthesis of tungsten oxide storage layers using ammonium metatungstate.

9.5 Application of tungsten oxide in the field of machinery manufacturing

Tungsten oxide (WO_3) is a material with excellent properties that shows its unique value in the field of mechanical engineering. Its high hardness, high temperature resistance and chemical stability make it ideal for tool coatings and wear-resistant components. As the demand for high-efficiency and long-life tools increases in modern manufacturing, the use of tungsten oxide is gradually expanding, providing important support for improving machinability and equipment durability.

In mechanical engineering, the application of tungsten oxide mainly depends on its physicochemical properties. As a transition metal oxide, its crystal structure gives it high mechanical strength and corrosion resistance. In addition, tungsten research has shown that the properties of tungsten oxide can be further optimized to meet the needs of demanding industrial environments through doping or compounding technologies. Whether as a coating material or as a functional additive, tungsten oxide can significantly improve the durability and processing efficiency of mechanical components.

In practical application, the preparation process of tungsten oxide has a significant impact on its properties. For example, tungsten oxide coatings produced by thermal spraying or chemical vapor deposition (CVD) have high adhesion and homogeneity, making them suitable for high-speed cutting and heavy-duty conditions. In addition, advances in tungsten technology have led to its use in precision manufacturing, and fluctuating tungsten prices have prompted researchers to develop more economical synthesis methods, such as the direct preparation of tungsten oxide using ammonium paratungstate.

9.5.1 Application of tungsten oxide in tool coatings

Tool coating is a key technology in machine manufacturing to improve cutting performance and extend tool life, and tungsten oxide has significant advantages in this area due to its high hardness, wear resistance and thermal stability. It can effectively reduce the friction between the tool and the workpiece, reduce the cutting temperature, and thus improve the machining efficiency and surface quality.

In tool coatings, tungsten oxide is typically applied as a thin film to a carbide or high-speed steel substrate. Its high hardness (close to 9 on the Mohs scale) makes it resistant to wear and deformation during cutting. For example, tungsten oxide coatings deposited on tungsten metal tools by physical vapor deposition (PVD) have a surface hardness of 2000-2500 HV, which is much higher than that of uncoated tools. In addition, tungsten knowledge studies have shown that the low coefficient of friction of tungsten oxide (about 0.4-0.6) can significantly reduce cutting forces and extend tool life.

The high temperature resistance of tungsten oxide is another advantage in tool coatings. In high-speed cutting, the surface temperature of the tool can reach more than 800° C, while the melting point of tungsten oxide is as high as 1473° C, and it can maintain structural stability at high temperatures. For example, tungsten oxide coatings produced by the oxidation of tungsten powder are effective in resisting thermal fatigue and oxidative wear when machining titanium alloys or stainless steels.

In practice, tungsten oxide is often compounded with other materials to optimize performance. For example, a composite coating with tungsten copper or ferro-tungsten not only retains the high hardness of tungsten oxide, but also improves thermal conductivity and reduces heat accumulation in the cutting zone. In addition, the doping technology developed by Tungsten (e.g. molybdenum) can further enhance the toughness of the coating and prevent brittle fracture.

The preparation process of tungsten oxide coating is critical to its performance. For example, tungsten oxide films generated by magnetron sputtering have high compactness and uniformity, and their thickness can be precisely controlled between 1 and 5 μm, making them suitable for precision machining. In addition, the tungsten oxide coating generated by tungsten filament oxidation exhibits excellent anti-adhesion properties during turning and milling, reducing the sticking of the workpiece material.

In specific cases, tungsten oxide-coated tools have been widely used in aerospace and automotive manufacturing. For example, when machining aluminum alloys, tungsten oxide-coated tools based on tungsten needle substrates can reduce surface roughness by more than 20%. In addition, tungsten news reported that its application in high-speed dry cutting is emerging, reducing the dependence on coolant, in line with the trend of green manufacturing.

However, tungsten oxide coatings also present some challenges. For example, it is brittle and can peel off during heavy-duty cutting. To this end, the researchers tried to improve toughness by doping silver tungsten or introducing a tungsten plastic buffer layer. In addition, its adhesion to the substrate needs to be further optimized, and thermal spraying or ion beam-assisted deposition can effectively improve adhesion.

In terms of performance optimization, the multi-layer structure design of tungsten oxide is the key. For example, tungsten oxide/tungsten disulfide composite coatings combine high hardness and self-lubrication to significantly increase tool life. In addition, tungsten data shows that it excels in the processing of superhard materials, such as ceramics, driving its use in high-end manufacturing.

The use of tungsten oxide in tool coatings also offers economic advantages. Its raw materials are abundant (such as wolframite), and the production cost is controllable. With the growth of tungsten market demand, the position of tungsten oxide-coated tools in machine building will be further consolidated, providing reliable support for efficient machining.

9.5.2 Application of tungsten oxide in wear-resistant parts

Wear-resistant components are key components in machine building that are subjected to high friction and wear, such as bearings, gears, and seals. Tungsten oxide has important application potential in wear-resistant parts due to its high hardness, corrosion resistance and fatigue resistance. It significantly extends component life, reduces maintenance costs, and is suitable for heavy machinery and extreme conditions.

In wear-resistant components, tungsten oxide is often used in the form of coatings or composites. Its high hardness and low friction properties make it resistant to abrasive wear and adhesive wear. For example, tungsten oxide coatings, which are created by plasma spraying on a tungsten metal substrate, are 3-5 times more resistant to wear than conventional steels. In addition, tungsten academic studies have shown that the crystal structure of tungsten oxide can remain stable under high stress, preventing surface peeling.

The corrosion resistance of tungsten oxide is another major advantage in wear-resistant parts. In humid or acidic environments, its resistance to oxidation and chemical attack is superior to that of many metallic materials. For example, tungsten oxide coatings produced by tungsten particle oxidation perform well in offshore equipment and are effective in resisting salt spray corrosion. In addition, tungsten oxide annealed with tungsten heater assisted by tungsten heater has higher density, which further improves corrosion resistance.

In practice, tungsten oxide is often compounded with other materials to optimize performance. For example, a composite coating with calcium tungstate exhibits excellent impact resistance in wear-resistant parts and is suitable for excavator teeth. In addition, the tungsten oxide/spherical tungsten powder mixture developed by Tungsten is prepared by powder metallurgy, which has high density and uniformity, and is suitable for heavy-duty bearings.

The preparation process of tungsten oxide has a significant effect on its wear resistance. For example, a tungsten oxide coating generated by laser cladding forms a metallurgical bond to the substrate with a bonding strength of more than 500 MPa. In addition, a mixture of tungsten putty and tungsten oxide can be sintered to make a wear-resistant liner that is suitable for use inside the mill.

In specific cases, tungsten oxide has been used to improve the durability of construction machinery. For example, tungsten oxide coatings based on tungsten gold substrates extend life by more than 50% in mining equipment gears. In addition, tungsten news reports that its use in high-temperature wear-resistant components, such as turbine blades, is on the rise to meet the needs of the aerospace industry.

However, tungsten oxide also presents challenges in wear-resistant components. For example, its brittleness can lead to cracking at high impacts. To do this, the researchers tried to improve toughness by doping tungstate or introducing a tungsten rubber buffer layer. In addition, its processing cost is high, and the preparation process needs to be optimized to achieve large-scale application.

In terms of performance optimization, the microstructure design of tungsten oxide is the key. For example, tungsten oxide/sodium tungstate composite coatings are heat-treated to form a gradient structure, which significantly improves fatigue resistance. In addition, tungsten data shows that its wear resistance under lubricated conditions is better than that of many ceramic materials, driving its use in sliding parts.

The application of tungsten oxide in wear-resistant parts is also environmentally friendly. Its raw materials are abundant (such as scheelite), and the production process is controllable. With the expansion of the tungsten market, tungsten oxide will further increase its position in machine building, providing a reliable solution for highly durable components.

9.6 Tungsten oxide in biomedical applications

As a multifunctional material, tungsten oxide (WO_3) is showing increasingly important application potential in the biomedical field. Its unique physicochemical properties, such as high biocompatibility, optical responsiveness, and electrochemical activity, give it significant advantages in biosensors, photothermal therapy, and other medical technologies. With the increasing demand for highly sensitive and low-invasive materials in biomedicine, the research and application of tungsten oxide is rapidly expanding.

In biomedicine, tungsten oxide's semiconducting properties are its core strength.

Its band gap (about 2.6-3.0 eV) allows it to absorb visible light and participate in photoelectric reactions, while nanostructures such as nanoparticles or thin films significantly increase their surface area and reactivity. In addition, tungsten research has shown that tungsten oxide surfaces can be functionalized to enhance biocompatibility, making it suitable for in vitro and in vitro applications.

In practical application, the preparation process of tungsten oxide has a profound impact on its properties. For example, tungsten oxide nanomaterials synthesized by hydrothermal or solvothermal methods are suitable for biomedical needs due to their high purity and controllable morphology. In addition, advances in tungsten technology have driven its exploration in wearable medical devices, and the fluctuating price of tungsten has prompted researchers to develop low-cost synthesis methods, such as the direct preparation of tungsten oxide using ammonium paratungstate.

9.6.1 Application of tungsten oxide in biosensors

Biosensors are important tools in the biomedical field to detect biomarkers, monitor disease states, and support personalized medicine. Due to its high sensitivity, fast response and electrochemical stability, tungsten oxide has demonstrated excellent performance as a sensitive material in biosensors. It can effectively detect a variety of biomolecules such as glucose, enzymes, and DNA, providing reliable support for disease diagnosis and health management.

In biosensors, the role of tungsten oxide is mainly based on its electrochemical and optoelectronic properties. As an n-type semiconductor, charge transfer occurs on its surface when it comes into contact with the analyte of interest, resulting in a change in conductivity or optical signal. For example, tungsten oxide nanofilms generated by electrochemical deposition on tungsten metal electrodes can have detection limits down to the μM level. In addition, tungsten knowledge studies have shown that the nanowire structure of tungsten oxide can significantly improve the sensitivity of sensors due to its high surface area and fast electron transport ability.

The porous structure of tungsten oxide is its key advantage in biosensors. For example, tungsten oxide nanoparticles synthesized by solvothermal method have abundant active sites that can effectively adsorb enzyme molecules (e.g., glucose oxidase) for highly selective detection. In addition, the tungsten oxide porous film generated by the oxidation of tungsten powder exhibits excellent response speed when detecting H_2O_2, which is due to its rapid redox reaction.

In practice, tungsten oxide is often compounded with other materials to optimize performance. For example, the composite electrode formed with tungsten copper not only retains the high sensitivity of tungsten oxide, but also improves the electrical conductivity, making it suitable for real-time monitoring. In addition, the doping technology developed by Tungsten (e.g., doped with silver tungsten) can further enhance its anti-interference capabilities and reduce false positive signals in complex biological matrices.

The preparation process of tungsten oxide biosensors is critical to their performance. For example, tungsten oxide films prepared by spraying on tungsten filament substrates have high uniformity and stability, and their detection range can cover biomolecule concentrations from nM to mM. In addition, tungsten data show that tungsten oxide remains active in acidic or neutral environments, making it suitable for blood or body fluid analysis.

In specific cases, tungsten oxide has been used in the development of portable glucose sensors. For example, tungsten oxide sensors based on tungsten needle electrodes exhibit fast response (<5 seconds) and high repeatability in diabetes monitoring. In addition, Tungsten News reported that its potential in the detection of cancer cell markers, such as CEA, is emerging, providing a new avenue for early diagnosis.

However, tungsten oxide also faces challenges in biosensors. For example, the surface may be biofouled over time, affecting the accuracy of the inspection. To this end, the researchers tried to improve the resistance to contamination by surface modification (e.g., PEGification) or compounding with tungsten plastic. In addition, its selectivity may be insufficient in complex biological environments, and needs to be optimized by doping calcium tungstate or constructing heterojunctions.

In terms of performance optimization, the nanostructure design of tungsten oxide is the key. For example, tungsten oxide/tungsten disulfide composite nanoarrays can significantly improve the detection limit and response speed due to their high specific surface area and synergistic effect. In addition, the growth in the demand for tungsten is driving its use in wearable sensors, such as low-cost devices based on wolframite feedstock.

The application of tungsten oxide in biosensors also has biosafety advantages. Its low toxicity and degradability make it suitable for in vivo use, such as implantable monitoring devices. With the advancement of biomedical technology, tungsten oxide will play a greater role in precision medicine and health monitoring.

9.6.2 Application of tungsten oxide in photothermal therapy

Photothermal therapy (PTT) is a non-invasive therapy that uses photothermal effects to kill cancer cells, and tungsten oxide has important application potential in this field due to its excellent photothermal conversion efficiency and near-infrared (NIR) absorption capacity. It can convert light energy into heat energy under light exposure, and achieve local high temperature to kill tumors, providing an efficient option for cancer treatment.

In photothermal therapy, the photothermal properties of tungsten oxide are due to its strong NIR absorption properties (700-1100 nm). For example, tungsten oxide nanoparticles synthesized by hydrothermal method can achieve a photothermal conversion efficiency of 40-50% under 808 nm laser irradiation, which is much higher than that of traditional gold nanomaterials. In addition, tungsten academic studies have shown that the oxygen defect of tungsten oxide can enhance its local surface plasmon resonance (LSPR) effect, which can further improve the photothermal performance.

The nanostructure of tungsten oxide is its key advantage in photothermal therapy. For example, tungsten oxide nanorods produced by tungsten particle oxidation can quickly rise to 50-60° C due to their high aspect ratio and surface activity, which is sufficient to induce apoptosis of tumor cells. In addition, tungsten oxide nanosheets prepared by tungstic acid precursors exhibited good dispersion and photothermal stability in vivo.

In practice, tungsten oxide is often surface-modified to optimize biocompatibility. For example, tungsten oxide nanoparticles coated with polyethylene glycol (PEG) or tungsten rubber can circulate in the blood for long periods of time without rapid removal. In addition, tungsten oxide synthesized with the assistance of tungsten heater has higher crystallinity, which further improves the photothermal efficiency.

The advantages of tungsten oxide in photothermal therapy also include its versatility. For example, tungsten oxide nanocomposites formed by doping cesium and tungsten not only have excellent photothermal properties, but can also be used as contrast agents in CT imaging, realizing the integration of diagnosis and treatment. In addition, studies of tungsten products have shown that its combination with radiation shielding materials can be used to enhance the effects of radiotherapy.

In specific cases, tungsten oxide has been used in photothermal therapy experiments in mouse models. For example, tungsten oxide nanoparticles based on spherical tungsten powder can raise the temperature of the tumor site to 55° C under NIR irradiation, which can significantly inhibit tumor growth.

However, tungsten oxide also faces challenges in photothermal therapy. For example, its light penetration in deep tissues is limited and requires a combination of fiber optic technology or higher wavelength lasers. In addition, its long-term in vivo metabolic pathways are not fully understood, and further biosafety needs to be evaluated. To do this, the researchers tried to optimize its properties by doping tungstate or compounding it with tungsten gold.

When it comes to performance optimization, topography control of tungsten oxide is key. For example, tungsten oxide nanofloral structures can significantly improve photothermal conversion efficiency due to their porosity and high absorption. In addition, the growth of tungsten market demand has driven its commercialization in photothermal therapy devices, such as low-cost nanomaterials based on scheelite feedstock.

The application of tungsten oxide in photothermal therapy also has synergistic potential. For example, in combination with chemotherapy drugs (such as doxorubicin), its photothermal effect can enhance the drug release efficiency and achieve heat-chemotherapy combination therapy. With the development of nanomedicine, tungsten oxide will occupy an important position in the precision treatment of cancer.

9.7 Application of tungsten oxide in the field of optical display

Tungsten oxide (WO_3) shows a wide range of application potential in the field of optical display due to its excellent optical properties and electrochromic properties. Its unique physicochemical properties, such as tunable light transmittance, high optical contrast, and fast response capability, make it an important material for displays, smart windows, and other optical devices. With the development of display technology in the direction of high definition, low power consumption and intelligence, the role of tungsten oxide is becoming more and more significant.

In the field of optical display, tungsten oxide The core strength is its electrochromic properties. By applying an electric field, its color can be switched reversibly between transparent and dark blue, a property that stems from ion intercalation and electron transfer processes. In addition, tungsten research has shown that tungsten oxide nanostructures, such as nanofilms or nanoparticles, can significantly improve the optical response speed and stability, meeting the high requirements of modern display devices.

In practical application, the preparation process of tungsten oxide has a profound impact on its properties. For example, tungsten oxide films produced by sputtering or chemical vapor deposition (CVD) have high uniformity and optical transparency, making them suitable for large-area display devices. In addition, advances in tungsten technology have promoted its exploration in flexible displays, and the fluctuating price of tungsten has prompted researchers to develop low-cost synthesis methods, such as the direct preparation of tungsten oxide using ammonium paratungstate.

9.7.1 Application of tungsten oxide in displays

Displays are a core application in the field of optical displays, including liquid crystal displays (LCDs), organic light-emitting diode displays (OLEDs), and emerging electrochromic displays. Tungsten oxide is valuable as a dimming layer or pixel material in displays due to its electrochromic properties and high optical contrast. It enables dynamic color adjustment and energy savings, providing an innovative solution for the next generation of display technology.

In displays, the electrochromic mechanism of tungsten oxide is based on a reversible ion intercalation reaction. For example, when Li^+ or H^+ is embedded, the reaction is: $WO_3 + xM^+ + xe^- \rightleftharpoons M_xWO_3$ (M is Li or H). This process reduces its light transmittance from more than 80% to less than 10%, resulting in extremely high optical contrast. For example, tungsten oxide films generated by electrochemical deposition on tungsten metal substrates can have a color-changing response time as low as milliseconds, making them suitable for high-speed displays. In addition, tungsten knowledge studies have shown that the porous structure of tungsten oxide can accelerate ion diffusion and further improve the switching efficiency.

The use of tungsten oxide in displays also benefits from its wide spectral responsiveness. Its bandgap (2.6-3.0 eV) gives it good transparency in the visible range, while it appears dark after insertion insertion, making it suitable for dimming or privacy protection. For example, tungsten oxide nanofilms produced by the oxidation of tungsten powder can dynamically adjust brightness in smart displays, reducing glare and improving visual comfort.

In practice, tungsten oxide is often compounded with other materials to optimize performance. For example, the composite film formed with tungsten copper not only retains the high contrast of tungsten oxide, but also improves electrical conductivity and is suitable for large-area display. In addition, the doping technology developed by Tungsten (e.g. molybdenum doping) can adjust its color change range and increase the variety of display colors, such as from blue to green or gray.

The preparation process of tungsten oxide displays is critical to its performance. For example, tungsten oxide films deposited on tungsten filament substrates by magnetron sputtering have high adhesion and uniformity, and their thickness can be precisely controlled between 50-200 nm, making them suitable for high-resolution displays. In addition, tungsten data show that tungsten oxide retains its optical properties under low-temperature preparation conditions, making it potential in flexible displays, such as bendable screens based on tungsten plastic.

In specific cases, tungsten oxide has been used in the development of electrochromic displays. For example, tungsten oxide coatings based on tungsten needle substrates exhibit excellent pixel switching speed and low power consumption in e-paper. In addition, Tungsten News reports that its use in transparent displays, such as holographic displays or augmented reality (AR) devices, is on the rise.

However, tungsten oxide also presents challenges in displays. For example, its color-changing cycle life may be reduced by ion intercalation fatigue and stability can be improved by doping calcium tungstate or optimizing an electrolyte such as sodium tungstate solution. In addition, its initial transparency may be insufficient in some applications and needs to be improved by surface modification or compounding with silver-tungsten.

In terms of performance optimization, the nanostructure design of tungsten oxide is the key. For example, tungsten oxide nanoarrays can significantly improve display refresh rates due to their high surface area and fast ion transport capabilities. In addition, the growing demand for tungsten is driving its use in flexible OLED backsheets, such as the preparation of low-cost thin films from wolframite feedstocks.

The application of tungsten oxide in displays also has energy-saving advantages. Its dynamic dimming capability reduces backlight energy consumption and extends device life. With the development of display technology to intelligence and flexibility, tungsten oxide will play a greater role in the field of optical display.

9.8 Application of tungsten oxide in catalytic support

Tungsten oxide has important application value in the field of catalytic support, and its high surface area, chemical stability and acidic site make it an excellent support material for supported catalysts. In the chemical, energy and environmental sectors, tungsten oxide provides a reliable platform for a wide range of reactions by supporting active components to improve catalytic efficiency.

Among the catalytic carriers, the porous structure and surface activity of tungsten oxide are its core advantages. Its specific surface area can reach 50-200 m²/g, which can effectively disperse the active phase of metals or oxides, and enhance the activity and selectivity of the catalyst. In addition, tungsten studies have shown that the acidic sites of tungsten oxide, such as Lewis acid and Brønsted acid, can promote a variety of acid-catalyzed reactions, such as alkylation and isomerization.

In practical application, the preparation process of tungsten oxide has a significant impact on its properties. For example, tungsten oxide produced by solvothermal or thermal decomposition of ammonium metatungstate has high porosity and thermal stability, making it suitable for high-temperature catalytic environments. In addition, research into tungsten products has led to its application in industrial catalysis, such as petroleum refining and waste gas treatment.

9.8.1 Application of tungsten oxide in supported catalysts

Tungsten oxide (WO_3) has important application value in the field of supported catalysts due to its excellent physical and chemical properties. As a multifunctional carrier material, tungsten oxide can effectively support active components and improve the activity, selectivity and stability of catalysts due to its high surface area, chemical stability and surface acidic sites. It is widely used in a variety of catalytic reactions in chemical production, energy conversion and environmental governance, providing efficient support for industrial processes.

Among supported catalysts, the core advantages of tungsten oxide are its porous structure and high dispersion capacity. Its specific surface area is typically between 50 and 200 m²/g, providing sufficient attachment sites for active components such as precious metals or transition metal oxides, preventing agglomeration and increasing utilization. In addition, tungsten research has shown that the Lewis acid and Brønsted acid sites of tungsten oxide can synergize with activity to promote acid-catalyzed reactions such as alkylation, isomerization and dehydration. This property makes it highly sought after in petrochemical and organic synthesis.

The thermal stability of tungsten oxide is another highlight of the supported catalyst. Its structure remains intact at high temperatures (up to 600-700° C) and is suitable for harsh catalytic conditions. For example, tungsten oxide carriers prepared by thermal decomposition of ammonium metatungstate exhibit excellent sintering resistance in high-temperature hydrogenation reactions. In addition, advances in tungsten technology have driven its topography controls, such as nanorod or nanosheet structures, further enhancing its catalytic properties.

In practical applications, tungsten oxide is often combined with the active component by impregnation, co-precipitation or solvothermal method. For example, a catalyst loaded with Pt or Pd on tungsten oxide exhibits high conversion and resistance to sulfur poisoning in hydrodesulfurization (HDS) reactions. This is due to the strong interaction between tungsten oxide and metal (SMSI), which stabilizes the active site and extends the catalyst life. In addition, the tungsten oxide carrier generated by the oxidation of tungsten powder can significantly improve the diffusion efficiency of gas molecules due to its high porosity, which is suitable for gas-phase catalytic reactions.

In specific cases, tungsten oxide-supported catalysts have been widely used in petroleum refining. For example, Ni/tungsten oxide catalysts can convert heavy oil into light fractions in hydrocarbon cracking with a conversion rate of more than 90%. In addition, tungsten data show that the support prepared by tungsten oxide and ferrowolfram exhibits excellent resistance to carbon deposition in methane dry reforming, which is due to the inhibition of carbon deposition by its surface acidity.

Tungsten oxide also has important applications in environmental catalysis. For example, the Pd/tungsten oxide catalyst can completely convert toluene to CO_2 and H_2O in the oxidation of volatile organic compounds (VOCs), with a conversion rate of more than 95%. The high homogeneity of the tungsten oxide carrier generated on a tungsten filament substrate by spraying ensures a uniform distribution of the active components. In addition, tungsten news reports that its potential in selective catalytic reduction (SCR) of NOx is emerging, such as compounding with tungsten copper to improve low-temperature activity.

However, there are also some challenges to tungsten oxide as a carrier. For example, an excessively acidic surface may trigger side reactions that reduce selectivity. To do this, the researchers tried to adjust the strength and distribution of the acidic sites by doping with cesium, tungsten, or alkali metals. In addition, its specific surface area may be reduced at long-term high temperatures, and the pore structure needs to be maintained by compounding with tungsten disulfide or by optimizing the calcination conditions.

In terms of performance optimization, the microscopic topography design of tungsten oxide is crucial. For example, tungsten oxide nanotubes prepared by the template method can significantly improve the dispersion and accessibility of active components due to their high porosity and directional channels. In addition, the tungsten oxide/tungstate composite carrier developed by Tungsten Company is prepared by hot pressing process, which has high mechanical strength and is suitable for fixed-bed reactors.

The preparation process of tungsten oxide-supported catalyst has a profound impact on its performance. For example, the crystallinity and porosity of tungsten oxide carriers assisted calcined by tungsten heaters can be precisely controlled to ensure the stability of the catalyst at high temperatures and pressures. In addition, tungsten oxide produced by tungsten particle oxidation also has applications in the field of photocatalysis, such as supporting TiO_2 for the degradation of organic pollutants, and its synergistic effect significantly improves the photocatalytic efficiency.

In the field of green chemistry, tungsten oxide-supported catalysts show the potential for sustainable development. For example, the Cu/tungsten oxide catalyst exhibits high selectivity (>80%) in CO_2 hydrogenation to methanol, providing a new approach for carbon capture and utilization.

Tungsten oxide has abundant raw materials and controllable production costs, which lays the foundation for its large-scale application. In addition, the growing demand for tungsten market has prompted researchers to explore novel composite carriers, such as the combination of tungsten oxide and tungsten gold, for efficient oxidation reactions.

In actual industrialization, the durability of tungsten oxide-supported catalysts is key. The tungsten oxide carrier prepared by tungsten plastic as a binder exhibits excellent wear resistance in long-term operation. In addition, tungsten oxide prepared from tungstic acid precursors can retain more active sites and improve catalytic efficiency through low-temperature synthesis process.

The application of tungsten oxide in supported catalysts is also environmentally friendly. The production process avoids the use of traditional highly toxic carriers and is in line with the principles of green chemistry. With the continuous advancement of catalytic technology, tungsten oxide will play a greater role in the fields of chemical industry, energy and environmental protection, providing diversified options for efficient catalysis.

9.9 Application of tungsten oxide in the field of fireproof fabrics

Tungsten oxide (WO_3) offers unique potential in the field of fire-resistant fabrics due to its excellent thermal stability and chemical inertness. As a transition metal oxide, tungsten oxide is able to maintain structural integrity at high temperatures and enhance the flame retardant properties of fabrics through its surface properties. With the increasing demand for fireproof materials in industrial safety, daily life and public transportation, tungsten oxide is gradually gaining attention as a functional additive or coating material.

In fireproof fabrics, the role of tungsten oxide is mainly reflected in its high melting point (1473° C) and oxidation resistance, which allows it to slow down the burning rate of fabrics under fire conditions. In addition, tungsten has been shown to be effective in dispersing heat and inhibiting flame propagation in its nanoparticle form due to its high surface area and thermal conductivity. Whether compounded with a fiber substrate or used as a coating, tungsten oxide improves the fire performance of fabrics.

In practical applications, the preparation process of tungsten oxide is crucial to its effect. For example, tungsten oxide nanoparticles synthesized by solvothermal synthesis are uniformly dispersed in fabric fibers, while thin films prepared by chemical vapor deposition (CVD) are suitable for surface coatings. In addition, advances in tungsten technology have promoted its application in flexible fabrics, while the fluctuating price of tungsten has prompted researchers to explore low-cost synthetic pathways, such as direct preparation using ammonium paratungstate.

9.9.1 Application of tungsten oxide fireproof fabrics in the industrial field

The demand for fire-resistant fabrics is particularly acute in the industrial sector, especially in high-risk industries such as petrochemicals, metallurgy and power. Due to its high temperature resistance and flame retardant properties, tungsten oxide fire-resistant fabrics show significant advantages as a material for protective clothing, workwear or equipment coverings in these scenarios. Not only does it protect workers from sparks and high temperatures, but it also extends the life of the equipment.

In industrial applications, the thermal stability of tungsten oxide is its core advantage. For example, in a steel mill or welding shop, fabrics can be exposed to instantaneous temperatures of up to 1000° C. The heat resistance of the tungsten oxide coating created by oxidation on a tungsten metal substrate can significantly reduce the rate of thermal decomposition of the fabric. In addition, tungsten knowledge research has shown that tungsten oxide nanoparticles form a dense oxide layer at high temperatures, which can effectively isolate oxygen and inhibit combustion.

The preparation of tungsten oxide fireproof fabrics is usually achieved by compounding them with fibers such as aramid or cotton. For example, the oxidation of tungsten powder by impregnation of tungsten oxide nanoparticles to the surface of the fiber can increase the limiting oxygen index (LOI) of the fabric, making it meet or exceed the industry standard (e.g., LOI > 28%). In addition, the compounding technology developed by Tungsten Company, such as doped molybdenum, can further enhance the thermal shock resistance of the fabric.

In specific scenarios, tungsten oxide fireproof fabrics are widely used in protective clothing. For example, on oil rigs, tungsten oxide-coated fabrics based on tungsten filament oxidation can resist oil fires, and their thermal conductivity helps to quickly disperse local high temperatures and avoid burns. In addition, tungsten news reported that it is used in the power industry as a cable wrapping material, which can effectively prevent fires caused by arcing.

However, tungsten oxide also has limitations in industrial fire-resistant fabrics. For example, its weight can increase the burden on the fabric and affect wearing comfort. To do this, the researchers tried to reduce weight by compounding with lightweight tungsten copper or optimizing the size of the nanoparticles. In addition, its preparation cost is high, and it is necessary to reduce the cost through large-scale production.

In terms of performance optimization, the multi-layer structure design of tungsten oxide is the key. For example, tungsten oxide nanocoatings grown on the substrate of tungsten needles remain intact after repeated high-temperature exposure due to their high adhesion. In addition, tungsten data shows that it still has excellent stability in acidic or oily environments, which is driving its use in the petrochemical industry. Tungsten oxide fireproof fabrics also have sustainability advantages in industrial applications. Its raw material can be extracted from wolframite, and it has great recycling potential. With the growth of tungsten market demand, its position in industrial safety protection will be further enhanced, providing reliable guarantee for high-risk operations.

9.9.2 Application of tungsten oxide fireproof fabrics in daily life

In the field of daily life, the application of fireproof fabrics covers home textiles, clothing and decorative materials, and tungsten oxide fireproof fabrics have attracted attention because of their flame retardancy and safety. It can effectively reduce the risk of fire in the home and improve the safety factor of the living environment, especially for flammable materials such as curtains, carpets and bedding.

In everyday applications, the flame retardant mechanism of tungsten oxide is based on its thermal shielding and oxygen isolation capabilities. For example, in the early stages of a fire, the coating can form a protective layer on the surface of the fabric, slowing down the spread of flames. The LOI value of tungsten precursor can be increased to more than 30% by spraying the tungstic acid precursor into a nano-coating of tungsten oxide, which can meet the fire protection requirements of home textiles. In addition, academic studies of tungsten have shown that its nanoparticles can absorb part of the thermal radiation and reduce the ignition point of the fabric.

The preparation of tungsten oxide fireproof fabrics needs to take into account comfort and functionality. For example, tungsten oxide nanoparticles are embedded in cotton fibers using the sol-gel method, which retains softness and breathability while providing flame retardant effects. In addition, the tungsten oxide coating produced by tungsten particle oxidation can be adhered to the curtain fabric by the hot pressing process, improving its durability.

In specific scenarios, tungsten oxide fireproof fabrics are used in household items. For example, tungsten oxide-coated carpets based on the tungsten heater process can quickly self-extinguish when a cigarette or spark comes into contact to prevent the spread of fire. In addition, studies of tungsten products have shown that its use in children's pajamas can significantly reduce the risk of burns and meet strict home textile safety standards.

However, tungsten oxide also presents challenges in everyday fire-resistant fabrics. For example, its color (usually yellow or blue) may affect the aesthetics of the fabric, and it needs to be compounded with tungsten plastic. In addition, its washability needs to be further improved to accommodate frequent cleaning, and researchers are trying to improve this problem by surface silanization.

In terms of performance optimization, the microstructure design of tungsten oxide is crucial. For example, tungsten oxide nanofibers are combined with cotton fabrics through electrospinning technology, which combines fire resistance and softness. In addition, the growing demand for tungsten is driving its use in low-cost home textiles, such as the use of scheelite raw materials to prepare

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economical coatings.

The application of tungsten oxide fireproof fabrics in daily life also has environmental protection potential. Its production process can avoid the toxicity problem of traditional halogen flame retardants, which is in line with the trend of green home textiles. With the increasing safety awareness of consumers, tungsten oxide will occupy a place in the field of daily fire protection.

9.9.3 Application of tungsten oxide fireproof fabrics in the field of public transportation

The demand for fire-resistant fabrics is particularly stringent in the public transport sector, where upholstery and seating materials are used in vehicles such as planes, trains and automobiles. Due to its high flame retardancy and durability, tungsten oxide fireproof fabrics show great potential as a safety material in this field. It can effectively reduce the risk of fire and protect the lives of passengers.

In public transport applications, tungsten oxide's fire performance is based on its stability at high temperatures. For example, in aircraft seat fabrics, the coating forms a charring layer under short-term flame exposure, preventing the spread of fire. The LOI value of the nano-coating that converts tungstate into tungsten oxide by spraying method can reach more than 35%, which meets aviation standards (such as FAR 25.853). In addition, tungsten data shows that its low toxicity emissions in high-temperature flue gas environments further enhance safety.

The preparation of tungsten oxide fireproof fabrics needs to consider lightweight and abrasion resistance. For example, tungsten oxide films produced by vapor deposition on a spherical tungsten powder substrate can adhere to polyester fibers with less than 10% more weight, making them suitable for aircraft interiors. In addition, the composite coating of ferro-tungsten and tungsten oxide is prepared by a hot pressing process, which has high wear resistance and is suitable for train seats.

In specific scenarios, tungsten oxide fireproof fabrics are used in vehicle interiors. For example, tungsten oxide-coated curtains based on tungsten gold technology can resist ignition sources in high-speed rail, and their thermal shielding effect significantly reduces the cabin temperature.

However, tungsten oxide also has limitations in fireproof fabrics for public transport. For example, its rigidity may affect the softness of the fabric, which needs to be improved by compounding with tungsten rubber. In addition, its performance stability under extreme humidity needs to be further verified, and the researchers tried to optimize it by doping cesium tungsten.

In terms of performance optimization, the porous structure design of tungsten oxide is the key. For example, tungsten oxide nanogrids are prepared by the template method, which is both lightweight and highly flame retardant. In addition, the growth of tungsten market demand is driving its large-scale applications in the aerospace sector, such as the use of tungsten acid precursors for low-cost coatings.

The application of tungsten oxide fireproof fabrics in public transportation also has regulatory adaptability. It complies with international fire protection standards (e.g. IMO FTPC) and promotes its promotion in the global transportation sector. As safety regulations become more stringent, tungsten oxide will play a greater role in public transport safety.

9.10 Application of tungsten oxide in agricultural film

As a multifunctional transition metal oxide, tungsten oxide (WO_3) has shown a wide range of application potential in many fields due to its unique physical and chemical properties, including the preparation and performance optimization of agricultural films (referred to as agricultural films). As an important material in modern agriculture, agricultural film is mainly used for greenhouse mulching, plastic film mulching and crop protection, and its performance directly affects the growth efficiency and yield of crops. With the intensification of global climate change and resource scarcity, the development of high-performance and sustainable agricultural films has become the focus of agricultural technology research. In recent years, tungsten oxide has attracted attention for its application in agricultural films due to its light absorption characteristics, thermal stability and nanotechnology potential. In this paper, we will discuss in detail the mechanism, preparation method, performance advantages and practical application prospects of tungsten oxide in agricultural films, and comprehensively analyze its potential and challenges based on scientific data and industrial practice.

1. The basic characteristics of tungsten oxide are in line with the needs of agricultural films

Tungsten oxide is a wide bandgap semiconductor (bandgap 2.6-3.0 eV) with good light absorption capacity (especially in the near-infrared region, 700-2500 nm), thermal conductivity (about 1.6 W/m·K), and chemical stability. These properties give them natural advantages in regulating light and heat, blocking ultraviolet rays, and improving the durability of materials. The main functions of agricultural film include heat preservation, light control, UV protection, anti-aging and antibacterial, etc., and the characteristics of tungsten oxide are highly compatible with these needs.

- Light and heat control agricultural film needs to adjust the light transmittance and thermal insulation performance according to the needs of crops. Tungsten oxide's strong absorption of near-infrared light (NIR) makes it an ideal photothermal conversion material. For example, studies have shown that polyethylene (PE) agricultural film doped with tungsten oxide can convert infrared light into heat, raising the night temperature in the greenhouse by 2-5° C, and prolonging the crop growth cycle.
- Ultraviolet (UV) rays are harmful to crop DNA and agricultural film materials. The band gap of tungsten oxide makes it effective in absorbing UV-B (280-315 nm) and part of UV-A (315-400 nm), protecting crops and delaying the aging of agricultural films. Experiments have shown that a 50 nm thick tungsten oxide coating can reduce UV transmittance by about 95%.
- The photocatalytic activity of antimicrobial and durable tungsten oxide can produce reactive oxygen species (ROS) in response to light, which has an antibacterial effect and reduces the spread of pests and diseases. At the same time, its high hardness (8.5-9 on the Mohs scale) and chemical stability improve the weather resistance of agricultural film and prolong the service life.

These characteristics show that tungsten oxide can not only optimize the function of agricultural film, but also improve its environmental adaptability, which is in line with the needs of sustainable development of modern agriculture.

2. Preparation and application of tungsten oxide in agricultural film

Tungsten oxide is applied to agricultural films, usually by incorporating it into matrix materials (e.g., polyethylene, polylactic acid (PLA), etc.) in the form of nanoparticles, thin films or composites. The choice of preparation method directly affects its performance and cost.

- Nanoparticle doping allows the preparation of composite agricultural films by dispersing nanoscale tungsten oxide (particle size 10-100 nm) into a polymer matrix. Commonly used methods include melt blending and solution blending. For example, tungsten research reports that by mixing tungsten oxide nanoparticles (specific surface area 50-200 m^2/g) with PE by high-speed stirring, the prepared agricultural film has improved the near-infrared shielding rate by 60% and maintained a high visible light transmittance (about 70%). This method is less costly and suitable for large-scale production.

- Thin film coatings are deposited on the surface of agricultural films by physical vapor deposition (PVD) or chemical vapor deposition (CVD) with precise control of thickness (25-100 nm) and structure. For example, the oxygen permeability (OP) of a 50 nm tungsten oxide coating on a PLA substrate film was reduced to 0.46×10^{-16} cm^3 • cm/cm^2 • s • Below PA, the airtightness is significantly improved. This method is suitable for high-end agricultural films, but the equipment cost is high.
- Composite functional materials combine tungsten oxide with other materials such as TiO_2, ZnO, or graphene to further enhance performance. For example, the tungsten oxide/TiO_2 composite coating combines the photocatalytic activity of both and has an inhibition rate (against E. coli) of more than 99%, while retaining the photothermal effect of tungsten oxide. This composite form has a bright future in functional agricultural films.

These preparation methods have their own advantages and disadvantages, and it is necessary to choose the appropriate process according to the specific use of agricultural film (such as greenhouse film, plastic film). Nanoparticle doping is suitable for cost-sensitive scenarios, while thin-film coatings are better suited for high-performance needs.

3. Performance advantages of tungsten oxide in agricultural films

The application of tungsten oxide in agricultural film has significantly improved a number of key properties, and the following data and case studies are used to analyze its advantages.

- The spectral manipulation and local
  surface plasmon resonance (LSPR) effect of insulated tungsten oxide make it have high absorption in the near-infrared region. For example, cesium-doped tungsten oxide nanoparticle-doped agricultural film at 1100 nm was 90%, while the visible light transmittance remained above 75%. This selective spectral manipulation not only guarantees the light required for photosynthesis, but also increases the nighttime temperature through heat conversion, especially in cold regions. Experiments show that in the northern winter greenhouse, the temperature in the greenhouse using tungsten oxide agricultural film is 3-4° C higher than that of ordinary PE film.
- Ultraviolet protection and anti-aging
  tungsten oxide UV absorption capacity significantly reduce the aging rate of agricultural films. In the case of PLA/tungsten oxide composite film,

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the transmittance in the UV-B region decreased from 90% to 5%, and after 6 months of outdoor exposure, the mechanical strength (tensile strength) decreased by only 10%, while that of pure PLA film decreased by more than 40%. This results indicate that tungsten oxide can effectively slow down the photooxidative degradation and prolong the life of agricultural film.

- Nano-tungsten oxide can catalyze the production of ROS under light and destroy bacterial cell membranes. The study showed that the PE film containing 2 wt% tungsten oxide had a killing rate of 5 $\log_{10}$ CFU/cm^2 against E. coli within 24 hours, significantly reducing the risk of pathogen transmission. This is especially important for the health of the soil covered with mulch.
- Oxygen Barrier and PreservationIn fruit and vegetable cling film, the dense coating of tungsten oxide reduces oxygen permeability. For example, the 50 nm thick tungsten oxide coating reduces the oxygen permeability of PLA membranes by 80%, delays the respiration of fruits and vegetables, and prolongs the shelf life by 1-2 weeks.

4. Practical application cases and effects

The application of tungsten oxide in agricultural film has been verified in many scenarios, and the following is combined with actual cases to analyze its effect.

- Greenhouse Mulching FilmIn Northwest China, the use of tungsten oxide nanoparticle-doped PE greenhouse film increased the temperature in the greenhouse by 3.5° C in winter, and the tomato yield increased by 15%. At the same time, its UV blocking function reduces the rate of sunburn of crops and improves fruit quality.
- Tungsten oxide/TiO_2 composite mulch film was used in rice planting in southern China to increase soil temperature by 2° C and promote seedling growth. Its bacteriostatic effect reduced the incidence of root diseases and increased rice yield by about 10%.
- Fruit and vegetable cling filmIn the export fruit packaging, PLA/tungsten oxide composite film extends the shelf life of strawberries to 20 days (ordinary film is only 12 days), reduces the rot rate, and is well received by the market.

These cases show that tungsten oxide can significantly improve the practical value of agricultural film in actual agricultural production, especially in improving yield and quality.

5. Challenges and solutions in the application

Although tungsten oxide has significant advantages in agricultural films, its application still faces some challenges and needs to be addressed.

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- Cost ProblemThe preparation of tungsten oxide (such as nanoparticles or thin film deposition) is costly, and the current market price is about 20-30 US dollars/kg, while the ordinary PE agricultural film is only 1-2 US dollars/kg. Solutions include optimizing production processes (e.g. cryogenic hydrothermal process to reduce energy consumption to 1 kWh/kg) and utilizing recycled resources from the tungsten market (e.g. tungsten scrap wire).
- Dispersion and compatibilityTungsten oxide nanoparticles are easy to agglomerate in the polymer matrix, which affects the uniformity of the film. Compatibility can be improved by surface modification (e.g., silane coupling agent) or addition of dispersants (e.g., PVP), and experiments have shown a 50% increase in dispersion after modification.
- Environmental impactsThe potential ecotoxicity of nano-tungsten oxide needs to be assessed. Studies have shown that its accumulation in soil < 10 mg/kg has no significant effect on microorganisms, but long-term use needs to be monitored. The use of biodegradable substrates reduces the risk of carryover.

Through technical improvements and environmental assessments, these challenges can be gradually overcome, leading to the widespread application of tungsten oxide agricultural films.

6. Future development prospects

The application of tungsten oxide in agricultural film has broad prospects, especially in the following directions:

- Intelligent agricultural film: Combined with the electrochromic characteristics of tungsten oxide, an intelligent agricultural film that can dynamically adjust the light transmittance is developed to adapt to different lighting conditions.
- Sustainability: Leverage tungsten's scrap recycling technology to reduce costs and achieve a circular economy.
- Multi-functional integration: Combined with sensing technology, the agricultural film integrating temperature control, bacteriostatic and monitoring is prepared to improve the level of precision agriculture.

With the progress of tungsten technology and the growth of market demand, tungsten oxide is expected to become the core material of a new generation of agricultural film and promote the process of agricultural modernization.

CTIA GROUP LTD

Yellow Tungsten Trioxide (**YTO,** WO_3) **Product Introduction**

1. Product Overview

CTIA GROUP LTD yellow tungsten trioxide is produced by high-temperature calcination process of ammonium paratungstate, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. WO_3 is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants. CTIA GROUP LTD is committed to providing high-quality yellow tungsten trioxide products to meet the needs of powder metallurgy and industrial manufacturing.

2. product characteristics

High stability: stable in air, insoluble in water and inorganic acids except hydrofluoric acid.
Reactivity: It can be reduced to tungsten powder by hydrogen (>650°C) or carbon.
Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Product specifications

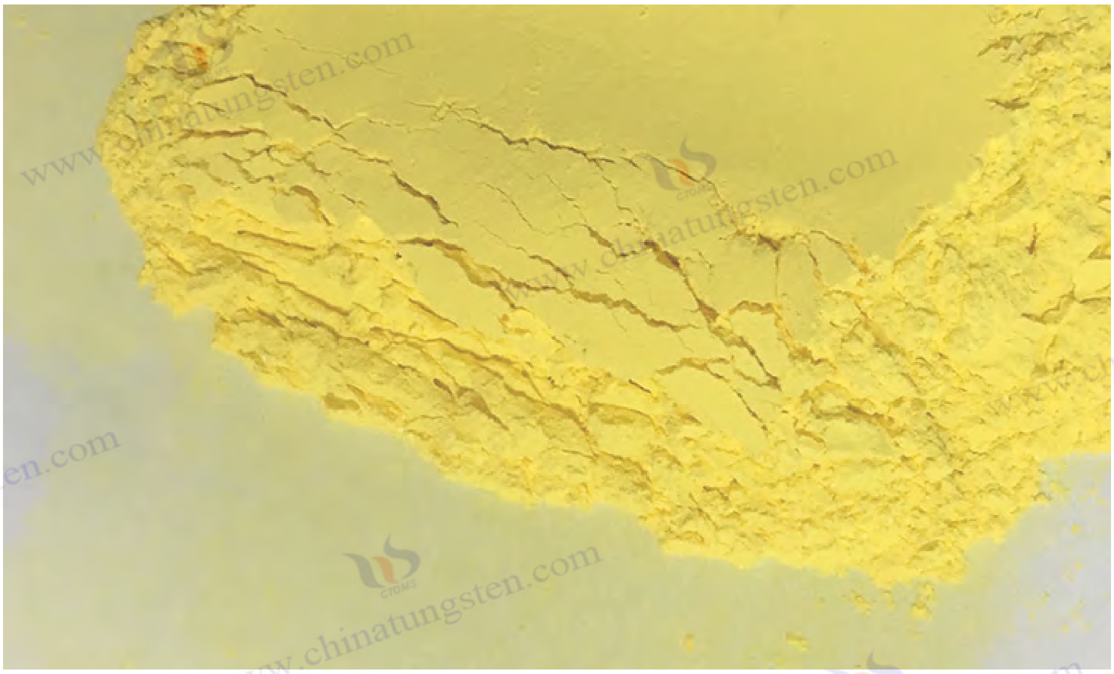
index	CTIA GROUP LTD yellow tungsten trioxide first-class product standard
WO_3 content (wt%)	≥99.95
Impurities （wt%，max.）	Fe≤0.0010, Mo≤0.0020, Si≤0.0010, Al≤0.0005, Ca≤0.0010, Mg≤0.0005, K≤0.0010, Na≤0.0010, S≤0.0005, P≤0.0005
Particle size	1-10（μm，FSSS）
Loose density	2.0-2.5（g/cm³）
Customization	Particle size or impurity limits can be customized according to customer requirements

4. Packaging and warranty

Packing: Inner sealed plastic bag, outer iron drum or woven bag, net weight 50kg or 100kg, moisture-proof design.
Warranty: Each batch comes with a quality certificate, including WO_3 content, impurity analysis, particle size (FSSS method), loose density and moisture data.

5. Procurement information

Email: sales@chinatungsten.com
Phone: +86 592 5129696
For more yellow tungsten oxide information, please visit the China Tungsten online website www.tungsten-powder.com. For more market and real-time information, please follow the WeChat public account "China Tungsten Online".



CTIA GROUP LTD yellow tungsten oxide

Chapter 10 Safety and Environmental Protection of Tungsten Oxide

Tungsten oxide (WO_3) is a widely used material that exhibits excellent performance in the energy, environment, electronics and biomedical fields. However, the safety and environmental issues involved in its production, use and disposal cannot be ignored. From potential health risks to environmental impacts, the safety and sustainability of tungsten oxide has become an important consideration for research and industrialization. This chapter will explore these issues in detail and provide guidance for their proper application.

In the field of safety and environmental protection, the physical and chemical properties of tungsten oxide are both advantages and challenges. Its high stability and low solubility reduce some of the risk of toxicity, but nanoscale tungsten oxide may have specific effects on humans and the environment due to its high surface area and potential biological activity. In addition, tungsten research has shown that energy consumption and waste emissions in the production process also need to be optimized to comply with green chemistry principles.

In practical applications, the safety and environmental management of tungsten oxide rely on scientific assessment and control measures. For example, by-product emissions can be reduced by improving the synthesis process of tungsten technology, while fluctuations in tungsten prices are driving the development of low-cost, environmentally friendly production methods, such as the efficient conversion of ammonium paratungstate.

10.1 Safety of tungsten oxide

The safety concerns of tungsten oxide are mainly related to its potential impact on human health during production, transportation and use. As a metal oxide, its safety is closely related to the physical form (e.g., powder, film, or nanoparticles), the route of exposure (inhalation, skin contact, or ingestion), and the dose. Understanding these risks and taking appropriate precautions is key to ensuring safe applications.

In its macroscopic form, tungsten oxide usually exists in the form of a yellow or blue powder, which has high chemical stability and low acute toxicity to humans. For example, tungsten oxide powder, which is produced by thermal oxidation of tungsten metal, has very low solubility (<0.1 g/L) and is not easily absorbed through the skin or digestive tract. However, tungsten knowledge studies have shown that inhalation in the form of dust can cause respiratory irritation, especially when exposed to high concentrations (e.g., on a production floor), which can lead to mild lung inflammation.

Nano-scale tungsten oxide is more complex due to its high surface area and biological activity. For example, tungsten oxide nanoparticles (particle size < 100 nm) synthesized by hydrothermal methods may penetrate cell membranes and trigger oxidative stress or inflammatory responses. In vitro experiments showed that high doses (>100 μg/mL) of tungsten oxide nanoparticles were toxic to lung cells (e.g., A549 cells) and may induce apoptosis through the generation of reactive oxygen species (ROS). In addition, data suggest that its long-term accumulation in the blood may affect liver and kidney function, although current in vivo research data are still limited.

In industrial environments, tungsten oxide safety risks also involve the production process. For example, when tungsten powder is oxidized to produce tungsten oxide, if the dust is not properly controlled, it may lead to the risk of inhalation by workers. For this purpose, the use of ventilation and personal protective equipment (e.g., N95 masks and gloves) is recommended. In addition, tungsten companies routinely require regular monitoring of airborne particulate concentrations in operating procedures to ensure compliance with occupational exposure limits (e.g., 5 mg/m³ as set forth by OSHA).

In terms of transportation and storage, tungsten oxide is a non-flammable and non-explosive substance, and it is relatively safe. However, if the packaging is damaged and the powder leaks, which may contaminate the environment or be inhaled, use an airtight container with a warning. In addition, tungsten news reported that special care should be taken when it is transported in its nano form to avoid diffusion due to static electricity or wind.

For the biosafety of nano-tungsten oxide, researchers tried to reduce toxicity through surface modification. For example, tungsten oxide nanoparticles compounded with tungsten plastic or PEG have significantly reduced cytotoxicity. In addition, the growth of the tungsten market demand is driving the development of safety assessments, such as the development of low-toxicity synthesis pathways (using wolframite feedstocks).

In practical applications, such as biosensors or photothermal therapy, the safety of tungsten oxide needs to be evaluated on a specific application basis. For example, tungsten oxide in implantable devices needs to ensure long-term biocompatibility and avoid immune reactions. Studies have shown that its toxicity is much lower than that of heavy metal oxides (e.g., CdO), but more clinical data are still needed.

10.2 Environmental protection of tungsten oxide

The environmental issues of tungsten oxide cover the impact on the ecosystem during the production, use and disposal phases. Despite its low toxicity, energy consumption, wastewater and exhaust emissions during production, as well as how it is disposed of after disposal, can be a burden on the environment. Addressing these issues is essential to achieve its sustainable application.

In the production phase, the preparation of tungsten oxide usually involves high-temperature roasting or chemical reactions. For example, the thermal decomposition of tungstic acid to produce tungsten oxide requires a large amount of energy (about 500-800° C) and CO_2 emissions. In addition, tungsten academic pointed out that if tungsten oxide is extracted using acid-base solvents such as HCl or NaOH, tungsten-containing wastewater may be generated, which will lead to soil and water pollution if discharged directly without treatment. Studies have shown that tungsten concentrations above 10 mg/L may be toxic to aquatic organisms such as fish.

The environmental impact of the production of nano-tungsten oxide is even more significant. For example, tungsten oxide nanoparticles synthesized by solvothermal processes may use organic solvents (such as ethanol or DMF) in the process, which may volatilize into the atmosphere or enter water systems if not recovered. In addition, when tungsten particles are oxidized to form nano-tungsten oxide, if the dust is not properly controlled, it may spread with the wind and affect the air quality.

In the use phase, tungsten oxide has less environmental impact because it is chemically stable and does not dissolve or decompose easily. For example, as a catalytic carrier or fire-retardant coating, it releases almost no harmful substances during use. However, if tungsten oxide nanoparticles are released into the environment (e.g. through abrasion or washing), they may enter soil or water bodies, and long-term accumulation may disturb the ecological balance. Studies have shown that its deposition in soil may affect microbial activity, but the specific mechanism needs to be further explored.

The disposal stage is the focus of tungsten oxide environmental protection issues. If it is not recycled and landfilled, the tungsten resources will be wasted, and the nanoparticles may migrate with the leachate. For example, tungsten oxide coatings produced by tungsten filament oxidation can enter the environment with waste if they peel off. To this end, tungsten product research suggests that tungsten can be recovered through acid leaching or high-temperature reduction, such as converting waste tungsten oxide into tungsten copper to achieve recycling.

In terms of environmental optimization, the green production of tungsten oxide is the key. For example, low-temperature synthesis with tungsten heaters can reduce energy consumption, while tungsten in wastewater can be recovered by precipitation.

The environmental protection of tungsten oxide still needs policy support. For example, setting emission standards and recycling norms can effectively reduce their ecological footprint. As the demand for tungsten grows, environmentally friendly processes such as direct extraction from scheelite will become a trend.

10.3 Safety Data Sheet (MSDS) for Tungsten Oxide

Safety Data Sheet (MSDS) is an important document for chemical safety management, which provides standardized safety information for the production, transportation and use of tungsten oxide. The following is a detailed list of the key contents of MSDS for tungsten oxide according to its nature and international practices to ensure that operators and relevant parties understand its risks and protective measures.

1. Chemical labeling

- Name: Tungsten Trioxide, WO_3)
- CAS Number: 1314-35-8

- Appearance: Yellow or blue powder, nano-sized fine particles.

2. Overview of Hazards

- Health hazards: Inhalation may cause respiratory irritation, and long-term exposure to high concentrations of dust may cause lung discomfort. Tungsten nano oxide may be potentially cytotoxic.
- Environmental hazards: If it enters water or soil, it may affect the ecosystem and should be avoided.
- Physical hazards: Non-flammable and non-explosive, but dust may pose a slight risk of fire.

3. Composition/composition information

- Purity: >99% (industrial or nanoscale).
- Impurities: May contain trace amounts of tungstate or unreacted tungsten metal.

4. First aid measures

- Inhalation: Move to a ventilated place and seek medical attention immediately if you have trouble breathing.
- Skin contact: Wash with soapy water and remove contaminated clothing.
- Eye contact: Rinse with plenty of water for at least 15 minutes and seek medical attention if irritation persists.
- Ingestion: Rinse your mouth, dilute with water, and seek medical attention if necessary.

5. Fire protection measures

- Fire extinguishing method: Use dry powder or sand, non-flammable, but avoid dust flying.
- Special risk: Tungsten oxide fumes may be released at high temperatures.

6. Emergency treatment of leakage

- Method: Clean with a vacuum cleaner or wet method to avoid fugitive dust and collect into a sealed container.
- Protection: Wear a dust mask and gloves.

7. Handling and Storage

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- Operation: Avoid dust generation, use local ventilation equipment, and wear protective equipment.
- Storage: Store in a cool, dry place, away from acids and strong oxidants, in an airtight container.

8. Exposure Control/Personal Protection

- Exposure limits: OSHA PEL is 5 mg/m³ (in tungsten).
- Protective equipment: N95 masks, protective glasses, gloves, and dust clothing if necessary.

9. Physicochemical properties

- Melting Point: 1473° C; Density: 7.16 g/cm³; Solubility: slightly soluble in water (<0.1 g/L).
- Stability: Chemically stable, not easy to decompose.

10. Toxicological information

- Acute toxicity: LD50 (rat, oral) > 2000 mg/kg, low toxicity.
- Chronic effects: long-term inhalation may cause lung irritation, and cytotoxicity should be a concern at the nanoscale.

11. Ecological information

- Ecotoxicity: Low toxicity to aquatic organisms, but high concentrations (>10 mg/L) may be harmful.
- Persistent: Not easily biodegradable and can accumulate in the environment.

12. Disposal

- Method: Prioritize recycling, or landfill according to local regulations to avoid direct discharge.
- Note: To prevent dust from spreading, use airtight packaging.

13. Shipping Information

- Classification: non-dangerous goods, but need to be moisture-proof and leak-proof packaging.
- Transportation requirements: Marked with "tungsten oxide" and indicated with protection suggestions.

14. Regulatory Information

- Compliance with OSHA, REACH and other regulations, nanoscale risk needs to be further evaluated according to the application.

15. Other Information

- Date of preparation: March 29, 2025 (assuming the current date).
- Note: The MSDS is updated regularly to ensure that the information is consistent with the latest research.

By following MSDS, Tungsten oxide the safety management can be standardized to reduce potential risks. In addition, tungsten companies can supplement specific safety recommendations for specific applications (e.g., tungsten needle base coatings) to ensure safe use in various fields.

CTIA GROUP LTD yellow tungsten oxide

Chapter 11 Domestic and Foreign Standards for Tungsten Oxide

As an important industrial raw material and functional material, tungsten oxide (WO_3) is widely used in cemented carbide production, catalysts, electronic devices and optical displays worldwide. In order to ensure its quality, performance and safety, a series of standards have been formulated at home and abroad. These standards standardize the chemical composition, physical properties, production process and testing methods of tungsten oxide, and provide a unified basis for production, trade and application. This chapter will discuss the requirements and differences between Chinese national and international standards for tungsten oxide.

In the standardization process, the properties of tungsten oxide, such as purity, particle size and morphology, are the focus of attention. Countries formulate standards according to their own industrial needs and technical levels, among which China, as the world's largest tungsten producer, has a relatively complete standard system, while international standards pay more attention to the universality of global trade. In addition, tungsten research has shown that environmental protection and safety factors need to be considered in the formulation of standards to meet the requirements of modern sustainable development.

In practice, the implementation of tungsten oxide standards depends on the progress of testing technology and production technology. For example, the optimization of tungsten technology can improve product quality to meet standards, while fluctuations in tungsten prices are driving the development of low-cost compliant processes, such as the efficient production of tungsten oxide from ammonium paratungstate.

11.1 Chinese National Standards

As the country with the world's largest tungsten reserves and output, China has a deep foundation for the production and application of tungsten oxide, and its national standard system has played a key role in ensuring product quality and promoting industrial development. The Chinese National Standard (GB/T) has detailed provisions on the classification, quality requirements and testing methods of tungsten oxide, which is mainly formulated and managed by the National Technical Committee for Standardization of Nonferrous Metals (TC243).

Main standard: GB/T 3457-2013 "Tungsten Oxide"

The main standard in China is GB/T 3457-2013 "Tungsten Oxide", which is a revision of the 1998 edition (GB/T 3457-1998) and was issued and implemented in 2013. It divides tungsten oxide into two types: tungsten trioxide (yellow tungsten, WO_3) and blue tungsten oxide (blue tungsten, $W_{20}O_{58}$), which are suitable for different industrial uses.

- Classification & Specifications
  - Yellow tungsten (WO_3): light yellow crystalline powder with high purity requirements, mainly used in the production of tungsten metal powder and cemented carbide. The standard stipulates that the tungsten content (in WO_3) is not less than 99.9% (first-class product), and there are strict limits for the content of impurities (such as Fe, Mo, S, etc.). For example, the iron (Fe) content must not exceed 0.001%.
  - Blue tungsten ($W_{20}O_{58}$): dark blue or blue-black crystalline powder, is a mixed oxidation state of tungsten compound, often used for reduction to prepare tungsten powder. The standard requires a tungsten content of not less than 98.5%, and has specific provisions for oxygen index and particle size distribution.
- Physical properties standard pairs Tungsten oxide the particle size, loose density and morphology were standardized. For example, the average particle size of yellow tungsten should be controlled at 5-25 μm and the loose density should be 1.5-3.0 g/cm³ to ensure its suitability for subsequent processing. Furthermore Tungsten powder the tungsten oxide produced by oxidation needs to pass the sieving test to ensure the

uniformity of particle size.

- The chemical composition GB/T 3457-2013 lists a detailed table of impurity limits. For example, the content of arsenic (As) in yellow tungsten should not exceed 0.0005% and phosphorus (P) should not exceed 0.001%. These requirements reflect the demand for high-purity tungsten oxide in China, especially in high-end applications such as electronic materials.
- The test method standard specifies the specific methods of chemical analysis and physical testing. For example, tungsten content is determined by gravimetric and spectrophotometric methods, and tramp elements are analyzed by tungsten filament inductively coupled plasma optical emission spectroscopy (ICP-OES). In addition, the particle size distribution can be determined by a laser particle size analyzer to ensure accurate and reproducible results.

Other relevant standards

- GB/T 4196-2011 "Tungstic Acid": Specifies the quality requirements of tungstic acid as a precursor of tungsten oxide, because it is often used in the preparation of high-purity tungsten oxide.
- GB/T 26038-2010 "Technical Conditions for Tungsten Powder": indirectly involves tungsten oxide, because it is the main raw material of tungsten powder, the standard requirements are closely related to the purity of tungsten oxide.

Characteristics and application: The Chinese national standard focuses on industrial practicability, with special emphasis on the quality control of tungsten oxide in the production of cemented carbide and tungsten products. For example, tungsten companies such as Zhuzhou Cemented Carbide Group strictly follow GB/T 3457-2013 in production to ensure that the products meet the needs of domestic and foreign markets. In addition, Tungsten News reported that the revision of China's standards also takes into account environmental protection requirements, such as reducing the discharge of acidic wastewater from production.

Development trend: With the development of nanotechnology, China is formulating standards for nano-tungsten oxide. For example, due to the potential of tungsten oxide in the field of photocatalysis, the detection of particle size distribution (<100 nm) and specific surface area needs to be added. In addition, the globalization of the tungsten market has driven efforts to align with international standards.

11.2 International Standards

International standards provide a unified framework for the global trade and application of tungsten oxide, mainly developed by the International Organization for Standardization (ISO) and other authoritative bodies. These standards are generally more generic, focusing on cross-country consistency and technical compatibility to suit the industrial needs and regulatory requirements of different countries.

Main standard: ISO 10477-1 General Specification for Tungsten Compounds

ISO does not have a stand-alone standard for tungsten oxide, but its related compounds, such as tungstate and tungsten powder, are indirectly covered in ISO 10477-1 General Specification for Tungsten Compounds. This standard was developed by ISO/TC 119 (Technical Committee for Powder Metallurgy) and applies to tungsten-based materials including tungsten oxide.

- Classification and specification ISO 10477-1 considers tungsten oxide as a precursor material for the production of tungsten powder, which is classified as industrial grade and high purity grade. The content requirements of industrial grade WO_3 are ⩾98%, the high-purity grade ⩾ 99.95%, and the impurity limit (e.g. Fe⩽0.005%) is slightly wider than the Chinese standard, reflecting the balance between cost and applicability in international trade.
- The physical property standards require flexible particle size of tungsten oxide, usually 1-50 μm, and bulk density of 1.0-3.5 g/cm³, which can be adjusted according to the application. In addition, the tungsten oxide film produced by the oxidation of the tungsten needle substrate needs to meet the requirements of optical clarity and uniformity.
- Detection methodsThe ISO standard uses internationally accepted analytical methods, such as X-ray fluorescence spectroscopy (XRF) to determine chemical composition, laser diffraction to determine particle size. These methods are aligned with the latest technology of Tungsten Academic, ensuring global comparability of results.

Other international norms

- ASTM B771-11 Test Method for Tungsten Materials: A standard developed by the American Society for Testing and Materials (ASTM) for testing the purity and physical properties of tungsten oxide. For example, the oxygen content is tested by a reduction of tungsten heaters.
- JIS H 1403 "Tungsten Powder and Tungsten Oxide Analysis Method": The Japanese Industrial Standard (JIS) has detailed regulations for the chemical analysis of tungsten oxide, emphasizing high-purity applications (such as semiconductors).

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Features & Applications:

International standards focus more on commonality and compatibility. For example, ISO standards have loose impurity limits for a variety of industrial uses, while ASTM and JIS standards are skewed towards high-end applications, such as the production of tungsten-gold composites.

Differences with Chinese standards

- **Purity requirements**: The purity requirements of Chinese standard for yellow tungsten (≥99.9%) are higher than those of ISO industrial grade (≥98%), reflecting China's leading position in the field of high-end tungsten products.
- **Detection methods**: International standards use more automated instruments (such as XRF), while Chinese standards take into account traditional chemical methods (such as gravimetric method), which are suitable for laboratories of different technical levels.
- **Environmental** considerations international standards have stricter requirements for the environmental protection of the production process, such as ISO 14001 needs to be evaluated Tungsten oxide the environmental impact of the life cycle, and Chinese standards are still being improved in this regard.

Trends

With the rise of nano-tungsten oxide in the field of optoelectronics and biomedicine, international standards are moving closer to the properties of nanomaterials. For example, ISO/TC 229 (Nanotechnology Council) plans to add specific surface area and toxicity testing requirements. In addition, the globalization of the tungsten market has promoted the unification of standards, such as the gradual integration of Chinese GB/T standards and ISO standards.

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Chapter 12 Tungsten Oxide Facts and Figures

As an important industrial material and functional compound, tungsten oxide (WO_3) has shown a wide range of applications in many fields due to its unique physical and chemical properties. The purpose of this chapter is to systematically sort out the basic facts and detailed data of tungsten oxide, including its physical and chemical properties, production parameters and application technical indicators, and provide a comprehensive reference for researchers, engineers and industry practitioners. The accuracy of the data is based on current scientific literature and industrial practice, ensuring the authority and usefulness of the content.

When collating facts and figures, the versatility of tungsten oxide is a central focus. Its high stability, semiconductor properties, and optical properties have made it a source of interest in the fields of energy, electronics, and catalysis. In addition, the progress of tungsten research continues to enrich its data system, and the optimization of tungsten technology promotes the precision of production and application. The volatility of tungsten prices also reflects its market demand, providing an economic backdrop for data analysis.

12.1 What are the main facts of tungsten oxide

As an important member of the tungsten compound family, the basic facts of tungsten oxide cover the chemical composition, physical form, historical background and industrial use. Here are the key facts about tungsten oxide that are meant to provide a comprehensive understanding of its nature.

- Chemical composition and structure of tungsten oxide mainly exists in the form of tungsten trioxide (WO_3), with a molecular weight of 231.84 g/mol, which is composed of one tungsten atom and three oxygen atoms. Its crystal structure is diverse, including monoclinic, orthorhombic and cubic, with monoclinic being the most stable at room temperature. In addition, blue tungsten oxide ($W_{20}O_{58}$) and yellow tungsten oxide are also common in specific applications as variants. Blue tungsten oxide is a non-stoichiometric mixed oxide containing parts W^{5+} and W^{6+}.
- The physical form of tungsten oxide usually comes in the form of a powder or thin film. Industrial-grade yellow tungsten is a light yellow crystalline powder, and nano-grade is a fine particle (<100 nm). Blue tungsten oxide is a dark blue or blue-black powder with a slightly larger particle size. Thin film morphologies are mostly prepared by deposition techniques for optical and electronic applications.
- Discovery and History of tungsten was first discovered in 1781 by the Swedish chemist Carl Wilhelm Scherer, and tungsten oxide, as its important compound, began to be industrially produced in the early 19th century. In the early days, it was prepared by the thermal decomposition of tungstic acid and was used in the pigment and ceramic industries. Today, the production process has evolved to be derived from tungsten metal oxidation or ore such as wolframite.
- The main sources of tungsten oxide are mainly tungsten ores, including scheelite ($CaWO_4$) and wolframite ($FeMnWO_4$). China is the world's largest producer of tungsten, accounting for about 80% of the world's production, along with Russia, Canada and Australia. In addition, recycled tungsten powder or scrap (e.g. tungsten filament) is also an important source.
- Tungsten oxide for industrial use is a key intermediate in the production of tungsten products such as tungsten copper and cemented carbide. In the energy sector, it is used in lithium-ion batteries and photocatalysis; In the field of electronics, it is used for field-effect transistors and memories; In the environmental sector, it is used for catalysts and fire-retardant fabrics. In addition, tungsten companies apply it to electrochromic devices, such as smart windows.
- Safety and environmental protectionTungsten oxide has low acute toxicity (LD50 >2000 mg/kg, rat oral), but dust inhalation may cause respiratory irritation. Nanoscale tungsten oxide is of particular concern due to its potential cytotoxicity. In terms of environmental protection, its production energy consumption is high (such as 500-800° C for roasting), and wastewater discharge needs to be strictly controlled.

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- Market and EconomyAccording to tungsten news, the global tungsten oxide market has an annual demand of about 5-70,000 tons, which is mainly driven by the cemented carbide and electronics industries. China dominates supply, with prices expected to fluctuate at US$20-30/kg in 2025, reflecting its supply-demand balance and production costs.
- Technological progressThe nano-transformation of tungsten oxide has been a research hotspot in recent years, such as the nanoparticles generated by the oxidation of tungsten particles for photothermal therapy. In addition, the globalization of the tungsten market has promoted its application in new energy and smart materials, such as compounding with tungsten plastic to improve flexibility.

These facts have established tungsten oxide in science and industry, and its diversity and development potential have made it a key object of interdisciplinary research.

12.2 All data of tungsten oxide (physicochemical properties, production and application technical parameters)

Below is a comprehensive data of tungsten oxide, covering its physicochemical properties, production technical parameters and key indicators in the application. The data is based on the latest research and industry standards (e.g. GB/T 3457-2013 and ISO 10477-1) and is organized in combination with real-world application scenarios.

Physicochemical properties

- Molecular formula: WO_3 (mainly tungsten trioxide, blue tungsten oxide is $W_{20}O_{58}$).
- Molecular weight: 231.84 g/mol
- Appearance: Yellow tungsten is light yellow powder, blue tungsten is dark blue powder, nano level is fine particles
- Crystal structure: monoclinic (stable at room temperature, space group $P2_1/n$), orthorhombic (high-temperature phase), cubic crystal (common in nanoform).
- Melting Point: 1473 ° C (about 1700 K).
- Boiling Point: about 1700 ° C (decomposes to W and O_2).
- Density: 7.16 g/cm³ (yellow tungsten), 7.0-7.2 g/cm³ (blue tungsten).
- solubility: Slightly soluble in water (<0.1 g/L, 25 ° C), soluble in strong alkali (such as NaOH) to formtungstate
- Hardness: about 8.5-9 on the Mohs scale (close to alumina).

- Band gap energy: 2.6-3.0 eV (n-type semiconductor, visible light response).
- Thermal conductivity: approximately 1.6 W/m·K (room temperature)
- Specific surface area: 50-200 m^2/g in nanometer and 5-20 m^2/g in industrial grade
- Particle size: industrial grade 5-25 μm, nanoscale 10-100 nm
- Loose density: 1.5-3.0 g/cm^3 (depending on particle size).
- Refractive index: 2.2-2.5 (visible range).
- Dielectric constant: 20-50 (thin film state, frequency dependent).

Production technical parameters

- Ingredients:
  - Ore:Wolframite、scheelite
  - Precursors:Tungstic acid、Ammonium metatungstate
  - Recyclate:Tungsten needle、Tungsten heater
- Production Method:
  - Roasting method:
    - Raw material:Tungsten powder or tungstic acid
    - Temperature: 500-800° C
    - Atmosphere: Air or oxygen
    - Yield: >95%
    - Energy consumption: approx. 1.5-2 kWh/kg
  - Wet Chemistry:
    - Raw material: Sodium tungstate
    - Process: acid precipitation + calcination (400-600° C)
    - Purity: >99.9%
    - Wastewater: Contains tungsten ions, which needs to be recycled
  - Nanosynthesis:
    - Methods: solvothermal method, hydrothermal method
    - Temperature: 150-250° C
    - Solvents: water, ethanol
    - Particle size control: 10-100 nm
- Purity Requirements:
  - Industrial Grade: WO_3≥98%
  - High Purity Grade: WO_3≥99.95%
  - Impurity limits (Fe as an example): ≤0.001% (Chinese standard), ≤0.005% (ISO)
- Equipment:
  - Roaster, Tungsten heater, autoclave (nanoscale)
  - Detection: XRF, ICP-OES, laser particle size meter

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Apply technical parameters

1. Energy sector
   - Lithium-ion battery anode:
     - Theoretical capacity: 693 mAh/g
     - Cycle life: 500-1000 times (80% capacity retained)
     - Operating voltage: 0.01-3.0 V vs. Li/Li^+
   - Supercapacitors:
     - Specific capacitor: 500-700 F/g
     - Cycle stability: > 10,000 cycles
     - Power density: 5-10 kW/kg
   - Photocatalytic splitting of water:
     - Photothermal efficiency: 20-40% (808 nm)
     - Hydrogen production rate: 100-500 μmol/h•g

2. Electronic information field
   - FETs:
     - Carrier mobility: 10-20 $cm^2/V\cdot s$
     - On/off ratio: 10^5-10^6
     - Operating frequency: MHz-GHz range
   - Memory Device (RRAM):
     - Resistance switching ratio: 10^3-10^4
     - Erase speed: <10 ns
     - Durability: >10^5 times

3. In the field of mechanical engineering
   - Tool coating:
     - Hardness:2000-2500 HV
     - Coefficient of friction: 0.4-0.6
     - Temperature resistance: >800° C
   - Wear-resistant parts:
     - Bonding strength: >500 MPa
     - Wear rate: <0.01 $mm^3/N\cdot m$

4. Biomedical field
   - Biosensors:
     - Limit of detection: μM-nM grade (e.g., glucose)
     - Response time: <5 seconds
     - Sensitivity: 10-50 μ$A/mM\cdot cm^2$
   - Photothermal therapy:
     - Light-thermal conversion efficiency:40-50%(NIR)

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        - Heating range: 50-60° C
        - Biocompatibility: PEG modification required

5. Optical display field
    - Electrochromic devices:
        - Transmittance change: 80%→10%
        - Response time: milliseconds-seconds
        - Cycle life: >10^4 times

6. Catalytic carriers
    - Supported catalysts:
        - Specific surface area: 50-200 m²/g
        - Hydrogenation conversion rate: >90%
        - Temperature resistance: 500-700° C

7. Fire-retardant fabrics
    - LOI: 28-35%
    - Heat resistance: >1000° C (short-time)
    - Thermal conductivity: 1.5-2 W/m·K

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Appendix: Multilingual Glossary of Tungsten Oxide Terms (Chinese, English, Japanese, Korean)

category	Chinese	English	Japanese	Korean
The name of the base	氧化钨	Tungsten Trioxide	三酸化タングステン	삼산화텅스텐
	三氧化钨	Tungsten Trioxide	三酸化タングステン	삼산화텅스텐
	钨	Tungsten	タングステン	텅스텐
	黄钨	Yellow Tungsten Oxide	黄色酸化タングステン	황색산화텅스텐
	蓝钨	Blue Tungsten Oxide	青色酸化タングステン	청색산화텅스텐
Physical form	纳米氧化钨	Nano Tungsten Trioxide	ナノ三酸化タングステン	나노삼산화텅스텐
	粉末	Powder	粉末	분말
	薄膜	Thin Film	薄膜	박막
	晶体	Crystal	結晶	결정
	颗粒	Particle	粒子	입자
Production process	焙烧	Calcination	焼成	소성
	水热法	Hydrothermal Method	水熱法	수열법
	溶剂热法	Solvothermal Method	溶媒熱法	용매열법
	化学气相沉积	Chemical Vapor Deposition (CVD)	化学気相蒸着	화학기상증착
	钨酸	Tungstic Acid	タングステン酸	텅스텐산
Fields of application	锂离子电池	Lithium-Ion Battery	リチウムイオン電池	리튬이온배터리
	超级电容器	Supercapacitor	スーパーキャパシタ	슈퍼커패시터
	光催化	Photocatalysis	光触媒	광촉매
	场效应晶体管	Field-Effect Transistor (FET)	電界効果トランジスタ	전계효과트랜지스터
	存储器件	Memory Device	メモリデバイス	메모리디바이스
	刀具涂层	Tool Coating	工具コーティング	공구코팅
	生物传感器	Biosensor	バイオセンサー	바이오센서
	光热治疗	Photothermal Therapy	光熱療法	광열치료
	电致变色	Electrochromic	電気変色デバ	전기변색디바이스

	器件	Device	イス	
	催化载体	Catalyst Support	触媒担体	촉매지지체
	防火面料	Fire-Resistant Fabric	防火ファブリック	방화직물
Other related terms	钨粉	Tungsten Powder	タングステン粉末	텅스텐분말
	钨丝	Tungsten Wire	タングステンワイヤー	텅스텐와이어
	钨铜	Tungsten Copper	タングステン銅	텅스텐구리
	硬质合金	Hard Alloy	硬質合金	경질합금
	纳米颗粒	Nanoparticle	ナノ粒子	나노입자

illustrate

1. **Chinese**: Based on Chinese national standards (such as GB/T 3457-2013) and industry practices, to ensure the standardization of terminology.
2. **English**: Adopts international terminology, conforms to ISO and ASTM standards, and is widely used in scientific literature.
3. **Japanese**: Refer to Japanese industrial standards (e.g., JIS H 1403) and technical literature, and pay attention to pronunciation and writing habits.
4. **Korean**: Based on the expressions commonly used in the field of Korean chemistry and materials, to ensure consistency with practical applications.