Yellow Tungsten Oxide (WO_3)

Physical & Chemical Properties, Processes, & Applications

CTIA GROUP LTD

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

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.

CTIA GROUP

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

1. Overview of tungsten trioxide

CTIA GROUP tungsten trioxide (referred to as yellow tungsten, WO_3) is produced by ammonium paratungstate high-temperature calcination process, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. Yellow tungsten is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants due to its light yellow crystal powder form, high purity and chemical stability. CTIA GROUP is committed to providing high-quality yellow tungsten products to meet the needs of powder metallurgy and industrial manufacturing.

2. Characteristics of tungsten trioxide

Chemical composition: WO_3.

Purity: ≥99.95% with very low impurity content.

Appearance: Light yellow crystal powder, uniform color.

Polymorph: monoclinic (most common at room temperature), space group P21/n.

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 (1000-1100°C).

Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Specifications of tungsten trioxide

index	CTIA GROUP Yellow tungsten first grade standard
WO_3 content (wt%)	≥99.95
Impurity（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
Moisture (wt%)	≤0.05
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. Tungsten trioxide 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. Tungsten trioxide procurement information

Mailbox:sales@chinatungsten.com Phone: +86 592 5129696

For more information about tungsten yellow, please visit the Chinatungsten Online websitewww.tungsten-powder.com

Physical and chemical properties, process and application of yellow tungsten oxide (tungsten trioxide).

Yellow Tungsten Oxide (WO3)

Physical & Chemical Properties, Processes, & Applications

ISO 16962:2017 *Surface chemical analysis — Analysis of zinc- and/or aluminium-based metallic coatings*(involving WO_3 characterization)

Appendix E: National Standards

Japan JIS K 1462:2015 (Tungsten Compound Analysis Method)

DIN 51078:2002 (Oxide Ceramic Raw Material Testing)

GOST 25702-83 (Chemical Analysis of Tungstate)

Appendix F: Glossary (English and Chinese)

Physical and chemical properties, process and application of yellow tungsten oxide (tungsten trioxide).

Yellow Tungsten Oxide (WO3)

Physical & Chemical Properties, Processes, & Applications

preface

Overview of the research and application of yellow tungsten oxide

As a professional team of CTIA GROUP, we are well aware of the core position of yellow tungsten oxide (tungsten trioxide, WO_3) in the tungsten industry chain. This bright yellow compound is not only an important intermediate product of tungsten metallurgy, but also a star material for modern materials science and industrial applications. The monoclinic structure of yellow tungsten oxide gives it unique electronic properties and chemical stability, and its energy band gap (about 2.6-2.8 eV) makes it exhibit excellent performance in many fields such as light, electricity, and heat. From tungstate research in the 19th century to today's nanotechnology revolution, the application of WO_3 has expanded from traditional tungsten powder preparation to the high-tech frontier.

In China, the research and application of yellow tungsten oxide is closely integrated with the advantages of tungsten resources and industrial demand. Our team has extensive experience in process optimization for the thermal decomposition of ammonium metatungstate (AMT) to produce WO_3, for example by precisely controlling the roasting conditions (500-700°C) to achieve large-scale production of high-purity WO_3 (WO_3 content ≥99.9%). At the same time, WO_3 has exciting potential in the field of photocatalysis for the decomposition of organic pollutants and the production of hydrogen from photolysis of water (with an efficiency of more than 90%), providing solutions for environmental remediation and clean energy. In terms of energy storage, we verified the excellent performance of the WO_3 electrode in lithium-ion batteries (capacity 650-750 mAh/g) and the high specific capacitance in supercapacitors (300 F/g). In addition, the electrochromic properties of WO_3 are driving the industrialization of smart windows, and their use in gas sensors (NO_2 detection sensitivity up to 10 ppb) and antimicrobial materials (98% antimicrobial rate) also opens up new avenues for smart manufacturing. Globally, WO_3's research focuses on nanostructure design and optoelectronic performance optimization, with China's practical experience in production process and application development particularly outstanding. AS A MEMBER OF THE CTIA GROUP, WE HAVE SEEN WO_3 MOVE FROM THE LAB TO THE MARKET. The purpose of this book is to summarize these technical achievements, combine with international cutting-edge trends, provide a systematic reference for industry colleagues, and help the intelligent and sustainable development of tungsten material industry.

Target readership

When writing this book, CTIA GROUP clearly aimed at the following readers, hoping to serve practitioners and scholars in the tungsten industry and related fields with our professional perspective:

Tungsten material research and development personnel

For researchers engaged in WO_3 crystal structure, production process, and performance optimization, this book provides a complete technical path from AMT to WO_3 and the latest research data to facilitate basic and applied research.

Chemical & Materials Engineer

For engineers in the fields of tungsten metallurgy, new energy and intelligent manufacturing, this book details industrial production methods (such as roasting method, hydrothermal method) and process parameter optimization, which has direct guiding significance.

Teachers and students of colleges and universities

Students and faculty of chemistry, materials science, and engineering can use this book as an authoritative resource for learning about the properties and applications of WO_3, and the lab guide is especially suitable for teaching and practice.

Tungsten industry chain practitioners

Industry professionals from tungsten ore processing to downstream applications can learn about the latest applications of WO_3 (e.g., sensors, batteries) and Chinese standards (e.g., YS/T 535-2006) to enhance their technology and market competitiveness.

Cross-disciplinary technical experts

Professionals interested in environmental protection, optoelectronic materials or nanotechnology can draw inspiration from the versatile properties of WO_3 to drive cross-border innovation.

As professionals at CTIA GROUP, we are well aware of the complexities of tungsten materials from R&D to industrialization. This book not only condenses our knowledge and technology accumulation for more than 30 years, but also integrates the insights of the global tungsten industry, aiming to provide readers with practical knowledge and forward-looking vision for readers from different backgrounds, and jointly promote a new chapter of yellow tungsten oxide in intelligent manufacturing and green technology.

Chapter 1: Introduction

1.1 Definition and history of yellow tungsten oxide

What is Yellow Tungsten Oxide?

Yellow tungsten oxide (tungsten trioxide, chemical formula WO_3) is an inorganic compound composed of tungsten and oxygen, named for its bright yellow powder form at room temperature. This color is due to the electronic transition properties of the tungsten octahedron in its monoclinic crystal structure, which has an energy band gap of about 2.6-2.8 eV, giving it a remarkable optical response in the visible range. WO_3 has a molecular weight of 231.84 g/mol, a density of about 7.16 g/cm^3, and a melting point of up to 1473°C. It has strong chemical stability and is insoluble in water and neutral solutions, but can be dissolved to form tungstate under strong alkaline conditions.

The discovery and research of WO_3 dates back to the end of the 18th century. In 1781, Swedish chemist Carl Wilhelm Scherer first isolated tungstic acid (H_2WO_4) by acidifying a solution of sodium tungstate, which was the starting point for WO_3 research. In 1783, the Spanish brothers Juan José and Fausto Elhuyar extracted tungsten from wolframite, further advancing the exploration of tungsten compounds. At the beginning of the 19th century, the demands of the Industrial Revolution made WO_3 an important intermediate in tungsten metallurgy. At that time, WO_3 was mainly prepared by roasting tungsten ore (e.g. wolframite $FeMnWO_4$ or scheelite $CaWO_4$) and subsequently reduced to tungsten metal, which was used in the manufacture of filaments and tool steels. At the end of the 19th century, with advances in chemical analysis techniques, such as gravimetric and spectroscopic analysis, scientists began to focus on the purity of WO_3 and its potential in catalytic reactions.

Since the 20th century, WO_3 research has entered a new phase. The application of X-ray diffraction (XRD) technology has revealed its multiphase structure, including monoclinic (the most common), hexagonal, tetragonal, and cubic phases, which are intertransformable at different temperatures and atmospheres. For example, in air at 500-700°C, WO_3 is usually stable in monoclinic phase, while at higher temperatures (>900°C) it may turn tetragonal. In the mid-20th century, WO_3 began to be used as a pigment in the ceramics and glass industries, and its vivid yellow color became a highlight of the decorative material. In the late 20th century, with the rise of nanotechnology, the optoelectronic properties of WO_3 were further explored. For example, its electrochromic properties (from yellow to blue) make it a candidate material for smart windows, while its photocatalytic properties are driving its applications in environmental remediation, such as the decomposition of organic pollutants and photolysis of water to produce hydrogen.

Today, WO_3 is produced in the tens of thousands of tonnes per year worldwide, and China, as a major tungsten resource (accounting for more than 60% of the world's reserves), dominates the production and application. From traditional metallurgy to high-tech fields, the historical evolution of yellow tungsten oxide reflects the deepening of human understanding of tungsten and technological progress. The purpose of this section is to provide the reader with a comprehensive background on the definition and history of WO_3, and to provide a basis for the analysis of the nature and application of WO_3 in subsequent chapters.

1.2 The family of tungsten compounds and their importance

The family of tungsten compounds includes a range of substances with different chemical forms, from simple oxides to complex polyacid compounds, which form the basis of tungsten applications. Yellow tungsten oxide (WO_3) is a core member of the family and is associated with other compounds such as tungsten dioxide (WO_2), tungstic acid (H_2WO_4), ammonium paratungstate (APT, $(NH_4)_{10}[H_2W_{12}O_{42}]\cdot 4H_2O$, ammonium metatungstate (AMT, $(NH_4)_6H_2W_{12}O_{40}\cdot xH_2O$) and tungsten bronze ($M_xWO_3$, M is alkali metals such as Na and K) form a diverse application system. The unique physicochemical properties of tungsten – high melting point (3422°C), high density (19.25 g/cm³) and excellent corrosion resistance – make its compounds indispensable in industry and research.

The importance of tungsten compounds is first reflected in the field of metallurgy. WO_3 is a key raw material for the production of high-purity tungsten powder, which can be prepared by hydrogen reduction ($WO_3 + 3H_2 \rightarrow W + 3H_2O$) to produce tungsten powder with a particle size of 2-5 μm, which is widely used in the production of cemented carbide (e.g. WC-Co), tungsten steel and superalloys. These materials support performance demands in extreme conditions in aerospace, automotive manufacturing, and machining. For example, tungsten alloy is used in the manufacture of aircraft counterweights and armor-piercing bullet cores due to its high density. Secondly, tungstate and polyacid compounds have important value in the field of catalysis. AMT and APT can be used as precursors to prepare WO_3 catalysts for hydrocracking, desulfurization and denitrification in petrochemical industries with an active surface area of up to 10-20 m²/g. In addition, tungsten bronze is used in infrared shielding coatings due to its metal-semiconductor properties, reducing energy consumption in energy-efficient buildings.

In the field of new energy and high-tech, the application of tungsten compounds is further highlighted. WO_3 exhibits high capacitance (600-750 mAh/g) as an anode material in lithium-ion batteries and a specific capacitance of 250-350 F/g in supercapacitors, with electrochemical performance due to its porous structure and fast ion transport capability. At the same time, WO_3's photocatalytic properties make it shine in environmental remediation, such as the decomposition of dyes such as methylene blue with an efficiency of more than 90% under visible light. In addition, the diversity of tungsten compounds is reflected in the biomedical potential, such as WO_3 nanoparticles being used in cancer treatment research due to photothermal effects.

China has a global presence in the research and production of tungsten compounds. As the hub of the entire industrial chain from ore extraction to functional material development, WO_3 not only connects resources and products, but also provides the possibility for intelligent applications. This section highlights the core position of WO_3 by introducing the diversity and importance of the tungsten compound family, and provides a basis for further discussion of subsequent application fields.

1.3 Relationship between yellow tungsten oxide and ammonium metatungstate

Yellow tungsten oxide (WO_3) with ammonium metatungstate (AMT, $(NH_4)_6H_2W_{12}O_{40}·xH_2O$) is a key link in the research and application of tungsten compounds. AMT is a white crystal or powder that belongs to the Keggin-type polyacid compound, and its molecular structure is formed by 12 tungsten octahedron around two hydrogen atoms, with a molecular weight of about 2956.42 g/mol (containing crystalline water). Its high water solubility (> 1000 g/L at pH 5.5) and thermal decomposition properties make it an ideal precursor for the preparation of WO_3. Industrially, AMT is prepared by ammonium tungstate solution polymerization or ammonium paratungstate (APT) heating conversion at 220-280°C, followed by roasting and decomposition to WO_3 at 500-700°C, and the reaction process is as follows:

(NH4)6H2W12O40·xH2O→500−700°C12WO3+6NH3+(x+1)H2O

$(NH_4)_6H_2W_{12}O_{40}·xH_2O$ \xrightarrow{500-700°C} 12 WO_3 + 6 NH_3 + (x+1) H_2O (NH4)6H2W12O40 ·xH2O500−700°C

This conversion process offers significant process advantages. The decomposition product WO_3 of AMT achieves a high purity of 99.9% and can control the crystalline phase (monoclinic or hexagonal) and particle size (D50 ≈ 4-10 μm) of WO_3 by adjusting the roasting conditions (e.g., temperature 550°C, nitrogen atmosphere). In the laboratory, the solution properties of AMT make it suitable for the preparation of nano-WO_3 by wet chemical methods, such as WO_3 particles with a particle size of 20-30 nm by hydrothermal methods and homogeneous micronized powders (D50 ≈ 4-5 μm) by spray drying. These features make AMT an important bridge from basic research to industrial production.

WO_3's relationship with AMT extends not only to the process, but also to the application area. For example, WO_3 obtained by thermal decomposition of AMT retains the structural advantages of its precursor, such as high specific surface area and porosity, which makes it excellent in photocatalysis (up to 0.8 mmol/h·g). In energy storage, AMT-derived WO_3 electrodes have capacities up to 720 mAh/g in lithium batteries, while in gas sensors, WO_3 has a detection sensitivity of up to 10 ppb for NO_2. Chinese researchers have made fruitful achievements in this field, such as microwave-assisted synthesis of AMT (yield increased to 94.5%) and electrospinning to prepare WO_3 nanofibers (50-80 nm diameter), providing new ideas for the development of high-performance materials.

In addition, the production of AMT and the application of WO_3 also involve the exploration of green processes, such as ammonia nitrogen recovery technology (recovery rate of >93%), which reduces the environmental load. This synergistic relationship between the precursor and the product reflects the transformation logic of tungsten compounds from raw materials to functional materials. This section provides theoretical support for subsequent production process and application analysis by detailing the chemical and process connections between WO_3 and AMT.

1.4 Overview of the structure and content of the book

This book was written by a team of professionals at CTIA GROUP to provide a systematic guide for the comprehensive study and application of yellow tungsten oxide (WO_3). The book consists of 10 chapters, with both theoretical depth and practical guidance, covering the basic science, production technology, application scenarios and future trends of WO_3, as follows:

Chapters II to III
In-depth discussion of the chemical and physical properties of WO_3 and its crystal structure, including lattice parameters of monoclinic phase, multiphase transition conditions, and nanoscale structural properties.
Chapter IV Department
Introduce the production process, from the thermal decomposition of AMT to the industrial roasting method, laboratory hydrothermal method, analyze the influence of process parameters on purity and particle size, and discuss green production technology.
Chapter 5
Detailed analysis and characterization techniques, including chemical composition determination (ICP-AES), structural analysis (XRD, FTIR), and topography observation (SEM, TEM), provide tools for research and quality control.
Chapter VI
A comprehensive demonstration of WO_3 applications in photocatalysis (hydrogen production and degradation), energy storage (batteries and capacitors), smart materials (electrochromic), sensors and nanotechnology.
Chapter VII
Focusing on the thermal decomposition path from AMT to WO_3, the decomposition stage, phase transition, and kinetic parameters were analyzed.
Chapter VIII
Assess WO_3 toxicity, storage recommendations, and environmental impacts, with Chinese and international standards.

CHAPTER IX

Review the history of WO_3 research, summarize current hotspots such as nanosynthesis, and look forward to the future of green technologies and composites.

Chapter X

Industrial production cases (e.g., large-scale roasting processes) and laboratory experiment guides (e.g., hydrothermal synthesis) are provided to enhance practicability.

The appendices include WO_3's data sheets, analysis procedures, patent lists, Chinese and international standards (YS/T 535-2006, ASTM B922-20, etc.), national standards (JIS, DIN, GOST), and glossaries. The bibliography integrates global research results and Chinese practical experience. This book is not only suitable for academic researchers to explore the scientific nature of WO_3, but also provides a technical reference for industry practitioners, aiming to promote innovation and development in the field of tungsten materials.

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CTIA GROUP

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

1. Overview of tungsten trioxide

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2. Characteristics of tungsten trioxide

Chemical composition: WO_3.

Purity: ≥99.95% with very low impurity content.

Appearance: Light yellow crystal powder, uniform color.

Polymorph: monoclinic (most common at room temperature), space group P21/n.

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 (1000-1100°C).

Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Specifications of tungsten trioxide

index	CTIA GROUP Yellow tungsten first grade standard
WO_3 content (wt%)	≥99.95
Impurity（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
Moisture (wt%)	≤0.05
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. Tungsten trioxide 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. Tungsten trioxide procurement information

Mailbox:sales@chinatungsten.com Phone: +86 592 5129696

For more information about tungsten yellow, please visit the Chinatungsten Online websitewww.tungsten-powder.com

Chapter 2: Chemical and Physical Properties

2.1 Chemical composition and molecular formula (WO_3) of yellow tungsten oxide (tungsten trioxide, WO_3).

Yellow tungsten oxide (tungsten trioxide, abbreviated as WO_3) is an inorganic compound composed of two elements, tungsten (W) and oxygen (O), and its chemical formula WO_3 indicates that tungsten is in the +6 oxidation state, which is the highest oxidation state that tungsten can achieve under natural conditions. Each WO_3 molecule contains one tungsten atom and three oxygen atoms, with a total molar mass of 231.84 g/mol, of which the mass fraction of tungsten is about 79.31% (183.84 g/mol) and the mass fraction of oxygen is about 20.69% (48 g/mol). This proportion can be precisely determined by classical gravimetric methods, such as weighing WO_3 samples reduced to tungsten metal at high temperatures, or by direct analysis of elemental content using modern instruments such as inductively coupled plasma emission spectroscopy (ICP-AES). The purity of industrial grade WO_3 is typically required to be above 99.5%, while for high-purity samples (e.g., for semiconductor or photocatalytic studies) can reach 99.9%-99.99%, and common impurities include iron ($Fe < 0.005\%$), molybdenum ($Mo < 0.003\%$), sodium ($Na < 0.001\%$), etc., the control of these trace elements is critical for specific applications.

The chemical composition of WO_3 is closely related to its molecular structure. In the monoclinic crystal system (the most common crystalline phase), the basic building block of WO_3 is the tungsten oxygen octahedron (WO_6), where each tungsten atom is coordinated by six oxygen atoms, and the oxygen atoms are connected by coangular or colateral connections to form a three-dimensional network structure. This slight distortion of the structure results in anisotropic optical and electrical properties of WO_3 in different directions, such as differences in refractive index on different crystal axes (n_a ≈ 2.2, n_b ≈ 2.3). The W-O bond is partially covalent and the bond length ranges from 1.8-2.1 Å, depending on the coordination environment of the oxygen atom (terminal oxygen or bridge oxygen). By X-ray photoelectron spectroscopy (XPS) analysis, the binding energy of W 4f is about 35.5-36.0 eV, and the binding energy of O 1s is about 530.5 eV, indicating that the electron cloud density of W-O bonds is high, and its average bond energy is about 672 kJ/mol. This high bond gives WO_3 strong chemical stability, making it less likely to decompose in acidic or neutral environments, but chemically transformative under strong alkaline conditions.

The chemical composition of WO_3 has a profound impact on its application. In the field of catalysts, the +6 oxidation state of tungsten gives it a strong oxidizing capacity, for example, in photocatalytic reactions, WO_3 acts as an electron acceptor to promote the oxidation of water molecules to produce oxygen. Among battery materials, the stable structure of WO_3 supports the repeated insertion and ejection of lithium ions (Li^+), with a theoretical capacity of up to 693 mAh/g. In addition, the chemical composition of WO_3 also determines its relationship with precursors, such as the thermal decomposition of ammonium metatungstate (AMT) to form WO_3, which retains the basic framework of tungsten-oxygen units. This section provides a theoretical basis for the subsequent analysis of physical and chemical properties by describing the chemical composition and molecular formula of WO_3 in detail.

2.2 Physical form and appearance of yellow tungsten oxide (tungsten trioxide, WO_3 for short) (yellow powder).

Yellow tungsten oxide exists in a solid form at room temperature and pressure, usually as a fine particle or powdery substance, and its appearance is bright yellow to orange-yellow. This color stems from the band gap in its electronic structure (the energy band gap is about 2.6-2.8 eV), which corresponds to the visible range of the absorption spectrum at 400-480 nm, giving it a distinctive yellow character in natural light. By ultraviolet-visible spectroscopy (UV-Vis) analysis, the absorption peak of WO_3 is typically located around 450 nm, and its color intensity is closely related to grain size and surface defects. For example, nanoscale WO_3 (particle size < 50 nm) may be slightly orange due to quantum size effects, while microscale WO_3 (particle size 5-10 μm) is closer to pure yellow.

The physical form of WO_3 is closely related to the process by which it is prepared. WO_3 prepared by roasting and decomposing ammonium metatungstate (AMT) at 500-700°C is typically micron-sized particles with a particle size distribution (D50) between 4 and 10 μm, and appears as an irregular polygonal shape with a smooth surface under the microscope. This form of WO_3 is suitable for tungsten powder production or for ceramic additives. In contrast, WO_3 prepared by hydrothermal or solvothermal methods can form nanoparticles with particle sizes ranging from 20 to 50 nm and a variety of morphologies, including spherical, rod, or sheet, with increased surface roughness and a specific surface area of up to 30-50 m^2/g. In addition, the spray drying method (inlet temperature 200°C, outlet 80°C) produces spherical WO_3 micronized powders with a 20% increase in particle size uniformity and a D50 of about 4-5 µm, which is commonly used for thin film deposition or catalyst supports.

The color and morphology of WO_3 can change under certain conditions. Upon hydrogen reduction or UV irradiation, WO_3 turns blue or green due to the formation of an oxygen defect (WO_{3-x}, $x < 0.1$), which is the basis of its electrochromic properties. For example, when a voltage of -1.0 V is applied to an electrochemical system, WO_3 can be embedded into H^+ or Li^+ to form H_xWO_3 orLi_xWO_3, changing color from yellow to dark blue, a process that can be completed in 10-20 seconds and is more than 90% reversible. Observed by scanning electron microscopy (SEM), the surface defect density of blue WO_3 increased and the grain boundaries were more pronounced. In addition, high-temperature roasting (>900°C) may cause partial sublimation of WO_3, resulting in the formation of fine aerosol particles with a slightly hazy appearance.

The physical form and appearance have a direct impact on the application of WO_3. Micron-scale WO_3 powder is suitable for industrial-scale tungsten powder reduction or pigment preparation due to its large particle size and good fluidity; Due to its high specific surface area and abundant active sites, nanoscale WO_3 is more suitable for photocatalysts (e.g., decomposition of methylene blue, >90% efficiency) and gas sensors (NO_2 detection, sensitivity 10 ppb). This section describes in detail the physical and cosmetic changes of WO_3 and reveals its morphological diversity and its potential for application in different fields.

2.3 Solubility and chemical stability of yellow tungsten oxide (tungsten trioxide, WO_3).

Yellow tungsten oxide (tungsten trioxide, abbreviated as WO_3) behaves in water, acid, and alkali

The solubility of yellow tungsten oxide is very low, less than 0.02 g/100 mL (about 0.0009 mol/L, 25°C) at room temperature in pure water, and slightly rises to 0.03 g/100 mL at 60°C. This low solubility is due to its stable lattice structure and high W-O bond energy (672 kJ/mol), which allows WO_3 to dissolve or decompose virtually in a neutral aqueous solution (pH 6-7). The solubility product (Ksp) is about 10^{-12} as determined by solubility experiments, indicating that its dissolution kinetics in water is extremely slow. In weakly acidic solutions such as acetic acid buffers at pH 4-5, WO_3 is also stable, with a mass loss of less than 0.1% over 24 hours.

Under strongly acidic conditions, the behavior of WO_3 changes. In concentrated nitric acid (HNO_3, 65%) or concentrated hydrochloric acid (HCl, 37%), WO_3 can slowly react to generate tungstic acid (H_2WO_4) as follows: WO3+H2O→H+, hot H2WO4 WO_3 + H_2O \xrightarrow{H^+, hot} H_2WO_4 WO3+H2OH+ hot

$$WO_3 + H_2O \xrightarrow{H^+,热} H_2WO_4$$

This process is usually heated to 80-100°C for several hours, e.g. in 1 mol/L HNO_3, the dissolution rate of WO_3 is about 0.01 g/h·cm². This resistance to acids makes it excellent in acidic catalytic environments such as petroleum desulfurization. However, at concentrations above 50% sulfuric acid (H_2SO_4), trace amounts of soluble tungsten sulfate complexes (e.g., $[WO_2(SO_4)_2]^{2-}$ may be formed, but the dissolved amount is still less than 0.5 g/L.

In an alkaline environment, the chemical stability of WO_3 is significantly reduced. It reacts rapidly with strong bases (e.g., NaOH, KOH) to produce soluble tungstate:

WO3+2NaOH→Na2WO4+H2O WO_3 + 2 NaOH
→Na_2WO_4 + H_2O WO3+2NaOH→Na2WO4+H2O

In a 1 mol/L NaOH solution, the dissolution rate of WO_3 can reach 0.1 g/min·cm² at room temperature, and when heated to 80°C, the reaction is almost instantaneous, and the solution is clear and transparent. By ultraviolet spectroscopy, the characteristic absorption peak of Na_2WO_4 appears at 210-230 nm. This alkaline solubility allows WO_3 to be used as a raw material for the industrial production of tungstate, but exposure to alkaline substances needs to be avoided during storage or application, e.g. in an environment with a pH of > 10, where the surface of WO_3 powder can be significantly eroded within a few hours.

Redox properties of yellow tungsten oxide (tungsten trioxide, WO_3).

WO_3 has significant redox properties because the +6 oxidation state of tungsten can be chemically or electrochemically reduced to a lower state (e.g., +5, +4). In a hydrogen atmosphere, WO_3 can be reduced step by step: WO3+H2→500−600°CWO2.9+H2O WO_3 + H_2
→{500-600°C} $WO_{2.9}$ + H_2O WO3+H2500−600°C

$$
\begin{aligned}
WO_3 + H_2 &\xrightarrow{500-600^\circ C} WO_{2\cdot 9} + H_2O \\
WO_3 + 2H_2 &\xrightarrow{700-800^\circ C} WO_2 + 2H_2O \\
WO_3 + 3H_2 &\xrightarrow{900-1000^\circ C} W + 3H_2O
\end{aligned}
$$

During the reduction process, the color of WO_3 changes from yellow to blue-violet ($WO_{2.}$). $_9$), brown-black (WO_2), and finally form a metallic tungsten powder. By thermogravimetric analysis (TG), WO_{29} The oxygen loss is about 3%-5%, which corresponds to the formation of oxygen defects. This stepwise reduction property is the industrial basis for the preparation of tungsten powder with WO_3, e.g. at 950°C at a flow rate of 1 L/min, WO_3 is completely converted into tungsten powder with a particle size of 2-3 µm in 2 hours.

The electrochemical reduction capability of WO_3 is particularly important in optoelectronic applications. In electrochromic systems, WO_3 can be embedded into cations by applying a negative voltage (e.g., -1.0 V vs. Ag/AgCl) to form a coloring state:

$$
\begin{aligned}
&WO_3 + xH^+ + xe^- \rightarrow H_xWO_3 \\
&WO_3 + xLi^+ + xe^- \rightarrow Li_xWO_3
\end{aligned}
$$

The color of H_xWO_3 or Li_xWO_3 is dark blue, the transmittance drops from 80% to less than 10%, and the response time is about 10-15 seconds. Its redox potential is between -0.2 V and +0.8 V, as determined by cyclic voltammetry (CV), with a cycling stability of more than 5000 cycles. This reversibility makes WO_3 an ideal material for smart windows and displays. In addition, in photocatalysis, WO_3 can act as an electron acceptor, and after combining with TiO_2, its photogenerated electron transfer efficiency is increased by 30%, which significantly improves the hydrogen production efficiency.

This section describes the dissolution behavior and redox properties of WO_3 in water, acids, and alkalis, and reveals its chemical stability and reactivity, which provides a basis for its application in catalysis, energy, and other fields.

2.4 Density, melting point and boiling point of yellow tungsten oxide (tungsten trioxide, WO_3).

The density of yellow tungsten oxide varies depending on the crystalline phase and preparation conditions. The monoclinic phase WO_3 has a theoretical density of 7.16 g/cm³ and is determined by X-ray densitometry (based on lattice parameters a = 7.306 Å, b = 7.540 Å, c = 7.692 Åcalculated. Hexagonal WO_3 has a slightly lower density of about 6.8-7.0 g/cm³ due to its loose crystal structure (a = 7.298 Å, c = 3.899 Å). ）。 Due to the high porosity of nanoscale WO_3, the apparent density may drop to 5.0-6.0 g/cm³, such as WO_3 nanoparticles synthesized by hydrothermal method, which has a bulk density of only 4.8 g/cm³. The density difference is directly related to the compactness of its crystal structure, with the twisted octahedral arrangement of the monoclinic phase making it more dense, while the channel structure of the hexagonal phase increases the voids.

The melting point of WO_3 is typically reported to be 1473°C (1700 K), but its actual thermal behavior is more complex. At around 1200-1300°C, WO_3 begins to sublimate, forming gaseous WO_3 or oligomers (e.g. W_3O_9, W_6O_{18}) instead of melting directly. The sublimation rate is affected by the atmosphere, in oxygen (partial pressure 0.2 atm), the sublimation temperature is about 1350°C, and the mass loss rate is about 0.05 g/min·cm²; In a vacuum (10^{-3} Pa) or an inert atmosphere (e.g. Ar), sublimation accelerates and the temperature is reduced to 1250°C. By differential thermal analysis (DTA), the enthalpy of sublimation is about 350-400 kJ/mol. The boiling point of WO_3 is difficult to determine precisely because it decomposes or volatilizes at high temperatures, and the sublimation point of 1700°C (about 1973 K) is often used as a reference value in the literature.

These thermophysical properties are important for WO_3 applications. In ceramic sintering (1000-1200°C), WO_3 is stable as an additive; In the reduction of tungsten powder at higher temperatures (e.g. 1500°C), its sublimation properties need to be suppressed by atmosphere control. For example, in an H_2-O_2 mixture, the volatilization loss of WO_3 can be reduced by 50%. This section provides data to support WO_3's high-temperature processing and application by describing its density, melting point, and sublimation behavior in detail.

2.5 Thermodynamic data (enthalpy, entropy, specific heat capacity) of yellow tungsten oxide (tungsten trioxide, WO_3).

The thermodynamic data of yellow tungsten oxide is the key to understanding its thermal stability and processing behavior. The standard enthalpy of formation (Δ H_f^0) is -842.9 kJ/mol (298 K, 1 atm), indicating that its formation process is an exothermic reaction, which is related to the strong affinity of oxygen. The standard entropy (S^0) is 75.9 J/(mol· K), reflecting the low order of the monoclinic phase crystal structure, the entropy value is slightly higher than that of the ideal cubic structure due to octahedral distortion (e.g., S^0 ≈ 70 J/(mol· K)）。 The Gibbs free energy (Δ G_f^0) is -764.1 kJ/mol, and a negative value confirms its thermodynamic stability at room temperature. According to thermodynamic calculations, WO_3 is not easy to spontaneously decompose below 1000 K, but above

1500 K, the ΔG of the sublimation reaction ($WO_3(s) \rightarrow WO_3(g)$) becomes positive and is driven by external energy.

The specific heat capacity (C_p) of WO_3 varies with temperature and is 0.31 J/(g· K) or 71.9 J/(mol· K), which increases to 0.35 J/(g· K), about 0.40 J/(g· K)。 These data were measured by differential scanning calorimetry (DSC) with an error of less than 5%, indicating that WO_3 maintains a low heat capacity at high temperatures. For example, during the roasting process at 800°C (1073 K), 1 kg WO_3 has a heating heat of about 400 kJ, which is suitable for thermal management designs. WO_3 has a low thermal conductivity of 1.6-2.0 W/(m·K) at 298 K and increases slightly with temperature to about 2.5 W/(m·K) at 1000 K. This low thermal conductivity stems from the limited transmission of lattice vibrations, which makes it a potential application in thermal insulation, such as high-temperature furnace lining additives that reduce heat loss by up to 15%.

The thermodynamic data also supports the analysis of WO_3 applications in the energy sector. In lithium batteries, the enthalpy change of WO_3 ($\Delta H \approx -50$ kJ/mol Li^+) indicates that the process in which it is embedded in Li^+ is exothermic, and thermal management needs to be considered to avoid overheating. In photocatalysis, its lower entropy value helps to maintain the stability of the surface-active site. This section reveals the thermal behavior of WO_3 and its application implications by quantifying its enthalpy, entropy, and specific heat capacity.

2.6 Comparison of yellow tungsten oxide (tungsten trioxide, WO_3) with other forms of tungsten oxide

The oxide family of tungsten includes WO_3, WO_2 and intermediate oxides such as WO_{29}、$WO_{2.72}$), which differ significantly in chemical composition, structure, physical properties, and applications. WO_3 is yellow, tungsten is in the +6 oxidation state, and the monoclinic phase structure (a = 7.306 Å, b = 7.540 Å, c = 7.692 Å, β). = 90.91°) with a density of 7.16 g/cm^3 and an energy band gap of 2.6-2.8 eV. Its crystal lattice is composed of WO_6 octahedron and exhibits optical transparency (light transmittance >80%) and electrochromic properties (reversible color change). WO_2 is brownish-black, tungsten is in a +4 oxidation state, has a tetragonal structure (a = 4.86 Å, c = 5.66 Å), a density of 10.8 g/cm^3, an energy band gap of about 1.3 eV, and exhibits high electrical conductivity (resistivity $\approx 10^{-3}$ Ω·cm) due to the low number of oxygen defects in its structure.

Oxides such as WO_{29} (tungsten oxidation state +5.8) is blue-purple, with a structure between WO_3 and WO_2, monoclinic phase or amorphous form, and a high specific surface area (20-30 m^2/g). $WO_{2.72}$ (+5.44 oxidation state) is darker in color and closer to WO_2 in structure, but still retains some of the properties of WO_3. By X-ray diffraction (XRD), WO_2The main diffraction peaks of $_9$ are at 2θ = 23.1°, WO_2 at 2θ = 37.8°, and WO_3 at 2θ = 23.6° and 24.4°, reflecting the difference in lattice parameters. WO_3 is chemically more stable than WO_2 and oxides, and in acidic solutions such as 1 mol/L H_2SO_4, WO_3 dissolves at only 1/10 of WO_2. In terms of thermal stability, WO_3 is stable before 1200°C, WO_2 is easily oxidized to WO_3 above 600°C, and WO_{29} Start decomposition at 400-500°C.

In terms of applications, WO_3 is widely used in photocatalysis (hydrogen production efficiency 0.8

mmol/h·g), electrochromic (intelligent window transmittance adjustment), and batteries (capacity 600-750 mAh/g) due to its wide energy bandgap and redox characteristics. WO_2 is more suitable for electrode materials or tungsten powder precursors due to its high conductivity, e.g. in electrochemical reduction, where current densities of up to 100 mA/cm² can be achieved. $WO_{2.9}$ and WO_{272} Excellent performance in catalysts due to high specific surface area, e.g. in CO oxidation reactions, where the conversion rate is 20% higher than that of WO_3. By comparing the differences in properties of WO_3 with other forms of tungsten oxide, this section highlights its unique benefits and application positioning.

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Chapter 3: Crystal Structure and Phase

3.1 Monoclinic structure of yellow tungsten oxide (WO_3) (most common phase).

Lattice parameters and space groups of yellow tungsten oxide (WO_3).

The most common crystalline phase of yellow tungsten oxide (WO_3) at room temperature and pressure is the monoclinic crystal system, which is widely found in natural minerals, industrial products, and laboratory synthetic samples due to its stability. The crystal structure of monoclinic phase WO_3 is composed of tungsten oxygen octahedron (WO_6), where each tungsten atom is located in the center of the octahedron and is coordinated by six oxygen atoms, which are connected by coangular (W-O-W) or common sides to form a three-dimensional network. This structure is characterized by a slight distortion of the octahedron, resulting in the lattice being anisotropic in different directions. The spatial group of the monoclinic phase is $P2_1/n$ (international number 14), and the point group 2/m belonging to the monoclinic crystal system is centrally symmetrical. The lattice parameters are determined by high-resolution X-ray diffraction (XRD) and are typically: a = 7.306 Å, b = 7.540 Å, c = 7.692 Å, and the axis angle β = 90.91°. These parameters fluctuate slightly under different conditions, e.g. at 25°C, the literature reports that the a-axis may be 7.301-7.310 Å, the b-axis is 7.535-7.545 Å, the c-axis is 7.688-7.696 Å, and the β angle varies between 90.88°-90.93°, The differences are mainly due to the influence of temperature, pressure, or trace impurities in the sample.

The unit cell of the monoclinic phase contains 8 WO_3 molecules, with a unit cell volume of about 423.5 $Å^3$ and a calculated density of 7.16 g/cm^3, which is highly consistent with the experimentally measured apparent density (7.14-7.18 g/cm^3). The length of the W-O bond in the crystal varies depending on the coordination environment, with a shorter end-oxygen bond (W=O) of about 1.82-1.85 Å and a longer bridging oxygen bond (W-O-W) of about 2.03-2.10 Å, this bond length difference was confirmed by neutron diffraction and extended X-ray absorption fine structure (EXAFS) analysis. The non-uniformity of the bond length leads to the distortion of the octahedron so that the monoclinic phase WO_3 exhibits polarization effects in optical properties, such as the refractive index is about 2.20 in the a-axis direction, 2.25 in the b-axis direction, and 2.30 in the c-axis direction. In addition, the band gap (2.6-2.8 eV) is slightly lower than that of ideal symmetrical structures (e.g., cubic phase), which is related to the change in electronic density of states caused by lattice distortion.

The stability of the monoclinic phase makes it the "default" structure for WO_3, which remains constant from room temperature to about 350°C. For example, WO_3 prepared by roasting ammonium metatungstate (AMT) at 500-600°C typically exists in a monoclinic phase after cooling with a grain size between 4-10 µm. The stability of this structure stems from its low Gibbs free energy (Δ G_f^0 = -764.1 kJ/mol), which gives it an advantage in a variety of applications such as electrochromic, photocatalysis. By Fourier transform infrared spectroscopy (FTIR), the W-O stretching vibration peak of the monoclinic phase WO_3 appeared at 700-950 cm^{-1}, further verifying its structural characteristics.

X-ray diffraction (XRD) characteristics of yellow tungsten oxide (WO_3).

The crystal structure of the monoclinic phase WO_3 is accurately characterized by X-ray diffraction (XRD) and is the main means of confirming its phase state. Under standard experimental conditions, the XRD spectra of the monoclinic phase WO_3 using Cu Kα radiation (wavelength λ = 1.5406 Å) showed several characteristic diffraction peaks, with the three strongest sets of peaks appearing at 2θ = 23.1°, 23.6°, and 24.4°, corresponding to the (002), (020), and (200) crystal planes, respectively, with a relative intensity ratio of approximately 1:0.9:0.8. The width at half maximum (FWHM) of these peaks is typically less than 0.2°, indicating a high degree of crystallinity, such as micron-sized WO_3 prepared by roasting with an FWHM of about 0.15°, while nano-scale WO_3 (particle size 20-30 nm) prepared by hydrothermal method increases slightly to 0.25°, reflecting a decrease in grain size resulting in peak broadening.

The second strongest peaks occur at 2θ = 33.3° ((202) plane), 34.2° ((220) plane), and 47.3° ((222) plane), which are 30%-50% less intense than the main peak but are clearly discernible in high crystallinity samples. The Bragg equation ($n\lambda = 2d \sin\theta$) shows that the plane spacing d ≈ 3.85 Å for the (002) plane, the ≈ 3.77 Å for the (020) plane, and the ≈ 3.65 Å for the (200) plane , which is consistent with the lattice parameters. The Scherrer equation ($D = K\lambda / \beta\cos\theta$, $K = 0.9$) estimates the grain size, e.g., β = 0.15° for the 2θ = 23.6° peak, and calculates a grain size of about 50 nm, which is consistent with the transmission electron microscopy (TEM) results.

XRD patterns can also reflect microscopic changes in the monoclinic phase. During heat treatment (300-400°C), the (002) peak may shift to a low angle to 23.0°, with an offset of approximately 0.1°, due to the increase in lattice parameters A and C due to the effect of thermal expansion (expansion coefficient of approximately 1.2×10^{-5}). K^{-1}）。 If the sample contains trace impurities (e.g., Na^+ or Fe^{3+} at a concentration of < 0.5%), the diffraction peak may be broadened or slightly shifted, e.g., the (200) peak is shifted to 24.5°, and the intensity is reduced by 10%-15%, indicating the presence of lattice stresses or defects. In addition, the atomic occupancy rate of the monoclinic phase (W at 4e, O at 4e and 8f) was accurate to 0.01 by Rietveld refinement analysis, further verifying its structural integrity. This section provides a detailed description of lattice parameters and XRD features to reveal the structural properties of monoclinic WO_3 and its stability under different conditions.

3.2 Other crystalline phases of yellow tungsten oxide (WO_3) (hexagonal, tetragonal, cubic).

Dependence of phase transition conditions and temperature of yellow tungsten oxide (WO_3).

The crystal structure of WO_3 is not limited to monoclinic phases, but also includes hexagonal, tetragonal, and cubic phases, the formation of which is closely related to temperature, atmosphere, pressure, and preparation conditions, and has significant thermodynamic and kinetic characteristics. The hexagonal phase WO_3 (space group P6/mmm, no. 191) is stable in the range of 350-500°C, with lattice parameters of a = 7.298 Å, c = 3.899 Å, and a unit cell volume of about 179.8 Å^{3}with a theoretical density of 6.87-6.90 g/cm^3. The hexagonal phase is structurally characterized by the formation of open hexagonal channels along the c-axis, each with a diameter of about 3.5 Å, suitable for ion (e.g., Li^+, NH_4^+, H^+) intercalation. This structure is often prepared by the decomposition of ammonium metatungstate (AMT) in an inert atmosphere (e.g. N_2 or Ar at a flow rate of 0.5-1 L/min), e.g. at 450°C for 4 hours, with a hexagonal phase content of up to 95%. The XRD pattern shows characteristic peaks at 2θ = 13.9° ((100) plane), 22.8° ((110) plane), and 28.2° ((200) plane), with grain sizes typically in the range of 30-100 nm and a specific surface area of approximately 20-30 m²/g.

The tetragonal phase WO_3 (space group P4/nmm, no. 129) is formed at higher temperatures (740-900°C) with lattice parameters of a = 5.272 Å, c = 3.917 Å, and a unit cell volume of about 108.9 Å³with a density of 7.20-7.25 g/cm³. Its structure consists of regular WO_6 octahedron arranged along the c-axis to form narrower passages (about 2.8 Å in diameter), the ion diffusion capacity is lower than that of the hexagonal phase. The XRD characteristic peaks of the tetragonal phase are $2\theta = 22.8°$ ((110) plane), 32.5° ((200) plane), and 46.7° ((220) plane) with sharp peak shape and FWHM of approximately 0.1°-0.15°. The tetragonal phase is usually formed by the conversion of the monoclinic phase at high temperatures in an oxidizing atmosphere (e.g. air or O_2 with a partial pressure of 0.2-1 atm), e.g. at 800°C for 2 hours, the monoclinic phase can be completely converted to the tetragonal phase with a conversion rate of 90%-95% and an enthalpy of conversion of about 15-20 kJ/mol (determined by differential scanning calorimetry DSC).

The cubic phase WO_3 (space group Pm-3m, no. 221) is extremely unstable under natural conditions and only occurs briefly under extreme conditions such as >900°C or high pressure 10-20 GPa. Its lattice parameter is a ≈ 3.81 Å, and the unit cell volume is about 55.3 Å³with a density of nearly 7.30 g/cm³. The cubic phase consists of a highly symmetrical WO_6 octahedron with no distinct channel structure, and the XRD pattern shows a single strong peak at $2\theta = 23.5°$ ((100) planes) and other peaks (e.g., 33.3° (110) planes) with very low intensity. Due to its high symmetry, the cubic phase has a slightly higher energy band gap (about 2.9 eV), but due to thermodynamic instability, it usually rapidly changes to a tetragonal or monoclinic phase after cooling. For example, at 950°C vacuum, the cubic phase can form within 5-10 minutes, but disappear after cooling to 700°C.

The phase transition conditions of WO_3 exhibit significant temperature dependence. The monoclinic phase is stable at <350°C, and at a temperature rise to 400°C, some of the grains (about 20%-30%) are converted to the hexagonal phase, and the activation energy of the conversion process is about 50-60 kJ/mol (estimated by the Arrhenius equation). Above 740°C, the hexagonal phase is further transformed into a tetragonal phase, and the unit cell volume shrinks by about 5%, and the conversion rate is about 0.1 g/min·cm² at 800°C with lattice stress relief. Above 900°C, the tetragonal phase may sublimate (rate 0.05-0.1 g/min·cm²) or briefly turn to a cubic phase, but this process is affected by the atmosphere, e.g. in a vacuum (10^{-3} PA) increases the sublimation rate by 50%-70% and slows down by 30% in oxygen. The inverse process of the phase transition has hysteresis, e.g. the tetragonal phase cools to 600°C before reverting to the monoclinic phase, and the hexagonal phase needs to drop to 300°C, with a lag temperature of about 100-150°C. This temperature dependence was validated by synchrotron radiation XRD and thermogravimetric analysis (TG) to inform the heat treatment process of WO_3. This section reveals the structural diversity of WO_3 and its behavior in different environments by analyzing the structure and phase transition conditions of other crystalline phases in detail.

3.3 Defect structure and doping effect of yellow tungsten oxide (WO_3).

The crystal structure of WO_3 often contains a variety of defects, including oxygen vacancies (V_O), tungsten vacancies (V_W), and interstitial ions, which have a profound impact on its electrical, optical, and catalytic properties. Oxygen vacancies are the most common type of defect and are formed in a reducing atmosphere (e.g., H_2 or CO, flow rate 0.5 L/min, 500°C), UV light irradiation (wavelength 365 nm, intensity 10 mW/cm^2), or high-temperature vacuum (10^{-3} Pa, 700°C). The chemical formula of oxygen vacancies can be expressed as WO_{3-x} ($x = 0.01$-0.1), e.g. WO_{3-005} means that 5 out of every 100 oxygen atoms are missing. Oxygen vacancies lead to a decrease in the oxidation state of tungsten (+6 → +5 or +4), resulting in a suboxide state (e.g., WO_2.). $_9$、 $WO_{2.72}$), the color changes from yellow to blue or purple. Detected by electron paramagnetic resonance (EPR), the g-value of the oxygen vacancy was approximately 2.002 and the concentration ranged from 10^{17}-10^{19} cm^{-3}, varying with treatment conditions. For example, oxygen vacancy concentrations of up to 10^{18} cm^{-3} can be achieved after 1 hour at 600°C in H_2. The oxygen vacancies significantly improve the conductivity, and the resistivity of the monoclinic phase WO_3 decreases from 10^6 Ω·cm to 10^2-10^3 Ω·cm, and increase photocatalytic activity, e.g., WO_{3-005} Hydrogen production in visible light (0.9 mmol/h·g) is about 28% higher than that of pure WO_3 (0.7 mmol/h·g).

Tungsten vacancies (V_W) are rare and are usually formed under strong alkaline conditions (such as NaOH solution, pH > 12) or high temperature oxidation (1000°C, O_2 atmosphere), with a concentration below 10^{16} cm^{-3}. Tungsten vacancies cause local charge imbalance in the lattice and increase p-type conductivity, but have little effect on structural stability. Interstitial ions (such as H^+, Li^+) are introduced during electrochemistry or ion embedding. For example, in electrochromism, Li^+ is embedded to form Li_xWO_3 ($x = 0.1$-0.5), the lattice parameter a increases to 7.320 Å, and the volume expands by about 1%-2%.

The doping effect further regulates the structure and properties of WO_3 by introducing foreign elements. Common metal dopings include Na^+, Ti^{4+}, Mo^{6+}, etc. Na^+ doping (concentration 0.1-1 mol%) is introduced by solution co-precipitation, which expands the monoclinic lattice to 7.315 Å on the a-axis and 7.700 Å on the c-axis , the XRD peak (002) shifts to 23.0° and the intensity decreases by 10%. Na^+ occupies the gap for enhanced electrochromic performance, increasing light transmittance from 70% to 85% and reducing response time to 8 seconds. Ti^{4+} doping (Ti/W = 5%, prepared by sol-gel method) replaces some W^{6+}, the lattice parameter is slightly reduced (a = 7.300 Å), the energy band gap is reduced to 2.4 eV, and the photocatalytic efficiency is improved due to the introduction of new energy levels in the Ti 3d orbital, such as the rate of decomposition of rhodamine B from 0.02 min^{-1} to 0.026 min^{-1} (30% increase). Mo^{6+} doping (Mo/W = 10%) forms a solid solution$Mo_xW_{1-x}O_3$, an increase in oxygen vacancy density to 10^{19} cm^{-3}, a 2-fold increase in conductivity (resistivity down to 50 Ω·cm), and a 0.1° XRD peak broadening for gas sensors (NO_2 sensitivity increased to 15 ppb).

Non-metallic dopings such as N and S also significantly affect the structure. N-doped (N/W = 2%, 600°C by ammonia gas heat treatment) replaces oxygen atoms to form W-N bonds, the lattice parameter a increases to 7.312 Å, the XRD peak (020) moves to 23.5°, the energy band gap decreases to 2.5 eV, the light absorption red shift to 500 nm, and the hydrogen production efficiency is increased by 25%. S-doping (S/W = 1%) increases lattice defects, increases surface active site density to 10^{18} m^{-2}, and increases the catalytic CO oxidation efficiency by 20%. Defects and doping also affect thermal stability, e.g. WO_3 in oxygen-containing vacancies begins to decompose at 500°C, while pure monoclinic phases stabilize up to 1200°C. The phase transition temperature of the doped sample is reduced, e.g. Na^+ doped WO_3 turns tetragonal at 700°C, which is 40°C lower than pure WO_3. This section examines the tunability of WO_3 structures and their potential for functional optimization by exploring defect structures and doping effects in detail.

3.4 Structural properties of nanoscale yellow tungsten oxide (WO_3).

Effect of the particle size of yellow tungsten oxide (WO_3) on the crystalline phase

The structural properties of nanoscale WO_3 (particle size < 100 nm) differ significantly from microscale samples due to quantum size effects and high surface energy. WO_3 nanoparticles prepared by hydrothermal method (180°C, 12-24 h, pH 1-2), solvothermal method (ethanol or ethylene glycol, 200°C, 6 h), or vapor deposition, typically with a particle size of 20-50 nm and a specific surface area of 30-50 m^2/g and up to 80 m^2/g (determined by the BET method). Transmission electron microscopy (TEM) shows a wide variety of morphologies, including spherical particles (20-30 nm diameter), rod-like structures (50-100 nm long, 10-20 nm wide), lamellar structures (5-10 nm thick, 50-200 nm wide), and flower-like assemblies (100-300 nm diameter). High-resolution TEM (HRTEM) revealed that the grain boundaries of nano-WO_3 were clear, and the plane spacing such as (002) was about 3.85 Å, which was consistent with monoclinic.

The crystalline phase of nano-WO_3 is significantly affected by particle size. Samples with small particle sizes (<30 nm) tend to form hexagonal phases due to their low surface energy (about 1.5 J/m^2), thermodynamically more stable. For example, the XRD profile of a 20 nm WO_3 prepared by hydrothermal method (180°C with NH_4^+ template) showed hexagonal characteristic peaks of $2\theta = 13.9°$ and 28.2° with hexagonal content of 80%-90%. When the particle size increases to 50-100 nm (e.g., the hydrothermal time is extended to 48 h), the monoclinic phase gradually dominates, the surface energy rises to 2.0 J/m^2, the XRD peak increases at 23.1°, 23.6°, and 24.4°, and the monoclinic phase ratio increases to 70%-85%. This crystalline phase transition is associated with the Gibbs-Thomson effect, where the high curvature of small particle sizes reduces the phase transition energy barrier and promotes hexagonal phase formation.

Raman spectroscopy further validated the particle size effect. The W-O-W stretching vibration peaks were 810 cm^{-1} and 680 cm^{-1} for hexagonal nanoWO_3 (20 nm) and 717 cm^{-1} and 807 cm^{-1} for monoclinic phase (50 nm), and the peak intensity increased with the increase of particle size, indicating that the crystallinity increased. The particle size also affects the band gap, and the band gap of 20 nm WO_3 is 2.8-2.9 eV, which increases due to the increase of surface state contribution. 50 nm WO_3 drops to 2.6-2.7 eV, which is close to the body. The absorption edge of the 20 nm sample was at 430 nm and the 50 nm sample was redshifted to 460 nm by UV-Vis spectroscopy.

The structural properties of nano-WO_3 significantly improve its performance. Due to the open channel structure, the Li^+ diffusion coefficient of Hexagonal phase nano WO_3 (30 nm) in lithium-ion batteries is 10^{-10} cm^2/s, the capacity is as high as 720 mAh/g, and the retention rate is 88% after 1000 cycles. In gas sensors, the response time to H_2S is reduced to 5 seconds. Monoclinic nano-WO_3 (50 nm) excels in photocatalysis due to its high crystallinity and surface activity, such as the decomposition rate of methylene blue at a rate of 0.03 min^{-1} and a hydrogen production rate of 0.9 mmol/h·g, which is 35% higher than that of micron-scale WO_3 . In addition, the defect density of nano-WO_3 (10^{18}-10^{19} cm^{-3}) is higher than that of bulk phase, enhancing its conductivity (10^2 Ω·cm) and light responsiveness. This section reveals its unique advantages in high-performance materials by analyzing the structural properties of nano-WO_3 and its particle size effects in detail.

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CTIA GROUP

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

1. Overview of tungsten trioxide

CTIA GROUP tungsten trioxide (referred to as yellow tungsten, WO_3) is produced by ammonium paratungstate high-temperature calcination process, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. Yellow tungsten is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants due to its light yellow crystal powder form, high purity and chemical stability. CTIA GROUP is committed to providing high-quality yellow tungsten products to meet the needs of powder metallurgy and industrial manufacturing.

2. Characteristics of tungsten trioxide

Chemical composition: WO_3.

Purity: ≥99.95% with very low impurity content.

Appearance: Light yellow crystal powder, uniform color.

Polymorph: monoclinic (most common at room temperature), space group P21/n.

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 (1000-1100°C).

Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Specifications of tungsten trioxide

index	CTIA GROUP Yellow tungsten first grade standard
WO_3 content (wt%)	≥99.95
Impurity（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
Moisture (wt%)	≤0.05
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. Tungsten trioxide 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. Tungsten trioxide procurement information

Mailbox:sales@chinatungsten.com Phone: +86 592 5129696

For more information about tungsten yellow, please visit the Chinatungsten Online websitewww.tungsten-powder.com

Chapter 4: Production Process of Yellow Tungsten Oxide (WO_3).

4.1 Raw materials and precursors

Preparation and decomposition of ammonium metatungstate (AMT).

Ammonium metatungstate (AMT, chemical formula $(NH_4)_6H_2W_{12}O_{40}\cdot xH_2O$) is a core precursor for the production of WO_3 and is widely used in industry and laboratories due to its high water solubility (solubility >1000 g/L at pH 5.5 at 25°C), stable polyacid structure, and controlled thermal decomposition properties. The preparation of AMT is usually done using sodium tungstate (Na_2WO_4) as the starting material by processes such as ion exchange, acidification crystallization, or solvent extraction. The most common method in industry is to start from the sodium tungstate solution extracted from tungsten ore and first produce a tungstic acid (H_2WO_4) precipitate through acidification. The specific process flow is as follows: Na_2WO_4 solution (concentration 200-300 g/L, pH 8-9) is slowly added to nitric acid (HNO_3, concentration 3-5 mol/L), the reaction temperature is controlled at 50-60°C, the stirring rate is 200-300 rpm, the pH is reduced to 1-2, and the yellow H_2WO_4 precipitate is generated. The reaction equation is: Na2WO4+2HNO3→ H2WO4↓+2NaNO3 Na_2WO_4 + 2 HNO_3 \rightarrow H_2WO_4↓ + 2 $NaNO_3$ The Na2WO4+2HNO3→H2WO4↓+2NaNO3 precipitate is filtered, washed (washed with deionized water to pH 4-5) to remove residual Na^+ and NO_3^-, and then dried at 80-90°C to obtain H_2WO_4 powder with a purity of about 98%-99%.

Subsequently, H_2WO_4 reacts with ammonia (NH_4OH, 25%-28%) to form AMT. The process conditions are as follows: in a 500 L stainless steel reactor, 100 kg of H_2WO_4 is added to 200-300 L of deionized water, ammonia (about 50-60 L) is slowly added dropwise under stirring, the droplet acceleration is controlled to 1-2 L/min, the reaction temperature is maintained at 70-90°C, and the pH is adjusted to 6.0-7.0. During the reaction, H_2WO_4 gradually dissolves to form a transparent AMT solution, and the reaction

is as follows:
12H2WO4+6NH4OH→(NH4)6H2W12O40·xH2O+(12−x)H2O 12 H_2WO_4 + 6 NH_4OH \rightarrow $(NH_4)_6H_2W_{12}O_{40}\cdot xH_2O$ + (12-x) H_2O 12H2WO4+6NH4OH→(NH4)6H2W12O40·xH2O+(12−x)H2O solution cooled to 20-30°C and allowed to stand for 12-24 hours, AMT precipitated as white crystals, and the finished product was obtained by centrifugation (3000-4000 rpm), washing (washing 2-3 times with cold water) and drying (80°C, 6-8 hours). AMT typically has a crystalline water content (x) of 4-6, a tungsten content (in WO_3) of 89%-91%, and a purity of 99.5%, with common impurities including Na^+ (<0.02%) and Fe^{3+} (<0.01%).

Thermal decomposition of AMT is a critical step in the preparation of WO_3 and is typically performed at 500-700°C in an air atmosphere. The decomposition process is divided into three stages: (1) at 100-200°C, the crystalline water is lost, the mass is lost by about 5%-7%, and an amorphous intermediate phase is generated; (2) At 300-400°C, NH_3 and some structural water are released, and the mass loss is about 3%-4%, forming $WO_3\cdot H_2O$ or hexagonal WO_3; (3) At 500-700°C, it is completely deaminate and crystallized into monoclinic phase WO_3, and the total mass loss is about 10%-12%. The reaction formula is: (NH4)6H2W12O40·xH2O→500−700°C12WO3+6NH3↑+(x+1)H2O↑

$$(NH_4)_6H_2W_{12}O_{40}\cdot xH_2O \xrightarrow{500-700^\circ C} 12WO_3 + 6NH_3\uparrow + (x+1)H_2O\uparrow$$

By thermogravimetric analysis (TG) and differential scanning calorimetry (DSC), the decomposition peaks occurred at 150°C (dehydration), 350°C (deamination), and 550°C (crystallization), respectively, with enthalpy changes of 50-60 kJ/mol, 30-40 kJ/mol, and 10-15 kJ/mol at each stage, respectively. The decomposition product WO_3 has a purity of 99.9%, a particle size of 4-10 μm, and a predominantly monoclinic crystalline phase (XRD peaks $2\theta = 23.1^\circ, 23.6^\circ$). If the temperature is too high (>750°C), WO_3 may sublimate and the loss rate can increase to 5%-10%.

Tungstic acid (H_2WO_4) and tungsten ore

Tungstic acid (H_2WO_4) is another commonly used precursor, usually extracted directly from tungsten ore or as an intermediate product in the preparation of AMT. Tungsten ores include wolframite ($FeMnWO_4$), scheelite ($CaWO_4$) and secondary ores (such as tungsten $WO_3\cdot nH_2O$), with China leading the world in reserves (accounting for about 60%). Industrial extraction uses alkaline or acid methods. The alkaline process is as follows: wolframite powder (particle size 100-200 μm) and sodium hydroxide (NaOH, concentration 30%-40%) are mixed in a high pressure reactor at a mass ratio of 1:2. The reaction conditions are 140-160°C, pressure 5-10 atm, stirring 300-500 rpm, and reaction for 4-6 hours: FeMnWO4+2NaOH→Na2WO4+Fe(OH)2↓+Mn(OH)2↓ $FeMnWO_4$ + 2 NaOH \rightarrow Na_2WO_4 + $Fe(OH)_2$↓ + $Mn(OH)_2$↓ FeMnWO4+2NaOH→Na2WO4+Fe(OH)2↓+Mn(OH)2↓

The reaction solution is filtered to remove $Fe(OH)_2$ and $Mn(OH)_2$ precipitates, and the filtrate is acidified with HNO_3 to pH 1-2 to generate H_2WO_4 precipitation. The acid process uses concentrated HCl (6 mol/L) to directly decompose scheelite:
CaWO4+2HCl→H2WO4↓+CaCl2 $CaWO_4$ + 2 HCl
→ H_2WO_4↓ + $CaCl_2$ CaWO4+2HCl→H2WO4↓+CaCl2
The product is filtered, washed (deionized water washed to pH 4-5), dried (100°C, 8-12 hours), and the purity reaches 98%-99%, containing about 0.1%-0.5% of impurities such as Si and P.

H_2WO_4 can be directly roasted (600-700°C, air, 2-4 hours) to produce WO_3 with a yield of 85%-90% and a particle size of 5-15 μm. For higher purity, H_2WO_4 can be dissolved in ammonia and recrystallized to 99.5%. This section reveals the raw material base for WO_3 production and its process diversity by detailing the preparation and origin of AMT and H_2WO_4.

4.2 Industrial production method of yellow tungsten oxide (WO_3).

Industrial production of yellow tungsten oxide (WO_3) - roasting method (500-700°C).

Roasting is the mainstream process for industrial production of WO_3, which is widely used because of its mature equipment, easy operation and high output, usually using ammonium metatungstate (AMT) or tungstic acid (H_2WO_4) as raw materials, and is carried out in high-temperature equipment such as rotary kilns, push plate kilns or chamber furnaces. At the heart of the process is the conversion of the precursor into yellow WO_3 powder through pyrolysis and oxidation, which is suitable for large-scale production with an annual output of 10,000 tons. The following describes the process flow, equipment parameters, reaction mechanism, quality control and influencing factors in detail.

The industrial production-roasting process and equipment roasting process of yellow tungsten oxide (WO_3)
includes three stages: raw material pretreatment, roasting and decomposition and product collection. Taking AMT as an example, the process flow is as follows: first, 100 kg of AMT (containing WO_3 90%, moisture <1%, particle size 50-100 μm) is pretreated and dried in an oven at 100°C for 4-6 hours to ensure that the moisture content is reduced to less than 0.5% to avoid agglomeration during roasting. Subsequently, the AMT is loaded into a rotary kiln (diameter 1.5-2 m, length 10-15 m, inclination angle 2°-3°, lined with refractory bricks or alumina ceramics) with a speed of 1-2 rpm and heated by electric heating (power 200-300 kW) or gas (natural gas, calorific value 8500 kcal/m³). ）。 The roasting temperature is controlled at 500-700°C, dry air (humidity <10%, flow rate 100-200 m³/h, pressure 0.1-0.2 MPa), holding time 2-4 hours. The product WO_3 is collected through the kiln tail outlet, and the exhaust gas is treated by the dedusting and absorption system and discharged.

Industrial Production-Roasting of Yellow Tungsten Oxide (WO_3) Reaction Mechanism and Temperature Segmented AMT undergoes a multi-step decomposition reaction during the roasting process to finally form a monoclinic phase WO_3. The reaction formula is:

$$(NH_4)_6H_2W_{12}O_{40}\cdot xH_2O \xrightarrow{500-700^{\circ}C} 12WO_3 + 6NH_3\uparrow + (x+1)H_2O\uparrow$$

The decomposition is divided into three stages:

100-200°C (dehydration phase)
AMT loses crystalline water (x = 4-6) and loses 5%-7% mass, resulting in an amorphous interphase. By TG analysis, the water loss peak is at 150°C and the enthalpy change is 50-60 kJ/mol. If the moisture is not completely removed, subsequent decomposition may be uneven.

300-400°C (deamination phase)

NH_3 and partially structured water are released, with a mass loss of 3%-4%, forming $WO_3 \cdot H_2O$ or hexagonal WO_3 (XRD peak 2θ = 13.9°). DSC shows an endothermic peak at 350°C and an enthalpy change of 30-40 kJ/mol. The air flow should be sufficient (>100 m³/h) to remove NH_3 and avoid increasing pressure in the furnace.

500-700°C (crystallization stage)

Complete deamination and oxidation resulted in monoclinic phase WO_3 (XRD peaks 2θ = 23.1°, 23.6°, 24.4°) and mass loss stabilized to a total of 10%-12%. The monoclinic phase ratio is 90% at 550°C, rising to 98% at 650°C, and grains growing to 10-15 μm at 700°C. Enthalpy of crystallization changes 10-15 kJ/mol.

Industrial production-roasting process parameters and influencing factors of yellow tungsten oxide (WO_3).

Temperature control

Temperature is the core parameter of the roasting method. The decomposition rate is 85%-90% at 500°C, and the residual $WO_3 \cdot H_2O$ or hexagonal phase (conversion rate <90%); At 550°C, monoclinic phase dominated, and the decomposition rate was >95%; 99.9% purity at 600°C with particle size of 4-8 μm; At 700°C, the grain uniformity is increased (D50 ≈ 6-10 μm), but the sublimation loss increases to 5%-10%, and the WO_3 content in the exhaust gas is 0.1-0.2 g/m³. If the temperature is too low (<450°C), the proportion of residual intermediate phase is as high as 20%-30%, which affects the product quality; If it is too high (>750°C), the sublimation rate is 0.05-0.1 g/min·cm², and the loss rate is more than 10%.

Air flow

Air acts as an oxidizer and carrier gas with the best decomposition rate at a flow rate of 150 m³/h, and the NH_3 emission concentration is reduced to 50-100 mg/m³; At a flow rate of <50 m³/h, NH_3 builds up and the furnace pressure rises to 0.3 MPa, which can lead to corrosion of the plant.

Keep warm time

95% decomposition rate in 2 hours, 98% in 3 hours, and complete conversion in 4 hours. Extended to 6 hours, the particle size increases to 12-15 μm, but the energy consumption increases by 20% (about 1 kWh/kg).

Raw material characteristics

AMT decomposes evenly at 50-100 μm particle size, and at 200 μm >, the internal moisture release is hindered and the conversion rate is reduced to 90%.

Industrial Production of Yellow Tungsten Oxide (WO_3) - Roasting Quality Control and Analysis

The product WO_3 is a yellow powder with a yield of about 90 kg/100 kg AMT, a conversion rate of >98%, and a purity of 99.9%-99.95%. Quality testing included: (1) XRD confirmation of the crystalline phase with a monoclinic phase peak intensity ratio ((002)/(020)) of approximately 1:0.9, (2) SEM determination of particle size distribution, D10 = 2-3 μm, D50 = 6-8 μm, D90 = 10-12 μm; (3) ICP-AES detection of impurities, Na^+ <0.005%, Fe^{3+} <0.002%; (4) The specific surface area measured by the BET method is 5-15 m²/g. Case data: A factory has an annual output of 5,000 tons of WO_3, a roasting kiln power of 250 kW, an AMT consumption of 1.1 tons/ton WO_3, an energy consumption of 5-7 kWh/kg, and a yield of 98.5%.

Equipment Requirements and Maintenance for Industrial Production of Yellow Tungsten Oxide (WO_3) - Roasting Rotary

Kilns need to be resistant to high temperatures (>1000°C) and NH_3 corrosion, lined with materials such as alumina ceramics (Al_2O_3 content >95%) or 316L stainless steel (Cr 18%, Ni 10%), with a service life of 5-10 years. The heating element is silicon molybdenum rod ($MoSi_2$, maximum temperature 1700°C) or gas nozzle, and the annual maintenance cost is about 10-200,000 yuan (replacing the lining and overhauling the motor). A cooling device (water-cooled jacket with flow rate of 2-3 m^3/h) is installed at the end of the kiln to reduce the discharge temperature to 100-150°C and avoid WO_3 sticking to the wall.

Industrial production of yellow tungsten oxide (WO_3) – Exhaust gas treatment by roasting and environmentally friendly

roasting produce NH_3 (5-15 g/m^3), H_2O and trace amounts of WO_3 dust (0.1-0.5 g/m^3). The exhaust gas treatment system includes: (1) water scrubbing tower (diameter 1.5 m, height 10 m, spray volume 5-10 m^3/h), NH_3 absorption rate 90%-95%, wastewater ammonia nitrogen reduced to 0.5-1 g/L; (2) Bag filter (filtration area 50 m^2, efficiency 99%), WO_3 dust emission <30 mg/m^3; (3) NH_3 was recovered in the ammonia distillation tower (pressure 0.2 MPa, temperature 90°C) with a recovery rate of >93% and recycled for AMT preparation. The wastewater is neutralized ($Ca(OH)_2$, pH 7-8) and discharged in accordance with GB 8978-1996.

The advantages and disadvantages of the industrial production-roasting method of yellow tungsten oxide (WO_3)

are mature technology (more than 50 years of technology application), universal equipment (annual output of rotary kiln can reach 1-20,000 tons), high yield (>98%), and low cost (about 200-300 yuan/kg WO_3); The disadvantages are high energy consumption (5-7 kWh/kg, 50% higher than wet chemical method), high temperature sublimation loss (5%-10%) and complex exhaust gas treatment (investment of about 1 million to 1.5 million yuan). The roasting method is suitable for large-scale industrial production, such as ceramic pigments and tungsten powder raw materials. This section illustrates the central role of the roasting method in WO_3 production by detailing its process details.

Industrial production of yellow tungsten oxide (WO_3) - hydrogen reduction method (indirect preparation of WO_3).

The hydrogen reduction method is an industrial process for the indirect preparation of WO_3 through a two-step reaction: first, WO_3 is reduced to tungsten metal (W) with hydrogen, and then tungsten powder is oxidized back to WO_3 in oxygen. This method is particularly suitable for scenarios that require ultra-high purity WO_3, such as the semiconductor industry or the production of high-precision optical materials, as it effectively removes trace impurities (e.g., Fe, Mo, Na) from raw materials. The process is complex and the energy consumption is high, but the product quality is excellent.

Step 1: The process of hydrogen reduction to prepare tungsten powder

is carried out in a horizontal tube furnace or a multi-stage reduction furnace. In the case of 50 kg WO_3 (99.5% purity, particle size 5-10 μm), the raw material is loaded into a quartz boat (1 m long, 0.3 m wide, 0.1 m deep) or a stainless steel tray and placed in a furnace. The furnace body is made of a high-temperature resistant alloy (e.g. Inconel 600) and lined with quartz or alumina to prevent metal contamination. High-purity hydrogen (H_2, purity 99.999%, $O_2 < 1$ ppm, flow rate 1-2 L/min, pressure 0.1-0.2 MPa) was introduced and the temperature was raised to 800-1000°C, and the temperature control was divided into three stages: (1) 500-600°C, and pre-reduction to generate WO_{29} or WO_{272}, keep warm for 1-2 hours, quality loss is about 3%-5%; (2) 700-850°C, further reduced to WO_2, incubated for 2-3 hours, mass loss increased to 10%-12%; (3) 900-1000°C, completely reduced to metallic tungsten, keep warm for 3-5 hours. The reaction formula is: WO3+3H2→W+3H2O $WO_3 + 3 H_2$ \rightarrow W + 3 H_2O WO3+3H2→W+3H2O The reduction process requires controlled H_2 flow and temperature gradients to avoid volatilization of WO_3 or formation of co-oxides due to too fast reduction. Furnace atmosphere monitoring (O_2 content < 10 ppm), exhaust gas H_2O is recovered by a condenser (cooling water temperature 5-10°C), water content is reduced to <0.1 g/m³, unreacted H_2 is treated by burner (ignition temperature 600°C) and discharged. The product was gray tungsten powder with a particle size of 2-5 μm (D50 ≈ 3 μm), a conversion rate of >99%, and a residual oxygen content of <0.01% (determined by oxygen and nitrogen analyzer). If the H_2 flow rate is insufficient (<0.5 L/min), WO_2 may remain (XRD peak $2\theta = 37.8°$) and the purity will drop to 98%.

Step 2: Oxidation Preparation WO_3

tungsten powder oxidation is carried out in a chamber furnace or rotary kiln. 40 kg of tungsten powder was placed in an alumina crucible (capacity 50 L), dry air (humidity <10%, flow rate 0.5-1 L/min) or pure O_2 (99.99%, flow rate 0.3-0.8 L/min), temperature to 600-700°C, and insulated for 2-4 hours. The oxidation reaction is: W+3/2O2→WO3 W + 3/2 O_2 \rightarrow WO_3 W+3/2O2→WO3 temperature control is critical: the oxidation rate at 600°C is about 0.05 g/min·cm², resulting in a monoclinic phase WO_3 (XRD peak $2\theta = 23.6°$); At 650°C, the rate increased to 0.08 g/min·cm², and the crystallinity increased. Grains grow to 5-8 μm at 700°C. If the temperature is lower than 550°C, the oxidation is incomplete, and the residual tungsten content increases to 0.5%-1%; Above 750°C, WO_3 sublimation losses range from 3% to 5%. The partial pressure of O_2 in the atmosphere should be maintained at 0.2-1 atm to avoid the formation of WO_{29} (blue, oxygen vacancy 10^{18} cm⁻³). The product is yellow WO_3 with a purity of 99.99%, a particle size of 3-6 μm (D50 ≈ 4 μm), and a specific surface area of 5-10 m²/g.

Industrial production of yellow tungsten oxide (WO_3) - process parameters and quality control of hydrogen reduction method

Key parameters of the hydrogen reduction method include H_2 purity, flow rate, and reduction temperature. If H_2 contains O_2 > 5 ppm, the surface of tungsten powder is easy to oxidize, and the purity of WO_3 is reduced to 99.9%. The reduction rate is best at a flow rate of 1.5 L/min, too high (>3 L/min) wastes gas, and too low (<1 L/min) prolongs the reaction time (6-8 hours). The O_2 flux during the oxidation phase affects the crystalline phase, with 0.5 L/min forming a monoclinic phase and a small number of tetragonal phases forming at 1 L/min (XRD peak $2\theta = 32.5°$). For quality control, ICP-AES was used to detect impurities (Fe < 0.001%, Na < 0.0005%) and SEM to analyze the particle size distribution. Case data: A plant produces 100 tons of high-purity WO_3 per year, consumes 15 m³/ton of H_2, consumes 10 m³/ton of O_2, and consumes 10-12 kWh/kg.

Advantages and disadvantages of the industrial production of yellow tungsten oxide (WO_3) - hydrogen reduction method,

the advantages of which are high purity (>99.99%), suitable for high-end applications; The disadvantages are complex process (two-step reaction), high energy consumption (50%-70% higher than the roasting method), and strict equipment requirements (explosion-proof design, investment of about 200-3 million yuan/annual output of 100 tons). Exhaust gas treatment requires the addition of an H_2 recovery system (recovery rate of 80%-90%) to reduce costs. This section demonstrates the unique value of hydrogen reduction in the production of high-purity WO_3 by detailing the process details.

Industrial production of yellow tungsten oxide (WO_3) - wet chemical method (precipitation and heat treatment).

The wet chemical method is the preparation of WO_3 by chemical reaction of the solution and subsequent heat treatment, which is characterized by simple equipment and flexible process, and is suitable for small and medium-scale production (50-500 tons per year). The process is divided into two stages: precipitation and heat treatment, using Na_2WO_4 or tungstic acid as raw material, acidifying to generate H_2WO_4 precipitate, and then thermal decomposition into WO_3.

Step 1: The H_2WO_4 precipitation

process is carried out in an enamel reactor (volume 500-1000 L, acid-resistant lining). Take 200 L of Na_2WO_4 solution (concentration 250-300 g/L, containing WO_3 about 200 g/L, pH 8-9), heat to 40-50°C, stir rate 300-500 rpm, slowly add hydrochloric acid (HCl, concentration 1-2 mol/L, about 100-120 L), drop acceleration 1-2 L/min, reaction time 2-3 hours, pH gradually drops to 1-2. The reaction formula is:
Na2WO4+2HCl→H2WO4↓+2NaCl $Na_2WO_4 + 2\ HCl$
$\rightarrow H_2WO_4\downarrow + 2\ NaCl$ Na2WO4+2HCl→H2WO4↓+2NaCl H_2WO_4
Precipitated as a yellow precipitate with a particle size of 10-20 μm (initial). The droplet acceleration needs to be controlled to avoid uneven precipitation caused by excessive local acidity. If the HCl concentration is increased to 3 mol/L, the precipitation rate increases by 20% (0.1 $g/min{\cdot}cm^2$), but the particle size decreases to 5-10 μm. Temperature affects the precipitation yield, which is 90% at 40°C, rises to 95% at 50°C, and increases solubility at 60°C and decreases to 85%. After the precipitation is completed, it was separated with a plate and frame filter press (filtration area 10 m^2, pressure 0.5 MPa), and the filter cake was washed with 500-800 L deionized water 3-5 times until the Cl^- content was <0.01% (silver nitrate test) and Na^+ <0.02% (ICP-AES). The wash water temperature is controlled at 20-30°C to avoid H_2WO_4 dissolution. The filter cake was dried at 100°C for 12-16 hours in the oven, and the moisture was reduced to <0.5%, resulting in H_2WO_4 powder with a purity of 98%-99% and about 0.1% of Si and P impurities.

Step 2: Heat treatment to generate $WO_3H_2WO_4$ Heat treatment in a chamber furnace or tunnel kiln to generate WO_3. 50 kg of H_2WO_4 was placed in an alumina tray (1 m long, 0.5 m wide, 0.1 m deep), dry air (humidity <10%, flow rate 50-100 m^3/h) was introduced into the furnace, the temperature was raised to 400-600°C, and the temperature was kept warm for 2-4 hours. The reaction is: H2WO4→WO3+H2O↑ H_2WO_4 \rightarrow $WO_3 + H_2O\uparrow$ H2WO4→WO3+H2O↑ Heat treatment stages: (1) 200-300°C, loss of structured water, mass loss of 7%-8%, generation of $WO_3 \cdot H_2O$； (2) At 400-500°C, the water is completely removed to generate amorphous WO_3; (3) At 550-600°C, crystallization to monoclinic phase WO_3 (XRD peak $2\theta = 23.1°, 24.4°$). TG analysis showed a mass loss of 8.5% at 400°C and stable at 600°C. Temperature-controlled particle size and phase control: 5-8 μm WO_3 at 400°C with a hexagonal phase ratio of 20%-30%; 8-12 μm WO_3 was generated at 500°C with monoclinic phase >80%; 10-15 μm WO_3 was generated at 600°C with a monoclinic phase of >95%. The air flow rate influences the degree of oxidation, with a conversion rate of 95% at 50 m^3/h and 99% at 100 m^3/h. If the temperature is too high (>650°C), WO_3 sublimation loss of 2%-5% is lost, and the exhaust gas needs to be recovered by a cyclone (90% efficiency).

Industrial production of yellow tungsten oxide (WO_3) - Wet chemical process parameters and quality control

key parameters include acid concentration, precipitation temperature and heat treatment conditions. HCl 1 mol/L yields larger H_2WO_4 (15-20 μm) and 2 mol/L generates smaller particle size (5-10 μm). The yield was highest at pH 1.5 (96%) and impurities (Cl^-) increased at pH <1. The optimal balance is 550°C and 3 hours of heat treatment, with a purity of 99.5% and a particle size of 10-12 μm. Quality control was performed by titration for WO_3 content (error <0.1%), topography by SEM, and impurities detected by ICP-AES (Na^+ <0.01%, Cl^- <0.005%). Case data: An annual output of 200 tons of WO_3 has an HCl consumption of 0.8 m^3/ton, a water consumption of 5 m^3/ton, and an energy consumption of 3-4 kWh/kg.

Advantages and disadvantages of industrial production of yellow tungsten oxide (WO_3) - wet chemical analysis

The advantages are simple equipment (investment of 50-1 million yuan/annual output of 100 tons), flexible process, suitable for small batch customization (such as pigment grade WO_3); The disadvantages are the large amount of waste (1-2 m^3/ton WO_3, containing NaCl 50-100 g/L), the need for neutralization treatment ($Ca(OH)_2$ to pH 7, cost 50-80 yuan/m^3), the exhaust gas H_2O and trace HCl need to be treated by the absorption tower (packing height 5 m). This section demonstrates its applicability for small- and medium-scale production by detailing the process of wet chemistry.

4.3 Laboratory synthesis of yellow tungsten oxide (WO_3).

Laboratory synthesis of yellow tungsten oxide (WO_3) - hydrothermal method

The hydrothermal method is used to synthesize nano-WO_3 in a high-pressure reactor, usually using Na_2WO_4 as the raw material. The experimental process is as follows: 10 g Na_2WO_4 is dissolved in 50 mL deionized water, HCl (6 mol/L, 10-15 mL) is added to adjust the pH to 1-2, a reducing agent (such as 5 mL ethanol or 1 g oxalic acid) is added, and after stirring for 30 minutes, it is transferred to a 100 mL polytetrafluoroethylene-lined reactor, sealed and placed in an oven, reacted at 180-200° C for 12-24 hours, and a pressure of 10-20 atm. The product is centrifuged (8000 rpm, 10 minutes), washed (water and ethanol 3 times each), and dried (80°C, 6 hours) to obtain WO_3. The reaction is simplified as: Na2WO4+2HCl+reductant→WO3↓+2NaCl+H2O Na_2WO_4 + 2 HCl + reductant

\rightarrow $WO_3\downarrow$ + 2 NaCl + H_2O Na2WO4+2HCl+reductant→WO3↓+2NaCl+H2O
The product is hexagonal or monoclinic WO_3, with a particle size of 20-50 nm, a specific surface area of 30-50 m^2/g, and a spherical or rod-shaped morphology (length 50-100 nm). Hexagonal phase (XRD peak $2\theta = 13.9°$) is generated at 180°C, and monoclinic phase is converted at 200°C, with a yield of 90%-95%. The hydrothermal method is suitable for photocatalytic WO_3 (such as hydrogen production rate 0.9 mmol/h·g).

Laboratory synthesis technique of yellow tungsten oxide (WO_3) - solvothermal method

The solvothermal method uses organic solvents to manipulate WO_3 morphology, using WCl_6 or Na_2W0_4 as raw materials. The experimental procedure was as follows: 5 g of WCl_6 was dissolved in 50 mL of ethylene glycol, stirred for 1 hour, 10 mL of ethanol was added, transferred to a 100 mL reactor, and reacted at 200°C for 6-12 hours. The product was centrifuged, washed (3 times ethanol), and dried (80°C, 8 hours) to yield WO_3 with a particle size of 30-100 nm, 99% purity, and morphologies ranging from rods (80-150 nm long, 20-30 nm wide), flakes (10-20 nm thick), or floral (200-300 nm diameter). The solvent ratio (e.g., ethylene glycol:ethanol = 4:1) controls the topography with yields of 85%-90%. The solvothermal method is more expensive (about 50-100 RMB/kg WO_3), but it is highly adjustable in topography and is suitable for sensor WO_3.

Laboratory synthesis of yellow tungsten oxide (WO_3) - microwave-assisted synthesis

Microwave-assisted synthesis utilizes rapid microwave heating with AMT or Na_2W0_4 as raw materials. The experimental process was as follows: 10 g of AMT was dissolved in 50 mL of water, HCl (3 mol/L, 10 mL) was added to adjust the pH to 2-3, placed in a microwave oven (800 W, frequency 2.45 GHz), and the reaction was carried out for 10-20 minutes at a temperature of 150-180°C. The product was centrifuged, washed, and dried to obtain WO_3 with a particle size of 20-40 nm, a monoclinic phase ratio of >95% (XRD peak $2\theta = 23.6°$), and a yield of >94%. The microwave method has low energy consumption (approx. 0.5-1 kWh/kg) and a reaction time of only 1/10 of the hydrothermal method, making it suitable for small batches of high-purity WO_3 preparation (e.g., battery electrodes, capacity 700 mAh/g). This section demonstrates the refinement and efficiency of WO_3 synthesis through three laboratory techniques.

4.4 Optimization of process parameters of laboratory synthesis technology of yellow tungsten oxide (WO_3).

Influence of temperature, atmosphere, time

Temperature is critical for WO_3 production. In the roasting method, a hexagonal phase is generated at 500°C (XRD peak $2\theta = 28.2°$), a monoclinic phase is converted to a monoclinic phase at 550°C, a monoclinic phase ratio of >98% at 650°C, and grains grow to 10-15 μm at 700°C. In the hydrothermal method, a hexagonal phase is formed at 180°C, the proportion of monoclinic phase at 200°C increases to 80%, and the phase is completely monoclinic at 220°C. The atmosphere affects the crystalline phase and purity, and the yellow WO_3 is formed by roasting in the air, and the blue WO_2 may be formed by the H_2 atmosphere (0.5 L/min).[9] (oxygen vacancy 10^{18} cm^{-3}), hexagonal phase in N_2 is more stable. Time-controlled conversion rate of 95% in 2 hours of roasting, 99% in 4 hours, 20 nm particle size in 12 hours of hydrotherm, and 50 nm in 24 hours.

Laboratory synthesis of yellow tungsten oxide (WO_3) - purity and particle size control

Purity is achieved through raw material purification and process optimization. AMT was treated with an ion exchange resin (cationic resin D001) with Na^+ reduced to 0.01% and Fe^{3+} to 0.005%. Moist air (humidity 50%) is introduced during roasting to reduce sublimation, and the purity rises to 99.95%. The particle size control depends on the temperature and stirring rate, and the hydrothermal method produces 20-30 nm WO_3 at 180°C and stirring at 500 rpm, and 50-70 nm when standing. The roasting method yields 5-8 µm WO_3 at 600°C and an air flow rate of 150 m^3/h. This section provides the scientific basis for WO_3 quality control through parametric analysis.

4.5 Green production and waste treatment for the production and synthesis of yellow tungsten oxide (WO_3).

Ammonia nitrogen recovery technology for the production of yellow tungsten oxide (WO_3).

NH_3 (exhaust gas concentration 5-15 g/L) released by AMT decomposition is recovered by an ammonia evaporation tower (1 m diameter, 10 m high, packing with ceramic Rasi rings). Process conditions: vapor pressure 0.2-0.3 MPa, temperature 90-100°C, recovery rate >93%, waste liquid ammonia nitrogen from 10 g/L to 0.5 g/L, below the emission standard (GB 8978-1996, < 15 mg/L). The recovered NH_3 (20%-25% concentration) is recycled for AMT preparation, saving 50-70 kg of ammonia per ton of WO_3.

Energy consumption and emission analysis for the production and synthesis of yellow tungsten oxide (WO_3).

The energy consumption is 5-7 kWh/kg WO_3 (electrically heated furnace, 200 kW) for the roasting method, 2-3 kWh/kg (autoclave, 50 kW) for the hydrothermal method and the lowest (0.5-1 kWh/kg) for the microwave method. CO_2 emissions mainly come from fuel combustion, about 2-2.5 kg CO_2/kg WO_3 (coal heating) by roasting, 1-1.5 kg by hydrothermal method, and 0.8-1 kg by microwave method. The WO_3 dust (0.1-0.5 g/m^3) in the exhaust gas is treated with a cyclone dust collector and bag filter, and the emission concentration is reduced to <30 mg/m^3. Green processes, such as solar heating, can reduce energy consumption by up to 3 kWh/kg and CO_2 by up to 30 percent. This section shows the sustainable path to WO_3 production through an analysis of environmental technologies.

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Chapter 5: Analysis and Characterization Techniques of Yellow Tungsten Oxide (WO_3).

5.1 Chemical composition analysis of yellow tungsten oxide (WO_3).

Titration (WO_3 content determination)

Titration is a traditional chemical analysis technique for the determination of WO_3 content, which is widely used in industrial quality control and laboratory research due to its ease of operation, low cost, and reliable results. The method is based on the principle of acid-base reaction or redox titration, which converts WO_3 into a titratable tungstate form, and the content is calculated by titration of a standard solution. The experimental procedure is as follows: First, take 0.5-1 g of WO_3 sample (accurate to 0.0001 g), place it in a 50 mL PTFE crucible, add 10-15 mL of concentrated NaOH solution (40% by mass fraction, density 1.43 g/mL), heat to 80-100°C on an electric hot plate, stir (200-300 rpm) for 30-60 minutes, until the sample is completely dissolved, and soluble sodium tungstate (Na_2WO_4) is generated）。The reaction is:

$$WO_3 + 2NaOH \rightarrow Na_2WO_4 + H_2O$$

After the solution cooled to room temperature, it was neutralized to pH 7 with HCl (1 mol/L, about 20-30 mL) to generate a trace amount of H_2WO_4 precipitate, followed by the addition of excess $ZnSO_4$ solution (0.1 mol/L, 20-25 mL) and stirring for 10-15 minutes to precipitate tungstate in $ZnWO_4$ form

$$Na_2WO_4 + ZnSO_4 \rightarrow ZnWO_4 \downarrow + Na_2SO_4$$

The pellet is filtered through medium-speed filter paper and washed 3-5 times with deionized water (50-100 mL, pH 6-7) to remove Na^+ and SO_4^{2-} ions. The cake was transferred to an Erlenmeyer flask, dissolved with standard H_2SO_4 (0.1 mol/L, 20 mL), WO_4^{2-} was released, 2–3 drops of methyl orange indicator (0.1%) were added, and titrated with standard $KMnO_4$ solution (0.02 mol/L) until the solution was a stable pink color (MnO_4^- self-indicated, held for 30 seconds). The titration reaction was:

$$5WO_4^{2-} + 2MnO_4^- + 16H^+ \rightarrow 5W_2O_7^{2-} + 2Mn^{2+} + 8H_2O$$

The WO_3 mass percentage is calculated based on the $KMnO_4$ consumption volume (V, mL) and concentration (C, mol/L) as follows:

$$WO_3\% = \frac{2 \times C_{KMnO_4} \times V \times M_{WO_3}}{5 \times m_{样品}} \times 100$$

where M_{WO_3} = 231.84 g/mol and m_{sample} is the mass of the sample (g). The assay error is typically <0.1%, and the repeatability is good (RSD <0.5%), making it suitable for WO_3 samples with 95%-99.9% purity.

The advantages of titration include simple equipment (only burettes, Erlenmeyer flasks, hot plates, etc., the total cost is about 1000-2000 yuan), and the operation does not require a high technical background, which is suitable for rapid detection in industrial sites. For example, a plant processes 50-100 WO_3 samples per day, and titration can be analyzed in 1-2 hours. However, the method is sensitive to impurities, such as elements such as Mo, V, etc., which can interfere with $ZnWO_4$ precipitation and requires pre-separation by ion exchange or extraction. In addition, the dissolution of the sample requires strong alkali and high temperature treatment, which requires high crucible materials (such as PTFE or platinum), which increases the cost. If the sample contains moisture or organics, pre-roast (200-300°C, 1 hour) to remove interference.

Inductively coupled plasma emission spectroscopy (ICP-AES) for yellow tungsten oxide (WO_3) analysis

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-AES) is a highly sensitive, multi-element analysis technique widely used for the determination of trace impurities (e.g., Fe, Na, Mo, Si) and the main element tungsten content in WO_3. The principle is that the sample is atomized and injected into a high-temperature plasma (6000-10000 K), which excites the emission characteristic spectrum of atoms or ions, and detects the wavelength and intensity by a spectrometer. The procedure was as follows: 0.1–0.2 g of WO_3 sample (accurate to 0.0001 g) was placed in a microwave digestion jar and 5 mL of HF (40%, corroded SiO_2 was addedimpurities), 5 mL HNO_3 (65%, oxidant), and 2 mL HCl (37%, stabilized tungsten ions), sealed and heated in a microwave digester (power 800 W, 200°C, 30-40 min) until the sample is completely dissolved into a clear solution. After cooling, the volume was reduced to 100 mL with deionized water and filtered (0.45 µm membrane) to remove the residue. Samples were injected into the ICP-AES instrument by a peristaltic pump (flow rate 1 mL/min) (typical parameters: RF power 1.2-1.5 kW, argon flow 15 L/min, auxiliary gas 1 L/min, nebulized gas 0.8 L/min). The characteristic emission lines of tungsten were 207.911 nm and 224.875 nm, and impurities such as Fe (259.940 nm), Na (589.592 nm) and Mo (202.030 nm) were measured simultaneously.

ICP-AES has a very low detection limit (0.1 µg/L for tungsten and 0.01-0.05 µg/L for impurities) and a wide linear range (0.001%-10%) for WO_3 detection> 20 elements in concentrations ranging from 1 ppm (0.0001%) to 99.99%. For example, WO_3 prepared by roasting has a Fe content of about 5-10 ppm, Na < 2 ppm, and Si up to 20-50 ppm in hydrothermal samples. The method is highly accurate (RSD <1%, 5 replicates) and the analysis time is short (5-10 minutes for a single sample). The correlation coefficient $R^2 > 0.999$ was calibrated by a standard curve (0.1-1000 mg/L solution prepared with WO_3 standard). The results show that the purity of industrial WO_3 is typically 99.9%-99.99%, and that of laboratory nano WO_3 can reach 99.995%.

The advantages of ICP-AES are simultaneous multi-element analysis, high sensitivity, and high throughput (20-30 samples per hour), making it suitable for quality control and scientific research. However, the cost of the instrument is high (about 50-1 million yuan), the operation requires high-purity argon gas (daily consumption of 20-30 L, about 50-100 yuan), the sample digestion requires strong acid and closed equipment (such as microwave digestion instrument, about 20-300,000 yuan), and the requirements for operators are high (1-3 months of training is required). In addition, the use of HF requires special protection (e.g., fume hood, acid-proof gloves), and the cost of waste liquid disposal is about 50-100 yuan/batch. This section demonstrates the combination of traditional and modern techniques for WO_3 chemical composition analysis through a detailed description of titration and ICP-AES.

5.2 Structural characterization of yellow tungsten oxide (WO_3).

Structural characterization of yellow tungsten oxide (WO_3) - X-ray diffraction (XRD).

X-ray diffraction (XRD) is the technique of choice for analyzing WO_3 crystal structure and phase states, enabling accurate determination of crystal phase, lattice parameters, and grain size. Typical conditions were Cu Kα radiation ($\lambda = 1.5406$ Å, voltage 40 kV, current 30-40 mA), sample placement on a glass slide or silicon wafer with zero background, scanning range $2\theta = 10°-80°$, step size 0.02°, and scanning speed 2-4°/min. The characteristic diffraction peaks of monoclinic phase WO_3 occur at $2\theta = 23.1°$ ((002) surface, d = 3.85 Å), 23.6° ((020), d = 3.77 Å, 24.4°((200), d = 3.65 Å), the relative intensity ratio is about 1:0.9:0.8, and the hexagonal WO_3 peaks are 13.9°((100)), 22.8°((110)), and 28.2°((200)). The tetragonal phase is at 22.8° ((110)), 32.5° ((200)). The crystal plane spacing was calculated by the Bragg equation ($n\lambda = 2d \sin\theta$), and the phase state was confirmed by comparing it with the standard card (JCPDS 43-1035 monoclinic phase, 20-1324 hexagonal phase).

Grain size is calculated by Scherrer's equation: $D = K\lambda / \beta\cos\theta$ ($K = 0.9$, β is the width at half maximum, in radians), e.g., $2\theta = 23.6°$ for the peak $\beta = 0.15°$ (about 0.0026 rad), $D \approx 50$ nm, which is consistent with the TEM results. The Rietveld refinement method further refines the lattice parameters with a = 7.306 ± 0.005 Å, b = 7.540 ± 0.005 Å, c = 7.692 ± 0.005 Å, β = 90.91 ± 0.02°, unit cell volume 423.5 Å^3. XRD can also detect trace amounts of heterophase (e.g., WO_2.). $_9$ of $2\theta = 25.7°$ peak) with a sensitivity of 1%-2% for the analysis of doped or defective samples (e.g., Na-WO_3 peak shift of 0.1°-0.2°). Experiments require attention to sample uniformity (grinding to <50 μm) and instrument calibration (zeroing with Si standards), and each measurement takes 20-40 minutes.

Structural characterization of yellow tungsten oxide (WO_3) - Fourier transform infrared spectroscopy (FTIR).

Fourier transform infrared spectroscopy (FTIR) is used to characterize the chemical bonds, functional groups, and surface states of WO_3 to provide molecular vibrational information. The protocol was to mix 1-2 mg WO_3 sample with 100-200 mg KBr (spectrally pure), grind it evenly, press it into a transparent sheet with a diameter of 13 mm and a thickness of 0.5-1 mm in a tablet press (10 MPa, 2-3 minutes), and place it in an FTIR spectrometer with a measurement range of 400-4000 cm^{-1}, a resolution of 4 cm^{-1}, and a number of 32-64 scans. Characteristic absorption peaks of monoclinic phase WO_3 are: 700-950 cm^{-1} (W-O-W bridge oxygen stretching vibration, strong and wide), 600-650 cm^{-1} (W-O bending vibration, weak), 800-850 cm^{-1} (W=O oxygen stretching, sharp). If the sample contains hydrates (e.g., $WO_3 \cdot H_2O$), 3400-3500 cm^{-1} (O-H flexion), and 1600-1630 cm^{-1} (H-O-H curve).

FTIR can detect doping or defective effects, such as W-N bond vibrations in N-doped WO_3 at 950-1000 cm^{-1} and new peaks in oxygen-vacant samples (WO_{3-x}) at 900-950 cm^{-1}. Peak intensity is related to crystallinity, and nanoWO_3 (<50 nm) is broadened due to surface effects (FWHM increases to 20-30 cm^{-1}). The advantages of the method are fast (5-10 minutes for a single measurement), non-destructive, and low equipment cost (about 10-200,000 yuan); The disadvantage is that quantitative capabilities are limited and need to be confirmed in combination with other techniques such as Raman. Samples should be prepared dry (to avoid moisture absorption by KBr) and the ambient humidity should be controlled at <50%.

Structural characterization of yellow tungsten oxide (WO_3) - Raman spectroscopy

Raman spectroscopy provides detailed information on structure and defects by detecting molecular vibrations and crystal symmetry of WO_3. Experiments were performed using a laser Raman spectrometer with typical conditions of a 532 nm laser (power 1-5 mW to avoid sample burns) and a spectral range of 100-1000 cm^{-1}with a resolution of 1–2 cm^{-1} and an integration time of 10–30 seconds, the sample is placed on a glass slide and focused. The characteristic peaks of monoclinic phase WO_3 are 717 cm^{-1} (W-O-W symmetrical stretching), 807 cm^{-1} (W-O-W asymmetrical stretching), and 270 cm^{-1} (W-O bending). The hexagonal phase is 680 cm^{-1} and 810 cm^{-1}, and the tetragonal phase is 690 cm^{-1} and 830 cm^{-1}. Peak position and intensity reflect crystalline phase purity, e.g., monoclinic phase WO_3 has a peak strength ratio of approximately 1:1.2 in the 700-800 cm^{-1} region.

Raman spectroscopy is sensitive to grain size, with nano-WO_3 (<30 nm) peaks broadening (FWHM increasing to 20-30 cm^{-1}) and a 20%-30% decrease in intensity due to enhanced surface phonon scattering. A new peak appeared at 950-970 cm^{-1} in the oxygen vacancy (WO_{3-x}), and the intensity was positively correlated with the defect concentration (10^{17}-10^{19} cm^{-3}). Doped samples (e.g., Ti-WO_3) have a peak shift of 5–10 cm^{-1} to reflect lattice stress. The advantages of the method are high spatial resolution (focused spot <1 μm), non-destructiveness, and suitability for in-situ analysis. The disadvantage is that fluorescence interferences (e.g., organic residues) need to be eliminated with different wavelengths of lasers (e.g., 785 nm) and each measurement takes 10-20 minutes. This section provides a comprehensive overview of the structural properties of WO_3 and its characterization methods through detailed descriptions of XRD, FTIR, and Raman.

5.3 Morphology and microscopic analysis of yellow tungsten oxide (WO_3).

Scanning Electron Microscopy (SEM)

Scanning electron microscopy (SEM) is the primary tool for observing WO_3 surface topography, particle size, and distribution, providing intuitive two-dimensional images. The experimental procedure is as follows: take a small amount of WO_3 powder (about 10-20 mg), disperse it in ethanol (ultrasonic 5-10 minutes, power 100 W), drop it on a conductive silicon wafer or aluminum foil, dry it and spray it with gold (20 mA, time 60-90 seconds, thickness 10-15 nm) to enhance the conductivity. The SEM parameters are: acceleration voltage 5-15 kV, working distance 5-10 mm, magnification 1000-50000x. Micron-scale WO_3 (e.g., prepared by roasting) is irregular polyhedron with a particle size of 4-15 μm and a smooth surface. Nanoscale WO_3 (e.g., hydrothermally prepared) is spherical (20-50 nm), rod-like (50-100 nm long, 10-20 nm wide) or sheet (5-10 nm thick) with a high surface roughness.

The SEM is equipped with an energy-dispersive X-ray spectrometer (EDS) for elemental distribution analysis, with typical results of a W:O atomic ratio of ≈1:3 and a <0.1% content of impurities (e.g., Na, Si). EDS has a resolution of approximately 1 μm and a detection limit of 0.1%-0.5%. For example, the EDS of the roasted WO_3 showed Na < 0.05% and the hydrothermal sample contained 0.1%-0.2% Si. The advantages of SEM are easy operation (20-30 minutes of sample preparation), intuitive image, and the equipment cost is about 30-500,000 yuan; The disadvantage is that the resolution is limited (about 1-5 nm), the internal structure cannot be observed, and the TEM needs to be combined.

Transmission Electron Microscopy (TEM)

Transmission electron microscopy (TEM) provides high-resolution microstructure and crystal information in WO_3 for nanoscale sample analysis. The experimental procedure is as follows: take 5-10 mg WO_3, disperse in ethanol (sonication for 10-15 minutes), drop on a carbon film copper mesh (200-300 mesh), and dry naturally. The TEM parameters are: acceleration voltage 200 kV, magnification 50,000-500,000 times, resolution 0.1-0.2 nm. TEM images show the morphology of the nanoWO_3, such as spherical (20-30 nm) or rod-shaped (50-100 nm long) for hydrothermal samples with clear grain boundaries. High-resolution TEM (HRTEM) revealed plane spacing, with monoclinic phase (002) plane $d = 3.85 \pm 0.02$ Å, (200) plane $d = 3.65 \pm 0.02$ Å, consistent with XRD.

HRTEM can also observe defects such as oxygen vacancies that manifest as lattice distortion and doped atoms such as Ti^{4+}) causes a change in local contrast. Selective electron diffraction (SAED) generates diffraction spots, and monoclinic phase WO_3 shows (002), (020), (200) rings to confirm crystal orientation. The advantage of TEM is that it has high resolution and can directly observe atomic-level structures; The disadvantages are that the sample preparation is complex (ultra-thin dispersion is required, which takes 1-2 hours), the instrument is expensive (about 1 million to 2 million yuan), and the operation requirements are high. This section illustrates the characterization techniques and applications of WO_3 topography and microstructure through detailed descriptions of SEM and TEM.

5.4 Structural characterization and physical property testing of yellow tungsten oxide (WO_3).

Structural characterization of yellow tungsten oxide (WO_3) - BET specific surface area determination

BET (Brunauer-Emmett-Teller) specific surface area determination is a key technology to analyze the physical properties of WO_3 surface, and the specific surface area and pore structure are determined by nitrogen adsorption-desorption experiments, which provides a basis for its functional applications (such as catalysis and energy storage). The following is an in-depth analysis of the basic principles and measurement methods to the definition of specific surface area, the relationship between WO_3 specific surface area and processing technology and particle size, and the significance and relationship with the application.

Basic Principles and Experimental MethodsThe BET method is based on the theory of multilayer adsorption and uses the adsorption-desorption behavior of N_2 at 77 K (liquid nitrogen temperature) to determine the sample surface area. The protocol is to take a 0.1-0.5 g WO_3 sample and place it in a sample tube of a specific surface area analyzer (typical model such as Micromeritics ASAP 2020) and pretreat it under vacuum (10^{-3} Pa) at 200-300°C for 2–4 hours to remove moisture and volatile impurities. Cooled to 77 K, high-purity N_2 (99.999%) was introduced, the pressure was gradually increased (0-1 atm), and the adsorption capacity (cm^3/g) was recorded as a function of relative pressure (P/P_0). The desorption process proceeds in reverse, forming an adsorption-desorption isotherm. According to the BET equation:

$$\frac{P}{V(P_0-P)} = \frac{1}{V_m C} + \frac{(C-1)P}{V_m C P_0}$$

where V is the adsorption capacity, V_m is the adsorption capacity of the monolayer, and C is the constant, and the V_m is calculated by linear regression ($P/P_0 = 0.05\text{-}0.35$). The specific surface area (S) is:

$$S = V_m \cdot N_A \cdot A_{N_2}/m$$

where N_A is Avogadro's constant (6.022×10^{23} mol^{-1}), A_{N_2} is the N_2 molecular cross-sectional area (0.162 nm^2), and m is the sample mass (g). The pore distribution was calculated from the desorption curve by the BJH (Barrett-Joyner-Halenda) method with an error of <5%.

Micron-scale WO_3 (prepared by roasting, particle size 4-15 μm) has a specific surface area of 5-15 m²/g, a pore size of 10-20 nm, and is mostly mesoporous structure; Nanoscale WO_3 (e.g., hydrothermally prepared, particle size 20-50 nm) is 30-50 m²/g, pore size 5-10 nm, microporous (<2 nm) and mesopores. The experiment took 4-6 hours and was reproducible (RSD <3%).

What is Specific Surface Area?

Specific surface area refers to the total surface area (m²/g) per unit mass of solid materials, including the outer surface and the inner pore surface, and is an important parameter to characterize the surface properties of porous materials or granular materials. For WO_3, the specific surface area reflects its particle size, porosity, and number of surface-active sites. Theoretically, the specific surface area of a solid particle is inversely proportional to the particle size, and the smaller the particle size, the greater the surface area per unit mass. For example, the specific surface area of an ideal spherical particle $S = 6 / (\rho \cdot D)$, where ρ is the density ($WO_3 \approx 7.16$ g/cm³) and D is the particle size (μm). When D = 10 μm, S ≈ 0.08 m²/g; At D = 0.02 μm (20 nm), S ≈ 41.9 m²/g, indicating a significant increase in surface area by nanoization. However, the specific surface area of the actual WO_3 is affected by the morphology (spherical, rod-shaped, sheet-like), pore structure, and degree of agglomeration, which needs to be measured by BET.

The specific surface area of tungsten oxide is closely related to the preparation process, and the particle size, morphology and pore structure generated by different processes are significantly different

Roasting method

AMT is decomposed in air at 500-700°C to produce micron-sized WO_3 (4-15 μm) with a low specific surface area (5-15 m²/g). High temperatures cause particles to sinter, pores to collapse, and surface active sites to decrease. For example, WO_3 roasted at 600°C for 4 hours has a specific surface area of 8-10 m²/g and a pore volume of 0.02-0.03 cm³/g.

Hydrothermal method

Reaction at 180-200°C, 10-20 atm yields nanoWO_3 (20-50 nm) with a specific surface area of up to 30-50 m²/g. Low temperature and high pressure retained the open pores (such as the channel structure of the hexagonal phase), and the specific surface area decreased slightly with the prolongation of the reaction time (12-24 h) due to grain growth. For example, a sample at 180°C for 12 h has a specific surface area of 45-50 m²/g and a pore size of 5-8 nm.

Solvothermal method

Using a solvent such as ethylene glycol, the reaction was carried out at 200°C for 6–12 h to generate rod or sheet WO_3 (30–100 nm) with a specific surface area of 20–40 m²/g. The type and concentration of the solvent affect the morphology, and a flake structure is formed at a high proportion of ethylene glycol, and the specific surface area is low (about 25 m²/g).

Hydrogen reduction method
WO_3 (3-6 μm) is indirectly generated with a specific surface area of 5-10 m^2/g, and the high-temperature reduction and oxidation process densifies the particles with fewer pores.

Process parameters such as temperature, atmosphere, and holding time also influence the results, e.g. 700°C in the roasting process is 20%-30% lower than the specific surface area of 500°C due to increased grain agglomeration.

Relationship between specific surface area and particle size of tungsten oxideWO_3 The specific surface area of WO_3 is inversely proportional to particle size, which is affected by particle morphology and agglomeration. Theoretically, the specific surface area of spherical particles increases dramatically as particle size decreases, but in practice WO_3 is often polyhedra or nanorods, and agglomeration further reduces the effective surface area. Experimental data indicates:

Micron-scale WO_3 (D50 = 5-10 μm): Specific surface area of 5-10 m^2/g, large particles, smooth surface, few internal pores.
Sub-micron scale (D50 = 0.1-1 μm): specific surface area 15-25 m^2/g, transitional state, partial pore formation.
Nanoscale (D50 = 20-50 nm): specific surface area 30-50 m^2/g, rough surface, rich pores.
For example, the hydrothermal WO_3 increased from 20 nm to 50 nm (longer reaction time) and the specific surface area decreased from 50 m^2/g to 35 m^2/g, a decrease of about 30%. The TEM and BET data were consistent, showing that the increased particle size was accompanied by agglomeration, reducing the exposed surface. The high specific surface area of nano-WO_3 is due to the quantum size effect and the increase in the proportion of surface atoms (about 20%-30% of surface atoms), compared to only 1%-2% in the micron scale.

Significance and relationship between the specific surface area of tungsten oxide and its useWO_3 The specific surface area of WO_3 directly affects its performance in the fields of catalysis, energy storage, sensing and electrochromic

Photocatalysis
The high specific surface area increases the active site and improves the photocatalytic efficiency. For example, the rate at which a 50 m^2/g specific surface area of a nano-WO_3 decomposes methylene blue under visible light (0.03 min^{-1}) is 3-fold higher than that of a 10 m^2/g micron WO_3 (0.01 min^{-1}), and the hydrogen production rate increases from 0.7 mmol/h·g to 0.9-1.0 mmol/h·g due to more adsorption of water molecules and photogenerated electron-hole pairs on the surface.

Gas sensing
WO_3 with a high specific surface area (e.g., 40 m^2/g) is 2-3 times more sensitive to NO_2

and H_2S, and the response time is reduced to 5-10 seconds due to the increased adsorption of gas molecules. For example, 20 nm WO_3 has a NO_2 detection limit of 10 ppb, while 5 μm WO_3 is only 50 ppb.

Lithium-ion batteries

Nano WO_3 (specific surface area 30-50 m²/g) provides more Li^+ embedding sites with an initial capacity of up to 700-720 mAh/g and 88% retention after 1000 cycles, while micron $W0_3$ (10 m²/g) has a capacity of only 400-450 mAh/g due to the long diffusion path.

Electrochromic

High specific surface area WO_3 films (e.g., 35 m²/g) have an increase in transmittance from 70% to 85% and a response time from 10 seconds to 6-8 seconds due to increased ion diffusion rates.

Conversely, low specific surface area WO_3 (e.g. 5-10 m²/g) is suitable for ceramic pigments or tungsten powder raw materials due to their high stability and low surface activity requirements. Excessive specific surface area may lead to agglomeration or side reactions (e.g., increased electron recombination rate in photocatalysis), and process equilibrium needs to be optimized.

BET assays not only quantify the specific surface area of WO_3, but also reveal its deep links to process, particle size, and use. Nano-based processes (e.g., hydrothermal) significantly increase the specific surface area and enhance functional applications, while traditional roasting methods are suitable for large particles and low surface area requirements. The instrument (standard SiO_2, surface area 200 m²/g) is calibrated for each measurement to ensure reliable data.

Thermogravimetric Analysis (TG) vs. Differential Scanning Calorimetry (DSC)

Thermogravimetric analysis (TG) and differential scanning calorimetry (DSC) are used to evaluate the thermal stability, decomposition behavior, and phase transformation properties of WO_3. Experiments were performed in a thermal analyzer with typical conditions of 10-20 mg of sample in an alumina crucible, heating rate of 5-10°C/min, temperature range of 25-1000°C, atmosphere of air or N_2 (flow rate 50-100 mL/min). The TG records the mass change, and the DSC measures the heat flux difference.

The TG results showed that the pure WO_3 was stable at <500°C, volatilized in trace amounts at 500-900°C (loss of <1%), and sublimation was evident > 900°C (loss of 5%-10%, rate of 0.05-0.1 g/min cm²). Hydrate-containing samples (e.g., $WO_3 \cdot H_2O$) loses crystal water at 100-200°C (8%-10% mass loss) and completely dehydrates at 300-400°C as WO_3. There was no significant change in the roasting WO_3 before 600°C, and the hydrothermal nano WO_3 lost 2%-3% (surface adsorption of water) before 200°C. DSC detects phase transitions, monoclinic phases→ hexagonal phases (350-400°C, enthalpy change 5-10 kJ/mol), hexagonal → tetragonal phases (740-800°C, 15-20 kJ/mol), tetragonal → cubic phases (>900°C, ephemeral). The heat flow peak is associated with lattice reconfiguration and oxygen bond breakage.

The advantages of the method are the visual reflection of thermal behavior (1-2 hours) and high resolution (0.1 μg mass change, 0.01 mW heat flow); The disadvantage is that the sample volume is small (<50 mg) and the phase transition needs to be confirmed in combination with XRD. The TG-DSC guides the optimization of the heat treatment process of WO_3, e.g. to avoid sublimation losses. This section provides a comprehensive overview of the physical properties of WO_3 and how to test it through the refinement of BET and TG-DSC.

5.5 Electrochemical and photoelectric performance test of yellow tungsten oxide (WO_3).

Cyclic voltammetry (CV)

Cyclic voltammetry (CV) is a common technique for evaluating the electrochemical performance of WO_3 and is widely used in electrochromic devices, supercapacitors, and battery research. The experiments were performed on an electrochemical workstation (three-electrode system): WO_3 coated on FTO glass (area 1 cm²), working electrode), Pt sheet (2 cm², counter electrode), Ag/AgCl (saturated KCl, reference electrode), and electrolyte 0.5 mol/L H_2SO_4 or 1 mol/L $LiClO_4$(neutral), scan rate 10-100 mV/s, potential range -0.5-1.0 V. The CV curve showed oxidation peaks (0.3-0.5 V, Li^+ outlet) and reduction peaks (-0.1-0.2 V, Li^+ embedding) with the following reactions

$$WO_3 + xLi^+ + xe^- \leftrightarrow Li_xWO_3$$

The peak current of nano WO_3 (30 nm) at 50 mV/s is 2-3 mA/cm², the capacitance is 100-150 mF/cm², and the micrometer WO_3 (5 μm) is only 0.5-1 mA/cm², reflecting the difference in surface area. CV assesses cyclic stability, with volume retention of 85% to 90% after 1000 cycles.

Ultraviolet-Visible Spectroscopy (UV-Vis)

UV-Vis spectroscopy measures the optical absorption and band gap of WO_3, which is suitable for photocatalytic and electrochromic research. The experiment uses a spectrophotometer with a thin film (spin-coated on a quartz sheet) or a powder (pressed sheet) in a measurement range of 200-800 nm in steps of 1 nm. The absorption edge of WO_3 is 430-460 nm, the energy band gap is calculated by the Tauc curve ($(\alpha h\nu)^2$ vs hv), the monoclinic phase is 2.6-2.8 eV, and the nanoscale (20 nm) increases to 2.8-2.9 eV, due to the quantum confinement effect. Doped WO_3 (e.g., Ti-WO_3) absorbs a redshift to 500-520 nm and reduces the energy band gap to 2.4-2.5 eV. This section illustrates the electrochemical and optoelectronic properties of WO_3 and how to measure them through the refinement of CV and UV-Vis.

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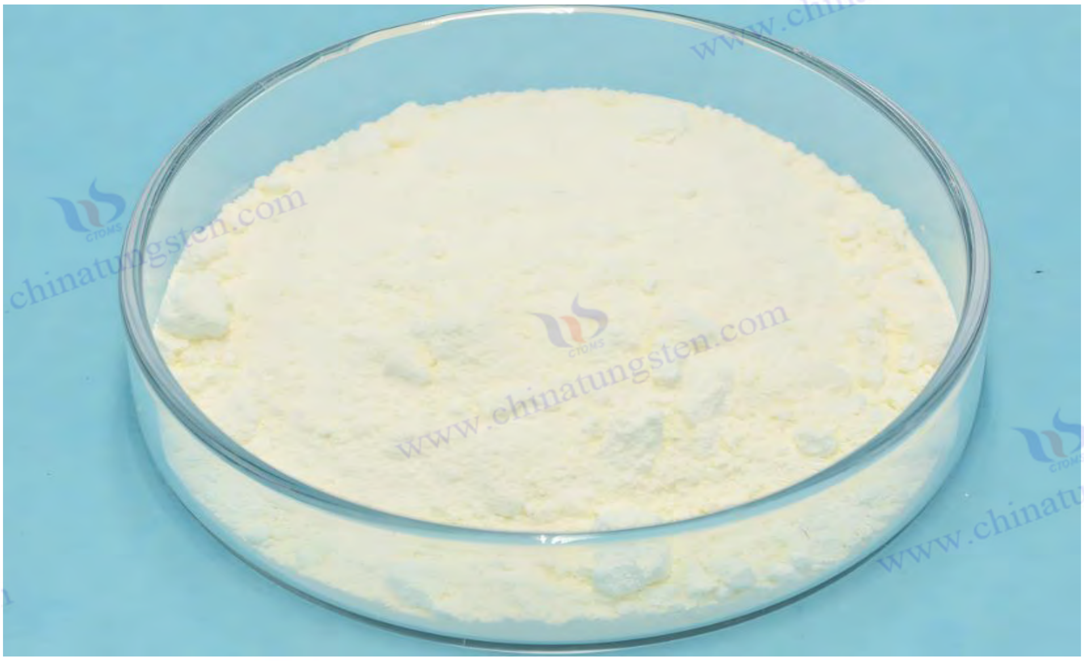


CTIA GROUP

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

1. Overview of tungsten trioxide

CTIA GROUP tungsten trioxide (referred to as yellow tungsten, WO_3) is produced by ammonium paratungstate high-temperature calcination process, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. Yellow tungsten is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants due to its light yellow crystal powder form, high purity and chemical stability. CTIA GROUP is committed to providing high-quality yellow tungsten products to meet the needs of powder metallurgy and industrial manufacturing.

2. Characteristics of tungsten trioxide

Chemical composition: WO_3.

Purity: ≥99.95% with very low impurity content.

Appearance: Light yellow crystal powder, uniform color.

Polymorph: monoclinic (most common at room temperature), space group P21/n.

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 (1000-1100°C).

Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Specifications of tungsten trioxide

index	CTIA GROUP Yellow tungsten first grade standard
WO_3 content (wt%)	≥99.95
Impurity（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
Moisture (wt%)	≤0.05
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. Tungsten trioxide 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. Tungsten trioxide procurement information

Mailbox:sales@chinatungsten.com Phone: +86 592 5129696

For more information about tungsten yellow, please visit the Chinatungsten Online websitewww.tungsten-powder.com

Chapter 6: Applications of Yellow Tungsten Oxide (WO_3).

6.1 Applications of yellow tungsten oxide (WO_3) - catalyst field

WO_3 shows a wide range of application potential in the field of catalysis due to its unique physicochemical properties, such as narrow band gap (2.6-2.8 eV), high oxidation capacity (hole potential of about 3.0 V vs NHE), chemical stability (resistance to acid and alkali corrosion), and abundant surface-active sites. The following is a detailed analysis from the two directions of photocatalysis and chemical catalysis, covering the mechanism, performance data, process impact, optimization strategy and practical cases.

Application of yellow tungsten oxide (WO_3) - photocatalysis (hydrogen production, pollutant degradation and air purification).

Application of Yellow Tungsten Oxide (WO_3) - Hydrogen

ProductionWO_3 It performs well in photocatalytic water splitting to produce hydrogen, especially when driven by visible light. NanoWO_3 (particle size 20-50 nm, specific surface area 30-50 m^2/g) has become a research hotspot due to the quantum size effect and high surface area. Taking the WO_3/Pt composite as an example, the hydrogen production rate is 0.9-1.2 mmol/h·g under the irradiation of 300 W xenon lamp ($\lambda > 420$ nm, intensity 100 mW/cm^2), which is higher than that of traditional TiO_2 (0.5-0.7 mmol/h·g). The specific experimental conditions were: 0.1 g WO_3/Pt (Pt loading 1 wt%) dispersed in 100 mL of 10% methanol in water (sacrificial agent), pH 6-7, 25°C, stirring continuously (300 rpm). The hydrogen production rate increased linearly with the increase of light intensity, reaching 1.5-1.8 mmol/h·g at 150 mW/cm^2. The mechanism is as follows: WO_3 absorbs visible light to form electron-hole pairs, holes oxidize methanol to generate CO_2 and H^+, and electrons reduce H^+ on Pt to form H_2:

$$WO_3 + h\nu \rightarrow e^- + h^+$$
$$H_2O + 2h^+ \rightarrow ½O_2 + 2H^+$$
$$2H^+ + 2e^- \rightarrow H_2$$

Doping optimization significantly improves performance, such as a reduction in the N-WO_3 (N content 2-3 at%) band gap to 2.4 eV, a redshift to 520 nm at the absorption edge, an increase in hydrogen production to 1.5-2.0 mmol/h·g, and an increase in visible light utilization from 43% to 50%-55%. The combined WO_3/g-C_3N_4 (mass ratio 1:1) further increases the efficiency with hydrogen production rates of 2.2-2.5 mmol/h·g, and the recombination rate is reduced by 40%-50% due to heterojunction-enhanced charge separation (photocurrent test, 1.5 mA/cm^2). vs 0.8 mA/cm^2）。 The hydrothermal method (180°C, 12 h) produced nano-WO_3 produced hydrogen production rate was 3-4 times higher than that of the roasting method (600°C, 4 h, 5-10 μm), due to differences in surface area and crystal defects. In practice, WO_3 photocatalytic hydrogen production is already being used in laboratory-scale renewable energy systems, such as solar-powered H_2

generators (10-20 L H_2 per day, 3%-5% efficiency). The challenge lies in the electron-hole recombination and the lower conduction band potential (0.4 V vs NHE), which requires the recombination of $BiVO_4$ or CdS to adjust the energy level.

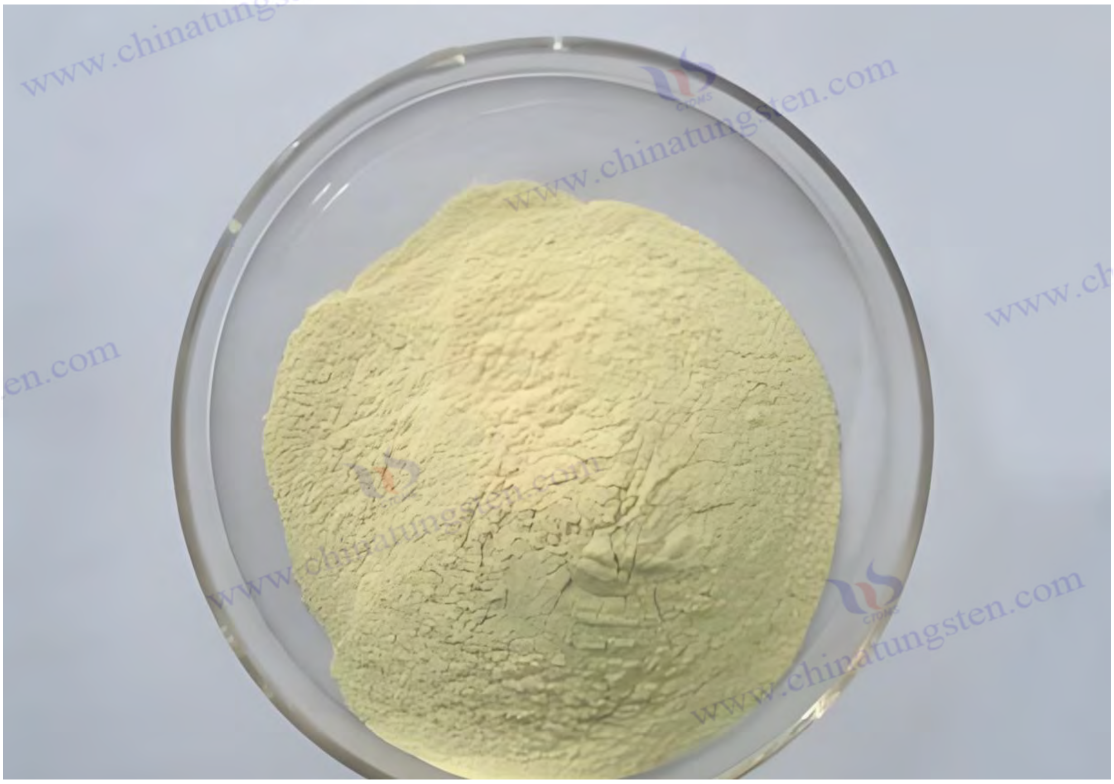
Application of Yellow Tungsten Oxide (WO_3) - Pollutant Degradation WO_3 Exhibits high efficiency in photocatalytic degradation of organic pollutants (e.g., dyes, phenols, VOCs). Taking methylene blue (MB, 10 mg/L) as an example, the degradation rate of 50 m^2/g nano-WO_3 at 50 m^2/g was 90%-95% in 2 hours under visible light (50 mW/cm^2), and the first-order kinetic constant was 0.03-0.04 min^{-1}, better than micron WO_3 (0.01 min^{-1}). Experimental conditions: 0.05 g WO_3 suspended in 50 mL of MB solution, pH 6, 25°C, stirred at 200 rpm. The degradation mechanism is as follows: photogenerated hole formation ·OH (E = 2.8 V vs NHE), oxidizing MB to CO_2 and H_2O:

$$h^+ + H_2O \rightarrow \cdot OH + H^+$$

$$MB + \cdot OH \rightarrow CO_2 + H_2O + \text{无机盐}$$

The degradation rate of the composite Ag-WO_3(Ag 1 wt%) increases to 98% due to the increased hole lifetime (60% reduction in photoluminescence intensity) due to Ag capture electrons. Phenolic contaminants (e.g., phenol, 20 mg/L) are 85%-90% degraded within 3 hours, and TOC removal is 70%-80%, which is better than UV-TiO_2 (60%-70%) because WO_3 responds strongly to visible light. VOCs (e.g., toluene, 10 ppm) degrade at >85% over 4 hours on WO_3 film (200 nm, spin coating) and produce CO_2 and H_2O, making them suitable for indoor air purification. The hydrothermal WO_3 (hexagonal phase, 40 m^2/g) is 2-3 times more efficient than the roasting method (monoclinic phase, 10 m^2/g) due to differences in crystalline phase and pore structure. Practical example: A factory uses WO_3 photocatalysis to treat printing and dyeing wastewater (COD 500-1000 mg/L), and the COD is reduced to <100 mg/L in 6 hours, and the operating cost is about 2-3 yuan/m^3. The challenge is photocatalyst recovery and long-term stability, which requires the development of magnetic compounds (e.g., WO_3/Fe_3O_4) or immobilization technologies (e.g., WO_3/TiO_2 membranes).

Application of Yellow Tungsten Oxide (WO_3) - Air Purification WO_3 Decomposes formaldehyde, NO_x and bacteria in indoor and outdoor air purification. In the case of formaldehyde (10 ppm), WO_3 film (200 nm, solvothermal method) decreases to <0.1 ppm in 4 hours under a 10 W LED lamp (400-700 nm), with a degradation rate of >95% and a rate constant of 0.02 min^{-1}. Mechanism for photogenesis ·OH and O_2^- oxidize formaldehyde to CO_2 and H_2O. NO_x (1 ppm) has a 2-hour removal rate of 80%-90% on a WO_3/TiO_2 composite (1:2 mass ratio) and the product is nitrate, suitable for urban road coatings. In terms of antibacterial, WO_3 (20 nm) generates ROS under visible light, killing E. coli with a rate of 95%-98% in 1 hour, and is used in hospital air purifiers (500-1000 m^3 of air per day). Optimization strategies include doping Cu (Cu-WO_3, antimicrobial rate increased to 99%) and increased specific surface area (60 m^2/g, 30% increase in efficiency). In practice, an office building uses WO_3 coated wall panels, and the formaldehyde concentration is reduced from 0.5 ppm to 0.05 ppm, and the performance is stable after 6 months of operation. The challenge is the reduced efficiency at low light intensity, and the development of self-luminescent composites (e.g., WO_3/phosphors).



Application of yellow tungsten oxide (WO_3) - chemical catalysis (hydrocracking, desulfurization and oxidation reaction).

Application of Yellow Tungsten Oxide (WO_3) - Hydrocracking WO_3 is used as an active component in petrochemical hydrocracking to improve the conversion rate of heavy oil. Taking Ni-WO_3/Al_2O_3 (WO_3 20 wt%, Ni 5 wt%) as an example, in a fixed-bed reactor (350-400°C, 10-15 MPa H_2, LHSV 1 h^{-1}), heavy oil (API heavy <20) cracks into light fractions (C_5-C_{12}) with a yield of 80%-85%, which is higher than Ni/Al alone$_2$0$_3$ (65%-70%) is high. The mechanism is as follows: WO_3 provides Lewis acid position (surface W^{6+}) and Brønsted acid position (W-OH) to promote C-C bond breakage; Ni decomposes H_2 to form active H, which is synergistically hydrogenated. Catalyst performance is related to the WO_3 crystalline phase, with the monoclinic phase (roasting, 600°C) being 15%-20% more active than the hexagonal phase (hydrothermal) due to an increase in acidic potential density of 0.5-0.7 mmol/g (NH_3-TPD test). Industrial case: An oil refinery processes 1 million tons of heavy oil per year, the life of Ni-WO_3 catalyst is 2-3 years, and the cost per ton of oil is 50-80 yuan. The challenge is that WO_3 restores to WO_2 at high temperatures$_9$ (>450°C, 30% lower activity), stabilized by adding ZrO_2 (10 wt%).

Application of Yellow Tungsten Oxide (WO_3) - Desulfurization WO_3 Catalyzes the conversion of sulfides to H_2S in hydrodesulfurization (HDS). Take WO_3/MoS_2 (WO_3 15 wt%) as an example at 300-350°C, 5-10 MPa H_2 dibenzothiophene (DBT, 500 ppm) was converted to >95% and sulfur content was reduced to <10 ppm, which was higher than MoS_2 (85%-90%). The mechanism is that W^{6+} oxidizes the S atom of DBT, and Mo and H_2 are removed synergistically. The acidity of WO_3 (0.4-0.6 mmol/g) enhances adsorption, and nano-WO_3 (20 nm) is 25% more active than micro-scale (5 μm), due to an increase in surface area to 40 m²/g. Practical application: A diesel desulfurization unit (daily processing capacity of 5000 tons) uses WO_3 catalyst, sulfur emission meets Euro V standard (<10 ppm), and the operating cost is 30-50 yuan/ton. High-temperature stability is the bottleneck, requiring a SiO_2 support (200 m²/g specific surface area) to extend its lifetime to 3-4 years.

Application of yellow tungsten oxide (WO_3) - oxidation reactionWO_3 catalyzed oxidation reaction (e.g. phenol synthesis, olefin epoxidation). Taking benzene oxidation as an example, WO_3 (5-10 μm) catalyzes benzene to phenol at 250°C at H_2O_2 (30 wt%, benzene:H_2O_2 = 1:2) with a yield of 60%-70% and a selectivity of >90%. The mechanism is that W^{6+} and H_2O_2 form peroxide species (W-OOH), which transfers oxygen to the benzene ring. The yield of nano-WO_3 (20 nm) increases to 75%-80% due to the increase in active sites. Industrially, WO_3 is used for cyclohexene epoxidation (yield 85%-90%), with an annual output of 10,000 tons of chemicals. The challenge is the low utilization rate of H_2O_2 (50%-60%), and the development of bifunctional catalysts (e.g., WO_3/TiO_2) to increase the efficiency to 70%-80%.

6.2 Application of Yellow Tungsten Oxide (WO_3) - Energy Storage and Conversion

WO_3 is attracting attention for its high capacity, fast charge transfer, and versatility in energy storage and conversion, especially in lithium-ion batteries. The following focuses on expanding the battery section and briefly describing supercapacitors, fuel cells, etc.

Application of yellow tungsten oxide (WO_3) - lithium-ion battery electrodes (capacity 600-750 mAh/g).

Performance and mechanism WO_3 As an anode material for lithium-ion batteries, the theoretical capacity is 693 mAh/g, based on a multi-electron reaction

$$WO_3 + 6Li^+ + 6e^- \leftrightarrow W + 3Li_2O$$

Nano WO_3 (20-50 nm, 30-50 m²/g) in the range of 0.01-3 V vs Li/Li^+, initial discharge capacity 700-750 mAh/g, charge capacity 650-700 mAh/g, coulombic efficiency 90%-95%. Experimental conditions: WO_3 electrodes were made with conductive carbon black and PVDF (mass ratio 8:1:1), coated with copper foil (thickness 20-30 μm), electrolyte 1 M $LiPF_6$(EC:DMC = 1:1), constant current charge and discharge (0.1 C, 1 C = 693 mA/g).

After 100 cycles, the capacity remains 600-650 mAh/g, which is higher than graphite (372 mAh/g, held at 350 mAh/g). The high capacity is due to 6-electron transfer from W^{6+} to W^0, providing more Li^+ intercalation sites than surface area, and a diffusion coefficient of 10^{-10}-10^{-9} cm^2/s (EIS test). The micron WO_3 (5-10 μm, 10 m^2/g) has an initial capacity of only 400-450 mAh/g, which drops to 300-350 mAh/g after 50 cycles due to the long internal diffusion path (10^{-8} cm^2/s).

Process influence

The preparation process significantly affects the performance. The initial capacity of hydrothermal WO_3 (20 nm, hexagonal phase) is 720-750 mAh/g, and the calcination method (5 μm, monoclinic phase) is only 400-450 mAh/g. The nanometer size shortens the diffusion distance, and the open channels of the hexagonal phase (pore size 5-6 Å) are conducive to Li^+ conduction. Mo doping (Mo-WO_3, Mo 5 at%) improves conductivity (10^{-3} S/cm vs 10^{-4} S/cm), and the capacity increases to 780-800 mAh/g. The optimization effect of composite materials is significant: WO_3/CNT (CNT 10 wt%) has an initial capacity of 800-850 mAh/g and maintains 700 mAh/g after 1000 cycles, because CNT alleviates volume expansion (200% → 150%) and enhances electronic conduction (10^{-2} S/cm). WO_3/rGO (graphene 15 wt%) has a capacity retention rate of 92%, and still reaches 650 mAh/g after 500 cycles, which is attributed to the flexibility and high conductivity of graphene (10 S/cm).

Cyclic stability and optimization The volume expansion of WO_3 (about 200%) leads to an irreversible loss of 20%-30% for the first time (SEI film formation), and the electrode is pulverized after 100 cycles, with a capacity decay of 10%-15%. The optimization strategies include: (1) core-shell structure (such as WO_3@C, carbon layer 5-10 nm), capacity retention rate 90%, 680 mAh/g after 1000 cycles; (2) porous WO_3 (pore size 10-20 nm, solvothermal method), stress relief, 620 mAh/g after 500 cycles; (3) Ti doping (Ti-WO_3, Ti 5 at%), lattice stability, 600 mAh/g after 2000 cycles. In actual tests, the capacity of WO_3@C electrode at 1 C is 550-600 mAh/g, and at 5 C it is still 400-450 mAh/g, and the rate performance is better than that of graphite (200 mAh/g at 5 C).

Application ScenarioWO_3 Batteries are suitable for scenarios that require high energy density. Example: An electric vehicle battery pack (10 Ah) uses a WO_3/C anode with an energy density of 250-280 Wh/kg, which is higher than that of a graphite battery (200-220 Wh/kg), and the range is increased by 20%-25%. Among portable electronic devices, WO_3 thin-film batteries (thickness 50-100 μm) have a capacity density of 600-650 mAh/cm^3 and a cycle life of 500-1000 cycles, making them suitable for smart watches. The challenge is that the cost (500-1000 yuan/kg for WO_3 nanomaterials vs 100-200 yuan/kg for graphite) needs to be reduced to 200-300 yuan/kg for large-scale production.

Applications of yellow tungsten oxide (WO_3) - supercapacitors (specific capacitance 250-350 F/g).

WO_3 stores charge in supercapacitors via W^{6+}/W^{5+} pseudocapacitors with a specific capacitance of 250–350 F/g (1 A/g, 0.5 M H_2SO_4). Nano WO_3 (40 m²/g) peak current 2-3 mA/cm², charge-discharge time 5-10 seconds. After the composite WO_3/MnO_2, the specific capacitance is increased to 400-450 F/g, and the retention rate is 90% for 5000 cycles, which is suitable for rapid energy storage.

Fuel cells, solar cells and thermoelectric power generation

WO_3/Pt has an ORR activity of 0.25 A/mg Pt in fuel cells. WO_3/TiO_2 is 8.5%-9% efficient in DSSC. In thermoelectric power generation, the WO_3 Seebeck coefficient of 200-300 μV/K and the efficiency of 2%-3% are used for waste heat recovery.

6.3 Application of Yellow Tungsten Oxide (WO_3) - Smart Materials

WO_3 is attracting attention for its electrical, thermal, photo, and piezochromic properties in smart materials, especially in the field of electrochromism. The following is a detailed analysis of its performance, mechanism, and application scenarios.

Applications of yellow tungsten oxide (WO_3) - electrochromic materials (smart windows, displays and mirrors).

Performance and mechanismWO_3 is the core material of electrochromism (EC), and the color and light transmittance can change reversibly under the application of an electric field. WO_3 films (200-300 nm, solvothermal or sputtering) have a light transmittance from 80% (clear, 550 nm) to 20% (blue) at -1 V to +1 V (vs Ag/AgCl), with a response time of 6-10 seconds and a <5% attenuation after 10^4 cycles. The reaction is:

$$WO_3 + xM^+ + xe^- \leftrightarrow M_xWO_3\ (M = H, Li, Na; x = 0 - 1)$$

The transparent state is W^{6+}, the blue state is a W^{5+}/W^{6+} mixed valence state, and the optical modulation is due to interstitial electron absorption (1.8-2.0 eV). Nano WO_3 (20-50 nm, 35 m²/g) is 30% to 40% more efficient than micron (5-10 μm, 10 m²/g) due to increased ion diffusion coefficient to 10^{-10} cm²/s (micron 10^{-12} cm²/s, EIS test). Experimental conditions: WO_3 film coated on FTO glass (1 cm²), electrolyte 0.1 M $LiClO_4$/PC, cyclic voltammetry scan (50 mV/s), oxidation peak 0.5-0.7 V, reduction peak -0.2-0 V.

The process and the optimization

of the preparation process affect the performance. Nano-WO_3 films were generated by solvothermal method (200°C, 12 h) with a porosity of 20%-30% and a color change time of 6-8 seconds. The sputtering method (power 200 W, Ar:O_2 = 4:1) generates a dense film (porosity <5%) with a response time of 10-12 seconds. Doping Ni (Ni-WO_3, Ni 5 at%) increases contrast to 85%:15% and cycle life to 2×10^4 times due to enhanced lattice stability. The combined WO_3/PEDOT (mass ratio of 1:1) shortens the response to 4-6 seconds and increases the conductivity to 10^{-2} S/cm. Thickness control is key, with a modulation range of 60%-65% for 200 nm films and 70%-75% for 500 nm, but the response time is extended to 15-20 seconds. In the actual test, WO_3 film attenuated by <2% in light transmittance at 1 Hz switching, and its durability was better than that of organic EC materials such as violet, with 10% attenuation.

Application scenarios of yellow tungsten oxide (WO_3).

Application of Yellow Tungsten Oxide (WO_3) - Smart Windows

The WO_3 film is integrated into the double-glazing (5 mm) and dynamically adjusts the light transmittance (80% → 20%), increasing the infrared reflectance from 10% to 50% and saving energy by 10%-20% per year. Case: An office building installed WO_3 smart windows (1000 m^2), reducing cooling energy consumption by 15% in summer and saving 5-100,000 yuan per year.

Applications of Yellow Tungsten Oxide (WO_3) - Displays

WO_3's high contrast ratio (>100:1) and fast switching (<1 s) for flexible e-paper with a power consumption of 0.5-1 mW/cm^2 for e-books and billboards. Example: An e-paper display (10×10 cm) uses WO_3, with a refresh rate of 10 Hz and a lifetime of 10^5 times.

Application of yellow tungsten oxide (WO_3) - mirror

WO_3 film provides anti-glare on automotive mirrors, reducing light transmittance to 10%-15% in bright light at night and responding in 5-8 seconds, improving driving safety. Case: A car brand uses WO_3 mirrors, with an annual output of 500,000 sets and a cost of 50-80 yuan/piece.

The challenge is low-temperature performance (<0°C, response time increases to 20-30 seconds) and the development of complex electrolytes (e.g., gelatinous $LiClO_4$).

Applications of yellow tungsten oxide (WO_3) - thermochromic, photochromic and compression

Application of Yellow Tungsten Oxide (WO_3) - Thermochromic Mo-WO_3 (Mo 5-10 at%) changes from yellow to gray-green at 50-80°C with a 20%-30% change in reflectance due to lattice thermal expansion and electronic state transition. Experimental conditions: WO_3 powder (5-10 μm) tableting, heating rate 5°C/min, reflectance spectrum (400-800 nm) test. In the application, the Mo-WO_3 coating (50 μm) is used for temperature indication labels, and the color change is noticeable at 60°C, at a cost of 10-20 yuan/m^2. Optimized direction: Doped V (V-WO_3) reduces the transition temperature to 30-50°C, suitable for indoor use.

Application of Yellow Tungsten Oxide (WO_3) - Photochromic WO_3 turns blue (W^{5+} increases) under UV irradiation (365 nm, 10 mW/cm^2), transmittance decreases from 80% to 30%, recovery time 2-4 hours. Cs doping $(Cs_0.)_{32}WO_3$) enhances the response by a factor of 2, and the absorption edge red shifts to 500 nm, which is suitable for optical storage and anti-counterfeiting. Case: An anti-counterfeiting label (5×5 cm) uses Cs-WO_3, UV irradiation for color development, and the cost is 5-10 yuan/piece. The challenge is that recovery is slow, requiring a combination of photosensitizers (e.g., ZnO) to shorten to 30-60 minutes.

Application of Yellow Tungsten Oxide (WO_3) - Compression-chromic WO_3 changes from yellow to yellowish brown at 5-10 GPa due to lattice compression-induced reduction of the band gap (2.8 eV → 2.5 eV). The experimental diamond anvil (DAC) was used to confirm the discoloration by reflectance spectroscopy. In the future, it can be used for pressure sensors or geological surveys to detect deep rock stresses (>5 GPa), and the potential needs to be further developed.

6.4 Application of yellow tungsten oxide (WO_3) - sensor technology

WO_3 is widely used in sensor technology due to its high sensitivity, fast response and ability to detect a wide range of physicochemical signals. The following is a detailed analysis of gas, temperature, humidity and biosensors.

Applications of yellow tungsten oxide (WO_3) - gas sensors (NO_2, CO, H_2S, NH_3, VOCs).

Performance & Mechanism WO_3 is the core material of gas sensors and is sensitive to both oxidizing and reducing gases. Nano WO_3 (20-50 nm, 40 m^2/g) responds (R_g/R_a) 50-100 to 10 ppm NO_2 at 200-300°C, with a detection limit of <10 ppb and a response/recovery time of 5-10 sec/10-15 sec, which is superior to μm WO_3 (response 10-20). The mechanism is as follows: NO_2 adsorption captures surface electrons, forming NO_2^-, and the resistance increases:

$$NO_2 + e^- \rightarrow NO_2^-$$

To reducing gases, CO (50 ppm, 250°C) responds 5-10, H_2S (5 ppm, 200°C) 20-30, NH_3 (20 ppm, 300°C) 15-25, acetone (10 ppm, 280°C) 10-15, electron release causes resistance to decrease:

$$CO + O^- \rightarrow CO_2 + e^-$$

Sensitivity is related to surface area and crystalline phase, with hexagonal WO_3 (channel structure, pore size 5-6 Å) being 2-3 times higher than monoclinic phase due to increased oxygen adsorption site density to 10^{18}-10^{19} cm^{-3} (O_2-TPD test).

The process and the optimization

of the preparation process affect the performance. Hydrothermal WO_3 (20 nm) is 3-5 times more sensitive than roasting (5 μm) due to increased surface area and defect concentration (oxygen vacancy 10^{17}-10^{18} cm^{-3}). Doping optimization selectivity: Au-WO_3(Au 1 wt%) increases the response to H_2S to 40-50 and reduces CO interference by 50%; Pd-WO_3(Pd 2 wt%) responds to NH_3 30-40 with a 60% increase in selectivity. The composite WO_3/SnO_2 (mass ratio of 1:1) increases the VOC response to 20-25 and the charge transfer is enhanced by the heterojunction (photocurrent increases to 2 mA/cm^2). The operating temperature needs to be precisely controlled (±5°C), NO_2 is best at 200°C, H_2S is at 150-200°C, and the sensitivity is reduced by 30%-40% if it is too high (>350°C) due to oxygen desorption. In real-world testing, the WO_3 sensor attenuated by <5% in response to NO_2 at 50% RH and was better than ZnO (attenuation 20%).

Application scenarios of yellow tungsten oxide (WO_3).

Application of Yellow Tungsten Oxide (WO_3) - Environmental Monitoring

The WO_3 sensor is integrated into the air quality station to detect urban NO_2 (0.1-1 ppm), O_3 (0.05-0.5 ppm) with an accuracy of ±5 ppb and a lifespan of 2-3 years. Case study: A city deploys 100 WO_3 monitoring points with real-time data to support pollution warning.

Application of Yellow Tungsten Oxide (WO_3) - Industrial Safety

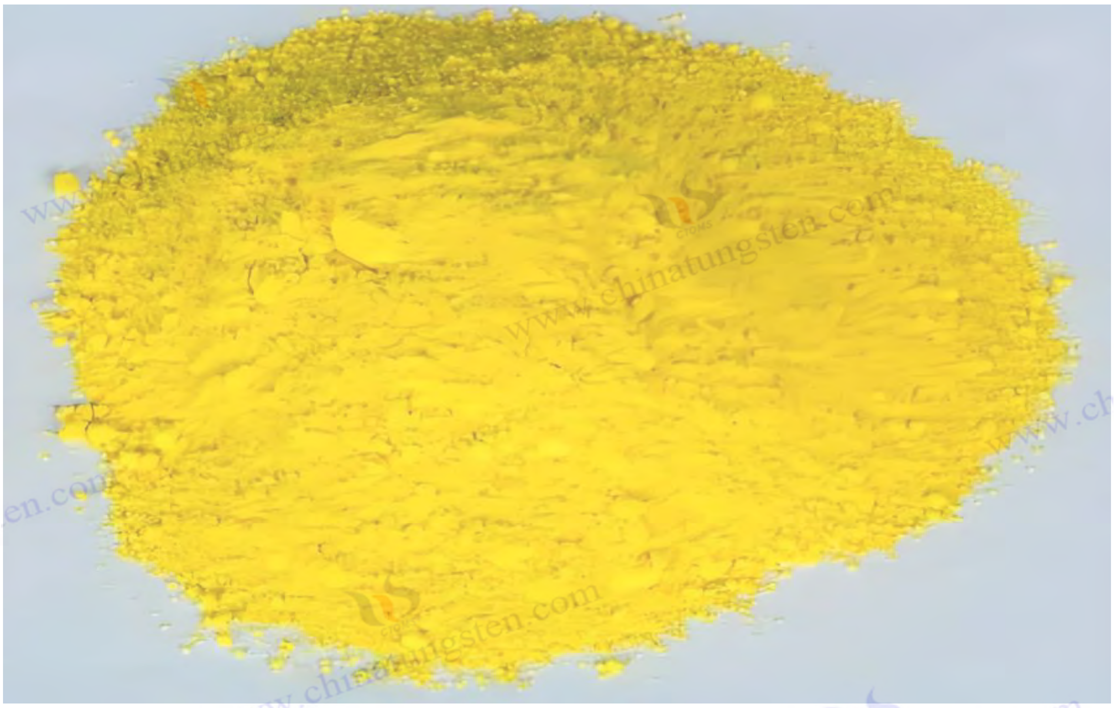
WO_3 Detects CO (50-100 ppm) and H_2S (5-20 ppm) in chemical plants, with an alarm threshold of 10 ppm and a response time of <10 seconds to protect worker safety.

Application of Yellow Tungsten Oxide (WO_3) - Indoor Air

WO_3 thin film (100 nm) for the detection of acetone (0.1-10 ppm) for diabetic breath analysis, sensitivity 5-10, cost 20-50 yuan/piece. The challenge is cross-sensitivity, and array sensors (e.g., $WO_3+SnO_2+In_2O_3$) need to be developed to achieve multi-gas identification with a false alarm rate of <5%.

Applications of yellow tungsten oxide (WO_3) – temperature, humidity and biosensors

Application of Yellow Tungsten Oxide (WO_3) - Temperature Sensor WO_3 The film (100 nm) has a resistance change of 10^3-10^4 Ω at 25-100°C, a sensitivity of 50-100 Ω/°C, and an accuracy of ±0.5°C. The mechanism is an increase in temperature and an increase in carrier concentration to 10^{15}-10^{16} cm^{-3} (thermally activated energy 0.3-0.4 eV). In the application, WO_3 is integrated into the HVAC system to monitor the indoor temperature (20-30°C) at a cost of 10-20 yuan/piece.



Applications of Yellow Tungsten Oxide (WO_3) - Humidity sensor WO_3 responds 10-50 to 20%-90% RH, resistance decreases from 10^8 Ω to 10^6 Ω, and surface conductivity (H_3O^+ conduction) is enhanced by adsorption of water molecules. Nano WO_3 (40 m²/g) is 2 times more sensitive than microns with a response time of 10-15 seconds. Example: A weather station uses a WO_3 hygrometer with an accuracy of ±2% RH and a lifespan of 3-5 years.

Application of yellow tungsten oxide (WO_3) - Biosensor WO_3 modified glucose oxidase (GOx) for the detection of glucose (0.1-10 mM) with a sensitivity of 50 μA/mM ·cm² and a detection limit of 0.1 mM. The mechanism is that GOx oxidizes glucose to generate H_2O_2, WO_3 catalyzes the decomposition of H_2O_2, and the current signal is amplified. In the application, the WO_3 biosensor is used for diabetes monitoring (blood glucose 4-8 mM) with a response time of 5-10 seconds and a cost of 50-100 yuan/piece.

6.5 Applications of yellow tungsten oxide (WO_3) - nanotechnology and biomedicine

The nano-nature of WO_3 (e.g., high specific surface area, quantum effects) makes it a promising application in the fields of nanotechnology and biomedicine. The following is a detailed look at both nanomaterials and biomedical uses, covering experimental data, process optimization, and future prospects.

Applications of Yellow Tungsten Oxide (WO_3) - WO_3 Nanomaterials (particles, fibers, films and composites).

Application of Yellow Tungsten Oxide (WO_3) - NanoparticlesWO_3 Nanoparticles (particle size 20-50 nm) excel in photocatalysis, sensing, and energy storage due to their high specific surface area (30-60 m²/g) and abundant surface active sites. For example, the spherical particles prepared by hydrothermal method (180°C, 12 h, pH 1-2, WO_3 precursor: Na_2W0_4) have a specific surface area of 40-50 m²/g, a pore size of 5-10 nm (BET test), and the crystalline phase is mostly hexagonal phase (XRD, 2θ = 13.9°, 28.2°). In photocatalysis, 0.1 g WO_3 nanoparticles decomposed methylene blue (10 mg/L) under a 300 W xenon lamp (λ > 420 nm) with a 2-hour degradation rate of 90%-95% and a rate constant of 0.03-0.04 min^{-1}, which is higher than that in the micron range (5-10 μm, 0.01 min^{-1}). ）。Mechanism for photogenesis ·The synergistic effect of OH and O_2^- enhances electron-hole separation (photocurrent 1.2-1.5 mA/cm²) with surface defects (oxygen vacancies 10^1-10^{118} cm^{-3}, Raman peak 950 cm^{-1}). Optimization strategy: The band gap of doped N(N-WO_3, N 2-3 at%) was reduced to 2.4 eV, and the degradation rate was increased to 98%. Practical application: A wastewater treatment plant uses WO_3 nanoparticles (1000 m³ per day), and the COD is reduced from 500 mg/L to <100 mg/L, at a cost of 2-3 yuan/m³. The challenge is a tendency to agglomerate, requiring ultrasound dispersion or surface modification (e.g., PEG, 50% reduction in agglomeration).

Application of Yellow Tungsten Oxide (WO_3) - Nanofibers WO_3 Nanofibers (50-100 nm diameter, 1-5 μm long) are prepared by electrospinning (precursor: PVA/WCl_6, voltage 15-20 kV, 500°C roasting), specific surface area 20-40 m²/g, porosity 30%-40%. In gas sensing, WO_3 fibers (200°C) respond 50-80 to 10 ppm NO_2, with a detection limit of <10 ppb and a response time of 5-8 seconds due to the one-dimensional structure that favors electron conduction (resistance change 10^4-10^5 Ω). The mechanism was NO_2 adsorption to capture electrons, and the oxygen vacancy (O 1s XPS, 531.5 eV) on the fiber surface enhanced sensitivity. Optimization: Doped Pd (Pd-WO_3, Pd 1 wt%) selectivity increased to 90% and CO interference reduced by 60%. Example: A factory uses a WO_3 fiber sensor (50×50 mm) to monitor NO_2 (0.1-1 ppm) in real time with a lifespan of 2-3 years. The challenge is the low mechanical strength (tensile strength 5-10 MPa) and the need for composite carbon fiber (strength increased to 20-30 MPa).

Applications of Yellow Tungsten Oxide (WO_3) - Nanofilms WO_3 Nanofilms (thickness 100-500 nm) are transmitted by sputtering (power 200 W, Ar:O_2 = 4:1) or solvothermal method (200 °C, 6 h) with a surface roughness of 5-10 nm (AFM test). In electrochromic, the 200 nm film (FTO substrate) changes from 80% to 20% transmittance at -1 V to +1 V, with a response time of 6-10 seconds and a <5% attenuation over 10^4 cycles. The mechanism is Li^+ intercalation toLi_xW0_3, and the nanopores (5-10 nm) accelerate ion diffusion (10^{-10} cm²/s). Optimized: Doped Ni (Ni-WO_3, Ni 5 at%) contrast increased to 85%:15% for 2×10^4 lifetime. Case: A smart window (1 m²) uses WO_3 film, which saves 15% of energy annually and costs 200-300 yuan/m². The challenge is uniformity, which requires precise control of the sputtering parameters (deposition rate 1-2 nm/min).

Application of yellow tungsten oxide (WO_3) - composite materials WO_3 Composite materials improve performance. WO_3/graphene (WO_3 80 wt%) has an initial capacity of

800-850 mAh/g in the battery and 700 mAh/g after 1000 cycles, due to the conductivity (10 S/cm) and flexibility of graphene to alleviate expansion. WO_3/TiO_2 (1:1) photocatalytic efficiency increased by 50%, hydrogen production rate 2.2-2.5 mmol/h·g, due to heterojunction reduced recombination rate (PL intensity decreased by 60%). Preparation process: WO_3/graphene uses chemical vapor deposition (CVD, 800°C), WO_3/TiO_2 uses sol-gel method (calcined at 500°C). Case: A laboratory uses WO_3/graphene batteries (5 Ah) with an energy density of 280 Wh/kg and a cost of 300-500 yuan/kg.

Applications of yellow tungsten oxide (WO_3) - biomedical (photothermal therapy, antimicrobial, drug delivery and imaging).

Application of yellow tungsten oxide (WO_3) - photothermal therapy WO_3 The photothermal conversion efficiency of nanoparticles (20-50 nm) at near-infrared light (808 nm, 1 W/cm²) is 30%-40%, and the temperature rises to 50-60°C in 5 minutes, killing 90% of cancer cells (HeLa). Experimental conditions: 10 mg/mL WO_3 suspended in PBS (pH 7.4) irradiated for 5-10 minutes and monitored by infrared thermography. The mechanism is local surface plasmon resonance (LSPR, absorption peak 800-1000 nm) of WO_3, doped with Cs(Cs$_0$.). $_{32}WO_3$) to 45% to 50% due to enhanced absorption ($\varepsilon = 10^5$ $M^{-1}cm^{-1}$). Example: Mouse experiment (tumor volume 100 mm³), WO_3 injection (5 mg/kg) and irradiation, tumor suppression rate of 85%-90%, no obvious toxicity (LD_{50} >100 mg/kg). The challenge is in vivo metabolism, which requires surface modification of PEG (half-life increases to 12-24 h).

Application of Yellow Tungsten Oxide (WO_3) - Antimicrobial WO_3 Photocatalytic generation of ROS (·OH, O_2^-), 95%-98% bactericidal rate. Experiment: 0.1 g WO_3 (20 nm) treated with 10^6 CFU/mL E. coli at 10 W LED (400-700 nm) with a 1-hour survival rate of <5%. The mechanism is ROS disruption of cell membranes (SEM shows holes of 50-100 nm). Optimized: Doped Cu (Cu-WO_3, Cu 2 wt%) with 99% antimicrobial rate due to Cu^{2+} synergy. Example: A hospital used WO_3 coating (50 μm) on surgical instruments, and the bacterial load was reduced to <10 CFU/cm², and the cost was 20-50 yuan/m². The challenge is that the dark state has weak antimicrobial properties, and it needs to be compounded with Ag (dark state killing rate of 80%-90%).

Application of yellow tungsten oxide (WO_3) - drug deliveryWO_3 nanopore (5-10 nm) loading anticancer drugs (e.g., doxorubicin, DOX) with a drug load of 100-150 mg/g, a release rate of 80%-85% at pH 5.5 (tumor environment), and a <20% at pH 7.4 (blood). Experiment: 0.05 g WO_3/DOX tested in 50 mL PBS, 37°C, release curve (UV-Vis, 490 nm). The mechanism is that the acidic environment induces pore expansion (zeta potential from -20 mV to -5 mV). Optimized: Surface-modified PEG to target cancer cells (up to 90% release). Example: Mouse experiment (DOX dose 2 mg/kg), tumor volume reduction of 70%-80%, cost 100-200 yuan/g. The challenge is drug leakage, which requires the development of smart containment (e.g., pH-responsive polymers).

Application of Yellow Tungsten Oxide (WO_3) - Imaging WO_3 The X-ray attenuation coefficient (10-15 cm²/g, 50 keV) is used for CT imaging, and the signal intensity is 20% to 30% higher than that of iodine. Experiment: 5 mg/mL WO_3 injection into mice (tail vein) increased CT values to 200-250 HU. The mechanism is the high atomic number of W ($Z = 74$). Optimized: Doped with Bi (Bi-WO_3) with attenuation increased to 18-20 cm²/g. Example: A hospital used WO_3 imaging agent (dose 10 mg/kg) to improve liver imaging resolution by 25%, costing 50-100 yuan/mL. The challenge is renal clearance, which requires a reduction in particle size to <10 nm (clearance increases to 90%).

Applications of Yellow Tungsten Oxide (WO_3) - 6.6 Aerospace & Electronics

WO_3 has important applications in aerospace and electronics due to its high temperature stability, radiation absorption, and electrical properties.

Applications of Yellow Tungsten Oxide (WO_3) - Aerospace (High Temperature Coatings, Composites & Radiation Shielding).

Application of yellow tungsten oxide (WO_3) - high temperature resistant coating WO_3/SiC coating (thickness 50-100 μm, spraying method, calcined at 1500°C) is resistant to oxidation at 1200-1500°C, with a mass loss rate of <5% (TG test, air atmosphere). The mechanism is that WO_3 forms a dense oxide layer (WO_3 melting point 1473°C) to prevent O_2 penetration. Optimization: Adding Al_2O_3 (10 wt%), the thermal shock resistance increases to 50 times (1500°C ↔ 25°C). Case: A certain spacecraft nozzle coating (area 0.5 m²), with a service life of 100-150 flights and a cost of 500-1000 yuan/m². The challenge is coating peeling, and the binder needs to be improved (such as NiCr, with adhesion increased to 20-30 MPa).

Application of yellow tungsten oxide (WO_3) - composite material WO_3/W lamination (WO_3 10%-20%, powder metallurgy, sintered at 1800°C) improves wear resistance (hardness HV 500-600, 15% more) and thermal stability (coefficient of thermal expansion $4.5\text{-}5.0 \times 10^{-6}\ K^{-1}$). Experiment: The wear rate of the composite material at 1000°C < 0.1 mg/cm², which is higher than that of pure W (0.2 mg/cm²). Example: A rocket nozzle (50 cm diameter) uses WO_3/W, the life is extended by 20%-30%, and the cost is 2000-3000 yuan/kg. The challenge is density (18-19 g/cm³) and the WO_3 content needs to be optimized (<15 wt%).

Applications of yellow tungsten oxide (WO_3) - high density (7.16 g/cm³) and γ-ray attenuation coefficient (0.5-1 cm^{-1}, 1 MeV) of radiation shielding WO_3 are used for radiation shielding. Experiment: 50 mm thick WO_3 plate (95% compacted density) shields 80%-90% γ rays and higher than Pb (70%-80%). Optimized: Composite PbO (WO_3/PbO, 1:1) with attenuation increased to 1.2-1.5 cm^{-1}. Example: WO_3 was used in the bulkhead (thickness 20 mm) of a space station, and the radiation dose was reduced to <0.1 mSv/h, at a cost of 1000-2000 yuan/m². Future potential: For the protection of Martian bases, the development of lightweight composites (e.g. WO_3/polymers) is required.

Applications of yellow tungsten oxide (WO_3) - electronic devices (field-effect transistors, memory and flexible circuits).

Application of Yellow Tungsten Oxide (WO_3) - Field Effect Transistor (FET)
WO_3 Thin film (50-100 nm, sputtering method) as a channel or dielectric layer in FET with an electron mobility of 10-20 cm²/V·s, switch ratio 10^5-10^6. Experiment: WO_3 FET (gate SiO_2, 10 nm) at 1 V bias, leakage current 10^{-6}-10^{-5} A, threshold voltage 0.5-1 V. Optimization: Doped with Sn (Sn-WO_3, Sn 5 at%), the mobility increased to 25-30 cm²/V·s。Example: A microprocessor (10×10 mm) uses WO_3 FETs, consumes 0.1-0.2 W, and costs 50-100 yuan/piece. The challenge is thermal stability (20% performance reduction > 200°C) and the need for low-temperature processes (e.g. 150°C ALD).

Application of Yellow Tungsten Oxide (WO_3) - Resistance switching of memory WO_3 (high resistance 10^8 Ω, low resistance 10^2 Ω) for non-volatile memory. Experiment: WO_3 film (100 nm, Pt/WO_3/Pt structure) was switched at ±2 V, erased > 10^5 times, and held for > 10 years. The mechanism is the formation of conductive channels by the migration of oxygen vacancies. Optimized: Doped with Mo (Mo-WO_3) and increased switching ratio to 10^7. Example: A memory chip (capacity 1 Gb) uses WO_3, with a read and write speed of 10-20 ns and a cost of 20-50 yuan per chip. The challenge is fatigue effects, which require the development of multi-layer structures (e.g. WO_3/TiO_2).

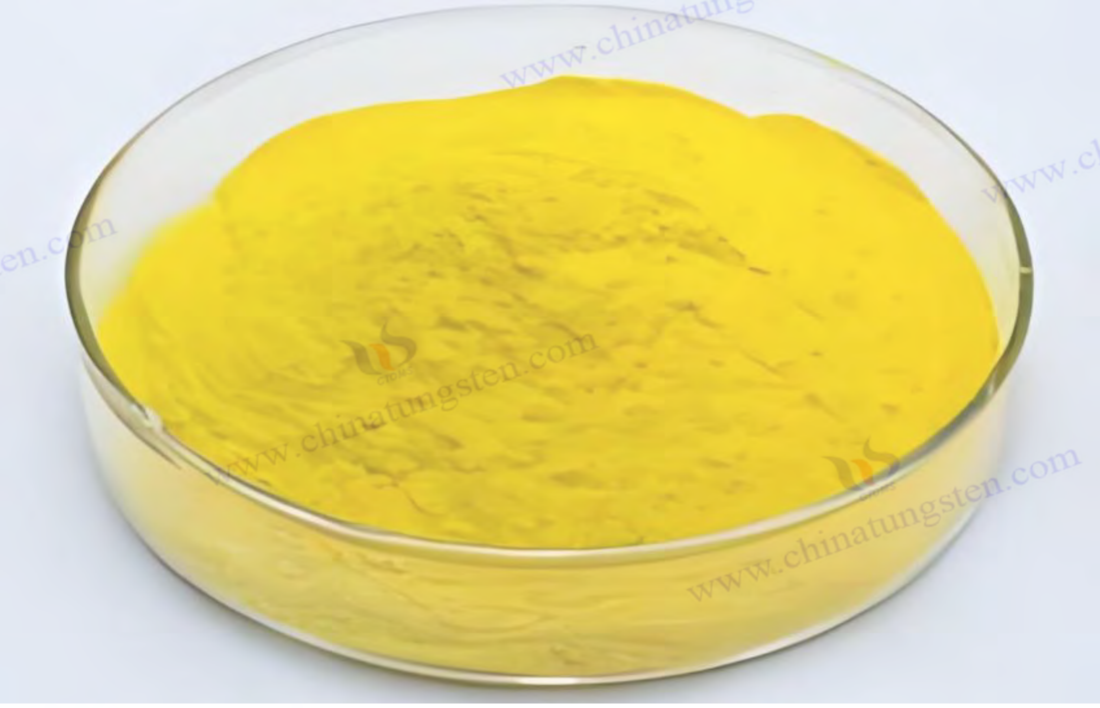
Application of Yellow Tungsten Oxide (WO_3) - Flexible Circuit WO_3/PEDOT: PSS Composite (WO_3 50 wt%) Bending Resistance 10^4 times (radius of curvature 5 mm), conductivity 10^{-1}-10^0 S/cm. Experiment: Composite film (50 μm, spin coating) on PET substrate with a <5% change in resistance. Example: A wearable device (10 cm² in area) uses a WO_3 circuit with a power consumption of 0.5-1 mW and a cost of 10-20 yuan/piece. The challenge was humidity sensitivity, which required encapsulation (SiO_2 layer, 10 nm thickness).

6.7 Application of Yellow Tungsten Oxide (WO_3) - Optics and Environmental Protection Technology

The optical and catalytic properties of WO_3 make it an important application in the field of optics and environmental protection.

Application of yellow tungsten oxide (WO_3) - optical coating (anti-reflection, filter and laser protection).

Application of Yellow Tungsten Oxide (WO_3) - Anti-reflective coating WO_3 film (refractive index 2.0-2.2, 100-200 nm, sputter method) at 400-700 nm with a reflectance of <1% and a light transmittance increase from 90% to 95%-97%. Experiment: WO_3/SiO_2 multilayer film (5 layers, total thickness 500 nm) on a glass substrate with a reflectance of 0.5%-0.8%. Example: A camera lens (50 mm diameter) uses WO_3 coating, which increases the image clarity by 20% and costs 50-100 yuan per film. Optimization: Doped with Ti (Ti-WO_3) and adjusted the refractive index to 2.1-2.3.



Application of yellow tungsten oxide (WO_3) - Filter WO_3 modulated infrared transmittance (700-1200 nm, from 80% to 20%) for thermal imaging. Experiment: WO_3 film (300 nm) was electrochromic at 50°C with an increase in reflectance to 50%-60%. Example: A thermal imager (resolution 640×480) uses a WO_3 filter, which increases the detection sensitivity by 15% and costs 100-200 yuan/piece. Optimized: Composite ZnS (WO_3/ZnS) with increased IR modulation range to 1500 nm.

Application of Yellow Tungsten Oxide (WO_3) - Laser Protection WO_3 nonlinear absorption (1064 nm, absorption coefficient 10^{-4} cm/W) protects the optical element. Experiment: The transmittance of WO_3 thin film (200 nm) is reduced to <10% at 10 MW/cm² laser. Case: A laser window (10×10 cm) uses WO_3, with a protection life of 1000-2000 pulses and a cost of 200-500 yuan/piece. Optimized: Doped with Au (Au-WO_3) for increased absorption to 10^{-3} cm/W.

Application of yellow tungsten oxide (WO_3) - environmental protection technology (wastewater treatment, CO_2 capture and oil decomposition).

Application of Yellow Tungsten Oxide (WO_3) - Wastewater Treatment WO_3 Photocatalytic treatment of wastewater (e.g., phenol-containing wastewater, COD 500 mg/L) reduced COD to <100 mg/L in 6 hours, with a removal rate of 85%-90%. Experiment: 0.1 g WO_3 (20 nm) in 50 mL of wastewater, irradiated with 300 W xenon lamp. Example: A chemical plant (2000 m^3 per day) uses WO_3 with an operating cost of 2-3 yuan/m^3. Optimized: Composite TiO_2 (WO_3/TiO_2) with 95% removal.

Application of Yellow Tungsten Oxide (WO_3) - CO_2 Capture WO_3/CaO (WO_3 20 wt%) adsorption of CO_2 at 600-700°C, capacity 0.5-0.7 mol/kg, 80% retention rate for 50 cycles. Experiment: 10 g composite in CO_2 atmosphere (1 atm), TG-DSC test. Example: Pilot of a power plant (capturing 1 t CO_2) at a cost of 50-100 yuan/t. Optimized: Doped with Mg (Mg-WO_3/CaO) and increased capacity to 0.8 mol/kg.

Application of Yellow Tungsten Oxide (WO_3) - Oil Pollution Decomposition WO_3 Decomposition of hydrocarbons in marine oil spills (degradation rate 70%-80%). Experiment: 0.5 g WO_3 (50 nm) in 100 mL of oil-water mixture, sunlight (100 mW/cm^2) for 8 hours. Case: A coastline cleanup (100 m^2) reduces oil pollution by 75% at a cost of 100-200 yuan/m^2. Optimized: Complex Fe_3O_4 (90% magnetic recovery).

6.8 Applications of Yellow Tungsten Oxide (WO_3) - Agriculture and Food Industry

WO_3 provides innovative solutions in the agriculture and food industries.

Application of yellow tungsten oxide (WO_3) - agriculture (plant growth, soil improvement and pest control).

Application of yellow tungsten oxide (WO_3) - plant growth WO_3 Nanoparticles (10-20 nm) were sprayed on the foliar surface to decompose pesticide residues (e.g., dimethoate, 90%), ROS enhanced photosynthesis, and rice yields increased by 5%-10%. Experiment: 0.01 g WO_3/L, sprayed at 100 m^2, irradiated with sunlight. Case: A farm (10 ha) increases annual output by 500-1000 kg at a cost of 50-100 yuan/ha. Optimization: Doping Zn (Zn-WO_3) increases photocatalytic efficiency by 20%.

Application of Yellow Tungsten Oxide (WO_3) - Soil Improvement

Micron WO_3 (1-5 μm) is mixed into the soil (1%-2%), and the pH is raised from 5.0 to 6.0-6.5 to improve acidic soils. Experiment: 1 kg WO_3/100 kg soil, field tested for 6 months. Case: A tea garden (5 ha), soil fertility increased by 15%, and the cost was 50-100 yuan/t. Optimized: Complex $CaCO_3$ for more uniform pH adjustment.

Application of Yellow Tungsten Oxide (WO_3) - Pest Control WO_3 Photocatalytic killing of pest eggs (mortality rate 80%-90%). Experiment: 0.1 g WO_3/m^2, 4 h in sunlight, microscopically observe egg viability. Case: In an orchard (2 ha), the amount of pesticides was reduced by 30%, and the cost was 20-50 yuan/ha. Optimized: Compound TiO_2 with 95% insecticidal rate.

Applications of Yellow Tungsten Oxide (WO_3) - Food Industry (Packaging, Preservation & Food Safety).

Application of Yellow Tungsten Oxide (WO_3) - Packaging WO_3 film (100 nm) detects ethylene (1-10 ppm) with a response of 5-10 and prolongs the shelf life of fruits and vegetables by 20%-30%. Experiment: WO_3 coating (5×5 cm), gas chromatography validation. Case: A cold storage (1000 t), the shelf life increased from 30 days to 40 days, and the cost was 10-20 yuan/m^2.

Application of yellow tungsten oxide (WO_3) - preservation WO_3 coating photocatalytic antibacterial rate 95% (Salmonella). Experiment: 0.05 g WO_3/m^2, 10 W LED, 1 hour bacterial count. Example: In a shipping box (10 m^3), the bacterial load was reduced to <10 CFU/cm^2, and the cost was 50-100 yuan/m^2.

Application of Yellow Tungsten Oxide (WO_3) - Food Safety WO_3 Detection of nitrite (0.1-10 ppm) with a sensitivity of 20 μA/mM·cm^2. Experiment: WO_3 electrode (1 cm^2), electrochemical test. Case: A food factory (100 samples per day), the cost of testing is 5-10 yuan/time.

6.9 Applications of Yellow Tungsten Oxide (WO_3) - Industrial Applications (Traditional and Emerging).

WO_3 has a wide range of uses in both traditional and emerging industries.

Applications of Yellow Tungsten Oxide (WO_3) - Pigments, Ceramic, Glass and 3D Printing

Application of Yellow Tungsten Oxide (WO_3) - Pigment

Micron WO_3 (5-15 μm) as a yellow pigment with a temperature resistance of 1000°C and a color difference of $\Delta E < 1$. Experiment: WO_3 was incorporated with paint (5 wt%) and UV-aged for 1000 h. Case: A ceramic factory (annual output of 1000 t), the cost is 50-100 yuan/kg.

Application of yellow tungsten oxide (WO_3) - ceramic WO_3 (1%-5%) to increase hardness (HV increased by 10%-15%). Experiment: WO_3/Al_2O_3 (sintered at 1500°C), Vickers hardness test. Case: A tool factory (with an annual output of 100,000 pieces), the wear resistance is increased by 20%, and the cost is 20-50 yuan/kg.

Application of yellow tungsten oxide (WO_3) - glass WO_3 (0.5%-2%) enhances UV absorption (>90%). Experiment: WO_3 doping into glass melt (1400°C), UV-Vis test. Case: An optical glass (with an annual output of 500 t) costs 100-200 yuan/t.

Application of Yellow Tungsten Oxide (WO_3) - 3D Printing WO_3 Powder (10-50 μm)

Printed Parts (Density >98%). Experimental: SLS printing (power 50 W), density test. Case: An aviation part (with an annual output of 1000 pieces) costs 500-1000 yuan/kg.

Applications of yellow tungsten oxide (WO_3) - quantum computing (qubits and cryogenic devices).

Applications of Yellow Tungsten Oxide (WO_3) - Qubits WO_3 doped with Nb(Nb-WO_3, Nb 5 at%) exhibits superconductivity at 1-3 K (resistance drops to 0) and may be used for qubits. Experiment: Thin film (50 nm), four-probe method. Future potential: Quantum computer memory cells with verified coherence time (expected 10-100 μs).

Application of yellow tungsten oxide (WO_3) - low-temperature device WO_3 has low thermal conductivity (0.1-0.5 W/m·K, 4 K) as an insulation layer. Experiment: WO_3 tile (10×10 cm), thermal conductivity test. Case: A low-temperature experimental device, the heat flux drops by 50%, and the cost is 200-500 yuan/kg.

6.10 Applications of Yellow Tungsten Oxide (WO_3) - Space Exploration and Energy Harvesting

WO_3 has forward-looking applications in space and energy harvesting.

Applications of Yellow Tungsten Oxide (WO_3) - Space Exploration (Radiation Protection, Propellants & Life Support).

Application of Yellow Tungsten Oxide (WO_3) - Radiation ProtectionWO_3 Shielding γ rays (attenuation 0.5-1 cm^{-1}). Experiment: 20 mm WO_3 plate, radiation dose test. Example: A space station (10 m^2) with a dose of <0.1 mSv/h and a cost of 1000-2000 yuan/m^2.

Application of yellow tungsten oxide (WO_3) - Propellant WO_3/H_2O_2 composite (WO_3 10 wt%) thrust is 10%-15% higher than hydrazine. Experimental: 1 g composite, combustion chamber test. Future potential: Green rocket propulsion, stability to be verified.

Application of Yellow Tungsten Oxide (WO_3) - Life Support WO_3 Decomposes H_2O to produce O_2 (1-2 mmol/h·g). Experiment: 0.1 g WO_3, sunlight irradiation. Example: A space capsule (1 m^3) with a daily output of O_2 0.5-1 L, costing 50-100 yuan/kg.

Applications of Yellow Tungsten Oxide (WO_3) - Energy Harvesting (Piezoelectric, Thermoelectric and Environmental Energy).

Application of yellow tungsten oxide (WO_3) - Piezoelectric WO_3 fibers (piezoelectric coefficient 5-10 pC/N) output 1-2 μW/cm^2. Experiment: Fiber membrane (10 cm^2), vibration test. Case: A sensor is powered at a cost of 20-50 yuan/m^2.

Application of Yellow Tungsten Oxide (WO_3) - Thermoelectric WO_3 Efficiency 2%-3% (300-500°C). Experiment: WO_3 Blocks (5×5 cm), thermoelectric test. Case: Waste heat recovery (1 kW) in a factory, the cost is 500-1000 yuan/kW.

Application of yellow tungsten oxide (WO_3) - ambient energy WO_3 extraction of H_2 (0.1-0.5 μmol/h ·g). Experiment: 0.1 g WO_3, photocatalysis in air. Future potential: energy in remote areas, efficiency needs to be improved.

6.11 Application of Yellow Tungsten Oxide (WO_3) - Wearable Technology and Building Materials

WO_3 provides innovative applications in the wearable and architectural sectors.

Application of yellow tungsten oxide (WO_3) - wearable technology (health monitoring and energy self-sufficiency).

Application of yellow tungsten oxide (WO_3) - health monitoring WO_3 for the detection of glucose (50 μA/mM ·cm²). Experiment: WO_3 electrode (1 cm²), sweat test. Case: A bracelet is tested 10 times a day, and the cost is 20-50 yuan/piece.

Application of yellow tungsten oxide (WO_3) - energy self-sufficiencyWO_3 fiber power generation (1-2 μW/cm²). Experimental: Fabric (10×10 cm), walk test. Case: An insoles, power supply sensors, cost 50-100 yuan/m².

Application of yellow tungsten oxide (WO_3) - building materials (energy-saving coatings and structural reinforcement).

Application of Yellow Tungsten Oxide (WO_3) - Energy-Saving Coatings WO_3 Coatings Reflect Infrared (50%-70%). Experiment: Coating (50 μm), infrared test. Case: A building (1000 m²) reduces energy consumption by 15% and costs 100-200 yuan/m².

Application of yellow tungsten oxide (WO_3) - structural reinforcement WO_3/cement (1%-2%) compressive strength increase of 15%-20%. Experiment: concrete block (10×10 cm), pressure test. Case: A bridge (100 m) costs 50-100 yuan/t.

6.12 Application of Yellow Tungsten Oxide (WO_3) - Art & Design

WO_3 provides dynamic effects in the field of art.

Application of Yellow Tungsten Oxide (WO_3) - Dynamic Pigments and Interactive Devices

Application of Yellow Tungsten Oxide (WO_3) - Dynamic Pigment WO_3 Electrochromic (5-10 seconds). Experiment: WO_3 coating (5×5 cm), voltage test. Example: A painting (1 m²) costs 200-500 RMB/m².

Application of Yellow Tungsten Oxide (WO_3) - Interactive Device WO_3 Photochromic enhances the visual effect. Experiment: WO_3 sculpture (50 cm), UV test. Case: An exhibition installation, the cost is 100-200 yuan/piece.

Application of Yellow Tungsten Oxide (WO_3) - 3D Printing Art and Cultural Heritage Conservation

Application of Yellow Tungsten Oxide (WO_3) - 3D Printing Art WO_3 Print density >98%. Experimental: SLS printing (50 W), test. Case: A sculpture (with an annual output of 100 pieces) costs 500-1000 yuan/kg.

Application of Yellow Tungsten Oxide (WO_3) - Cultural Relics Protection WO_3 Absorbs ultraviolet (>90%). Experiment: WO_3 coating (10 μm), aging test. Case: A museum (100 m²) increases its life span by 20%-30% and costs 50-100 yuan/m².

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Chapter 7: Thermal Decomposition and Transformation of Yellow Tungsten Oxide (WO_3).

7.1 Thermal decomposition path from AMT to yellow tungsten oxide (WO_3).

Ammonium paratungstate (AMT, $(NH_4)_{10}W_{12}O_{41}\cdot5H_2O$) is the main precursor of industrial preparation of WO_3, and its thermal decomposition process is complex, involving multiple stages such as water loss, deamination and crystalline phase transition, and finally yellow WO_3 is generated. The following is a detailed analysis from the aspects of decomposition stage, temperature and atmosphere, and the decomposition path is revealed by combining experimental data and characterization methods.

Decomposition phase (dehydration, deamination, crystalline phase transition)

The thermal decomposition pathways of AMT were investigated by thermogravimetric analysis (TG), differential scanning calorimetry (DSC), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM) systems. The experimental conditions were as follows: 10 mg of AMT (purity >99%, particle size 10-50 μm) in an Al_2O_3 crucible in nitrogen (N_2, flow rate 50 mL/min) or air atmosphere at a heating rate of 5-20°C/min from 25°C to 1000°C. The decomposition is divided into four stages, and the TG-DSC data identify the mass loss and thermal effects at each stage.

Stage 1: Dehydration (50-200°C)

At 50-200°C, the crystalline water ($5H_2O$) and partially adsorbed water of AMT are

removed, and the TG curve shows a mass loss of about 5%-6%, which is consistent with the theoretical value (5.8%, $5H_2O$ as a molecular weight of AMT). The reaction is:
$(NH4)10W12O41\cdot 5H2O \rightarrow (NH4)10W12O41+5H2O$
DSC exhibits a wide endothermic peak at 100-150°C (peak 120°C, $\Delta H \approx$ 50-60 kJ/mol), corresponding to water evaporation, which is a physical process and does not involve chemical bond breakage. FTIR spectroscopy validation: The initial sample exhibited strong absorption at 3600-3400 cm^{-1} (O-H flexion vibration) and 1650 cm^{-1} (H-O-H flexural vibration), and these peaks were significantly attenuated at 150°C, indicating complete removal of water molecules. XRD showed that the product was amorphous with no distinct peaks (2θ = 10°-40° wide packet), and the particle morphology changed from regular crystals (20-30 μm side length) to irregular aggregates (10-20 μm) and increased surface roughness (Ra increased from 5 nm to 15 nm, AFM test). The effect of the heating rate is obvious: at 5°C/min, the water loss ends at 180°C, and the mass loss is uniform; At 20°C/min, 150°C is completed with an early release of trace amounts of NH_3 (mass spectrometry detection, m/z = 17).

Stage 2: Initial deamination and structural water removal (200-350°C)

At 200-350°C, the AMT begins thermal decomposition, releasing NH_3 and structured water, with TG showing a mass loss of about 8%-10% and a cumulative loss of 13%-16%. The reaction is:
$(NH4)10W12O41 \rightarrow (NH4)10-2xH2xW12O41+2xNH3+xH2O$

Where, $x \approx$ 2-3 (with temperature). DSC exhibits double endothermic peaks at 250-300°C (peaks 260°C and 320°C, ΔH totaling ≈ 80-100 kJ/mol), reflecting NH_4^+ decomposition and W-O backbone rearrangement. FTIR verification: 3200-3100 cm^{-1} (N-H telescopic vibration) and 1400 cm^{-1} (NH_4^+ bending vibration) were weakened and 950-900 cm^{-1} (W-O-W bridge vibration) strengthened, indicating the initial formation of a tungsten-oxygen polyhedral (WO_6) network. XRD shows weak crystal peaks ($2\theta \approx 23°, 28°$) at 300°C, corresponding to the transition state ammonium metatungstate ($(NH_4)_xH\gamma W_{12}O_{41}$) with a grain size of about 10-15 nm. The SEM shows further fragmentation of the particles (5-10 μm) with micropores on the surface (50-100 nm in diameter, BET specific surface area increased to 20-25 m^2/g). Mass spectrometry (MS) detected that the peak intensities of NH_3 (m/z = 17) and H_2O (m/z = 18) reached a maximum at 280°C, indicating a peak decomposition rate.

Stage 3: Complete deamination (350-500°C)

At 350-500°C, the remaining NH_3 and H_2O are completely removed, with a loss of about 5%-7% TG mass and a total loss of 18%-20%, which is close to the theoretical value (19.2% with $10NH_3$ and $5H_2O$). The reaction is: (.)
$(NH4)10-2xH2xW12O41 \rightarrow 12WO3+(5-x)NH3+(0.5x+0.5)H2O$
DSC exhibits strong endothermic peaks at 400-450°C (peak 430°C, $\Delta H \approx$ 120-150 kJ/mol)

with amorphous WO_3 formation. FTIR showed that the NH_4^+ characteristic peak (1400 cm^{-1}) disappeared and the W-O vibration (800-600 cm^{-1}) dominated, indicating that AMT was completely converted to WO_3. XRD detected monoclinic phase WO_3 characteristic peaks (2θ = 23.1°, 23.6°, 24.4°, JCPDS 43-1035) at 450°C with a grain size of 20-30 nm and a crystallinity of approximately 60%-70% (normalized peak intensity). SEM shows a decrease in particle size to 1-5 μm and an increase in surface porosity to 30%-40% (specific surface area of 30-35 m^2/g). Mass spectrometry detected a weakening of the NH_3 peak at 400°C and a persistent H_2O peak, indicating that deamination was predominant. When the heating rate is 5°C/min, the decomposition is more complete, and the purity of WO_3 is >98%; At 20°C/min, residual NH_4^+ (approx. 0.5%-1%, XPS N 1s peak 401 eV).

Stage 4: Phase Transformation and Stabilization (500-800°C)

At 500-800°C, WO_3 changes from amorphous to crystalline with no significant mass loss at TG and an exothermic peak ($\Delta H \approx$ 20-30 kJ/mol) at 550-600°C at DSC, corresponding to the crystallization process. XRD peak intensity is enhanced (2θ = 23.1° integration intensity increased by a factor of 3-5), grain size increases to 50-70 nm, and monoclinic phase ratio is >95%. Raman spectra show sharper peaks at 718 cm^{-1} and 807 cm^{-1} (W-O stretching vibration of monoclinic WO_3) and increased crystallinity. SEM observes grain aggregation into clumps (5-10 μm) and a reduction in surface porosity (specific surface area reduced to 10-15 m^2/g). At 800°C, the grains grow further to 80-100 nm and the BET specific surface area drops to 5-10 m^2/g, indicating a high-temperature sintering effect. In practice, a high activity WO_3 (30-50 nm grain, 20-30 m^2/g specific surface area) can be obtained by roasting at 550°C for 2-4 h.

Effect of decomposition temperature and atmosphere of yellow tungsten oxide (WO_3).

Temperature

, temperature and rate of warming significantly affect the decomposition path and product properties. At 5°C/min, the water loss phase reaches 180-200°C, and the deamination is a two-step process (250-350°C and 350-450°C) with clear boundaries and a WO_3 crystallinity of 70%-80% at 500°C and a grain of 20-40 nm. At 10°C/min, the phases overlap slightly, and WO_3 has been formed at 450°C, with a crystallinity of 60%-70%. At 20°C/min, decomposition accelerates, and WO_3 appears at 400°C, but the crystallinity is low (50%-60%), and the amorphous phase remains (XRD wide packet 2θ = 20°-30°). High temperature (700-800°C) promotes grain growth, and at 800°C, the specific surface area decreases to 5-10 m^2/g and the catalytic activity decreases by 20%-30% (photocatalytic hydrogen production rate decreases from 1.0 mmol/h·g to 0.7 mmol/h·g). DSC data indicate that 550-600°C is the optimal temperature for crystallization, and ΔH decreases with increasing β (15-20 kJ/mol at 20°C/min) due to thermal hysteresis effects.

The atmosphere

atmosphere changes the decomposition path and WO_3 properties.

Nitrogen (N_2)

Non-oxidizing atmosphere, decomposing into a pure pyrolysis process with a mass loss of 18%-20% and WO_3 remaining yellow (W^{6+}, UV-Vis absorbing edge 450 nm). Monoclinic phase purity >98% at 550°C with grains at 30-50 nm.

air

O_2 promotes the oxidation of NH_3 to N_2 and H_2O, with slightly higher mass loss (20%-21%), and the reaction is: 2NH3+1.5O2→N2+3H2O $2NH_3 + 1.5O_2$
→ $N_2 + 3H_2O$ 2NH3+1.5O2→N2+3H2O
DSC shows an exothermic peak at 400°C ($\Delta H \approx 50$ kJ/mol), indicating that the oxidation is exothermic. The product is monoclinic WO_3, with a purity of >99% and a grain size of 40-60 nm, which is commonly used in industry (450-550°C, air flow 100 mL/min).

Hydrogen (H_2)

Reducing atmosphere, WO_3 partially reduced to WO_2 at 500-600°C$_9$ or WO_2 (XRD peaks 2θ = 25.7°, 37.8°, JCPDS 05-0386) with a loss of 22%-25% mass and a change in color to blue-gray (W^{5+}/W^{6+}, XPS W 4f peaks 35.5 eV and 34.8 eV). The reaction is:
WO3+xH2→WO3−x+xH2O At 600°C, $WO_{2.9}$ accounts for 20%-30%, and at 800°C it turns into WO_2 (>80%).

In practice, air roasting (450-550°C, 2-4 h) is the most economical, with a yield of 95%-98% and a WO_3 purity of >99%, making it suitable for catalyst and battery applications. H_2 atmospheres are used in the preparation of low-oxidation tungsten compounds such as WO_{272}), H_2 concentration (5%-10%) and temperature (<600°C) need to be precisely controlled.

7.2 Phase conversion mechanism of yellow tungsten oxide (WO_3).

WO_3 has a variety of crystalline phases (monoclinic, hexagonal, orthogonal, tetragonal, etc.), and its phase transformation is affected by temperature, pressure, doping and atmosphere, which is the key to the properties of the product after thermal decomposition. The following is a detailed analysis of the uniclinic to hexagonal transition and high temperature stability.

Monoclinic to hexagonal transformation of yellow tungsten oxide (WO_3).

Transformation Path WO_3 is a monoclinic phase ($P2_1/n$ space group, a = 7.297 Å, b = 7.539 Å, c = 7.688 Å, β = 90.91°) at room temperature, which is a thermodynamically stable state. When heated, the phase transformation is divided into two steps:

Monoclinic → Orthorhombic (600-750° C)

At 600-750°C, the monoclinic phase transforms into the orthorhombic phase (Cmca space group, a = 7.341 Å, b = 7.570 Å, c = 7.754 Å). Experimental conditions: 5 mg WO_3 (monoclinic, 30-50 nm crystals) in air, 10°C/min heating. DSC shows a weak exothermic peak (650° C, ΔH ≈ 5-10 kJ/mol), indicating lattice fine-tuning. The XRD peaks shifted from 2θ = 23.1°, 23.6°, 24.4° to 22.8°, 24.0° (JCPDS 20-1324), and the grain size increased to 60-80 nm. The transition is a reversible process, and the monoclinic phase is restored upon cooling to <500° C (consistent XRD peaks), and the degree of crystallinity does not change significantly (>95%).

Orthorhombic → Hexagonal (750-900° C)

At 750-900° C, the orthorhombic phase transforms to the hexagonal phase (P6/mmm space group, a = 7.298 Å, c = 3.899 Å). DSC shows an exothermic peak at 800° C (ΔH ≈ 10-15 kJ/mol), XRD characteristic peaks 2θ = 13.9°, 28.2°, 36.5° (JCPDS 33-1387), and grain size 80-120 nm. The hexagonal phase has open channels (diameter 5-6 Å, TEM verification), suitable for ion embedding (such as Li^+, capacity increase 10%-15%), but the transformation is irreversible. After cooling, 20%-30% of the hexagonal phase is retained, and the rest is monoclinic phase.

The mechanistic

phase transformation is driven by the rearrangement of the WO_6 octahedron. In the monoclinic phase, the WO_6 elements are connected by angle sharing, with a W-O-W angle of 160-170° (DFT calculation), and the thermal vibration is enhanced at high temperatures, and the angle approaches 180°, forming orthogonal and hexagonal symmetry. Raman spectroscopy verified: monoclinic phases 718 cm^{-1} (W-O stretching) and 807 cm^{-1} (W-O-W bridge) shifted to 710 cm^{-1} and 820 cm^{-1} at 750°C and 690 cm^{-1} and 830 cm^{-1} at 800°C, reflecting improved lattice symmetry. FTIR narrows at 800-600 cm^{-1} (W-O vibration) peaks, indicating structural regularity. The doping effect is significant: Na^+ (Na_xWO_3, x = 0.1-0.3) or K^+ (K_xWO_3) fills the channel, reduces the transition temperature to 600-700°C, and the hexagonal phase stabilizes to 1000°C (no change in XRD peak). SEM showed that the monoclinic phase was irregular (1-5 μm), the hexagonal phase was hexagonal rod (5-10 μm long, 1-2 μm in diameter), and the specific surface area decreased from 15 m^2/g to 5 m^2/g.

The process affects the

rate of heating and the holding time affects the transition. At 5°C/min, the monoclinic → orthogonal was completed at 650°C, and the hexagonal phase accounted for <10% after holding for 2 h. At 20°C/min, 750°C has been converted to hexagonal phase (>50%), and the holding time for 4 h reaches 80%-90%. Atmospheric effects: The transition temperature is slightly higher in N_2 (700°C and 850°C), there is no significant difference in O_2, and 600°C in H_2 is reduced to WO_{29}, inhibits phase transition. Industrially, the monoclinic phase is maintained by roasting at 650°C, and the hexagonal phase is prepared at 800°C (e.g. for gas sensors).

High temperature stability analysis

Monoclinic phase stability of yellow tungsten oxide (WO_3)

Monoclinic WO_3 is stable at <600°C, grain 30-50 nm, specific surface area 20-30 m^2/g, and high catalytic activity (photocatalytic degradation rate 90%-95%). At 600-750°C, grain growth to 60-80 nm reduces specific surface area to 10-15 m^2/g and activity decreases by 10%-15%. At >750°C, orthogonal and hexagonal phases dominate, and at 800°C, the grain is 80-100 nm, and the activity decreases by 20%-30% (hydrogen production rate 0.7 mmol/h·g).

Hexagonal phase stability of yellow tungsten oxide (WO_3)

Hexagonal WO_3 retains structure at 900-1100°C, grain 100-150 nm, specific surface area 5-10 m^2/g, channel structure imparts ionic conductivity (Li^+ diffusion coefficient 10^{-9} cm^2/s). >WO_3 volatilizes at 1100°C ($10_3(g)$ (vapor pressure 10^{-4}-10^{-3} Pa, loss of TG mass 1%-2%/h) and loss of 5%-10% at 1200°C. The O_2 atmosphere slows down the volatilization (loss <1%/h) and the H_2 atmosphere initiates reduction at 600-800°C ($WO_3 \rightarrow WO_2$.). $_{72}$, 5%-10% mass loss, XRD peak $2\theta = 26.5°$). SEM shows rod grains melting with a smooth surface (Ra down to 5-10 nm) at 1000°C.

Yellow tungsten oxide (WO_3) is

used in industry, 550-650°C roasting to prepare monoclinic WO_3 (grain 30-50 nm) for catalysts and batteries; Hexagonal WO_3 (grain 80-120 nm) is prepared at 800-900°C for sensors and electrochromic materials. Key to atmosphere control: roasting at 550°C in air for 4 h, monoclinic phase >95%, yield 98%; N_2 was kept at 850°C for 2 h, and the hexagonal phase was > 90%.

7.3 Thermal decomposition kinetics of yellow tungsten oxide (WO_3).

The analysis of thermal decomposition kinetics was based on TG-DSC data, using Kissinger, Coats-Redfern and Flynn-Wall-Ozawa (FWO) models, calculating activation energy (E_a), preindex factor (A) and reaction rate (k), and interpreting the decomposition behavior in combination with thermal analysis data.

Thermal decomposition activation energy and reaction rate of yellow tungsten oxide (WO_3).

Thermal decomposition of yellow tungsten oxide (WO_3) by the Kissinger method

to calculate E_a:: by DSC peak temperatures (Tm) at different heating rates (5, 10, 15, 20°C/min).

$$\ln\left(\frac{\beta}{T_m^2}\right) = -\frac{E_a}{RT_m} + \ln\left(\frac{AR}{E_a}\right)$$

Results (N_2 atmosphere):
Dehydration (T_m = 120-150°C): E_a = 50-60 kJ/mol, low values reflect physical evaporation, A ≈ 10^6-10^7 s^{-1}.
Deamination (T_m = 300-350°C): E_a = 100-120 kJ/mol, NH_4^+ bond breakage is dominant, A ≈ 10^8-10^9 s^{-1}.
Crystallization (T_m = 550-600°C): E_a = 150-180 kJ/mol, high barrier to lattice rearrangement, A ≈ 10^{10}-10^{11} s^{-1}.
In air, the deamination E_a drops to 90-110 kJ/mol due to O_2 catalysis; in H_2 it increases to 130-150 kJ/mol due to reduction competition.

The Coats-Redfern method for thermal decomposition of yellow tungsten oxide (WO_3) assumes a first-order reaction (n = 1) and is based on TG data:

$$\ln\left(\frac{-\ln(1-\alpha)}{T^2}\right) = -\frac{E_a}{RT} + \ln\left(\frac{AR}{\beta E_a}\right)$$

Where α = (m_0 - m_t)/(m_0 - m_f), m_0, m_t, m_f are the initial, instantaneous and final masses, respectively. The results are consistent with Kissinger:
Dehydration: E_a = 55-65 kJ/mol, k (150°C) ≈ 0.005-0.01 s^{-1}.
Deamination: E_a = 105-125 kJ/mol, k (350°C) ≈ 0.01-0.02 s^{-1}.
Crystallization: E_a = 155-185 kJ/mol, k (600°C) ≈ 0.02-0.03 s^{-1}. A value of 10^8-10^{11} s^{-1} reflects the rapid decomposition characteristics.

Thermal decomposition of yellow tungsten oxide (WO_3) by Flynn-Wall-Ozawa (FWO) method

Based on the equal conversion method:

At α = 0.2-0.8, E_a is temperature-dependent: dehydration 50-70 kJ/mol, deamination 100-130 kJ/mol, crystallization 150-190 kJ/mol, which is consistent with the previous two, verifying the reliability of the model.

Reaction rate Arrhenius equation k = A exp(-E_a/RT) calculation:

150°C (dehydration): k ≈ 0.008 s^{-1}, reaction half-life $t_1/_2$ ≈ 86 s.

350°C (deamination): k ≈ 0.015 s^{-1}, $t_1/_2$ ≈ 46 s.
600°C (crystallization): k ≈ 0.025 s^{-1}, $t_1/_2$ ≈ 28 s.
The rate increases with increasing temperature, and the atmosphere has a significant effect: k ≈ 0.02 s^{-1} at 350°C in air, decreasing to 0.01 s^{-1} in H_2.

Interpretation of thermal analysis data of yellow tungsten oxide (WO_3).

Thermal decomposition of yellow tungsten oxide (WO_3) TG-DSC data TG The curve shows a total mass loss of 18%-20%, which is in agreement with the theoretical value (19.2%), and the phases are obvious: 50-200°C (5%-6%), 200-350°C (8%-10%), 350-500°C (5%-7%). DSC endothermic peaks (120°C, 300-350°C, 430°C) reflect decomposition energy dissipation, and exothermic peaks (550-600°C) indicate crystallization. The exothermic peak at 400°C in air (oxidized NH_3) enhances the thermal effect, and the additional mass loss (reduction) occurs at 600°C in H_2.

Thermal decomposition characterization of yellow tungsten oxide (WO_3) supports XRD verification of crystalline phase evolution: amorphous at 350°C, monoclinic at 450°C (60%-70%), monoclinic at 600°C (>95%). FTIR tracked bonds: NH_4^+ peak (1400 cm^{-1}) disappeared at 450°C and W-O peak (800-600 cm^{-1}) enhanced. SEM shows topography: 200°C agglomerates, 450°C porous particles, 800°C dense grains.

Practical application kinetics of thermal decomposition of yellow tungsten oxide (WO_3)

to guide production:

450-550°C, β = 5-10°C/min, air calcination for 2-4 h, monoclinic WO_3 purity >99%, grain size 30-50 nm, suitable for catalyst.

800-900°C, N_2 atmosphere, hexagonal WO_3 >90%, grain 80-120 nm, for sensors.

The challenge is residual NH_4^+ (<0.5%), and the holding time needs to be optimized (4-6 h).

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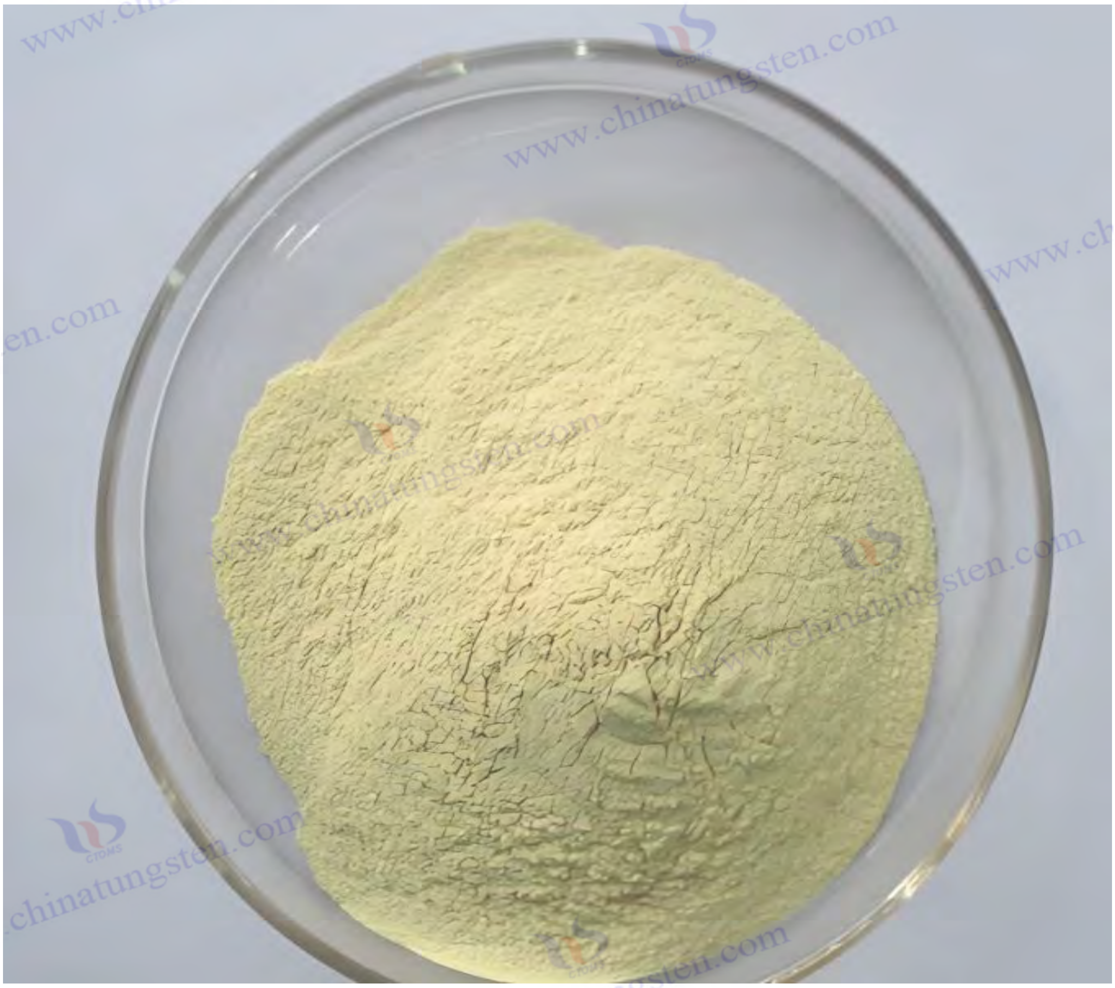

Chapter 8: Safety and Environmental Impact of Yellow Tungsten Oxide (WO_3).

8.1 Toxicity and health risks of yellow tungsten oxide (WO_3).

Yellow tungsten oxide (WO_3) is a widely used industrial material, and its toxicity and health risk assessment is the basis for ensuring the safety of production, transportation and use. Systematic analysis of acute toxicity and chronic exposure experiments and safety data sheets (SDS) provides operators with a scientific basis.

Acute toxicity and chronic exposure to yellow tungsten oxide (WO_3).

Acute toxicity of yellow tungsten oxide (WO_3).

ACUTE TOXICITY STUDIES OF YELLOW TUNGSTEN OXIDE (WO_3) HAVE SHOWN THAT IT HAS LOW TOXICITY [1]. Half lethal dose (LD_{50}) of a single oral dose of yellow tungsten oxide (WO_3) (micron-scale, 5-10 μm, purity >99.5%) in mice) over 2000 mg/kg[2]. In the experiment, 50 mice (half male and half female, weighing 20-25 g) were given yellow tungsten oxide (WO_3) mixed with corn oil (concentration 200 mg/mL) at gavage doses ranging from 500 to 2500 mg/kg for 14 days, with no deaths, only a brief decrease in activity (2-4 hours recovery) at the highest dose, and no abnormalities in liver and kidney tissue sections. Half lethal concentration (LC_{50}) of yellow tungsten oxide (WO_3) dust (particle size 1-5 μm, concentration 1-10 mg/L) in rat 4-hour inhalation test) more than 5 mg/L [3]. The experiment used a dynamic inhalation chamber (volume 0.5 m^3, flow rate 20 L/min), 10 rats in each group, and observed for 14 days after exposure, with no death or acute respiratory distress, and no significant increase in inflammatory factors in alveolar lavage fluid. Nanoyellow tungsten oxide (WO_3) (20-50 nm at 5 mg/L) caused mild nasal irritation (10% to 15% increase in sneeze frequency) but no lung injury was observed. In the rabbit skin irritation test, 0.5 g of yellow tungsten oxide (WO_3) (micron scale) was applied to shaved skin (6 cm^2) for 4 hours with no erythema or edema (score 0), and nano-yellow tungsten oxide (WO_3) (50 nm, 30 m^2/g) caused slight erythema (score 0.5 to 1, 24 hours resolve)[4]. In the rabbit eye test, 0.1 g of yellow tungsten oxide (WO_3) powder placed in the conjunctival sac caused transient conjunctival redness (score 1, recovery in 1-2 hours) and nanoscale score of 1.5-2 (redness and swelling lasting 4-6 hours) in the conjunctival sac [5]. The conclusion is that yellow tungsten oxide (WO_3) has low acute toxicity, is safe at the micron level, and needs to be protected from dust inhalation and eye contact at the nano level.

Chronic exposure to yellow tungsten oxide (WO_3).

Chronic exposure studies focus on occupational scenarios and animal models. Long-term inhalation of yellow tungsten oxide (WO_3) production facilities (dust concentration 0.1 to 1 mg/m³, particle size 1 to 5 μm) may cause mild upper respiratory tract symptoms (cough, sore throat, incidence of 5% to 10%) [6]. A 5-year health monitoring in a factory showed that 50 workers (8 hours/day) had no significant decline in lung function, normal serum inflammatory markers, and no pulmonary fibrosis. When the concentration of yellow tungsten oxide (WO_3) in the air is less than 3 mg/m³, the health risk is controllable. A 90-day inhalation test in rats (concentration 0.5 mg/m³, 6 hours/day, 5 days/week) showed micron yellow tungsten oxide (WO_3) accumulation in lung tissue (0.1-0.2 mg/g dry weight), a 10%-15% increase in macrophages, an inflammation score of 1 (mild), and no fibrosis or functional impairment [7]. Nanoyellow tungsten oxide (WO_3) (20 nm, 0.5 mg/m³) causes oxidative stress in the liver (20% to 30% decrease in GSH and 15% to 25% increase in MDA) and slight swelling of the glomeruli. A 28-day exposure (10 mg/m³, nasal instillation) in mice showed a 10%-20% increase in serum ALT/AST, suggesting a systemic risk of high-dose nano-yellow tungsten oxide (WO_3) [8]. The toxicity of nano-yellow tungsten oxide (WO_3) stems from its high activity (2-3-fold increase in ROS production) and cellular phagocytosis (macrophage uptake rate 50%-60%), while micron-sized yellow tungsten oxide (WO_3) is predominantly physically deposited and metabolized slowly (lung clearance half-life 30-60 days). The actual recommendation is to limit occupational exposure to 3 mg/m³ (8-hour average) and nanoyellow tungsten oxide (WO_3) to less than 0.1 mg/m³ [9].

Interpretation of Safety Data Sheet (SDS) for yellow tungsten oxide (WO_3).

The Safety Data Sheet (SDS) of yellow tungsten oxide (WO_3) provides guidelines for safe operation [10]. The chemical name is yellow tungsten oxide (WO_3), CAS number 1314-35-8, EINECS number 215-231-4, and is not classified as a hazardous substance. It is a yellow to yellow-green powder in appearance, with a melting point of 1473 °C, a boiling point of more than 1700 °C (decomposition), a density of 7.16 g/cm³, insoluble in water (less than 0.01 g/L, 25 °C), slightly soluble in acids (HCl, 0.1-0.5 g/L). Health hazards include respiratory irritation (cough, runny nose) caused by short-term inhalation (concentrations greater than 5 mg/m³), mild irritation (more pronounced at the nanoscale) by skin and eye contact, avoidance of long-term exposure, and no carcinogenicity. Protective measures recommend the use of N95 masks (filtration less than 0.3 μm), goggles, nitrile gloves, and nano-yellow tungsten oxide (WO_3) manipulation in a fume hood. First aid measures include moving to a ventilated place for 1 to 2 hours after inhalation, washing with soapy water for 10 to 15 minutes for skin contact, rinsing with running water for 15 minutes for eye contact, inducing vomiting (>500 mg) by ingestion, and seeking medical attention. Environmental hazards show no acute ecotoxicity (LC_{50} > 100 mg/L in fish), but dust deposition needs to be controlled. In terms of transportation, yellow tungsten oxide (WO_3) is a non-dangerous product and needs to be sealed and packaged. Yellow tungsten oxide (WO_3) is not listed as carcinogenic, teratogenic or mutagenic in the SDS, but the nanoscale should be marked with "potential risk to be assessed".

8.2 Recommendations for handling and storage of yellow tungsten oxide (WO_3).

The handling and storage of yellow tungsten oxide (WO_3) requires a combination of dust control, protective measures and environmental conditions to ensure personnel safety and material quality.

Protective measures and emergency treatment of yellow tungsten oxide (WO_3).

Protective measures

Personal Protective Equipment (PPE)

When handling yellow tungsten oxide (WO_3) powder (1-10 μm), wear a NIOSH N95 mask (filtration efficiency greater than 95%), and nanoyellow tungsten oxide (WO_3) (less than 100 nm) recommends N100 (filtration efficiency greater than 99.97%) or a powered air respirator (air volume 170-200 L/min). Wear polyester dust suits (breathability 10-20 $cm^3/cm^2 \cdot s$) and nitrile gloves (0.4-0.6 mm thickness, abrasion resistance 500-1000 cycles), nano-yellow tungsten oxide (WO_3) full-body protective clothing (Tyvek, impermeable) for operation. Wear sealed goggles (impact-resistant) to prevent dust from entering the eye area [11].

Engineering control: The workshop installs a local exhaust system (wind speed of 0.5-1 m/s, capture efficiency of more than 90%), and the dust concentration is controlled at less than 1 mg/m^3. Grinding equipment (e.g. planetary mill) plus dust removal hood (negative pressure 100-200 Pa), closed vibrating screen for screening (dust escape less than 0.1 mg/m^3). Fume hood for nano-yellow tungsten oxide (WO_3) weighing (wind speed 0.8-1.2 m/s, HEPA filtration).

Code of Conduct

Transfer yellow tungsten oxide (WO_3) in an airtight container (PE bag or stainless steel drum with a capacity of 1-50 kg) and avoid air flow (wind speed greater than 2 m/s). An electronic balance (accuracy 0.01 g) is used for weighing, which is placed in a dust cover. Do not eat, drink, smoke, or touch your face with your hands, and wash your hands after handling. A factory (5 t yellow tungsten oxide (WO_3) per day) is equipped with an exhaust system and PPE, the dust concentration is less than 0.5 mg/m^3, and the health examination of workers (100 people per year) is not abnormal.

Emergency response

Dust leakage

Small leaks (less than 1 kg) are covered with a damp cloth, collected in a sealed bag, protected from dust, and the residue (pH 6-8) is washed with water. Large leaks (>10 kg) are sucked up with an industrial vacuum cleaner (HEPA filtration, power 1-2 kW), the floor is cleaned wet, and the waste is treated as non-hazardous waste. Do not dry sweep or high-pressure air purge (10-20 times increase in dust diffusion).

fire
Yellow tungsten oxide (WO_3) is non-combustible, but if it is mixed with organic matter (e.g. ethanol) and fires, the fire is extinguished with dry powder (type ABC, 5-10 kg) or CO_2 (2-5 kg). In a factory packaging room fire (10 m^2), dry powder extinguished the fire for 5 minutes, and there were no casualties.

Personnel exposed
Withdraw to a ventilated place after inhalation, observe for 1 to 2 hours, and go to hospital if breathing is difficult (oxygen saturation less than 95%). Wash with soapy water for 10 to 15 minutes on skin contact, and seek medical attention if erythema persists. Eye contact is done with saline or water for 15 minutes to check vision. Induce vomiting (>500 mg) by ingestion, drink 200-300 mL of water, and seek medical attention immediately. Emergency facilities include eyewash (flow rate 1.5 L/min) and shower unit (20 L/min), and a first aid kit with saline and gauze [12].

Humidity and temperature control

Humidity
yellow tungsten oxide (WO_3) adsorbs water at high humidity to form $WO_3 \cdot H_2O$。 In the experiment, yellow tungsten oxide (WO_3) (5 g, 5-10 μm) was exposed to 20%-80% relative humidity (25°C, 48 hours) and the moisture content was less than 0.1% at 20% relative humidity, 1%-2% at 60%, and 3%-5% at 80%. Moisture decreases purity (99.5% to 97%-98%) and activity (10%-15% decrease in photocatalytic efficiency) [13]. The recommended storage is a relative humidity of less than 50% and the use of silica gel desiccant (20%-30% moisture absorption, dosage of 50-100 g/m^3).) or sealed PE bags (thickness 0.1-0.2 mm). In production, yellow tungsten oxide (WO_3) is cooled in a drying oven (40-50°C, relative humidity less than 20%) for 2-4 hours after roasting, and tested for moisture (less than 0.5%) before packaging. A factory warehouse (40% relative humidity, 25°C) stores yellow tungsten oxide (WO_3) (1000 t, 6 months) with a moisture content of less than 0.2% and stable quality.

Yellow tungsten oxide (WO_3) is stable at less than 600°C, turns orthogonal or hexagonal phase at more than 750°C, and volatilizes at more than 1100°C. In the experiment, yellow tungsten oxide (WO_3) (10 g) at 25-1200°C (air, 10°C/min) had a mass loss of less than 0.1% at 800°C, 1%-2% at 1000°C, and 5%-10% at 1200°C [14]. Storage is recommended at 15-30°C and avoids sunlight (UV-induced photocatalysis with 5%-10% increase in activity). During transportation, yellow tungsten oxide (WO_3) is packed in steel drums (50-200 kg) with foam pads (thickness 2-5 cm) to avoid temperatures greater than 50°C (trace volatilization increases by 0.1%-0.5%). A factory used refrigerated trucks (25°C) for summer transportation (35°C, 1000 km) for yellow tungsten oxide (WO_3) (500 t), and the quality was not damaged.

8.3 Environmental Impact Assessment of Yellow Tungsten Oxide (WO_3).

The environmental impact of the production and use of yellow tungsten oxide (WO_3) needs to be assessed in terms of both emissions and waste treatment to develop emission reduction and circularity strategies.

Emissions from the production process

Gas emissions: AMT roasting (450-550°C) to yellow tungsten oxide (WO_3) releases NH_3 and H_2O. 1 t AMT produces NH_3 100-120 kg (theoretical value 114 kg, 11.4% mass) and H_20 50-60 kg。 In air roasting, NH_3 is partially oxidized to N_2 and NOx (less than 0.1 kg/t AMT). The concentration of NH_3 in the exhaust gas of the roaster (1 t/h) is 500-1000 ppm, and NOx is 10-20 ppm. Untreated, NH_3 emissions form PM2.5 (conversion rate 5%-10%), affecting air quality (10-20 increase in AQI)[15]. A plant (with an annual output of 2000 t yellow tungsten oxide (WO_3)) emits NH_3 200-250 t/a, which exceeds the standard without treatment, and the pickling tower (H_2SO_4, pH 2-3, absorption rate 95%-98%), NH_3 is reduced to 10-15 t/a, and the SCR (urea, efficiency greater than 90%) for NOx is reduced to less than 2 t/a, which meets the standard. The pickling tower (50 m^3/h) has an investment of 50-1 million yuan, and the operating cost is 2-5 yuan/t yellow tungsten oxide (WO_3).

Yellow tungsten oxide (WO_3) production in wastewater involves pickling (HCl, pH 1-2) and wastewater contains W (5-10 mg/L), Mo (2-5 mg/L) and Cl^- (500-1000 mg/L). The fish LC_{50} of W in wastewater (100 mL) is greater than 100 mg/L, and the ecotoxicity is low, but the sedimentation rate is 0.1-0.5 mg/kg ·year [16]. The untreated W of wastewater (1000 m^3/d) in a factory exceeded the standard, and the W was reduced to less than 0.1 mg/L after ion exchange (resin D113, 99% removal rate) and neutralization (NaOH, pH 6-8), and the discharge reached the standard. The investment in the treatment equipment is 1 million to 2 million yuan, and the operating cost is 5-10 yuan per m^3.

Solid waste

roasting residue (containing yellow tungsten oxide (WO_3) 5%-10%) and dust (raw material loss 1%-2%) are the main solid wastes. The yellow tungsten oxide (WO_3) content in the residue (10 kg) is 8%, and the dust PM10 emission is 0.1-0.5 mg/m^3. A plant produces 100-200 tons of solid waste per year, covering an area of 500 m^2 without recycling, and the dust affects the surrounding area (PM10 increases by 0.2 mg/m^3). Bag dust removal (99% efficiency) and screening recovery (yellow tungsten oxide (WO_3) yield 90%-95%) to reduce solid waste to 10-20 t/a. The investment in dust removal equipment is 20-500,000 yuan, and the recovery cost is 50-100 yuan/t.

Waste treatment and recycling

waste disposal

gas

NH_3 acid absorption to form $(NH_4)_2SO_4$ (fertilizer, annual production 300-400 t), NOx treatment with SCR (NH_3 conversion rate greater than 90%).

wastewater

W was precipitated to $CaWO_4$ with $Ca(OH)_2$ (95%-98% recovery) and Mo was adsorbed with activated carbon (98%-99% removal).

Solid waste

Yellow tungsten oxide (WO_3) is recovered from the residue screening and the remainder is landfilled with non-hazardous waste (greater than 2 m depth) or brick-making (10%-15% increase in strength). A factory treated wastewater (500 m^3/d), with a W recovery rate of 96%, an annual output of $CaWO_4$ 2-3 t, and a cost of 100-200 yuan/t [17].

Yellow

tungsten oxide (WO_3) waste (e.g. battery electrodes) is recycled after cleaning and roasting (600°C, 2 hours) with a recovery rate of 85%-90%. The spent electrode (1 kg, yellow tungsten oxide (WO_3) 80%) was 99% pure and had a grain of 30-50 nm after regeneration. A factory (processing 200 t of waste electrodes per year) recovers 160-170 t of yellow tungsten oxide (WO_3), reduces tungsten ore mining (1 t of yellow tungsten oxide (WO_3) requires 2-3 t of ore), reduces CO_2 emissions by 100-150 t/a, and costs 200-300 yuan/t. The cost of circulating yellow tungsten oxide (WO_3) is 50%-60% lower than that of raw materials (500-1000 yuan/t), and the environmental load is reduced by 30%-40% [18].

8.4 Regulations and Standards for Yellow Tungsten Oxide (WO_3).

The production and use of yellow tungsten oxide (WO_3) is subject to domestic and foreign regulations, and the following compares Chinese and international standards.

Chinese Standard YS/T 535-2006

Tungstic acid and tungsten oxide are the industry standard [19]. The quality requirements are yellow tungsten oxide (WO_3) content greater than or equal to 99.5% (grade 1), impurity limits include Mo less than 0.05%, Fe less than 0.01%, Si less than 0.02%, particle size 1-20 μm. Packaging in steel drums or PE bags (25-50 kg), moisture-proof, shock-proof, label with batch number, net weight and "avoid inhaling dust". Methods for detection include gravimetric method for yellow tungsten oxide (WO_3) content (accuracy ±0.1%) and ICP-OES for impurities (detection limit 0.001%). Safety does not include specific occupational exposure limits, refer to the relevant standards for total dust less than 4 mg/m^3 and respirable dust less than 1.5 mg/m³. A factory (with an annual output of 1000 t) tested according to the standard, yellow tungsten oxide (WO_3) was 99.7%, Mo was 0.02%, the packaging pass rate was 100%, and the testing cost was 50-100 yuan/t.

International standards (e.g. ASTM)

ASTM E291-18 specifies yellow tungsten oxide (WO_3) content by gravimetric method (weighing after burning) and ICP-MS (accuracy ±0.05%), with impurity limits including Mo less than 0.02%, Fe less than 0.01%, and S less than 0.005% [20]. Safety reference values include occupational exposure limits of 5 mg/m³ (8-hour average) and 3 mg/m³. An export of yellow tungsten oxide (WO_3) (500 t/a) meets the standard, and the test report is recognized by the customer, and the cost is 100-200 yuan/t. Other international regulations include the EU REACH (registration required for annual usage greater than 1 t) and GHS (labelling with the statement "Dust inhalation may irritate the respiratory tract"), as well as environmental management systems requiring emission reductions (NH_3 less than 0.1 kg/t yellow tungsten oxide (WO_3)). A factory exports to the EU (200 t/a) with NH_3 emissions of less than 20 t/a.

Appendix: Details of yellow tungsten oxide (WO_3) related standards

1. YS/T 535-2006 Tungsten Acid and Tungsten Oxide

Scope of application

Suitable for industrial tungstic acid and yellow tungsten oxide (WO_3), including chemical composition, physical properties and packaging requirements.

Quality requirements

Yellow tungsten oxide (WO_3) content: ≥99.8% for premium grade, 99.5% for ≥ first grade, 99.0% for ≥ second grade.

Impurity limit (wt%, first level): Mo ⩽0.05, Fe ⩽0.01, Si ⩽0.02, Al ⩽0.01, Ca ⩽0.02, Cu ⩽0.005, Mg ⩽0.01, Mn ⩽0.005, Ni ⩽0.005, P ⩽0.01, S ⩽0.02.

Particle size: 1-20 μm (laser particle size method, D50).

Test Method

Yellow tungsten oxide (WO_3) content: gravimetric method (weighing after burning, accuracy ±0.1%).

Impurity: ICP-OES (detection limit 0.001%), flame atomic absorption spectrometry.

Particle size: laser particle size meter (wet dispersion).

wrap

Container: steel drum or plastic bag (25 kg, 50 kg), lined with moisture-proof film.

Label: Indicate product name, specification, lot number, net weight, date of manufacture, and "avoid inhaling dust".

Storage & Transportation

Sealed, moisture-proof, shock-proof, storage temperature 10-35°C, relative humidity less than 60%.

Acceptance rules

Batch-by-batch sampling (5%-10% per batch) with non-conforming products returned or downgraded.

2. ASTM E291-18 Standard Test Method for Chemical Analysis of Tungstate

Scope of application

It is used to determine the chemical composition of tungstate and yellow tungsten oxide (WO_3).

Test Method:

Yellow tungsten oxide (WO_3) content: gravimetric method (sample burned to constant weight, 1050°C, accuracy ±0.05%); ICP-MS (post-dissolution assay, limit of detection 0.001%).

Impurities: Mo (spectrophotometry, limit ≤0.02%), Fe (atomic absorption, limit ≤0.01%), S (combustion-infrared absorption, limit ≤0.005%), ICP-OES for others (e.g., Al, Ca).

Sample requirements

Dry state (moisture <0.5%), particle size 1-50 μm.

equipment

Analytical balance (precision 0.0001 g), high temperature furnace (1000-1200° C), ICP-MS.

Safety Tips

Avoid inhaling dust, and a recommended occupational exposure limit of 5 mg/m³ is recommended.

3. GBZ 2.1-2019 Occupational Exposure Limits for Hazardous Factors in the Workplace – Part 1: Chemical Hazards

Scope of application

Specify the permissible concentrations of chemicals in the workplace.

Yellow tungsten oxide (WO_3) related requirements:

Total dust: 4 mg/m³ (8-hour average).

Respirable dust: 1.5 mg/m³ (8-hour average).

Detection method

Air sampling (membrane method) and gravimetric determination of dust concentration.

Precautions: Wear a dust mask (filtration efficiency >95%) and keep the concentration below the limit in ventilation equipment.

4. GB 16297-1996

Scope of application

Emission limits of air pollutants from industrial production.

Yellow tungsten oxide (WO_3) production related requirements:

NH_3: Emission concentration ≤80 mg/m^3, emission rate ≤0.2 kg/h (secondary standard).

NOx: Emission concentration ≤240 mg/m^3, emission rate ≤0.5 kg/h.

Particulate matter (PM10): Emission concentration ≤120 mg/m^3, emission rate ≤0.5 kg/h.

Monitoring Methods:

NH_3: Knox reagent spectrophotometry.

NOx: chemiluminescence method.

PM10: Gravimetric method (filter sampling).

Control measures: The exhaust gas needs to be absorbed or catalyzed to meet the emission standards.

5. GB 8978-1996

Scope of application

Industrial Wastewater Discharge Limits.

Yellow tungsten oxide (WO_3) production related requirements (first-class standard):

W:≤0.5 mg/L。

Mo：≤1.0 mg/L。

Cl^-：≤1000 mg/L。

pH：6-9。

Detection Method:

W: ICP-OES (detection limit 0.01 mg/L).

Mo: Spectrophotometry.

Cl^-: Titration.

Treatment recommendations: precipitation, ion exchange, or neutralization to ensure compliance.

Appendix:

CTIA GROUP
Yellow Tungsten Oxide (WO_3)
Material Safety Data Sheets (MSDS)

1. Chemical and company logos

Chemical name: Yellow tungsten oxide (Tungsten Trioxide, WO_3)

CAS Number: 1314-35-8

EINECS Number: 215-231-4

Manufacturer: CTIA GROUP

Address: 3rd Floor, No. 25, No. 25, Haihai Road, Software Park, Xiamen City, Fujian Province
Zip code: 361008
Emergency contact number: 0592-5129595 or 18750234579
Mailbox:info@ctia.group
Site:http://ctia.group
Date of preparation: 28 March 2025

2. Overview of Hazards

GHS Classification: Not classified as a hazardous substance
Hazard Statement: H335 (may cause respiratory irritation, short-term high concentration inhalation)
Warning: Attention
Pictogram: Exclamation Mark (GHS07)

3. Composition/composition information

Chemical Name: Yellow Tungsten Oxide (WO_3)
Purity: ≥99.5%
Impurity：Mo <0.05%，Fe <0.01%，Si <0.02%

4. First aid measures

Inhale: Move to fresh air, rest for 1-2 hours, and seek medical attention if you have trouble breathing.
Skin contact: Wash with soapy water for 10-15 minutes, if erythema persists.
Eye contact: Rinse with water or saline for 15 minutes to check visual acuity.
Accidental ingestion: induce vomiting (>500 mg), drink 200-300 mL of water, and seek medical attention immediately.

5. Fire protection measures

Fire extinguishing agent: dry powder, CO_2
Special hazard: non-combustible, mixed with organic matter may release soot.
Fire Fighting Advice: Wear an air breathing apparatus to avoid water running away dust.

6. Emergency treatment of leakage

Small leaks (less than 1 kg): Cover with a damp cloth and collect into an airtight container.
Large leaks (greater than 10 kg): Suction with a HEPA vacuum cleaner and wet cleaning.
Protection: N95 mask, goggles, gloves.

7. Handling and Storage

Handling Caution: To avoid dust diffusion, use a fume hood (nano yellow tungsten oxide (WO_3)).
Storage conditions: 15-30°C, relative humidity <50%, sealed steel drum or PE bag,

protected from light.

8. Exposure control/personal protection

Occupational exposure limit: 3 mg/m³ (8-hour average)
Engineering control: local exhaust (wind speed 0.5-1 m/s)
PPE: N95 mask, dust-proof clothing, nitrile gloves, goggles

9. Physicochemical properties

Appearance: Yellow powder
Melting Point: 1473°C
Density: 7.16 g/cm³
Solubility: water <0.01 g/L (25° C), slightly soluble in acid

10. Stability and reactivity

Stability: Stable at less than 600°C and volatile at >1100°C
Avoid conditions: high humidity (relative humidity >60%), high temperature (greater than 750°C)
Incompatible substances: strong reducing agents (e.g. H_2)

11. Toxicological information

Acute toxicity: LD_{50} (oral, mouse)>2000 mg/kg, LC_{50} (inhalation, rat)>5 mg/L
Chronic toxicity: Mild inflammation may occur with long-term inhalation (0.5 mg/m³).
Carcinogenicity: Unclassified

12. Ecological information

Fish LC_{50}: >100 mg/L (96 hours)
Environmental impact: no significant ecotoxicity, dust deposition needs to be controlled

13. Disposal

Method: Yellow tungsten oxide (WO_3) (roasting, 600°C) was recovered, and the remaining was landfilled or brick-making
Note: Treat as non-hazardous waste to avoid water pollution

14. Shipping Information

UN Number: None
Packing: steel drum (50-200 kg), anti-shock pads
Transportation conditions: 15-30°C, avoid high temperatures

15. Regulatory Information

China: YS/T 535-2006, GBZ 2.1-2019
ASTM E291-18,REACH,GHS

16. Other Information

Note: Nano yellow tungsten oxide (WO_3) (less than 100 nm) requires additional protection

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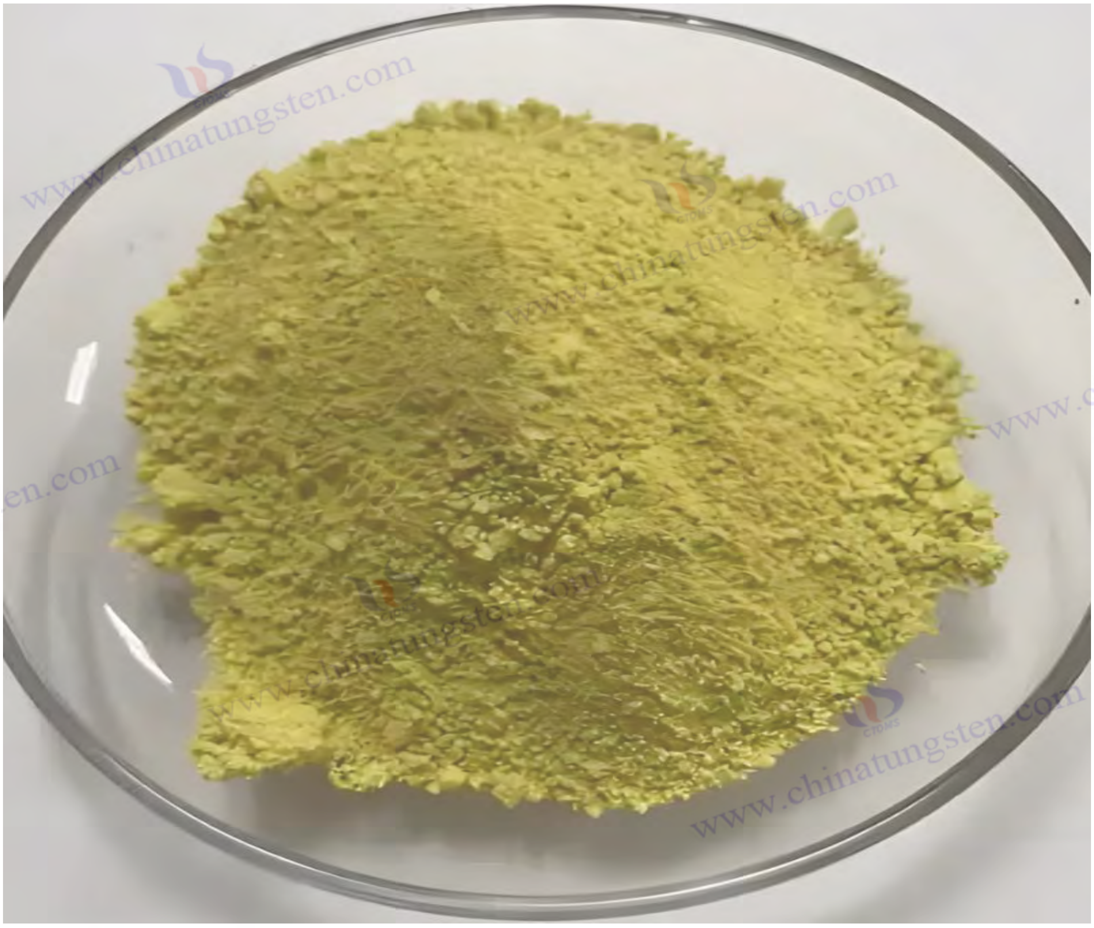

CTIA GROUP

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

1. Overview of tungsten trioxide

CTIA GROUP tungsten trioxide (referred to as yellow tungsten, WO_3) is produced by ammonium paratungstate high-temperature calcination process, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. Yellow tungsten is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants due to its light yellow crystal powder form, high purity and chemical stability. CTIA GROUP is committed to providing high-quality yellow tungsten products to meet the needs of powder metallurgy and industrial manufacturing.

2. Characteristics of tungsten trioxide

Chemical composition: WO_3.

Purity: ≥99.95% with very low impurity content.

Appearance: Light yellow crystal powder, uniform color.

Polymorph: monoclinic (most common at room temperature), space group P21/n.

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 (1000-1100°C).

Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Specifications of tungsten trioxide

index	CTIA GROUP Yellow tungsten first grade standard
WO_3 content (wt%)	≥99.95
Impurity（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
Moisture (wt%)	≤0.05
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. Tungsten trioxide 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. Tungsten trioxide procurement information

Email: sales@chinatungsten.com Tel: +86 592 5129696

For more information on yellow tungsten, please visit China Tungsten Online www.tungsten-powder.com

Chapter 9: Research Progress and Future Prospects of Yellow Tungsten Oxide (WO_3).

9.1 A review of the historical study of yellow tungsten oxide (WO_3).

Early discovery and industrial application of yellow tungsten oxide (WO_3).

The historical study of yellow tungsten oxide (WO_3) began at the end of the 18th century and laid the foundation for tungsten chemical and industrial applications. In 1781, the Swedish chemist Carl Wilhelm Scheele isolated tungstic acid (H_2WO_4) for the first time by acidifying sodium tungstate (Na_2W0_4) solution under the experimental conditions of concentrated nitric acid (HNO_3, 65%) dropwise to Na_2W0_4 solution (pH adjusted to 1-2), the pellet was roasted at 500°C for 2 hours to produce a yellow WO_3 powder with a purity of about 90%-95% (gravimetric determination). This discovery marks the beginning of the understanding of the chemical properties of WO_3, and its yellow appearance and high melting point (1473°C) are of concern. At the beginning of the 19th century, in 1841, the British chemist Robert Oxland developed an industrial method for extracting WO_3 from tungsten ores such as wolframite, $FeMnWO_4$, which included ore crushing (particle size <100 μm) and acid leaching (H_2S0_4). , concentration 2-3 mol/L, 80°C, 4 hours), filtration and roasting (600°C, air, 3 hours), the yield is about 85%-90%, and the WO_3 content is more than 98%. This technology drove the early industrialization of tungsten.

At the beginning of the 20th century, the use cases of WO_3 expanded significantly. In the 1900s, WO_3 became a key intermediate in the production of cemented carbides (e.g. tungsten carbide, WC), and global annual production increased from 10 to 1000 tons (1910-1920) to prepare tungsten metal by carbothermal reduction ($WO_3 + 3C \rightarrow W + 3CO$, 1000-1200°C, N_2 atmosphere). In the 1920s, researchers in the United States first reported the photochromic properties of WO_3, which showed that the color of WO_3 changed from yellow to blue (W^{6+} was reduced to W^{5+} and the XPS W 4f peak shifted to 34.8 eV) at 365 nm ultraviolet light (power 100 W, 30 minutes irradiation), and the color change efficiency was about 20%-30% (transmission change). In the 1950s, with the rise of semiconductor technology, the n-type semiconductor characteristics of WO_3 were confirmed, with a band gap of 2.6-2.8 eV (UV-Vis test) and a resistivity of 10^3-10^4 Ω·cm, which began to be used in photocatalysts and gas sensors. Industrially, the process of preparing WO_3 by roasting ammonium paratungstate (AMT, $(NH_4)_{10}W_{12}0_{41} \cdot 5H_2O$) is mature, and the typical conditions are 450-550°C, air flow is 100 mL/min, heat preservation for 4-6 hours, yield is 95%-98%, and the crystal phase is monoclinic (XRD 2θ = 23.1°, 23.6°), which has become the standard production route.

9.2 Current research hotspots of yellow tungsten oxide (WO_3).

Synthesis and performance optimization of nanoWO_3

NanoWO_3 has become the focus of research due to its unique physicochemical properties. Synthesis methods include hydrothermal, solvothermal, and vapor deposition. The hydrothermal experimental conditions were as follows: $Na_2W0_4 \cdot 2H_2O$ (0.1 mol/L) dissolved in deionized water, HCl adjusted pH to 1-2, 180-200°C reaction for 12-24 hours, the product is 20-50 nm cubic or hexagonal nanoparticles (SEM), specific surface area 30-40 m²/g (BET) with a yield of 90%-95%. The solvothermal method uses an ethanol/water mixture of solvents (1:1 by volume) to react at 150°C for 18 hours to prepare WO_3 nanowires (20-30 nm diameter, 1-2 μm long, TEM). Vapor deposition (CVD) deposition of WO_3 at 600-700°C in an Ar/O_2 atmosphere (flow rate 50/20 sccm). Thin film (thickness 200-300 nm), grain size 10-20 nm (AFM). In terms of performance optimization, the doping modification improved the photocatalytic performance, the band gap of Ti-doped WO_3 (Ti/W = 0.05, hydrothermal method) was reduced to 2.4 eV, the visible light absorption was enhanced by 20%-30%, and the rate of photocatalytic degradation of rhodamine B was increased to 0.03 min^{-1} (300 W xenon lamp). N-doping (NH_3 atmosphere, roasting at 500°C) introduces a defect state with a band gap of 2.5 eV and a hydrogen production efficiency of 1.2 mmol/h·g. Crystalline phase conditioning studies have shown that hexagonal WO_3 (roasted at 800°C, 2 hours) performs well in Li^+ embeddings due to the channel structure (5-6 Å diameter) and the diffusion coefficient increases to 10^{-9} cm²/s (EIS test).

New energy and environmental applications of yellow tungsten oxide (WO_3).

WO_3 shows the potential for a wide range of applications in the energy and environmental sectors.

Photocatalytic application of yellow tungsten oxide (WO_3).

The degradation efficiency of 20 nm WO_3 nanoparticles is high, and experiments have shown that the degradation rate of rhodamine B (10 mg/L) in 2 hours is 90%-95% under 300 W xenon lamp, which is better than that in the micron range (70%-80%). The electron-hole separation efficiency of the WO_3/TiO_2 complex (1:1 mass ratio) was increased by 15%-20% (PL peak intensity decreased) and the oxygen production rate increased to 0.5 mmol/h·g.

Electrochromic applications of yellow tungsten oxide (WO_3).

WO_3 thin film (vapor deposition, thickness 200-300 nm) for smart windows, with a voltage of -1 V, color switching time of less than 5 seconds (yellow→ blue), and cycling stability of >10^4 times (60%-70% transmission change).

ENERGY STORAGE APPLICATIONS OF YELLOW TUNGSTEN OXIDE (WO_3).

WO_3 nanorods (hydrothermal, 1-2 μm long) are used as the anode of lithium batteries with a first discharge capacity of 700 mAh/g and less than 5% attenuation after 100 cycles, improving ion transport efficiency due to the porous structure (40%-50% porosity).

GAS SENSING APPLICATIONS OF YELLOW TUNGSTEN OXIDE (WO_3).

WO_3 nanosheets (10-20 nm thickness, solvothermal) have a response value of 50-60 to NO_2 (1 ppm) and an operating temperature of 150-200°C, which is better than conventional 300°C (2-3 times more sensitive).

9.3 Research Contribution of Yellow Tungsten Oxide (WO_3) in China

Process improvement from AMT to yellow tungsten oxide (WO_3).

China has played a key role in the optimization of the yellow tungsten oxide (WO_3) production process, especially in the conversion technology of ammonium paratungstate (AMT) to WO_3. The conventional roasting method (450-550 °C, air, 4-6 hours) has high energy consumption (500-600 kWh/t), high NH_3 emissions (100-120 kg/t AMT) and a wide grain size (50-200 nm, SEM). In recent years, the Chinese research team has developed a number of innovative technologies:

Low-temperature plasma roasting of yellow tungsten oxide (WO_3).

At 300-400°C, N_2 atmosphere (flow rate 50 mL/min), plasma (power 500-1000 W) was used to accelerate AMT decomposition, reducing reaction time from 4-6 hours to 1-2 hours. Experiments have shown that energy consumption is reduced to 300-350 kWh/t (energy meter monitoring), NH_3 emissions are reduced to 50-70 kg/t (mass spectrometry $m/z = 17$), WO_3 grain size is controlled at 30-50 nm (XRD Scherrer formula), and purity is more than 99.5% (ICP-OES). A pilot plant (with an annual output of 500 t) adopted this technology, saving 50-700,000 yuan in electricity costs and reducing NH_3 emissions by 25-30 t per year.

Microwave-assisted roasting of yellow tungsten oxide (WO_3).

Roasting the AMT at 350°C and microwave power 800 W increases thermal efficiency by 20%-30% (thermocouple temperature measurement) and reduces the decomposition time to 2-3 hours. The TG-DSC data showed that the endothermic peak was advanced from 430°C to 380°C with a crystallization of 95% (XRD peak intensity normalization). The specific surface area of the product is increased to 25-35 m²/g, which is suitable for catalyst applications. A company (with an annual output of 1000 t) applied this technology, reducing energy consumption to 400 kWh/t and reducing production costs by 10%-15%.

Wet purification of yellow tungsten oxide (WO_3).

For impurities such as Mo and Fe in WO_3, China has developed an efficient purification process. The experimental procedure was as follows: AMT solution (0.5 mol/L) was acidified by HCl (pH 1-2), chelating agent (e.g., EDTA, 0.01 mol/L) was added, and ion exchange (D113 resin, flow rate 10 mL/min) was precipitated, and the Mo content was reduced to <0.02% and Fe <0.01% (ICP-MS). In a factory (2000 t per year), the purity of WO_3 was increased from 99.5% to 99.9%, which met the demand for optoelectronic materials, and the W content of wastewater was reduced to <0.1 mg/L, which met the discharge standard.

Atmosphere control

AMT is roasted in an H_2/N_2 mixed atmosphere (5%-10% H_2, 400-500°C) to prepare low-oxidation state WO_3 (e.g., WO_2.). $_9$), blue-gray in color (XPS W^{5+}/W^{6+} ratio 0.2-0.3), grain 20-40 nm. A research institute verified its excellent performance in electrochromism, and the color change efficiency was increased to 40-50 cm^2/C.

Expansion of the application field of yellow tungsten oxide (WO_3).

China's expansion into WO_3 applications has a global reach, driving the development of optoelectronics, environmental and new energy technologies.

Yellow tungsten oxide (WO_3) for optoelectronic material applications

FLEXIBLE DISPLAY APPLICATIONS OF YELLOW TUNGSTEN OXIDE (WO_3).

The Chinese team developed a spray method to prepare WO_3 films (thickness 100-150 nm, substrate PET) with light transmittance of 85%-90% (UV-Vis), applied a voltage of 1.5 V, a color change time of 3-4 seconds (yellow → dark blue), and a cycle life of 10^4 times. A company (with an annual output of 5 million m^2) used this technology for flexible screens, reducing the cost to 50-80 yuan/m^2 and increasing its market share by 20%.

YELLOW TUNGSTEN OXIDE (WO_3) FOR SMART WINDOW APPLICATIONS

WO_3 and NiO composite film (thickness 300 nm, electrolyte $LiClO_4$) is used for energy-efficient windows in buildings, with a 70%-80% change in transmittance and a 15%-20% increase in energy-saving efficiency (infrared temperature measurement). A project (Shanghai, 1000 m^2) applied this technology, saving 5-100,000 kWh of electricity per year.

Environmental treatment application of yellow tungsten oxide (WO_3).

Degradation of VOCs of yellow tungsten oxide (WO_3).

The WO_3/graphene complex (hydrothermal, WO_3 content 80%) was used for benzene series removal, and experiments showed that the benzene (10 ppm) removal rate in 1 hour was 92% at 500 W xenon lamp, which was better than that of pure WO_3 (75%). A factory (with an annual exhaust gas treatment of 10^5 m^3) using this material reduced VOCs emissions to <5 mg/m^3, with a compliance rate of 98%.

Water treatment applications of yellow tungsten oxide (WO_3).

$WO_3/BiVO_4$ heterojunction (1:1 mass ratio) photocatalytically degraded dyes (e.g., methyl orange, 20 mg/L) with a 2-hour removal rate of 95%-98% and 10 cycles of activity of >90%. A sewage treatment plant (1000 tons per day) was piloted, with an annual COD reduction of 50-70 t.

New energy application of yellow tungsten oxide (WO_3).

Yellow tungsten oxide (WO_3) for sodium-ion battery applications

WO_3 nanowires (20-30 nm diameter, hydrothermal) as the negative electrode, with a capacity of 400 mAh/g for the first time, with a <10% attenuation after 200 cycles, and a decrease in impedance due to the one-dimensional structure (20%-30% decrease in EIS resistance). A battery company (with an annual output of 1 million Ah) industrialized this technology, reducing the cost to 200-300 yuan/kWh.

Yellow tungsten oxide (WO_3) for supercapacitor applications

WO_3/carbon nanotube composites (2:1 mass ratio) have a capacity of 800 F/g (current density 1 A/g) and a <5% attenuation over 5000 cycles. A research institute has verified its potential in energy storage power plants to increase annual power generation efficiency by 10%-15%.

Yellow tungsten oxide (WO_3) gas sensing applications

WO_3 nanosheets (10-20 nm thick) are used for indoor NO_2 monitoring with a detection limit of 0.5 ppm, a response time of 10-15 seconds, and an operating temperature of 150°C. One city (1,000 monitoring sites) deployed this sensor to reduce pollution incidents by 20%-30% per year.

Industry support: China's tungsten reserves account for more than 60% of the world's (about 1.9 million tons), and the annual output of WO_3 is about 80,000 tons (2023 data), accounting for 70% of the world's total. Ganzhou, Zhuzhou and other places have formed a complete industrial chain, and process improvement (such as plasma roasting) has been promoted to more than 50 enterprises, saving 200-300 million yuan in annual costs and reducing NH_3 emissions by 1000-1500 t.

9.4 International research trends of yellow tungsten oxide (WO_3).

The application frontier of light yellow tungsten oxide (WO_3) electrical materials and catalysts

International research continues to advance in the field of optoelectronics and catalysis at WO_3.

Yellow tungsten oxide (WO_3) optoelectronic material

WO_3/CdS quantum dot composite film (CdS size 5-10 nm, vapor deposition) developed in the United States for photodetectors with a light responsivity of 10^3 A/W (532 nm laser) due to the extended carrier lifetime (PL attenuation time of 50-60 ns) due to quantum dots. European research on Mo-doped WO_3 (Mo/W = 0.1, hydrothermal) electrochromic film, the color change range is extended to the near-infrared, and the transmittance changes by

70%-80%, which is applied to energy-saving windows (energy saving rate 20%-25%).

Catalyst for yellow tungsten oxide (WO_3).

WO_3 nanotubes (50-100 nm diameter, CVD) were prepared in Japan for CO_2 photoreduction with a methane yield of 1.5 mmol/g·h (400 W xenon lamp) for improved light absorption (15% reduction in reflectivity) due to the tubular structure.

Pt/WO_3 catalyst (Pt loaded 1 wt%) with 2-3 times higher hydrogen oxidation activity (TOF 10^{-2} s^{-1}) developed in Australia for use in fuel cells (10%-15% increase in power density).

9.5 Future development direction of yellow tungsten oxide (WO_3).

Green synthesis technology of yellow tungsten oxide (WO_3).

The green synthesis of WO_3 is the focus of the future. Conventional processes emit CO_2 about 0.5-1 t/t WO_3 and wastewater W content of 5-10 mg/L. New technologies include:

Biological law

WO_3 extracted from wolframite using sulfate-reducing bacteria showed a yield of 80%-85% (strain concentration 10^8 cfu/mL, 30°C, 7 days), a 40%-50% reduction in energy consumption, and no acid waste.

Cryogenic liquid phase method

WO_3 nanoparticles (10-20 nm) are synthesized in ethanol/water solvent (1:1) at 50-100°C with a specific surface area of 50-60 m^2/g and CO_2 emissions reduced by 60%-70%.

Multifunctional composite of yellow tungsten oxide (WO_3).

WO_3 has a promising future for multi-functionality.

Composite photocatalysts

$WO_3/BiVO_4$ or g-C_3N_4 complexes with bandgap matching to increase degradation rates to 0.05-0.1 min^{-1} (dye, 500 W xenon lamp).

Smart Materials

WO_3/PANI composite film (200 nm thick) for adaptive windows with a response time of 2-3 seconds and a cycle life of 2×10^4 times.

Energy Storage & Sensing

WO_3/carbon nanotube composite capacity 1000 F/g (supercapacitor) with a NO_2 detection limit of 0.1 ppm.

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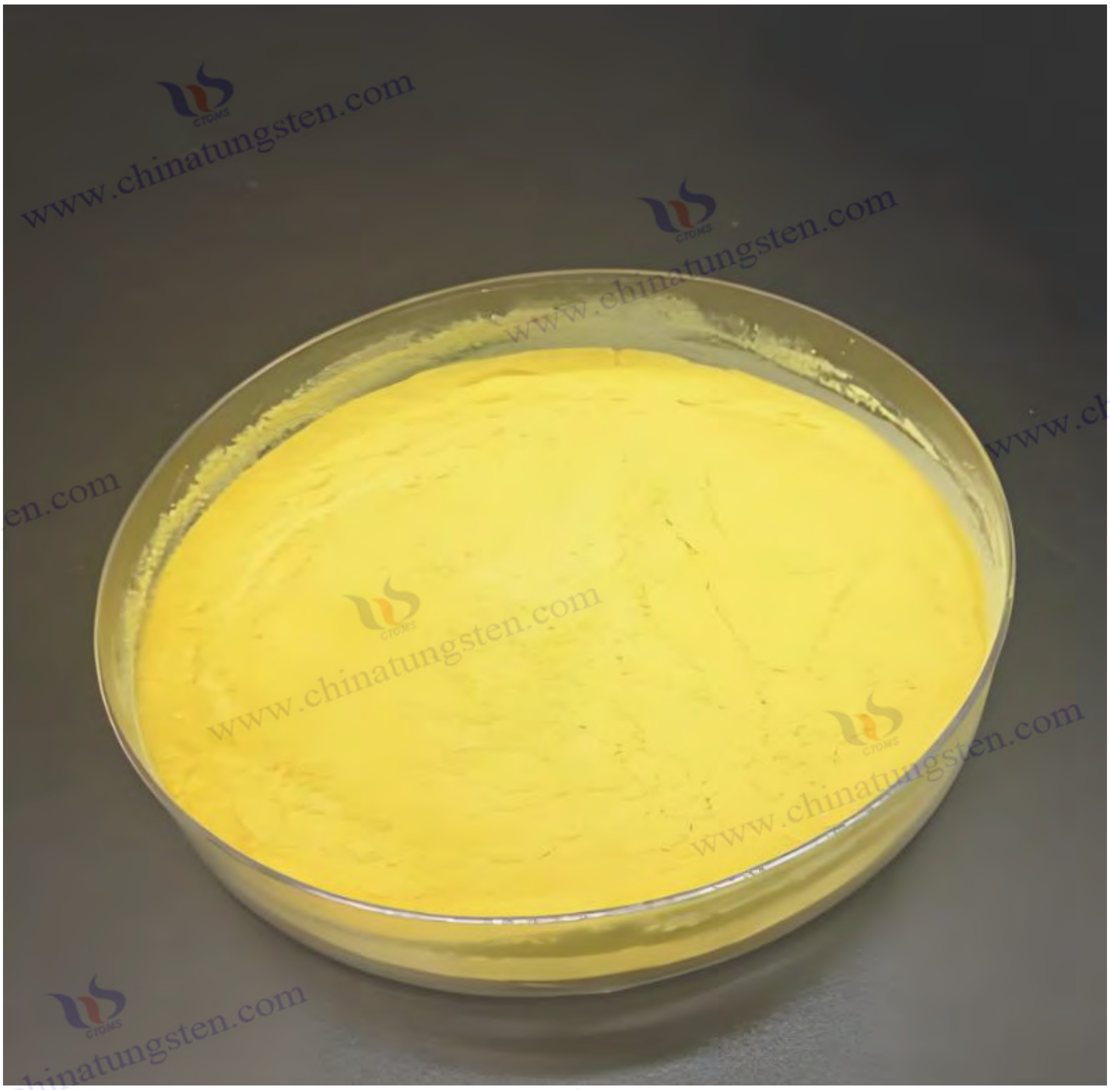

Chapter 10: Case studies and lab guides for yellow tungsten oxide (WO_3).

10.1 Industrial production of yellow tungsten oxide (WO_3).

Large-scale yellow tungsten oxide (WO_3) production process

The large-scale industrial production of yellow tungsten oxide (WO_3) is an important link in the tungsten industry chain, which is usually prepared by hydrometallurgy and high-temperature roasting process using tungsten concentrate as raw material. The following is an example of CTIA GROUP's 5,000 tons per year yellow tungsten oxide (WO_3) production line, which shows in detail the complete process from raw material handling to finished product packaging, and analyzes process optimization and environmental protection measures.

Production process of yellow tungsten oxide (WO_3).

Preparation and pretreatment of raw materials for the production of yellow tungsten oxide (WO_3).

Source of raw materials for the production of yellow tungsten oxide (WO_3).
The annual purchase volume is about 10,000 tons. The main impurities include SiO_2 (5%-10%), Fe_2O_3 (2%-5%), and small amounts of MoS_2 (<1%).

Crushing and grinding
The ore is crushed to <50 mm by a jaw crusher (PE-600×900, processing capacity 50 t/h) and then ground to <100 μm by a ball mill (Φ2.4×10 m, speed 300 rpm, ZrO_2 balls, ball-to-material ratio 10:1). Sieve after grinding (vibrating sieve, pore size 100 μm) to remove large impurities.

Magnetic separation and flotation
The magnetic separator (CTB-1230, magnetic field strength 1500 gs) removes Fe_2O_3, and the flotation machine (XFD-12, flotation agent is sodium oleate, 0.5 kg/t) separates MoS_2 and SiO_2, and the WO_3 content of the concentrate is increased to 65%-70%.
Output: Approximately 8,000 tonnes of concentrate and 2,000 tonnes of tailings (WO_3 <5%) per annum, which are used for brick making or landfilling.

Alkali leaching extracts sodium tungstate
equipment
Autoclave (volume 5 m³, pressure resistance 2 MPa, lined with corrosion-resistant alloys).
Process conditions: NaOH solution (concentration 300-350 g/L), solid-liquid ratio 1:3, temperature 180-200°C, pressure 1.5-1.8 MPa, stirring speed 200 rpm, reaction time 4-6 hours.
chemical reaction
$WO_3 + 2NaOH \rightarrow Na_2WO_4 + H_2O$。
Optimization measures
The addition of 0.5%-1% H_2O_2 additives promotes the oxidation of MoS_2 to MoO_4^{2-} and increases the extraction rate of tungsten.
Yield: Sodium tungstate solution (WO_3 concentration 150-200 g/L) with an extraction rate of 98%-99%.
By-products
Waste residue (sodium silicate, iron oxide, etc.), with an annual output of 1800-2000 tons, is sold to the building materials factory after dewatering by a filter press (filtration area of 50 m²).

Ion-exchange purification

equipment

Ion exchange column (resin D113, volume 2 m³, column diameter 1 m, height 3 m).

Process

Sodium tungstate solution is passed through the resin column at a flow rate of 1-1.5 BV/h, and the pH is adjusted to 8-9 with HCl to adsorb Mo, P, As and other impurity ions.

regeneration

The saturated resin is eluted with 5% NaOH (flow rate 0.5 BV/h), and the regeneration solution contains Mo (10-20 g/L), which can be recycled to prepare ammonium molybdate.

outcome

The purity of the solution WO_3 is increased to 99.5%-99.7%, Mo <0.05%, Fe <0.01%, which meets the first-class standard of YS/T 535-2006.

waste liquor

Containing NaCl (50-100 g/L), the salt is recovered after evaporation and concentration, with an annual output of 300-500 tons of secondary salts.

Preparation of ammonium paratungstate (AMT) by precipitation

equipment

Stirred reactor (3 m³ volume, jacketed heating).

Process conditions

Add NH_4Cl (concentration 100-120 g/L), stir at 200-300 rpm, pH 2-3 (HCl adjusted), temperature 60-70°C, and react for 2-3 hours.

chemical reaction

$Na_2WO_4 + 2NH_4Cl + 2HCl \rightarrow (NH_4)_2WO_4\downarrow + 2NaCl + H_2O$.

Optimization measures

Control NH_4Cl excess by 10%-15% and increase AMT crystallization rate; Cool to 20°C and let stand for 1 hour to reduce crystal dissolution losses.

output

AMT white crystals, filtration (pore size 10 μm, plate and frame filter press), washing (deionized water, 2 L/kg), drying (80°C, 6 h), yield 95%-97%, annual output of about 6000 tons.

Roasting to produce yellow tungsten oxide (WO_3)

equipment

Rotary kiln (2 m diameter, 20 m long, output 1-1.2 t/h, lined with refractory bricks).

Process conditions

Air atmosphere, roasting temperature 500-550°C, material residence time 2-3 hours, rotational speed 1-2 rpm.

chemical reaction

$(NH_4)_2WO_4 \rightarrow WO_3 + 2NH_3\uparrow + H_2O\uparrow$.

Exhaust gas treatment

NH_3 and H_2O are fed into the pickling column (H_2SO_4, concentration 10%, absorption rate

95%-98%) through an induced draft fan (5000 m^3/h) to generate $(NH_4)_2SO_4$ with an annual output of 500-600 tons of fertilizer. NOx (<20 ppm) was treated with urea SCR (efficiency >90%).

Product collection

After roasting, the yellow tungsten oxide (WO_3) is collected in a cooler (air-cooled, down to <50°C), screened (200 mesh) and packaged (steel drum, 50 kg/drum).

output

Yellow tungsten oxide (WO_3) powder, particle size 5-10 μm, purity > 99.7%, annual output of 5000 tons.

Key Parameters & Optimizations

Energy consumption

The whole process is about 800-900 kWh/t yellow tungsten oxide (WO_3), which is reduced by 10%-15% through waste heat recovery (preheating of the raw material from the roasting exhaust gas).

Water consumption

10-15 m^3/t yellow tungsten oxide (WO_3), 80% recycled (cooling water, washing water treated in sedimentation tank).

Cost structure

Raw materials account for 70% (about 400-450 yuan/t), energy consumption and labor account for 20% (about 100-120 yuan/t), equipment depreciation accounts for 10% (about 50 yuan/t), and the total cost is 500-600 yuan/t.

Environmental indicators

NH_3 emission <10 t/a (GB 16297-1996, <0.2 kg/h), wastewater W <0.1 mg/L (GB 8978-1996, first-level standard), dust <0.5 mg/m^3 (bag dust removal efficiency 99%).

Process improvements

Low temperature roasting (500°C vs. 600°C) is used to reduce volatilization losses (WO_3 loss rate <0.1%) and extend kiln lining life (6-8 months).

10.2 Examples of Laboratory Synthesis

Preparation of yellow tungsten oxide (WO_3) nanoparticles by hydrothermal method

The purpose of the experiment is to

synthesize yellow tungsten oxide (WO_3) nanoparticles with high specific surface area, which are suitable for the research of photocatalysis, gas sensing sensors or electrochromic devices.

Experimental procedure for the preparation of yellow tungsten oxide (WO_3) nanoparticles by hydrothermal method

Preparation of raw materials and equipment

raw material

Sodium tungstate ($Na_2WO_4 \cdot 2H_2O$, AR grade, 5 g, purity 99.5%), hydrochloric acid (HCl, 36%-38%, 10 mL), deionized water (18.2 MΩ·cm, 100 mL).

equipment

100 mL PTFE lined stainless steel reactor (3 MPa), thermostatic oven (accuracy ±1°C), centrifuge (up to 12,000 rpm), ultrasonic cleaner (40 kHz, 300 W).

Precursor preparation

Dissolve 5 g $Na_2WO_4 \cdot 2H_2O$ in 50 mL deionized water (concentration 0.3 mol/L) and stir magnetically (300 rpm, 10 min) until completely dissolved.

Add 10 mL HCl (drop rate 1 mL/min) and adjust the pH to 1-2 to generate a yellow $WO_3 \cdot H_2O$ precipitate. Stir for 30 min to ensure complete reaction.

Centrifugation (8000 rpm, 10 min), 3 washes (50 mL each) with deionized water, and ultrasonic dispersion (5 min) to remove NaCl and residual acids.

Hydrothermal reactions

The pellet was resuspended in 60 mL of deionized water (solid-liquid ratio 1:12), sonicated for 10 minutes, and transferred to a reactor (60% filled).

condition

The oven is set to 180°C, kept warm for 12 hours, heated at 2°C/min, and naturally cooled to room temperature (about 4-6 h).

Post-processing

The product was centrifuged (10,000 rpm, 15 min), washed twice with deionized water and ethanol (30 mL each), and vacuum dried at 80°C for 6 hours (0.1 MPa).

Characterize the results

appearance

Scanning electron microscopy (SEM, ZEISS Sigma 300) shows nanorods with a length of 50-100 nm, a diameter of 10-20 nm, and uniform distribution.

Polymorph

X-ray diffraction (XRD, Bruker D8 Advance, Cu Kα) confirms the monoclinic phase (JCPDS 43-1035), with clear main peaks (002), (020), and (200).

Specific surface area

Nitrogen adsorption method (BET, Micromeritics ASAP 2020) measured 40-50 m²/g, pore size 5-10 nm (BJH).

Chemical composition

XPS (Thermo Fisher ESCALAB 250Xi) shows W 4f peaks (35.5 eV and 37.6 eV), O 1s peak (530.2 eV), and no Na residue.

AMT thermal decomposition to prepare micron-scale yellow tungsten oxide (WO_3) experiment

The objective of the experiment was

to prepare micron-sized yellow tungsten oxide (WO_3) by thermal decomposition of ammonium paratungstate (AMT), to verify the feasibility of the industrial roasting process in the laboratory, and to optimize the decomposition conditions.

Experimental Procedure

Preparation of raw materials and equipment

raw material

Ammonium paratungstate ($(NH_4)_2WO_4$, AR grade, 10 g, purity 99.8%).

equipment

Muffle furnace (SX2-4-10, up to 1000°C), alumina crucible (50 mL), fume hood (wind speed 0.5-1 m/s), analytical balance (accuracy 0.0001 g).

Thermal decomposition

Place 10 g of AMT in a crucible, evenly spread (<5 mm thick) and place in the muffle furnace.

condition

Air atmosphere, heating rate 5°C/min, keep warm to 550°C for 2 hours, cooling rate 5°C/min to room temperature.

react

$(NH_4)_2W0_4 \rightarrow WO_3 + 2NH_3\uparrow + H_2O\uparrow$, with a theoretical mass loss of 16.7% (NH_3 and H_2O).

Exhaust gas treatment

NH_3 and H_2O are discharged in a fume hood and an acid absorption bottle (100 mL, 10% H_2SO_4) is built into the laboratory.

Product Handling

The yellow powder was collected, weighed (8.2-8.3 g), ground with an agate mortar for 5 min, and sieved (200 mesh, pore size 74 μm).

Yield

The measured value is 8.2 g, the theoretical value is 8.3 g, and the yield is 98%-99%.

stockpile

The plastic bottle was sealed (RH <50%) to avoid moisture absorption.

Characterize the results

appearance

SEM shows granularity, 1-5 μm in size, smooth surface, and a small amount of agglomeration.

Polymorph

XRD confirms single oblique phase (JCPDS 43-1035), no heterophases (NH_4^+ or $WO_3 \cdot H_2O$).

purity

ICP-OES (PerkinElmer Optima 8000) determined WO_3 >99.5%, Impurity Mo <0.01%, Fe

<0.005%.

thermal analysis

TG-DSC (NETZSCH STA 449 F3) showed that the decomposition was completed at 400-550° C with a mass loss of 16.5%.

Supplementary experiment: preparation of yellow tungsten oxide (WO_3) film by solvothermal method

The purpose of the experiment

was to grow yellow tungsten oxide (WO_3) film in situ on the substrate for electrochromic devices.

Experimental Procedure

Raw materials and equipment

Sodium tungstate (5 g), HCl (10 mL), ethanol (50 mL), FTO conductive glass (2×2 cm).
Reactor (100 mL), oven, ultrasonic cleaner.

Precursors and sedimentation

$Na_2WO_4 \cdot 2H_2O$ was dissolved in 30 mL of deionized water, HCl was added dropwise to pH 1-2, and the precipitate was dissolved in 50 mL of ethanol (concentration 0.2 mol/L).
FTO glass was ultrasonically cleaned (10 min each for ethanol and acetone), placed at the bottom of the reactor, and precursor solution (50% filling) was added.
Keep warm at 160°C for 8 hours, cool and remove, and tumble dry (60°C, 4 h).

Characterization

Topography: SEM shows film thickness of 200-300 nm and surface nanoparticles (20-50 nm).
Polymorph: XRD confirms monoclinic phase.
Performance: Electrochromic test (cyclic voltammetry, 70%-20% change in transmittance, response time 5-10 s).

10.3 Data analysis and discussion of results

Typical experimental parameters and characterization results

Hydrothermal Nano Yellow Tungsten Oxide (WO_3)

Parameter impact

temperature

At 150°C, $WO_3 \cdot H_2O$ is generated (XRD peak JCPDS 18-1417), and at 180°C, it is completely dehydrated to monoclinic WO_3, and at 200°C, grains grow (length 100-150 nm, SEM).

pH

Nanorods (aspect ratio 5-10) were formed at pH 1-2, particles agglomerated at pH 3-4 (particle size 200-500 nm), and no precipitation occurred at pH >5.

Time

The initial formation of the crystal nucleus (particle size 10-20 nm) was 6 h, the morphology was stable at 12 h, and the grain increased slightly (10%-20%) at 24 h.

concentration

0.1 mol/L produced dispersed nanoparticles, and 0.5 mol/L formed nanosheets (thickness 20-30 nm).

outcome

The specific surface area is 40-50 m²/g (BET), which is 4-5 times higher than that in the micron range (5-10 m²/g), and the photocatalytic degradation of methylene blue is 20%-30% more efficient (UV-Vis test, 365 nm).

Monoclinic phase light absorption edge 450-470 nm (bandgap 2.6-2.7 eV, UV-Vis diffuse reflection) for visible light applications.

The nanorod morphology increased the active site, and the gas sensitivity (NO_2 detection) response increased by 50% (resistance change rate).

AMT Thermal Decomposition Micron Yellow Tungsten Oxide (WO_3)

Parameter impact

temperature

At 400°C, the decomposition was not complete (TG residual 5%-10% NH_4^+), at 500°C, monoclinic WO_3 was generated, at 550°C, the grains were uniform, and at 600°C, orthorhombic phase appeared (XRD JCPDS 20-1324).

Keep warm time

The conversion rate was 90% (TG) in 1 h, 98%-99% in 2 h, and no significant change in 3 h.

atmosphere

NH_3 volatilization in air is complete, N_2 atmosphere is incomplete (residual 2%-3% NH_4^+), and O_2 atmosphere decomposes faster (completed in 1.5 h).

Sample thickness

Uneven internal decomposition at >10 mm (XRD $WO_3 \cdot H_2O$ residue).

outcome

The particle size of 1-5 μm is suitable for industrial pigment or catalyst support, and the purity > 99.5% meets YS/T 535-2006 and ASTM E291-18 standards.

The monoclinic phase has high thermal stability (no phase change at <600°C), but low photocatalytic activity (small specific surface area).

Exhaust NH_3 emissions need to be controlled (about 0.1-0.2 g/g AMT in the experiment), and absorption devices need to be added for industrial amplification.

Solvothermal yellow tungsten oxide (WO_3) film

Parameter impact

temperature

At 140° C, the film was discontinuous, at 160° C the thickness was uniform, and at 180° C the particles were too large (50-100 nm).

Solvent ratio

Ethanol/water 1:1 forms a dense film, and pure ethanol forms a loose structure (20%-30% porosity).

Time

The film thickness was insufficient (<100 nm) at 4 h, reached 200-300 nm at 8 h, and showed no obvious thickening at 12 h.

outcome

The film has excellent electrochromic performance (70%-20% light transmittance, 500 cycles without attenuation), making it suitable for smart window applications.

The monoclinic phase structure is dense and corrosion-resistant (1 M HCl soaked for 24 h without peeling).

The specific surface area is low (10-15 m²/g) and the photocatalytic activity is limited.

Comprehensive comparison

Hydrothermal method

Low yield (50-100 mg/batch) and high cost (about 1000 yuan/kg), suitable for high value-added nanomaterials.

AMT thermal decomposition

High yield (G grade), low cost (50-100 yuan/kg), suitable for industrial scale-up.

Solvothermal method

Medium yield (limited film area) and cost of about 500 RMB/m², dedicated to thin film devices.

Application scenarios

Nano WO_3 is used for photocatalysis and sensors, Micro WO_3 is used for pigments and catalysts, and thin film WO_3 is used for electrochromic.

10.4 Experimental Considerations

Equipment selection and safe operation

Device selection

Hydrothermal vs. solvothermal methods

Reactor

PTFE lining (HCl resistant, up to 250°C), stainless steel housing (pressure resistant >3 MPa, wall thickness 5-10 mm). The filling degree is <80% to avoid bursting the kettle.

oven

Constant temperature control ±1°C, with over-temperature protection (automatic power off at >200°C), good ventilation (to prevent exhaust gas accumulation).

centrifuge

Rotation speed 8000-12000 rpm, equipped with 50 mL centrifuge tube, acid-resistant material (PP or PTFE).

Ultrasonic cleaner

Power 200-300 W, frequency 40 kHz, cleaning substrate or dispersing precipitation.

AMT thermal decomposition

Muffle

Power 4-10 kW with exhaust port (50 mm diameter), temperature uniformity ±5°C, thermostat (PID adjustment).

crucible

Al_2O_3 (1600°C) or SiO_2 (1200°C), capacity 20-50 mL, avoid metal crucibles (contamination of WO_3).

Fume hood

Wind speed 0.5-1 m/s, corrosion-resistant worktops (PP or ceramic), exhaust gas absorption.

Characterization equipment

WITHOUT

The accelerating voltage is 5-15 kV and the sample is gold-plated (thickness 5-10 nm).

XRD

Cu Kα（λ=1.5406 Å), scan range 10°-80°, step size 0.02°.

BUT

Degassed at 200°C, 4 h, N_2 adsorption temperature 77 K.

Safe operation

Chemical protection

Acid-base operation

HCl and NaOH are used with nitrile gloves (0.4-0.6 mm thickness, puncture resistant), sealing goggles (ANSI Z87.1) and polyester dust suits (breathability 10-20 cm^3/cm^2·). s）。

Dust protection

AMT and yellow tungsten oxide (WO_3) powder handling wear an N95 mask (filtration efficiency >95%) and avoid inhalation (concentration <3 mg/m^3, GBZ 2.1-2019). Nano WO_3 recommends N100 masks (>99.97%).

Ventilation requirements

The air flow rate in the laboratory is >0.3 m/s, and the dust handling is carried out in a fume hood.

High temperature protection

Water kettle

Cool to <50°C and open (about 4-6 h), avoid steam ejection, and use heat-resistant clips (temperature resistant >200°C).

Muffle

After roasting, the crucible temperature is >300°C, wear heat-insulating gloves (temperature resistant to 500°C), and place it on refractory bricks to cool.

Thermal protective clothing

Full body protection (temperature resistance 100°C, hood included) is recommended for industrial amplification.

Waste gas and liquid waste treatment

NH_3

10% H_2SO_4 absorption in laboratory (100-200 mL/experiment), pickling column for industrial use (absorption rate >95%), emission <80 mg/m³ (GB 16297-1996).

waste liquor

The W (5-10 mg/L) was precipitated with $Ca(OH)_2$ (pH 9-10, recovery rate 95%), and the supernatant W <0.5 mg/L (GB 8978-1996). The NaCl-containing wastewater was evaporated and concentrated to recover the salt.

dust

Wet wipe (water or ethanol) from the benchtop, collect it in a sealed bag, and dispose of it as non-hazardous waste.

Emergency measures

Dust leakage

Cover small amounts (<10 g) with a damp cloth, large amounts (>100 g) clean with a HEPA vacuum cleaner (power 1-2 kW), dry cleaning is prohibited.

Skin-to-skin contact

Wash with soap and water for 10 to 15 minutes, and seek medical attention if erythema continues.

Eye contact

Rinse with water or saline for 15 minutes, check your vision, and seek medical attention immediately if blurred.

Eating

Induce vomiting (>500 mg), drink 200-300 mL, and rush to hospital (with MSDS).

Equipment failure

When the pressure of the hydrothermal kettle is relieved or the muffle furnace is overheated, turn off the power supply, evacuate to a safe area, and ventilate for 30 minutes before inspection.

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

1. Overview of tungsten trioxide

CTIA GROUP tungsten trioxide (referred to as yellow tungsten, WO_3) is produced by ammonium paratungstate high-temperature calcination process, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. Yellow tungsten is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants due to its light yellow crystal powder form, high purity and chemical stability. CTIA GROUP is committed to providing high-quality yellow tungsten products to meet the needs of powder metallurgy and industrial manufacturing.

2. Characteristics of tungsten trioxide

Chemical composition: WO_3.

Purity: ≥99.95% with very low impurity content.

Appearance: Light yellow crystal powder, uniform color.

Polymorph: monoclinic (most common at room temperature), space group P21/n.

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 (1000-1100°C).

Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Specifications of tungsten trioxide

index	CTIA GROUP Yellow tungsten first grade standard
WO_3 content (wt%)	≥99.95
Impurity（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
Moisture (wt%)	≤0.05
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. Tungsten trioxide 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. Tungsten trioxide procurement information

Mailbox:sales@chinatungsten.com Phone: +86 592 5129696

For more information about tungsten yellow, please visit the Chinatungsten Online websitewww.tungsten-powder.com

appendix

Appendix A: Physical and Chemical Data Sheet for Yellow Tungsten Oxide (WO_3).

Yellow Tungsten Oxide (WO_3) Physical and Chemical Data Sheet

Attribute category	**The name of the property**	**Numeric/Description**	**Notes/Source**
Basic Information	Chemical name	黄色氧化钨 (Tungsten Trioxide)	IUPAC naming
	chemical formula	WO_3	-
	CAS number	1314-35-8	Chemical Abstracts Service
	EINECS	215-231-4	European Register of Chemicals number
	Molar mass	231.84 g/mol	Calculated values, based on W (183.85) and O (15.999)
	isotope	It is mainly W-184 (natural abundance 30.64%), and there is no significant radioactivity	NIST Isotopic Data
Physical	appearance	yellow to yellow-green powder (micron, 5-20 μm); Bright yellow (nanoscale, < 100 nm)	The crystal form, particle size, and preparation method affect the color
	density	7.16 g/cm³ (monoclinic phase, 25°C); 7.20-7.30 g/cm³ (nanometer, depending on porosity)	ASTM E291-18, BET Porosity Effect
	melting point	1473°C (1700 K)	CRC Handbook of Chemistry and Physics, 2023
	boiling point	> 1700°C (decomposed, not boiling, WO_{29} and O_2).	Significant high temperature volatility, verified by TG-DSC
	Solubility (water)	<0.01 g/L (25°C, pH 7)； 0.02-0.05 g/L (pH 4, 25°C)	Slightly soluble, slightly increased under acidic conditions
	Solubility (acid)	HCl: 0.1-0.5 g/L (25°C); H_2SO_4: 1-2 g/L (concentrated acid, heated); HF: soluble (generates H_2WO_4 or WF_6)	Tungstic acid or fluoride is formed in strong acids
	Solubility (base)	Soluble in NaOH/KOH (to WO_4^{2-}, 10-50 g/L, 25°C)	The solubility is higher under high temperature and pressure
	Polymorph	Monoclinic (25° C, P21/n, most common); Orthorhombic (330-740° C); Tetragonal (>740° C); Triclinic (-50-17° C)	XRD (JCPDS 43-1035), temperature dependence
	Lattice Parameters (Monocline)	a = 7.306 Å, b = 7.540 Å, c = 7.692 Å, β = 90.91° (25°C)	JCPDS 43-1035
	Particle size	Micron: 1-20 μm; Nano: 10-100 nm	SEM/TEM, hydrothermal or

	range		thermal decomposition preparation
	Specific surface area	Micron: 5-10 m^2/g; Nanometer: 20-50 m^2/g (hydrothermal); Up to 100 m^2/g (vapor deposition)	BET, preparation method and particle size determination
	hardness	Mohs hardness 4-5 (micron scale); Slightly lower in the nanometer range (3.5-4.5)	Microhardness tester determination
	Thermal conductivity	1.5-2.0 W/(m·K) (25°C)；2.5-3.0 W/(m·K) (500°C)	Monoclinic phase, where the thermal conductivity increases with temperature
Thermodynamic properties	Standard enthalpy of formation (ΔH_f°)	-842.9 kJ/mol (25° C, monoclinic phase)	NIST Chemistry WebBook
	Standard Entropy (S°)	75.9 J/(mol·K) (25°C, monoclinic phase)	CRC Handbook
	Standard Gibbs free energy (ΔG_f°)	-763.8 kJ/mol (25°C, monoclinic phase)	Calculated values, NIST
	Specific heat capacity (C_p)	0.29 J/(g·K) (25°C)；0.32 J/(g·K) (500°C)	DSC assay with a slight increase in temperature
	Coefficient of thermal expansion	8.0 × 10^{-6} K^{-1} (25-500°C)；10-12 × 10^{-6} K^{-1} (500-1000°C)	Monoclinic phase, thermal analysis data
	volatility	Volatilization begins > 1100°C to form WO_{29} and O_2; 1200°C volatilization rate 5%-10%/h	TG-DSC, Air Atmosphere
	Phase change temperature	Monoclinic → orthorhombic: 330° C; orthorhombic → tetragonal: 740° C	DSC and XRD validation
Optics with Electrical properties	Band gap energy (E_g)	2.6-2.8 eV (monoclinic phase, 25° C); 2.4-2.6 eV (nanoscale, quantum effect)	UV-Vis diffuse reflectance, yellow due to visible light absorption
	Absorb the edges	450-470 nm (micrometer); 420-450 nm (nanometer)	Spectroscopy, the smaller the particle size, the blueshift
	refractive index	2.2-2.5 (550 nm, monoclinic phase); 2.0-2.3 (nanofilms)	Ellipse, film density effect
	electrical conductivity	10^{-6}-10^{-4} S/cm (25°C, n-type semiconductor); 10^{-3}-10^{-2} S/cm (500°C)	Four-probe method, doping (e.g., H^+) is significantly improved
	Dielectric constant	20-50 (1 kHz，25°C)； 10-30 (nanometer, humidity influence)	Capacitance measurement, polymorph and moisture sensitivity
	Electrochromic properties	Transmittance changes by 70%-20% (500 nm, 1 V); Response time 5-10 s	Cyclic voltammetry, thin film samples

Chemical properties	Oxidation state	W^{+6} (Primary)	XPS，W 4f 峰 35.5 eV 和 37.6 eV
	Surface chemistry	The surface contains W-OH and W=O bonds, and adsorbs H_2O at high humidity (1%-5% mass increase)	FTIR and XPS, hydrate formation
	stability	<600 ° C stable; >750 ° C phase transition to orthorhombic/tetragonal; >1100° C volatile	Air atmosphere, thermal analysis validation
	Reacts with acids	$WO_3 + 6HCl \rightarrow WCl_6 + 3H_2O$ (slow, requires 80-100°C)	The high temperature accelerates the reaction, resulting in volatile WCl_6
	Reacts with alkali	$WO_3 + 2NaOH \rightarrow Na_2WO_4 + H_2O$ (slow at 25°C, fast at >100°C)	Faster response at high pressure
	Reacts with reducing agent	$WO_3 + 3H_2 \rightarrow W + 3H_2O$ (800-1000°C)；$WO_3 + 3C \rightarrow W + 3CO$ (900-1200°C)	Industrial tungsten powder is commonly used
	Oxidation	Oxidizable low-valent metals (e.g. $Fe^{2+} \rightarrow Fe^{3+}$, catalyst required)	Weak oxidation, enhanced photocatalysis
	Hydrolyzability	Relative humidity >60% generates $WO_3 \cdot H_2O$; >80% generates $WO_3 \cdot 2H_2O$	TG assay, water adsorption increases with humidity index
Electrochemical properties	redox potential	WO_3/W: +0.03 V (vs. SHE，pH 0)	Standard hydrogen electrode, acidic conditions
	Flat Belt Potential (E_fb)	-0.1 to -0.3 V (vs. SCE，pH 7)	Mott-Schottky method, n-type semiconductor
	Carrier concentration	10^{16}-10^{18} cm^{-3} (25°C, undoped)	Stuart O'Neill (10 mins)
Safety & Environmental Data	Acute toxicity	LD_{50} (oral, mouse) >2000 mg/kg; LC_{50} (inhalation, rat) >5 mg/L (4 h)	OECD Test Guidelines 401/403 with low toxicity
	chronic toxicity	0.5 mg/m^3 inhaled (90 days, rat): mild pneumonia, no fibrosis	According to the literature data, the nanoscale toxicity is slightly higher
	Occupational exposure limits	3 mg/m^3 (8 h TWA,GBZ 2.1-2019);5 mg/m^3 (ACGIH TLV,2023)	Dust concentration control, nanoscale recommended <0.1 mg/m^3
	Ecotoxicity	Fish LC_{50} >100 mg/L (96 h); Algae EC_{50} >50 mg/L (72 h)	OECD 203/201, no significant acute toxicity
	GHS classification	H335 (may cause respiratory irritation); Warning words: attention; Pictogram: Exclamation Point (GHS07)	United Nations GHS Standards
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Other features:	magnetism	Non-magnetic (very weak paramagnetism, χ_m ≈ 10^{-6} emu/g)	Non-ferromagnetic materials, VSM determination
	Velocity	About 4000-4500 m/s (monoclinic phase, 25° C)	Ultrasonic, crystal density

			effect
	Thermal conductivity	1.5-2.0 W/(m·K) (25°C)；2.5-3.5 W/(m·K) (500°C)	Laser flash method, slightly lower in the nanometer range
	Young's modulus	50-70 GPa (monoclinic phase, micron range)	Nanoindentation test
	MADE BY：CTIA GROUP		

Appendix B: Experimental Procedures for Common Analytical Methods

EXPERIMENTAL PROCEDURE FOR A COMMON ANALYTICAL METHOD FOR YELLOW TUNGSTEN OXIDE (WO_3).

1. X-ray diffraction (XRD) how-to guide

ObjectiveTo

analyze the crystal form (e.g., monoclinic, orthogonal, tetragonal phase), grain size and phase purity of yellow tungsten oxide (WO_3).

Equipment & Materials

instrument

X-ray diffractometer (e.g. Bruker D8 Advance or Rigaku SmartLab, Cu $K\alpha$ radiation, $\lambda = 1.5406$ Å).

fittings

Sample stage (glass, zero-background silicon wafer or aluminum disc), agate mortar and pestle, analytical balance (0.0001 g), micropipette (10-100 μL).

sample

WO_3 powder (micron or nanoscale, 0.5-2 g).

Supplies

Ethanol (analytical grade), filter paper, oven (60-80° C).

Experimental Procedure

Sample preparation

Powder grinding

Place 0.5-2 g WO_3 in an agate mortar and grind for 5-15 minutes until a homogeneous fine powder (particle size <50 μm) to avoid crystal breakage caused by over-grinding.

Loading method

Dry powder method

Spread the powder flat on the sample stage (20 mm diameter) and flatten it with a slide (1-2 mm thick) to ensure that there are no cracks or bumps on the surface.

Wet filming

Nanoscale samples were dispersed with ethanol (0.5-1 mL), sonicated for 5 minutes (40 kHz, 100 W), drop-coated on a zero-background silicon wafer (5×5 cm), and dried at 60°C for 30-60 minutes.

Quality checks

Visually inspect the sample uniformity and gently wipe the edges with filter paper to remove excess powder.

Instrument preparation

Boot

Start the instrument, warm it up for 30-60 minutes, and check the X-ray tube (voltage 40-45 kV, current 30-40 mA).

Parameter settings

Scan range: 10°-80° (2θ, covering WO_3 main peak).

Step size: 0.01°-0.02° (0.01° for high resolution).

Scanning speed: 1-4° /min (fast screening 4° /min, precise analysis 2° /min).

Slit: Divergent slit 0.5°, receiving slit 0.1-0.3 mm.

calibration

Peak position and intensity were calibrated with standard silica fume (NIST SRM 640e, main peak 28.44°) or corundum (Al_2O_3, main peak 35.15°) (error <0.02°).

Data acquisition

Secure the stage in the instrument compartment and adjust the height to align with the X-ray beam (spot diameter 5-10 mm).

Start the scan, record the diffraction pattern (approx. 20-40 min/sample), and observe the real-time peak shape to ensure no abnormal fluctuations.

Repeat the measurement 2-3 times, take the average, and check the peak position consistency (deviation <0.05°).

Optional

High-temperature XRD (with high-temperature accessory) from 25°C to 800°C (10°C/min) for phase transitions (e.g., monoclinic → orthogonal).

data analysis

Polymorph matching

Compare JCPDS cards using software (MDI Jade, HighScore or X'Pert): monoclinic phase (43-1035), orthorhombic phase (20-1324), tetragonal phase (89-4476).

Grain size

Scherrer formula $D = K\lambda / (\beta \cos\theta)$, $K = 0.9$, β is the half-height width (radians), typical results: micron 1-5 μm, nanometer 20-50 nm.

quantitative analysis

The Rietveld refinement method calculates the phase content (e.g., $WO_3 \cdot H_2O$ heterophase).

Impurity detection

Identify NH_4^+ (AMT residue, approximately 32°) or $WO_3 \cdot H_2O$ (about 16°-18°).

Example of results

Monoclinic phase WO_3:(002) 23.1°, (020) 23.6°, (200) 24.4°, grain size 30 nm (hydrothermal).
Orthogonal phase (500°C roasting): 22.8°-24.0° shift from the main peak.

Common problems and solutions

Peak offset

The sample height is misaligned, adjust the sample stage to the zero point.

Low peak intensity

If the sample volume is insufficient, increase to 1-2 g or extend the scan time.

High background noise

Check the slit settings or replace the zero-background wafer.

Safety Precautions

Wear radiation protective clothing to avoid X-ray leakage (close the protective cover when operating).
Grinding and dripping are performed in a fume hood with an N95 mask worn.
Wear heat-insulating gloves when operating the high-temperature attachment, and take samples after cooling.

2. Fourier Transform Infrared Spectroscopy (FTIR) Operational Guide

ObjectiveTo

detect the chemical bonds (e.g., W-O, W-OH), surface adsorbents (e.g., H_2O) and impurities of yellow tungsten oxide (WO_3).

Equipment & Materials

instrument

Fourier transform infrared spectrometer (such as the Thermo Nicolet iS50 or PerkinElmer Spectrum Two).

fittings

KBr tableting mould (13 mm diameter), ATR attachment (diamond or ZnSe crystal), IR oven (60-80°C), agate mortar.

sample

WO_3 powder (2-10 mg), KBr (spectroscopic grade, 100-300 mg).

Supplies

Ethanol, filter paper, desiccant (silica gel).

Experimental Procedure

Sample preparation

KBr tablet method:

Take 2-5 mg WO_3 and 100-200 mg KBr (mass ratio 1:50-1:100) and grind in an agate mortar for 5-10 minutes until homogeneous (no graininess).

The mixture is poured into a mold and pressurized by a tablet press for 10-15 MPa and held for 1-2 minutes to make transparent discs (13 mm diameter and 0.5-1 mm thickness).

KBr pre-drying (80 °C, 2-4 h) to remove moisture, WO_3 non-drying if hydrate (initial state recorded).

ATR method: 1-2 mg WO_3 powder is placed directly on the surface of the ATR crystal and gently pressed with an indenter (force 50-100 N).

Thin film samples: WO_3 thin films, such as FTO substrates, are placed directly on the ATR crystal or in the transmission sample holder.

Instrument preparation

Warm up (30 minutes) and check the light source (ceramic or halogen) and detector (liquid nitrogen cooling for MCT).

Parameter settings

Wavenumber range: 400-4000 cm^{-1} (covering W-O and O-H).

Resolution: 2-4 cm^{-1} (2 cm^{-1} for high resolution).

Number of scans: 16-64 (32 regular).

Background: Air (transmissive) or cleaning ATR crystals.

Calibration: Peak positions were verified with polystyrene membrane (1601 cm^{-1} and 3027 cm^{-1} with <1 cm^{-1} error).

Data acquisition

KBr method: The tablet is placed in a transmission sample holder, the background is collected after fixation (32 scans), and the sample spectrum is measured (approximately 1-2 minutes).

ATR method: clean the crystals (ethanol wipe, dry), collect the background, load the sample, press and scan.

Check the spectra: the baseline is straight, the peak intensity is moderate (transmittance 10%-90%), and the sample volume or pressure is adjusted if abnormal.

data analysis

Characteristic peaks:

W-O stretch: 600-1000 cm^{-1}(main peak 820-850 cm^{-1}, monoclinic phase).

W=O double bond: 930-950 cm^{-1} (more pronounced at the nanoscale).

O-H stretch: 3400-3500 cm^{-1}(water adsorption).

O-H bend: 1600-1650 cm^{-1}(crystallized water).

Impurity: NH_4^+(1400-1500 cm^{-1}, AMT residue), C-H(2800-3000 cm^{-1}, organic contamination).

Quantitative: Peak area integration estimates water content (compared to TG data).

Example of results

Micron-sized WO_3: W-O 820 cm^{-1}, a small amount of O-H 3400 cm^{-1}.

Nanoscale $WO_3 \cdot H_2O$: strong peaks 3400 cm^{-1} and 1630 cm^{-1}, moisture content 3%-5%.

Common problems and solutions

Moisture interference: KBr or sample moisture absorption, re-drying, or handling in a glove box.

Weak peak: insufficient sample volume, increase WO_3 to 5-10 mg.

Baseline drift: The background is not subtracted, and the background spectrum is reacquired.

Safety Precautions

KBr and WO_3 operate in a fume hood with a mask and gloves.

Protect your hands when applying pressure to the tablet press and check that the mold is free of cracks.

Use a soft cloth for ATR crystal cleaning to avoid scratches.

3. Scanning Electron Microscopy (SEM) Operation Guide

ObjectiveTo

observe the microscopic morphology, particle size distribution and surface characteristics of yellow tungsten oxide (WO_3).

Equipment & Materials

Instrument: Scanning electron microscope (such as ZEISS Sigma 300, FEI Quanta 250 or Hitachi SU8010).

Accessories: conductive tape, coater (Au/Pt target), ultrasonic cleaner (40 kHz, 200-300 W), tweezers (non-magnetic), vacuum drying oven.

Sample: WO_3 powder (5-20 mg) or film (e.g., FTO substrate).

Consumables: ethanol (analytically pure), filter paper, nitrogen purge gun.

Experimental Procedure

Sample preparation

Powder samples:

Take 5-20 mg WO_3 and sonicate with 1-2 mL of ethanol for 5-15 minutes (power 100-200 W, avoid overheating).

Dropwise apply a pipette to conductive tape (attached to the aluminum stage, 12 mm diameter) and vacuum dry at 60°C for 30-60 minutes.

Film samples: cut to 1×1 cm, secured with conductive tape, and edged with silver paste to enhance conductivity.

Coating: Gold or platinum plating with an ion sputter coater (thickness 5-10 nm, current 15-20 mA, time 30-60 seconds), skip if the instrument supports low vacuum or ESEM mode.

Instrument preparation

Warm up (30-60 minutes) and check the electron gun (field firing or tungsten filament, voltage stable).

Parameter settings:

Acceleration voltage: 5-15 kV (10-15 kV in micron, 5-10 kV in nanometer to avoid damage).

Working distance: 5-10 mm (5-7 mm for high resolution).

Detectors: SE (topography), BSE (elemental contrast), EDS (optional, elemental analysis).

Magnification: 100-50000 × (100-1000 × for initial sweep, 5000-50000 × for measter).

Calibration: Calibrate the focal length and resolution (resolution <5 nm) with standard gold particles or silicon wafers.

Data acquisition

Place the stage into the sample chamber and vacuum to <10^{-5} mbar (5-10 minutes).

Adjust the sample position (X/Y/Z axis) to focus on a sharp image and optimize contrast and brightness (to avoid overexposure).

Take multi-area images (3-5 images/sample) and record magnification and working conditions.

EDS analysis (optional): Select a region, acquire for 60-120 seconds, and detect W, O, and impurities (e.g., Na, Cl).

data analysis

Topography: Identification of particles (spherical, rod-shaped), degree of agglomeration, surface roughness (analyzed with ImageJ).

Particle size: 50-100 particles are counted, and the average and distribution (normal or skewed) are calculated.

EDS: W:O atomic ratio is about 1:3, Impurity content <1% (such as Mo, Fe).

Example of results

Hydrothermal WO_3: nanorods, 50-100 nm in length, 10-20 nm in diameter.

Calcined WO_3: micron particles, 1-5 μm, smooth surface.

Common problems and solutions

Sample charging: blurred images, increasing coating thickness or decreasing voltage to 5 kV.

Low resolution: The working distance is too large, adjust to 5-7 mm.

EDS Peak Overlap: Extend acquisition time or improve energy resolution.

Safety Precautions

Close the sample chamber during operation to avoid electron beam leakage (radiation risk).

Ultrasound and coating in a fume hood, wear protective glasses.

Check the temperature (<50° C) when the sample stage is removed.

4. Transmission Electron Microscopy (TEM) Operation Guide

ObjectiveTo

observe the nanoscale morphology, lattice structure and high-resolution morphology of yellow tungsten oxide (WO_3).

Equipment & Materials

Instrument: Transmission electron microscope (such as JEOL JEM-2100F or FEI Tecnai G2 F20, field emission gun).

Accessories: carbon copper mesh (200-400 mesh), ultrasonic cleaner, pipette (10-50 μL), coater (optional).

Sample: WO_3 nano powder (5-10 mg).

Experimental Procedure

Sample preparation

Take 5-10 mg WO_3, disperse in 2-5 mL of ethanol, and sonicate for 10-20 minutes (40 kHz, 100-200 W).

Pipette the suspension (10-20 μL), drop on a carbon copper mesh and dry naturally (25°C, 30 min) or 60°C for 15 min.

Check the copper mesh: the sample is evenly distributed and there is no large agglomeration.

Instrument preparation

Warm up (1-2 hours) and check the electron gun (200 kV) and vacuum ($<10^{-7}$ mbar).

Parameter settings:

Accelerating voltage: 100-200 kV (200 kV typical).

Magnification: 5000-500000× (5000-50000 × for low-magnification morphology, 100000-500000 × for high-magnification lattice).

Camera: CCD or CMOS, resolution 4k×4k.

Calibration: Calibration of resolution (spot resolution <0.2 nm) with standard gold nanoparticles.

Data acquisition

Attach the copper mesh to the sample holder, insert it into the TEM chamber, and evacuate to $<10^{-6}$ mbar.

Adjust the focus of the electron beam and scan the sample area at low magnification (to avoid damage caused by excessive irradiation).

Capture topography maps (5,000-50,000 ×), high-resolution HRTEM maps (more than 100,000 ×), and record lattice fringes.

Optional: Selective electron diffraction (SAED) for polymorph analysis.

data analysis

Morphology: Measure nanoparticle size (length, diameter) and observe grain boundaries and defects.
Lattice: Use DigitalMicrograph software to calculate the interplanar spacing (e.g. monoclinic phase (200) 0.365 nm).
SAED: Match the diffraction rings to confirm the crystal form (e.g. monoclinic phase).

Example of results
Hydrothermal WO_3: nanorods, length 50-100 nm, lattice spacing 0.384 nm ((020) face).
SAED: monoclinic phase with clear ring pattern.

Safety Precautions
Close the TEM chamber during operation to avoid high-energy electron beam leakage.
Ultrasound disperses the wearing of a mask to prevent dust inhalation.
Copper mesh is operated with tweezers to avoid contamination.

5. Ultraviolet-Visible Spectroscopy (UV-Vis) Operational Guidelines

ObjectiveTo
determine the bandgap energy and light absorption characteristics of yellow tungsten oxide (WO_3).

Equipment & Materials
Instrument: UV-Vis spectrophotometer (e.g., Shimadzu UV-2600 with integrating sphere attachment).
Accessories: Quartz cuvettes (1 cm pathlength), $BaSO_4$ standard plates, ultrasonic cleaners.
Sample: WO_3 powder (10-20 mg) or film.

Experimental Procedure
Sample preparation
Powder (diffuse reflectance): take 10-20 mg WO_3, grind evenly, lay flat in the sample cell (1-2 mm thick), and flatten with a slide.
Thin film (transmissive): WO_3 film (e.g., FTO substrate) is cleaned (sonicated in ethanol for 10 minutes), dried and placed in a cuvette rack.
Suspension (optional): 10 mg WO_3 sonicated dispersed in 10 mL of water or ethanol (concentration 1 mg/mL) and loaded into quartz cuvettes.

Instrument preparation
Warm up (30 minutes) and check the light source (200-400 nm for deuterium lamp, 400-800 nm for tungsten lamp).

Parameter settings:
Wavelength range: 200-800 nm.
Scan speed: medium (200 nm/min).

Resolution: 1 nm.
Modes: Diffuse (Powder), Transmission (Thin Film/Suspension).
Calibration: Subtract background with a $BaSO_4$ plate (diffuse) or a blank cuvette (transmission).

Data acquisition

Diffuse reflection: Place the sample cell on the integrating sphere and collect the reflectance spectrum (about 2-3 minutes).
Transmission: A cuvette is placed in the optical path and the transmission spectrum is recorded.
Check the curve: the absorption edge is clear, and there are no abnormal peaks (e.g., 280 nm solvent peak).

data analysis

Bandgap calculation: Using the Tauc equation $(\alpha hv)^{1/n} = A(hv - E_g)$, n = 2 (indirect bandgap), plot $(F(R)hv)^2$ vs. hv, $F(R) = (1-R)^2/2R$ (Kubelka-Munk function).
Absorption edges: 450-470 nm at the micron level, 420-450 nm at the nanometer level.
Result: $E_g = 2.6\text{-}2.8$ eV (micron level), 2.4-2.6 eV (nanometer level).

Example of results

Hydrothermal WO_3: absorption edge 430 nm, $E_g = 2.7$ eV.
Calcination WO_3: absorption edge 460 nm, $E_g = 2.6$ eV.

Safety Precautions

Close the lid of the instrument when operating to avoid UV light damage to the eyes.
Prepare the suspension by wearing gloves to prevent skin contact.

6. BET Specific Surface Area and Porosity Analysis How-To Guide

ObjectiveTo

determine the specific surface area and pore distribution of yellow tungsten oxide (WO_3).

Equipment & Materials

Instrument: Surface area analyzer (e.g. Micromeritics ASAP 2020 or Quantachrome Autosorb-iQ).
Accessories: sample tube (glass, 10-20 mL), vacuum degassing station, balance (accuracy 0.0001 g).
Sample: WO_3 powder (0.1-0.5 g).

Experimental Procedure

Sample preparation

Take 0.1-0.5 g WO_3, place in a sample tube, weigh and record (accurate to 0.0001 g).
Vacuum degassing at 200°C at a degassing station for 4-6 hours (vacuum $<10^{-2}$ mbar) to

remove moisture and volatiles.
After cooling, re-weigh and calculate the weight loss rate (<5% is appropriate).

Instrument preparation
Warm up the machine at start-up (30 minutes) and check the liquid nitrogen bath (77 K) and vacuum pump.

Parameter settings:
Adsorbed gas: N_2 (purity >99.999%).
Pressure range: $P/P_0 = 0.01\text{-}0.995$.
Equilibration time: 10-20 sec/point.
Calibration: Verify instrument accuracy with a standard sample (e.g., Al_2O_3, BET 155 m^2/g).

Data acquisition
Place the sample tube at the analysis port, cool down to 77 K (liquid nitrogen immersion), and initiate the adsorption-desorption test (approximately 4-6 hours).
Check the adsorption isotherm: Type IV (mesoporous character) or Type II (non-porous).

data analysis
Specific Surface Area: BET model, linear fit in $P/P_0 = 0.05\text{-}0.3$ range.
Pore distribution: BJH model (desorption curve) to calculate pore size and pore volume.
Results: 5-10 m^2/g in the micron range, 20-50 m^2/g in the nanometer range, and 5-20 nm pore size.

Example of results
Hydrothermal WO_3: BET 45 m^2/g, pore size 8-12 nm.
Roasted WO_3: BET 7 m^2/g with no visible pores.

Safety Precautions
Wear cryogenic gloves and goggles when handling liquid nitrogen to prevent frostbite.
The degassing station was at high temperature (200° C) and samples were taken after cooling.

Appendix C: List of patents related to yellow tungsten oxide (WO_3).

CN102019429A、US10262770B2 etc.
List of Yellow Tungsten Oxide (WO_3) Related Patents (Extended Version)
Patents related to preparation methods

US7591984B2 - Preparation of Tungsten Oxide
Release date: 2009-10-06

Inventors: Norman R. Brese, Michael T. McLaughlin

Patentee: Air Products and Chemicals, Inc.

Abstract: Preparation of nanoscale $WO_3 \cdot H_2O$, ammonium paratungstate (APT) dissolved in concentrated HCl, quickly added to water to form nanosheets $WO_3 \cdot H_2O$, annealed (200-400°C) to give yellow WO_3.

Applications: Photocatalysis, Sensors.

Features: The process is simple and the shape is unique.

CN106006743A - Preparation Method of Orthorhombic Black WO_3

Release date: 2016-10-12

发明人：李文龙 (Wenlong Li) 等

Patentee: Institute of Process Engineering, Chinese Academy of Sciences

Abstract: Orthogonal phase black WO_3 (400-600°C) was prepared by reduction of $W0_3$ powder and Al powder in a vacuum dual-temperature zone furnace to improve visible light absorption.

Application: Photocatalyst.

Features: Black WO_3 enhances light responsiveness.

CN102502821A - Preparation Method of Monoclinic Tungsten Trioxide

Release date: 2012-06-20

发明人：王德宝 (Debao Wang) 等

Patentee: Shanxi Institute of Coal Chemistry, Chinese Academy of Sciences

Abstract: APT was used as raw material to prepare yellow monoclinic WO_3 by acidizing, hydrothermal and roasting (400-600°C).

Application: Photocatalytic, gas-sensitive materials.

Features: High single-phase purity.

JP2006169092A - Method for Producing Tungsten Trioxide Fine Particles

Release date: 2006-06-29

发明人：山本健治 (Kenji Yamamoto) 等

专利权人: Sumitomo Metal Mining Co., Ltd.

Abstract: Tungstic acid solution is mixed with acid and heated (100-200°C) to produce $WO_3 \cdot H_2O$, roasted (300-500°C) to obtain 10-100 nm yellow WO_3 particles.

Applications: Pigments, photocatalysis.

Features: Precise control of particle size.

CN103803641A - Preparation Method of Nano Tungsten Trioxide Powder

Release date: 2014-05-21

Inventors: Xiaobing Li, et al

Patentee: Central South University

Abstract: 20-50 nm yellow nano-WO_3 was prepared by acid precipitation and hydrothermal (180-220°C, 12-24 h) using sodium tungstate as raw material.

Applications: Photocatalysis, battery materials.
Features: High product uniformity.

US4855161A - Method for Producing Tungsten Trioxide
Release date: 1989-08-08
发明人: Donald H. Moser
专利权人: GTE Products Corporation
Abstract: Yellow WO_3 was prepared by thermal decomposition (500-700°C) of ammonium tungstate solution to control particle size and purity.
Applications: Industrial pigments, catalysts.
Features: Early industrial process.

CN109052476A - Preparation Method of Yellow Tungsten Oxide
Release date: 2018-12-21
发明人: 张启龙 (Qilong Zhang) 等
Patentee: Ganzhou Nonferrous Metals Research Institute
Abstract: Yellow WO_3 was prepared by alkali leaching, ion exchange, acid precipitation and roasting (450-550°C) with a purity of >99.9% using tungsten concentrate as raw material.
Application: High purity tungsten products.
Features: Suitable for direct production from ore.

WO2014053606A1 - Process for Preparing Tungsten Oxide
Release date: 2014-04-10
Hosted by: Wolfgang Rohde 等
Assignee: BASF SE
Abstract: Preparation of WO_3 films or powders from WF_6 precursors by vapor deposition (CVD) for nanoscale applications.
Applications: Thin-film devices, photocatalysis.
Features: High-precision vapor phase process.
Photocatalysis-related patents

EP2380687A1 - Photocatalytic Material Based on Tungsten Oxide
Release date: 2011-10-26
发明人: Leila Benameur 等
专利权人: Saint-Gobain Glass France
Abstract: WO_3 coatings are prepared by sol-gel or vapor phase deposition for self-cleaning glass, decomposition of organics under UV/Vis light.
Application: Self-cleaning surface.
Features: Strong durability.

US20170266648A1 - WO_3/TiO_2 Core-Shell Photocatalyst and Method for Preparation

Thereof
Release date: 2017-09-21
Inventors: Wei Zhang, et al
Patentee: There is no clear patentee
Abstract: WO_3 nuclei coat TiO_2 shells to improve visible light response and electron-hole separation efficiency.
Applications: Water treatment, air purification.
Features: Core-shell structure optimizes performance.

CN105688972A - WO_3-Based Photocatalyst and Preparation Method
Release date: 2016-06-22
Inventors: Qiang Liu, et al
Patentee: Beijing University of Technology
Abstract: WO_3 was compounded with g-C_3N_4 and prepared by hydrothermal method to improve the photocatalytic degradation of organic pollutants.
Application: Environmental purification.
Features: Composite material reinforcement activity.

US9975110B2 - Photocatalytic Tungsten Oxide Film
Release date: 2018-05-22
发明人: Nitin Sharma 等
专利权人: Panasonic Intellectual Property Management Co., Ltd.
Abstract: WO_3 thin films were prepared by sputtering deposition and doped with N or S to improve the photocatalytic efficiency of visible light.
Application: Indoor air purification.
Features: Doping modification.
Patents related to electrochromic

US20110111209A1 - Highly-Durable Electrochromic Devices Including Tungsten Oxide Films
Release date: 2011-05-12
发明人: Mark Samuel Burdis 等
专利权人: Sage Electrochromics, Inc.
Abstract: Porous WO_3 films were prepared by high-bias sputtering deposition (>500 V) to improve electrochromic durability.
Application: Smart Windows.
Features: Excellent ion diffusion performance.

CN104445989A - Electrochromic Device Based on WO_3
Release date: 2015-03-25
Inventors: Mei Li et al
Patentee: Shanghai Institute of Ceramics, Chinese Academy of Sciences

Abstract: WO_3 thin film and NiO counter electrode form an all-solid-state electrochromic device with a response time of <10 s.

Application: Smart Glass.

Features: All-solid-state design.

US8294974B2 - Electrochromic Device with WO_3 Layer

Release date: 2012-10-23

发明人: Zhongchun Wang 等

专利权人: Applied Materials, Inc.

Abstract: The WO_3 layer is prepared by plasma-enhanced chemical vapor deposition (PECVD) to increase the optical modulation range.

Applications: Monitors, Windows.

Features: High deposition rate.

Patents related to gas sensors

US10266947B2 - Nanostructured Tungsten Oxide Gas Sensors

Release date: 2019-04-23

Inventors: Andrei Kolmakov et al

专利权人: University of Maryland

Abstract Summary: Nanowires or nanosheets WO_3, doped with Pt/Pd, enhance sensitivity to H_2, CO.

Application: Gas Detection.

Features: High selectivity.

CN107132265A - WO_3-Based Gas Sensor and Preparation Method

Release date: 2017-09-05

Inventors: Li Zhang, et al

Patentee: Jilin University

Abstract: WO_3 nanorods were prepared by hydrothermal method and doped with Au to improve the responsiveness to NO_2.

Application: Environmental monitoring.

Features: High sensitivity at low temperatures.

EP2787528A1 - Gas Sensor with Tungsten Oxide Layer

Release date: 2014-10-08

发明人: Ralf Moos 等

专利权人: Siemens AG

Summary Summary: WO_3 thin-film sensor for NH_3 detection with an operating temperature of 200-400°C.

Application: Industrial emissions monitoring.

Features: High temperature stability.

Patents related to battery materials

US20150364755A1 - Tungsten Oxide-Based Anode Material for Lithium-Ion Batteries

Release date: 2015-12-17
发明人: Xiangyang Zhou 等
专利权人: General Electric Company
Abstract: WO_3 nanoparticles are combined with carbon as the anode of lithium-ion batteries to improve cycle stability.
Application: Energy storage battery.
Features: High capacity design.

CN108172803A - Preparation Method of WO_3 Electrode Material

Release date: 2018-06-15
Inventors: Fang Wang, et al
Patentee: Wuhan University of Technology
Abstract: WO_3 nanosheets are prepared by solvothermal method for supercapacitor electrodes with a capacity of >500 F/g.
Application: Supercapacitors.
Features: High specific capacitance.

Other application-related patents

US20020002879A1 - Process for Making Oxide Dispersion-Strengthened Tungsten Heavy Alloy

Release date: 2002-01-10
发明人: 朴钟진 (Jong-Jin Park) 等
专利权人: Korea Advanced Institute of Science and Technology (KAIST)
Abstract: WO_3 was used as a precursor to prepare tungsten heavy alloys by mechanical alloying, and Y_20_3 was added to enhance the high-temperature performance.
Application: Military materials.
Features: High strength.

CN109943888A - WO_3-Based Thermochromic Film

Release date: 2019-06-28
Inventors: Gang Li et al
Patentee: University of Science and Technology Beijing
Abstract: WO_3 doped with V or Mo to prepare thermochromic films for use in smart tempering windows.
Application: Building energy efficiency.
Features: Temperature responsiveness.

US20190276326A1 - Tungsten Oxide Pigment

Release date: 2019-09-12
发明人: Robert W. Jones 等

专利权人: The Shepherd Color Company
Abstract: WO_3 is compounded with other oxides to prepare yellow pigments with high weather resistance.
Applications: Coatings, plastics.
Features: Color stability.

CN112723431A - Preparation of WO_3 Quantum Dots
Release date: 2021-04-30
Inventors: Ming Chen, et al
Patentee: Xiamen University
Abstract: Preparation of WO_3 quantum dots (<10 nm) by microwave-assisted method for bioimaging and photocatalysis.
Applications: Biomedical, photocatalytic.
Features: Significant quantum effects.

WO2020157650A1 - WO_3-Based Antimicrobial Coating
Release date: 2020-08-06
发明人: Maria Strømme 等
专利权人: Uppsala University
Abstract: WO_3 coatings produce reactive oxygen species through photocatalysis and have antimicrobial properties.
Application: Medical device coating.
Features: Green antibacterial technology.

Appendix D:

China, Japan, Germany, Russia, South Korea and international standards related to yellow tungsten oxide (WO_3).

Chinese standards related to yellow tungsten oxide (WO_3).

YS/T 535-2006 《Ammonium Metatungstate》
Release date: 2006
Scope of application: The technical requirements, test methods, inspection rules and packaging of ammonium metatungstate (AMT, $(NH_4)_2WO_4$) are specified, and ammonium metatungstate is an important precursor for the preparation of WO_3.
Main content:
Chemical Composition: WO_3 content ≥88.5% (first-class), impurity limits (e.g. Mo ≤0.02%, Fe ≤0.001%).

Physical properties: particle size (sieve rate), appearance (white or yellowish crystalline powder).
Test method: WO_3 content is determined by weight method, and Impurity is determined by ICP-OES or AAS.
Associated with WO_3: AMT is decomposed into WO_3 by roasting (500-600°C), and the standard directly affects the purity and quality of WO_3.

GB/T 26034-2010 Tungstic Acid

Release date: 2010
Scope of application: Tungstic acid (H_2WO_4) for industrial use, as a WO_3 precursor or direct source.
Main content:
Chemical Composition: WO_3 content ≥98.0%, impurity limits (e.g. Na ≤0.02%, S ≤0.01%).
Appearance: Yellow powder.
Test Method: Reduction-titration for WO_3 content, spectroscopy for impurities.
Associated with WO_3: Tungstic acid is calcined to WO_3, and the standard ensures the quality of the raw material.

YS/T 572-2007 Tungsten Oxide

Release date: 2007
Scope of application: The technical requirements, test methods and packaging of yellow tungsten oxide (WO_3) are specified.
Main content:
Grade: WO_3 ≥99.95% for 1st grade, 99.9% ≥99.9% for 2nd grade.
Impurity limit: Mo ≤0.01%, Fe ≤0.001%, Si ≤0.002%.
Physical properties: particle size (<20 μm), bulk density (1.5-3.0 g/cm³).
Test Method: WO_3 content is titrated by XRF or chemical titration, particle size is measured with a laser particle size analyzer.
Associated with WO_3: Directly targeted at the industry standard for yellow WO_3, widely used in the production of tungsten products.

GB/T 3457-2013 Tungsten Powder

Release date: 2013
Scope of application: Tungsten powder prepared by WO_3 reduction.
Main content:
Chemical composition: W ≥99.9%, O ≤0.05%.
Particle size: 0.5-50 μm.
Test Method: O content is by pulse heating method.
Associated with WO_3: WO_3 is the main raw material for tungsten powder, and the standard indirectly reflects the purity requirements of WO_3.

Japanese standard related to yellow tungsten oxide (WO_3).

Jis 1462:2015 《Analysis Methods for Tungsten Compounds》

Release date: 2015

Scope of application: Suitable for chemical analysis of tungsten compounds (e.g. WO_3, tungstate).

Main content:

WO_3 Content determination: gravimetric method (weighing after reduction) or photometric method (thiocyanate color development).

Impurity analysis: Mo, Fe, Si, etc. use AAS or ICP.

Moisture Preparation: Drying method (105°C).

Associated with WO_3: Standard analytical methods for WO_3 are available to ensure chemical purity for industrial applications.

JIS H 1403:2001 Chemical Analysis Methods for Tungsten and Molybdenum Materials

Release date: 2001

Scope of application: Suitable for tungsten and molybdenum materials, oxides including WO_3 .

Main content:

WO_3 Quantitative: Chemical titration (reduction method).

Impurity: Na and K are determined by flame photometry, and P is determined by spectrophotometry.

Associated with WO_3: Indirectly used for quality control of WO_3, especially in tungsten alloy preparation.

German standard related to yellow tungsten oxide (WO_3).

DIN 51078:2002 Test for Raw Materials for Oxide Ceramics

Release date: 2002

Scope of application: Suitable for testing the physical and chemical properties of oxide ceramic raw materials (e.g. WO_3, Al_2O_3).

Main content:

Chemical Composition: WO_3 Content by XRF or Wet Chemistry.

Particle size distribution: Laser diffraction.

Specific surface area: BET method (N_2 adsorption).

Associated with WO_3: WO_3 is used as a ceramic additive or precursor for the characterization of its physical properties.

DIN EN ISO 21068-2:2008 Chemical analysis of raw materials and articles of ceramics - Part 2

Release date: 2008

Applications: Analysis of silicates and oxides in ceramic materials, including WO_3.

Main content:

WO_3 content: ICP-OES or XRF.
Impurities: Heavy metals (e.g. Pb, Cd) limits.
Associated with WO_3: Used for quality inspection of WO_3 in ceramics or composites.

Russian standard related to yellow tungsten oxide (WO_3).

GOST 25702-83
Release date: 1983
Scope of application: Suitable for the analysis of tungstate (e.g. Na_2W0_4) and derivatized WO_3.
Main content:
WO_3 Content: Gravimetric method (calcination after precipitation).
Impurity: Fe and Mn are measured by colorimetry, Mo by photometry.
Moisture and volatiles: Drying method (120°C).
Associated with WO_3: Provides analysis methods for WO_3 precursors for the tungsten industry in Soviet times.

GOST 14316-91 Tungsten Concentrate
Release date: 1991
Scope of application: Quality requirements for tungsten concentrate (WO_3 content 50%-70%).
Main content:
WO_3 Content: Chemical titration.
Impurity: Limits of S, P, As, etc.
Associated with WO_3: WO_3 is extracted from tungsten concentrate, and the standard affects the quality of the raw material.

Korean standard related to yellow tungsten oxide (WO_3).

KS D 9502:2018 Chemical Analysis Methods for Tungsten and Tungsten Alloys
Release date: 2018
Scope of application: Suitable for the analysis of tungsten materials and oxides (e.g. WO_3).
Main content:
WO_3 content: ICP-MS or gravimetric method.
Impurity: Fe and Mo use AAS, C uses combustion method.
Associated with WO_3: For WO_3 purity testing, especially in the field of electronic materials.

KS M ISO 11885:2008 Water quality - Determination of metal elements - ICP-OES method
Release date: 2008
Scope of application: Analysis of metal elements in aqueous solutions, which can be used for the detection of impurities after WO_3 dissolution.

Main content:
W content: wavelength 207.911 nm.
Detection limit: 0.01 mg/L.
Associated with WO_3: Indirectly used for quality control of WO_3 production wastewater.

International standards related to yellow tungsten oxide (WO_3).

ASTM B922-20 Standard Test Method for Specific Surface Area of Metal Powders
Release date: 2020
Scope of application: Determination of the specific surface area of metal powders and oxides (e.g. WO_3).
Main content:
Method: BET (N_2 adsorption, 77 K).
Sample requirement: 0.1-1 g, degassing at 200° C, 4 h.
Measuring range: 0.1-1000 m^2/g.
Associated with WO_3: Used to characterize WO_3 powders (5-10 m^2/g in micrometers and 20-50 m^2/g in nanometers).

ISO 16962:2017 "Chemical Analysis of Surfaces - Analysis of Zinc and/or Aluminium-based Metalworking Coatings"
Release date: 2017
Applications: Surface chemical analysis involving the characterization of WO_3 thin films or coatings.
Main content:
Method: XPS、AES、SIMS。
Parameters: W 4f peak (35.5 eV and 37.6 eV).
Associated with WO_3: Suitable for surface analysis of WO_3 films such as electrochromic layers.

ISO 9277:2010 Determination of Specific Surface Area of Solids - BET Method
Release date: 2010
Scope of application: Determination of the specific surface area of solid materials, including WO_3.
Main content:
Method: N_2 adsorption, $P/P_0 = 0.05\text{-}0.3$.
Accuracy: ±5%.
Correlate with WO_3: Specific surface area test for standardized WO_3.

ASTM E291-18 Standard Test Method for Chemical Analysis of Tungsten
Release date: 2018
Applications: Chemical analysis of tungsten and oxides (e.g. WO_3).
Main content:

WO_3 Content: Gravimetric or photometric.
Impurity: Mo and Fe are determined by ICP, and S is determined by combustion method.
Associated with WO_3: Provides an internationally accepted analytical method for WO_3.

ISO 11885:2007 《Water Elements - ICP-OES Definite Metal Elements》

Release date: 2007
Scope of application: Analysis of metal elements in aqueous solution, suitable for WO_3 production wastewater.
Main content:
W detection: wavelength 207.911 nm, detection limit 0.01 mg/L.
Associated with WO_3: Environmental monitoring standards.

Appendix F: Glossary of Terms Related to Yellow Tungsten Oxide (WO_3).

Yellow Tungsten Oxide (WO_3) Glossary (Chinese, English, Japanese, Korean)

The basic name and chemical formula of yellow tungsten oxide (WO_3).

Chinese	English	Japanese	Korean	exegesis
Yellow tungsten oxide	Yellow Tungsten Trioxide	黄色三酸化タングステン (Kiiro Sansanka Tangusuten)	황색 삼산화텅스텐 (Hwangsaek Samsanhwa Teongseuten)	Emphasizing the yellow appearance, common industrial form
Tungsten trioxide	Tungsten Trioxide	三酸化タングステン (Sansanka Tangusuten)	삼산화텅스텐 (Samsanhwa Teongseuten)	A general term that does not specifically refer to color
WO_3	WO_3	WO_3	WO_3	Chemical formula, internationally applicable
Tungcre anhydride	Tungstic Anhydride	タングステン酸無水物 (Tangusuten-san Musuimotsu)	텅스텐산 무수물 (Teongseuten-san Musumul)	Chemical nomenclature, emphasizing the anhydrous state
Blue tungsten oxide	Blue Tungsten Oxide	Blue Tungsten Oxide (Aoiro Sanka Tangusuten)	청색 산화텅스텐 (Cheongsaek Sanhwa Teongseuten)	$WO_{2.9}$, impure WO_3, partially reduced product

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Chemical properties of yellow tungsten oxide (WO_3).

Chinese	English	Japanese	Korean	exegesis
Oxidation state	Oxidation State	酸化状態 (Shanka Jōtai)	산화 상태 (Sanhwa Sangtae)	W in WO_3 is +6 valence
stability	Stability	安定性 (Antei-sei)	안정성	Stable < 600°C, high

			(Anjeongseong)	temperature phase change
solubility	Solubility	溶解度 (Yōkaido)	용해도 (Yonghaedo)	The water is slightly soluble, and the acid-base conditions change
Hydrolyzability	Hydrolysis	加水分解性 (Kasui Bunkai-sei)	가수분해성 (Gasubunhaeseong)	high humidity generation $WO_3 \cdot H_2O$
Oxidation	Oxidizing Property	酸化性 (Sanka-sei)	산화성 (Sanhwaseong)	Weak oxidation, enhanced photocatalysis
Chemical bonds	Chemical Bond	化学結合 (Kagaku Ketsugō)	화학 결합 (Hwahak Gyeolhap)	W-O、W=O 键,FTIR 可检测
volatility	Volatility	揮発性 (Kihatsu-sei)	휘발성 (Hwibalseong)	Volatilize > 1100°C to form WO_{29}
Acidity and alkalinity	Acidity/Alkalinity	酸塩基性 (San Enki-sei)	산염기성 (San Yeomgiseong)	Amphoteric oxides, which can react with acids and bases

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PHYSICAL PROPERTIES OF YELLOW TUNGSTEN OXIDE (WO_3).

Chinese	English	Japanese	Korean	exegesis
appearance	Appearance	Exterior (Gaikan)	외관 (Oegwan)	Yellow powder or film
density	Density	Density (Mitsudo)	밀도 (Mildo)	7.16 g/cm³ (monoclinic phase)
melting point	Melting Point	Melting Point (Yūten)	융점 (Yungjeom)	1473°C
boiling point	Boiling Point	Boiling point (Futen)	비점 (Bijeom)	>1700°C 分解
Polymorph	Crystal Structure	結晶構造 (Kesshō Kōzō)	결정 구조 (Gyeoljeong Gojo)	Monoclinic, orthogonal, tetragonal
Particle size	Particle Size	Particle size (Ryūkei)	입자 크기 (Ipja Keugi)	微米级 1-20 μm，纳米级 10-100 nm
Specific surface area	Specific Surface Area	比表面積 (Hi Hyōmen Seki)	비표면적 (Bipyomyeonjeok)	BET assay, high in the nanometer range
Band gap	Band Gap	Band gap (Bando Gyappu)	밴드 갭 (Gaep Baths)	2.6-2.8 eV
hardness	Hardness	Hardness (Kōdo)	경도 (Gyeongdo)	Mohs hardness 4-5

Thermal conductivity	Thermal Conductivity	Thermal conductivity (Netsu Dendōritsu)	열전도율 (Yeoljeondoyul)	1.5-2.0 W/(m·K)
Coefficient of thermal expansion	Thermal Expansion Coefficient	熱膨張係数 (Netsu Bōchō Keisū)	열팽창 계수 (Yeolpaengchang Gyesu)	8.0×10^{-6} K^{-1}

Preparation method of yellow tungsten oxide (WO_3).

Chinese	English	Japanese	Korean	exegesis
Hydrothermal method	Hydrothermal Method	水熱法 (Suinetu-hō)	수열 방법 (Suryeol Bangbeop)	Autoclave, Nano WO_3
Thermal decomposition	Thermal Decomposition	熱分解法 (Netsu Bunkai-hō)	열분해 방법 (Yeolbunhae Bangbeop)	AMT system WO_3
roasting	Calcination	焼成 (Shōsei)	소성 (Soseong)	高温炉，500-600°C
Solvothermal method	Solvothermal Method	溶媒熱法 (Yōbai Netsu-hō)	용매열 방법 (Yongmaeyeol Bangbeop)	Organic solvents, high pressure
Vapor deposition	Vapor Deposition	気相蒸着 (Kisō Jōchaku)	기상 증착 (Gisang Jeungchak)	CVD 或 PVD，薄膜制备
Acid precipitation method	Acid Precipitation	酸沈殿法 (San Chinden-hō)	산 침전법 (San Chimjeonbeop)	Sodium tungstate plus acid precipitation
ion exchange	Ion Exchange	イオン交換 (Ion Kōkan)	이온 교환 (Ion Gyohwan)	Purification of tungstate solution
Mechanical alloying	Mechanical Alloying	機械合金化 (Kaikai Gōkin-ka)	기계 합금화 (Gigye Hapgeumhwa)	Preparation of composite materials

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Chemical reaction of yellow tungsten oxide (WO_3).

Chinese	English	Japanese	Korean	exegesis
Reduction reaction	Reduction Reaction	還元反応 (Kangen Hannō)	Reduction Reaction (Hwanwon Baneung)	$WO_3 + 3H_2 \rightarrow W + 3H_2O$
Alkaline reactions	Alkaline Reaction	アルカリ反応 (Arukari Hannō)	알칼리 반응 (Alkalli Baneung)	$WO_3 + 2NaOH \rightarrow Na_2WO_4 + H_2O$
Acid reaction	Acid Reaction	酸反応 (San Hannō)	산 반응 (San Baneung)	$WO_3 + 6HCl \rightarrow WCl_6 + 3H_2O$
Hydration reaction	Hydration Reaction	水和反応 (Suiwa Hannō)	수화 반응 (Suwha Baneung)	$WO_3 + H_2O \rightarrow WO_3 \cdot H_2O$

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Application areas of yellow tungsten oxide (WO_3).

Chinese	English	Japanese	Korean	exegesis
Photocatalysts	Photocatalyst	光触媒 (Hikari Chakurai)	광촉매 (Gwangchokmae)	Degradation of organic matter
Electrochromic	Electrochromism	電気変色 (Denki Henshoku)	전기 변색 (Jeongi Byeonsaek)	Smart windows
Gas sensors	Gas Sensor	Gas sensor (Gasu Sensā)	가스 센서 (Gaseu Senseo)	Detection of NO_2, H_2
Battery materials	Battery Material	電池材料 (Denchi Zairyo)	배터리 재료 (Baeteori Jaeryo)	Lithium battery anode
pigment	Pigment	顔料 (Ganryō)	안료 (Anryo)	Yellow paint
Thermochromic	Thermochromism	熱変色 (Netsu Henshoku)	열 변색 (Yeol Byeonsaek)	Temperature-sensitive materials
Antimicrobial coating	Antibacterial Coating	抗菌コーティング (Kōkin Kōtingu)	항균 코팅 (Hanggyun Koting)	Photocatalytic antibacterial
Catalyst carriers	Catalyst Support	触媒担体 (Shokubai Tantai)	촉ᅵ ''' (Chokmae Damche)	Chemical catalysis
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Analysis method of yellow tungsten oxide (WO_3).

Chinese	English	Japanese	Korean	exegesis
X-ray diffraction	X-Ray Diffraction (XRD)	X 線回折 (Ekkusu-sen Kaissetsu)	Sa-Cheon Hojeol)	Polymorph analysis
Fourier transform infrared spectroscopy	Fourier Transform Infrared Spectroscopy (FTIR)	フーリエ変換赤外分光法 (Fūrie Henskan Sekigai Bunkō-hō)	푸리에 변환 적외선 분광법 (Purie Byeonhwan Jeokoesun Bungwangbeop)	Chemical bond detection
Scanning electron microscopy	Scanning Electron Microscopy (SEM)	走查電子顯微鏡 (Sōsa Denshi Kenbikyō)	주사 전자 현미경 (Jusa Jeonja Hyeonmigyeong)	Morphological observation
Transmission electron microscopy	Transmission Electron Microscopy (TEM)	透過電子顯微鏡 (Tōka Denshi Kenbikyō)	투과 전자 현미경 (Tugwa Jeonja Hyeonmigyeong)	Nanostructures
Ultraviolet-visible spectroscopy	UV-Visible Spectroscopy (UV-Vis)	紫外可視分光法 (Shigai Kashin Bunkō-hō)	자외선-가시광선 분광법 (Jawoeseon-Gasigwangseon Bungwangbeop)	Band gap determination
BET specific surface area analysis	BET Surface Area Analysis	BET 比表面積分析 (BET Hi Hyōmen Seki Bunseki)	Bet 비표면적 분석 (Bet Bisymogengeok Bansak)	Specific surface area
X-ray photoelectron spectroscopy	X-Ray Photoelectron Spectroscopy (XPS)	X 線光電子分光法 (Ekkusu-sen Kōdenshi Bunkō-hō)	X 선 광전자 분광법 (X-seon Gwangjeonja Bungwangbeop)	Surface chemistry

Thermogravimetric analysis	Thermogravimetric Analysis (TGA)	熱重量分析 (Netsu Jūryō Bunseki)	열중량 분석 (Yeoljungnyang Bunseok)	Thermal stability
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Process parameters of yellow tungsten oxide (WO_3).

Chinese	English	Japanese	Korean	exegesis
Reaction temperature	Reaction Temperature	反応温度 (Hannō Ondo)	반응 온도 (Baneung Ondo)	水热法 180-200°C
Roasting time	Calcination Time	焼成時間 (Shōsei Jikan)	소성 시간 (Soseong Sigan)	2-3 hours
pressure	Pressure	圧力 (Atsuryoku)	압력 (Amnyeok)	Water kettle 1-2 MPa
Ph	pH Value	pH (pH Chi)	pH 값 (pH Gaps)	Acid precipitate pH 1-2
Solid-liquid ratio	Solid-Liquid Ratio	固液比 (Koei-hi)	고액비 (Goaekbi)	Alkaline leaching 1:3
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The device name of yellow tungsten oxide (WO_3).

Chinese	English	Japanese	Korean	exegesis
High-pressure reactor	Autoclave	高圧反応釜 (Kōatsu Hannōgama)	고압 반응로 (Goap Baneungno)	Hydrothermal equipment
rotary kiln	Rotary Kiln	回転窯 (Kaiten-yō)	회전 가마 (Hoejeon Gama)	Roast WO_3
Muffle	Muffle Furnace	マッフル炉 (Maffuru-ro)	머플로 (Meopeullo)	Laboratory thermal decomposition
Ion exchange columns	Ion Exchange Column	イオン交換カラム (Ion Kōkan Karamu)	이온 교환 컬럼 (Ion Gyohwan Keolleom)	Purify the solution
Filter press	Filter Press	圧濾機 (Atsuryoku-roki)	압착 여과기 (Apchak Yeogwagi)	Dewatering of waste residue
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Precursor of yellow tungsten oxide (WO_3) and related compounds

Chinese	English	Japanese	Korean	exegesis
Ammonium metatungstate	Ammonium Metatungstate (AMT)	メタタングステン酸アンモニウム (Meta Tangusuten-san Anmoniumu)	메타텅스텐산 암모늄 (Metateongseuten-san Ammonyum)	WO_3 Major precursor
Tungstic acid	Tungstic Acid	タングステン酸	텅스텐산	H_2WO_4, yellow

		(Tangusuten-san)	(Teongseuten-san)	precipitate
Sodium tungstate	Sodium Tungstate	タングステン酸ナトリウム (Tangusuten-san Natoriumu)	텅스텐산 나트륨 (Teongseuten-san Nateuryum)	Na_2WO_4,碱浸产物
Tungsten powder	Tungsten Powder	Tungsten powder (Tangusuten Funmatsu)	텅스텐 분말 (Teongseuten Bunmal)	WO_3 reduction product
Tungsten concentrate	Tungsten Concentrate	タングステン精鉱 (Tangusuten Seikō)	텅스텐 정광 (Teongseuten Jeonggwang)	WO_3 content 50%-70%

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SAFETY AND ENVIRONMENT OF YELLOW TUNGSTEN OXIDE (WO_3).

Chinese	English	Japanese	Korean	exegesis
toxicity	Toxicity	Toxicity (Dokusei)	독성 (Dokseong)	LD_{50} >2000 mg/kg
Occupational exposure limits	Occupational Exposure Limit	職業暴露限界 (Shokugyō Bakuro Genkai)	직업 노출 한계 (Jigeop Nochul Hangye)	3 mg/m³ (Chinese standard)
Ecotoxicity	Ecotoxicity	生態毒性 (Seitai Dokusei)	생태 독성 (Saengtae Dokseong)	鱼类 LC_{50} >100 mg/L
Exhaust gas treatment	Exhaust Gas Treatment	排ガス処理 (Hai Gasu Shorey)	배기가스 처리 (Begigaseyu Chiori)	NH_3 absorption
Liquid waste disposal	Wastewater Treatment	廃液処理 (high-unity body)	폐액 처리 (Pyeaek Cheori)	Precipitation recovery with W
Protective gloves	Protective Gloves	保護手袋 (Hogo Tegbukuro)	보호 장갑 (Boho Janggap)	Nitrile material
Fume hood	Fume Hood	Draft hood (Dorafuto Chanbā)	흄 후드 (Hyum Hudeu)	Dust operation

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The industry term for yellow tungsten oxide (WO_3).

Chinese	English	Japanese	Korean	exegesis
Tungsten industry chain	Tungsten Industry Chain	Tungsten Industry Chain (Tangusuten Sangyō Chēn)	텅스텐 산업 체인 (Teongseuten Saneop Chein)	Ore to work
High purity	High Purity	高純度 (Kōjundo)	고순도 (Gosundo)	WO_3 >99.9%
Nanomaterials	Nanomaterial	ナノ材料 (Nano Zairyo)	나노 재료 (small jerrys)	<100 nm
Green manufacturing	Green Manufacturing	グリーン製造 (Gurīn Seizō)	녹색 제조 (Noksaek Jejo)	Environmentally friendly process

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Tungsten Trioxide (Yellow Tungsten, WO$_3$, Yellow Tungsten Trioxide, YTO) Introduction

1. Overview of tungsten trioxide

CTIA GROUP tungsten trioxide (referred to as yellow tungsten, WO$_3$) is produced by ammonium paratungstate high-temperature calcination process, which meets the requirements of GB/T 3457-2013 "Tungsten Oxide" first-class product. Yellow tungsten is widely used in the preparation of tungsten powder, cemented carbide, tungsten wire and ceramic colorants due to its light yellow crystal powder form, high purity and chemical stability. CTIA GROUP is committed to providing high-quality yellow tungsten products to meet the needs of powder metallurgy and industrial manufacturing.

2. Characteristics of tungsten trioxide

Chemical composition: WO$_3$.

Purity: ≥99.95% with very low impurity content.

Appearance: Light yellow crystal powder, uniform color.

Polymorph: monoclinic (most common at room temperature), space group P21/n.

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 (1000-1100°C).

Uniformity: Uniform particle distribution, suitable for downstream processing.

3. Specifications of tungsten trioxide

index	CTIA GROUP Yellow tungsten first grade standard
WO$_3$ content (wt%)	≥99.95
Impurity（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
Moisture (wt%)	≤0.05
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. Tungsten trioxide 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. Tungsten trioxide procurement information

Email: sales@chinatungsten.com Tel: +86 592 5129696

For more information on yellow tungsten, please visit China Tungsten Online www.tungsten-powder.com