Encyclopedia of Tungsten Crucible

中钨智造科技有限公司

CTIA GROUP LTD

CTIA GROUP LTD

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

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INTRODUCTION TO CTIA GROUP

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

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

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

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

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Tungsten Crucible Introduction

1. Overview of Tungsten Crucibles

Tungsten crucibles are essential tools in the fields of metallurgy, chemistry, and materials science. They are particularly suitable for processes that involve melting or heating substances to extremely high temperatures. Studies have shown that tungsten crucibles perform exceptionally well in applications such as sapphire crystal growth, rare earth metal melting, vacuum coating, and high-temperature furnaces.

2. Features of Tungsten Crucibles

Ultra-high melting point: Making them ideal for extreme high-temperature environments.

High purity: purity of ≥99.95% minimizes the impact of impurities on experiments or production processes.

Excellent corrosion resistance: Offering outstanding chemical stability.

High density and low vapor pressure: Ensuring material stability.

High strength and wear resistance: Ensuring long service life.

Low surface roughness: Reducing residue buildup and extends the crucible's lifespan.

3. Applications of Tungsten Crucibles

Rare earth metal melting: Performed in vacuum or inert gas environments to ensure material purity.

Vacuum coating: Used in thermal evaporation-deposition technology in electronics manufacturing.

High-temperature furnaces: Functions as a key component capable of withstanding environments below 2400℃.

Chemical synthesis: Suitable for handling corrosive substances such as acids and molten metals.

Metal smelting and refining: Used for melting and refining high-purity metals.

Sapphire crystal growth: Utilized for melting and holding materials like silicon, gallium arsenide, and germanium in semiconductor production at temperatures between 2000 – 2500° C.

4. Specifications of Tungsten Crucibles

Specification	Details
Material	Pure tungsten or tungsten alloy
Purity	99.95%
Diameter	20–620 mm
Height	20–500 mm
Wall Thickness	3.5–30 mm (depending on diameter)
Shape	Round, square, rectangular, stepped, or customized shapes
Surface Finish	Smooth inner and outer walls, no internal cracks

5. Purchasing Information

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Content

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Chapter 1 General Theory of Tungsten Crucible

1.1 Definition and basic concept of tungsten crucible

Tungsten crucible is a high-temperature and corrosion-resistant container made of high-purity tungsten (purity usually ≥ 99.95%) as the main raw material, through powder metallurgy, sintering, machining and other processes, and is widely used in industrial fields such as high-temperature smelting, crystal growth, chemical reaction and material testing. The core properties of tungsten crucible are derived from tungsten's ultra-high melting point (3422°C, the highest among metals), excellent chemical stability, and mechanical strength in extreme environments, making it an indispensable component in high-temperature processes. Its primary functions include accommodating and handling molten metals, alloys, ceramics or chemicals, and maintaining structural integrity and stable performance at temperatures up to 3000°C or in highly corrosive environments.

The typical structure of a tungsten crucible is cylindrical or conical, the inner wall is usually precision polished to reduce the adhesion of molten material, and the wall thickness and size are customized according to the application. For example, tungsten crucibles used for the growth of monocrystalline silicon in the semiconductor industry are generally 100-300mm in diameter and 5-10mm in wall thickness, while crucibles used in the metallurgical industry for rare earth metal melting may be more than 500mm in diameter and 15-20mm in wall thickness. The performance of tungsten crucibles is affected by a variety of factors, including material purity, grain size, surface quality, and manufacturing process. For example, high-purity tungsten crucibles (purity ≥ 99.999%) significantly reduce impurity contamination in semiconductor crystal growth, while lower purity crucibles (99.95%) are more commonly used in cost-sensitive metallurgical applications.

The design of tungsten crucibles requires a combination of thermal, mechanical and chemical properties. For example, at high temperatures, tungsten crucibles must withstand thermal stress and mechanical loads while avoiding chemical reactions with molten substances. In a vacuum or inert atmosphere, the low vapor pressure of the tungsten crucible (only 10^{-7} Pa at 3000°C) ensures that it does not volatilize and pollute the environment. In addition, tungsten crucibles have a low coefficient of thermal expansion (about 4.5×10^{-6}/K) and are well matched to materials such as molten silicon or sapphire, reducing the risk of cracking caused by thermal stress. In recent years, advances in additive manufacturing and surface coating technologies have further expanded the capabilities and applications of tungsten crucibles, such as emerging applications in nuclear fusion reactors and aerospace.

1.2 Historical development of tungsten crucibles

The origin of tungsten crucible is closely related to the industrial application of tungsten metal. Tungsten, as a rare metal, began to attract attention in the mid-19th century, but its early applications were extremely limited due to its high melting point and processing difficulty. In the 1870s, tungsten began to be used in the form of tungsten steel in tool making, but tungsten crucibles were developed as late as the early 20th century. In 1909, William Brown of the General Electric Company of the

United States William D. Coolidge invented the preparation method of ductile tungsten wire to produce high-purity tungsten products through powder metallurgy and high-temperature sintering technology, marking a major breakthrough in tungsten processing technology. This technology lays the foundation for the industrial production of tungsten crucibles.

At the beginning of the 20th century, tungsten crucibles were mainly used in high-temperature laboratory experiments such as precious metal melting, chemical analysis, and vacuum distillation. In the 1920s, with the advancement of vacuum furnace technology, tungsten crucibles began to be used in industrial-scale smelting of rare metals, such as molybdenum, niobium and tantalum. During World War II, tungsten crucibles made their mark in the military industry, where they were used in the melting of superalloys and special steels, and in the production of aircraft engines and armor materials.

In the 1950s, the maturity of powder metallurgy technology promoted the large-scale production of tungsten crucibles. The introduction of isostatic compression molding and vacuum sintering technology has significantly increased the density and strength of the crucible, allowing it to withstand higher temperatures and mechanical loads. In the 1960s, the rise of the semiconductor industry became a turning point in the development of tungsten crucibles. Monocrystalline silicon and sapphire crystal growth processes (such as the Czochralski and Kyropoulos processes) place extremely high demands on the purity and surface quality of crucibles, and high-purity tungsten crucibles (purity ≥ 99.99%) are beginning to become standard in the semiconductor industry.
In the 21st century, the application field of tungsten crucible has been further broadened. In the aerospace field, tungsten crucibles are used to manufacture rocket engine nozzles and high-temperature structural materials; The nuclear industry uses it for reactor high-temperature components and nuclear fusion experiments; New energy fields (such as photovoltaics and fuel cells) rely on tungsten crucibles to produce high-purity silicon and ceramic materials. According to industry reports from Chinatungsten Online, from 2000 to 2020, the global tungsten crucible market size increased from about 300 million US dollars to 1.2 billion US dollars, with an average annual compound growth rate of about 7.5%. In recent years, the introduction of additive manufacturing (3D printing) and smart manufacturing technologies has further promoted the customized and efficient production of tungsten crucibles.

1.3 The strategic significance of tungsten crucible in modern industry

Tungsten crucible has an irreplaceable strategic position in modern industry, and its importance is reflected in many aspects of technology, economy and geopolitics:

Technology at the core

Tungsten crucibles are the cornerstone of high-temperature processes, especially in the semiconductor, aerospace and new energy sectors. In the semiconductor industry, tungsten crucibles are used for the growth of monocrystalline silicon and compound semiconductors (such as GaAs, GaN), which directly affect the quality and efficiency of chip manufacturing. In the aerospace sector, tungsten crucibles are used in the melting of superalloys and composites, supporting the development of advanced engines and structural components. In the field of new energy, tungsten crucibles are indispensable in the production of photovoltaic silicon wafers and the preparation of nuclear fusion reactor materials. For example, in the International Thermonuclear Experimental Reactor (ITER) project, tungsten crucibles are used to test plasma-facing materials and contribute to breakthroughs in clean energy technology.

Economic value

The tungsten crucible market is an important part of the global tungsten industry chain. According to Chinatungsten Online, the global tungsten crucible market size was approximately US$1.3 billion in 2023 and is expected to reach US$2 billion by 2030, driven by surging demand for semiconductors and increased aerospace investment. The high added value of tungsten crucible makes it the core product of tungsten products enterprises.

Geopolitics and resource security

Tungsten is a rare metal with limited global reserves, and supply chain security directly affects the production of tungsten crucibles. China accounts for 57% of the world's tungsten reserves and 80% of production, and is a major supplier of tungsten crucibles. In recent years, Western countries have stepped up efforts to develop and recycle tungsten resources to reduce their dependence on China. As a result, the production and supply of tungsten crucibles have become the focus of geopolitical games.

Support industrial upgrading and innovation

The research and development of tungsten crucibles has promoted the progress of materials science, manufacturing technology and intelligence. For example, the development of nano-tungsten powder and ultra-fine-grained tungsten crucibles has improved the thermal shock resistance and service life of crucibles, and adapted to the higher requirements of the semiconductor and nuclear industries. The application of smart manufacturing technologies, such as AI-optimized sintering processes, has further reduced production costs and enhanced global competitiveness.

In summary, tungsten crucible is not only an industrial component, but also the embodiment of the country's technical strength and resource strategy, and its development direction is closely related to the global high-tech industry and energy transition.

1.4 Global tungsten resource distribution and mining status

Tungsten resources are mainly in the form of wolframite ($FeMnWO_4$) and scheelite ($CaWO_4$), with global proven reserves of about 3.3 million tons (in terms of tungsten metal). The specific distribution is as follows:

China: reserves of about 1.9 million tons, accounting for 57% of the world's total, mainly distributed in Hunan (Chaling, Zixing), Jiangxi (Dayu, Ganzhou) and Henan (Luanchuan). China's tungsten ore grade is high, with an average WO_3 content of 0.3-0.5%.
Russia: reserves of about 250,000 tons, mainly in the Far East and Siberia, most of the mines are

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small and medium-sized.

Vietnam: With reserves of about 100,000 tons, Nui Phao mine is the world's largest single tungsten mine, with an annual output of about 6,000 tons.

Canada: Reserves of about 80,000 tons, concentrated in British Columbia, with the Cantung mine being the main producing area.

Other regions: Tungsten mining in Australia (King Island mine), Bolivia (Lllallagua mine) and Africa (e.g. Rwanda, Congo) is gradually increasing, but reserves and production are limited.

Mining status

In 2023, the global production of tungsten concentrate (WO_3) will be about 85,000 tons, a year-on-year decrease of 2%, mainly due to stricter environmental regulations and aging mines. China's output is about 68,000 tons, accounting for 80% of the world's total; Vietnam is about 6,000 tons, and Russia is about 4,000 tons. Tungsten mining faces the following challenges:

Environmental stress

Traditional open-pit and underground mining is highly damaging to land and water resources, and tailings treatment costs are high. Since 2015, China has implemented strict environmental policies and closed some highly polluting mines, resulting in a decline in production.

Grade declines

The average grade of the world's major tungsten ore has fallen from 1% in the 20th century to 0.3-0.5%, increasing the cost of beneficiation and refining.

Geopolitical risks

Tungsten resources are concentrated in a small number of countries, and the supply chain is susceptible to political and trade frictions.

Response

In order to alleviate the shortage of resources, tungsten waste recycling has become an important supplement. About 20% of the world's tungsten supply comes from recycling, mainly by chemical dissolution or mechanical crushing to extract tungstate from waste tungsten crucibles, knives and alloys. In addition, deep-sea tungsten exploration and bioleaching technologies, such as the use of microorganisms to decompose tungsten ore, are being studied and may provide new sources for the future.

1.5 Overview of tungsten crucible industry chain

The tungsten crucible industry chain covers multiple links from raw material mining to terminal application, involving mining, smelting, manufacturing, application and recycling, forming a closed-loop economic system:

Upstream: tungsten mining and refining

Mining: Tungsten ore is obtained through open-pit or underground mining, and the beneficiation

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process includes gravity separation, flotation and magnetic separation to produce tungsten concentrate (WO_3 content 65-70%).
Refining: Tungsten concentrate is converted into ammonium tungstate (APT) by alkali leaching or acid leaching, and then calcined and hydrogen reduced to produce high-purity tungsten powder (purity ≥ 99.95%).

Midstream: tungsten crucible manufacturing
Process: including tungsten powder pressing, sintering, machining and surface treatment, the core technology is isostatic pressing forming and vacuum sintering.
Products: Standard and custom tungsten crucibles for semiconductor, metallurgical and aerospace needs.

Downstream: Applications & Distribution
Applications: Semiconductors (crystal growth), metallurgy (rare earth and precious metal smelting), aerospace (superalloys), new energy (photovoltaics and nuclear energy).
Distribution: Through direct sales or agent distribution, some companies provide customized services.

Recycling & Recycling
Recycling process: Waste tungsten crucibles are recycled by chemical dissolution (to generate sodium tungstate) or mechanical crushing to make tungsten powder or crucibles.

Significance: Reduce resource dependence, reduce environmental pollution, and recycled tungsten accounts for 20-25% of global supply.

Market size and trends
According to Chinatungsten Online, the global tungsten crucible market size will be about US$1.35 billion in 2024 and is expected to reach US$2 billion by 2030, with an average annual growth rate of about 6.5%. Growth drivers include:

Semiconductor demand: 5G, AI, and electric vehicles are driving the demand for chips, and the market for monocrystalline silicon and tungsten crucibles for compound semiconductors is growing rapidly.
Aerospace investment: The global space budget has increased, and the demand for tungsten crucibles for superalloys has risen.
New energy development: photovoltaic silicon wafer production and nuclear fusion research increase tungsten crucible applications.
Technological advancements: Additive manufacturing and intelligent production reduce costs and improve customization capabilities.

Challenge
The industrial chain is exposed to fluctuations in raw material prices, environmental pressure and

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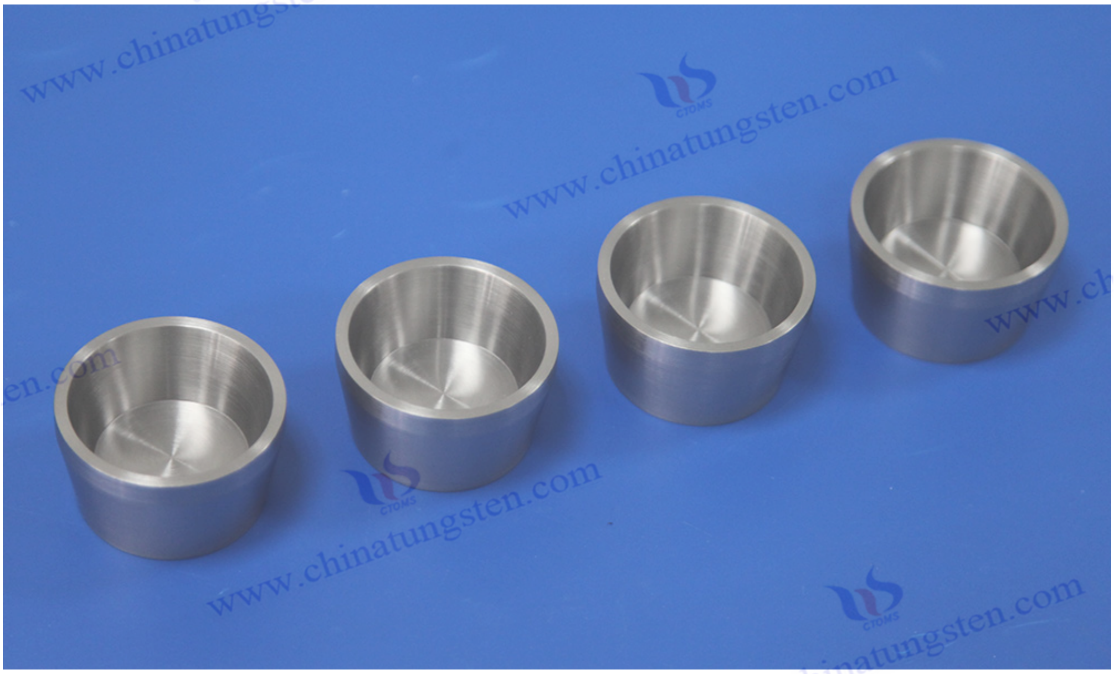
geopolitical risks. For example, the price of tungsten concentrate will increase by 15% in 2023, resulting in an increase in the cost of crucible production. Companies are responding to these challenges by optimizing processes and expanding the proportion of recycling.



CTIA GROUP LTD tungsten crucible

Chapter 2 Product Characteristics of Tungsten Crucible

As the core component of high-temperature industry and scientific research, the product characteristics of tungsten crucible directly determine its performance and application effect in extreme environments. This chapter will comprehensively analyze the technical characteristics and performance advantages of tungsten crucibles from various aspects such as geometry and dimensional specifications, surface quality, material purity, thermal properties, chemical stability, mechanical properties, other properties, and material safety data sheet (MSDS) of tungsten crucibles.

2.1 Tungsten crucible geometry and size specifications

The geometry and size specifications of tungsten crucibles are the basis for their design and application, which directly affect their volume, heat conduction efficiency and structural stability. Different application scenarios, such as semiconductor crystal growth, metallurgical melting, or aerospace material testing, have specific requirements for crucible geometry and dimensions. The following is a detailed description from four aspects: standard size, customized design, volume and load capacity, and shape design.

2.1.1 Standard dimensions (diameter, wall thickness, height)

The standard size of tungsten crucibles is typically designed according to industry specifications and application needs to meet general industrial and scientific use. The Chinese national standard GB/T 3459-2022 Technical Requirements for Tungsten Crucibles clearly stipulates the standard size

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range. The specific size parameters are as follows:

Diameter: Tungsten crucibles typically range from 10 mm to 500 mm in diameter, with common specifications concentrated between 50 mm and 200 mm. Small-diameter crucibles (e.g., 10-50 mm) are mostly used for small laboratory experiments or high-precision crystal growth, such as monocrystalline silicon or sapphire crystal production; Large-diameter crucibles (e.g. 200-500 mm) are suitable for industrial-scale metallurgical melting or rare earth metal refining.

Wall thickness: Wall thicknesses range from 2 mm to 10 mm, depending on the purpose and load-bearing requirements of the crucible. Thin-walled crucibles (2-4 mm) are suitable for light loads and fast heat transfer scenarios, such as Czochralski crystal growth in the semiconductor industry; Thick-walled crucibles (6-10 mm) are used for heavy-duty and high-temperature long-term operation, e.g. for superalloy melting. The wall thickness design needs to balance the heat conduction efficiency and mechanical strength to avoid deformation due to too thin or increase material costs due to too thickness.

Height: The height range is from 20 mm to 600 mm, which is closely related to the volume and application of the crucible. Low-height crucibles (20-100 mm) are suitable for shallow melting or thin film deposition; High-height crucibles (300-600 mm) are used for high-volume melting or deep reactions, such as precious metal refining or high-temperature experiments in the nuclear industry.

2.1.2 Customized design and non-standard size

With the diversification of industrial and scientific research needs, the demand for customized design of non-standard size tungsten crucibles is increasing. Non-standard crucibles usually refer to special specifications crucibles with a diameter of more than 500 mm, a wall thickness of less than 2 mm or a height of more than 600 mm, which are suitable for high-end fields such as aerospace, nuclear industry or cutting-edge materials research. For example, plasma material testing in nuclear fusion reactors may require extra-large diameter (>600 mm) tungsten crucibles to accommodate complex experimental setups; The semiconductor industry may require ultra-thin-walled (<1.5 mm) crucibles to optimize heat transfer and reduce material usage.

The challenge of custom design lies in the difficulty of mold development and processing. Oversized crucibles require dedicated large-scale isostatic pressing equipment and sintering furnaces, which increases production costs; Ultra-thin-walled crucibles require a high degree of precision in the forming and sintering process, and a slight deviation may lead to cracking or deterioration of the crucible's performance. In addition, the dimensional tolerances of the non-standard crucibles need to be controlled within ±0.1 mm to meet the needs of high-precision applications.

According to Chinatungsten Online's industry report, the market demand for customized tungsten crucibles has increased by about 20% over the past decade, mainly driven by the aerospace and semiconductor industries. Custom designs often require customers to work closely with the manufacturer to define the geometrical parameters, thermal properties, and mechanical strength

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requirements of the crucible, and to simulate the stress distribution and thermal expansion behavior of the crucible at high temperatures through finite element analysis (FEA) to ensure design feasibility.

2.1.3 Volume and carrying capacity

The volume and load-bearing capacity of tungsten crucible are the key indicators of its functionality, which directly determine its applicability in specific applications. Volumes range from a few milliliters to several liters, depending on the crucible's inner diameter, height, and wall thickness design. For example, a cylindrical crucible with a diameter of 50 mm and a height of 50 mm has a volume of about 98 ml, making it suitable for small-scale laboratory experiments; With a diameter of 300 mm and a height of 400 mm, the crucible has a volume of up to 28 litres and is suitable for metal melting on an industrial scale.

Load-bearing capacity refers to the weight of molten material that a crucible can safely carry at high temperatures, and is usually determined by material density, wall thickness, and geometry. Tungsten has a density of 19.25 g/cm³, which gives the crucible its extremely high structural strength. Tungsten crucibles with standard wall thicknesses (4-6 mm) can carry thousands of grams of molten metals such as aluminum, copper or rare earth metals; Thick-walled crucibles (8-10 mm) can carry even tons of molten gold and are suitable for the production of superalloys.

The design of volume and bearing capacity should take into account the following factors:
Heat conduction efficiency: Excessive volume may lead to uneven heat distribution, affecting the uniformity of the melt.
Structural stability: Excessive load-bearing capacity requirements can lead to an increase in wall thickness, which in turn increases thermal inertia and material costs.
Thermal expansion matching: The coefficient of thermal expansion of the crucible and the melt needs to be matched to avoid cracking due to thermal stress.

2.1.4 Shape design (cylindrical, conical, special-shaped)

The shape design of tungsten crucible has an important impact on its functionality and application scenarios. Common shapes include cylindrical, conical, and profiled crucibles, each optimized for specific use needs.

Cylindrical crucible: This is the most common shape with uniform wall thickness and inner diameter, making it suitable for scenarios that require a stable thermal field and uniform heating, such as monocrystalline silicon growth (Czochralski method) or precious metal melting. The advantages of cylindrical crucibles are that the manufacturing process is relatively simple, the thermal stress distribution is uniform, and it is suitable for standardized production. The disadvantage is that it may not be convenient to pour the melt and it is less adaptable to complex experimental setups.

Conical crucible: The bottom diameter of the conical crucible is smaller than the top, which facilitates the pouring and collection of molten material, and is commonly used in the refining of

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rare earth metals or precious metals in the metallurgical industry. The tapered design reduces melt residue on the crucible wall and improves material utilization. However, the thermal field distribution of a conical crucible is not as uniform as that of a cylindrical and may require an additional heating system to compensate.

Conformal crucibles: Conformal crucibles include oval, polygonal, or other non-standard shapes and are often customized for specific experiments or industrial applications. For example, rocket engine nozzle testing in the aerospace sector may require an elliptical crucible to accommodate a test piece with complex geometries; Plasma experiments in the nuclear industry may require polygonal crucibles to match the shape of the reaction device. Special-shaped crucibles are difficult to manufacture and require advanced molding techniques (such as spinning or 3D printing) and precision mold design.

Shape design takes into account thermal expansion, stress distribution, and manufacturing costs. For example, the thermal expansion of cylindrical crucibles is relatively uniform, which is suitable for high-temperature cycling; The conical crucible may produce local stress concentrations during the pouring process, and the structural stability needs to be enhanced by wall thickness optimization. The stress distribution of special-shaped crucibles is complex, and the design verification is usually carried out by finite element analysis.

2.2 Surface quality of tungsten crucible

Surface quality is an important indicator of tungsten crucible performance, which directly affects its corrosion resistance, melt adhesion and service life. The surface of tungsten crucibles usually needs to be polished, ground or coated to meet the stringent requirements of different application scenarios. The following is discussed in detail from four aspects: polishing and machining, surface roughness standards, defect detection and control, and surface coating and modification.

2.2.1 Polishing, grinding and machined surfaces

The surface treatment process of tungsten crucible includes turning, milling, grinding and polishing, each of which targets different surface quality requirements. Turning and milling are used for preliminary forming, removing the rough layer on the surface of the green body; Grinding further improves surface flatness and reduces microscopic defects; Polishing is used to achieve a mirror effect, which significantly reduces surface roughness.

Turning and milling: Machining accuracy up to ±0.05 mm is carried out by a numerical control machining center (CNC). Turning is suitable for the outer wall machining of cylindrical crucibles, while milling is used for forming the inner wall or bottom of complex shapes. Tungsten carbide tools are used in the machining process to cope with the high hardness of tungsten (8-9 on the Mohs scale).

Grinding: Grinding uses diamond grinding wheels or ceramic grinding wheels, which can reduce the surface roughness to Ra 0.8-1.6μm. The grinding process requires strict control of coolant usage

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to avoid micro-cracks caused by thermal stress.

Polishing: Polishing is divided into mechanical polishing and chemical polishing. Mechanical polishing uses nano-level polishing agents, which can achieve a mirror effect of Ra <0.4μm; Chemical polishing further improves smoothness by etching the surface with an acidic solution, such as a mixture of nitric acid and hydrofluoric acid. The polished surface significantly reduces the adhesion of melts such as silicon or aluminum, extending crucible life.

The choice of polishing and grinding process depends on the application. The semiconductor industry requires mirror polishing to ensure the purity of crystal growth; In the metallurgical industry, it may only be necessary to grind surfaces to control costs. According to Chinatungsten Online's technical manual, the service life of polished tungsten crucibles is on average 15%-20% longer than that of unpolished crucibles.

2.2.2 Surface roughness standards (Ra, Rz)

Surface roughness is the core measure of the surface quality of tungsten crucibles, which is usually expressed in Ra (arithmetic mean roughness) and Rz (maximum height). Ra reflects the average of the microscopic fluctuations of the surface, and Rz represents the distance between the highest and lowest points of the surface. The industry standard has the following requirements for surface roughness for different application scenarios:

Semiconductor industry: Ra < 0.4 μm, Rz < 2.0 μm, to ensure that no impurities are introduced during crystal growth. Mirror polishing is a necessary process, which needs to be used with a laser interferometer for surface inspection.

Metallurgical industry: Ra 0.8-1.6μm, Rz 4.0-8.0μm, grinding or medium polishing can meet the demand, the cost is relatively low.

Aerospace & Nuclear Industry: Ra 0.4-0.8 μm, Rz 2.0-4.0 μm, balancing surface quality and high-temperature mechanical properties.

Surface roughness is usually measured using a contact profiler or a non-contact laser microscope to ensure a measurement accuracy of ±0.01 μm. Excessive surface roughness may lead to melt adhesion or local stress concentrations, reducing crucible life; Roughness that is too low may increase processing costs and needs to be optimized according to the application scenario.

2.2.3 Surface defect detection and control

Surface defects (e.g., cracks, porosity, inclusions) have a significant impact on the high-temperature performance and service life of tungsten crucibles. Common defect detection methods include:

Ultrasonic testing: Detection of internal and surface defects by ultrasonic reflection for thick-walled crucibles. The detection sensitivity can reach 0.1 mm.

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X-ray inspection: used to detect porosity and inclusions inside crucibles, especially for large crucibles. X-ray computed tomography (CT) provides a three-dimensional map of defect distribution.

Visual surface inspection: Combined with optical microscopy or scanning electron microscopy (SEM), it detects surface microcracks and roughness anomalies.

The key to defect control is to optimize the preparation process. For example, atmosphere control during the sintering process reduces porosity; Coolant management and tool selection in machining avoids surface cracks. According to the test report ofCTIA GROUP LTD, the pass rate of tungsten crucible can be increased to more than 98% through strict defect control.

2.2.4 Surface coating and modification

In order to further improve the oxidation and abrasion resistance of tungsten crucibles, a coating can be applied to the surface or modified. Common surface treatment techniques include:

Anti-oxidation coatings: such as alumina (Al_2O_3), silicide (SiC) or zirconia (ZrO_2) coatings, applied by chemical vapor deposition (CVD) or plasma spraying. These coatings form a protective layer at high temperatures that prevent tungsten from reacting with oxygen, extending the life of the crucible in an oxidizing atmosphere.

Abrasion-resistant coatings, such as tungsten carbide (www.tungsten-carbide-powder.com) or titanium nitride (TiN) coatings, are applied by physical vapor deposition (PVD) to improve surface hardness and wear resistance, making them suitable for long-term high-temperature operation [27].

Surface modification: Ion implantation (e.g., nitrogen or carbon implantation) can change the surface crystal structure, improve hardness and corrosion resistance; Nitriding or carburizing treatments can enhance the thermal shock resistance of the surface.

The coating and modification process needs to be selected according to the actual environment in which the crucible will be used. For example, the semiconductor industry generally avoids the use of coatings to prevent contamination; The aerospace industry tends to use anti-oxidation coatings to cope with complex atmospheres.

2.3 Tungsten crucible material purity

Material purity is the core of tungsten crucible performance, which directly affects its high temperature stability, anti-fouling ability and mechanical strength. Tungsten crucibles are usually prepared with high-purity tungsten (www.tungsten.com.cn), and the purity requirements are ≥ 99.95%. The following is a detailed analysis from three aspects: the characteristics of high-purity tungsten, the analysis of impurity elements and the influence of purity on high-temperature performance.

2.3.1 High purity tungsten

High-purity tungsten refers to metal materials with a tungsten content of ≥99.95%, which are prepared by multi-stage purification processes such as ammonium paratungstate (www.ammonium-paratungstate.com) calcination and hydrogen reduction). High-purity tungsten has the following key properties:

Ultra-high melting point: 3410°C, the highest of all metals, suitable for extremely high temperature environments.
High density: 19.25 g/cm³, which gives the crucible excellent mechanical strength and resistance to deformation.
Low vapor pressure: almost non-volatile below 3000°C, reducing material loss at high temperatures.
Excellent chemical stability: inert to most chemicals in an inert atmosphere, suitable for the preparation of high-purity materials.

The preparation of high-purity tungsten requires strict control of raw material quality and production environment. According to the technical report of Chinatungsten Online, the production cost of high-purity tungsten powder accounts for about 30%-40% of the total cost of tungsten crucible, which is the key factor affecting the price of tungsten crucible.

2.3.2 Analysis of impurity elements

The impurity elements in tungsten crucibles include carbon, oxygen, iron, molybdenum, nitrogen, etc., and are usually measured in parts per million (ppm). The following methods are mainly used for the detection of impurity content:

X-ray fluorescence spectrometer (XRF): used for rapid detection of major impurity elements with an accuracy of ±1ppm.
Inductively Coupled Plasma Mass Spectrometry (ICP-MS): for trace element analysis with detection limits as low as 0.01 ppm.
Scanning electron microscopy (SEM) combined with energy spectroscopy (EDS): used to locate impurity distributions and analyze elemental enrichment at grain boundaries.

According to ASTM E1447-09, tungsten crucibles are required to contain impurities within the following ranges:

carbon	<50ppm
oxygen	<100ppm
iron	<20ppm
molybdenum	<50ppm
nitrogen	<10ppm

Excessively high impurity levels may lead to weakening of grain boundaries, degradation of thermal shock performance, or volatile contamination at high temperatures.

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2.3.3 Effect of purity on high temperature performance

The purity of the material has the following specific effects on the high-temperature performance of the tungsten crucible:

High temperature stability: The grain boundaries of high-purity tungsten are cleaner, reducing the possibility of grain boundary slip and creep at high temperatures. Tungsten crucibles with a purity of ≥ 99.99% can operate stably above 3000°C, while crucibles with a purity of 99.9% may be microscopicly deformed at 2800°C.

Thermal shock resistance: Impurities, such as oxygen or carbon, can form brittle phases at grain boundaries, resulting in thermal shock cracks. The higher the purity, the stronger the thermal shock resistance, which is suitable for rapid temperature rise and fall scenarios.

Resistance to contamination: Impurities in low-purity tungsten (such as iron or molybdenum) can volatilize at high temperatures, contaminating the melt and affecting crystal growth or alloy purity. High-purity tungsten crucibles minimize the risk of contamination.

2.4 Thermal properties of tungsten crucible

The thermal properties of tungsten crucible are its core advantages in high-temperature environments, which determine its performance in terms of heat conduction, thermal stability and thermal expansion matching. The following is a detailed analysis from four aspects: high temperature stability, thermal shock resistance, thermal conduction and thermal radiation characteristics, and thermal expansion matching.

2.4.1 High temperature stability of tungsten crucible

The high temperature stability of tungsten crucibles is due to the ultra-high melting point (3410°C) and low vapor pressure of tungsten. Below 3000°C, tungsten crucibles have little to no volatilization or deformation, making them suitable for extremely high-temperature environments, such as plasma material testing in nuclear fusion reactors or superalloy melting.

The key to high-temperature stability lies in the optimization of the microstructure of the material. Tungsten crucible with fine grain structure (grain size < 10 μm) can reduce grain boundary slip and improve creep resistance. The high density (>98% theoretical density) can reduce the local stress concentration caused by stomata.

2.4.2 Tungsten crucible thermal shock resistance and thermal fatigue life

Thermal shock resistance refers to the ability of a tungsten crucible to resist cracking under rapid temperature changes. Tungsten's low coefficient of thermal expansion (4.5×10^{-6}/K) and high thermal conductivity (174 W/(m·K)) give it excellent thermal shock resistance, but its brittleness at room temperature may lead to crack propagation.

Thermal shock resistance is usually tested using water quenching or laser pulse heating. For example,

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a tungsten crucible is quickly cooled from 2000°C to room temperature to observe crack formation. Fine-grained and high-purity tungsten crucibles can withstand temperature differences of >1000°C/s without cracking, while the limit of ordinary crucibles is about 500°C/s.

Thermal fatigue life refers to the structural stability of a crucible after multiple thermal cycles. Thermal fatigue cracks typically originate from surface defects or weakening of grain boundaries. Through surface polishing and grain refinement, thermal fatigue life can be extended by more than 50%.

2.4.3 Thermal conductivity and thermal radiation characteristics of tungsten crucible

Tungsten has a thermal conductivity of 174 W/(m·K) and maintains a high thermal conductivity at high temperatures, making it suitable for scenarios that require a fast thermal response, such as monocrystalline silicon growth or thin film deposition. The thermal conductivity decreases slightly with increasing temperature and is about 120 W/(m·K) at 2000°C.

Thermal radiation properties are determined by surface emissivity. The surface emissivity of the unpolished tungsten crucible is 0.3-0.4, which can be reduced to 0.1-0.2 after polishing, reducing the loss of heat radiation. At high temperatures (> 2000°C), heat radiation becomes the main route of heat loss, and thermal efficiency needs to be optimized through crucible design, such as the addition of reflective coatings.

2.4.4 Tungsten crucible thermal expansion matching

The coefficient of thermal expansion of tungsten is 4.5×10^{-6}/K, which is much lower than that of most melts (e.g., silicon: 2.6×10^{-5}/K; Aluminum: 2.3×10^{-5}/K). A mismatch in thermal expansion can lead to thermal stress at the crucible-melt interface, causing cracks or peeling.

To improve the matching of thermal expansion, the following measures can be taken:

Geometric optimization: Finite element analysis is used to design the crucible wall thickness and bottom curvature to disperse the thermal stresses.

Buffer layer: A graphite or zirconia buffer layer is applied to the inner wall of the crucible to mitigate the difference in thermal expansion.

Preheating process: Slow preheating of the crucible and melt before heating up to reduce stress caused by temperature differences.

2.5 Chemical stability of tungsten crucible

The chemical stability of tungsten crucibles is an important advantage in corrosive environments and high-temperature reactions, determining its compatibility with melts, chemicals and atmospheres. The following is discussed in detail from three aspects: acid and alkali corrosion resistance, high temperature inertness and anti-pollution ability, and compatibility with molten metals and alloys.

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2.5.1 Acid and alkali corrosion resistance of tungsten crucible

Tungsten has excellent corrosion resistance to most acids and bases, especially in normal and neutral or weakly acidic environments. The specific corrosion resistance is as follows:

Acidic Environment: Tungsten crucibles are resistant to hydrochloric acid, sulfuric acid, and phosphoric acid, but dissolve slowly in strong oxidizing acids such as concentrated nitric acid or aqua regia. Experiments show that the corrosion rate of tungsten crucible with 99.95% purity in 10% sulfuric acid solution (25°C) < 0.01 mm/year.

Alkaline environment: Tungsten is relatively stable in strong alkaline solutions (such as sodium hydroxide), but oxidation reaction may occur in alkaline melts at high temperatures (>500°C), and direct contact should be avoided.

Neutral environment: Tungsten crucible has almost no corrosion in neutral solutions (such as water or salt solution), which is suitable for high-purity chemical refining in the chemical industry.

Acid and alkali corrosion resistance is usually tested by immersion or electrochemical corrosion to ensure that there is no significant mass loss or morphological change on the surface of the crucible.

2.5.2 Tungsten crucible high temperature inertness and anti-pollution ability

Tungsten crucibles are extremely chemically inert in inert atmospheres (e.g. argon, helium) or vacuum, which can effectively prevent contamination and are suitable for the preparation of high-purity materials such as monocrystalline silicon, sapphire or compound semiconductors (GaAs, GaN).

The key to high-temperature inertness lies in tungsten's low vapor pressure and stable crystal structure. Below 3000°C, tungsten is almost non-volatile, reducing the contamination of the melt by the crucible material. In contrast, impurities in low-purity crucibles, such as iron or carbon, may volatilize at high temperatures, resulting in crystal defects or deviations in alloy composition.

The test of the resistance to contamination is usually done by heating the crucible in a vacuum environment to analyze the chemical composition of the volatiles.

2.5.3 Compatibility of tungsten crucible with molten metal and alloy

Tungsten crucibles have good compatibility with most molten metals and alloys, but may react with certain reactive metals. The specific compatibility analysis is as follows:

Inert metals: Tungsten crucibles are highly compatible with molten aluminum, copper, gold, silver and other inert metals, without obvious chemical reaction or dissolution, and are suitable for precious metal refining.

Active metals: Tungsten may react at the interface with molten titanium, zirconium, hafnium and

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other active metals to form brittle compounds (such as titanium tungsten). To avoid reactions, a graphite or zirconia protective layer can be applied to the inner wall of the crucible.

Alloy: Tungsten crucible can be used for the melting of high-temperature alloys (such as nickel-based alloys and cobalt-based alloys), but the melting time and atmosphere need to be controlled to avoid trace dissolution caused by long-term contact.

Compatibility testing typically uses high-temperature melting experiments combined with scanning electron microscopy (SEM) and X-ray diffraction (XRD) to analyze interfacial reaction products.

2.6 Tungsten crucible mechanical properties

The mechanical properties of tungsten crucible determine its structural integrity and service life in high temperature and complex stress environments. The following is a detailed analysis from four aspects: high temperature deformation resistance, crack propagation resistance, structural stability under circulating heating, and shock and vibration resistance.

2.6.1 High temperature deformation resistance of tungsten crucible

Tungsten retains high strength and rigidity at high temperatures, and its resistance to deformation is superior to that of other refractories such as graphite or alumina. At 2000°C, the yield strength of tungsten can still reach 100-150 MPa, which is much higher than that of graphite (about 20 MPa).

The key to resistance to deformation at high temperatures lies in grain size and density. Tungsten crucibles with fine grains (<10 μm) and high density (>98%) are effective against creep and plastic deformation. The test data of Chinatungsten Online shows that the deformation rate of tungsten crucible can be controlled below 0.1% at 2500°C by optimizing the sintering process.

2.6.2 Tungsten crucible crack propagation resistance

The brittleness of tungsten makes it prone to crack propagation at room temperature, but it shows some toughness at high temperature (>1000°C). Crack propagation resistance can be improved by:

Grain refinement: The fine grain structure can disperse the crack energy and reduce the crack growth rate.
Surface strengthening: e.g. nitriding or ion implantation to improve surface hardness and crack resistance.
Defect control: Removal of porosity and inclusions through non-destructive testing (e.g. ultrasonic or X-ray) to reduce crack initiation.

Crack propagation testing typically uses a three-point bending or fracture toughness test.

2.6.3 Structural stability of tungsten crucible under circulating heating

Circulating heating can lead to thermal fatigue cracks and microstructural degradation, affecting the structural stability of the crucible. Influencing factors include:

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Thermal stress: Thermal stress caused by rapid ramp and fall of temperature can lead to cracks.
Grain boundary weakening: Prolonged operation at high temperatures may cause grain boundary slippage or impurity enrichment.
Surface damage: Surface oxidation or melt erosion can accelerate structural degradation.

Structural stability can be significantly improved by optimizing the sintering process (e.g., multi-stage sintering) and surface treatments (e.g., anti-oxidation coatings).

2.6.4 Tungsten crucible shock and vibration resistance

Tungsten crucible has weak resistance to shock and vibration, especially at room temperature, and is prone to cracks due to mechanical shock or vibration. At high temperatures (>1000°C), the toughness of tungsten is slightly improved, but strong impacts still need to be avoided.

Impact resistance is usually tested using a drop weight test or a shaker test. In practical use, shock-absorbing brackets and protective packaging are required to reduce the risk of impact during transportation and operation.

2.7 Other characteristics of tungsten crucible

In addition to thermal, chemical and mechanical properties, tungsten crucibles also have some special properties that are suitable for specific application scenarios. The following is analyzed from three aspects: high-temperature electrical properties, anti-wear and abrasion resistance, and anti-radiation properties.

2.7.1 High-temperature electrical properties of tungsten crucible

Tungsten has a stable resistivity at high temperatures, making it suitable as an electric heating element or as a high-temperature electrode (http://tungsten.com.cn/chinese/tungsten-electrodes.html). At 2000°C, the resistivity of tungsten is 50-60 μΩ·cm, which is only 5 times that of room temperature, and exhibits excellent electrical stability.

Applications for high-temperature electrical properties include:
Arc melting: Tungsten crucibles can be used as electrodes to withstand high currents and high heat loads.
Resistance heating: The tungsten crucible can be directly heated by electricity, simplifying the design of the heating system.

2.7.2 Tungsten crucible wear and wear resistance

Tungsten has a hardness of 8-9 on the Mohs scale, high surface hardness, excellent wear resistance, and is suitable for long-term high-temperature operation. The test of abrasion resistance usually uses a friction and wear test, which simulates the contact of a crucible with a molten substance or tool. Improved wear resistance can be achieved by surface coatings such as tungsten carbide or titanium nitride, or by ion implantation. These treatments increase the surface hardness to HV 2000 and further extend the crucible life.

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2.7.3 Radiation resistance of tungsten crucibles (nuclear industry applications)

Tungsten has a high absorption capacity for neutrons and gamma rays, making it suitable for high-temperature components in nuclear reactors and nuclear fusion devices. The radiation resistance of tungsten is due to its high density and high atomic number, which can effectively shield against radiant energy.

In the nuclear industry, tungsten crucibles are commonly used for plasma material testing and high-temperature component manufacturing. The test data showed that the tungsten crucible remained structurally intact under gamma radiation of 10^6 Gy without obvious lattice damage.

2.8 Tungsten Crucible MSDS from CTIA GROUP LTD

The Safety Data Sheet (MSDS) of tungsten crucible materials provided byCTIA GROUP LTD (http://cn.ctia.group) lists the chemical composition, physical properties, safety operation guidelines and emergency treatment measures of the products in detail. The main contents of MSDS include:

Part I: Product Name
Name：Tungsten Crucible
CAS No.:7440-33-7

Part II: Composition/Composition Information
Main content　W≥99.95%
Total impurity content　≤0.05%

Part III: Overview of Hazards
Health hazards: This product is non-irritating to the eyes and skin.
Explosion hazard: This product is non-flammable and non-irritating.

Part IV: First Aid Measures
Skin-to-skin contact: Remove contaminated clothing and rinse with plenty of running water.
Eye contact: Lift the eyelid and rinse with running water or saline. Medical treatment.
Inhalation: Remove from the scene to fresh air. If you have difficulty breathing, give oxygen. Medical treatment.
Intake: Drink plenty of warm water to induce vomiting. Medical treatment.

Part V: Fire Protection Measures
Harmful Combustion Products: Natural decomposition products are unknown.
Fire extinguishing method: Firefighters must wear gas masks and full-body firefighting suits to extinguish the fire in the upwind direction. Fire extinguishing agent: dry leather powder, sand.

Part 6: Emergency Handling of Spills
Emergency treatment: Isolate the leakage contaminated area and restrict access. Cut off the source of fire. Emergency responders are advised to wear dust masks (full face masks) and protective

clothing. Avoid dust, sweep it up carefully, put it in a bag and transfer it to a safe place. If there is a large amount of leakage, cover it with plastic cloth or canvas. Collect and recycle or transport to a waste disposal site for disposal.

Part VII: Handling, Handling and Storage

Precautions for operation: Operators must be specially trained and strictly follow the operating procedures. It is recommended that operators wear self-priming filtering dust masks, chemical safety glasses, anti-poison penetration overalls, and rubber gloves. Keep away from fire and heat sources, and smoking is strictly prohibited in the workplace. Use explosion-proof ventilation systems and equipment. Avoid dust generation. Avoid contact with oxidants and halogens. When handling, it is necessary to load and unload lightly to prevent damage to the packaging and containers. Equipped with corresponding varieties and quantities of fire-fighting equipment and leakage emergency treatment equipment. Empty containers may leave harmful substances behind.

Storage precautions: Store in a cool, ventilated warehouse. Keep away from fire and heat sources. It should be stored separately from oxidants and halogens, and should not be mixed. Equipped with the corresponding variety and quantity of fire-fighting equipment. The storage area should be equipped with suitable materials to contain the spill.

Part VIII: Exposure Control/Personal Protection

China MAC (mg/m3): 6

USSR MAC (mg/m3): 6

TLVTN:ACGIH 1mg/m3

TLVWN:ACGIH 3mg/m3

Monitoring method: potassium thiocyanide-titanium chloride spectroluminescence method

Engineering control: the production process is dust-free and fully ventilated.

Respiratory protection: When the dust concentration in the air exceeds the standard, a self-priming filtering dust mask must be worn. In the event of an emergency evacuation, air breathing apparatus should be worn.

Eye protection: Wear chemical safety glasses.

Body protection: Wear anti-poison penetration overalls.

Hand protection: Wear rubber gloves.

Part IX: Physicochemical properties

Main ingredient: Pure

Appearance and properties: solid, bright white metal

Melting Point (°C): N/A

Boiling point (°C): N/A

Relative density (water = 1): 13~18.5 (20 °C)

Vapor density (air = 1): No data

Saturation vapor pressure (kPa): no data available

Heat of combustion (kj/mol): no data

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Critical temperature (°C): No data available
Critical pressure (MPa): No data available
Logarithm of water partition coefficient: no data
Flash point (°C): No data available
Ignition temperature (°C): No data
Explosion Limit % (V/V): No data
Lower explosion limit % (V/V): No data
Solubility: soluble in nitric acid, hydrofluoric acid
Main uses: used to make shielding parts, tungsten alloy dart shafts, tungsten alloy balls, etc

Part X: Stability and Reactivity
Prohibited substances: strong acid and alkali.

Part 11:
Acute toxicity: no data available
LC50: No data

Part XII: Ecological data
There is no data for this section

Part XIII: Disposal
Waste disposal method: Refer to relevant national and local laws and regulations before disposal. Recycle if possible.

Part XIV: Shipping Information
Packaging category: Z01
Precautions for transportation: The packaging should be complete when shipping, and the loading should be secure. During transportation, it is necessary to ensure that the container does not leak, collapse, fall, or damage. It is strictly forbidden to mix with oxidants, halogens, edible chemicals, etc. During transportation, it should be protected from exposure to sun, rain and high temperature. Vehicles should be thoroughly cleaned after transportation.

Part 15: Supplier Information
Supplier: CTIA GROUP LTD
Tel: +86 0592-5129696/5129595

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CTIA GROUP LTD tungsten crucibles

CTIA GROUP LTD

Tungsten Crucibles

1. Overview of Tungsten Crucibles

Tungsten crucibles are essential tools in the fields of metallurgy, chemistry, and materials science. They are particularly suitable for processes that involve melting or heating substances to extremely high temperatures. Studies have shown that tungsten crucibles perform exceptionally well in applications such as sapphire crystal growth, rare earth metal melting, vacuum coating, and high-temperature furnaces.

2. Features of Tungsten Crucibles

Ultra-high melting point: Making them ideal for extreme high-temperature environments.

High purity: purity of ≥99.95% minimizes the impact of impurities on experiments or production processes.

Excellent corrosion resistance: Offering outstanding chemical stability.

High density and low vapor pressure: Ensuring material stability.

High strength and wear resistance: Ensuring long service life.

Low surface roughness: Reducing residue buildup and extends the crucible's lifespan.

3. Applications of Tungsten Crucibles

Rare earth metal melting: Performed in vacuum or inert gas environments to ensure material purity.

Vacuum coating: Used in thermal evaporation-deposition technology in electronics manufacturing.

High-temperature furnaces: Functions as a key component capable of withstanding environments below 2400℃.

Chemical synthesis: Suitable for handling corrosive substances such as acids and molten metals.

Metal smelting and refining: Used for melting and refining high-purity metals.

Sapphire crystal growth: Utilized for melting and holding materials like silicon, gallium arsenide, and germanium in semiconductor production at temperatures between 2000－2500° C.

4. Specifications of Tungsten Crucibles

Specification	Details
Material	Pure tungsten or tungsten alloy
Purity	99.95%
Diameter	20–620 mm
Height	20–500 mm
Wall Thickness	3.5–30 mm (depending on diameter)
Shape	Round, square, rectangular, stepped, or customized shapes
Surface Finish	Smooth inner and outer walls, no internal cracks

5. Purchasing Information

Email: sales@chinatungsten.com; Phone: +86 592 5129595; 592 5129696

Website: www.tungsten.com.cn

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Chapter 3 Preparation Process and Technology of Tungsten Crucible

The preparation of tungsten crucible is a complex process involving raw material preparation, powder metallurgy, molding, sintering, machining, post-processing and quality control. The technical details of each link directly affect the performance and cost of the crucible. This chapter will discuss in detail the process flow, equipment requirements, optimization strategies of each link, and the latest technological advances of the world's major tungsten products companies.

3.1 Preparation of tungsten crucible raw materials

The quality of the raw material is the basis of the performance of the tungsten crucible, which directly determines its purity, microstructure and high-temperature performance. The following is a detailed discussion from four aspects: tungsten ore refining, tungsten powder characteristics, particle size control and quality inspection.

3.1.1 Tungsten ore refining and high-purity tungsten powder production

The raw materials of tungsten crucible are mainly derived from wolframite and scheelite (www.tungsten.com.cn). The refining process includes ore crushing, flotation, gravity separation, chemical leaching, and ammonium paratungstate (APT) preparation. APT produces high-purity tungsten powder through hydrogen reduction, and the process flow is as follows: APT calcination (500-800 °C) → hydrogen reduction (800-1000 °C) → powder screening.

The purity of high-purity tungsten powder is usually required to reach more than 99.95%, and some high-end applications (such as semiconductors) require 99.999% (5N). Atmosphere control (hydrogen purity > 99.999%) and temperature gradient (±5°C) during APT reduction are key to achieving high purity. Reduction furnaces are usually designed with multi-zone temperature control, and the furnace tube material is high-purity molybdenum or quartz to avoid impurity contamination.

Challenges in the refining process include energy consumption and environmental issues. The traditional hydrometallurgical process requires the use of a large number of acid and alkali reagents, which produce waste liquid and waste gas. Chinatungsten Online's green metallurgical technology reduces waste liquid emissions to 0.1 m^3/ton through closed-loop water treatment and catalytic conversion of exhaust gases, in accordance with ISO 14001 [67].

3.1.2 Chemical and physical characteristics requirements of tungsten powder

The chemical properties of tungsten powder include low oxygen content (<200 ppm), low impurity content (iron<50 ppm, nickel < 20 ppm, carbon <30 ppm) and high purity (>99.95%). Physical properties include particle size, topography, fluidity, and apparent density. The particle size range is typically 1 μm to 10 μm, and the topography is preferably nearly spherical to improve the density and sintering properties of the powder. The flow rate is measured using a Hall velocity meter, and the flow of high-quality tungsten powder should be less than 20 s/50g. The apparent density (about 4-6 g/cm^3) reflects the packing characteristics of the powder and directly affects the density of the molded body.

The technical specifications of Chinatungsten Online require that the oxygen content of tungsten powder is controlled below 100 ppm by high-temperature hydrogen reduction, and iron impurities are removed by magnetic separation and pickling. Plasma spheroidization was used to optimize the irregular shape of the powder to a near-spherical shape, with a nodularization rate of more than 90% [68]. Global companies such as the Austrian Plansee Group have controlled the particle size distribution of tungsten powder at ±0.5μm through airflow classification technology to improve the microstructure uniformity of the crucible.

3.1.3 Tungsten powder particle size distribution and morphology control

The particle size distribution of tungsten powder directly affects the density, mechanical properties and sintering shrinkage of the crucible. The narrow particle size distribution (D90/D10<2) improves crucible uniformity and reduces porosity and cracks. Particle size control is typically done using airflow classification, ultrasonic sieving, or wet sedimentation techniques. The airflow classification separates powders of different particle sizes by adjusting the airflow velocity (5-20 m/s) with an accuracy of ±0.1 μm. Ultrasonic sieving is used to remove ultrafine powders (<0.5 μm) to avoid abnormal grain growth during the sintering process.

Topography control is the key to particle size optimization. The bulk density of near-spherical powder is about 20% higher than that of irregular powder, and the density of sintering can reach more than 99%. Plasma spheroidization technology melts tungsten powder with high-temperature plasma (>10000°C) to form a spherical shape under surface tension.

3.1.4 Raw material quality inspection

The testing of raw materials includes chemical composition analysis, particle size analysis, morphology observation and physical property testing. Chemical composition was analyzed using X-ray fluorescence spectrometry (XRF), inductively coupled plasma mass spectrometry (ICP-MS), and gas analyzers with an accuracy of 1 ppm. The particle size analysis is carried out by a laser particle size analyzer with a measurement range of 0.1 μm to 100 μm. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used for topography observation with a resolution of 1 nm. Physical property testing includes flow and apparent density measurements to ensure that the powder meets molding and sintering requirements.

3.2 Tungsten crucible powder metallurgy process

Powder metallurgy is the core technology of tungsten crucible preparation, which involves steps such as mixing, cold pressing and densification. The following is a detailed discussion of three aspects: mixing and additives, cold pressing and preforming, and densification and debinder.

3.2.1 Tungsten powder mixture and additives

To improve the performance of the crucible, trace elements (e.g., lanthanum, cerium, yttrium) or binders (e.g., polyvinyl alcohol PVA, polymethyl methacrylate PMMA) are usually added to tungsten powder. Lanthanum (0.5-1%) improves tungsten's high-temperature strength and creep resistance, while cerium (0.2-0.5%) improves thermal shock resistance. Binders are used to enhance

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the strength of cold-pressed bodies, typically at a dosage of 1-3 wt%. The mixing process uses planetary ball mills or V-mixers with a mixing time of 4-8 hours and a speed of 100-300 rpm to ensure even distribution of additives.

3.2.2 Cold pressing and preforming technology

Cold press forming is achieved by uniaxial pressing or isostatic pressing technology with a pressure range of 100 MPa to 300 MPa. Single-shaft pressing is suitable for small crucibles (diameter < 200 mm) with molds made of high-strength steel or carbide and surface polished to Ra<0.1 µm. Isostatic pressing (CIP) applies pressure evenly through a liquid medium and is suitable for large crucibles (diameter > 300 mm) with a density of 60%-70% of the theoretical density. The shape of the preform body needs to consider the sintering shrinkage (15%-20%), and the mold size is usually enlarged by 1.2 times.

3.2.3 Powder densification and debinder

The debinder process is carried out in a hydrogen atmosphere of 400°C to 600°C, with a holding time of 2-4 hours and a removal rate of more than 99%. The hydrogen atmosphere prevents the oxidation of tungsten powder and removes oxygen impurities from the surface. Densification is achieved by sintering, and the final density of the crucible can reach more than 99%. The pre-sintering body is pre-sintered (800-1000°C) to increase the initial strength.

3.3 Tungsten crucible forming process

The forming process determines the geometric accuracy, structural uniformity and production efficiency of the crucible. The following is a detailed discussion from five aspects: isostatic pressing, molding, spinning, complex shape forming and mold design.

3.3.1 Isostatic pressing (cold isostatic pressing, hot isostatic pressing)

Cold isostatic pressing (CIP) applies pressure (100-200 MPa) evenly through a liquid medium such as water or oil, and is suitable for the forming of large crucibles. The pressure chamber of a CIP plant is usually made of high-strength steel and lined with a rubber mold to protect the surface of the green body. Hot isostatic pressing (HIP) is carried out at high temperatures (1000-1500°C) and high pressures (100-200 MPa) to further increase the density of the crucible and reduce the porosity to less than 0.1%.

3.3.2 Compression molding and extrusion

Compression molding is achieved by uniaxial or biaxial pressing, which is suitable for low-volume production with low tooling costs. Extrusion is used to produce slender crucibles (e.g. height > 1000 mm) with a high aspect ratio (> 10:1) achieved by continuous extrusion. Both processes require precise control of powder flow and mold lubricants (e.g. graphite emulsion).

3.3.3 Spinning and stretching

Spinning moulding shapes crucibles by rotating molds at high speed (500-2000 rpm) and is suitable for the production of thin-walled crucibles (wall thickness < 3 mm). The mold is made of carbide

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or ceramic, and the surface is polished to Ra<0.05μm. Stretch forming is achieved by means of a drawing die and is suitable for crucibles with large heights. According to Chinatungsten Online's technical report, the wall thickness uniformity of the spun-formed crucible is ±0.1 mm, and the production efficiency is about 50% higher than that of molding.

3.3.4 Forming technology for crucibles with complex shapes

Crucibles with complex shapes, such as flanged, multi-cavity or stepped designs, are often spun by CN spinning, isostatic pressing, or additive manufacturing. CNC spinning enables complex geometries through multi-axis linkage, while isostatic pressing is formed by flexible molds.

3.3.5 Mold design and manufacturing

Mold design needs to consider sinter shrinkage, thermal stress distribution, and mold life. The mold material is usually high-strength steel, carbide or ceramic, and the surface needs to be chrome-plated or coated with DLC (diamond-like coating) to improve wear resistance.

3.4 Tungsten crucible sintering process

The sintering process of tungsten crucible is the core step in its preparation process, which directly determines the density, microstructure, mechanical properties, high temperature stability and final service life of the crucible. Sintering causes tungsten powder particles to diffuse and combine through high-temperature treatment to form a high-density, uniform solid structure. Due to the ultra-high melting point (about 3422°C), high hardness and chemical inertness of tungsten, the sintering process needs to be carried out under precisely controlled conditions to ensure consistent product quality and reliable performance. This chapter will discuss in depth the various technologies of tungsten crucible sintering, including vacuum sintering, hydrogen or inert gas shielded sintering, sintering parameter optimization, multi-stage sintering, gradient sintering, sintering shrinkage and size control, combined with the technical practices of global tungsten products companies, the latest academic research and the industry information provided by Chinatungsten Online, to comprehensively analyze the principles, equipment, parameters and challenges of the sintering process.

3.4.1 Vacuum sintering technology

Vacuum sintering is the process of choice for the production of high-purity tungsten crucibles, which are widely used in demanding fields such as semiconductor crystal growth, rare earth metal smelting, and the nuclear industry. The vacuum environment significantly reduces the oxidation of tungsten by oxygen and other reactive gases, thus ensuring high purity and excellent performance of the crucible.

Process principle

Vacuum sintering heats the tungsten body at a temperature below the melting point of tungsten (typically between 1800°C and 2600°C) to promote surface diffusion, grain boundary diffusion and stereoscopic diffusion between particles to form a dense microstructure. Under vacuum, gas molecules are removed from the environment, reducing the formation of oxides (e.g. tungsten

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trioxide) and other impurities. During the sintering process, tungsten particles are bonded by atomic migration and pore closure to form a crucible structure with a density close to the theoretical density (19.25 g/cm³).

Equipment Requirements:

Vacuum sintering typically uses a high-temperature vacuum sintering furnace equipped with molybdenum, tungsten, or graphite heating elements to achieve extreme high temperatures. The furnace body should have the following characteristics:

Vacuum system: Equipped with mechanical, diffusion or turbomolecular pumps to ensure a vacuum level of 10^{-3} Pa to 10^{-5} Pa.

Heating elements: Molybdenum or graphite heating elements need to withstand high temperatures above 2600°C and have uniform temperature distribution.

Temperature control: infrared thermometer or thermocouple is used, and the accuracy is controlled within ±5°C.

Furnace material: Lined with high-purity graphite or molybdenum to prevent reaction with tungsten body at high temperatures.

Process parameters

Key process parameters have a significant impact on the sintering effect:

Sintering temperature: usually between 2000°C and 2400°C. High temperature (>2500°C) may lead to abnormal grain growth and reduce the crack propagation resistance of the crucible. Temperatures that are too low (<1900°C) may result in insufficient density (<95%).

Holding time: Depending on the size of the crucible and the wall thickness, the holding time is generally 2 to 10 hours. It takes 2 to 4 hours for thin-walled crucibles (wall thickness <5 mm) and 6 to 10 hours for thick-walled crucibles (wall thickness > 10 mm).

Vacuum: Below 10^{-3} Pa, some high-end applications (e.g. crucibles for semiconductors) require 10^{-4} Pa or higher.

Heating rate: control at 3°C/min to 10°C/min, too fast may cause thermal stress and cause cracking of the green body.

Cooling rate: controlled below 5°C/min, using sectional cooling to reduce residual stress.

Technological advantages

High purity: The vacuum environment effectively prevents oxidation and impurity pollution, and the purity of the crucible can reach more than 99.99%.

Homogeneous microstructure: Grain sizes from 10 to 50 μm can be controlled by precise control of temperature and time, optimizing mechanical properties.

Low defect rate: Reduces porosity and inclusions, resulting in densities of 98% to 99.5% to meet the needs of high-end applications.

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Technical challenges

High equipment costs: Vacuum sintering furnaces are expensive to manufacture and maintain, especially for the operation of high vacuum systems.

High energy consumption: High energy consumption due to high temperature and long-term sintering, and the process needs to be optimized to improve economy.

High requirements for the green body: The initial density and uniformity of the green body directly affect the sintering effect, and the previous process (such as isostatic pressure molding) needs to be strictly controlled.

3.4.2 Hydrogen or inert gas shielded sintering

Hydrogen or inert gases (e.g. argon, nitrogen) shielded sintering is another important technology in tungsten crucible production for cost-sensitive or relatively low purity applications, such as precious metal melting in the metallurgical industry and silicon material processing in the photovoltaic industry.

Process principle

Protected by hydrogen or inert gas, the sintering environment can effectively prevent the reaction of tungsten body with oxygen or other reactive gases. Hydrogen sintering improves the purity of tungsten materials by reducing trace oxides such as WO_3 and promotes diffusion bonding between particles. Inert gases (such as argon) prevent tungsten from reacting with oxygen or nitrogen at high temperatures by forming an inert atmosphere, which is suitable for scenarios with high requirements for chemical stability.

Equipment Requirements:

Hydrogen sintering furnaces and inert gas sintering furnaces need to have the following characteristics:

Heating system: tungsten wire, molybdenum wire or graphite heating element is used to withstand high temperature above 2300°C.

Gas Purification System: Equipped with molecular sieve or catalyst to ensure that the purity of hydrogen reaches 99.999%, and remove water and oxygen impurities.

Atmosphere circulation system: control the gas flow and pressure to prevent local uneven atmosphere.

Safety system: Hydrogen sintering furnaces need to be equipped with explosion-proof devices and leak detection systems to ensure safe operation.

Process parameters

Sintering temperature: usually between 1800°C and 2300°C, lower than vacuum sintering to reduce energy consumption.

Atmosphere Control:

Hydrogen: $\geq$ 99.999% purity, flow rate 0.5 to 2 L/min, moisture content $<$ 5 ppm.

Argon: purity$\geq$ 99.999%, oxygen content$<$ 10 ppm, pressure 0.1 to 0.5 MPa.

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Holding time: 3 to 12 hours, depending on the size of the crucible and density requirements.
Heating rate: 5°C/min to 15°C/min, balancing efficiency and thermal stress.
Cooling rate: 3°C/min to 8°C/min, inert gas assisted cooling to reduce stress.

Technological advantages

Lower cost: Compared with vacuum sintering, hydrogen sintering has lower equipment and operating costs, and is suitable for high-volume production.
Oxide reduction: Hydrogen can effectively remove trace oxides in tungsten powder and improve the purity of materials.
Flexibility: Inert gas sintering can be adapted to a variety of scenarios by selecting different gases (e.g. argon or helium) according to the application requirements.

Technical challenges

Hydrogen safety: The flammability of hydrogen requires strict safety measures, adding to the complexity of equipment design.
Difficulty in atmosphere control: Precise control of gas purity and flow to prevent the introduction of moisture or other impurities.
Purity limitations: Atmosphere sintering has a slightly lower purity than vacuum sintering and may not be suitable for ultra-high purity applications.

3.4.3 Sintering temperature, time and atmosphere optimization

Optimization of sintering temperature, time and atmosphere is the key to achieving high-performance tungsten crucibles, which directly affect density, grain size, mechanical properties and high temperature stability. By systematically optimizing these parameters, the best balance between performance and cost can be struck.

Temperature optimization

The sintering temperature is the core factor affecting the diffusion rate and grain growth of tungsten particles. Studies have shown that:
Below 2000°C, the particle diffusion rate is slower and the density is typically less than 95%, making it unsuitable for demanding applications.
At 2200°C to 2400°C, the density can reach 97% to 99.5%, and the grain size is controlled from 20 to 50µm, taking into account strength and toughness.

Above 2500°C, grain overgrowth (>100µm) may lead to a decrease in crack propagation resistance and affect crucible life. The optimization strategy includes the use of gradient heating curves (e.g., 1000°C preheating, 1800°C medium-temperature sintering, 2300°C high-temperature densification) to balance densification and grain control. According to a technical article by Chinatungsten Online, accurate temperature optimization can improve the thermal shock resistance of the crucible by up to 20%.

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Time optimization

The holding time needs to match the crucible size, wall thickness and density targets:

Small crucible (diameter < 100mm): keep warm for 2 to 4 hours, and the density can reach more than 97%.
Medium-sized crucibles (100 to 300 mm diameter): keep warm for 4 to 8 hours to ensure uniform densification.
Large crucibles (diameter > 300 mm): hold for 8 to 12 hours, extended to compensate for diffusion delay in thick-walled areas. Holding too long can lead to increased energy consumption and coarse grains, while too short can lead to residual porosity. Studies have shown that production efficiency can be increased by 10 to 15 percent by dynamically adjusting the holding time.

Atmosphere optimization

The selection and control of the atmosphere is critical to the purity and performance of the tungsten crucible:
Hydrogen atmosphere: Increases tungsten purity to more than 99.95% by reducing trace oxides (e.g. WO_2, WO_3). The moisture content (<5 ppm) should be strictly controlled to avoid the reaction of water vapor with tungsten to form volatile compounds.
Argon atmosphere: suitable for ultra-high purity applications, such as crucibles for the nuclear industry, where oxygen content < 10 ppm.
Helium atmosphere: High thermal conductivity, suitable for rapid cooling scenarios, but at a higher cost. Dynamic atmosphere conditioning technologies, such as stage switching of hydrogen and argon, further optimize the sintering effect. Research by the Plansee Group has shown that dynamic atmosphere control can reduce the chemical impurity content of crucibles by up to 30%.

3.4.4 Multi-stage sintering and gradient sintering process

Multi-stage sintering and gradient sintering are cutting-edge technologies in tungsten crucible manufacturing, which are designed to solve the problems of inhomogeneity, thermal stress, and microstructure defects in the sintering process of large-scale crucibles.

Multi-stage sintering

Multi-stage sintering gradually realizes the densification of the green body by controlling the temperature and holding time in stages, which is divided into:
Low temperature phase (800°C to 1200°C): Removes binders, volatile impurities and adsorbed gases to prevent the formation of pores in the subsequent high temperature phase.
Medium temperature stage (1600°C to 1800°C): promotes the initial binding of particles and reduces porosity to less than 20%.
High temperature phase (2200°C to 2400°C): Final densification with a density of more than 98%.
The advantages of multi-stage sintering are reduced thermal stress, reduced microcracks, and improved structural uniformity. Studies have shown that multi-stage sintering can reduce the defect rate of large crucibles by up to 25%.

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Gradient sintering

Gradient sintering optimizes the distribution of properties by applying different temperatures, atmospheres, or pressures to different areas of the crucible. For example:

High temperature sintering of outer wall: high temperature of 2400°C is used to enhance hardness and wear resistance.

Low temperature sintering of the inner wall: controlled at 2200°C, optimized toughness and thermal shock resistance.

Atmosphere gradient: argon atmosphere is used on the outer wall to improve purity, and hydrogen atmosphere is used on the inner wall to remove oxides. Gradient sintering requires advanced sintering furnace designs such as zonal heating and multi-atmosphere control systems. According to Chinatungsten Online's technical report, gradient sintering technology can reduce the incidence of cracking by 35% in the production of large diameter (>400mm) tungsten crucibles.

Equipment & Control

Multi-stage and gradient sintering requires an intelligent sintering furnace with the following features:

Zone heating: Independent temperature control of different zones through multiple heating elements.

Dynamic Atmosphere Regulation: Equipped with a gas distribution system to support the switching of hydrogen, argon or mixed atmospheres.

Real-time monitoring: Infrared temperature measurement and laser ranging are used to monitor the temperature field and size changes of the crucible.

3.4.5 Sintering shrinkage and size control

Shrinkage during the sintering process is a key challenge in tungsten crucible manufacturing, directly impacting the final dimensional accuracy, geometric tolerances, and production consistency.

Shrinkage mechanism

Sinter shrinkage is due to the pore closure and densification process between tungsten particles. Shrinkage is typically between 15% and 22%, depending on the following factors:

Tungsten powder particle size: fine particle size (<5 μm) has a high shrinkage (18% to 22%), large particle size (>10 μm) has a lower shrinkage (15% to 18%).

Density of the green body: The higher the initial density of the cold isostatic pressed green body, the lower the shrinkage.

Sintering conditions: High temperature and long sintering will increase shrinkage, but may lead to dimensional deviations. The shrinkage process is divided into three phases: initial shrinkage (initial closure of the pores), intermediate shrinkage (particle binding), and final shrinkage (completion of densification).

Dimensional control technology

To ensure the dimensional accuracy of the crucible, the following measures need to be taken:

Mold design: Margin is reserved according to shrinkage, usually 1.15 to 1.25 times the final size. Finite element analysis (FEA) is used to simulate shrinkage behavior and optimize the mold geometry.

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Homogeneity: By optimizing the cold isostatic pressing or molding process, the density uniformity of the green body (deviation <2%) is ensured and irregular shrinkage is reduced.
Sintered supports: High-purity graphite, molybdenum or zirconia supports are used to prevent the crucible from deforming or collapsing at high temperatures.
Real-time monitoring: Laser rangefinder or X-ray imaging is used to monitor the crucible size change in real time, and the accuracy can reach ±0.05mm.
Segmented sintering: The shrinkage rate is controlled by multi-stage sintering to avoid stress concentrations caused by rapid shrinkage.

Technical challenges
Dimensional deviations: Non-uniformity in shrinkage of large crucibles (> 500mm diameter) can cause tolerances to be exceeded.
Thermal stress: Rapid shrinkage can cause microcracks, which need to be mitigated by optimizing the cooling curve.
Tooling cost: The manufacturing cost of high-precision molds is high, and it is necessary to balance cost and performance.

3.5 Tungsten crucible machining and finishing

Machining and finishing of tungsten crucibles are a critical step in ensuring their geometric accuracy, surface quality and performance after sintering. Due to the high hardness of tungsten alloy (about 7.5 on the Mohs scale), high density and embrittleness at room temperature, the machining process requires high-precision equipment, advanced tools and strict process control. This chapter will comprehensively discuss the technologies of turning, milling, drilling, EDM, laser cutting, precision grinding, polishing and surface coating, combined with the practical experience and latest research progress of global tungsten products companies, and deeply analyze the principles, equipment, parameters, advantages and challenges of each process.

3.5.1 Turning, Milling and Drilling

Process principle
Turning, milling and drilling are the basic processes of tungsten crucible machining and are used to form the shape, cavity and functional holes of the crucible:
Turning: Cutting materials by rotating the workpiece and stationary tools, mainly for the outer and inner walls of cylindrical crucibles, ensuring roundness and concentricity.
Milling: Cutting materials by rotating tools and moving workpieces, suitable for machining complex geometries, such as steps or grooves of crucibles.
Drilling: Machining of functional holes (e.g. vent holes or mounting holes) in the crucible by rotating the drill bit ensures hole diameter accuracy and position tolerances.

Equipment Requirements:
Tungsten crucibles are usually machined using high-precision numerical control machines (CNCs) equipped with the following equipment:
Machine tool: 5-axis CNC lathe or machining center with high rigidity and vibration suppression.

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Tools: Diamond (PCD) or cubic boron nitride (CBN) tools with hardness higher than tungsten (HV>2000).
Cooling system: high-pressure oil-based or water-based coolant injection system with a pressure of 10 to 20 MPa to prevent the tool from overheating.
Dust removal system: high-efficiency pulse dust collector collects tungsten dust (particle size <10μm) to ensure a safe operating environment.

Process parameters
Cutting speed: 10 to 50 m/min, too high may cause tool wear, too low will reduce efficiency.
Feeds: 0.02 to 0.2 mm/rev, optimized for crucible wall thickness and tool performance.
Depth of cut: 0.1 to 0.5 mm, deep cutting may cause microcracks.
Coolant flow: 10 to 30 L/min to ensure that the cutting zone temperature is below 200°C.

Technological advantages
High precision: CNC machine tools can achieve dimensional tolerances of ± 0.02mm, which meets semiconductor and aerospace applications.
Flexibility: Milling and drilling can be used to machine complex shapes and adapt to customization needs.
Surface Quality: The surface roughness (Ra) can be controlled from 0.8 to 1.6 μm by optimizing the parameters.

Technical challenges
Tool wear: The high hardness of tungsten results in a short tool life and requires frequent replacement of diamond or CBN tools.
Microcracks: Microcracks can be caused by mechanical stress during the cutting process and can be caused by surface or internal microcracks, which need to be investigated by non-destructive testing (ultrasonic or X-ray).
Dust management: Tungsten dust is a potential health risk and requires strict adherence to occupational safety standards (e.g., OSHA).

3.5.2 EDM and laser cutting

Electrical Discharge Machining (EDM)
EDM removes material from the surface of the workpiece by arcing and is suitable for machining tungsten crucibles with high hardness or complex shapes. EDM is divided into two forms: wire EDM and die EDM:
Wire-cut EDM: Uses a thin metal wire (e.g., molybdenum wire) as an electrode to cut complex contours.
Die EDM: Machining of internal cavities or grooves using prefabricated electrodes such as copper or graphite.

Process parameters
Discharge current: 5 to 50 A, affecting processing speed and surface quality.

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Pulse width: 10 to 100 µs, short pulses for finishing and long pulses for roughing.
Electrode material: copper or graphite, according to the processing accuracy to choose.
Working fluid: deionized water or oil-based media, which needs to maintain high insulation.

Technological advantages

No mechanical stress: Non-contact machining avoids cutting stress and reduces micro-cracks.
Complex shapes: special-shaped crucibles or small features (e.g. 0.1mm hole diameter) can be processed.
High hardness adaptability: suitable for tungsten materials with very high hardness.

Technical challenges

Slow processing speeds: EDM has a lower material removal rate (0.1 to 10 mm³/min) compared to machining.
Surface defects: Discharge may cause surface burns or micropores, requiring subsequent polishing.
Electrode wear: The loss of electrode material increases processing costs.

Laser cutting

Laser cutting uses a high-energy laser beam (fiber laser or CO_2 laser) to melt or vaporize tungsten materials and is suitable for high-precision and thin-walled crucible processing.

Process parameters

Laser power: 2 to 10 kW, depending on wall thickness.
Cutting speed: 0.5 to 5 m/min, higher speeds are available for thin-walled crucibles.
Focus position: 0.1 to 0.5 mm below the surface of the material to ensure the quality of the cut.
Assist gas: nitrogen or argon at a pressure of 5 to 15 bar to prevent oxidation.

Technological advantages

High precision: 0.1mm < cut, tolerance ±0.02mm.
Small heat-affected zone: the laser focuses on energy concentration, and the depth of heat-affected zone < 0.05mm.
Efficient: Suitable for high-speed machining of thin-walled crucibles (wall thickness < 3mm).

Technical challenges

Thermal stress: Rapid heating can cause microcracks, and the laser pulse parameters need to be optimized.
Equipment cost: High investment in high-power laser equipment and complex maintenance.
Surface Quality: Cut surfaces may require secondary processing to reduce roughness.

3.5.3 Precision grinding and polishing

Process principle

Precision grinding and polishing are used to improve the surface quality of tungsten crucibles and reduce surface roughness (Ra) to meet the demanding requirements of semiconductor, optical and high-temperature melting:

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Grinding: Removal of surface material by means of a diamond grinding wheel, improving geometric accuracy and surface flatness.
Polishing: Chemical-mechanical polishing (CMP), electrolytic polishing or ultrasonic polishing is used to further reduce roughness and improve the finish.

Equipment Requirements:
Grinding machines: high-precision surface grinding machines or cylindrical grinding machines with spindle speeds from 5,000 to 10,000 rpm.
Grinding wheel: diamond grinding wheel, grain size 400 to 2000 mesh, need to be trimmed regularly.
Polishing equipment: The CMP machine is equipped with a high-precision polishing head, and the ultrasonic polishing machine needs to support high-frequency vibration (20 to 40 kHz).
Testing equipment: surface roughness meter (such as Talysurf) with a resolution of 0.01 µm.

Process parameters
Grinding:
Grinding wheel size: 400 to 2000 mesh, 400 to 800 mesh for coarse grinding, 1200 to 2000 mesh for fine grinding.
Feed rate: 0.005 to 0.05 mm/min, ensuring no scratches on the surface.
Coolant: water-based or oil-based, flow rate 15 to 30 L/min.
Polished:
CMP slurry: alumina (Al_2O_3) or silicon dioxide (SiO_2), particle size 0.05 to 0.5 µm.
Polishing pressure: 0.1 to 0.5 MPa, too high may cause surface damage.
Polishing time: 1 to 4 hours, depending on roughness target.

Technological advantages
Ultra-low roughness: Ra can reach 0.05 to 0.1 µm after polishing, which meets the requirements of sapphire crystal growth.
Corrosion resistance: Smooth surface reduces chemical reactivity and extends crucible life.
Anti-fouling: The low-roughness surface reduces the adsorption of impurities, making it suitable for high-purity applications.

Technical challenges
Low efficiency: The high hardness of tungsten leads to slow grinding and polishing speeds and long processing times.
Micro-scratches: Micro-scratches can be introduced during the polishing process and need to be eliminated by multi-stage polishing.
High cost: Diamond grinding wheels and CMP slurry are costly, and the process needs to be optimized to reduce consumption.

3.5.4 Surface coatings (anti-oxidation coatings, wear-resistant coatings)
Process principle
The surface coating is deposition of anti-oxidation, abrasion-resistant or corrosion-resistant coatings

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on the surface of tungsten crucible by physical vapor deposition (PVD), chemical vapor deposition (CVD), plasma spraying or arc ion plating technology, which significantly extends the service life. Common coating materials include:

Anti-oxidation coatings: alumina (Al_2O_3), zirconia (ZrO_2), molybdenum silicide ($MoSi_2$).

Wear-resistant coatings: tungsten carbide (WC), titanium nitride (TiN), chromium nitride (CrN).

Corrosion-resistant coatings: silicon carbide (SiC), tungsten boride (WB).

Equipment Requirements:

PVD/CVD equipment: Vacuum deposition furnace with electron beam evaporation or magnetron sputtering system.

Plasma spraying equipment: Plasma gun power 50 to 100 kW, spraying distance 100 to 200 mm.

Testing equipment: coating thickness gauge (resolution 0.1μm), scratch tester (adhesion test).

Process parameters

PVD:

Deposition temperature: 400°C to 800°C to avoid changes in tungsten matrix properties.

Coating thickness: 2 to 10 μm, depending on the balance of performance and cost.

Vacuum: 10^{-2} to 10^{-4} Pa to ensure deposition quality.

CVD：

Deposition temperature: 800°C to 1200°C, thermal stress controlled.

Gas precursors: e.g. SiH_4 (for SiC coatings) or CH_4 (for WC coatings).

Coating thickness: 5 to 20 μm, suitable for high temperature environments.

Plasma spraying:

Spray power: 40 to 80 kW, affecting the density of the coating.

Spraying distance: 100 to 150 mm for optimal adhesion.

Coating thickness: 20 to 100 μm, suitable for wear-resistant applications.

Technological advantages

Oxidation resistance: Al_2O_3 or $MoSi_2$ coatings can extend the life of tungsten crucibles in an oxidizing environment at 1500°C by a factor of 2 to 5.

Abrasion resistance: WC or TiN coatings significantly increase surface hardness (HV>2500) and reduce wear.

Corrosion resistance: SiC coating effectively resists acid-base and molten metal corrosion, making it suitable for the chemical industry.

Technical challenges

Coating adhesion: The difference in thermal expansion coefficient between the coating and the tungsten matrix may lead to spalling, and the interface design needs to be optimized.

High temperature stability: Some coatings (e.g. TiN) may decompose at > 1000°C, so it is necessary to select a suitable material.

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High cost: CVD and PVD equipment are heavily invested, and the coating process needs to balance performance and economy.

3.6 Tungsten crucible post-treatment technology

After the tungsten crucible has been sintered and machined, post-treatment technology is a critical step to ensure its performance, surface quality and service life. Due to the high hardness, melting point and chemical inertness of tungsten, the post-treatment process needs to be carried out under precisely controlled conditions to optimize the mechanical properties, chemical stability and high temperature adaptability of the crucible. This chapter will discuss in depth the post-treatment technologies of tungsten crucible, such as heat treatment, annealing, surface strengthening, cleaning and decontamination, stress relief, etc., and comprehensively analyze the principles, equipment, parameters, advantages and challenges of each process based on the practical experience of global tungsten products companies and the industry information provided by Chinatungsten Online.

3.6.1 Heat treatment and annealing process

Process principle

The heat treatment and annealing process optimizes the microstructure, eliminates residual stresses and improves mechanical properties of tungsten crucibles by heating and cooling them at specific temperatures and atmospheres. Heat treatment is mainly used to adjust grain size and phase structure, while annealing focuses on eliminating the internal stresses introduced during processing and enhancing the toughness and thermal shock resistance of the crucible.

Equipment Requirements:

Heat treatment and annealing are usually carried out in high-temperature vacuum furnaces or atmosphere protection furnaces, and the equipment needs to have the following characteristics:

Heating system: molybdenum or graphite heating element, resistant to high temperature above 2000°C.
Temperature control: infrared thermometer or thermocouple with an accuracy of ± 3°C to ensure uniform heating.
Atmosphere control: vacuum (below 10^{-3} Pa) or inert gas (such as argon, helium, purity≥ 99.999%) to prevent oxidation.
Cooling system: Equipped with a gas or water cooling system to control the cooling rate to avoid thermal stress.

Process parameters

Heat treatment temperature: typically between 1200°C and 1800°C, depending on the application of the crucible. Crucibles for semiconductors require lower temperatures (1200°C to 1400°C) to maintain fine grains; Metallurgical crucibles can be used at higher temperatures (1600°C to 1800°C) to increase strength.
Holding time: 1 to 6 hours, 1 to 2 hours for thin-walled crucibles (wall thickness < 5mm), and 4 to 6 hours for thick-walled crucibles (wall thickness > 10mm).

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Atmosphere: Vacuum or argon atmosphere, oxygen content < 5 ppm, preventing surface oxidation.
Cooling rate: 2°C/min to 10°C/min, segmented cooling to reduce residual stress.
Number of cycles: Some processes require multiple heat treatments (e.g., 2 to 3 times) to optimize the microstructure.
Stress relief: Annealing can reduce the processing stress by more than 80%, significantly improving the crack propagation resistance of the crucible.
Grain optimization: Heat treatment can control the grain size from 10 to 50 μm, balancing strength and toughness.
Stable performance: improve the structural stability of the crucible under high temperature cycle and prolong the service life.
High temperature adaptability: After optimizing the microstructure, the thermal shock resistance of the crucible can be increased by 20 to 30 percent.

Technical challenges

Temperature uniformity: Large crucibles (> 300mm in diameter) are prone to temperature gradients at high temperatures, resulting in uneven performance.
Oxidation Risk: Improper atmosphere control can lead to surface oxidation, requiring high purity gas and tight sealing.
High energy consumption: High temperature and long-term processing increase energy consumption, and the process needs to be optimized to improve economy.
Dimensional variations: Heat treatment can cause small dimensional deviations, which need to be pre-compensated by the mold design.

3.6.2 Surface strengthening (carburizing, nitriding, ion implantation)

Process principle

Surface strengthening improves the performance of tungsten crucibles in harsh environments by introducing carbon, nitrogen, or other elements to the surface to form a layer of compounds that are highly hard, wear-resistant, or corrosion-resistant. Common surface strengthening techniques include:
Carburizing: Carbon atoms are infiltrated into the surface of tungsten at high temperatures to form a tungsten carbide (WC) layer.
Nitriding: Tungsten nitride (WN) or nitride composite layer is formed by nitrogen atmosphere treatment.
Ion implantation: Carbon, nitrogen, or metallic elements (e.g., chromium, titanium) are implanted into a surface using high-energy ion beams to improve hardness and chemical stability.

Equipment Requirements:

Carburizing equipment: vacuum carburizing furnace or gas carburizing furnace equipped with a carbon source (e.g. methane, acetylene) supply system.
Nitriding equipment: plasma nitriding furnace or gas nitriding furnace to support nitrogen or ammonia atmosphere.
Ion implantation equipment: High vacuum ion implantation machine equipped with ion source (e.g.,

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carbon, nitrogen, titanium) and accelerator.
Testing equipment: X-ray diffractometer (XRD) to analyze the structure of the compound layer, nanohardness tester to test the surface hardness.

Process parameters

Carburizing:
Temperature: 1000°C to 1400°C to avoid coarse grains due to excessive temperature.
Carbon source: methane (CH_4) or acetylene (C_2H_2) with a flow rate of 0.2 to 1 L/min.
Processing time: 2 to 8 hours, layer thickness controlled at 5 to 20 μm.
Atmosphere: Vacuum or low pressure (10^{-1} Pa) to prevent oxidation.

Nitriding:
Temperature: 800°C to 1200°C, balancing nitride layer thickness and substrate performance.
Nitrogen source: nitrogen (N_2) or ammonia (NH_3), purity ≥ 99.999%.
Processing time: 4 to 12 hours, layer thickness 10 to 30 μm.
Plasma voltage: 500 to 1000 V (plasma nitriding).

Ion implantation:
Ion energy: 50 to 200 keV, controlled implantation depth (0.1 to 1 μm).
Ionic dose: 10^{16} to 10^{18} ions/cm² for optimal surface properties.
Vacuum: 10^{-4} Pa or less to ensure ion beam purity.

Technological advantages

High hardness: The hardness of the WC layer formed by carburizing can reach HV 2500, and the hardness of the nitriding layer can reach HV 2000.
Abrasion resistance: The surface reinforcement layer significantly reduces high-temperature wear and extends crucible life by 2 to 3 times.
Corrosion resistance: The nitride layer and ion implantation layer are effectively resistant to acid-base and molten metal corrosion.
Microstructure improvement: Ion implantation can form an amorphous surface layer and improve fatigue resistance.

Technical challenges

Layer thickness uniformity: The complex geometry of large crucibles can lead to uneven reinforcing layer thicknesses.
Thermal stress: High-temperature carburizing or nitriding may cause interfacial stress between the matrix and the reinforcing layer, and the process needs to be optimized.
Equipment cost: Ion implantation equipment has a high investment and is suitable for high-end applications.
Process complexity: The multi-step intensification process requires strict control of parameters, which increases the difficulty of production.

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3.6.3 Cleaning and decontamination processes

Process principle

The cleaning and decontamination process removes oxides, oils, metal residues and particulate contaminants from the surface of tungsten crucibles by physical, chemical or ultrasonic methods to ensure high purity and anti-fouling properties. The cleaning process is particularly critical for semiconductor, photovoltaic, and scientific research crucibles, where any trace contaminants can affect the quality of the final product.

Equipment Requirements:

Cleaning equipment: Ultrasonic cleaner (frequency 20 to 80 kHz) with multi-tank cleaning system.
Chemical cleaning equipment: acid and alkali cleaning tank, equipped with stirring and heating functions.
Drying equipment: vacuum drying oven or infrared dryer to ensure no water mark residue.
Testing equipment: laser particle size analyzer (detection of surface particles), X-ray fluorescence spectrometer (XRF, analysis of residual elements).

Process parameters

Ultrasonic cleaning:
Frequency: 40 kHz (normal cleaning) or 80 kHz (precision cleaning).
Cleaning solution: deionized water (resistivity>18 MΩ·cm) or neutral cleaning agent.
Temperature: 40°C to 60°C to avoid surface damage caused by high temperatures.
Time: 5 to 20 minutes, depending on the level of contamination.

Chemical Cleaning:
Pickling: dilute nitric acid (HNO_3, 5% to 10%) or hydrochloric acid (HCl, 5%) to remove oxides and metal residues.
Caustic washing: sodium hydroxide (NaOH, 2% to 5%) to remove organic contaminants.
Time: 2 to 10 minutes, tightly controlled to avoid corrosion.

Dry:
Temperature: 80°C to 120°C, vacuum or inert gas atmosphere.
Time: 10 to 30 minutes to ensure no water marks or secondary pollution.

Technological advantages

High purity: Surface contaminants can be reduced to less than 10 ppb after cleaning, which meets the requirements of the semiconductor industry.
Anti-pollution: Smooth, pollution-free surface reduces impurity adsorption and prolongs crucible life.
Consistency: A standardized cleaning process ensures consistent surface quality from batch to batch.
Environmental protection: Modern cleaning process uses low-toxicity cleaning agents to reduce environmental impact.

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Technical challenges

Particle removal: Sub-micron particles (<0.1 μm) are difficult to remove completely and require multi-stage cleaning.

Chemical Corrosion: Acid and alkali cleaning can damage the surface, and the concentration and timing need to be precisely controlled.

Drying control: Improper drying may introduce water marks or secondary pollution, and a high-purity environment is required.

High cost: The investment in ultrasonic and chemical cleaning equipment is large, and the operating cost needs to be optimized.

3.6.4 Stress Relief and Structural Optimization

Process principle

Stress Relief & Structural Optimization Reduces the residual stress inside and on the surface of the tungsten crucible by means of heat treatment, mechanical vibration or laser treatment, and optimizes its structural stability. The stresses introduced during processing and sintering can cause the crucible to crack or deform under high temperature cycles, and the stress relief process is the key to extending life.

Equipment Requirements:

Heat treatment furnace: vacuum or inert gas shielded furnace, temperature control accuracy ± 2°C.

Vibrating equipment: mechanical shaker with a frequency of 10 to 100 Hz and an amplitude of 0.1 to 1 mm.

Laser machines: pulsed lasers with a power of 1 to 5 kW for local strain relief.

Testing equipment: X-ray stress analyzer to measure residual stress (accuracy ± 5 MPa).

Process parameters

Thermal Stress Relief:

Temperature: 1000°C to 1400°C, below the recrystallization temperature to avoid grain growth.

Holding time: 1 to 4 hours, depending on the size of the crucible.

Atmosphere: argon or vacuum, oxygen content < 5 ppm.

Cooling rate: 1°C/min to 5°C/min, segmented cooling.

Vibration Stress Relief:

Frequency: 20 to 80 Hz for optimized strain relief efficiency.

Amplitude: 0.2 to 0.8 mm to avoid surface damage.

Time: 30 to 120 minutes, depending on stress distribution.

Laser Stress Relief:

Laser power: 1 to 3 kW, pulse width 10 to 100 ns.

Scanning speed: 0.5 to 2 m/min, controlled heat input.

Focus diameter: 0.1 to 0.5 mm, topical.

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Technological advantages

Low stress: The residual stress can be reduced to less than 5 MPa to improve the crack resistance.

Structural stability: After optimization, the deformation rate of the crucible under high temperature cycling is reduced by 50%.

Flexibility: Vibration and laser treatment can be targeted in localized areas of high stress and suitable for complex shapes.

Non-damaging: The non-destructive process does not affect the microstructure of the crucible.

Technical challenges

Complex stress distribution: The stress distribution of large crucibles is uneven, and multiple methods need to be combined.

Equipment accuracy: Laser and vibration equipment need to be controlled with high precision to avoid secondary stress.

Energy consumption and cost: Heat treatment consumes a lot of energy and needs to be optimized to reduce costs.

Difficulty: Accurate measurement of residual stresses requires expensive equipment and technology.

3.7 Quality control and testing of tungsten crucible

Quality control and testing is the core link in the production of tungsten crucibles, ensuring that their dimensional accuracy, material properties and reliability meet industry standards. The high-value and demanding application scenarios of tungsten crucibles (e.g. semiconductors, aerospace) require strict quality management systems. This section will discuss in detail dimensional and geometric tolerance testing, non-destructive testing, chemical composition and microstructure analysis, high-temperature performance testing, and quality certification and traceability systems.

3.7.1 Dimensional and geometric tolerance testing

Process principle

Dimensional and geometric tolerance testing verifies the geometric dimensions (diameter, wall thickness, height) and geometric tolerances (roundness, parallelism, concentricity) of the tungsten crucible by means of precision measuring equipment to ensure that it meets the design requirements. The test results directly affect the installation and use performance of the crucible.

Equipment Requirements:

Coordinate Measuring Machine (CMM): Accuracy ±0.001mm, suitable for complex geometry measurements.

Laser rangefinder: resolution 0.01mm, for fast dimensional inspection.

Profilometer: Measure roundness and surface profile with an accuracy of ± 0.005mm.

Height gauge and caliper: for simple dimensional verification with an accuracy of ± 0.01mm.

Detection parameters

Dimensional tolerances: Diameter and height tolerances ± 0.05mm, wall thickness tolerances ± 0.02mm (crucibles for semiconductors).

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Geometric tolerances:
Roundness: ≤0.02mm.
Parallelism: ≤0.01mm.
Concentricity: ≤0.015mm.
Measurement frequency: 10% to 20% sampling of each batch, full inspection of key applications.
Environmental requirements: temperature 20°C±2°C, humidity <60%, to avoid the influence of thermal expansion.

Technological advantages
High precision: CMM and laser equipment ensure that the measurement error is < 0.01mm.
Efficiency: The automated measuring system can handle large quantities of crucibles.
Consistency: The standardized inspection process ensures the geometric accuracy of each crucible.

Technical challenges
Complex shapes: The measurement of special-shaped crucibles requires multi-axis CMM, and the equipment cost is high.
Surface Effects: High-finish surfaces can cause measurement reflection errors and require calibration.
Large-size inspection: crucibles with a diameter of >500mm require special equipment, which increases costs.

3.7.2 Non-destructive testing (ultrasound, X-ray, CT scan)
Process principle
Non-destructive testing (NDT) uses ultrasonic, X-ray or CT scans to detect defects (e.g. porosity, cracks, inclusions) inside tungsten crucibles without damaging their structure. NDT is a critical step in ensuring crucible reliability.

Equipment Requirements:
Ultrasonic detector: frequency 1 to 10 MHz, probe diameter 5 to 10 mm.
X-ray inspection equipment: energy 100 to 300 kV, suitable for thick-walled crucibles.
CT scanner: 0.01mm resolution for 3D defect analysis.
Calibration Sample: Tungsten sample with known defects for equipment calibration.

Detection parameters
Ultrasonic:
Frequency: 5 MHz (conventional detection), 10 MHz (high precision detection).
Couplant: water or gel to ensure sound wave transmission.
Defect resolution: ≥0.1mm.
X-ray:
Exposure time: 10 to 60 seconds, depending on wall thickness.
Energy: 150 kV (wall thickness <10mm), 250 kV (wall thickness >10mm).
Defect resolution: ⩾0.2mm.

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CT scan:
Scanning layer thickness: 0.05 to 0.2 mm.
Rebuild time: 5 to 20 minutes, depending on the size of the crucible.
Defect resolution: ≥0.05mm.

Technological advantages
High sensitivity: CT scans can detect small defects as small as 0.05mm.
Comprehensive: X-ray and CT provide three-dimensional defect distribution, and ultrasound is suitable for rapid screening.
No damage: does not affect the performance and life of the crucible.

Technical challenges
High-density interference: The high density of tungsten (19.25 g/cm³) weakens X-ray penetration, requiring high-energy equipment.
Complex geometry: The detection of special-shaped crucibles requires multi-angle scanning, which increases the difficulty.
High cost: CT scanning equipment and operating costs are high, making it suitable for high-end applications.

3.7.3 Chemical composition and microstructure analysis

Process principle
Chemical composition and microstructure analysisThe material purity and microstructure characteristics (such as grain size and phase distribution) of tungsten crucible are verified by spectroscopic analysis and microscopic observation to ensure that they meet the application requirements.

Equipment Requirements:
X-ray fluorescence spectrometer (XRF): detects elemental content with an accuracy of ± 0.01%.
Inductively Coupled Plasma Mass Spectrometry (ICP-MS): Analyze trace impurities with a detection limit of <1 ppb.
Scanning electron microscopy (SEM): Observe grains and defects with a resolution of < 1 nm.
Electron Backscatter Diffraction (EBSD): Analyze grain orientation and phase structure.

Detection parameters
Chemical composition:
Tungsten purity: ≥ 99.95% (conventional), ≥ 99.999% (for semiconductors).
Testing frequency: 5% to 10% of each batch.
Microstructure:
Grain size: 10 to 50 μm (conventional), 5 to 20 μm (high performance).
Porosity: <1%, analyzed by SEM images.
Phase distribution: Ensure no abnormal phases (e.g. oxides or carbides).

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Technological advantages

High accuracy: ICP-MS detects ppb-level impurities to ensure ultra-high purity.

Comprehensive: SEM and EBSD provide complete information on grains, defects, and phases.

Quality Assurance: Chemical and structural analysis ensures consistent crucible performance.

Technical challenges

Sample Preparation: The hardness of tungsten makes cutting and polishing difficult, requiring diamond tools.

Trace detection: Ultra-low impurity detection requires high-sensitivity equipment and high cost.

Complex analysis: EBSD data processing requires specialized software and personnel.

3.7.4 High temperature performance test (thermal shock, creep, fatigue)

Process principle

The high-temperature performance test evaluates the thermal shock performance, creep behavior and fatigue life of tungsten crucibles by simulating actual use conditions to ensure their reliability in high-temperature environments.

Equipment Requirements:

Thermal shock test furnace: temperature range from 25°C to 2500°C, heating rate > 100°C/s.

Creep tester: apply constant stress (10 to 100 MPa) at a temperature of 1800°C to 2200°C.

Fatigue testing machine: cyclic loading frequency 1 to 10 Hz, temperature 1000°C to 2000°C.

Testing equipment: infrared thermometer, displacement sensor, accuracy ±0.01mm.

Detection parameters

Thermal Shock Test:

Temperature difference: 1000°C to 2000°C (e.g. 2000°C to 25°C cycle).

Number of cycles: 50 to 500 cycles, depending on application requirements.

Crack detection: microscope or dye penetration, crack length < 0.1mm.

Creep test:

Stress: 20 to 80 MPa.

Temperature: 1800° C to 2200° C.

Time: 100 to 1000 hours, measured deformation rate (<0.1%).

Fatigue test:

Cyclic stress: ±50 MPa.

Temperature: 1000°C to 2000°C.

Number of cycles: 10^4 to 10^6 to detect fatigue cracks.

Technological advantages

Realistic simulation: The test conditions are close to the actual use environment to ensure reliability.

Performance optimization: Test data guides process improvements and increases crucible life.

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Quality verification: Ensure that crucibles meet the stringent requirements of the aerospace and nuclear industries.

Technical challenges

High equipment requirements: high temperature test equipment needs to withstand 2500°C, which is costly.

Long test cycles: Creep and fatigue testing can take weeks, impacting productivity.

Complex data: High-temperature performance data needs to be professionally analyzed, which increases technical difficulty.

3.7.5 Quality certification and traceability system

Process principle

The quality certification and traceability system ensures that the production, testing and delivery of tungsten crucibles meet international and industry standards through the establishment of standardized quality management processes and product traceability mechanisms. The traceability system records information at every step from raw materials to finished products, facilitating troubleshooting and quality improvement.

Equipment & Tools

Quality Management System: A software platform based on ISO 9001:2015 that records production and inspection data.

Traceability system: barcode or RFID tag that correlates the batch, process parameters and test results of the crucible.

Data analysis tools: Statistical Process Control (SPC) software to analyze quality fluctuations.

Documentation system: electronic archiving of production records, test reports and certification documents.

Implementation parameters

Accreditation Criteria:

ISO 9001:2015 (Quality Management).

ISO 14001:2015 (Environmental Management).

GB/T 3459-2022 (technical requirements for tungsten crucibles).

Traceability:

Raw materials: tungsten powder batch, supplier, chemical composition.

Process: sintering, machining, post-processing parameters.

Inspection: Dimension, NDT, performance test results.

Data retention: at least 5 years, more than 10 years for high-end applications (e.g. nuclear industry).

Audit frequency: internal audits are conducted every 6 months, and external audits are conducted once a year.

Technological advantages

Compliance: Meet international and domestic standards and enhance market competitiveness.

Transparency: The traceability system improves customer trust and facilitates problem locateing.

Continuous improvement: SPC analysis identifies quality bottlenecks and optimizes production processes.

Technical challenges

Data management: Large-scale production requires efficient data storage and retrieval systems.

High cost: The implementation of certification and traceability systems requires additional investment.

Complexity: Multi-link traceability requires cross-departmental collaboration, which increases the difficulty of management.

3.7 Quality control and testing of tungsten crucible

Quality control and testing are at the heart of ensuring the performance, reliability and consistency of tungsten crucibles. Due to the application of tungsten crucibles in demanding fields such as semiconductors, aerospace, and nuclear industries, their dimensional accuracy, material purity, microstructure, and high-temperature performance must meet strict standards. This chapter will comprehensively discuss dimensional and geometric tolerance testing, non-destructive testing, chemical composition and microstructure analysis, high-temperature performance testing, and quality certification and traceability systems, and combine the practical experience of global tungsten products companies and the industry information provided by Chinatungsten Online to deeply analyze the principles, equipment, parameters, advantages and challenges of each testing technology.

3.7.1 Dimensional and geometric tolerance testing

Process principle

Dimensional & Geometric Tolerance TestingVerify the geometric dimensions (diameter, wall thickness, height) and geometric tolerances (roundness, parallelism, concentricity) of the tungsten crucible with high-precision measuring equipment to ensure that it meets the design specifications. Precise geometry is critical for the installation, heat transfer, and performance of the crucible, especially in applications such as monocrystalline silicon growth or high-temperature melting.

Equipment Requirements:

Coordinate Measuring Machine (CMM): Equipped with a laser or contact probe, the measurement accuracy is ±0.001mm, suitable for complex geometries.

Laser rangefinder: non-contact measurement with a resolution of 0.01mm for fast dimensional verification.

Profilometer: Measure roundness, surface profile and geometric tolerance with an accuracy of ± 0.005mm.

Optical projector: for two-dimensional measurement of small crucibles with 50 to 200x magnification.

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Height gauge and digital caliper: used for simple dimensional inspection, the accuracy ± 0.01mm.

Detection parameters

Dimensional Tolerances:

Diameter & Height: ±0.05mm (Conventional Applications), ±0.02mm (Crucibles for Semiconductors).

Wall thickness: ±0.03mm (conventional), ±0.01mm (high precision).

Geometric tolerances:

Roundness: ≤0.02mm (regular), ≤0.01mm (high precision).

Parallelism: ≤0.015mm.

Concentricity: ≤0.01mm.

Measurement frequency: 10% to 20% sampling per batch, 100% full inspection for critical applications such as aerospace.

Environmental requirements: temperature 20°C±1°C, humidity <50%, avoid thermal expansion or humidity interference.

Calibration standard: ISO 10360 certified calibration blocks are used to ensure the accuracy of the equipment.

Technological advantages

High accuracy: CMMs and laser rangefinders achieve sub-micron accuracy and meet tight tolerances.

Automation: An integrated automated measuring system can handle large batches of crucibles for increased efficiency.

Versatility: Profilers and optical projectors inspect both dimensional and surface features.

Data recording: Digitizing measurement results for easy quality traceability and statistical analysis.

Technical challenges

Complex geometries: Special-shaped or large-size crucibles (diameter > 500mm) require multi-axis CMMs, which can lead to high equipment costs.

Surface reflection: High-finish tungsten surfaces can cause laser measurement errors, and the optical path needs to be calibrated.

Measurement time: It takes a long time to fully inspect large crucibles, and it is necessary to balance efficiency and accuracy.

Environmental sensitivity: Temperature or vibration fluctuations may affect the measurement results, and a constant temperature and humidity environment is required.

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Tungsten Crucibles

1. Overview of Tungsten Crucibles

Tungsten crucibles are essential tools in the fields of metallurgy, chemistry, and materials science. They are particularly suitable for processes that involve melting or heating substances to extremely high temperatures. Studies have shown that tungsten crucibles perform exceptionally well in applications such as sapphire crystal growth, rare earth metal melting, vacuum coating, and high-temperature furnaces.

2. Features of Tungsten Crucibles

Ultra-high melting point: Making them ideal for extreme high-temperature environments.

High purity: purity of ≥99.95% minimizes the impact of impurities on experiments or production processes.

Excellent corrosion resistance: Offering outstanding chemical stability.

High density and low vapor pressure: Ensuring material stability.

High strength and wear resistance: Ensuring long service life.

Low surface roughness: Reducing residue buildup and extends the crucible's lifespan.

3. Applications of Tungsten Crucibles

Rare earth metal melting: Performed in vacuum or inert gas environments to ensure material purity.

Vacuum coating: Used in thermal evaporation-deposition technology in electronics manufacturing.

High-temperature furnaces: Functions as a key component capable of withstanding environments below 2400℃.

Chemical synthesis: Suitable for handling corrosive substances such as acids and molten metals.

Metal smelting and refining: Used for melting and refining high-purity metals.

Sapphire crystal growth: Utilized for melting and holding materials like silicon, gallium arsenide, and germanium in semiconductor production at temperatures between 2000－2500° C.

4. Specifications of Tungsten Crucibles

Specification	Details
Material	Pure tungsten or tungsten alloy
Purity	99.95%
Diameter	20–620 mm
Height	20–500 mm
Wall Thickness	3.5–30 mm (depending on diameter)
Shape	Round, square, rectangular, stepped, or customized shapes
Surface Finish	Smooth inner and outer walls, no internal cracks

5. Purchasing Information

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3.7.2 Non-destructive testing (ultrasound, X-ray, CT scan)

Process principle

Non-destructive testing (NDT) uses ultrasonic, X-ray, or computed tomography (CT) techniques to detect defects (e.g., porosity, cracks, inclusions) inside and on the surface of tungsten crucibles without damaging their structure. NDT is key to ensuring the reliability and safety of crucibles, especially in the nuclear industry and semiconductor applications.

Equipment Requirements:

Ultrasonic detector: Equipped with a high-frequency probe (1 to 15 MHz), it is suitable for detecting small cracks.

X-ray inspection equipment: energy 100 to 400 kV, equipped with digital imaging system.

CT scanner: high resolution (0.01mm), support 3D defect reconstruction.

Couplant system: water or gel medium to ensure ultrasonic transmission.

Calibration Sample: Tungsten sample with known defects (e.g., 0.1mm porosity) for equipment calibration.

Detection parameters

ultrasonic testing:

Frequency: 5 MHz (conventional detection), 10 to 15 MHz (high accuracy detection).

Probe type: longitudinal or shear wave probe, 5 to 10 mm diameter.

Defect resolution: ≥ 0.1mm (crack), ≥ 0.2mm (porosity).

Couplant: water or gel, thickness 0.1 to 0.5 mm.

X-ray inspection:

Energy: 150 kV (wall thickness <10 mm), 300 kV (wall thickness >10 mm).

Exposure time: 10 to 60 seconds, depending on crucible thickness.

Defect resolution: ≥0.2mm (porosity), ≥0.1mm (crack).

CT scan:

Scan layer thickness: 0.05 to 0.2 mm, depending on crucible size.

Resolution: 0.01 to 0.05 mm for detection of small inclusions.

Reconstruction time: 5 to 30 minutes to generate a 3D defect model.

Technological advantages

High sensitivity: CT scans can detect tiny defects as small as 0.05mm, and ultrasound is suitable for rapid screening.

Comprehensiveness: X-rays and CT provide a three-dimensional distribution of internal defects, revealing hidden problems.

Non-destructive: does not affect the performance and service life of the crucible.

Data visualization: The 3D model generated by CT facilitates defect analysis and process improvement.

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Technical challenges

High-density interference: The high density of tungsten (19.25 g/cm³) weakens X-ray penetration, requiring high-energy equipment.

Complex geometry: Special-shaped crucibles need to be scanned from multiple angles, which increases the detection time and complexity.

High cost: CT scanning equipment has high investment and operating costs, making it suitable for high-end applications.

Operation technology: NDT requires professional operation and high requirements for data interpretation.

3.7.3 Chemical composition and microstructure analysis

Process principle

Chemical composition and microstructure analysisThe material purity, impurity content and microstructure properties (e.g., grain size, phase distribution, porosity) of tungsten crucibles are verified by spectroscopic analysis, microscopic observation and diffraction techniques. These analyses ensure that the chemical stability and mechanical properties of the crucible meet the requirements of the application.

Equipment Requirements:

X-ray fluorescence spectrometer (XRF): detects major elements and impurities with an accuracy of ± 0.01%.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS): Trace impurities are analyzed with a detection limit of < 0.1 ppb.

Scanning electron microscopy (SEM): Observe grains, pores, and defects with a resolution of < 1 nm.

Electron Backscatter Diffractometer (EBSD): Analyzes grain orientation and phase structure with an accuracy of ± 0.1°.

Transmission electron microscopy (TEM): Analyze nanoscale structures with a resolution < 0.1 nm.

Detection parameters

Chemical composition:

Tungsten purity: ≥ 99.95% (conventional), ≥ 99.999% (semiconductor or nuclear industry).

Impurity elements: C, O, N, Fe, Ni, Mo, etc., content <50 ppm (conventional), <10 ppm (high purity).

Testing frequency: 5% to 10% sampling per batch, full inspection of key applications.

Microstructure:

Grain size: 10 to 50 μm (conventional), 5 to 20 μm (high performance).

Porosity: <1% (SEM image analysis), <0.5% (high-end applications).

Phase distribution: no abnormal phases (e.g., oxides, carbides), verified by XRD.

Grain boundary characteristics: EBSD analyzes grain boundary angles to optimize crack resistance.

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Technological advantages

Ultra-high accuracy: ICP-MS detects impurities in the ppb range to ensure material purity.

Comprehensive analysis: SEM and EBSD provide complete information on grains, defects, and phases.

Performance prediction: Microstructure data guides high-temperature performance optimization.

Quality Assurance: Ensure chemical and structural consistency of each batch of crucibles.

Technical challenges

Sample Preparation: The hardness of tungsten makes cutting, polishing and thinning difficult, requiring diamond tools and ion thinning.

Trace detection: Ultra-low impurity analysis requires high-sensitivity equipment and high operating costs.

Complex data: EBSD and TEM data require professional software and personnel to interpret.

Time-consuming: High-precision analysis (e.g., TEM) takes a long time, which affects production efficiency.

3.7.4 High temperature performance test (thermal shock, creep, fatigue)

Process principle

The high-temperature performance test evaluates the thermal shock performance, creep behavior, and fatigue life of tungsten crucibles by simulating real-world usage conditions (e.g., high-temperature cycling, long-term stress). These tests ensure the reliability and durability of the crucible in extreme environments such as above 2000°C.

Equipment Requirements:

Thermal shock test furnace: temperature range from 25°C to 2600°C, heating rate > 100°C/s, equipped with rapid cooling system.

Creep tester: apply constant stress (10 to 100 MPa), temperature 1800°C to 2300°C, displacement accuracy ± 0.001mm.

Fatigue testing machine: cyclic loading frequency 1 to 20 Hz, temperature 1000°C to 2200°C, force accuracy ± 0.1 N.

Testing equipment: infrared thermometer (accuracy ± 1 °C), laser displacement sensor (accuracy ± 0.01mm), microscope (crack analysis).

Detection parameters

Thermal Shock Test:

Temperature difference: 1000°C to 2000°C (e.g. 2000°C to 25°C fast cycle).

Number of cycles: 50 to 1000 cycles, depending on application requirements.

Crack detection: optical microscope or dyeing penetration, crack length <0.1mm is qualified.

Environment: Vacuum or inert gas (argon, oxygen content < 5 ppm).

Creep test:

Stress: 20 to 100 MPa, simulated real load.

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Temperature: 1800°C to 2300°C, close to the conditions of use.
Time: 100 to 2000 hours, measured deformation rate (<0.1% is qualified).
Atmosphere: vacuum or argon to prevent oxidation.

Fatigue test:
Cyclic stress: ±50 to ±200 MPa, simulates thermal cyclic loading.
Temperature: 1000°C to 2200°C.
Number of cycles: 10^4 to 10^7 times, fatigue crack detection (<0.05mm is qualified).
Frequency: 5 to 10 Hz, balancing efficiency and accuracy.

Technological advantages

Realistic simulation: The test conditions are close to the actual use environment and predict the crucible life.
Performance optimization: Test data guides process improvements to improve thermal shock and creep resistance.
Reliability verification: Ensure that the crucible meets the stringent requirements of the aerospace and nuclear industries.
Data support: Provide quantitative indicators (such as creep rate, fatigue life) for easy customer evaluation.

Technical challenges

High equipment requirements: High temperature test equipment needs to withstand 2600°C, and the manufacturing and maintenance costs are high.
Long test cycles: Creep and fatigue testing can take weeks to months, impacting productivity.
Environmental control: High temperature vacuum or inert atmospheres need to be strictly managed to prevent oxidation or pollution.
Data interpretation: Complex test data needs to be professionally analyzed, which increases technical difficulty.

3.7.5 Quality certification and traceability system

Process principle

The quality certification and traceability system ensures that the production, testing and delivery of tungsten crucibles comply with international and industry standards (such as ISO 9001, GB/T 3459-2022) by establishing a standardized quality management process and product traceability mechanism. The traceability system records information every step of the way, from raw materials to finished products, for easy troubleshooting, quality improvement, and customer trust.

Equipment & Tools

Quality Management System: A digital platform based on ISO 9001:2015 that records production, inspection and delivery data.
Traceability system: Barcode, QR code or RFID tag with batch, process parameters and test results of the crucible.

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Data analysis tools: Statistical process control (SPC) software to analyze quality fluctuations and defect trends.
Documentation system: electronic archiving of production records, test reports, certification documents and customer feedback.
Blockchain technology: Some enterprises use blockchain to ensure that data cannot be tampered with and enhance the credibility of traceability.

Implementation parameters
Accreditation Criteria:
ISO 9001:2015 (Quality Management System).
ISO 14001:2015 (Environmental Management System).
GB/T 3459-2022 (technical requirements for tungsten crucibles).
ASTM B760-07 (Standard Specification for Tungsten Products).

Traceability:
Raw materials: tungsten powder batch, supplier, chemical composition, particle size distribution.
Process parameters: sintering temperature, machining tolerances, post-processing conditions.
Test results: size, non-destructive testing, chemical composition, high temperature performance.
Delivery information: customer name, delivery date, batch number.
Data retention: 5 years for routine applications and more than 10 years for high-end applications (such as nuclear industry).
Audit frequency: internal audit every 6 months, external audit once a year, third-party certification review every 3 years.

Technological advantages
Compliance: Meet international and domestic standards and enhance market competitiveness.
Transparency: Traceability of the whole process improves customer trust and facilitates the rapid location of quality issues.
Continuous improvement: SPC analysis identifies process bottlenecks and optimizes production efficiency and quality.
Digital management: Electronic systems reduce manual errors and improve data reliability.

Technical challenges
Data management: Large-scale production requires efficient data storage, retrieval, and analysis systems.
Implementation costs: Certification, traceability and digitization systems are expensive to invest in and maintain.
Cross-departmental collaboration: Traceability needs to cover the supply chain, production, and inspection, and the management is complex.
Data security: It is necessary to prevent data leakage or tampering, and it is difficult to implement blockchain technology.

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3.8 Advanced manufacturing technology of tungsten crucible

With the rise of Industry 4.0 and intelligent manufacturing, the manufacturing technology of tungsten crucibles is developing in the direction of high precision, high efficiency and sustainability. Advanced manufacturing technologies have significantly improved crucible performance, productivity, and customization capabilities through the introduction of additive manufacturing, laser processing, micro-nano fabrication, and smart manufacturing systems. This chapter will deeply discuss additive manufacturing (3D printing), laser melting and plasma spraying, micro-nano fabrication technology, intelligent manufacturing and Industry 4.0 applications, combined with the practice of global tungsten products companies and Chinatungsten Online's industry information, and comprehensively analyze the principles, equipment, parameters, advantages and challenges of these technologies.

3.8.1 Additive manufacturing (3D printed tungsten crucible)

Process principle

Additive manufacturing (3D printing) directly builds tungsten crucibles with complex geometries by depositing tungsten powder or tungsten alloy materials layer by layer. In contrast to traditional powder metallurgy and machining, 3D printing does not require molds and enables rapid prototyping of complex structures such as cavity stiffeners or porous designs. Common techniques include selective laser melting (SLM), electron beam melting (EBM), and binder jetting.

Equipment Requirements:

SLM equipment: high-power fiber laser (500 W to 2 kW) with an inert gas shielded chamber.

EBM equipment: electron beam power 3 to 6 kW, vacuum environment (up to 10^{-4} Pa).

Binder injection equipment: high-precision nozzle (resolution < 50 μm) equipped with sintering furnace.

Powder handling system: sieving and recovery system to ensure uniform powder particle size (10 to 50 μm).

Inspection equipment: CT scanner (to detect internal defects), laser profiler (to verify geometric accuracy).

Process parameters

Above sea level:

Laser power: 500 to 1000 W.

Scanning speed: 0.5 to 2 m/s.

Layer thickness: 20 to 50 μm.

Atmosphere: Argon, oxygen content < 100 ppm.

EBM:

Electron beam power: 3 to 5 kW.

Scanning speed: 1 to 5 m/s.

Layer thickness: 50 to 100 μm.

Vacuum: 10^{-4} to 10^{-5} Pa.

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Binder Jetting:
Binder injection rate: 10 to 50 pL/drop.
Sintering temperature: 1800°C to 2200°C.
Sintering time: 4 to 8 hours.
Atmosphere: Vacuum or hydrogen.

Technological advantages

Complex geometries: Special-shaped crucibles that are difficult to achieve with conventional processes (e.g. built-in cooling channels) can be manufactured.
Material efficiency: Powder recovery rate >95%, reducing raw material waste.
Rapid prototyping: It only takes a few days from design to finished product, suitable for low-volume customization.
Performance optimization: Gradient material design can improve local properties (e.g., inner wall corrosion resistance).

Technical challenges

Density: The density of 3D printed crucibles (<99%) is slightly lower than that of traditional sintering, and needs to be optimized for post-processing.
Surface quality: The roughness of the printed surface (Ra 5 to 20 μm) needs to be machined or polished.
Equipment cost: SLM and EBM equipment have high investment and high operating costs.
Powder requirements: ultra-fine, spherical tungsten powder (<20μm) is required, which increases the material cost.

3.8.2 Laser melting and plasma spraying

Process principle

Laser melting and plasma spraying use a high-energy heat source to deposit functional coatings on the surface of tungsten crucibles or repair local defects, improving their abrasion, oxidation and corrosion resistance. Laser melting uses a laser beam to melt tungsten powder or alloy powder to form a coating; Plasma spraying sprays the powder onto the surface through a plasma arc, creating a thick coating.

Equipment Requirements:

Laser melting equipment: fiber lasers (1 to 10 kW) with a five-axis motion stage.
Plasma spraying equipment: Plasma gun (power 40 to 100 kW) with powder feeding system.
Powder handling system: sieving and drying equipment, to ensure that the powder particle size is 10 to 100 μm.
Testing equipment: coating thickness gauge (accuracy ± 1μm), scratch tester (adhesion test).
Atmosphere control: Inert gas chamber (argon or helium) with oxygen content < 50 ppm.

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Process parameters

Laser Fusion:

Laser power: 2 to 5 kW.

Scanning speed: 0.5 to 2 m/min.

Powder feed rate: 5 to 20 g/min.

Coating thickness: 50 to 500 µm.

Atmosphere: Argon, oxygen content < 100 ppm.

Plasma spraying:

Plasma power: 50 to 80 kW.

Spraying distance: 100 to 200mm.

Powder feed rate: 20 to 50 g/min.

Coating thickness: 100 to 1000 µm.

Gas flow rate: argon 50 L/min, hydrogen 5 L/min.

Technological advantages

High-performance coatings: SiC or WC coatings formed by laser melting have a hardness of HV 2500 and plasma sprayed $MoSi_2$ coatings have excellent oxidation resistance.

Local repair: Precise repair of worn or cracked areas to extend crucible life.

Flexibility: Suitable for a wide range of coating materials (e.g. tungsten alloy, ceramic).

Fast process: The deposition time of a single layer coating is <1 hour, which is suitable for large-scale production.

Technical challenges

Adhesion: The difference in the coefficient of thermal expansion between the coating and the tungsten substrate may lead to spalling, and the interface needs to be optimized.

Thermal stress: High-energy heat sources can cause micro-cracks in the substrate, and heat input needs to be controlled.

Surface roughness: Plasma spray coating Ra > 10µm, secondary processing is required.

High cost: Laser and plasma equipment investment is large, powder materials are expensive.

3.8.3 Microfabrication technology

Process principle

Microfabrication uses laser micromachining, ion beam etching, or chemical vapor deposition (CVD) to fabricate micro-sized (1 to 100 µm) or nano-scale (<1 µm) structures on the surface of tungsten crucibles, such as microvias, microgrooves, or nanocoatings. These structures enhance the thermal radiation, wettability, or anti-fouling properties of crucibles, making them particularly suitable for semiconductor and optical applications.

Equipment Requirements:

Femtosecond lasers: pulse width < 500 fs, power 1 to 5 kW, for micromachining.

Focused Ion Beam (FIB) devices: Ion energy 10 to 50 keV, resolution < 10 nm.

CVD equipment: low-temperature CVD system (400°C to 800°C) for deposition of nanocoatings.

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Detection equipment: Atomic force microscope (AFM, resolution< 0.1 nm), SEM (observation of micro-nano structures).
Cleanroom: ISO Class 5 (Class 100) to avoid particulate contamination.

Process parameters
Femtosecond laser micromachining:
Pulse width: 100 to 500 fs.
Power: 1 to 3 kW.
Scanning speed: 0.1 to 1 m/s.
Feature size: 1 to 50 μm (microgroove or microwell).

Ion Beam Etching:
Ion energy: 20 to 40 keV.
Beam density: 0.1 to 1 A/cm^2 .
Etch depth: 0.1 to 10 μ m.
Vacuum: below 10^{-6} Pa.
Nano CVD Coating:
Temperature: 400° C to 600° C.
Precursor: SiH_4 (SiC coating) or WF_6 (tungsten-based coating).
Coating thickness: 10 to 100 nm.
Atmosphere: low pressure (10^{-1} Pa).

Technological advantages
Enhancements: The microporous structure improves the efficiency of thermal radiation, and the nano-coating improves the anti-fouling performance.
High precision: Femtosecond laser and FIB can achieve sub-micron machining accuracy.
Customization: Specific microstructures (e.g., optical reflectors) can be designed according to application requirements.

Technical challenges
Processing efficiency: Micro-nano processing speed is slow, suitable for small area or high value-added applications.
Equipment cost: Femtosecond laser and FIB equipment have high investment and complex maintenance.
Surface damage: Ion beam etching can introduce crystal defects that require post-treatment.
Clean requirements: Micro-nano processing requires an ultra-clean environment, which increases operating costs.

3.8.4 Intelligent manufacturing and Industry 4.0 applications
Process principle
Intelligent manufacturing and Industry 4.0 optimizes the production process of tungsten crucibles through the Internet of Things (IoT), artificial intelligence (AI), big data analysis and automation

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technology, and realizes the digital management of the whole chain from design to delivery. These technologies improve productivity, quality consistency, and process control, while reducing energy consumption and scrap rates.

Equipment & Tools

Internet of Things system: sensors (temperature, pressure, displacement) and industrial Internet platform to collect production data in real time.

AI system: Machine learning models to optimize process parameters and predict equipment failures.

Automation equipment: six-axis robot (for handling, processing), automatic loading and unloading system.

Digital Twin Platform: Simulate the crucible production process and optimize the design and process.

Big data analysis tools: Hadoop or Spark-based analysis systems that process terabytes of production data.

Implementation parameters

Internet of Things:

Number of sensors: 10 to 50 per device, sampling frequency 1 Hz to 1 kHz.

Data transmission: 5G or Industrial Ethernet with a latency of < 10 ms.

Data storage: Cloud storage, with a capacity of > 1 PB, stored for more than 5 years.

AI Optimization:

Model type: Deep Neural Network (DNN) or Reinforcement Learning (RL).

Training data: >10^5 process records, covering temperature, pressure, defect rate.

Optimization target: < 0.5% scrap rate and 10% reduction in energy consumption.

Automation:

Robot accuracy: ±0.01mm (handling), ±0.05mm (processing).

Cycle time: 5 to 10 minutes per crucible.

Automation rate: >80% (key processes).

Digital Twin:

Simulation accuracy: geometric error <0.1mm, performance error <5%.

Update frequency: real-time (<1 second) or batch (hourly).

Simulation range: from powder pressing to post-processing.

Technological advantages

Efficient production: Automation and AI optimization increase production efficiency by 20% to 30%.

Consistent quality: IoT and big data analytics have reduced the scrap rate to less than 0.3%.

Predictive maintenance: AI predicts equipment failures and reduces downtime by 80%.

Flexible customization: The digital twin supports rapid design iteration to meet the individual needs

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of customers.

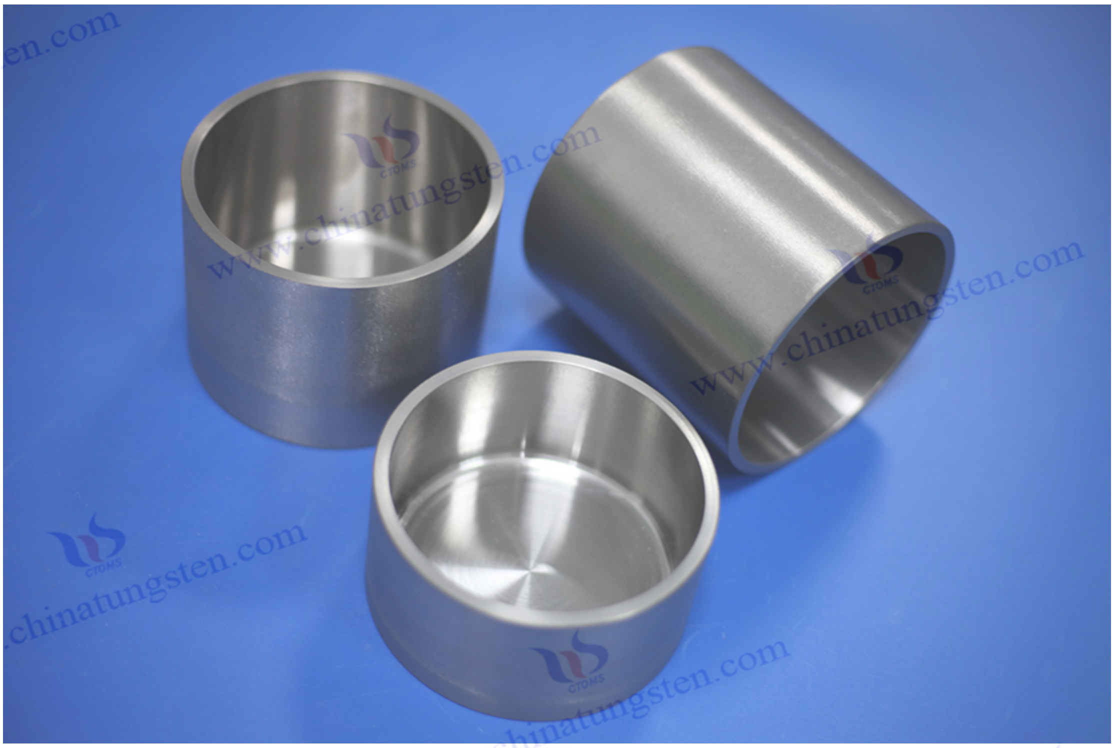
Technical challenges

Technology integration: IoT, AI, and automation need to be seamlessly integrated and systems are complex.

Data security: Production data needs to be protected from leakage, and advanced encryption and access control are required.

Implementation cost: The investment in intelligent manufacturing system is large, and it is difficult for small and medium-sized enterprises to bear it.

Personnel training: It is necessary to cultivate interdisciplinary talents who master AI and Industry 4.0 technologies.



CTIA GROUP LTD tungsten crucible

Chapter 4 Tungsten Crucible Production Technology and Innovation

The production technology of tungsten crucible is developing rapidly in the direction of automation, intelligence, green and high performance to meet the strict needs of semiconductor, aerospace, nuclear industry and other fields. This chapter will deeply discuss the automation and intelligent production, energy-saving and environmental protection technology, circular economy and resource management of tungsten crucible, as well as the exploration of cutting-edge technologies, combined with the practical experience of global tungsten products companies and the industry information provided by Chinatungsten Online, and comprehensively analyze the principles, equipment, parameters, advantages and challenges of these technologies.

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4.1 Tungsten crucible automation and intelligent production

Automation & Intelligent Production has significantly improved the production efficiency, quality consistency, and process controllability of tungsten crucibles through the introduction of CNC machining, robotics, Internet of Things (IoT), artificial intelligence (AI), and data-driven decision-making. These technologies are at the heart of Industry 4.0 in the tungsten products industry.

4.1.1 CNC machining and robotic automation

Process principle

Numerical control machining (CNC) utilizes computer-controlled, high-precision machine tools to turn, mill, drill and grind tungsten crucibles to ensure geometric accuracy and surface quality. Robotic automation automates material handling, workpiece loading and unloading, processing assistance, and inspection through six-axis robots or collaborative robots (Cobots), reducing manual intervention and improving production efficiency.

Equipment Requirements:

CNC machines: 5- or 7-axis machining centers with diamond or cubic boron nitride (CBN) tools, spindle speeds from 5,000 to 20,000 rpm, and positioning accuracy ± 0.001 mm.

Robotic system: Six-axis robot (load 5 to 50 kg) with visual recognition system (resolution < 0.1 mm) and force control sensors (accuracy ± 0.1 N).

Automated assembly line: integrated loading and unloading system, conveyor belt and fixture, cycle time 5 to 15 seconds per piece.

Testing equipment: laser rangefinder (accuracy ±0.01mm) and coordinate measuring machine (CMM, accuracy ±0.001mm).

Process parameters

CNC Machining:

Cutting speed: 10 to 50 m/min (high hardness of tungsten requires high torque at low speed).

Feed: 0.02 to 0.2 mm/rev.

Depth of cut: 0.1 to 0.5 mm to prevent micro-cracks.

Coolant: high-pressure oil-based medium with a flow rate of 20 to 40 L/min.

Robotic Automation:

Handling speed: 0.5 to 2 m/s, accuracy ± 0.05 mm.

Visual recognition: The processing time is < 0.1 seconds, and the recognition rate > 99.5%.

Clamping force: 50 to 500 N, suitable for different crucible sizes.

Automation rate: 90% > key processes.

Technological advantages

High precision: CNC machining controls the dimensional tolerance at ±0.01mm, which meets the requirements of the semiconductor industry.

Efficiency: Robotic automation reduces cycle times by 30 to 50 percent.

Consistency: Automation reduces human error and increases batch consistency to 99.8%.

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Safety: Robots replace dangerous processes (such as high-temperature handling) and reduce occupational risks.

Technical challenges

Equipment cost: The investment in five-axis CNC and robot systems is high, which is difficult for small and medium-sized enterprises to afford.

Complex programming: CNC and robots need to be customized to increase development time.

Maintenance difficulty: High-precision equipment needs to be calibrated and maintained regularly, and the technical requirements are high.

Adaptability: Complex design of automated fixtures for small or special-shaped crucibles.

4.1.2 Digitalization of production lines and integration of the Internet of Things

Process principle

The digital production line connects equipment, sensors, and management systems through IoT technology to collect and analyze production data (such as temperature, pressure, and size) in real time to monitor and optimize the whole process. IoT integration enables device connectivity, data sharing, and remote management to improve production transparency and control.

Equipment Requirements:

IoT sensors: temperature (accuracy±0.1°C), pressure (±0.1 kPa), displacement (±0.01mm) sensors, sampling frequency 1 Hz to 10 kHz.

Industrial Internet platform: support 5G or industrial Ethernet, data transmission delay < 5 ms.

Edge computing devices: process real-time data with > 10 TFLOPS of computing power.

Data storage system: cloud or local server, capacity > 1 PB, data retention > 5 years.

Visualization system: real-time monitoring dashboard, resolution 4K, support multi-terminal access.

Process parameters

Sensor deployment: 10 to 50 sensors per machine, covering sintering, processing and inspection processes.

Data acquisition: Sampling frequency 1 to 100 Hz (conventional), 1 kHz (highly dynamic process).

Transmission rate: >100 Mbps to ensure real-time performance.

Data processing: The edge computing latency < 10 ms, and the cloud analysis cycle < 1 minute.

System reliability: The online rate of the equipment is > 99.9%, and the data integrity > 99.99%.

Technological advantages

Real-time monitoring: The whole process data is collected, and the anomaly detection time is <1 second.

Transparent management: The production status is visualized in real time, and managers can make decisions remotely.

Efficiency improvement: The Internet of Things optimizes resource scheduling and increases production efficiency by 20% to 30%.

Quality traceability: Data recording supports defect traceability, and the positioning time is shortened by 70%.

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Technical challenges

Data security: Advanced encryption (such as AES-256) and access control are required to prevent leakage.

System integration: The multi-brand device protocol is not unified and requires customized interfaces.

Network dependency: 5G or Ethernet outages can affect real-time performance.

Implementation costs: Sensor and cloud platform deployments require a high initial investment.

4.1.3 Application of artificial intelligence in process optimization

Process principle

Artificial intelligence (AI) analyzes production data through machine learning (ML), deep learning (DL), and reinforcement learning (RL) to optimize process parameters, predict equipment failures, and improve quality control. AI identifies the best combination of key variables such as sintering temperature, machining tolerances, etc., reducing the cost of trial and error.

Equipment Requirements:

AI computing platform: GPU cluster (computing power > 100 TFLOPS) or TPU to run ML/DL models.

Data acquisition system: high-frequency sensor (above 1 kHz) to collect data such as temperature, pressure, defect rate, etc.

Model development tools: TensorFlow, PyTorch, or AutoML, which supports rapid iteration.

Human-computer interaction interface: support process parameter recommendation and abnormal alarm, and the response time is < 0.5 seconds.

Data storage: support $>10^5$ process records, storage period > 5 years.

Process parameters

Model types: Convolutional Neural Network (CNN, Image Analysis), Recurrent Neural Network (RNN, Time Series), Reinforcement Learning (Process Optimization).

Training data: $>10^6$ records, covering sintering, processing, testing and other processes.

Optimization Objectives:

Scrap rate: <0.3%.

Energy consumption: 10% to 20% reduction.

Production efficiency: 15% to 25% increase.

Prediction accuracy: The fault prediction rate is >95%, and the parameter optimization error is <1%.

Update frequency: The model is updated weekly or monthly to adapt to new data.

Technological advantages

Process optimization: AI recommends the optimal sintering temperature and processing parameters, and the scrap rate is reduced to 0.2%.

Predictive Maintenance: Equipment failure prediction reduces downtime by up to 80%.

Adaptive control: Adjust the process in real time in response to changes in raw materials or the environment.

Cost savings: Optimize energy consumption and material use, reducing production costs by 10 to

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15 percent.

Technical challenges

Data quality: High-quality, multi-dimensional data is required, and the collection cost is high.
Complex models: DL model training requires a lot of computing power and time.
Interpretability: AI recommended parameters need to be verified by engineers to ensure reliability.
Technical barriers: AI development requires interdisciplinary teams, making it difficult for SMEs to implement.

4.1.4 Data-driven manufacturing decisions

Process principle

Data-driven manufacturing decision-making uses big data analysis and statistical process control (SPC) to analyze production data (e.g., size, defect rate, energy consumption) from production data in real time to guide process improvement, resource allocation, and quality management. These decisions increase productivity, reduce costs, and ensure product quality.

Equipment Requirements:

Big data platform: Based on Hadoop or Spark, it processes terabytes of data with an analysis time of < 1 hour.
SPC software: Minitab or JMP, analyze quality fluctuations, control chart accuracy ± 0.01%.
Data visualization tools: Tableau or Power BI to generate real-time reports and control charts.
Cloud computing system: AWS or Azure, which supports petabyte-level data storage and parallel computing.
Decision Support System (DSS): Integrates AI and SPC to provide automated decision-making recommendations.

Process parameters

Data types: dimensional tolerances, defect rates, energy consumption, equipment operating status, raw material characteristics.
Frequency: real-time (<1 second) or batch (hourly or daily).
Control limit: SPC upper and lower limit (e.g., ±3σ), defect rate < 0.5%.
Report types: Pareto chart, control chart, histogram, scatter chart.
Decision-making cycle: real-time (critical processes) or daily (summary analysis).

Technological advantages

Accurate decision-making: Data analysis reduces the time to locate quality issues by 60%.
Resource optimization: 15 to 20 percent increase in equipment and raw material utilization.
Quality improvement: SPC controls the batch defect rate below 0.3%.
Dynamic adjustment: Real-time data supports rapid response to changes in market demand.

Technical challenges

Data integration: Multi-source data needs to be standardized and complex to process.

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Analysis complexity: Terabytes of data require efficient algorithms and computing power.
Personnel requirements: Data scientists and engineers are required to collaborate, and the training cost is high.
System stability: The cloud platform needs to be highly available to prevent data loss.

4.2 Tungsten crucible energy-saving and environmental protection technology

Energy saving and environmental protection technology reduces the energy consumption and environmental impact of tungsten crucible production by optimizing sintering furnace design, waste heat recovery, low-carbon production and clean technology, and achieves the goal of green manufacturing.

4.2.1 Design of high-efficiency sintering furnace

Process principle

High-efficiency sintering furnaces reduce heat losses and improve energy efficiency by optimizing heating elements, insulation, and temperature control systems. Modern sintering furnaces use simulated thermal fields and intelligent control to ensure temperature uniformity and minimal energy consumption.

Equipment Requirements:

Heating element: high-purity tungsten or graphite, resistant to 2600°C, life > 5000 hours.
Thermal insulation: Zirconia (ZrO_2) or carbon fiber composites, thermal conductivity < 0.1 W/m·K.
Temperature control: PID controller, accuracy ± 1°C, integrated infrared thermometer.
Vacuum system: Turbomolecular pump, vacuum degree 10^{-5} Pa, prevent oxidation.
Simulation software: ANSYS or COMSOL to simulate thermal fields and energy distributions.

Process parameters

Sintering temperature: 1800°C to 2400°C, gradient controlled (±5°C).
Heating rate: 5 to 15°C/min, balancing efficiency and stress.
Holding time: 2 to 12 hours, depending on the size of the crucible.
Energy consumption: 10 kWh per kilogram of tungsten < (high-efficiency furnace), 15 to 20 kWh for conventional furnaces.
Thermal efficiency: >80%, optimized by thermal insulation and thermal field.

Technological advantages

Low energy consumption: High-efficiency sintering furnaces reduce energy consumption by 20 to 30 percent.
High uniformity: thermal field deviation < 10°C, reducing defect rate.
Long life: 50% longer life of heating elements and insulation.
Environmentally friendly: Reduce electricity and emissions, in line with green manufacturing standards.

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Technical challenges

Equipment cost: High investment in high-efficiency sintering furnace, payback period of 3 to 5 years.

Complex design: Thermal field simulation requires professional team and software support.

Maintenance requirements: high-temperature insulation materials need to be replaced regularly, which is costly.

Technical barriers: advanced control systems need to be customized and developed.

4.2.2 Waste heat recovery and energy recycling

Process principle

Waste heat recovery captures waste heat generated during sintering and processing through heat exchangers and energy storage systems for preheating raw materials, heating cleaning fluids or heating. Energy recycling converts recovered heat energy into electrical or mechanical energy, further reducing energy consumption.

Equipment Requirements:

Heat exchanger: plate or tubular type, heat transfer efficiency > 90%, 1000°C resistance.

Energy storage system: phase change material (PCM) or molten salt heat storage with an energy storage density of > 200 kJ/kg.

Thermoelectric generators: based on the Seebeck effect, the conversion efficiency is 10% to 15%.

Piping system: high-temperature resistant stainless steel, heat loss <5%.

Control system: PLC controller, real-time monitoring of heat flow and energy distribution.

Process parameters

Waste heat temperature: 300°C to 1000°C (sintering furnace exhaust), 100°C to 200°C (processing cooling).

Recovery rate: The heat exchanger recovers 70% to 90% of the waste heat.

Energy storage time: 6 to 24 hours to meet intermittent demand.

Power generation efficiency: 10% to 12% for thermoelectric generators, generating 0.1 to 0.2 kWh per kilogram of waste heat.

System life: 10 years > heat exchanger, 5000 cycles > energy storage material.

Technological advantages

Reduced energy consumption: Waste heat recovery reduces total energy consumption by 15 to 25 percent.

Cost savings: Reduced electricity and fuel bills, payback period of 2 to 4 years.

Environmental benefits: Reduced CO_2 emissions, 0.5 to 1 ton per ton of tungsten.

Flexibility: Waste heat can be used for a variety of purposes, improving energy efficiency.

Technical challenges

Equipment investment: Heat exchangers and energy storage systems are costly and require long-term recovery.

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Heat loss: Heat loss in pipelines and energy storage processes needs to be minimized.
System integration: Waste heat recovery needs to be seamlessly integrated into existing production lines.
Complex maintenance: High-temperature heat exchangers need to be cleaned and inspected regularly.

4.2.3 Low-carbon production and green manufacturing

Process principle

Low-carbon production lowers the carbon footprint of tungsten crucible production through the use of renewable energy, optimized processes, and reduced dependence on fossil fuels. Green manufacturing combines clean technology and environmental management to achieve sustainable development goals.

Equipment Requirements:

Renewable energy systems: solar (photovoltaic, efficiency >20%) or wind (power>5 MW).
Low-carbon sintering furnace: electric heating instead of gas, the efficiency > 90%.
Carbon Capture System: Chemical absorption or membrane separation, capture rate > 80%.
Environmental monitoring equipment: emission analyzer (CO_2, NOx) with an accuracy of ± 0.1 ppm.
ISO 14001 Management System: A digital platform that records carbon emissions and environmental data.

Process parameters

Energy mix: >50% renewable energy and 20% <fossil fuels.
Carbon emissions: 1 tonne CO_2 per tonne of tungsten < (low carbon), 2 to 3 tonnes for conventional production.
Capture rate: Carbon capture systems recover 80% to 90% of emissions.
Monitoring frequency: real-time (emission data), monthly (environmental report).
Certification cycle: ISO 14001 audited annually, carbon footprint assessed quarterly.

Technological advantages

Low emissions: 50% to 70% reduction in carbon footprint, in line with global emission reduction targets.
Brand value: Green manufacturing enhances corporate image and attracts environmentally conscious customers.
Policy support: In line with the carbon neutrality policy, receive subsidies or tax incentives.
Sustainability: Reduce resource consumption and extend the life of the industrial chain.

Technical challenges

Energy costs: Renewable energy infrastructure investment is high, with a payback period of 5 to 10 years.
Technological transformation: Low-carbon equipment needs to transform existing production lines,

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affecting short-term production capacity.

Cost of capture: Carbon capture systems are expensive to operate and need to be optimized for efficiency.

Regulatory pressure: Global carbon emission standards are different, and they need to adapt to the requirements of multiple countries.

4.2.4 Cleaner production technologies

Process principle

Cleaner production technologies enable environmentally friendly production by reducing exhaust gases, liquid wastes and solid waste, and optimizing cleaning, processing and post-treatment processes. These technologies include non-toxic cleaning agents, dead water circulation, and high-efficiency filtration systems.

Equipment Requirements:

Cleaning equipment: Ultrasonic cleaner (40 to 80 kHz) using neutral or bio-based cleaning agents.

Water Circulation System: Reverse Osmosis (RO) Purifier with > 95% recovery.

Waste gas treatment equipment: activated carbon adsorption or catalytic combustion, treatment efficiency > 99%.

Solid waste treatment equipment: high-temperature incinerator or compressor, the treatment rate is >90%.

Monitoring system: Real-time emissions monitoring with an accuracy of ± 0.01 ppm.

Process parameters

Cleaning agent: pH 6 to 8, biodegradable > 90%.

Water recovery rate: >95%, purified water quality < 10 µS/cm.

Waste gas treatment: NOx<10 ppm, VOCs<5 ppm.

Solid waste reduction: 50 kg per ton of tungsten < (cleaner production), 100 kg for conventional >.

Monitoring frequency: real-time (exhaust gas, waste liquid), daily (solid waste).

Technological advantages

Environmental protection: 70% to 90% reduction in waste discharge, in line with environmental regulations.

Cost savings: Water and material recycling reduces operating expenses by 20%.

Health and safety: Non-toxic cleaning agents reduce occupational health risks.

Compliance: Meets international standards such as REACH and RoHS.

Technical challenges

Technical costs: High investment in cleaning equipment and monitoring systems.

Process adaptation: Cleaning agents and circulation systems need to be compatible with existing processes.

Complex regulation: Many countries have different environmental standards and need to be flexible and adaptable.

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Balanced performance: Detergents need to be both effective and environmentally friendly.

4.3 Tungsten crucible circular economy and resource management

Circular Economy & Resource Management achieves resource efficiency and environmental sustainability in tungsten crucible production through waste recycling, gas and liquid disposal, supply chain optimization and life cycle assessment.

4.3.1 Tungsten scrap recycling and reuse

Process principle

Tungsten scrap recycling converts processing scraps, end-of-life crucibles and recycled materials into high-purity tungsten powder through physical sorting, chemical purification and metallurgical treatment, which can be reused in production. The recycling process reduces raw material extraction, reducing costs and environmental impact.

Equipment Requirements:

Sorting equipment: magnetic separator and eddy current separator to separate tungsten and other metals.

Chemical purification equipment: acid leaching tank and ion exchange column, purity > 99.95%.

Metallurgical equipment: vacuum melting furnace or electric arc furnace, processing temperature> 3000°C.

Powder preparation equipment: ball mill and spray dryer with particle size 5 to 20 μm.

Detection equipment: ICP-MS (impurity < 10 ppm), particle size analyzer (accuracy ± 0.1 μm).

Process parameters

Recovery rate: >90% (tungsten scrap), >95% (high-purity scrap).

Purity: Recycled tungsten powder>99.95%, impurities (Fe, Ni)<50 ppm.

Particle size: 5 to 20 μm, suitable for sintering and 3D printing.

Energy consumption: 5 MWh per tonne of tungsten < recovered, 10 MWh > conventional mining.

Processing time: 1 to 2 days for sorting and purification, 3 to 5 days for metallurgical treatment.

Technological advantages

Resource saving: Recycling tungsten reduces ore mining by 80% to 90%.

Cost reduction: 50% to 60% of the cost of recycling new materials.

Environmental benefits: Reduced mining waste and energy consumption, 70% reduction in CO_2 emissions.

Dead Loop System: Enables recycling from waste to new crucibles.

Technical challenges

Impurity control: Non-tungsten elements in scrap need to be removed efficiently.

Technically complex: Chemical purification and metallurgical treatment require precise control.

Waste diversity: The composition of waste from different sources varies greatly, requiring flexible processes.

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Economy: Small-scale recycling facilities have low economies of scale and need to be centralized.

4.3.2 Waste gas and liquid waste treatment in the production process

Process principle

Exhaust gas and waste treatment uses adsorption, catalysis, filtration and neutralization technologies to remove pollutants (e.g. NOx, VOCs, acid waste) generated during sintering, processing and cleaning to ensure that emissions meet environmental standards.

Equipment Requirements:

Waste gas treatment: activated carbon adsorption tower (adsorption rate >99%), catalytic combustion furnace (treatment rate > 98%).
Waste treatment: neutralization reactor (pH 6 to 8), membrane filtration system (recovery > 90%).
Filtration equipment: High-efficiency particulate air (HEPA) filter, particle size < 0.3μm.
Monitoring equipment: gas chromatography mass spectrometer (GC-MS, accuracy ±0.01 ppm), pH meter (accuracy ± 0.01).
Automatic control: PLC system, real-time adjustment of processing parameters.

Process parameters

Exhaust gas:
NOx:<10 ppm,VOCs:<5 ppm.
Treatment rate: >99% (catalytic combustion), >95% (adsorption).
Emission frequency: continuous monitoring, hourly recording.
Waste liquor:
pH: 6.5 to 7.5 (after neutralization).
Heavy metals:<0.1 ppm (tungsten, nickel, etc.).
Recovery: >90% (water), >80% (chemicals).
Energy consumption: <0.5 kWh per ton of exhaust gas, <1 kWh per ton of waste liquor.

Technological advantages

Compliant emissions: Meets EPA, EU and GB standards with no environmental fines.
Resource recovery: Water and chemicals in the waste liquid can be reused, reducing costs.
Environmental protection: 90% reduction in pollutant emissions and protection of the ecosystem.
Automatic management: real-time monitoring reduces labor costs and improves efficiency.

Technical challenges

Disposal costs: High efficiency equipment and high chemical costs.
Diversity of pollutants: The composition of waste gas and waste liquid in different processes is complex, which requires the combination of multiple technologies.
Monitoring requirements: Continuous monitoring requires high-precision equipment and professionals.
System maintenance: Filters and reactors need to be replaced regularly, increasing operating costs.

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4.3.3 Sustainable supply chain management

Process principle

Sustainable supply chain management reduces carbon footprint, resource waste, and environmental impact by optimizing raw material procurement, logistics, and supplier collaboration. These measures include green procurement, logistics optimization and supplier environmental assessment.

Equipment & Tools

Supply chain management system: SAP or Oracle SCM to integrate procurement, inventory, and logistics data.

Carbon footprint analysis tools: SimaPro or GaBi to calculate supply chain carbon emissions.

Logistics optimization software: Route4Me or OptimoRoute, to plan low-carbon transport routes.

Environmental Assessment System: ISO 14001 certified platform to assess the environmental performance of suppliers.

Blockchain technology: Records the origin of raw materials to ensure transparency and traceability.

Implementation parameters

Green procurement: > 80% of raw materials come from sustainable sources (e.g. recycled tungsten or low-carbon minerals).

Carbon footprint: 0.5 tonnes CO_2 per tonne <of tungsten supply chain emissions.

Logistics efficiency: 20% reduction in transportation energy consumption and 90% > vehicle utilization.

Supplier Assessment: Audited annually, the environmental score is > 85 out of 100.

Data transparency: Blockchain records cover 95% of > supply chain.

Technological advantages

Low-carbon supply: 50% to 70% reduction in supply chain carbon emissions.

Cost optimization: 15% to 20% savings in logistics and inventory management.

Compliance: Meet customer and regulatory green requirements.

Brand enhancement: Sustainable supply chain enhances corporate social responsibility image.

Technical challenges

Complex coordination: The global supply chain requires multi-party collaboration and is difficult to manage.

Data collection: It is difficult to standardize supplier environmental data, and a unified platform is needed.

Initial cost: high investment in green procurement and blockchain system.

Regulatory differences: Environmental standards vary from country to country, requiring flexibility to adapt.

4.3.4 Life Cycle Assessment (LCA)

Process principle

Life Cycle Assessment (LCA) guides process improvement and sustainable design by quantifying

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the environmental impact (e.g., energy consumption, emissions, resource consumption) of tungsten crucibles from raw material extraction to end-of-life recycling. LCA covers the raw materials, production, use, and disposal phases.

Equipment & Tools

LCA software: SimaPro, GaBi or OpenLCA for multi-dimensional data.

Database: Ecoinvent or ELCD, which provides environmental data on materials and energy.

Computing platform: A high-performance computer that processes terabytes of data and takes < 1 day to analyze.

Environmental Indicator System: ReCiPe or TRACI, assesses carbon footprint, water footprint, etc.

Reporting tools: Tableau or Excel to generate LCA reports and charts.

Implementation parameters

Scope of assessment: Cradle-to-Grave, including mining, production, use, recycling.

Environmental Indicators:

Carbon footprint: <2 tons CO_2 per ton of tungsten.

Energy consumption: <20 MWh.

Water footprint: <500 m^3 .

Data sources: internal data (80%), Ecoinvent database (20%).

Analysis period: annually or per new product release.

Uncertainty: The data error is <10%, which is verified by Monte Carlo simulation.

Technological advantages

Comprehensive Assessment: LCA reveals environmental hotspots throughout the life cycle and guides improvements.

Decision support: Provide quantitative data to optimize designs and processes.

Compliance: Meets ISO 14040/14044 standards and meets customer requirements.

Market competition: Products with a low environmental impact are more attractive.

Technical challenges

Data complexity: Multi-stage data collection and integration takes a long time.

Model accuracy: The external database may deviate from the actual situation and needs to be verified.

Professional requirements: LCA requires knowledge of environmental science and engineering, and the team has a high threshold.

High cost: Software, databases, and analytics are expensive and difficult for SMEs to afford.

4.4 Exploration of cutting-edge technology of tungsten crucible

Cutting-edge technology exploration promotes breakthroughs in tungsten crucible performance through the introduction of nanomaterials, high-entropy alloys, quantum computing and biomimetic manufacturing to meet the needs of future high-tech applications.

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4.4.1 Nano tungsten powder and ultra-fine tungsten crucible

Process principle

Tungsten nano powder (particle size < 100 nm) is prepared by vapor deposition or chemical reduction for sintering ultrafine-grained tungsten crucibles (grain < 1 μm). The ultra-fine-grained structure improves the strength, toughness, and thermal shock resistance of the crucible, making it suitable for extreme environments such as nuclear fusion reactors.

Equipment Requirements:

Nano powder preparation: chemical vapor deposition (CVD) reactor at 800 °C to 1200 °C.
Sintering equipment: Hot isostatic pressing (HIP) furnace with pressure from 100 to 200 MPa and temperature from 1800°C to 2200°C.
Powder handling: ultrasonic disperser to prevent the agglomeration of nano powder.
Detection equipment: transmission electron microscope (TEM, resolution<0.1 nm), particle size analyzer (accuracy±1 nm).
Cleanroom: ISO class 4 (class 10) to avoid nano powder contamination.

Process parameters

Powder particle size: 10 to 100 nm, uniformity ± 5 nm.
Sintering conditions:
Temperature: 1800° C to 2000° C (reduced grain growth).
Pressure: 150 MPa (HIP).
Duration: 1 to 3 hours.
Grain size: 0.5 to 1 μm (ultra-fine grain), conventional > 10 μm.
Density: >99.5%, porosity <0.1%.
Performance improvement: strength > 1000 MPa (traditional < 800 MPa), thermal shock resistance > 1000 cycles.

Technological advantages
High performance: 30 to 50 percent increase in strength and toughness of ultra-fine grain crucibles.
Resistant to extreme environments: 2 times more resistant to thermal shock and radiation, suitable for nuclear applications.
Fine structure: nanopowder supports complex geometries and is suitable for 3D printing.
Long life: The service life is extended by 50%, reducing the replacement cost.

Technical challenges

Powder cost: The price of nano tungsten powder is 5 to 10 times that of ordinary powder.
Aggregation problem: nano powder is easy to agglomerate, and special dispersion technology is required.
Sintering difficulty: ultra-fine crystals need to accurately control the temperature and pressure, and the equipment requirements are high.
Large-scale: Large-scale application of nanopowder production and sintering has not yet been realized.

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4.4.2 High-entropy alloys and composite crucibles

Process principle

High-entropy alloys (HEAs) are composed of five or more metals (e.g., tungsten, molybdenum, niobium, tantalum, zirconium) at near-equimolar ratios and have excellent high-temperature strength, oxidation resistance, and creep resistance. Composite crucibles combine tungsten with ceramics (e.g., SiC, ZrC) or carbon materials (e.g., graphene) to improve corrosion resistance and thermal stability.

Equipment Requirements:

Alloy preparation: vacuum arc melting furnace, temperature > 3000°C, vacuum degree 10^{-5} Pa.
Composite molding: hot press sintering furnace with pressure from 50 to 100 MPa and temperature 2000°C.
Powder mixing: planetary mill, uniformity ±1%.
Testing equipment: XRD (phase analysis), SEM (microstructure), high temperature testing machine (performance test).
Processing equipment: laser cutting machine (accuracy ± 0.01mm), CNC grinding machine (surface roughness Ra<0.1μm).

Process parameters

High-entropy alloys:
Composition: W-Mo-Nb-Ta-Zr (molar ratio 1:1:1:1:1).
Melting times: 3 to 5 times to ensure uniformity.
Performance: Strength > 1500 MPa (2000 °C), antioxidant temperature > 1800 °C.

Composites:
Composition: tungsten + 20% SiC or 5% graphene.
Sintering conditions: 2000° C, 80 MPa, 2 hours.
Properties: hardness> HV 3000, thermal conductivity > 100 W/m・K.
Density: >99%, porosity <0.5%.

Technological advantages

Ultra-high performance: HEA crucibles are twice as strong as pure tungsten at 2000°C.
Versatility: Composites combine hardness, thermal conductivity and corrosion resistance.
Resistant to extreme environments: suitable for the fusion, aerospace and chemical industries.
Design flexibility: Adjustable alloy and composite ratios to meet specific needs.

Technical challenges

Preparation difficulty: HEA needs to be melted many times, and the composition control is complex.
Compatibility issues: Composites have large differences in thermal expansion coefficients, which can easily lead to cracking.
High cost: High-purity metals and nano-ceramics are expensive.

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Processing difficulty: The molding and post-processing of high-hardness materials require special processes.

4.4.3 Application of quantum computing in material design

Process principle

Quantum computing uses qubits and quantum algorithms such as variational quantum intrinsic solvers (VQEs) to simulate the atomic-level behavior of tungsten crucible materials to optimize alloy ratios, crystal structures, and performance predictions. Quantum computing is hundreds of times faster than classical computing, accelerating the development of new materials.

Equipment Requirements:

Quantum calculators: superconducting quantum processors (>100 qubits) such as IBM Quantum or Google Sycamore.
Classic computing cluster: assists data processing, with a computing power of > 1 PFLOPS.
Simulation software: Qiskit, Cirq or Pennylane for quantum-classical hybrid computing.
Database: Materials Project, which provides tungsten and alloy data.
Testing equipment: synchrotron radiation light source (to verify simulation results), TEM (atomic level structure).

Process parameters

Qubits: 50 to 200 qubits with an error rate of <0.1%.
Simulation scale: >10^4 atoms, simulation time < 1 hour (classical calculations> 1 week).
Algorithms: VQE (Structural Optimization), Quantum Monte Carlo (Performance Prediction).
Accuracy: Energy calculation error < 0.01 eV, structural error < 0.1 Å.
Data entry: Crystal and electronic structure data for tungsten, alloys, and composites.

Technological advantages

Rapid design: New material development cycles have been shortened from years to months.
High accuracy: The prediction performance error of quantum simulation is <1%, which is better than that of classical methods.
Complex systems: Simulate high-entropy alloys and nanostructures, pushing the limits of classical computing.
Innovation-driven: Accelerate the high performance of tungsten crucibles to meet future needs.

Technical challenges

Equipment scarcity: Quantum calculators are limited in number and expensive to access.
Technology maturity: Quantum computing is currently in its early stages, and the error rate needs to be further reduced.
Data requirements: Simulation requires high-quality experimental data, which is difficult to obtain.
Professionals: Quantum computing requires interdisciplinary knowledge of physics, computation, and materials science.

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4.4.4 Bio-inspired materials and biomimetic manufacturing

Process principle

Bio-inspired materials mimic nature's high-performance structures (e.g., layered structure of shells, porous design of bones) to develop tungsten-based materials with self-healing, lightweighting, and high strength. Biomimetic manufacturing uses 3D printing and self-assembly technology to replicate biological structures to create new tungsten crucibles.

Equipment Requirements:

3D printing equipment: multi-material SLM printer, supporting tungsten and ceramic composites.
Self-assembling system: nano-manipulation platform to control molecular-level structure (accuracy < 1 nm).
Biomimetic design software: BioMimicry or CAD to simulate biological structures.
Detection equipment: AFM (surface structure, resolution < 0.1 nm), micro CT (internal structure).
Experimental equipment: high temperature testing machine (testing self-healing performance), fatigue testing machine.

Process parameters

Material composition: tungsten + nanoceramics (e.g. ZrC) or polymers, ratio 10:1 to 5:1.

Printing Parameters:
Layer thickness: 10 to 50 μm.
Laser power: 500 to 1000 W.
Print speed: 0.5 to 2 m/s.

Self-assembly:
Temperature: 25 °C to 100 °C (molecular self-assembly).
Time: 1 to 24 hours.
Structure size: 1 nm to 100 μm.

Performance:
Strength:>1200 MPa.
Self-healing rate: >80% (microcrack repair).
Weight: 10% to 20% lighter than pure tungsten.

Technological advantages

High performance: Biomimetic structure increases strength and toughness by 30% to 40%.
Self-healing: Micro-cracks are automatically repaired, and the service life is extended by 2 times.
Lightweight: Porous or layered designs reduce weight by 15% and reduce energy consumption.
Environment-friendly: Biomimetic materials reduce resource consumption and are in line with green manufacturing.

Technical challenges

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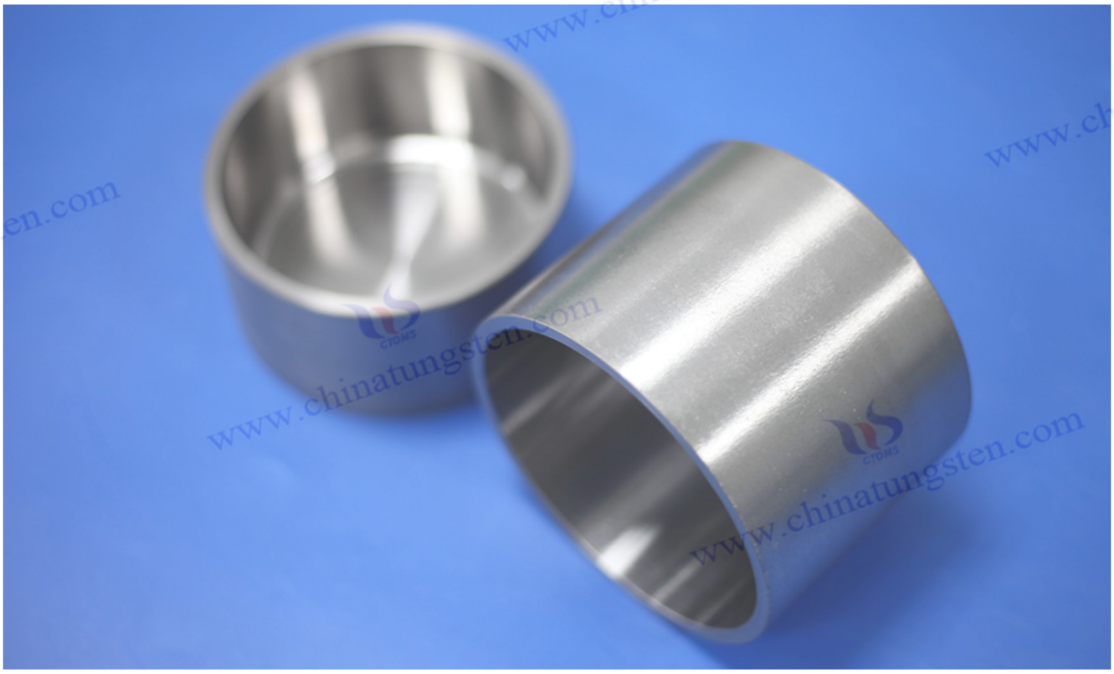
Technically complex: Biomimetic design and self-assembly require interdisciplinary technology.
Manufacturing difficulty: The precision of nanoscale structure control is extremely high.
High cost: 3D printing and self-assembly equipment investment is large, and commercialization is difficult.
Verification cycle: New materials need to be tested for a long time, and the application and promotion are slow.



CTIA GROUP LTD tungsten crucible

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Tungsten Crucibles

1. Overview of Tungsten Crucibles

Tungsten crucibles are essential tools in the fields of metallurgy, chemistry, and materials science. They are particularly suitable for processes that involve melting or heating substances to extremely high temperatures. Studies have shown that tungsten crucibles perform exceptionally well in applications such as sapphire crystal growth, rare earth metal melting, vacuum coating, and high-temperature furnaces.

2. Features of Tungsten Crucibles

Ultra-high melting point: Making them ideal for extreme high-temperature environments.

High purity: purity of ≥99.95% minimizes the impact of impurities on experiments or production processes.

Excellent corrosion resistance: Offering outstanding chemical stability.

High density and low vapor pressure: Ensuring material stability.

High strength and wear resistance: Ensuring long service life.

Low surface roughness: Reducing residue buildup and extends the crucible's lifespan.

3. Applications of Tungsten Crucibles

Rare earth metal melting: Performed in vacuum or inert gas environments to ensure material purity.

Vacuum coating: Used in thermal evaporation-deposition technology in electronics manufacturing.

High-temperature furnaces: Functions as a key component capable of withstanding environments below 2400℃.

Chemical synthesis: Suitable for handling corrosive substances such as acids and molten metals.

Metal smelting and refining: Used for melting and refining high-purity metals.

Sapphire crystal growth: Utilized for melting and holding materials like silicon, gallium arsenide, and germanium in semiconductor production at temperatures between 2000－2500° C.

4. Specifications of Tungsten Crucibles

Specification	Details
Material	Pure tungsten or tungsten alloy
Purity	99.95%
Diameter	20–620 mm
Height	20–500 mm
Wall Thickness	3.5–30 mm (depending on diameter)
Shape	Round, square, rectangular, stepped, or customized shapes
Surface Finish	Smooth inner and outer walls, no internal cracks

5. Purchasing Information

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Chapter 5 Applications of Tungsten Crucible

Tungsten crucibles play a key role in a number of high-tech fields due to their high melting point (3422°C), excellent high temperature resistance, corrosion resistance and high hardness. This chapter will explore in detail the wide range of uses of tungsten crucibles in the metallurgical industry, semiconductor and electronics industry, chemical industry, scientific research, aerospace and defense, energy industry, and emerging and interdisciplinary applications, and provide an in-depth analysis of the process requirements, performance indicators, benefits, and challenges of each application scenario.

5.1 Metallurgical industry

Tungsten crucibles are used in the metallurgical industry for high-temperature smelting, alloy preparation and powder metallurgy processes to meet the high requirements of rare earth metals, precious metals, superalloys and metal powder forming. Its high melting point and chemical stability make it an irreplaceable container under extreme conditions.

5.1.1 Smelting of rare earth metals and precious metals

Application Overview

Tungsten crucibles are used for vacuum or inert atmosphere melting of rare earth metals (e.g. lanthanum, cerium, neodymium) and precious metals (e.g. gold, platinum, rhodium) to ensure high purity and no contamination. Rare earth metals are widely used in magnetic materials and catalysts, and precious metals are used in jewelry and industrial catalysis.

Performance requirements

High temperature resistance: Withstands 1800°C to 2800°C to prevent crucible deformation or melting.

Chemically inert: non-reactive to molten rare earths and precious metals, impurities introduced < 10 ppm.

Surface finish: Ra<0.1 μ m, reducing metal adhesion.

Dimensional stability: coefficient of thermal expansion < 4.5×10^{-6}/K, dimensional deviation < 0.05mm.

Life: > 50 melting cycles, wall thickness uniformity ± 0.02mm.

Technological advantages

High purity: Tungsten crucible ensures a > 99.99% purity of the smelted metal, which meets the needs of high-end applications.

Anti-corrosion: Resistant to the strong reduction of rare earth metals and prolongs the service life.

Efficient heat transfer: Thermal conductivity > 100 W/m·K, uniform heating of the melt.

Customization: Crucibles with diameters from 50 to 500 mm can be produced to suit different furnace types.

Technical challenges

High temperature stress: Repeated thermal cycling can lead to microcracks, which require optimized heat treatment.

High cost: High-purity tungsten crucibles are expensive, and it is necessary to balance performance and economy.

Complex cleaning: The residue after melting needs to be cleaned in multiple stages, which increases the difficulty of the process.

Size limitations: Extra-large crucibles (>500mm) are difficult to manufacture and the cost is doubled.

5.1.2 Production of superalloys and superalloys

Application Overview

Tungsten crucibles are used in vacuum induction melting (VIM) or arc melting of superalloys (such as nickel-based, cobalt-based alloys) and superalloys to produce aero-engine turbine blades, gas turbine components, etc. Superalloys are melted between 1600°C and 2000°C, and tungsten crucibles provide a stable high-temperature environment.

Performance requirements

High temperature resistance: withstand more than 2000°C, thermal shock resistance > 500 cycles.

Antioxidant: Oxygen content < 5 ppm in vacuum or argon atmosphere.

Mechanical strength: tensile strength > 800 MPa, to prevent deformation at high temperatures.

Wall thickness uniformity: ±0.01mm, to ensure the consistency of the thermal field.

Abrasion resistance: hardness > HV 400, resistance to melt erosion.

Technological advantages

High temperature stability: tungsten crucible keeps the structure intact at 2000°C, and the deformation rate < 0.1%.

Chemical stability: does not react with nickel, cobalt or added elements (e.g. niobium, tantalum).

Long life: It can be reused 30 to 50 times, reducing production costs.

Efficient production: Support high-volume alloy melting to meet aerospace needs.

Technical challenges

Thermal stress: High temperature cycling leads to stress accumulation, which needs to be eliminated by post-treatment.

Alloy contamination: Trace amounts of tungsten dissolution may affect the properties of the superalloy, and surface coating is required.

Manufacturing difficulty: Large-size crucibles (>300mm) need to be precision sintered, and the cost is high.

High energy consumption: High temperature smelting consumes a lot of energy, so it is necessary to optimize the thermal field design.

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5.1.3 Metal powder metallurgy and injection molding

Application Overview

Tungsten crucibles are used in the sintering process of metal powder metallurgy (PM) and metal injection molding (MIM) to prepare high-performance parts (e.g. tungsten alloy components, tungsten carbide tools). The crucible holds tungsten powder or other metal powders at high temperatures, ensuring the quality of the sintering.

Performance requirements

High temperature performance: 1600°C to 2200°C, thermal shock resistance > 300 cycles.
Chemical stability: does not react with powders or binders, impurities < 20 ppm.
Dimensional accuracy: inner diameter tolerance ±0.02mm, suitable for precision molds.
Surface quality: Ra<0.2 μ m, to prevent powder adhesion.
Thermal conductivity: >120 W/m • K, uniform sintering.

Technological advantages

High consistency: The crucible provides a uniform thermal field with a density of > 99% sintered parts.
Durability: It can withstand multiple sintering cycles and has a life > 200 times.
Flexibility: Supports a wide range of powders (e.g. tungsten, molybdenum, cobalt) to suit different processes.
Efficient production: Shorten sintering time and increase part yield.

Technical challenges

Powder contamination: Binder volatilization can contaminate the crucible and needs to be cleaned regularly.
Thermal expansion: The difference in thermal expansion between the crucible and the powder can lead to stress, and the design needs to be optimized.
Miniaturization requirements: It is difficult to manufacture small crucibles (<50mm) for MIM.
Cost control: High-performance crucibles need to balance performance and economy.

5.2 Semiconductor and electronics industry

Tungsten crucibles are used in the semiconductor and electronics industries for crystal growth, compound semiconductor preparation, thin film deposition and thermal management, and their high purity and high temperature resistance meet the stringent requirements of the microelectronics industry for material cleanliness and stability.

5.2.1 Crystal growth of monocrystalline silicon and sapphire (Czochralski method, Kyropoulos method)

Application Overview

Tungsten crucibles are used in the Czochralski (CZ) and Kyropoulos (KY) methods for the growth of monocrystalline silicon and sapphire (Al_2O_3), for the production of silicon wafers (photovoltaics, integrated circuits) and sapphire substrates (LEDs, lasers). Crucibles are subjected to high

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temperatures from 1600°C to 2000°C and melt corrosion.

Performance requirements

Ultra-high purity: Tungsten purity > 99.999% and impurities < 1 ppb to prevent crystal defects.

High temperature resistance: 1800°C to 2000°C, thermal shock > 1000 times.

Surface finish: Ra <0.05μm, reduce crystal inclusions.

Dimensional stability: diameter 100 to 500mm, wall thickness deviation ± 0.01mm.

Corrosion-resistant: Resistant to chemical attack by molten silicon and alumina.

Technological advantages

High Purity Crystals: Tungsten crucibles reduce impurity introduction to 0.1 ppb and < crystal defect rate of 0.01%.

Long life: It can be reused 50 to 100 times, reducing production costs.

Uniform thermal field: thermal conductivity > 110 W/m·K to ensure consistent crystal growth.

Large size support: meet the needs of 300mm silicon wafers and large sapphire crystals.

Technical challenges

High-temperature deformation: Long-term high temperature may cause micro-deformation of the crucible, and the wall thickness needs to be optimized.

Silicon adhesion: Molten silicon may adhere to crucibles and requires special coating or cleaning.

High cost: Ultra-high purity tungsten crucible has high manufacturing cost and needs to be produced on a large scale.

Thermal stress: Rapid temperature rise and fall may cause cracks, and temperature control needs to be controlled in stages.

5.2.2 Preparation of compound semiconductor materials (GaAs, GaN)

Application Overview

Tungsten crucibles are used in liquid-phase epitaxy (LPE) or horizontal Brinell (HB) to grow compound semiconductors such as gallium arsenide (GaAs, 5G chips), gallium nitride (GaN, power devices). Crucibles need to withstand 1400°C to 1800°C and corrosive melts.

Performance requirements

Chemical stability: does not react with molten gallium, arsenic or nitrogen, impurities < 5 ppb.

High temperature performance: 1500°C to 1800°C, thermal shock > 500 times.

Surface quality: Ra<0.1μm, to prevent crystal defects.

Dimensional accuracy: inner diameter tolerance ±0.02mm, suitable for precision crystal growth.

Anti-oxidation: Oxygen content < 1 ppm in a vacuum or inert atmosphere.

Technological advantages

High-purity crystals: The crucible ensures > 99.9999% purity of GaAs and GaN.

Efficient growth: Uniform thermal field increases crystal yield by 20%.

Corrosion resistance: Resistant to strong corrosion of arsenic and gallium, with a life > 50 times.

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Customization: Supports small (50mm) to medium (200mm) crucibles.

Technical challenges

Corrosion risk: Molten arsenic may erode the crucible and requires surface strengthening.

Atmosphere control: high purity inert gas is required, which increases operating costs.

Minor defects: Slightly higher surface roughness can cause crystal dislocations.

High cost: The price of high-purity tungsten crucibles is high, and the production process needs to be optimized.

5.2.3 PVD and CVD

Application Overview

Tungsten crucibles are used for physical vapor deposition (PVD) and chemical vapor deposition (CVD) to evaporate or reactively deposit thin film materials (e.g. metals, ceramics, oxides) for chip manufacturing, displays, and optical coatings. Crucibles need to withstand 1200°C to 2000°C and reactive gases.

Performance requirements

High temperature stability: 1500°C to 2000°C without volatilization or decomposition.

Chemically inert: Resistant to reaction gases such as chloride and fluoride, impurities < 10 ppb.

Thermal conductivity: >100 W/m·K to ensure uniform evaporation.

Size range: diameter 20 to 200 mm, wall thickness 1 to 5 mm.

Surface finish: Ra <0.2μm to prevent material splashing.

Technological advantages

High-purity films: Crucibles introduce impurities down to 1 ppb to meet chip requirements.

Efficient deposition: Uniform thermal field increases deposition rate by 30%.

Multi-material support: suitable for the evaporation of titanium, aluminum, silicon and other materials.

Long life: It can be reused more than 100 times, reducing costs.

Technical challenges

Gas corrosion: CVD reaction gases can corrode crucibles and need to be protected by coatings.

Temperature control: Precise temperature control (±2°C) is required to avoid uneven deposition.

Miniaturization: Micro crucibles (<20mm) are difficult to manufacture and costly.

Complex cleaning: The deposited residue needs to be cleaned in multiple stages, which increases the process.

5.2.4 Microelectronic packaging and thermal management

Application Overview

Tungsten crucibles are used for high-temperature sintering and thermal management in microelectronic packaging, preparing high thermal conductivity substrates (such as tungsten-copper composites) or heat sinks, and are used in high-power chips and LED packaging. Crucibles need to

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withstand 1000°C to 1500°C.

Performance requirements
Thermal conductivity: >120 W/m·K, fast heat dissipation.
Chemical stability: does not react with copper, silver and other encapsulation materials, impurities < 20 ppm.
Dimensional accuracy: tolerance ±0.01mm, suitable for precision molds.
Surface quality: Ra <0.1μm, prevent material from sticking.
Thermal shock resistance: > 300 cycles, no cracks.

Technological advantages
Efficient heat dissipation: It supports the operation of high-power chips with a thermal resistance of < 0.5 K/W.
High reliability: The crucible ensures that the purity of the encapsulation material > 99.99%.
Miniaturization: Support micro crucible (<30mm) to adapt to chip packaging.
Long life: 50 to 80 times of reuse, reducing costs.

Technical challenges
Micro manufacturing: Small crucibles require high-precision machining and are costly.
Thermal expansion: The difference in thermal expansion between tungsten and the encapsulation material can cause stress.
Surface contamination: An ultra-clean environment is required to prevent particulate pollution.
Energy consumption control: High temperature sintering has high energy consumption, and the process needs to be optimized.

5.3 Chemical industry

Tungsten crucibles are used in the chemical industry for high-temperature catalyst synthesis, strong corrosive reactions and high-purity chemical refining, and its corrosion resistance and high-temperature stability meet the requirements of harsh chemical environments.

5.3.1 High-temperature catalyst synthesis

Application Overview
Tungsten crucibles are used in high-temperature synthesis catalysts (such as platinum-based and palladium-based catalysts), petrochemical and environmental protection catalysis. Crucibles need to withstand 1200°C to 1800°C and reactive gases (e.g. ammonia, chlorine).

Performance requirements
Corrosion resistance: Resistant to acidic, alkaline and oxidizing gases, the surface loss < 0.01mm/year.
High temperature performance: 1500°C to 1800°C, thermal shock > 200 times.
Chemically inert: does not react with catalyst precursors, impurities < 10 ppm.
Surface finish: Ra<0.2 μ m, to prevent catalyst adhesion.

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Size range: diameter 50 to 300 mm, wall thickness 2 to 10 mm.

Technological advantages

High-purity catalyst: The crucible reduces the introduction of impurities to 5 ppm, ensuring catalytic efficiency.
Durability: It can be reused more than 50 times, reducing production costs.
Uniform heating: Thermal conductivity > 100 W/m·K for improved synthesis consistency.
Flexibility: Supports a wide range of catalyst systems (e.g., precious metals, oxides).

Technical challenges

Gas corrosion: Chlorine or ammonia can erode the crucible and require surface strengthening.
High temperature volatilization: Some catalyst precursors may be deposited and need to be cleaned regularly.
High cost: Highly corrosion-resistant tungsten crucibles are expensive to manufacture and need to be optimized.
Atmosphere control: high purity inert gas is required, which increases operating costs.

5.3.2 Highly corrosive chemical reaction vessels

Application Overview

Tungsten crucibles are used as containers for strong corrosive chemical reactions to treat strong acids (such as nitric acid, hydrofluoric acid), strong alkalis or high-temperature molten salts in the production of specialty chemicals. Crucibles need to withstand 1000°C to 1600°C and extreme chemical environments.

Performance requirements

Corrosion Resistant: Resistant to chemicals pH 0 to 14 with a corrosion rate of <0.005mm/year.
High temperature stability: 1200°C to 1600°C, no volatilization or decomposition.
Mechanical strength: tensile strength > 600 MPa, preventing container breakage.
Surface quality: Ra <0.1μm, reducing reactant residue.
Wall thickness uniformity: ±0.02mm, to ensure pressure resistance.

Technological advantages

Extremely corrosion-resistant: supports strong acid-base reactions, crucible life > 100 times.
High safety: Chemically inert ensures contamination-free reaction processes.
Versatile: Suitable for molten salt, acidic solutions and high-temperature gas reactions.
Efficient production: Uniform thermal field increases the reaction rate by 20%.

Technical challenges

Extreme corrosion: Hydrofluoric acid can cause micro-corrosion and requires a special coating.
Cleaning difficulty: The reaction residue needs to be cleaned in multiple stages, which increases the process.

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High temperature stress: Rapid ramp and fall in temperature can lead to cracks, and heat treatment needs to be optimized.
High cost: High corrosion-resistant crucibles require ultra-high purity tungsten, which is expensive.

5.3.3 Refining and refining of high-purity chemicals

Application Overview

Tungsten crucibles are used for vacuum distillation or sublimation of high-purity chemicals (such as high-purity silicon, boron, phosphorus) in the semiconductor and photovoltaic industries. The crucible needs to be ultra-high purity and free of contamination.

Performance requirements

Ultra-high purity: Tungsten purity > 99.9999%, impurities < 0.1 ppb.
High temperature performance: 1400°C to 1800°C, thermal shock > 300 times.
Surface finish: Ra<0.05μm, prevents chemical adhesion.
Chemical stability: does not react with vapors or melts, contaminates < 1 ppb.
Dimensional accuracy: tolerance ± 0.01mm, suitable for precision equipment.

Technological advantages

Ultra-high purity: The crucible reduces chemical impurities to 0.05 ppb to meet semiconductor requirements.
Long life: can be reused 80 to 120 times, reducing costs.
Efficient refining: Uniform thermal field improves refining efficiency by 25%.
Customization: Supports small (20mm) to medium (150mm) crucibles.

Technical challenges

Ultra-clean requirements: ISO Class 4 clean room production and cleaning are required.
High temperature volatilization: Trace amounts of tungsten volatilization may contaminate chemicals and need to be protected by coatings.
Manufacturing difficulty: Ultra-high purity tungsten crucible requires complex process and high cost.
Atmosphere control: Ultra-high vacuum (10^{-6} Pa) is required, which increases equipment requirements.

5.4 Scientific research

Tungsten crucibles are used in scientific research for high-temperature materials testing, extreme environment simulation, advanced materials synthesis and synchrotron radiation experiments, and their high stability and durability support cutting-edge scientific exploration.

5.4.1 Performance testing of high-temperature materials

Application Overview

Tungsten crucibles are used to test the melting point, thermal stability, oxidation resistance and mechanical properties of new materials, and are used in materials science and engineering research.

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The test temperature range is 1500°C to 3000°C.

Performance requirements

Extremely high temperature: withstand 2800°C to 3000°C, resistant to thermal shock > 200 times.

Chemically inert: does not react with test materials, impurities < 10 ppm.

Mechanical strength: tensile strength > 700 MPa, resistant to high temperature breakage.

Flexible size: 20 to 200 mm in diameter, suitable for different experiments.

Thermal conductivity: >100 W/m·K to ensure uniform heating.

Technological advantages

High temperature support: close to tungsten melting point (3422°C) for extreme testing needs.

High reliability: The crucible structure is stable, and the consistency of experimental data > 99.5%.

Multi-material compatible: Supports metal, ceramic, and composite testing.

Long life: 50 to 100 reuses, reducing the cost of experiments.

Technical challenges

High-temperature deformation: It may be slightly deformed when it is close to the melting point, and the design needs to be optimized.

Material contamination: Trace amounts of tungsten volatilization may affect the test and need to be protected by coating.

Miniaturization: Micro crucibles (<20mm) are difficult to manufacture and costly.

Atmosphere control: High-purity vacuum or inert gas is required, increasing the complexity of the experiment.

5.4.2 Extreme environment simulation experiments

Application Overview

Tungsten crucibles are used to simulate extreme environments (e.g. nuclear reactors, planetary atmospheres) and test the performance of materials under high temperature, high pressure, or corrosive conditions. The experimental temperature is 1500°C to 2800°C, and the atmosphere includes vacuum, oxidizing or reducing gases.

Performance requirements

High temperature resistance: 2500°C to 2800°C, thermal shock > 300 times.

Corrosion resistance: Resistant to oxidation, reduction and plasma environments, the corrosion rate < 0.01mm/year.

Mechanical stability: compressive strength > 1000 MPa to prevent breakage.

Surface quality: Ra <0.1μm, reducing material interaction.

Atmosphere compatible: Vacuum (10^{-5} Pa) or high pressure (>10 MPa) is supported.

Technological advantages

Extreme Tolerance: Supports experimental conditions close to the melting point for nuclear and aerospace research.

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High reliability: The crucible performance is stable, and the experimental repeatability is > 99%.
Flexibility: Adapt to a variety of atmospheres and pressures to meet complex experiments.
Long life: 50 to 80 times can be reused, reducing costs.

Technical challenges

Complex environment: Variable atmospheres and pressures make crucible design difficult.
High temperature stress: Extreme conditions can cause microcracks and require post-treatment.
High cost: High-performance tungsten crucibles are expensive to manufacture and need to be optimized.
Detection difficulty: The crucible state needs to be non-destructive testing after the experiment, and the technical requirements are high.

5.4.3 Synthesis and characterization of advanced materials

Application Overview

Tungsten crucibles are used to synthesize advanced materials (such as high-entropy alloys, superconducting materials, nanomaterials) and characterize their physical properties at high temperatures. The crucible provides a stable high-temperature environment to ensure the purity of the material's synthesis.

Performance requirements

Ultra-high temperature: synthesis temperature up to 2500°C, thermal shock > 200 times.
Purity requirements: 1 ppm < impurities to avoid contamination of the material.
Uniform heating: Thermal conductivity > 120 W/m·K to ensure synthesis consistency.
Atmosphere control: Adjustable oxidizing and reducing atmospheres to support fine characterization.

Technological advantages

Material purity: The crucible does not participate in chemical reactions, ensuring the quality of the material.
High stability: It can be stably synthesized at high temperatures to ensure consistent material properties.
Versatility: Supports a variety of synthesis methods, such as superalloying, vapor deposition.
Long life: can be reused 50 to 100 times, reducing costs.

Technical challenges

Atmosphere control: Precise control of the atmosphere is required, which increases the complexity of the experiment.
Difficulty of synthesis: Temperature fluctuations during synthesis can affect the structure of the material.
High temperature volatilization: Tungsten materials volatilize in small amounts at high temperatures, so the design needs to be optimized.

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5.4.4 Synchrotron radiation and neutron scattering experiments

Application Overview

Tungsten crucibles are used in synchrotron radiation and neutron scattering experiments to accommodate high-temperature samples (e.g., metals, ceramics) for structural and physical analysis. The experimental temperature is 1000°C to 2000°C, which requires high stability and low background interference.

Performance requirements

High temperature stability: 1500°C to 2000°C without volatilization or decomposition.
Low background: Tungsten purity > 99.99%, reducing X-ray or neutron scattering interference.
Mechanical strength: tensile strength > 600 MPa, resistant to high temperature breakage.
Dimensional accuracy: tolerance ±0.01mm, suitable for precision instruments.
Surface quality: Ra <0.1μm, reducing sample contamination.

Technological advantages

Low interference: high-purity tungsten reduces the background noise of the experiment, and the data accuracy > 99.5%.
High-temperature support: Meets the high-temperature needs of synchrotron radiation and neutron scattering.
High reliability: The crucible structure is stable, and the experimental repeatability is > 99%.
Customization: Support micro (10mm) to medium (100mm) crucibles.

Technical challenges

Ultra-high purity: 99.999% tungsten is required, and the manufacturing cost is high.
High temperature volatilization: Trace amounts of tungsten volatilization may interfere with the data and need to be protected by coatings.
Miniaturization: Micro crucibles require high-precision machining, which is difficult.
Experimental complexity: It needs to be seamlessly matched with synchrotron radiation equipment.

5.5 Aerospace & Defense

Tungsten crucibles are used in aerospace and defense for high-temperature component manufacturing, materials testing, and thermal control systems with their high melting point and mechanical strength to meet extreme environmental requirements.

5.5.1 Manufacture of rocket engine nozzles and combustion chambers

Application Overview

Tungsten crucible is used for smelting and sintering of rocket engine nozzles and combustion chamber materials to prepare tungsten matrix composites or superalloys, which can withstand combustion temperatures above 3000°C.

Performance requirements

Extremely high temperature: 2800°C to 3100°C, resistant to thermal shock > 200 times.

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Mechanical strength: tensile strength > 1000 MPa, to prevent high temperature breakage.
Antioxidant: vacuum or argon atmosphere, oxygen content < 1 ppm.
Dimensional stability: wall thickness deviation ±0.01mm, thermal expansion < 4.5×10^{-6}/K.
Abrasion resistance: hardness > HV 500, resistance to high temperature air washout.

Technological advantages

High temperature resistance: close to tungsten melting point, supporting extreme combustion environments.
High reliability: The crucible ensures that the purity of the material is > 99.99% and the performance is consistent.
Long life: 30 to 50 times reuse, reducing production costs.
Large size support: 300 to 500mm diameter to meet the needs of large components.

Technical challenges

High temperature stress: Micro-cracking may occur near the melting point, and heat treatment needs to be optimized.
Oxidation risk: ultra-high vacuum or inert gas is required, which increases costs.
Manufacturing difficulty: Large-size high-purity tungsten crucibles have high cost and complex process.
Complex cleaning: high-temperature residues need to be cleaned in multiple stages, increasing the process.

5.5.2 Testing of high-temperature structural materials

Application Overview

Tungsten crucibles are used to test the performance of high-temperature structural materials (e.g., tungsten alloys, ceramic matrix composites) for aerospace applications, simulating engine or re-entry environments at temperatures ranging from 2000°C to 3000°C.

Performance requirements

Extremely high temperature: 2500°C to 3000°C, resistant to thermal shock > 200 times.
Chemically inert: does not react with test materials, impurities < 5 ppm.
Mechanical strength: compressive strength> 1200 MPa, to prevent breakage.
Thermal conductivity: >100 W/m·K to ensure uniform heating.
Flexible size: 20 to 200 mm in diameter, suitable for different experiments.

Technological advantages

High temperature support: close to tungsten melting point, meet the re-entry environment simulation.
High reliability: The crucible performance is stable, and the consistency of the test data > 99.5%.
Multi-material compatible: Supports metal, ceramic, and composite testing.
Long life: 50 to 80 reuses, reducing the cost of experiments.

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Technical challenges

High-temperature deformation: Long-term high temperature may lead to micro-deformation, and the design needs to be optimized.

Material contamination: Trace amounts of tungsten volatilization may affect the test and need to be protected by coating.

Miniaturization: Micro crucibles (<20mm) are difficult to manufacture and costly.

Atmosphere control: High purity vacuum or inert gas is required, adding complexity.

5.5.3 Military high-temperature equipment components

Application Overview

Tungsten crucibles are used for the melting and sintering of military high-temperature equipment components, such as missile nozzles, armor materials, and high-temperature sensors, and withstand 2000°C to 2800°C.

Performance requirements

High temperature performance: 2500°C to 2800°C, thermal shock > 200 times.

Mechanical strength: tensile strength > 1000 MPa to prevent breakage.

Antioxidant: vacuum or argon atmosphere, oxygen content < 1 ppm.

Abrasion resistance: hardness > HV 500, resistance to high temperature erosion.

Dimensional accuracy: tolerance ± 0.01mm, suitable for precision parts.

Technological advantages

High temperature resistance: support extreme military environment, stable performance.

High purity: The crucible ensures that the purity of the material is > 99.99%, which meets the military standard.

Long life: 40 to 60 times reuse, reducing production costs.

Customization: Supports complex geometries and small crucibles (<50mm).

Technical challenges

High temperature stress: Rapid ramp and fall of temperature may cause cracks, and heat treatment needs to be optimized.

Manufacturing cost: The price of high-purity tungsten crucible is high, and large-scale production is required.

Complex cleaning: Military material residues need special cleaning to increase the process.

Confidentiality requirements: Military applications require strict data and process management.

5.5.4 Satellite thermal control system

Application Overview

Tungsten crucibles are used for sintering and testing of materials for satellite thermal control systems, and for the preparation of high thermal conductivity tungsten matrix composites (such as tungsten copper) for heat sinks and heat pipes, which can withstand 1000°C to 1500°C.

Performance requirements

Thermal conductivity: >120 W/m·K, fast heat dissipation.

Chemical stability: does not react with copper, silver, etc., impurities < 10 ppm.

Dimensional accuracy: tolerance ±0.01mm, suitable for precision molds.

Surface quality: Ra <0.1μm, prevent material from sticking.

Thermal shock resistance: > 300 cycles, no cracks.

Technological advantages

Efficient heat dissipation: Supports high-power satellite devices with a thermal resistance of < 0.5 K/W.

High reliability: The crucible ensures that the purity of the material > 99.99%.

Miniaturization: Support micro crucible (<30mm) to adapt to heat pipe manufacturing.

Long life: 50 to 80 times of reuse, reducing costs.

Technical challenges

Micro manufacturing: Small crucibles require high-precision machining and are costly.

Thermal expansion: The difference in thermal expansion between tungsten and composite materials can lead to stress.

Surface contamination: An ultra-clean environment is required to prevent particulate pollution.

Energy consumption control: High temperature sintering has high energy consumption, and the process needs to be optimized.

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Tungsten Crucibles

1. Overview of Tungsten Crucibles

Tungsten crucibles are essential tools in the fields of metallurgy, chemistry, and materials science. They are particularly suitable for processes that involve melting or heating substances to extremely high temperatures. Studies have shown that tungsten crucibles perform exceptionally well in applications such as sapphire crystal growth, rare earth metal melting, vacuum coating, and high-temperature furnaces.

2. Features of Tungsten Crucibles

Ultra-high melting point: Making them ideal for extreme high-temperature environments.

High purity: purity of ≥99.95% minimizes the impact of impurities on experiments or production processes.

Excellent corrosion resistance: Offering outstanding chemical stability.

High density and low vapor pressure: Ensuring material stability.

High strength and wear resistance: Ensuring long service life.

Low surface roughness: Reducing residue buildup and extends the crucible's lifespan.

3. Applications of Tungsten Crucibles

Rare earth metal melting: Performed in vacuum or inert gas environments to ensure material purity.

Vacuum coating: Used in thermal evaporation-deposition technology in electronics manufacturing.

High-temperature furnaces: Functions as a key component capable of withstanding environments below 2400℃.

Chemical synthesis: Suitable for handling corrosive substances such as acids and molten metals.

Metal smelting and refining: Used for melting and refining high-purity metals.

Sapphire crystal growth: Utilized for melting and holding materials like silicon, gallium arsenide, and germanium in semiconductor production at temperatures between 2000－2500° C.

4. Specifications of Tungsten Crucibles

Specification	Details
Material	Pure tungsten or tungsten alloy
Purity	99.95%
Diameter	20–620 mm
Height	20–500 mm
Wall Thickness	3.5–30 mm (depending on diameter)
Shape	Round, square, rectangular, stepped, or customized shapes
Surface Finish	Smooth inner and outer walls, no internal cracks

5. Purchasing Information

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5.6 Energy industry

Tungsten crucibles are used in the energy industry in nuclear reactors, photovoltaics, fuel cells and nuclear fusion, where their high-temperature performance and radiation resistance meet the demanding requirements of energy technology.

5.6.1 High-temperature components of nuclear reactors

Application Overview

Tungsten crucibles are used for the melting and sintering of high-temperature components of nuclear reactors (such as control rods and heat exchangers) to prepare tungsten-based materials, which can withstand 2000°C to 2800°C and strong radiation environments.

Performance requirements

Extremely high temperature: 2500°C to 2800°C, > 200 times of thermal shock.
Radiation resistance: Resistant to neutron and gamma radiation, performance attenuation <5% (10 years).
Chemical stability: does not react with molten sodium or uranium, impurities < 5 ppm.
Mechanical strength: tensile strength > 1000 MPa to prevent breakage.
Dimensional stability: wall thickness deviation ±0.01mm, thermal expansion < 4.5×10^{-6}/K.

Technological advantages

High temperature resistance: support the extreme environment of nuclear reactors, and stable performance.
Radiation resistance: Resistant to high-energy radiation, suitable for nuclear energy applications.
Long life: 30 to 50 times reuse, reducing production costs.
High purity: The crucible ensures that the purity of the material > 99.99%.

Technical challenges

Radiation aging: High radiation may cause material deterioration, and the exposure time needs to be controlled.
Risk of oxidation: High vacuum or inert gas is required to prevent oxidation.
Manufacturing difficulty: The production cost of high-purity tungsten crucible is high and the process is complex.

5.6.2 Manufacture of photovoltaic solar materials

Application Overview

Tungsten crucibles are used in the sintering and melting of photovoltaic solar materials, such as perovskite solar cells, and withstand high temperatures from 1000°C to 1500°C.

Performance requirements

High temperature performance: >1200°C, strong stability.
Chemically inert: does not react with perovskite materials, impurities < 5 ppm.
Dimensional accuracy: tolerance ±0.01mm, suitable for precision molds.

Surface quality: Ra<0.1μm, prevent material contamination.

Technological advantages

High temperature stability: support the manufacture of high-efficiency photovoltaic materials, and the performance is stable.

High purity: The crucible ensures that the purity of the material > 99.99%.

Long life: 30 to 50 times reuse, reducing production costs.

Technical challenges

High purity requirements: The crucible needs to maintain high purity to prevent contamination.

High temperature control: A precise temperature control system is required to avoid overheating.

Miniaturized manufacturing: small crucibles are difficult and expensive to manufacture.

5.6.3 Manufacture of nuclear fusion reactor components

Application Overview

Tungsten crucibles are used for the sintering and melting of nuclear fusion reactor components, such as the first wall material of tokamak reactors, and are subjected to extremely high temperatures and radiation.

Performance requirements

Extremely high temperature: 2800°C to 3000°C, resistant to thermal shock > 500 times.

Radiation resistance: Neutron radiation resistance, attenuation <2% (100 years).

Mechanical strength: tensile strength > 1200 MPa, to prevent breakage.

Chemical stability: does not react with deuterium and tritium, and impurities < 5 ppm.

Dimensional accuracy: tolerance ± 0.01mm, suitable for precision design.

Technological advantages

Extreme High Temperature: Close to tungsten melting point, supporting fusion environment.

Radiation resistance: Resistant to neutron radiation, suitable for long-term use.

High purity: The crucible ensures that the purity of the material > 99.99%.

Long life: 50 to 100 times of reuse, reducing production costs.

Technical challenges

High temperature stress: Long-term use may lead to thermal stress, and the structural design needs to be optimized.

Radiation effects: Neutron radiation has a greater impact on the performance of the crucible.

5.6.4 Nuclear fusion reactor materials

Application Overview

Tungsten crucibles are used for the melting and sintering of nuclear fusion reactor materials such as tungsten-based plasma-facing materials, PFMs, and withstand 2500°C to 3000°C and strong plasma impacts.

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Performance requirements

Extremely high temperature: 2800°C to 3000°C, resistant to thermal shock > 200 times.

Radiation resistance: Resistant to neutron and plasma bombardment, performance attenuation <3% (10 years).

Mechanical strength: tensile strength > 1200 MPa, to prevent breakage.

Corrosion resistance: resistant to helium and hydrogen plasma, the corrosion rate < 0.005mm/year.

Dimensional stability: wall thickness deviation ±0.01mm, thermal expansion < 4.5×10^{-6}/K.

Technological advantages

High temperature resistance: close to the melting point of tungsten to meet the needs of fusion environment.

Radiation resistance: Tungsten crucible ensures long-term stability of the material and meets ITER requirements.

High purity: Impurities are introduced < 1 ppm to ensure PFM performance.

Long life: 30 to 50 times of reuse, reducing costs.

Technical challenges

Plasma shock: Strong plasma can cause surface damage and requires coating protection.

High temperature stress: Micro-cracking may occur near the melting point, and heat treatment needs to be optimized.

Manufacturing cost: Ultra-high purity tungsten crucible has a high price and needs to be produced on a large scale.

Complex cleaning: Fusion material residues need special cleaning to increase the process.

5.7 Emerging and cross-cutting applications

Tungsten crucibles have shown unique advantages in emerging fields such as high-end jewelry, medical, 3D printing and quantum technology, expanding their application boundaries.

5.7.1 High-end jewellery and luxury manufacturing

Application Overview

Tungsten crucibles are used in high-end jewelry and luxury manufacturing to smelt precious metals (e.g., platinum, gold) and synthetic gemstones (e.g., man-made diamonds, sapphires) and withstand 1400°C to 2000°C.

Performance requirements

High purity: Tungsten purity > 99.99%, impurities < 10 ppm.

High temperature resistance: 1600° C to 2000° C, thermal shock > 200 times.

Surface finish: Ra<0.05 μ m, to prevent metal adhesion.

Dimensional accuracy: tolerance ±0.01mm, suitable for precision molds.

Chemical stability: Does not react with precious metals or gemstones.

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Technological advantages

High-purity product: The crucible reduces the introduction of impurities to 5 ppm, ensuring jewelry quality.
Uniform Thermal Field: Improves the consistency of gemstones and metals, and the defect rate < 0.1%.
Long life: 50 to 80 times of reuse, reducing costs.
Customization: Supports small (20mm) to medium (100mm) crucibles.

Technical challenges

Surface contamination: An ultra-clean environment is required to prevent particulate pollution.
High temperature volatilization: Trace amounts of tungsten volatilization may affect gemstones, and coating protection is required.
Miniaturization: Micro crucibles are difficult to manufacture and costly.
Cost control: high-purity tungsten crucibles need to balance performance and economy.

5.7.2 Production of medical implants and devices

Application Overview

Tungsten crucibles are used for the melting and sintering of medical implants (such as titanium alloys, cobalt-chromium alloys) and device parts, the preparation of bone implants, cardiac stents, etc., and withstand 1200°C to 1800°C.

Performance requirements

Ultra-high purity: Tungsten purity > 99.999%, impurities < 1 ppb.
High temperature resistance: 1400°C to 1800°C, thermal shock > 200 times.
Surface quality: Ra<0.05μm, prevent material contamination.
Chemical stability: does not react with titanium, chromium, etc., and < contamination of 1 ppb.
Dimensional accuracy: tolerance ±0.01mm, suitable for precision molds.

Technological advantages

Biocompatibility: The crucible ensures that the purity of the material > 99.999% and meets medical standards.
Uniform thermal field: improve implant consistency, defect rate < 0.05%.
Long life: 60 to 100 times of reuse, reducing costs.
Miniaturization: Supports miniature crucibles (<30mm) to adapt to medical components.

Technical challenges

Ultra-clean requirements: ISO Class 3 clean room production and cleaning are required.
High temperature volatilization: trace amounts of tungsten volatilization may contaminate the material and need to be protected by coating.
Manufacturing cost: Ultra-high purity tungsten crucible has a high price, and the process needs to be optimized.
Highly regulated: Medical applications are subject to FDA and ISO 13485 standards.

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5.7.3 High-temperature molds in 3D printing and additive manufacturing

Application Overview

Tungsten crucibles are used as high-temperature molds in 3D printing and additive manufacturing to hold metal powders (e.g., titanium, tungsten alloys) for selective laser melting (SLM) or electron beam melting (EBM) and withstand 1500°C to 2200°C.

Performance requirements

High temperature performance: 1800° C to 2200° C, thermal shock > 300 times.
Chemical stability: does not react with molten metal, impurities < 10 ppm.
Surface finish: Ra<0.1 μ m, prevent powder adhesion.
Dimensional accuracy: Tolerance ±0.02mm, suitable for precision molds.
Abrasion resistance: hardness > HV 400, resistance to powder washout.

Technological advantages

High precision: The crucible supports complex geometric molds, and the molding accuracy > 99.5%.
Uniform thermal field: increase the density of 3D printed parts by >99.8%.
Long life: 50 to 80 times of reuse, reducing costs.
Multi-material support: suitable for tungsten, titanium, nickel and other powders.

Technical challenges

Powder contamination: Molten powder may adhere to the crucible and need to be coated or cleaned.
High temperature stress: Rapid ramp and fall of temperature may cause cracks, and heat treatment needs to be optimized.
Miniaturization: Micro molds (< 50mm) are difficult to manufacture and costly.
High energy consumption: High-temperature 3D printing consumes a lot of energy, and the process needs to be optimized.

5.7.4 Quantum technology and the preparation of superconducting materials

Application Overview

Tungsten crucibles are used in the synthesis and sintering of quantum technology and superconducting materials (such as yttrium-barium-copper-oxygen, YBCO), for the preparation of quantum computing chips and superconducting coils, which withstand 1200°C to 1800°C.

Performance requirements

Ultra-high purity: Tungsten purity > 99.9999%, impurities < 0.1 ppb.
High temperature resistance: 1400°C to 1800°C, thermal shock > 200 times.
Surface finish: Ra<0.05μm, prevent material contamination.
Chemical Stability: Does not react with oxides or copper, contamination < 0.5 ppb.
Dimensional accuracy: the tolerance ± 0.01mm, suitable for precision experiments.

Technological advantages

Ultra-high purity: The crucible introduces impurities down to 0.05 ppb, meeting the requirements of quantum chips.

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Uniform thermal field: improve the consistency of superconducting materials, and the defect rate < 0.01%.
Long life: 60 to 100 times of reuse, reducing costs.
Miniaturization: Support miniature crucible (<20mm) to adapt to quantum devices.

Technical challenges
Ultra-clean requirements: ISO Class 3 clean room production and cleaning are required.
High temperature volatilization: trace amounts of tungsten volatilization may contaminate the material and need to be protected by coating.
Manufacturing cost: Ultra-high purity tungsten crucible has a high price, and the process needs to be optimized.
Experimental complexity: It needs to be seamlessly matched with superconducting equipment, which increases the difficulty.

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Chapter 6 Advantages, Disadvantages and Challenges of Tungsten Crucible

Tungsten crucibles are widely used in high-temperature fields due to their excellent properties, but they also face challenges in manufacturing and application. This chapter analyzes its strengths, limitations, and areas for improvement.

6.1 Tungsten crucible advantage analysis

6.1.1 Ultra-high melting point and thermal stability

Characteristics: Tungsten melting point 3422 °C, thermal expansion coefficient 4.5×10^{-6}/K, 3000 °C still maintains structural stability.

Advantages: Resistant to extreme heat, thermal shock cycles > 500 times, suitable for nuclear fusion, aerospace, etc.
Application: Monocrystalline silicon growth, superalloy melting, uniform thermal field, deformation rate <0.1%.

6.1.2 Excellent chemical inertness

Characteristics: Resistant to acid and alkali, molten metal and reactive gas, corrosion rate < 0.01mm/year.
Advantages: Does not react with molten silicon, gallium, platinum, etc., and impurities are introduced into <1 ppb.
Application: semiconductor crystal growth, high-purity chemical refining, purity > 99.999%.

6.1.3 High reliability and long life

Characteristics: tensile strength > 800 MPa, hardness > HV 400, life 50-100 times.
Advantages: Stable performance under repeated use, batch consistency > 99.5%.
Application: Photovoltaic silicon wafer production, catalyst synthesis, reduce replacement costs.

6.1.4 Ability to adapt to extreme environments

Characteristics: Resistant to radiation and plasma impact, performance attenuation <5% (10 years).
Advantages: Support extreme conditions such as nuclear reactors and planetary atmosphere simulations.
Application: nuclear fusion PFM material, aerospace high temperature test, stable operation > 1000 hours.

6.2 Limitations and challenges of tungsten crucibles

6.2.1 High manufacturing and processing costs

Problem: High-purity tungsten crucibles need complex sintering and CNC machining, and the cost is 5-10 times that of ordinary crucibles.
Impact: Difficult for small and medium-sized enterprises to afford, payback period of 3-5 years.
Challenge: The process needs to be optimized to reduce raw material and energy costs.

6.2.2 Brittleness and processing difficulty at room temperature

Problem: Tungsten has high hardness (HV 400) at room temperature, is easy to brittle, and diamond tools are required for processing.
Impact: Micro or complex crucibles are difficult to process, with a scrap rate of >5%.
Challenge: Develop tungsten alloys with higher toughness or new processing technologies.

6.2.3 Manufacturing Restrictions for Large Size Crucibles

Problem: A crucible with a diameter of >500mm requires a large sintering furnace, and the uniformity of wall thickness ± 0.05mm is difficult to guarantee.
Impact: Long production cycle, multiplying costs, limiting photovoltaic and metallurgical applications.

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Challenge: Improve the sintering equipment and improve the consistency of large crucibles.

6.2.4 Raw material supply and geopolitical risks

Problem: Tungsten ore is globally concentrated, the supply is affected by geopolitics, and the price fluctuates by > 20%.

Impact: Raw material shortages can disrupt production and cost uncontrollable.

Challenge: Establish a recycling system to reduce dependence on raw ores.

6.3 Improvement direction of tungsten crucible

6.3.1 Cost optimization and large-scale production

Direction: Adopt automatic assembly line and waste heat recovery to reduce energy consumption by 20%-30%.

The goal: to reduce production costs to 50% of the current level and reduce the payback period to 2 years.

Technology: Modular sintering furnace, AI optimization of process parameters.

6.3.2 Development of new materials and composite processes

Direction: Research and development of tungsten-based high-entropy alloy and tungsten-ceramic composite materials, with 30% increase in toughness.

Goal: Reduce brittleness at room temperature and extend life to 150 times.

Technology: nano tungsten powder sintering, 3D printing composite crucible.

6.3.3 Improvement of machining accuracy and efficiency

Direction: Laser processing, ultra-precision CNC is introduced, and the tolerance ± 0.005mm.

Target: Scrap rate reduced to <2% and processing efficiency increased by 50%.

Technology: Robot-assisted processing, real-time detection system.

6.3.4 Intelligent and automated manufacturing

Direction: Integrate the Internet of Things and AI, monitor temperature and pressure in real time, and the error is <1%.

Goal: 30% increase in production efficiency and 99.9% > quality consistency.

Technology: 5G networked production line, data-driven decision-making system.

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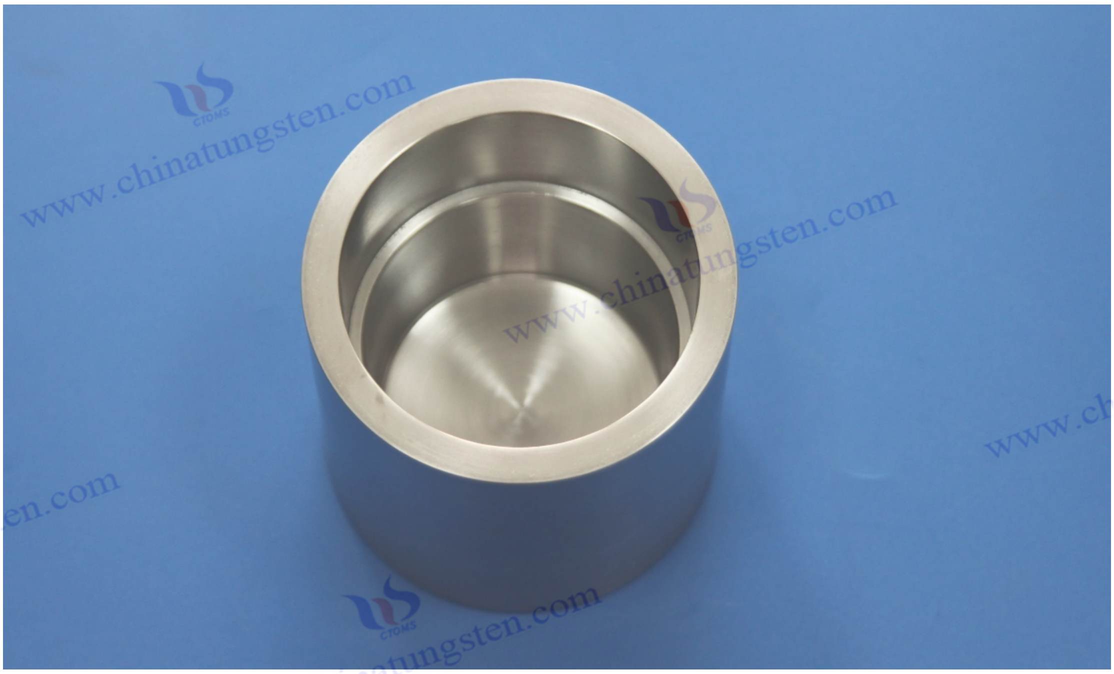

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Tungsten Crucibles

1. Overview of Tungsten Crucibles

Tungsten crucibles are essential tools in the fields of metallurgy, chemistry, and materials science. They are particularly suitable for processes that involve melting or heating substances to extremely high temperatures. Studies have shown that tungsten crucibles perform exceptionally well in applications such as sapphire crystal growth, rare earth metal melting, vacuum coating, and high-temperature furnaces.

2. Features of Tungsten Crucibles

Ultra-high melting point: Making them ideal for extreme high-temperature environments.

High purity: purity of ≥99.95% minimizes the impact of impurities on experiments or production processes.

Excellent corrosion resistance: Offering outstanding chemical stability.

High density and low vapor pressure: Ensuring material stability.

High strength and wear resistance: Ensuring long service life.

Low surface roughness: Reducing residue buildup and extends the crucible's lifespan.

3. Applications of Tungsten Crucibles

Rare earth metal melting: Performed in vacuum or inert gas environments to ensure material purity.

Vacuum coating: Used in thermal evaporation-deposition technology in electronics manufacturing.

High-temperature furnaces: Functions as a key component capable of withstanding environments below 2400℃.

Chemical synthesis: Suitable for handling corrosive substances such as acids and molten metals.

Metal smelting and refining: Used for melting and refining high-purity metals.

Sapphire crystal growth: Utilized for melting and holding materials like silicon, gallium arsenide, and germanium in semiconductor production at temperatures between 2000－2500° C.

4. Specifications of Tungsten Crucibles

Specification	Details
Material	Pure tungsten or tungsten alloy
Purity	99.95%
Diameter	20–620 mm
Height	20–500 mm
Wall Thickness	3.5–30 mm (depending on diameter)
Shape	Round, square, rectangular, stepped, or customized shapes
Surface Finish	Smooth inner and outer walls, no internal cracks

5. Purchasing Information

Email: sales@chinatungsten.com; Phone: +86 592 5129595; 592 5129696

Website: www.tungsten.com.cn

Chapter 7 Precautions for the Use of Tungsten Crucible

The use of tungsten crucibles needs to strictly follow the specifications to ensure safety, efficiency and longevity. This chapter describes installation, environment, maintenance, and troubleshooting requirements.

7.1 Tungsten crucible installation and operation specifications

7.1.1 Inspection and preparation of crucibles before installation

Inspection: No cracks and scratches on the visual surface, and the dimensional tolerance ± 0.01mm.
Cleaning: Ultrasonic cleaning (40 kHz) with high-purity ethanol with residual < 0.1 μg/cm².
Preparation: Ensure that the furnace is clean, the vacuum is <10^{-5} Pa, and the purity of the inert gas is > 99.999%.
Installation: With a special clamp, the force control < 500 N to avoid mechanical damage.

7.1.2 Safety procedures in high-temperature operation

Protection: Wear high-temperature resistant gloves and goggles, and isolate the operation area.
Temperature control: heating rate 5-15°C/min, maximum 3000°C, error ±2°C.
Monitoring: Real-time recording of temperature and pressure, abnormal alarm response < 1 second.
Emergency: Equipped with a fire extinguishing system, cool down > 2 hours after power failure before opening the furnace.

7.1.3 Prevent thermal stress and mechanical damage

Thermal stress: Rise and fall temperature in stages, moisturizing time 2-12 hours, thermal shock cycle < 500 times.
Mechanical damage: Avoid impact with hard objects, clamping force < 300 N.
Protection: The use of ceramic gasket reduces the contact stress, and the deformation rate < 0.1%.

7.2 Environmental requirements for the use of tungsten crucibles

7.2.1 Temperature and atmosphere control

Temperature: 1500-3000°C, temperature control accuracy ±1°C, thermal field uniformity ±5°C.
Atmosphere: vacuum (10^{-6} Pa) or high-purity argon (oxygen content < 1 ppm).
Monitoring: Infrared thermometer (accuracy ± 0.1°C), gas analyzer (accuracy ± 0.01 ppm).

7.2.2 Avoid contact with incompatible materials

Contraindications: strong oxidizing agents (such as nitric acid), molten alkali metals, to prevent corrosion.
Protection: Surface coating (e.g. SiC, WC), corrosion rate < 0.005mm/year.
Isolation: Liner with high-purity graphite or zirconia with impurities introduced < 1 ppb.

7.2.3 Prevent contamination and introduction of impurities

Cleanliness: Operated in an ISO Class 4 cleanroom with a particulate < of 0.1 μm.
Cleaning: Ultrasonic, deionized water (conductivity<1 μS/cm) before each use.

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Storage: Vacuum-sealed, humidity < 30%, prevent oxidation or adsorption.

7.3 Maintenance of tungsten crucible during use

7.3.1 Regular inspection and cleaning

Inspection: After every 10 uses, check for cracks and deformations with a microscope resolution of < 1 μm.

Cleaning: Ultrasonic (40-80 kHz) + neutral detergent with < residue of 0.05 μg/cm².

Frequency: Clean after each use and check thoroughly every month.

7.3.2 Monitoring of surface damage and cracks

Monitoring: Laser scanning (accuracy ± 0.01mm), crack detection > 0.1mm.

Log: Depth of damage, location, archiving period> 5 years.

Treatment: Minor damage grinding (Ra<0.1μm), severe crack scrapping.

7.3.3 Evaluation and optimization of service life

Evaluation: Record the number of uses, temperature, atmosphere, and <5% of life prediction error.

Optimization: Adjust the ramp rate (<10°C/min) to extend the life to 80 times.

Replacement: Replace when the wall thickness loss > 10% or the crack > 0.2mm.

7.4 Tungsten crucible troubleshooting

7.4.1 Common Problems (Cracks, Deformation, Contamination)

Crack: Due to thermal stress or mechanical impact, the length > 0.1mm.

Deformation: The deviation of wall thickness at high temperature > 0.05mm, which affects the thermal field.

Contamination: Surface residue > 0.1 μg/cm², affecting material purity.

7.4.2 Fault diagnosis and repair methods

Diagnosis: X-ray non-destructive testing (resolution < 0.01mm) to analyze the crack depth.

Repair: Minor crack grinding + coating, deformation crucible recalibration (tolerance ± 0.02mm).

Contamination treatment: multi-stage cleaning (ultrasonic + pickling) with residual < 0.01 μg/cm².

7.4.3 Emergency Response and Shutdown Procedures

Emergency: Stop the furnace immediately if cracks or leaks are found, and cool for > 2 hours.

Shutdown: Power off, argon gas (> 99.999%), pressure 0.1 MPa.

Records: failure time, causes, and treatment measures, and the archiving period > 5 years.

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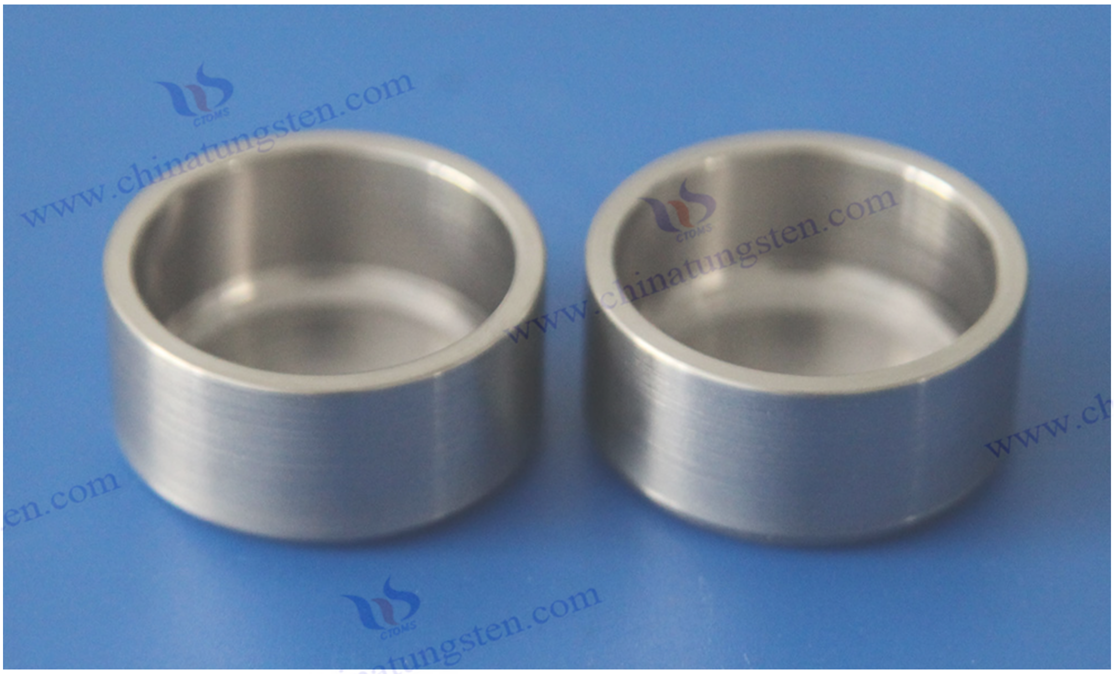

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Chapter 8 Transportation and Storage of Tungsten Crucibles

As a valuable and high-performance metal container, tungsten crucibles require special management measures during transportation and storage to ensure that the products are not physically damaged, corroded or other quality problems before and after delivery. This chapter will introduce the basic operating specifications and precautions that should be followed in the circulation process of tungsten crucibles.

6.1 Tungsten crucible transportation requirements

The tungsten crucible should be avoided from severe vibration, collision and compression as much as possible during transportation to prevent deformation, rupture or surface scratches. To this end, the transportation packaging should be made of strong, dry, and shockproof materials, such as wooden boxes, foam pads, soft pads, etc. At the same time, warning signs such as "fragile" and "do not weigh up" should be clearly marked to attract the attention of transportation personnel.

If it is a long-distance transportation or multiple transshipment, it is recommended to use a special wooden box or metal box for packaging, and set a buffer layer inside the package to absorb external impact. In addition, it should be avoided during transportation to avoid mixing with corrosive, wet or volatile goods to avoid chemical damage.

6.2 Tungsten crucible storage conditions

When storing tungsten crucible, it should be placed in a dry, ventilated and clean environment, and avoid direct sunlight and high humidity to prevent surface oxidation or moisture rust. The storage location should be away from corrosive chemicals such as strong acids, strong alkalis, and salts to avoid contact reactions.

When stored in the warehouse, the tungsten crucible should be placed in its original packaging or wrapped in a soft material to prevent scratches on the surface. For long-term storage, it is advisable to inspect regularly to ensure that the packaging is in good condition and that the ambient humidity is properly controlled.

6.3 Precautions for handling tungsten crucibles

When handling tungsten crucibles, they should be handled with care to avoid brutal handling. For larger crucibles, auxiliary tools such as lifting belts and trucks should be used to ensure the safety of people and products. At the same time, the handling should be carried out by personnel who are familiar with the characteristics of the product to prevent damage caused by improper operation.

When taking the tungsten crucible out of the transport package, it should be confirmed that the packaging structure is stable first to avoid accidental slipping or damage caused by accidental unpacking.

6.4 Tungsten crucible documentation and marking

In order to strengthen management, each batch of tungsten crucible should be accompanied by transportation records, warehousing documents and necessary product labels, including model, quantity, production batch number, arrival date and other information, so as to facilitate subsequent traceability and quality management. The label should be firmly attached and should not come off or blur.

6.5 Tungsten crucible exception handling

If the packaging is damaged, the surface of the product is scratched, deformed, etc., it should be suspended immediately and the relevant management personnel should be notified for disposal during transportation or storage. If necessary, damage should be reported or re-tested according to the process to ensure that the subsequent use of the product meets the basic quality requirements.

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Chapter 9 Tungsten Crucible Sustainability and Recycling

As a high-value, high-temperature resistant industrial component, the sustainability and recycling of tungsten crucibles are crucial for resource conservation, environmental protection and economic benefits. This chapter discusses in detail the life cycle management, recycling, compliance with environmental regulations and circular economy practices of tungsten crucibles, combined with the experience of global tungsten products companies and the industry information provided by Chinatungsten Online, analyzes the technical details, process challenges and future development directions, and aims to promote the green transformation of the tungsten crucible industry.

9.1 Tungsten crucible life cycle management

Life cycle management covers the entire process of tungsten crucible from raw material mining to production, use and recycling, with the aim of reducing environmental impact, optimizing resource use and improving sustainability.

9.1.1 Full cycle evaluation from production to use

Process principle

Life Cycle Assessment (LCA) identifies key links and optimizes design by quantifying the resource consumption, energy use and environmental emissions of tungsten crucibles at each stage. The tungsten crucible life cycle includes raw material extraction, refining, production, transportation, use and recycling.

Assessment process

Raw material mining: tungsten ore (wolframite or scheelite) mining, beneficiation purity > 99.5%,

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energy consumption of about 5000 kWh per ton of tungsten concentrate.
Refining and production: tungsten powder preparation (purity>99.999%), sintering (temperature 1800-2500°C), energy consumption of about 10-15 MWh/ton crucible.
Transportation: air or sea, with an average carbon emission of 0.5-2 kg CO_2/ton·km.
Usage: High temperature application (1500-3000°C), life 50-100 times, maintenance energy consumption of about 0.1-0.5 MWh/time.
Recycling: Waste crucible collection, cleaning, crushing, and chemical purification, with an energy consumption of about 5-8 MWh/ton.

Technical parameters
Resource consumption: 1.5-2 tons of tungsten ore per ton of crucible, and about 10-15 tons of by-products (tailings).
Energy efficiency: 70% of the energy consumption in the production stage accounts for the whole cycle, and 50% of the energy consumption < the production energy consumption in the recovery stage.
Emissions: Emissions of about 20-30 tons of CO_2 per ton of crucible production, and <5 tons of emissions during the use phase.
Life cycle length: about 2-5 years from production to scrapping, depending on the frequency of use.

Advantages and challenges
Advantages: LCA identifies high-energy consumption links (such as sintering), which can reduce energy consumption by 20% after optimization; Extend crucible life (> 80 cycles) and reduce resource requirements.
Challenge: High environmental impact in the mining and refining stage, high tailings treatment cost; LCA data collection needs to be coordinated across the supply chain, which is highly complex.

9.1.2 Environmental impact and carbon footprint analysis
Process principle
Carbon footprint analysis quantifies the greenhouse gas emissions of tungsten crucibles throughout the cycle, combined with environmental impact assessment (water resources, soil, ecology) to provide a basis for green design. The environmental impact of tungsten crucibles comes mainly from energy-intensive production and mineral extraction.

Analyze the content
Carbon Footprint:
Mining: CO_2 is emitted about 5-8 tons per ton of tungsten concentrate, and the energy source is mainly fossil fuels.
Production: Sintering and processing emits about 15-20 tons of CO_2, and electricity accounts for >80%.
Transportation: 0.5-1 kg CO_2/ton·km from air transport and 0.1-0.2 kg CO_2/ton·km from sea.
Use: Indirect emissions (electricity) from high-temperature operation are about 0.05-0.2 tons CO_2/time.

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Recycling: Chemical purification emits about 3-5 tons of CO_2, accounting for 25% of production emissions.

Other Environmental impacts:

Water resources: Beneficiation consumes 50-100 m³ per ton of tungsten concentrate, and wastewater needs to be treated to COD<50 mg/L.

Soil and ecology: Mining and destroying land about 0.1-0.5 hm²/10,000 tons of mine, ecological restoration is required.

Solid waste: tailings and sintering waste are about 10-20 tons/ton crucible, which needs to be treated harmlessly.

Technical parameters

Total carbon footprint: CO_2 emissions of about 25-35 tons per ton of crucible cycle, and the production stage accounts for 60%-70%.

Water consumption: 100-200 m³/ton crucible in the whole cycle, 10 m³ < in the recovery stage.

Solid waste recovery rate: The recovery rate of tailings is >50%, and the recovery rate of waste crucibles is >90%.

Ecological restoration: The land reclamation rate is > 80%, and the restoration period is 3-5 years.

Advantages and challenges

Advantages: Carbon footprint analysis guides low-carbon production (e.g. the use of renewable energy), which can reduce emissions by 15%-20%; Wastewater recycling reduces water consumption by 30%.

Challenge: It is difficult to significantly reduce the energy consumption of high-purity tungsten production; The carbon emission data of the global supply chain is not uniform, and the accuracy of analysis is limited.

9.1.3 Sustainable Design and Manufacturing

Process principle

Sustainable design reduces resource consumption and environmental impact, extends tungsten crucible life and improves recyclability by optimizing material selection, manufacturing processes and product mix.

Design measures

Material optimization: The use of high-purity tungsten powder (purity > 99.999%) reduces impurities and improves the crucible life to 100 times.

Structural design: the uniformity of wall thickness ± 0.01mm, reduce thermal stress, reduce crack rate < 0.1%.

Energy-saving process: Plasma sintering (20% reduction in energy consumption) or waste heat recovery (15% increase in efficiency).

Modular design: the crucible is assembled in sections, which is convenient for partial replacement and reduces the waste rate by 50%.

Green energy: More than 70% of the electricity used for production comes from wind or solar energy,

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and carbon emissions are reduced by 30%.

Manufacturing technology

3D printing: Precise control of crucible shape, material utilization > 95%, waste <5%.

Automatic sintering: AI optimizes the temperature curve (error ± 1°C), reducing energy consumption by 10%.

Surface treatment: SiC or WC coating (thickness 0.05-0.1mm), improve corrosion resistance, extend life by 30%.

Quality inspection: X-ray non-destructive testing (resolution <0.01mm), defect rate <0.05%.

Technical parameters

Material utilization: >90%, scrap < 0.1 tons/ton crucible.

Energy consumption: The production energy consumption < 12 MWh/ton, which is 15% lower than the traditional process.

Lifespan: Average 80-120 cycles, scrap rate <5%.

Carbon emissions: Green manufacturing reduces CO_2 emissions to 15-20 tons/ton crucibles.

Advantages and challenges

Advantages: Sustainable design extends the life of the crucible by 50% and reduces the carbon emissions of the whole cycle by 20%; Modular design for easy recycling.

Challenge: High investment in 3D printing and green energy equipment, increasing initial cost by 20%; The new process needs to be verified for stability over a long period of time.

9.2 Tungsten crucible recycling and reuse

Recycling and reuse is at the heart of tungsten crucible sustainability, and waste crucibles are transformed into high-value products through efficient recycling processes and quality control, reducing resource waste.

9.2.1 Tungsten crucible recycling process

Process principle

Tungsten crucible recovery extracts tungsten (purity > 99.9%) from waste crucibles through physical crushing, chemical purification and reprocessing to prepare new products (such as tungsten powder, crucibles or alloys).

Recycling process

Collection and sorting: Waste crucibles are sorted by size (20-500mm), purity (>99.9%) and contamination degree and transported to the recycling center.

Cleaning: Ultrasonic cleaning (40-80 kHz), deionized water (conductivity <1 μS/cm), removal of residual < 0.01 μg/cm² from the surface.

Crushing: hydraulic crusher (pressure > 100 MPa), particle size 0.1-5mm, crushing efficiency > 95%.

Chemical Purification:

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Acid leaching: HNO_3 or HCl (concentration 5-10 mol/L) was used to dissolve impurities, and the recovery rate of tungsten was >98%.
Precipitation: NH_4OH was added to generate ammonium paratungstate (APT) with a purity of > 99.95%.
Calcination: 800-1000°C, WO_3 is generated, oxygen content <0.1 ppm.
Reduction: H_2 atmosphere (900-1100°C), tungsten powder (particle size 0.5-5 μm) was prepared, purity > 99.999%.
Reprocessing: sintering or pressing to form new crucibles or other tungsten products.

Technical parameters
Recovery: Tungsten recovery >95% and impurities < 10 ppm.
Energy consumption: 5-8 MWh/ton of recycling energy, accounting for 50% of production energy consumption.
Waste treatment: Neutralize acidic waste to pH 6-8 with COD<50 mg/L.
Processing cycle: 15-30 days for single batch recovery, with a production capacity of 0.5-2 tons/month.

Advantages and challenges
Advantages: The recycling process reduces resource waste to <5% and reduces raw ore demand by 30%; High-purity tungsten powder can be used directly in the production of new crucibles.
Challenge: Waste crucible contamination (e.g., silicon, gallium residues) increases the difficulty of purification; Chemical purification waste liquid treatment costs are high.

9.2.2 Current Status and Challenges of Recycling Technology

status quo
Mainstream technologies: hydrometallurgy (acid leaching + precipitation) and pyrometallurgy (high temperature roasting + reduction), recovery rate 90%-98%.
Equipment: automatic crusher (efficiency > 95%), high-temperature furnace (temperature control ± 1°C), ion exchange system (purity > 99.99%).
Scale: The global recycling capacity is about 5,000-10,000 tons/year, accounting for 20% of the demand for tungsten products.
Application: Recycled tungsten is used in crucibles, alloys, hard tools, and the quality is close to virgin tungsten.

Technical challenges
Impurity separation: The waste crucible contains trace amounts of silicon, gallium and platinum, and the separation cost accounts for 30% of the recovery cost.
High energy consumption: The energy consumption of chemical purification and high-temperature reduction is 5-8 MWh/ton, and the process needs to be optimized.
Small crucibles: crucibles with a diameter of <50mm are difficult to crush, and the recovery efficiency is < 90%.

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Waste liquid treatment: 0.5-1 m^3 waste liquid is generated per ton of waste crucible, and multi-stage neutralization is required to treat it to COD<50 mg/L.

Direction of improvement

New technologies: electrochemical purification (20% reduction in energy consumption), plasma roasting (15% increase in efficiency).

Automation: AI controls purification parameters (error < 0.1%), and the recovery rate is increased to >98%.

Green chemistry: low-acid concentration purification (<5 mol/L), reducing the amount of waste liquid by 50%.

Small-scale equipment: Development of micro crusher, suitable for small-sized crucibles, with an efficiency of >95%.

Technical parameters

Recycling efficiency: 90%-98% currently, 99% target >.

Energy consumption target: <5 MWh/tonne, 30% lower than the current situation.

Waste liquid discharge: <0.3 m^3 /ton, COD<30 mg/L.

Impurity content: 5 ppm of tungsten powder impurities < recovered to meet high-purity applications.

Advantages and challenges

Advantages: Recycling technology reduces raw ore mining by 30% and environmental impact by 20%; High-purity tungsten powder meets the needs of semiconductors.

Challenge: The industrialization of new technologies takes 3-5 years to prove; The investment in small crucible recycling equipment is high, and it is difficult for small and medium-sized enterprises to promote it.

9.2.3 Quality control of recycled products

Process principle

Quality control of recycled products ensures that recycled tungsten products (e.g. crucibles, alloys) have the same properties (purity, strength, longevity) as virgin products to meet the needs of high-tech applications.

Quality control measures

Chemical analysis: ICP-MS detects tungsten powder purity (>99.999%), impurities <1 ppb (Si, Fe, C).

Physical test: laser particle size analysis (particle size 0.5-5 μm), microscopic inspection of grain uniformity (deviation <5%).

Mechanical properties: tensile strength > 800 MPa, hardness > HV 400, thermal shock > 500 cycles.

Surface quality: roughness Ra <0.05 μm, surface residue <0.01 μg/cm^2 .

Non-destructive testing: X-ray CT (resolution <0.01mm), defect rate <0.05%.

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Verification process

Batch testing: 10%-20% sampling per batch, pass rate > 99.5%.

Performance test: simulated high temperature use (1500-3000°C), life test > 80 times.

Certification: Complies with ISO 9001, ASTM B760 (standard for tungsten products), records > 5 years.

Traceability system: RFID or blockchain records the recovery batch and process parameters, and the traceability rate > 99.9%.

Technical parameters

Purity: The purity of the recovered crucible > 99.999%, which is comparable to the original.

Lifespan: 80-100 times, accounting for 90% of the original crucible.

Defect rate: <0.1%, crack <0.1mm.

Detection accuracy: 0.1 ppb for chemical analysis <, 0.01 μm for physical measurement.

Advantages and challenges

Advantages: Strict quality control ensures that the performance of the recycling crucible reaches more than 90% of the original, and the cost is reduced by 30%; Traceability systems increase customer trust.

Challenge: High investment in high-precision testing equipment, accounting for 15% of the recovery cost; Trace impurities can affect semiconductor applications and require further optimization.

9.3 Tungsten crucible environmental regulations and compliance

The production, recycling and waste disposal of tungsten crucibles are subject to international and domestic environmental regulations to ensure environmentally friendly and compliant operations.

9.3.1 International and domestic environmental regulations

Process principle

Environmental regulations regulate resource extraction, production emissions, waste treatment and recycling in the tungsten crucible industry, aiming to reduce ecological damage and pollution and ensure sustainable development.

International Regulations

REACH: EU regulation to limit hazardous chemicals (e.g. sulphur hexafluoride) in tungsten production with volatile < 0.1 ppm.

RoHS: Restriction of toxic substances in tungsten products in electronic equipment, lead and cadmium content < 0.01%.

Basel Convention: Control of cross-border transportation of tungsten waste, export license required, compliance rate > 99%.

ISO 14001: Environmental Management System, Carbon Emissions, Wastewater, Solid Waste Require Annual Audit.

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Domestic Regulations

Environmental Protection Law of the People's Republic of China: the tailings treatment rate is > 80%, and the wastewater COD is < 50 mg/L.

"Law on the Prevention and Control of Environmental Pollution by Solid Waste": Waste crucibles need to be recycled separately, and the recovery rate is > 90%.

"Cleaner Production Promotion Law": production energy consumption < 15 MWh/ton, and green energy accounts for >30%.

"Tungsten Industry Standard Conditions": the mining recovery rate is >85%, and the beneficiation recovery rate is >90%.

Implementation requirements

Compliance process: Submit an Environmental Impact Assessment (EIA) with an approval period of < 3 months.

Monitoring: On-line monitoring of waste gas (SO_2<200 mg/m³) and wastewater (pH 6-9) with an accuracy of ±0.01%.

Records: Environmental data is archived for 5 years > and transparency > 95%.

Penalty: A fine of 10-1 million yuan for illegal discharge will be imposed, and the permit will be revoked in serious cases.

Technical parameters

ompliance rate: > 99.5%, annual audit pass rate > 98%.

Emission standard: CO_2<30 tons/ton crucible, wastewater<100 m³/ton.

Recovery rate: >90% of waste crucibles, >50% of tailings.

Monitoring frequency: daily for waste gas and wastewater, monthly for solid waste.

Advantages and challenges

Advantages: Compliant operation reduces legal risks and enhances market competitiveness; Regulations drive the development of green technologies.

Challenge: Multi-country regulatory differences increase compliance costs; Small and medium-sized enterprises cannot afford the cost of high-frequency monitoring.

9.3.2 Waste disposal and discharge standards

Process principle

The waste materials (tailings, waste liquid, waste gas) generated by the production and recycling of tungsten crucibles should be treated according to standards to reduce environmental pollution and meet emission requirements.

Scrap types and disposal

Tailings: beneficiation waste slag, containing < 0.5% tungsten, impermeable membrane (thickness >1mm) is required for storage, and the recovery rate is >50%.

Waste liquid: pickling waste liquid (pH<2), neutralized to pH 6-9, COD<50 mg/L, heavy metals<0.1 mg/L.

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Waste gas: sintering waste gas (containing SO_2, NOx), discharged after desulfurization and denitrification, SO_2<200 mg/m³, NOx<100 mg/m³.
Solid waste: waste crucible fragments, the recovery rate is >90%, and the non-recyclable part is harmlessly landfilled.

Processing technology

Tailings: flotation + magnetic separation, 50% of tungsten > recovered, and the rest is used for building materials (strength > 10 MPa).
Waste liquid: multi-stage neutralization + ion exchange, waste liquid recycling rate > 80%.
Exhaust gas: wet desulfurization (efficiency > 95%), SCR denitrification (efficiency > 90%).
Solid waste: crushing + chemical purification, tungsten recovery rate >95%, waste residue solidification (heavy metal leaching<0.01 mg/L).

Technical parameters

Tailings disposal rate: >80%, recovered tungsten > 0.3%.
Waste liquid discharge: COD <50 mg/L, heavy metal <0.05 mg/L, circulation rate >80%.
Waste gas emission: SO_2 <150 mg/m³, NOx <80 mg/m³, particulate matter <10 mg/m³.
Solid waste recovery rate: >90%, landfill rate <5%.

Advantages and challenges

Advantages: Efficient waste treatment reduces environmental pollution by 80%, recycling saves resources by 30%; Comply with laws and regulations to enhance corporate image.
Challenge: High investment in waste liquid and waste gas treatment equipment, accounting for 20% of operating costs; The tailings recovery technology needs to be further optimized.

9.3.3 Compliance Certification and Audit

Process principle

Compliance certification and audit verifies the compliance of tungsten crucible enterprises in terms of environmental protection, quality and safety, and ensures compliance with regulations and customer requirements.

Type of Certification

ISO 14001: Environmental Management System, covering production, recycling, waste disposal, certification cycle of 3 years.
ISO 9001: Quality management system, crucible purity, performance test pass rate > 99.5%.
OHSAS 18001: Occupational Health and Safety, Accident Rate < 0.1%, Employee Training Coverage 100%.
Green certification: such as China Environmental Label, carbon emission < 25 tons/ton crucible.

Audit process

Internal Audit: Quarterly inspection of environmental data and waste disposal records, with a coverage rate of > 95%.

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External audit: third-party organization (such as SGS, TÜV), annual audit, compliance rate > 98%.
Data submission: Waste gas, waste water, solid waste discharge data, real-time upload to the environmental protection department, error <1%.
Rectification: If non-compliance items are found, the rectification period will be < 30 days, and the pass rate of the review will > 99%.

Technical parameters
Certification pass rate: >98%, valid for 3-5 years.
Audit frequency: every 3 months internally, 1 time per year externally.
Data accuracy: Emission monitoring <± 0.01%, archived >for 5 years.
Rectification rate: The rectification rate of non-compliant items > 99%, and the response time < 7 days.

Advantages and challenges
Advantages: Certification enhances market trust and attracts green investment; Audits ensure compliance and reduce the risk of fines.
Challenge: High certification and audit fees, accounting for 10% of management costs; Multi-standard coordination increases the administrative burden.

9.4 Tungsten crucible circular economy practice
Circular economy maximizes the value of tungsten crucibles and reduces resource waste and environmental impact through closed-loop management, resource recovery and industry cooperation.

9.4.1 Closed-loop management of tungsten resources
Process principle
Closed-loop management integrates the recovery, reuse and reproduction of tungsten crucibles to form a resource recycling system, reduce dependence on raw ore, and improve resource efficiency.

Management measures
Recycling network: Establish a global waste crucible recycling point with a coverage rate of > 80% and a collection efficiency of > 90%.
Reuse chain: Recycled tungsten powder is used directly in new crucibles, alloys or tools with a recycling rate of > 70%.
Data platform: The blockchain records the life cycle of the crucible (production, recycling, processing), and the traceability rate > 99.9%.
Green supply chain: Prioritize the purchase of recycled tungsten, reduce the use of raw ore by 30%, and > supplier compliance rate by 95%.

Technical parameters
Recycling rate: The recycling rate of tungsten resources > 70%, and the target > 85%.
Recycling coverage: 80% > major markets and 50% > small and medium-sized markets.

Data integrity: Lifecycle data is archived for > 5 years, with an error of < 0.1%.
Raw ore dependence: 30%-50% reduction, mining capacity < 5000 tons/year.

Advantages and challenges

Advantages: Closed-loop management reduces resource consumption by 30% and carbon emissions by 20%; The data platform improves supply chain efficiency by 25%.
Challenge: It takes 5-10 years to build a global recycling network, with high initial investment; The uneven quality of the recovery crucible needs to be standardized.

9.4.2 Analysis of the economic benefits of recycling

Process principle

The economic benefits of recycling achieve the sustainable development of the tungsten crucible industry by reducing the cost of raw materials, reducing environmental treatment expenses and creating new revenue streams.

Benefit analysis

Cost saving: The cost of recycled tungsten is about 50%-60% of virgin tungsten, saving 0.5-10,000 yuan per ton.
Environmental costs: reduce tailings and waste liquid treatment, save 20%-30% environmental protection costs, about 0.1-030000 yuan/ton.
New income: sales of recycled tungsten powder, profit margin of 10%-15%, annual income of up to 50 million yuan (medium-sized enterprises).
Return on Investment: The payback period of the recycling equipment is 3-5 years, and the net present value (NPV) is >0.

Technical parameters

Cost reduction: the cost of recycling crucibles < 80,000 yuan/ton, and the original cost > 150,000 yuan/ton.
Profit margin: The profit margin on the sale of recycled products > 10%, and the comprehensive profit margin >8%.
Investment scale: Medium-sized recycling line investment of 0.5-100 million yuan, production capacity of 500-1000 tons/year.
Payback period: 3-5 years, internal rate of return (IRR) >15%.

Advantages and challenges

Advantages: recycling reduces production costs by 30% and enhances the competitiveness of enterprises; New revenue streams, diversified profit models.
Challenge: The initial investment in recycling equipment is high, and the financial pressure of small and medium-sized enterprises is high; Market acceptance of recycled products needs to be improved.

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Tungsten Crucibles

1. Overview of Tungsten Crucibles

Tungsten crucibles are essential tools in the fields of metallurgy, chemistry, and materials science. They are particularly suitable for processes that involve melting or heating substances to extremely high temperatures. Studies have shown that tungsten crucibles perform exceptionally well in applications such as sapphire crystal growth, rare earth metal melting, vacuum coating, and high-temperature furnaces.

2. Features of Tungsten Crucibles

Ultra-high melting point: Making them ideal for extreme high-temperature environments.

High purity: purity of ≥99.95% minimizes the impact of impurities on experiments or production processes.

Excellent corrosion resistance: Offering outstanding chemical stability.

High density and low vapor pressure: Ensuring material stability.

High strength and wear resistance: Ensuring long service life.

Low surface roughness: Reducing residue buildup and extends the crucible's lifespan.

3. Applications of Tungsten Crucibles

Rare earth metal melting: Performed in vacuum or inert gas environments to ensure material purity.

Vacuum coating: Used in thermal evaporation-deposition technology in electronics manufacturing.

High-temperature furnaces: Functions as a key component capable of withstanding environments below 2400℃.

Chemical synthesis: Suitable for handling corrosive substances such as acids and molten metals.

Metal smelting and refining: Used for melting and refining high-purity metals.

Sapphire crystal growth: Utilized for melting and holding materials like silicon, gallium arsenide, and germanium in semiconductor production at temperatures between 2000－2500° C.

4. Specifications of Tungsten Crucibles

Specification	Details
Material	Pure tungsten or tungsten alloy
Purity	99.95%
Diameter	20–620 mm
Height	20–500 mm
Wall Thickness	3.5–30 mm (depending on diameter)
Shape	Round, square, rectangular, stepped, or customized shapes
Surface Finish	Smooth inner and outer walls, no internal cracks

5. Purchasing Information

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9.4.3 Industry cooperation and circular economy models

Process principle

Industry cooperation builds a circular economy ecosystem by integrating upstream and downstream enterprises, governments and scientific research institutions to promote the sustainable production and recycling of tungsten crucibles.

Cooperation model

Industry-university-research cooperation: Develop high-efficiency recovery technologies (such as electrochemical purification) with universities and research institutes, and increase the recovery rate to >99%.

Supply Chain Alliance: Cooperate with miners, producers, and recyclers to establish a closed-loop supply chain, with a resource utilization rate of > 80%.

Policy support: cooperate with the government to strive for recycling subsidies (0.1-05,000 yuan/ton), tax reduction > 10%.

Industry standard: Formulate tungsten crucible recovery specifications (such as purity > 99.99%, impurities < 5 ppm), and the promotion rate > 90%.

Technical parameters

Cooperation coverage: 70% of industry alliance members >, and 50% of small and medium-sized enterprises >.

Recovery rate: 85% > pilot projects, and 70% industry average >.

Technology promotion rate: 60% of the application of new recycling technology >, and the promotion cycle < 3 years.

Public awareness: Circular economy publicity covers 80% of > target customers, and the awareness rate > 90%.

Advantages and challenges

Advantages: Industry cooperation reduces R&D costs by 20% and accelerates technology promotion; The policy supports a 30% increase in the recycling rate.

Challenges: The distribution of upstream and downstream benefits needs to be coordinated, and the management cost of the alliance is high; Small and medium-sized enterprises (SMEs) have low participation and need incentives.

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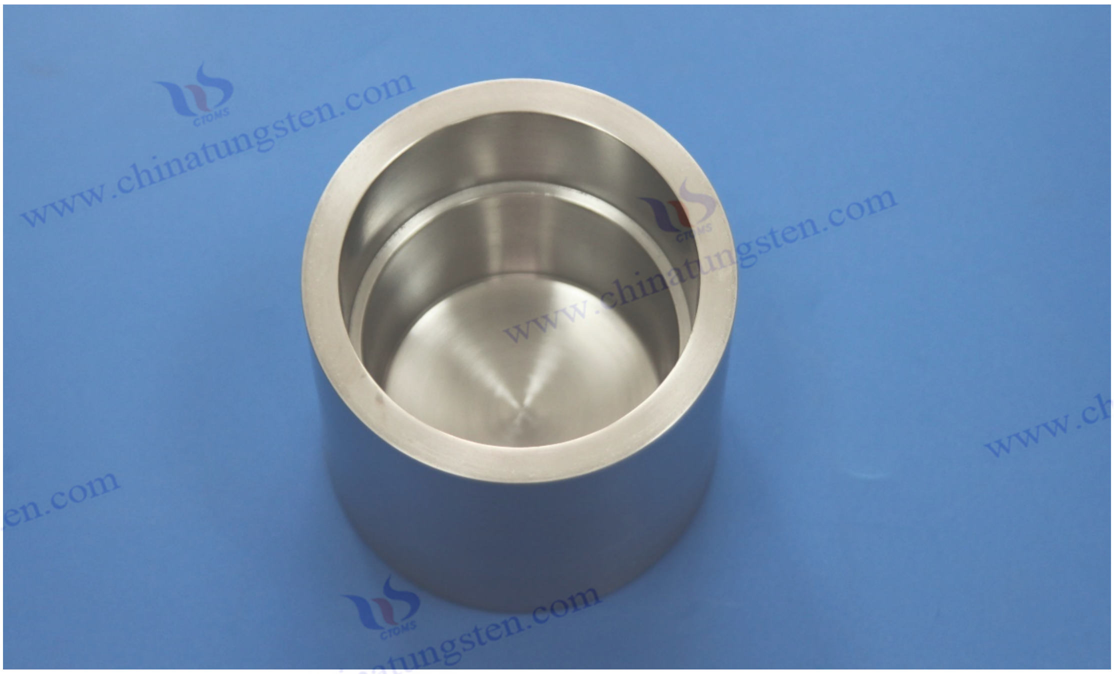

CTIA GROUP LTD tungsten crucible

Chapter 10 Tungsten Crucible Standards and Regulations

As high-performance industrial components, tungsten crucibles are manufactured, tested, and applied to strict standards and regulations to ensure quality, performance, and safety. This section discusses in detail the requirements of Chinese National Standards (GB), International Organization for Standardization (ISO), American Standards (ASTM) and other international standards for tungsten crucibles, combined with the practical experience of global tungsten products companies and the industry information provided by Chinatungsten Online, analyzes the technical details, test methods and compliance requirements of the standards, and provides standardized guidance for manufacturers and users.

10.1 Chinese National Standard (GB)

The Chinese National Standard (GB) provides detailed technical specifications for the production, inspection and application of tungsten crucibles, covering material properties, manufacturing processes and quality control to ensure that the domestic and international market needs are met.

10.1.1 GB/T 3875-2017: General technical conditions for tungsten products

Overview of the standard

GB/T 3875-2017 stipulates the chemical composition, physical properties, manufacturing process and test methods of tungsten products (including tungsten crucibles, tungsten plates, tungsten rods, etc.), which are suitable for high-temperature industrial applications (such as semiconductors, aerospace).

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Technical requirements
Chemical composition: Tungsten purity>99.95%, impurity content (Fe, Ni, C, etc.) <100 ppm, gas elements (O, N) <50 ppm.

Physical Properties:
Density: > 19.1 g/cm³ (sintered), > 19.25 g/cm³ (forged).
Tensile strength: > 600 MPa (room temperature), > 300 MPa (1000°C).
Hardness: > HV 350 (room temperature).
Surface quality: roughness Ra<0.2 µm, no cracks, porosity or inclusions (diameter > 0.1 mm).
Dimensional tolerances: diameter ± 0.05 mm, wall thickness ± 0.02 mm, suitable for crucible diameters 20-500 mm.
Manufacturing process: powder metallurgy (sintering temperature 1800-2500°C), vacuum or inert atmosphere (oxygen content < 10 ppm).

Test Method:
Chemical analysis: ICP-MS (accuracy ± 0.1 ppm) to detect impurities, gas analyzer (accuracy ± 0.01 ppm) to measure O and N content.
Physical test: universal testing machine to measure tensile strength (error ±1%), Vickers hardness tester to measure hardness (error ±5 HV).
Surface inspection: optical microscope (resolution < 1 µm) to check for defects, surface roughness meter (accuracy ± 0.01 µm).
Dimensional measurements: laser rangefinder (accuracy ± 0.01 mm) with tolerances according to ISO 2768.

Compliance requirements
Inspection report: Each batch provides chemical composition, physical properties and size test report, which is archived >for 5 years.
Quality certification: ISO 9001 compliant, batch pass rate > 99.5%.
Applications: It is suitable for the growth of monocrystalline silicon, rare earth metal smelting, etc., and meets the needs of high purity (>99.999%).

Advantages and challenges
Advantages: The standard fully covers the performance of tungsten products, and the detection method is accurate to ensure the reliability of the crucible; Support the export competitiveness of China's tungsten industry.
Challenge: High purity requirements increase production costs; It is difficult for small businesses to be equipped with high-precision inspection equipment.

10.1.2 GB/T 3459-2022: Technical requirements for tungsten crucibles
Overview of the standard
GB/T 3459-2022 is formulated specifically for tungsten crucibles and specifies their design, manufacturing, inspection and packaging requirements for high-temperature applications in the

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semiconductor, photovoltaic and metallurgical industries.

Technical requirements

Material: Tungsten purity >99.99%, impurities (Si, Fe, Mo) <50 ppm, gas elements <20 ppm.

Performance:

Temperature resistance: > 3000° C, thermal shock > 500 times, no cracks (>0.1 mm).

Thermal conductivity: > 100 W/m • K (1000° C), ensuring a uniform thermal field ±5° C.

Surface finish: Ra<0.1 μm, to prevent material adhesion.

Dimensions & Construction:

Diameter: 20-500 mm, wall thickness 1-10 mm, tolerance ± 0.02 mm.

Shape: round or customized, bottom thickness deviation < 0.05 mm.

Manufacturing process: isostatic pressing (pressure > 200 MPa), vacuum sintering (temperature> 2200°C, oxygen content<5 ppm).

Packing: Vacuum-sealed (<10 Pa), shockproof foam (thickness > 10 mm), in accordance with GB/T 191.

Test Method:

Performance test: high-temperature furnace simulated 3000°C operation, thermal shock test (temperature rise and fall rate 10°C/min), crack detection (X-ray, resolution < 0.01 mm).

Surface analysis: Atomic force microscopy (AFM, accuracy ± 0.001 μm) to measure roughness, scanning electron microscopy (SEM) to check microscopic defects.

Dimensional inspection: Coordinate measuring machine (CMM, accuracy ± 0.005 mm) with tolerances according to ISO 1101.

Chemical detection: GD-MS (glow discharge mass spectrometry, accuracy ±0.05 ppm) for impurities.

Compliance requirements

Batch inspection: 5%-10% sampling per batch, pass rate > 99.8%.

Certification: It needs to pass third-party testing (such as SGS) and report that it meets CNAS requirements.

Application: It is used for the growth of single crystal silicon by Czochralski method and the production of sapphire crystals, with a purity of > 99.999%.

Advantages and challenges

Advantages: Standard optimized for high-temperature applications in crucibles to ensure stable performance; The detection method is advanced and supports high-precision manufacturing.

Challenge: Stringent surface and purity requirements make the process more difficult; The investment in testing equipment is high, and the implementation cost of small and medium-sized enterprises is high.

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10.1.3 YB/T 5174-2020: Tungsten crucible industry standard

Overview of the standard

YB/T 5174-2020 is the industry standard for tungsten crucibles, supplementing GB/T 3459-2022, focusing on standardizing the production process, quality control and environmental protection requirements, and is applicable to enterprises in China's tungsten industry.

Technical requirements

Raw materials: tungsten powder particle size 0.5-5 μm, purity > 99.99%, O content < 10 ppm.

Performance:

Corrosion resistance: resistant to molten silicon and gallium corrosion, with a corrosion rate of < 0.01 mm/year.

Mechanical strength: tensile strength > 700 MPa (room temperature), > 200 MPa (2000° C).

Thermal stability: deformation rate < 0.1% at 3000°C, thermal expansion coefficient < 4.5×10^{-6}/K.

Manufacturing: CVD coating (SiC, thickness 0.05-0.1 mm) for improved corrosion resistance, sintering atmosphere purity > 99.999%.

Environmental protection: production wastewater COD < 50 mg / L, waste gas SO_2 < 200 mg / m³, tailings recovery rate > 50%.

Test Method:

Corrosion test: immersion in molten silicon (1600°C, 24 hours), measurement of corrosion depth (accuracy ± 0.001 mm).

Mechanical test: high temperature tensile test (2000°C, error ±1%), hardness test (error ±5 HV).

Environmental protection testing: on-line monitoring of wastewater (pH 6-9, accuracy ± 0.01), exhaust gas (particulate matter< 10 mg/m³).

Quality control: full inspection of the size of each batch (tolerance±0.01 mm), sampling performance (pass rate> 99.5%).

Compliance requirements

Records: Production, testing, environmental protection data archiving > 5 years, traceability rate > 99.9%.

Certification: ISO 14001 compliant, waste disposal subject to local environmental protection approval.

Application: It is suitable for the production of photovoltaic silicon wafers and the preparation of compound semiconductors (such as GaN).

Advantages and challenges

Advantages: standards combined with environmental protection requirements to promote green production; Strong industry-oriented and suitable for the Chinese market.

Challenge: High frequency of environmental protection testing, increasing operating costs; It is difficult for small businesses to meet the full inspection requirements.

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10.2 International Organization for Standardization (ISO) standards

The ISO standard provides a global uniform specification for the quality management, environmental management and high-temperature performance testing of tungsten crucibles, ensuring the consistency and reliability of the products in the international market.

10.2.1 ISO 9001:2015: Quality Management System

Overview of the standard

ISO 9001:2015 specifies the requirements for a Quality Management System (QMS) applicable to tungsten crucible production, inspection and supply chain management to ensure product consistency and customer satisfaction.

Technical requirements

Process control: from the procurement of raw materials to the delivery of finished products, the process is documented, and the deviation is <1%.

Quality objectives: batch pass rate > 99.5%, customer complaint rate < 0.1%.

Testing: Chemical composition (purity> 99.99%), dimensions (tolerance±0.02 mm), performance (thermal shock> 500 times) are fully recorded.

Continuous improvement: annual quality audit, the implementation rate of improvement measures > 95%.

How to do it

Document management: electronic quality records, archiving > 5 years, traceability rate > 99.9%.

Training: The annual training > of employees is 20 hours, the coverage rate is 100%, and the pass rate > 95%.

Audit: Internal audit every 6 months, external audit every year, certification valid for 3 years.

Customer feedback: Complaint response < 24 hours, resolution rate > 98%.

Compliance requirements

Certification: Third-party certification (such as TÜV, SGS) is required, and the pass rate is >98%.

Application: Covering tungsten crucible production, testing, packaging, suitable for semiconductors, aerospace.

Records: Quality data and audit reports are archived for > 5 years, and the transparency > 90%.

Advantages and challenges

Advantages: improve product quality consistency and enhance market competitiveness; High global recognition, good for exports.

Challenges: High cost of certification and audit, difficult implementation for small and medium-sized enterprises; Document management needs to be digitally supported.

10.2.2 ISO 14001:2015: Environmental Management System

Overview of the standard

ISO 14001:2015 specifies the requirements for an Environmental Management System (EMS) to

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guide environmental management in the production and recycling of tungsten crucibles to reduce carbon emissions and waste pollution.

Technical requirements

Environmental objectives: carbon emissions < 30 tons/ton crucible, wastewater COD<50 mg/L, tailings recovery rate > 50%.

Resource management: 90% > utilization of raw materials and 15% improvement in energy efficiency.

Waste treatment: waste gas SO_2<200 mg/m³, waste liquid heavy metals<0.1 mg/L, solid waste recovery rate>90%.

Monitoring: Online environmental monitoring (accuracy ± 0.01%), data archiving > 5 years.

How to do it

Environmental Assessment: Annual Environmental Impact Assessment (EIA), 100% coverage.

Training: Employee environmental protection training > 10 hours/year, with a coverage rate of > 95%.

Audit: Quarterly internally, annually externally, with a rectification rate of > 99%.

Green technology: waste heat recovery (efficiency > 15%), renewable energy (> 30%).

Compliance requirements

Certification: ISO 14001 certification is required, the cycle is 3 years, and the pass rate is >98%.

Application: Covering production, recycling, waste disposal, REACH, RoHS compliance.

Report: Environmental data is open, transparency > 95%, and archiving > 5 years.

Advantages and challenges

Advantages: reduce environmental impact by 20% and enhance the green image of the enterprise; Regulatory compliance reduces the risk of fines.

Challenge: High investment in environmental monitoring equipment, accounting for 10%-15% of operating costs; Small and medium-sized businesses struggle to meet high-frequency audit requirements.

10.2 International Organization for Standardization (ISO) Standards (continued)

10.2.3 ISO 15730:2000: Testing of high-temperature properties of metallic materials

Overview of the standard

ISO 15730:2000 specifies a test method for the performance of metallic materials in high-temperature environments, which is suitable for the evaluation of the thermal stability, mechanical strength and corrosion resistance of tungsten crucibles to ensure their reliability under extreme conditions.

Technical requirements

Test temperature: 1000°C to 3000°C, temperature control accuracy ± 2°C.

Performance indicators:

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Tensile strength: > 200 MPa (2000°C), error ±1%.
Thermal shock performance: > 500 cycles (temperature rise and fall rate 10°C/min), no cracks (>0.1 mm).
Corrosion resistance: Resistant to molten silicon and gallium, the corrosion rate < 0.01 mm/year.
Test environment: vacuum (<10^{-5} Pa) or inert atmosphere (oxygen content<1 ppm).
Sample requirements: crucible sections (thickness 1-5 mm), surface roughness Ra<0.2 µm.

Test Method:
High temperature tensile: high temperature universal testing machine (load accuracy± 0.5%), test the strength at 2000°C.
Thermal shock test: fast ramp and temperature furnace (rate 10-20 °C/min), X-ray detection of cracks (resolution < 0.01 mm).
Corrosion test: immersion test (1600-2000°C, 24 hours), SEM analysis of corrosion depth (accuracy ± 0.001 mm).
Data recording: electronic archiving of test parameters and results for a period of > 5 years.

Compliance requirements
Reporting: High temperature performance reports are provided for each batch, in accordance with ISO 17025 laboratory standards.
Certification: Test equipment needs to be calibrated (error < 0.5%), and the results can be traced.
Application: Used in nuclear reactors, aerospace high-temperature component verification.

Advantages and challenges
Advantages: Standard test methods ensure consistent high-temperature performance of crucibles to meet the needs of extreme applications; High international recognition.
Challenge: High temperature test equipment is expensive, the cost of a single test is about 0.5-10,000 yuan, and complex environment simulation requires professional skills.

10.3 American Standards (ASTM)
ASTM standards provide detailed guidance on material specifications, performance testing, and chemical analysis of tungsten crucibles, which are widely used in the North American and global markets.

10.3.1 ASTM B760-07(2019): Standard Specification for Tungsten Sheets, Sheets, and Foils
Overview of the standard
ASTM B760-07 (2019) specifies the chemical composition, mechanical properties, and manufacturing requirements of tungsten plates, sheets, and foils, and is applicable to the production of tungsten crucible raw materials or components.

Technical requirements
Chemical composition: Tungsten purity>99.95%, impurities (Fe, Ni, C)<100 ppm, O<20 ppm.

Mechanical Properties:
Tensile strength: > 550 MPa (room temperature), > 150 MPa (1000°C).
Elongation: >2% (room temperature), >5% (1000°C).
Hardness: > HV 300.
Surface quality: no cracks, porosity (>0.1 mm), roughness Ra<0.3 μm.
Dimensional tolerances: thickness ± 0.01 mm, width ± 0.05 mm, suitable for crucible wall thickness 1-10 mm.
Manufacturing process: hot press sintering (2000-2500°C), vacuum or hydrogen atmosphere (oxygen content<5 ppm).

Test Method:
Chemical analysis: ICP-OES (accuracy ± 0.1 ppm) to detect impurities, LECO analyzer to detect O, N (accuracy ± 0.01 ppm).
Mechanical Testing: Tensile Test (ASTM E8, Error ±1%), Hardness Test (ASTM E18, Error ±5 HV).
Surface inspection: ultrasonic flaw detection (resolution < 0.1 mm), roughness meter (accuracy ± 0.01 μm).
Dimensional inspection: laser measurement (accuracy ± 0.005 mm) in accordance with ANSI B46.1.

Compliance requirements
Inspection: A Certificate of Material (CoA) is provided for each batch, including chemical composition, performance data.
Certification: Complies with AS9100 (Aerospace Quality System), with a pass rate of > 99.5%.
Application: Used as raw material for aerospace nozzles and semiconductor crucibles.

Advantages and challenges
Advantages: The standard regulates the performance of raw materials in detail to ensure the consistency of crucible manufacturing; The test method is mature and can be used worldwide.
Challenge: High purity requirements increase refining costs; Ultra-thin foils (<0.1 mm) are difficult to inspect.

10.3.2 ASTM E696-07(2018): Standard Specification for Tungsten Products

Overview of the standard
ASTM E696-07 (2018) addresses the performance, manufacturing, and acceptance requirements for tungsten products, including crucibles, and is suitable for high-temperature industry and scientific research.
Technical requirements
Material: Tungsten purity > 99.99%, impurities (Si, Mo, Fe) < 50 ppm, gas elements < 10 ppm.
Performance:
Temperature resistance: > 3000° C, thermal shock cycle > 500 times, deformation rate < 0.1%.
Corrosion resistance: Resistant to molten metals (silicon, gallium), corrosion rate < 0.01 mm/year.
Thermal conductivity: >100 W/m·K (1000°C).
Manufacturing: powder metallurgy or plasma spraying, sintering temperature > 2200°C, atmosphere

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purity > 99.999%.
Dimensions: diameter 20-500 mm, wall thickness tolerance ± 0.02 mm, bottom flatness < 0.05 mm.

Test Method:
Performance test: high temperature furnace (3000°C, temperature control ±2°C) simulated use, thermal shock test (ASTM E1461).
Corrosion test: molten silicon immersion (1600°C, 48 hours), measurement of mass loss (accuracy±0.001 g).
Dimensional inspection: CMM (accuracy ±0.005 mm), surface analysis (SEM, accuracy ± 0.001 μm).
Chemical analysis: GD-MS (accuracy±0.05 ppm) to detect impurities.

Compliance requirements
Reporting: Performance, size, chemical analysis reports are provided for each batch, and the archive > 5 years.
Certification: Meets MIL-STD-810 (Military Environmental Testing) with a pass rate of > 99.8%.
Application: used in nuclear fusion, photovoltaic silicon wafer production.

Advantages and challenges
Advantages: The standard covers high-temperature performance and is suitable for extreme environment applications; The test method is accurate and the data is credible.
Challenge: The cost of high-temperature testing is high, about 0.5-10,000 yuan for a single time, and the strict tolerance requirements increase the difficulty of manufacturing.

10.3.3 ASTM E1447-09(2016): Method for chemical analysis of tungsten materials
Overview of the standard
ASTM E1447-09 (2016) specifies a chemical analysis method for tungsten materials to detect the purity and impurity content of tungsten crucibles to ensure that high-purity applications are met.

Technical requirements
Detection elements: Fe, Ni, Si, Mo, C, O, N, etc., detection limit <0.1 ppm.
Purity: Tungsten >99.99%, total impurities <50 ppm, gas elements <10 ppm.
Sample preparation: crucible sections (0.5-1 g), surface wash (residual < 0.01 μ g/cm²).
Accuracy: relative error <1%, repeatability > 99.5%.

Test Method:
ICP-MS: Detection of metal impurities (Fe, Ni, Si), accuracy ± 0.1 ppm, detection limit 0.01 ppm.
LECO analysis: C, O, N content was measured, the accuracy was ± 0.01 ppm, and the detection limit was 0.005 ppm.
GD-MS: High purity tungsten analysis with a detection limit of < 0.05 ppm covering > 20 elements.
Sample treatment: acid solubilization (HNO_3+HCl, concentration 5 mol/L), ultrasonic cleaning (40 kHz).

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Compliance requirements

Laboratory: ISO 17025 accreditation required, equipment calibration interval < 6 months.

Report: Analysis results, methods, errors, archived >for 5 years, > traceability rate 99.9%.

Application: Used for semiconductor and photovoltaic high-purity tungsten crucible verification.

Advantages and challenges

Advantages: High-precision analysis ensures that the purity of the crucible is > 99.999%, which meets the needs of semiconductors; Methodological standardization, global recognition.

Challenge: The cost of GD-MS equipment is high, and the > of a single device is 10 million yuan; Sample preparation requires an ultra-clean environment, which increases costs.

10.4 Other International Standards

Other international standards (e.g., Japan JIS, Germany DIN, European EN) provide supplementary specifications for the manufacture, inspection and analysis of tungsten crucibles for specific markets and applications.

10.4.1 JIS H 4701:2015: Tungsten and tungsten alloy products

Overview of the standard

JIS H 4701:2015 specifies the chemical composition, properties and manufacturing requirements of tungsten and tungsten alloy products, including crucibles, for the high-temperature industry in the Japanese market.

Technical requirements

Chemical composition: Tungsten purity>99.95%, impurities (Fe, Ni, C)<100 ppm, O<20 ppm.

Performance:

Tensile strength: > 600 MPa (room temperature), > 200 MPa (1000° C).

Hardness: > HV 350, thermal shock > 500 cycles.

Surface roughness: Ra<0.2 μm, no cracks (>0.1 mm).

Manufacturing: Hot isostatic pressing (HIP, pressure> 150 MPa), sintering temperature 2000-2500° C.

Dimensions: diameter 20-300 mm, tolerance ± 0.05 mm, wall thickness 1-8 mm.

Test Method:

Chemical analysis: ICP-OES (accuracy ± 0.1 ppm), gas analysis (accuracy ± 0.01 ppm).

Mechanical tests: tensile test (JIS Z 2241, error ±1%), hardness test (JIS Z 2245).

Surface inspection: optical microscopy (resolution < 1 μm), ultrasonic flaw detection (resolution < 0.1 mm).

Dimensional inspection: laser measurement (accuracy ± 0.01 mm) in accordance with JIS B 0405.

Compliance requirements

Reporting: A material certificate is provided for each batch, in accordance with JIS Z 9001.

Certification: JQA (Japan Quality Assurance Association) verification is required, and the pass rate is > 99.5%.

Application: used in compound semiconductor (GaAs, GaN) preparation, precision instruments.

Advantages and challenges

Advantages: The standard is suitable for the Asian market, and the detection method is simple and efficient; Supports the production of small crucibles (<50 mm).

Challenges: High certification costs in the Japanese market and high entry barriers for small and medium-sized enterprises; The standard update cycle is long (5-10 years).

10.4.2 DIN EN 10204:2004: Inspection documents for metal products

Overview of the standard

DIN EN 10204:2004 specifies the type and content of inspection documents for metal products, including tungsten crucibles, ensuring quality traceability and suitability for the European market.

Technical requirements

File type:

2.1: Declaration of Conformity, confirming that the product meets the requirements of the order.

2.2: Test report, providing chemical composition and performance data.

3.1: Certificate of Inspection, issued by the manufacturer's authorized personnel, with detailed test results.

3.2: Third-party inspection certificate (e.g. TÜV) verifying independence.

Contents: App: Chemical composition (> 99.99%), dimensions (±0.02 mm), performance (thermal shock> 500 cycles).

Records: inspection data, batch number, test date, archived > 5 years.

How to do it

Data logging: electronic file, PDF or XML format, traceability rate > 99.9%.

Verification: Manufacturer or third party (such as SGS) audit, pass rate > 99.5%.

Language: English or German, font > 12 pt, legible.

Distribution: Paper or electronic version is provided with the goods, and the delivery time < 7 days.

Compliance requirements

Certification: Complies with EN ISO/IEC 17050 and the document is valid for > 3 years.

Application: Used in aerospace, semiconductor tungsten crucible exported to Europe.

Audit: Annual document review, error rate < 0.1%, rectification rate > 99%.

Advantages and challenges

Advantages: Standard documentation increases customer trust and simplifies EU market access; Digitalization reduces management costs.

Challenge: Type 3.2 certificate needs to be verified by a third party, and the cost is about 0.5-10,000 yuan/batch; Multilingualism requires increased translation costs.

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10.4.3 EN 10276-1:2000: Chemical analysis of high-temperature materials

Overview of the standard

EN 10276-1:2000 specifies methods for the chemical analysis of high-temperature materials, such as tungsten, to ensure that the purity and impurity content meet the requirements for high-temperature applications.

Technical requirements

Detection elements: Fe, Ni, Si, Mo, C, O, N, detection limit <0.1 ppm.

Purity: Tungsten >99.99%, total impurities <50 ppm, gas elements <10 ppm.

Sample: crucible sections (0.5-2 g) with residual < 0.01 μg/cm² .

Accuracy: relative error <1%, repeatability > 99.5%.

Test Method:

ICP-MS: Detection of metal impurities with an accuracy of ± 0.1 ppm and a detection limit of 0.01 ppm.

TGA-MS: Measurement of O and N content, accuracy ± 0.01 ppm, detection limit 0.005 ppm.

XRF: Rapid analysis (± 0.5 ppm) for initial screening.

Sample treatment: acid soluble (HNO_3, 5 mol/L), ultrasonic cleaning (40 kHz).

Compliance requirements

Laboratory: EN ISO/IEC 17025 accreditation required, equipment calibration interval < 6 months.

Report: Analysis results, methods, errors, archived for 5 years, > traceability rate> 99.9%.

Application: Used for nuclear reactor, aerospace tungsten crucible verification.

Advantages and challenges

Advantages: High-precision analysis for high-purity applications (> 99.999%); The method is ASTM compatible and can be used worldwide.

Challenge: TGA-MS equipment is expensive, with a single > of 5 million yuan; Sample preparation requires a clean room, which is costly.

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CTIA GROUP LTD tungsten crucibles

Appendix

A. Glossary

Tungsten Crucible: a container made of high-purity tungsten as the main material for high-temperature melting or material handling.

Powder Metallurgy: the technology of manufacturing metal products through powder pressing, sintering and other processes.

Isostatic Pressing: The process of applying pressure evenly in a liquid or gaseous medium to form a powder.

Czochralski Method: a process used for the growth of single crystals, commonly used in the preparation of semiconductor materials.

Thermal Shock Resistance: The ability of a material to resist cracking under rapid temperature changes.

Sintering: The process of heating a powdered material below its melting point to form a solid.

Non-destructive Testing: ultrasonic, X-ray and other methods to detect internal defects of materials without damaging the sample.

Hot Isostatic Pressing (HIP): A post-processing technology to improve the density of materials at high temperatures and pressures.

Grain Size: The average size of the crystals in the microstructure of a material, which affects the mechanical properties.

High-temperature Creep: The slow deformation of a material under long-term stress at high temperatures.

Coefficient of Thermal Expansion: The rate of change in volume or length of a material under a change in temperature.

Surface Roughness: A measure of the micro-geometric characteristics of a surface, usually

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expressed in Ra or Rz.

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C. List of Commonly Used Tools and Equipment

High Temperature Sintering Furnace (Vacuum, Atmosphere Protection)
Isostatic press (cold and hot isostatic pressing)
CNC machining centers (turning, milling, grinding)
Scanning Electron Microscopy (SEM)
X-ray fluorescence spectroscopy (XRF)
Ultrasonic detector
High temperature performance test equipment

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