Complete Guide to Molybdenum 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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Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

Molybdenum crucibles are made of high-purity molybdenum powder through isostatic pressing, high-temperature sintering and precision machining. They have excellent high-temperature strength, corrosion resistance and dimensional stability, making them widely used in sapphire crystal growth, rare earth smelting, glass industry, vacuum coating and high-temperature heat treatment.

2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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Contents

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Chapter 1 Introduction

1.1 Definition and Importance of Molybdenum Crucible

Molybdenum crucible is a high temperature resistant container made of high purity molybdenum metal as the main raw material, which is widely used in high temperature smelting, material synthesis and scientific research. Its main features are high melting point (about 2623°C), excellent corrosion resistance and high temperature strength, as well as good thermal conductivity and low thermal expansion coefficient. These characteristics enable molybdenum crucible to maintain structural stability and chemical inertness in extreme environments, making it an indispensable tool in many industries and scientific research processes.

Molybdenum crucible can be explained from two aspects: its material and purpose. From the perspective of material, molybdenum crucible is usually made of molybdenum metal or molybdenum alloy with a purity of more than 99.95%, and is formed by processes such as powder metallurgy, forging, machining or welding. From the perspective of purpose, molybdenum crucible is mainly used for processes such as material melting, evaporation, sintering and crystal growth in high-temperature environments, such as rare earth metal smelting, sapphire crystal growth, semiconductor material preparation and high-temperature alloy synthesis.

Importance

Molybdenum crucibles in modern industry and scientific research is reflected in the following aspects:

High temperature stability: Molybdenum 's high melting point and excellent high temperature strength enable it to work stably at temperatures of 1100°C to 1700°C or even higher, far exceeding many other metal crucibles (such as aluminum, copper or low melting point alloy crucibles). This makes molybdenum crucibles the preferred container for high temperature smelting and material synthesis. For example, in rare earth metal smelting, molybdenum crucibles can withstand extreme high temperatures and maintain chemical stability to avoid impurity contamination.

Corrosion resistance: Molybdenum crucibles have good corrosion resistance to a variety of acids, alkalis and molten metals, especially when in contact with rare earth metals, oxides or certain corrosive chemicals. In contrast, tungsten crucibles, although with a higher melting point, may not be as corrosion-resistant as molybdenum crucibles in certain chemical environments.

Preparation of high-purity materials: The high purity and low impurity release characteristics of molybdenum crucibles make them particularly suitable for the production of high-purity materials. For example, in the process of sapphire crystal growth, molybdenum crucibles can provide a pollution-free high-temperature environment to ensure the quality and optical properties of the crystal. Similarly, in the semiconductor industry, molybdenum crucibles are used to prepare high-purity silicon and other compound materials.

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Process flexibility: According to different application requirements, molybdenum crucibles can be prepared by a variety of processing methods, including machining, welding, riveting and stamping. These processing methods give molybdenum crucibles a variety of sizes, shapes and performances, meeting various needs from small-scale laboratory experiments to large-scale industrial production.

Economy and life: Although the manufacturing cost of molybdenum crucible is relatively high, its long service life and reliability in high temperature environment make it highly cost-effective. Compared with other crucible materials (such as tantalum crucible), molybdenum crucible has a longer service life in rare earth smelting and other fields, reducing the replacement frequency and maintenance cost in the production process.

Driving force of scientific research: In the field of scientific research, molybdenum crucibles are widely used in material science, physics and chemistry experiments. For example, in the development of high-temperature superconducting materials, nanomaterials and new alloys, molybdenum crucibles provide a stable experimental platform and promote the development of cutting-edge technologies.

1.2 Historical Development and Technological Evolution

Molybdenum was discovered and applied relatively late, but its development in crucible manufacturing has profoundly influenced modern industry and scientific research. The following discusses its historical development in detail from the discovery of molybdenum, the early application of molybdenum crucibles to the evolution of modern technology.

Discovery and early applications of molybdenum

Molybdenum was first discovered by Swedish chemist Carl Wilhelm Scheele in 1778, who separated molybdenum acid from molybdenite and confirmed it as a new element. In 1792, another Swedish chemist successfully extracted metallic molybdenum by reducing molybdenum acid. Due to its high melting point and difficulty in processing, the early application of molybdenum was mainly limited to the production of chemical reagents and pigments.

At the end of the 19th century, with the advancement of metallurgical technology, molybdenum began to be used as an alloying element in the steel industry. For example, the alloy of molybdenum and steel significantly improved the high-temperature strength and corrosion resistance of steel, and was widely used in weapons manufacturing and machinery industry. However, the development of molybdenum crucibles was still limited by material purity and processing technology. It was not until the beginning of the 20th century that the rise of powder metallurgy technology laid the foundation for the manufacture of molybdenum crucibles.

Molybdenum Crucibles

In the early 20th century, molybdenum crucibles began to appear in laboratories and small industrial

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applications. Early molybdenum crucibles were mainly prepared by powder metallurgy, that is, molybdenum powder was pressed into shape and then sintered at high temperature. Although this method can produce high-purity molybdenum crucibles, the density and mechanical strength of the crucibles are low, which limits their application in high temperature and high-pressure environments.

During World War II, the demand for molybdenum crucibles surged due to the rapid development of the military and aviation industries. For example, molybdenum crucibles were used in the smelting of high-temperature alloys and special materials, providing support for the manufacture of aircraft engines and armor materials. During this period, the processing technology of molybdenum crucibles was significantly improved, and machining and forging processes began to be applied to crucible manufacturing, improving the density and durability of the product.

Modern technology evolution

In the second half of the 20th century, with the rise of rare earth metals, semiconductors and sapphire crystal industries, the application areas of molybdenum crucibles expanded rapidly, and manufacturing technology also made revolutionary progress. The following are several key aspects of the evolution of molybdenum crucible technology:

High-purity molybdenum material: Modern molybdenum crucibles usually use molybdenum metal with a purity of more than 99.95%, and impurities are removed through advanced purification technologies such as electron beam melting and zone melting. This significantly improves the chemical stability and high-temperature performance of the crucible, meeting the needs of high-purity material preparation.

Diversified processing technology: According to application requirements, the manufacturing process of molybdenum crucible has developed into various types, including:

Machined crucible: processed from molybdenum rods or molybdenum plates through turning, milling and other processes, suitable for crucibles with high precision and complex shapes.

Welding crucible: It is made by cutting and curling molybdenum plates and then vacuum welding. It has low cost but the weld quality needs to be strictly controlled.

Riveted crucible: Made by mechanically connecting molybdenum plates, suitable for the manufacture of large crucibles.

Stamped crucible: It is formed by stamping molybdenum plate through a mold, suitable for mass production of small crucibles.

Doping and alloying: In order to improve the high temperature strength and corrosion resistance of molybdenum crucibles, modern manufacturing processes often add trace elements (such as cerium

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oxide, titanium hydride or rare earth elements) to molybdenum. For example, adding cerium oxide can significantly extend the service life of molybdenum crucibles in rare earth smelting.

Advanced sintering technology: The sintering process of modern molybdenum crucibles is usually carried out in a vacuum or hydrogen protective atmosphere to prevent oxidation and increase the density of the crucible. The application of isostatic pressing technology further improves the uniformity and mechanical properties of the crucible.

Customized design: With the diversification of industrial and scientific research needs, the size, shape and performance of molybdenum crucibles can be customized according to customer needs. For example, sapphire crystal growth requires large, thick-walled molybdenum crucibles, while the semiconductor industry requires small, high-precision crucibles.

Environmental protection and sustainability: In recent years, the manufacturing process of molybdenum crucibles has begun to focus on environmental protection and resource recycling. For example, waste molybdenum crucibles can be recycled through chemical treatment and re-smelting to recover molybdenum metal, reducing production costs and environmental impact.

CTIA GROUP LTD plays an important role in the R&D and production of molybdenum crucibles. Its website provides a wealth of technical information and market trends on molybdenum crucibles. For example, the high-purity molybdenum crucibles developed by the company are widely used in rare earth smelting and sapphire crystal growth. Its products are known for their high density ($\geq$ 9.8g /cm^3) and long life.

1.3 The role of molybdenum crucible in modern industry and scientific research

In modern industry and scientific research, molybdenum crucible plays a vital role with its excellent performance and wide range of application scenarios. The following discusses its role in detail from three aspects: industrial application, scientific research contribution and future trends.

Industrial Applications

Rare earth metal smelting: Molybdenum crucible is the main container for smelting rare earth metals and their oxides. Rare earth metals (such as neodymium, dysprosium, and terbium) are highly corrosive at high temperatures, and molybdenum crucibles can effectively resist the erosion of these corrosive substances, ensuring the purity and efficiency of the smelting process. For example, in the production of NdFeB magnets, molybdenum crucibles are used to melt high-purity neodymium metal.

Sapphire crystal growth: Sapphire crystals are widely used in LED substrates, optical windows and watch mirrors. Their growth needs to be carried out at high temperatures (about 2050°C). Molybdenum crucibles are ideal containers for crystal growth using the Czochralski method and the Heat Exchanger Method due to their high temperature stability and low impurity release characteristics.

Semiconductor industry: In the preparation of semiconductor materials (such as silicon and gallium arsenide), molybdenum crucibles are used in high-temperature evaporation and deposition processes. Its high purity and corrosion resistance ensure the quality of semiconductor materials and meet the stringent requirements of chip manufacturing for material purity.

High temperature alloys and special materials: Molybdenum crucibles are used for sintering and melting high temperature alloys (such as nickel-based alloys, titanium alloys) and special ceramics. These materials are widely used in aerospace, energy and medical fields. For example, in the manufacture of aircraft engine turbine blades, molybdenum crucibles are used to melt high temperature alloy raw materials.

Photovoltaic and new energy: Molybdenum crucibles are used in the photovoltaic industry to produce polysilicon and monocrystalline silicon. Their high temperature performance supports the smelting and purification of silicon ingots. In addition, molybdenum crucibles are also used in the research and development of solid-state batteries and fuel cell materials.

Scientific research contribution

Materials Science: Molybdenum crucibles provide a reliable experimental platform for the synthesis of new materials. For example, in the preparation of high-temperature superconducting materials (such as yttrium barium copper oxide), molybdenum crucibles can provide a stable high-temperature environment to support complex chemical reactions.

Physics and chemistry experiments: In high temperature and high-pressure experiments, molybdenum crucibles are used to study phase transitions, thermodynamic properties and chemical reaction kinetics of materials. For example, molybdenum crucibles are used to study the sintering behavior of metal-ceramic composites.

Nanotechnology: Molybdenum crucibles play a role in the preparation of nanomaterials (such as carbon nanotubes and graphene). Their high temperature stability and chemical inertness support processes such as vapor deposition and pyrolysis.

Energy research: In the field of nuclear energy and renewable energy, molybdenum crucibles are used to study the performance of high-temperature fuel cell and nuclear reactor materials. For example, molybdenum crucibles are used to test the compatibility of materials in high-temperature molten salt reactors.

Future Trends

Intelligent manufacturing: With the advancement of Industry 4.0, the manufacturing of molybdenum crucibles will become more intelligent. For example, sensors and data analysis can be used to optimize the sintering process and improve the density and consistency of the crucible.

Green production: The tightening of environmental regulations has promoted the greening of

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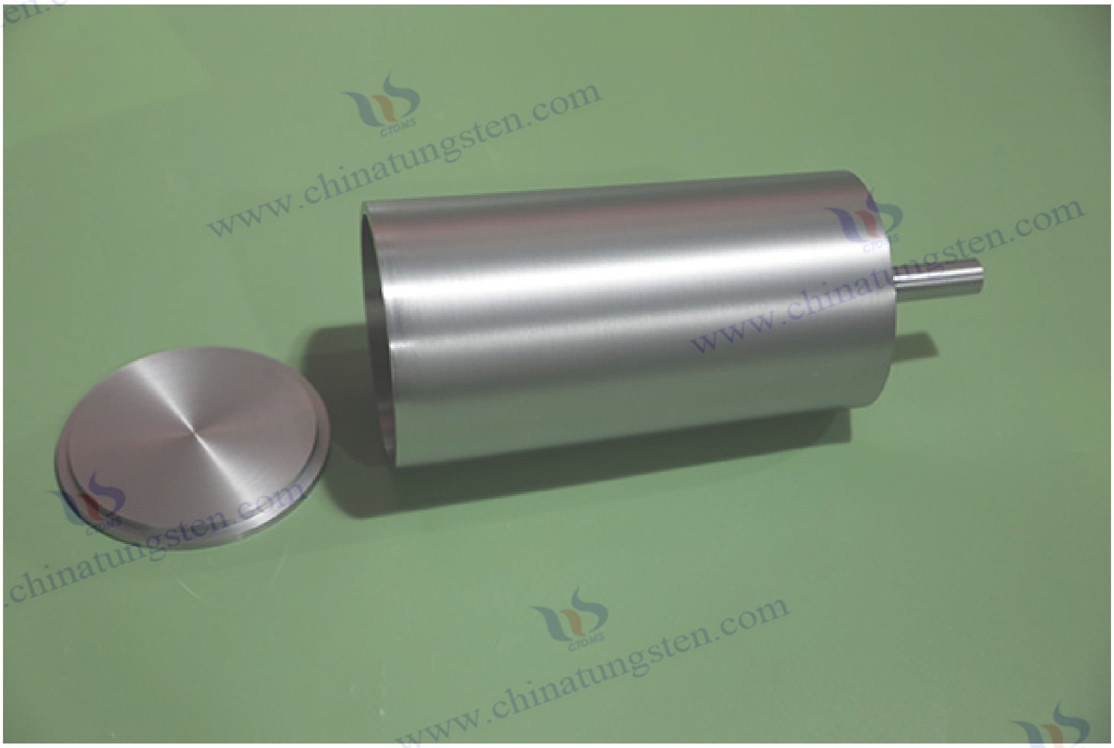
molybdenum crucible manufacturing. In the future, molybdenum crucible production will pay more attention to energy efficiency and waste recycling to reduce environmental footprint.

New material development: Molybdenum crucibles will play a greater role in the preparation of emerging fields such as graphene, two-dimensional materials and quantum materials. For example, molybdenum crucibles may be used for high-temperature synthesis of two-dimensional transition metal sulfides (such as MoS_2).

Cross-industry applications: With the development of biomedicine and space exploration, molybdenum crucibles may be used for high-temperature synthesis of biomaterials or preparation of materials in space environments.



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Chapter 2 Basic Principles of Molybdenum Crucible

2.1 Physical and chemical properties of molybdenum metal

Molybdenum is a transition metal with the element symbol Mo and atomic number 42, belonging to the sixth group of the periodic table. It is known for its high melting point, corrosion resistance and excellent mechanical properties, and is the main material for making molybdenum crucibles. The following discusses in detail the properties of molybdenum metal and its influence on the performance of molybdenum crucibles from two aspects: physical and chemical properties.

Physical properties

Melting Point and Boiling Point:

molybdenum is 2623℃ (about 2896K), second only to a few metals such as tungsten and rhenium. This enables the molybdenum crucible to maintain structural stability in extremely high temperature environments (such as rare earth metal smelting and sapphire crystal growth).

The boiling point is about 4639℃, which indicates that molybdenum has low volatility at high temperatures and is suitable for long-term high-temperature operations.

Density:

Molybdenum is 10.28 g/cm³, which is lower than tungsten (19.25 g/cm³) but higher than many other metals (such as aluminum at 2.7 g/cm³). This gives the molybdenum crucible high strength and relatively light weight, making it easy to process and transport.

Thermal conductivity and thermal expansion coefficient:

Molybdenum has a thermal conductivity of 138 W/(m·K) at room temperature, indicating that it has good thermal conductivity and can quickly transfer heat to ensure uniform temperature distribution inside the crucible. This is crucial for processes such as sapphire crystal growth that require precise temperature control.

The low coefficient of thermal expansion is 4.8×10^{-6} / K (20-1000℃), which means that the size of the molybdenum crucible changes little at high temperatures, reducing the risk of cracking caused by thermal stress.

Conductivity:

Molybdenum has an electrical conductivity of 1.9×10^{7} S/m, which shows good electrical conductivity. This makes molybdenum crucibles advantageous in certain electric heating or plasma environments, such as in vacuum evaporation coating processes.

Mechanical properties:

Molybdenum has high hardness (Mohs hardness about 5.5) and tensile strength (about 600-700 MPa) at room temperature. Although the strength of molybdenum decreases at high temperatures, its high-

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temperature strength can be significantly improved by doping (such as adding cerium oxide or rare earth elements).

Molybdenum has good ductility and can be processed into thin plates or complex shapes by forging, rolling or stretching. It is suitable for manufacturing crucibles of various specifications.

Chemical properties

Corrosion resistance:
Molybdenum has good corrosion resistance to most acids (such as hydrochloric acid, sulfuric acid) and alkalis at room and moderate temperatures, but may react with strong oxidizing acids (such as nitric acid) or molten alkalis at high temperatures.

In high-temperature non-oxidizing atmospheres (such as vacuum or inert gas), molybdenum exhibits excellent chemical stability to molten metals (such as rare earth metals, aluminum, magnesium) and oxides, and is suitable for high-purity material smelting.

Molybdenum reacts easily with oxygen and forms molybdenum trioxide when heated to above 600°C in air. Therefore, molybdenum crucibles are usually used in vacuum or inert atmosphere (such as argon or nitrogen).

Oxidation Behavior:
At low temperatures (<400°C), a dense oxide protective layer will form on the surface of molybdenum to slow down further oxidation. However, at high temperatures, the oxide volatilizes and causes rapid oxidation of molybdenum, requiring a protective atmosphere or surface coating (such as a silicide coating) to extend the life of the crucible.

Reactivity with other elements:
Molybdenum reacts slowly with non-metals such as carbon, nitrogen, and sulfur at high temperatures, but may form molybdenum carbide (Mo_2C) or molybdenum nitride (MoN) at extremely high temperatures (>1500°C), affecting the performance of the crucible. Therefore, caution should be exercised when using it in carbon-based materials or nitrogen-containing atmospheres.

Molybdenum has good corrosion resistance to certain molten metals (such as lithium and sodium), but slight corrosion may occur when in contact with molten nickel or iron alloys.

The performance of molybdenum crucible
Molybdenum directly determines the performance of molybdenum crucibles in high temperature environments. For example, the high melting point and low thermal expansion coefficient ensure the structural stability of the crucible in environments above 1700°C; good thermal conductivity ensures uniform temperature inside the crucible and reduces defects in crystal growth; corrosion

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resistance reduces the reaction between the crucible and the molten material, ensuring the purity of the product.

2.2 Working mechanism in high temperature environment

Molybdenum crucible in high temperature environment involves complex interactions of heat conduction, heat radiation, chemical reaction and mechanical response. The following is a detailed analysis of its working principle from three aspects: thermal, chemical and mechanical.

Thermal mechanism

Heat conduction:
The high thermal conductivity of the molybdenum crucible enables it to quickly transfer energy from an external heat source (such as resistance heating or induction heating) to the inside of the crucible, ensuring that the molten material or reactants are heated evenly. For example, in sapphire crystal growth, the molybdenum crucible promotes the stable crystallization of alumina melt by uniform heating.

Under non-uniform heating conditions, the low thermal expansion coefficient of the molybdenum crucible reduces thermal stress and avoids cracking or deformation of the crucible.

Heat radiation:
At high temperatures (>1000°C), the surface of the molybdenum crucible emits energy to the surrounding environment through thermal radiation. The emissivity of molybdenum is about 0.1-0.3 (varies with temperature and surface state). A lower emissivity helps reduce heat loss and improve energy efficiency.

To further improve thermal efficiency, modern molybdenum crucibles often have a polished surface or add a reflective coating (such as zirconium oxide coating) to reduce radiation losses.

Temperature gradient management:
During crystal growth or smelting, the molybdenum crucible needs to maintain a specific temperature gradient. For example, Czochralski crystal growth requires that the temperature at the bottom of the crucible is slightly lower than that at the top to promote directional crystal growth. The thermal conductivity and geometric design of the molybdenum crucible (such as wall thickness and shape) can be optimized through simulation to ensure an ideal temperature distribution.

Chemical mechanism

Chemical stability:
In vacuum or inert atmosphere, molybdenum crucibles do not react significantly with most molten metals and oxides. For example, in rare earth metal smelting, molybdenum crucibles can withstand high temperature corrosion of neodymium or cerium and maintain material purity.

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In an oxygen-containing atmosphere, molybdenum crucibles need to be protected from oxidation by a protective atmosphere or surface coating. For example, molybdenum silicide ($MoSi_2$) coating can form a stable SiO_2 protective layer at high temperatures, significantly extending the life of the crucible.

Impurity Control:
High purity molybdenum crucibles (impurity content <0.05%) minimize reactions with molten materials and avoid contamination. For example, in semiconductor silicon ingot production , the low impurity release of molybdenum crucibles ensures high purity of silicon (>99.9999%).

Mechanics

High temperature strength:
molybdenum at high temperature decreases with increasing temperature, but after doping with rare earth oxides (such as La_2O_3 or CeO_2) , its high temperature strength can be significantly improved. For example, a cerium-doped molybdenum crucible can still maintain a tensile strength of about 200 MPa at 1700°C, which is suitable for long-term high-temperature operation.

Molybdenum crucibles (i.e. slow deformation at high temperatures) are also optimized through grain refinement and doping, extending the service life of the crucible.

Thermal fatigue resistance:
Molybdenum crucibles may develop microcracks due to thermal stress during repeated heating and cooling cycles. Modern manufacturing processes improve the thermal fatigue resistance of crucibles by controlling grain size and adding strengthening phases such as oxide particles.

Impact resistance:
Molybdenum crucibles still maintain a certain toughness at high temperatures and can resist mechanical shock during loading or unloading. For example, in a large rare earth smelting furnace, the molybdenum crucible needs to withstand the impact of molten metal without breaking.

2.3 Comparison with other high temperature resistant materials

molybdenum crucibles with other high temperature resistant materials such as tungsten, tantalum, graphite, alumina and zirconia help to understand their unique advantages and limitations. The following is a detailed comparison from four aspects: physical properties, chemical stability, cost and application scenarios.

1. Tungsten

Physical properties:
The melting point of tungsten (3422℃) is higher than that of molybdenum, and it is suitable for higher temperature environments (>2000℃). However, the density of tungsten (19.25 g/cm³) is

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almost twice that of molybdenum, which makes the tungsten crucible heavy and difficult to process.

The thermal conductivity of tungsten (173 W/(m·K)) is slightly higher than that of molybdenum, but its thermal expansion coefficient (4.5×10^{-6} /K) is similar to that of molybdenum, and its thermal stress performance is similar.

Chemical stability:
Tungsten is more resistant to corrosion by molten metals than molybdenum, especially when in contact with molten iron or nickel. However, tungsten oxidizes faster in an oxygen-containing atmosphere and requires a stricter protective atmosphere.

Cost:
Tungsten is usually more expensive than molybdenum, and the processing cost is higher due to its high hardness and brittleness. Molybdenum crucibles are more economical in applications below 1700°C.

Application scenarios:
Tungsten crucibles are mostly used in ultra-high temperature environments (such as >2000°C processes that molybdenum cannot withstand), while molybdenum crucibles are more common in rare earth smelting and sapphire crystal growth.

2. Tantalum

Physical properties:
The melting point of tantalum (3017°C) is between molybdenum and tungsten, and its density (16.6 g/cm^3) is higher than molybdenum but lower than tungsten. The thermal conductivity of tantalum (57 W/(m·K)) is much lower than that of molybdenum, resulting in uneven heat distribution.

Chemical stability:
Tantalum has excellent corrosion resistance to acids and molten metals, especially better than molybdenum in strong acidic environments. However, tantalum is easily oxidized in high-temperature oxygen-containing atmospheres and requires a strict vacuum environment.

Cost:
The price of tantalum is much higher than that of molybdenum and tungsten, and its resource is scarce, which leads to extremely high manufacturing costs of tantalum crucibles. It is usually only used in special chemical processes.

Application scenarios:
Tantalum crucibles are mostly used in highly corrosive chemical reactions (such as fluoride smelting), while molybdenum crucibles dominate in more extensive high-temperature smelting and crystal growth.

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CTIA GROUP LTD

Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

Molybdenum crucibles are made of high-purity molybdenum powder through isostatic pressing, high-temperature sintering and precision machining. They have excellent high-temperature strength, corrosion resistance and dimensional stability, making them widely used in sapphire crystal growth, rare earth smelting, glass industry, vacuum coating and high-temperature heat treatment.

2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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

Website: www.molybdenum.com.cn

3. Graphite

Physical properties:
Graphite has an extremely high melting point (>3500°C), but its density (1.8-2.2 g/cm³) is much lower than that of molybdenum, making it lightweight and easy to process. The thermal conductivity of graphite (100-200 W/(m·K)) is comparable to that of molybdenum, but its thermal expansion coefficient is higher, which makes it prone to thermal stress.

Chemical stability:
Graphite has good chemical stability in non-oxidizing atmospheres, but is easily oxidized in oxygen-containing environments, which limits its use in air. Graphite may also react with certain molten metals and contaminate the product.

Cost:
The manufacturing cost of graphite crucible is much lower than that of molybdenum, which is suitable for large-scale and low-cost production. However, its life is short and needs to be replaced frequently.

Application scenarios:
Graphite crucibles are widely used in non-ferrous metal smelting (such as aluminum and copper), while molybdenum crucibles are more suitable for high-purity and high-temperature processes (such as semiconductor silicon production).

4. Alumina (Al_2O_3) and zirconium oxide (ZrO_2)

Physical properties:
The melting point of aluminum oxide is about 2072°C, and that of zirconium oxide is about 2715°C, both lower than that of molybdenum. The thermal conductivity of both (20-30 W/(m·K)) is much lower than that of molybdenum, resulting in uneven heat distribution.

The density of ceramic materials (about 3.9 g/cm³ for alumina and about 5.8 g/cm³ for zirconia) is lower than that of molybdenum, but they are highly brittle and susceptible to cracking due to thermal shock.

Chemical stability:
Alumina and zirconia perform well in oxidizing atmospheres, but can react when in contact with certain molten metals, such as rare earth metals, contaminating the product.

Cost:
Ceramic crucibles cost less than molybdenum, but have a shorter lifespan at high temperatures and pressures and higher maintenance costs.

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Application scenarios:
Ceramic crucibles are mostly used for small-scale laboratory experiments or sintering of non-metallic materials, while molybdenum crucibles are more suitable for high-temperature smelting on an industrial scale.

Summarize
Molybdenum crucibles have the best performance-cost balance in the temperature range below 1700°C, combining high melting point, corrosion resistance and processing flexibility. Compared with tungsten and tantalum, molybdenum crucibles are more economical and easier to process; compared with graphite and ceramics, molybdenum crucibles are superior in high purity and high temperature stability. According to Chinatungsten Online (news.chinatungsten.com), the market share of molybdenum crucibles in the rare earth and semiconductor industries continues to grow, reflecting its wide applicability.

2.4 Thermodynamic and mechanical properties

Molybdenum crucibles in high temperature environments determine their working efficiency and service life. The following is a detailed analysis from the two aspects of thermodynamics and mechanics.

Thermodynamic properties

Heat Capacity and Specific Heat:
molybdenum is about 0.25 J/(g·K) (room temperature), which increases slightly with increasing temperature. The lower specific heat capacity means that the molybdenum crucible requires less energy during heating and is suitable for rapid heating processes.

The heat capacity is directly related to the mass and size of the crucible. Large molybdenum crucibles require longer heating times, but their high thermal conductivity can effectively shorten this process.

Thermal Expansion and Thermal Stress:
molybdenum (4.8×10^{-6} /K) reduces volume changes at high temperatures and reduces the risk of cracking caused by thermal stress. For example, in sapphire crystal growth, molybdenum crucibles can remain shape-stable at 2050°C.

Thermal stresses can be further reduced by optimizing crucible wall thickness and geometry (e.g. rounded corners).

Phase stability:
Molybdenum has no phase change in the solid-state range (<2623°C) and has high thermodynamic stability, avoiding volume change or performance degradation caused by phase change.

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At temperatures close to the melting point, molybdenum has a low vapor pressure (about 10^{-5} Pa at 2000 °C), which reduces material loss.

Heat radiation and energy loss:
molybdenum crucible reduces thermal radiation loss and improves energy utilization. Modern molybdenum crucibles are often further optimized for thermal radiation performance by surface polishing or coating.

Mechanical properties

High temperature strength and creep:
molybdenum at 1700°C is about 100-200 MPa, which is much higher than many metals. By doping with oxides (such as CeO_2 or La_2O_3), the high temperature strength can be increased to more than 300 MPa.

Molybdenum accelerates with increasing stress at high temperature, but creep can be significantly reduced by grain refinement and doping. For example, the creep rate of cerium-doped molybdenum crucible at 1700°C can be controlled below 10^{-5} / s.

Fatigue and thermal shock:
Molybdenum crucibles may develop microcracks due to fatigue during repeated thermal cycles. Modern manufacturing processes improve fatigue resistance by controlling the grain size (usually <50 μm) and adding strengthening phases.

Molybdenum 's toughness allows it to withstand certain thermal shocks, such as rapid cooling, while still maintaining its integrity.

Hardness and wear resistance:
The Vickers hardness of molybdenum at room temperature is about 200-250 HV, which decreases slightly at high temperatures. The hardness of the molybdenum -doped crucible can be increased to 300 HV, which enhances its wear resistance and is suitable for long-term use.

Processing performance:
molybdenum allows it to be made into crucibles of complex shapes by forging, rolling or machining. However, molybdenum is brittle at room temperature and needs to be hot-worked at high temperatures (>1000°C) to avoid cracking.

Performance in practical applications
In rare earth smelting, the thermodynamic and mechanical properties of molybdenum crucibles ensure their long-term stability at 1700°C. For example, molybdenum crucibles can withstand the corrosion and mechanical impact of molten neodymium while maintaining uniform temperature distribution. In sapphire crystal growth, the low thermal expansion and high temperature strength

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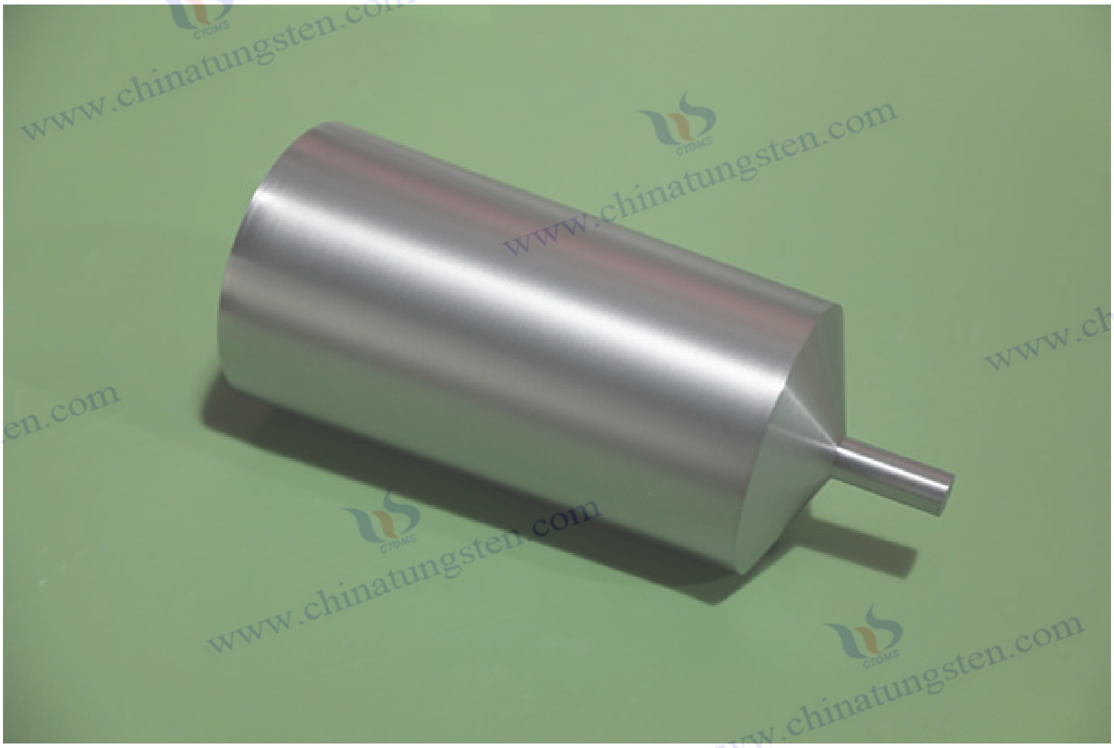
of molybdenum crucibles support continuous operation for weeks.



CTIA GROUP LTD Molybdenum Crucible

Chapter 3 Molybdenum Crucible Performance

3.1 Physical and chemical properties of molybdenum crucible

Molybdenum crucible mainly comes from the physical and chemical properties of its basic material, molybdenum. These properties determine the performance of molybdenum crucible in high temperature and high corrosion environment. The following is a detailed discussion from four aspects: melting point and thermal stability, density and thermal conductivity, oxidation resistance and corrosion resistance, mechanical strength and toughness.

3.1.1 Melting point and thermal stability of molybdenum crucible

Molybdenum is 2623°C, which is one of the materials with higher melting points among known metals, second only to tungsten and rhenium. This high melting point gives molybdenum crucibles excellent stability in extremely high temperature environments, making them widely used in rare earth metal smelting, sapphire crystal growth and semiconductor material preparation processes.

Thermal stability performance:

Molybdenum crucibles can operate stably for a long time at temperatures below 1700°C, and can even withstand temperatures above 2000°C for a short time. For example, during the growth of sapphire crystals, molybdenum crucibles need to operate continuously at 2050°C for several weeks while maintaining structural integrity and chemical stability.

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low vapor pressure of molybdenum (about 10^{-5} Pa at 2000 °C) ensures minimal material loss at high temperatures, extending the crucible life.
molybdenum crucible is also reflected in its phase-change-free characteristics. Molybdenum does not undergo crystal structure changes in the solid-state range (<2623°C), avoiding volume expansion or performance degradation caused by phase change.

Influencing factors:
Impurity content: High purity molybdenum (≥99.95%) crucibles have better thermal stability than low purity products, because impurities (such as carbon, oxygen) may cause local melting or grain boundary weakening at high temperatures.

Molybdenum crucibles prepared by powder metallurgy may have micropores, which reduce thermal stability; forged or machined crucibles have higher density and better thermal stability.

Protective atmosphere: Molybdenum is easily oxidized in an oxygen-containing environment and needs to be used in a vacuum or inert atmosphere (such as argon, nitrogen) to maintain thermal stability.

3.1.2 Density and thermal conductivity of molybdenum crucible
Density:
Molybdenum is 10.28 g/cm³, which is lower than tungsten (19.25 g/cm³) but higher than aluminum (2.7 g/cm³). This density gives the molybdenum crucible high strength and relatively light weight, making it easy to process, transport and install.
High-density molybdenum crucibles (close to 99.5% of theoretical density) are produced by isostatic pressing and high-temperature sintering, ensuring the mechanical strength and corrosion resistance of the crucible. In contrast, low-density crucibles (<95% theoretical density) may lack strength due to pores.

Thermal Conductivity:
The thermal conductivity of molybdenum is 138 W/(m·K) at room temperature, which decreases slightly with increasing temperature (about 100 W/(m·K) at 1000°C). The high thermal conductivity enables the molybdenum crucible to transfer heat quickly, ensuring uniform temperature distribution inside.

In sapphire crystal growth, uniform temperature distribution is critical to crystal quality. The high thermal conductivity of molybdenum crucibles reduces crystal defects caused by temperature gradients.

In contrast, the thermal conductivity of ceramic crucibles (such as alumina, with a thermal conductivity of about 20-30 W/(m·K)) is much lower than that of molybdenum, resulting in uneven heat distribution, which limits its application in high-precision processes.

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Practical Application:
In rare earth smelting, the high thermal conductivity of the molybdenum crucible supports rapid heating and uniform melting, improving production efficiency.

3.1.3 Molybdenum crucible anti-oxidation and anti-corrosion performance

Antioxidant Properties:
Molybdenum forms a dense oxide layer on the surface at low temperatures (<400°C), which slows down further oxidation. However, at high temperatures (>600°C), the oxide volatilizes, leading to rapid oxidation.

To improve oxidation resistance, molybdenum crucibles are usually used in vacuum or inert atmosphere. For example, in semiconductor silicon ingot production, molybdenum crucibles are operated in a high vacuum ($<10^{-4}$ Pa) environment to avoid oxidation.

Surface coating technology (such as molybdenum silicide $MoSi_2$ or zirconium oxide ZrO_2 coating) can significantly improve oxidation resistance. Molybdenum silicide coating forms a stable SiO_2 protective layer at high temperatures, extending the life of the crucible.

Corrosion resistance:

Molybdenum crucibles have excellent corrosion resistance to a variety of molten metals (such as rare earth metals, aluminum, magnesium) and oxides. For example, in the production of NdFeB magnets, molybdenum crucibles can withstand the corrosion of molten neodymium and maintain product purity.

Molybdenum has good corrosion resistance to acids (such as hydrochloric acid and sulfuric acid) and alkalis, but may react in strong oxidizing acids (such as nitric acid) or molten alkalis.

When in contact with certain high-temperature materials (such as nickel and iron alloys), molybdenum may be slightly corroded, which needs to be controlled by surface modification or selection of appropriate operating conditions.

Improvement measures:
Doping with rare earth oxides (such as CeO_2, La_2O_3) can enhance the corrosion resistance of molybdenum crucibles, especially when in contact with molten rare earth metals.

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Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

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2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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3.1.4 Mechanical strength and toughness of molybdenum crucible

Mechanical strength:

Molybdenum at room temperature is about 600-700 MPa, which drops to 100-200 MPa at high temperature (1700°C). By doping (such as CeO_2), the high temperature strength can be increased to 300 MPa.

molybdenum crucible is about 200-250 HV, which can reach 300 HV after doping, which enhances the wear resistance and impact resistance.

Forged molybdenum crucibles are higher than that of powder metallurgy crucibles because the forging process eliminates pores and refines the grains.

Toughness:

Molybdenum is brittle (limited ductility) at room temperature, but exhibits good toughness at high temperatures (>1000°C), making it suitable for hot working and high-temperature operations.

The molybdenum crucible enables it to withstand mechanical shock during loading or unloading. For example, in rare earth smelting, the molybdenum crucible needs to withstand the impact of molten metal without breaking.

Oxide doping or grain size control (<50 μm) can further improve toughness and reduce crack growth during thermal cycling.

Practical Application:

In large rare earth smelting furnaces, the mechanical strength and toughness of molybdenum crucibles ensure their reliability under high temperature and high pressure.

3.2 Thermal and mechanical properties of molybdenum crucible

molybdenum crucibles determine their performance in high temperature environments, especially in terms of thermal expansion, thermal shock resistance, creep and fatigue performance. The following is a detailed analysis.

3.2.1 Thermal expansion and high temperature deformation of molybdenum crucible

Thermal Expansion:

molybdenum is 4.8×10^{-6} /K (20-1000°C), which is much lower than many metals (such as aluminum: 23×10^{-6} /K) and ceramics (such as alumina: 8×10^{-6} /K). The low thermal expansion coefficient reduces volume changes at high temperatures and reduces the risk of cracking caused by thermal stress.

In sapphire crystal growth, the low thermal expansion of the molybdenum crucible ensures that the crucible shape remains stable at 2050°C, avoiding defects in crystal growth.

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High temperature deformation:
At high temperatures, molybdenum crucibles may deform slightly due to thermal stress or external forces. The degree of deformation is related to the crucible wall thickness, geometry and heating rate.

Optimizing the design (such as increasing the wall thickness or using rounded corners) can reduce deformation. For example, the wall thickness of large molybdenum crucibles is usually 10-20 mm to improve the ability to resist deformation.

Doping with rare earth oxides can enhance high temperature rigidity and reduce deformation. For example, the deformation of a cerium-doped molybdenum crucible at 1700°C is about 20% lower than that of a pure molybdenum crucible.

3.2.2 Thermal shock resistance of molybdenum crucible

Thermal shock resistance:
Molybdenum crucibles come from their high thermal conductivity, low thermal expansion coefficient and certain toughness. These characteristics enable them to withstand thermal stress caused by rapid heating or cooling.

In rare earth smelting, the molybdenum crucible needs to undergo a rapid temperature increase from room temperature to 1700°C. Its thermal shock resistance ensures that the crucible does not crack.

Influencing factors:
Grain size: Fine grains (<50 μm) can disperse thermal stress and improve thermal shock resistance.
Surface quality: Polished surfaces or coatings can reduce crack propagation caused by surface defects.
Operating conditions: Slow heating and cooling rates (e.g. <10°C/min) can further enhance thermal shock resistance.

Improvement measures:
Adding oxides (such as La_2O_3) can increase the toughness of molybdenum and enhance its thermal shock resistance.

3.2.3 Creep and long-term stability of molybdenum crucible

Creep properties:
Creep is the slow deformation of a molybdenum crucible under continuous stress at high temperature. The creep rate of molybdenum at 1700°C is about 10^{-5} /s (stress 100 MPa), which can be reduced to 10^{-6} /s by doping.

The creep rate is closely related to temperature, stress and grain size. High temperature and large grains accelerate creep; while doping and fine grains slow it down.

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Long-term stability:
molybdenum crucible depends on its creep resistance and oxidation resistance. In vacuum or inert atmosphere, cerium-doped molybdenum crucible can operate at 1700℃ for thousands of hours without significant deformation.

Improvement measures:
Controlled grain size (<30 μm) to improve creep resistance.
Add oxide or carbide strengthening phases (such as ZrO_2, TiC) to enhance high temperature rigidity.

3.2.4 Molybdenum crucible fatigue and cyclic use
Fatigue performance:
Molybdenum crucibles may produce micro cracks due to fatigue during repeated thermal cycles. Fatigue performance is related to grain size, surface defects and doping elements.

Fine-grained and oxide-doped molybdenum crucibles have higher fatigue resistance. For example, cerium-doped molybdenum crucibles can withstand more than 200 thermal cycles at 1500°C.

Recycling:
the molybdenum crucible depends on the operating conditions and maintenance measures. Under the conditions of proper protective atmosphere and slow temperature rise and fall, the molybdenum crucible can be reused hundreds of times.

Surface coatings (such as $MoSi_2$) can reduce fatigue crack growth and extend cycle life.

Practical Application:
In the semiconductor industry, molybdenum crucibles need to undergo multiple heating-cooling cycles, and their fatigue resistance directly affects production costs.

3.3 Relationship between Molybdenum Crucible Microstructure and Performance
molybdenum crucible is closely related to its microstructure, including grain structure, doping elements and surface morphology. The following is a detailed analysis.

3.3.1 Grain structure and orientation
Grain Structure:
molybdenum crucible is usually between 10-100 μm. Fine grains (<50 μm) improve strength, toughness and creep resistance by increasing grain boundary density.

Large grains (>100 μm) may lead to reduced high temperature strength and accelerated crack growth, so modern molybdenum crucibles tend to adopt a fine grain structure.

Grain Orientation:
Molybdenum crucible has a significant effect on the mechanical properties. Forging or rolling

processes can induce texture (such as <110> orientation), improving tensile strength and thermal shock resistance.

Randomly oriented grain structures, such as powder metallurgy crucibles, are more common in isotropic applications but are slightly weaker than textured crucibles.

Practical Application:
molybdenum crucible ensures consistent temperature distribution and reduces crystal defects during sapphire crystal growth.

3.3.2 Effect of doping elements

Doping elements:
Commonly used doping elements include cerium oxide (CeO_2), lanthanum oxide (La_2O_3), yttrium oxide (Y_2O_3) and titanium carbide (TiC). These elements improve the performance of molybdenum crucibles through solid solution strengthening or second phase strengthening.

Cerium oxide (0.5-2 wt %) can refine grains, improve high temperature strength and creep resistance, and enhance corrosion resistance.
Lanthanum oxide improves toughness and thermal shock resistance, making it particularly suitable for recycling scenarios.

Mechanism of action:
The doping elements form a pinning effect at the grain boundaries, inhibiting grain growth and creep.
Oxide particles can disperse thermal stress and reduce crack growth.
Doping can also improve the oxidation resistance of molybdenum. For example, cerium oxide can promote the formation of a stable protective layer.

3.3.3 Surface morphology and high temperature performance

Surface morphology:
molybdenum crucible has an important influence on its high temperature performance. Polished surface ($Ra < 0.8$ μm) can reduce the crack starting point and improve thermal shock resistance and corrosion resistance.

Rough surfaces ($Ra>2$ μm) may cause cracks due to stress concentration, reducing service life.

Surface modification:
Coatings (such as $MoSi_2$, ZrO_2) can improve surface oxidation resistance and corrosion resistance.
For example, $MoSi_2$ coating forms a SiO_2 protective layer at 1700°C , significantly extending the life of the crucible.

Plasma spraying or chemical vapor deposition (CVD) can produce uniform surface coatings to improve high temperature performance.

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Practical Application:
In the semiconductor industry, the low surface defects of polished molybdenum crucibles ensure the preparation of high-purity silicon.

3.4 Molybdenum crucible life and reliability

Molybdenum crucibles are key indicators for their industrial applications. The following is an analysis from three aspects: factors affecting life, failure modes and reliability testing methods.

3.4.1 Factors affecting lifespan

Operating conditions:
Temperature: Operating temperatures above 1700°C will accelerate creep and oxidation, shortening life.
Atmosphere: Oxygen-containing atmosphere leads to rapid oxidation and requires vacuum or inert gas protection.
Thermal Cycling: Frequent heating-cooling cycles increase the risk of fatigue cracks.

Material Quality:
high purity Mo (≥99.95%) and doped Mo crucibles is significantly longer than lower purity products. Fine grains and uniform microstructure lead to longer life.
Processing technology:
The density and mechanical properties of forged or machined crucibles are better than those of powder metallurgy crucibles, and their life is longer.
The weld quality of the welding crucible has an important influence on the service life and needs to be strictly controlled.

3.4.2 Failure Mode Analysis

Oxidation failure:
In an oxygen-containing atmosphere, MoO_3 forms on the surface of the molybdenum crucible and volatilizes, resulting in material loss and pore formation.
Solution: Use protective atmosphere or anti-oxidation coating.

Creep failure:
At high temperatures, continuous stress causes the crucible to slowly deform and eventually fail.
Solution: doping oxides or optimizing grain structure.

Thermal fatigue failure:
Repeated thermal cycles induced microcrack growth leading to crucible rupture.
Solution: Polish the surface, refine the grain and slowly increase and decrease the temperature.

Corrosion failure:
Reaction with the molten metal or oxides causes thinning or perforation of the crucible walls.
Solution: Choose corrosion-resistant doped materials or add protective coatings.

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3.4.3 Reliability test method

High temperature creep test:

Constant stress was applied at 1700°C, and the creep rate and deformation were measured to evaluate long-term stability.

Standard: ASTM E139 (Creep Test Specification).

Thermal Cycle Test:

Simulating actual operating conditions, multiple heating-cooling cycles were performed to observe crack formation and growth.

Standard: ISO 1893 (Thermal shock tests on refractory materials).

Antioxidant Test:

Heating to 600-1000°C in an oxygen-containing atmosphere, measuring oxidation weight gain or material loss.

Standard: ASTM G54 (high temperature oxidation test).

Corrosion testing:

The crucible is exposed to molten metal or oxide and wall thickness loss and surface changes are measured.

Standard: ASTM G31 (Corrosion Test Specification).

3.5 China Tungsten Intelligent Molybdenum Crucible MSDS

The Material Safety Data Sheet (MSDS) provides safety guidance for the use, storage and handling of molybdenum crucibles. The following is a summary of the MSDS for Chinatungsten Intelligent Molybdenum Crucibles, based on industry standards and Chinatungsten Online information.

1. Product Identification

Product Name: Molybdenum Crucible

Chemical name: Molybdenum (Mo)

CAS No.: 7439-98-7

2. Hazards Identification

Physical state: solid metal, silvery white, odorless.

Main dangers:

Molybdenum oxide (MoO_3) vapor may be released at high temperatures, which may cause respiratory irritation if inhaled.

Dust or cutting chips may cause skin or eye irritation.

Environmental impact: Molybdenum is a low-toxic metal, but waste must be handled in accordance with regulations.

3. Ingredient Information
Main ingredient: Molybdenum (≥99.95%)
Impurities: Carbon (<0.01%), Oxygen (<0.005%), Nitrogen (<0.003%)
Doping elements: lanthanum oxide (La_2O_3, 0.5-1%)

4. First aid measures
Inhalation: Move victim to fresh air and get medical attention if symptoms persist.
Skin Contact: Wash exposed area with soap and water, consult a physician if irritation occurs.
Eye contact: Rinse with plenty of water for at least 15 minutes and seek medical attention if necessary.
Ingestion: Uncommon, if occurs, seek medical attention immediately.

5. Firefighting measures
Fire extinguishing method: Use dry powder or carbon dioxide fire extinguisher, do not use water.
molybdenum oxide vapor may be released at high temperatures. Firefighters must wear respiratory protection equipment.

6. Leakage treatment
Cleaning method: Collect the leaked molybdenum dust or fragments and put them into a sealed container to avoid dust.
Protective measures: Wear dust mask, gloves and goggles.

7. Handling and storage
Operation Notes:
Use in a well-ventilated area to avoid creating dust.
High temperature operations must be carried out in a vacuum or inert atmosphere to prevent oxidation.

Storage conditions:
Store in a dry, cool place, avoid contact with strong oxidants.
Use moisture-proof packaging to prevent surface oxidation.

8. Exposure Controls and Personal Protection
Engineering Controls: Use local exhaust ventilation to control dust and vapor.
Personal protective equipment:
Respiratory protection: NIOSH certified dust mask.
Hand protection: high temperature resistant gloves.
Eye protection: Safety goggles.

Exposure Limits: OSHA PEL (Molybdenum): 5 mg/m³ (Respirable Dust).

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9. Physical and chemical properties
Melting point: 2623℃
Density: 10.28 g/cm³
Thermal conductivity: 138 W/(m·K)
Solubility: Insoluble in water, soluble in nitric acid and molten alkali.

10. Stability and Reactivity
Stability: Stable at room temperature, easily oxidized at high temperature.
Conditions to avoid: oxygen-containing atmospheres, strong oxidants, high temperature open flames.
Incompatible materials: strong acids, strong bases, oxidizing agents.

11. Toxicological Information
Acute toxicity: Low toxicity. Inhalation of high concentrations of molybdenum dust may cause mild respiratory irritation.
Chronic toxicity: Long-term exposure may cause lung irritation and regular health checks are required.
Carcinogenicity: Not classified as a carcinogen by IARC.

12. Ecological information
Environmental impact: Molybdenum is a low-toxic metal, but waste must be properly handled to avoid water pollution.
Bioaccumulation: No significant bioaccumulation.

13. Waste Disposal
Disposal method: Recycle according to local regulations or entrust a professional organization to handle it.
Note: Avoid direct dumping to prevent dust spread.

14. Shipping Information
Transport classification: non-dangerous goods.
Packaging requirements: Use moisture-proof and shock-proof packaging to ensure transportation safety.

15. Regulatory Information
International regulations: Compliant with OSHA, REACH and RoHS requirements.
Chinese regulations: Comply with the Regulations on the Safety Management of Hazardous Chemicals.

16. Other Information
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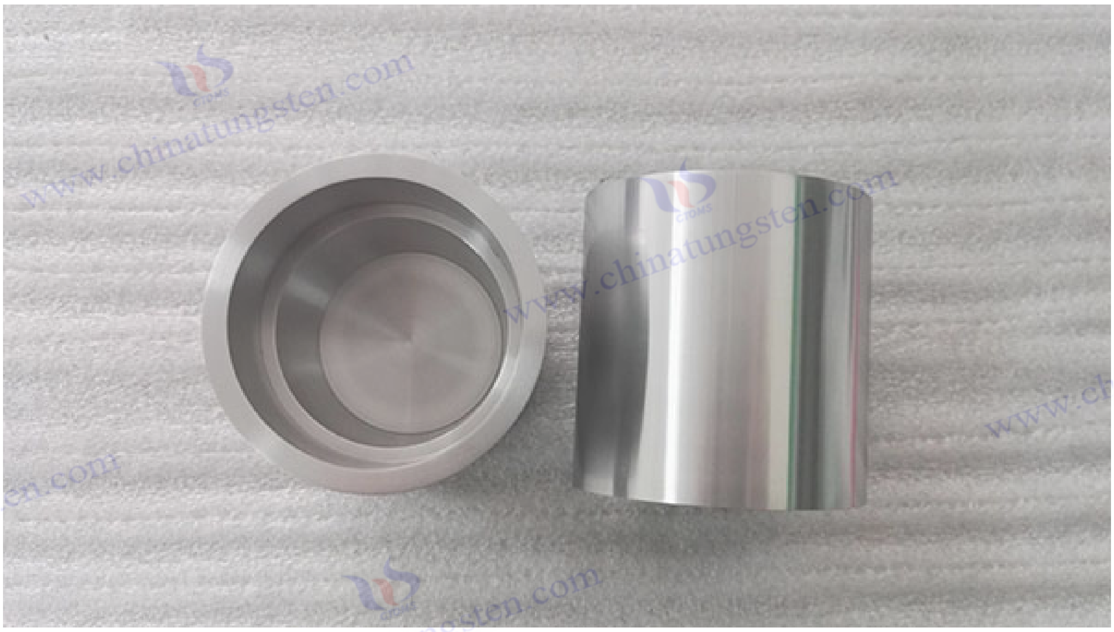

CTIA GROUP LTD Molybdenum Crucible

Chapter 4 Uses of Molybdenum Crucible

Molybdenum crucibles are widely used in many industries and scientific research fields due to their high melting point (2623℃), excellent corrosion resistance and high temperature stability. This chapter discusses in detail the specific uses of molybdenum crucibles in crystal growth, high temperature smelting and melting, vacuum and high temperature heat treatment, scientific research and laboratory applications, and emerging fields, covering process details, performance requirements and global industry practices.

4.1 Crystal Growth

Molybdenum crucibles play a key role in the field of crystal growth, especially in the preparation of sapphire, silicon single crystals and other crystalline materials. Its high purity (≥99.95%), low impurity release and high temperature stability ensure the high quality of the crystal.

4.1.1 Sapphire crystal (Czochralski method, heat exchange method)

Sapphire (Al_2O_3) single crystals are widely used in LED substrates, optical windows, watch mirrors and lasers due to their high hardness (Mohs hardness 9), excellent optical transparency and thermal stability. Molybdenum crucibles are indispensable containers in the growth of sapphire crystals, mainly used in the Czochralski method and the Heat Exchanger Method (HEM).

Chai's method:

Process Overview: The Czochralski method melts high-purity alumina in a molybdenum crucible (about 2050°C) and slowly pulls out a single crystal from the melt using a seed crystal. The molybdenum crucible needs to withstand high temperatures and maintain a uniform temperature distribution to ensure stable crystal growth.

Molybdenum crucible requirements:
High temperature stability: Molybdenum crucibles must maintain structural integrity at 2050°C to prevent deformation or cracks.
High purity: Impurities (such as carbon and iron) may contaminate the melt and affect the optical properties of the crystal. The purity of molybdenum crucibles is usually required to be ≥99.95%.
Thermal conductivity: Molybdenum 's high thermal conductivity (138 W/(m·K)) ensures uniform melt temperature and reduces crystal defects.
Size and design: The Czochralski process requires large molybdenum crucibles (200-500 mm diameter, 10-20 mm wall thickness), prepared by forging or welding.

Heat exchange method:
Process Overview: The heat exchange method melts alumina in a molybdenum crucible, uses bottom cooling and top heating to form a temperature gradient, and promotes the growth of crystals from the bottom to the top. This method is suitable for the production of large sapphire crystals (diameter>300 mm).

Molybdenum crucible requirements:
Thermal shock resistance: The heat exchange method involves complex temperature gradients, and the molybdenum crucible needs to withstand rapid thermal cycles without cracking.
Corrosion resistance: Molybdenum crucibles need to resist slight corrosion from molten alumina. Doping with cerium oxide (CeO_2) can enhance corrosion resistance.
molybdenum crucibles with thicker walls (15-30 mm) to withstand mechanical and thermal stresses.

4.1.2 Silicon single crystal (Czochralski method)
The core material of semiconductor and photovoltaic industry, and is widely used in chip manufacturing and solar cells. Czochralski method is the main method for producing silicon single crystal, and molybdenum crucible is used as auxiliary container or high temperature component in some special processes.

Process Overview:
The Czochralski method usually uses a quartz crucible to melt high-purity silicon (>99.9999%), but in some high-temperature auxiliary processes (such as silicon ingot purification or special doping), molybdenum crucibles are used to handle high-temperature silicon melts or related materials.

Molybdenum crucibles are also used for hot field components of Czochralski equipment (such as heat shields or heater supports) due to their high temperature stability and corrosion resistance.

Molybdenum crucible requirements:
High purity: The impurity release of the molybdenum crucible must be extremely low to avoid contamination of the silicon melt.

Corrosion resistance: Silicon melt (about 1414℃) has little corrosion on molybdenum crucible, but long-term use needs to prevent trace erosion.
Thermal stability: Molybdenum crucible needs to maintain performance at 1500-1600℃ to adapt to the thermal environment of the Czochralski method.

Practical Application:
In the semiconductor industry, molybdenum crucibles are used in the doping process of special silicon single crystals, such as the preparation of boron-doped or phosphorus-doped silicon crystals. The auxiliary application of its high-purity molybdenum crucible in the production of silicon single crystals improves the crystal purity and production efficiency.

Limitations: The direct use of molybdenum crucibles in the Czochralski method is limited by the cost advantage of quartz crucibles, but it is still irreplaceable in high purity or special processes.

4.1.3 Other crystal materials

Molybdenum crucibles are also used for the growth of other crystalline materials, including gallium arsenide (GaAs), indium phosphide (InP), lithium tantalate ($LiTaO_3$) and quartz crystals.

Gallium Arsenide and Indium Phosphide:
Uses: Gallium arsenide and indium phosphide are high-frequency semiconductor materials used in 5G communications and optoelectronic devices.
Process: In the horizontal Bridgman method or vertical gradient solidification method (VGF), molybdenum crucibles are used for melting and crystal growth, and need to be operated at 1200-1400℃.
Requirements: Molybdenum crucibles need to resist corrosion from arsenic or phosphorus vapors and are usually coated with a surface coating (such as $MoSi_2$) to enhance durability.

Lithium Tantalate and Quartz Crystal:
Application: Lithium tantalate is used in surface acoustic wave devices, and quartz crystals are used in oscillators and sensors.
Process: Molybdenum crucible is used as a container in the Czochralski process or melting process, and the operating temperature is usually 1200-1600℃.
Requirements: Molybdenum crucibles need to provide a stable thermal field and low-impurity environment to ensure the optical and electrical properties of the crystal.

4.2 High temperature smelting and melting

Molybdenum crucibles are used to process rare earth metals, non-ferrous metals, alloys and precious metals in high temperature smelting and melting. Their corrosion resistance and high temperature strength make them an ideal choice.

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Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

Molybdenum crucibles are made of high-purity molybdenum powder through isostatic pressing, high-temperature sintering and precision machining. They have excellent high-temperature strength, corrosion resistance and dimensional stability, making them widely used in sapphire crystal growth, rare earth smelting, glass industry, vacuum coating and high-temperature heat treatment.

2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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4.2.1 Rare earth metals

Rare earth metals (such as neodymium, cerium, and dysprosium) are in high demand due to their applications in magnets, alloys, and catalysts. Molybdenum crucibles are used for smelting and purification in rare earth metal smelting.

Process Overview:

Rare earth metals are extracted from oxides or halides by electrolysis or vacuum smelting, usually at operating temperatures of 1500-1700°C.

the molybdenum crucible needs to withstand the strong corrosiveness of molten rare earth metals and maintain high purity.

Molybdenum crucible requirements:

corrosive at high temperatures. Molybdenum crucibles need to be doped (such as CeO_2) or surface coated to enhance corrosion resistance.

High temperature strength: Molybdenum crucible needs to maintain mechanical strength at 1700°C to prevent deformation or cracking.

Low impurities: The purity of the molybdenum crucible (≥99.95%) ensures the high purity of rare earth metals (>99.9%).

Practical Application:

In the production of NdFeB magnets, molybdenum crucibles are used to melt high-purity neodymium to meet the high-performance requirements of the magnets.

4.2.2 Nonferrous metals and alloys

Molybdenum crucibles are widely used in the smelting of non-ferrous metals (such as aluminum, magnesium, titanium) and high-temperature alloys (such as nickel-based alloys and cobalt-based alloys).

Process Overview:

Non-ferrous metals and alloys are produced by vacuum induction melting or arc melting at temperatures ranging from 1200-1800°C.

Molybdenum crucibles are used to melt high- purity metals or alloys to ensure product quality and consistency.

Molybdenum crucible requirements:

Corrosion resistance: Molybdenum crucibles need to resist the corrosion of molten aluminum or magnesium, and doping with oxides can extend their service life.

Thermal stability: Molybdenum crucible needs to maintain its shape at high temperatures to avoid deformation due to thermal stress.

Size flexibility: From small laboratory crucibles (capacity <1 L) to industrial-grade crucibles (capacity >10 L), molybdenum crucibles can be customized according to needs.

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Practical Application:
In the aerospace industry, molybdenum crucibles are used to melt nickel-based high-temperature alloys to produce turbine blades and engine components.

4.2.3 Precious metal purification

Molybdenum crucibles are used for high-temperature smelting and refining in the purification and recovery of precious metals (such as gold, silver, platinum, and palladium).

Process Overview:
Precious metals are purified by vacuum melting or chemical refining at temperatures ranging from 1000-2000°C.
Molybdenum crucibles are used as melting containers to ensure high purity (>99.99%) and low impurities of precious metals.

Molybdenum crucible requirements:
Chemical inertness: Molybdenum crucibles must avoid reaction with molten precious metals to prevent contamination.
High purity: Low impurity release of molybdenum crucibles (such as carbon <0.01%) ensures the quality of precious metals.
Oxidation resistance: In an oxygen-containing atmosphere, molybdenum crucibles need to be protected from oxidation by a protective atmosphere or coating.

Practical Application:
In the jewelry and electronics industries, molybdenum crucibles are used to purify high-purity platinum to meet precision manufacturing needs.

4.3 Vacuum and high temperature heat treatment

Molybdenum crucibles are used for material sintering, annealing and performance optimization in vacuum and high temperature heat treatment processes, and are widely used in powder metallurgy, aerospace and electronics industries.

4.3.1 Vacuum heat treatment furnace

Vacuum heat treatment furnaces are used to improve the mechanical properties of metals and alloys, and molybdenum crucibles are used as containers or heat field components.

Process Overview:
Vacuum heat treatment is carried out in a vacuum environment of 10^{-4}-10^{-6} Pa at a temperature range of 1000-1800°C.
Molybdenum crucibles are used to carry materials to be processed (such as titanium alloy, steel), or as components such as heat shields and heater supports.

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Molybdenum crucible requirements:
Oxidation resistance: The vacuum environment effectively prevents molybdenum from oxidation and ensures the life of the crucible.
High temperature strength: Molybdenum crucibles need to withstand mechanical stress at high temperatures, and doping with oxides can increase their strength.
Thermal conductivity: The high thermal conductivity of molybdenum ensures a uniform thermal field and optimizes the heat treatment effect.

Practical Application:
In the aerospace industry, molybdenum crucibles are used for vacuum heat treatment of titanium alloys to improve their strength and corrosion resistance.

4.3.2 Powder Metallurgy and Sintering
Powder metallurgy prepares high-performance materials through pressing and sintering, and molybdenum crucibles are used in high-temperature sintering processes.

Process Overview:
Metal or ceramic powder is sintered in a molybdenum crucible at 1200-1800°C to form a dense material.
Molybdenum crucibles need to operate in a vacuum or inert atmosphere to prevent oxidation and contamination.

Molybdenum crucible requirements:
Chemical stability: Molybdenum crucibles must avoid reaction with powder materials to maintain product purity.
Creep resistance: Long-term high-temperature operation requires the molybdenum crucible to have a low creep rate.
Surface quality: Polished surface (Ra<0.8 μm) reduces powder adhesion and facilitates cleaning.

Practical Application:
In cemented carbide production, molybdenum crucibles are used to sinter tungsten carbide powder to ensure high hardness and wear resistance of the cutting tools.

4.3.3 High temperature annealing
High temperature annealing is used to eliminate internal stress of materials and improve crystal structure, and molybdenum crucible is used as annealing container.

Process Overview:
The annealing temperature is usually 1000-1600°C and is carried out in a vacuum or inert atmosphere.
Molybdenum crucibles hold metal, alloy or ceramic samples and ensure uniform heating and cooling.

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Molybdenum crucible requirements:
Thermal stability: Molybdenum crucible needs to maintain stable shape at high temperature to avoid deformation.
Low thermal expansion: Molybdenum 's low coefficient of thermal expansion (4.8×10^{-6} /K) reduces thermal stress.
Corrosion resistance: Molybdenum crucibles need to resist slight corrosion from certain annealed materials (such as nickel alloys).

Practical Application:
In stainless steel production, molybdenum crucibles are used for high temperature annealing to improve the ductility and corrosion resistance of the material.

4.4 Scientific research and laboratory applications

Molybdenum crucibles are used in scientific research and laboratories for high temperature experiments, material testing and cutting-edge research. Their high purity and stability support accurate experimental results.

4.4.1 High temperature test equipment

Molybdenum crucibles are used as reaction vessels or heating components in high-temperature experimental equipment (such as tube furnaces and crucible furnaces).

Application scenarios:
Material synthesis: Molybdenum crucibles are used for high-temperature synthesis of new alloys, ceramics or composite materials.
Chemical reactions: Molybdenum crucibles support high temperature chemical reactions such as oxide reduction or vapor deposition.
Temperature range: 1000-2000°C, usually in vacuum or inert atmosphere.

Molybdenum crucible requirements:
High purity: avoid impurities interfering with experimental results.
Small Design: Laboratory License Requirements: Laboratory molybdenum crucibles are usually small (capacity < 500 mL) for easy handling.
Thermal shock resistance: supports rapid temperature rise and fall experiments.

Practical Application:
high-temperature superconducting materials (such as YMCO), molybdenum crucibles are used to sinter superconducting ceramics to ensure high-temperature stability.

4.4.2 Material performance test

Molybdenum crucibles are used to test material properties at high temperatures, such as creep, fatigue and corrosion resistance.

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Application scenarios:
Creep test: Constant stress is applied at 1700°C and the deformation of the material is measured.
Corrosion testing: Exposes materials to molten metals or oxides to assess corrosion resistance.
Thermal fatigue testing: simulates thermal cycles and observes crack growth.

Molybdenum crucible requirements:
High temperature strength: supports long-term testing without failure.
Chemically inert: avoids reaction with test materials.
Surface Quality: Polished surface reduces interference.

Practical Application:
In aerospace material testing, molybdenum crucibles are used to evaluate the high temperature properties of nickel-based alloys.

4.4.3 Nuclear materials and plasma research

Molybdenum crucibles are used for high temperature experiments and material preparation in nuclear materials and plasma research.

Application scenarios:
Nuclear materials: Molybdenum crucibles are used to test the compatibility of high temperature molten salt reactor materials.
Plasma research: Molybdenum crucible is used as a container for plasma generator, which is subjected to high temperature and strong radiation.
Temperature range: 1500-2000°C, extremely high durability required.

Molybdenum crucible requirements:
Radiation resistance: Molybdenum crucibles must resist damage caused by neutron or plasma radiation.
High temperature stability: supports long-term high temperature operation.
Corrosion resistance: Resistant to corrosion by molten salts or plasma.

Practical Application:
In the International Thermonuclear Experimental Reactor (ITER) research, molybdenum crucibles are used to test the performance of high-temperature plasma materials.

4.5 Emerging Applications

molybdenum crucibles in emerging fields such as additive manufacturing, aerospace and nuclear fusion is rapidly expanding, reflecting its potential in high-tech industries.

4.5.1 Additive Manufacturing

Additive manufacturing (3D printing) is used to produce complex metal parts, and molybdenum crucibles play a role in high-temperature powder melting.

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Application scenarios:
Laser or electron beam melting: Molybdenum crucible is used to melt titanium alloy, nickel alloy and other powders at a temperature of 1500-1800°C.
Powder Bed Fusion: Molybdenum crucibles serve as powder containers to ensure high temperature uniformity.

Molybdenum crucible requirements:
Thermal conductivity: supports rapid melting and solidification.
Corrosion resistance: Resistant to erosion by metal powders.
Miniaturization: Suitable for small 3D printing equipment.

Practical Application:
In the manufacture of aviation parts, molybdenum crucibles are used for 3D printing of titanium alloy parts, which improves production efficiency.

4.5.2 Aerospace
Molybdenum crucibles are used in the aerospace field for high temperature material preparation and testing.

Application scenarios:
High temperature alloys: Molybdenum crucibles are used to melt nickel-based or cobalt-based alloys to produce turbine blades.
Composite materials: Molybdenum crucibles are used for sintering ceramic matrix composites (CMC) at a temperature of 1600-1800°C.
Thermal protection materials: Molybdenum crucibles are used to test the performance of thermal protection materials for spacecraft.

Molybdenum crucible requirements:
High temperature strength: supports long-term high temperature operation.
Thermal shock resistance: Withstands rapid thermal cycling.
High purity: ensures consistent material properties.

Practical Application:
Boeing uses molybdenum crucibles to produce high-temperature alloys to meet the needs of its next-generation engines.

4.5.3 Nuclear fusion device
Nuclear fusion devices (such as tokamaks and inertial confinement fusion) require high-temperature materials, and molybdenum crucibles are used for material preparation and testing.

Application scenarios:

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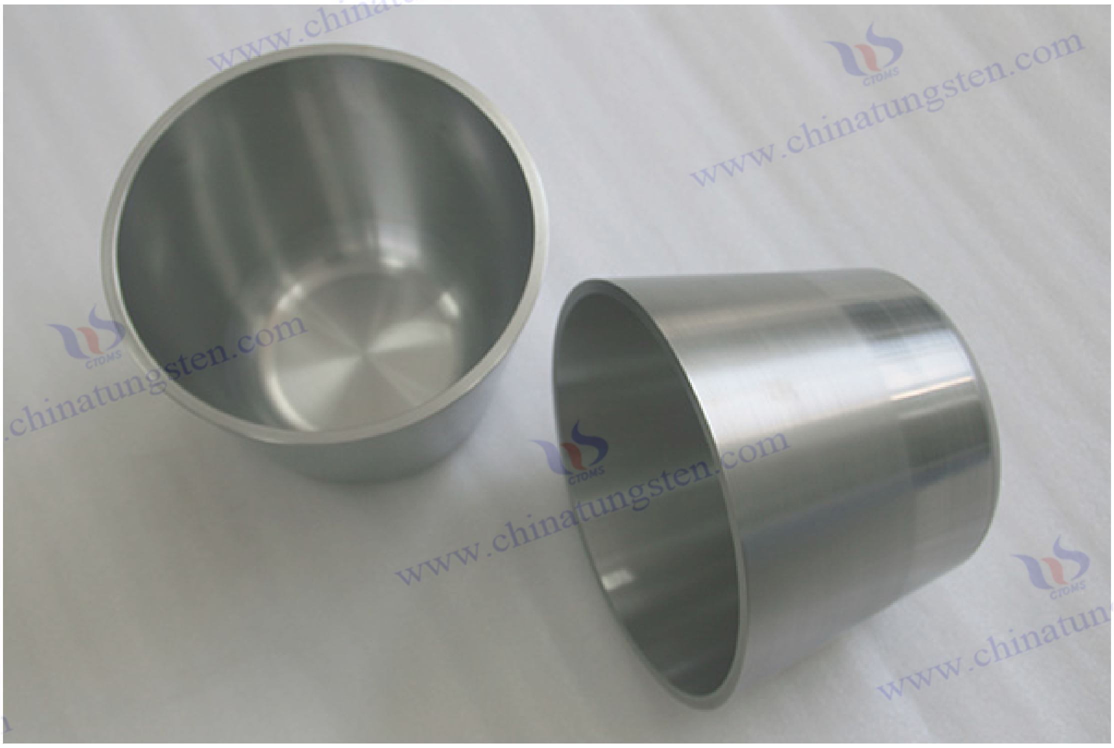
Plasma Faced Material (PFM): Molybdenum crucible is used to sinter tungsten-based or molybdenum -based PFM at a temperature of 1800-2000°C.
Fuel Containers: Molybdenum crucibles are used to melt deuterium-tritium fuel or other high temperature materials.
High temperature testing: Molybdenum crucibles are used to simulate fusion environments and test material properties.

Molybdenum crucible requirements:
Radiation Resistance: Resistant to high energy neutrons and plasma radiation.
High temperature stability: supports operation at extremely high temperatures (>2000°C).
Corrosion resistance: Resistant to erosion by plasma and molten materials.

Practical Application:
In China's EAST tokamak device, molybdenum crucibles are used to test the durability of materials in the face of plasma.



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Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

Molybdenum crucibles are made of high-purity molybdenum powder through isostatic pressing, high-temperature sintering and precision machining. They have excellent high-temperature strength, corrosion resistance and dimensional stability, making them widely used in sapphire crystal growth, rare earth smelting, glass industry, vacuum coating and high-temperature heat treatment.

2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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Chapter 5 Molybdenum Crucible Preparation Process and Technology

Molybdenum crucible is a complex technical system that integrates raw material purification, powder metallurgy, precision machining and surface treatment. Its goal is to produce high-purity, high-density, high-temperature and corrosion-resistant crucibles to meet the needs of high-end applications such as sapphire crystal growth, rare earth smelting, and semiconductor manufacturing. This chapter comprehensively and in-depth explores the preparation process of molybdenum crucibles, covering raw material selection and preparation, metallurgical processes, processing and finishing, production equipment and automation, etc., and refers to the technical practices and academic research of leading global companies to provide detailed technical details and process parameters.

5.1 Raw material selection and preparation

Molybdenum crucibles directly depend on the quality of raw materials, especially the purity, particle size distribution and microstructure of molybdenum powder. The selection and preparation of raw materials are the basis for ensuring the consistency and reliability of crucible performance.

5.1.1 Molybdenum ore purification

Molybdenum is mainly extracted from molybdenite (MoS_2) , and the purification process involves ore dressing, roasting, chemical treatment and refining to produce high-purity molybdenum compounds.

Ore dressing:

Process flow: Molybdenite is separated from the raw ore by crushing, grinding and flotation. The raw ore usually contains 0.1-0.5% molybdenum, and after flotation, a concentrate containing 50-60% molybdenum is obtained.

Flotation technology:

Collectors: Xanthate (such as butyl xanthate, concentration 0.1-0.5 g/L) enhances the hydrophobicity of molybdenum sulfide.

Foaming agent: Pine oil (concentration 0.05-0.2 g/L) generates stable foam.

Inhibitor: Sodium silicate (0.5-2 g/L) inhibits silicate minerals and improves molybdenum selectivity.

Recovery rate: High-quality flotation process can reach 90-95%, and the molybdenum content in tailings is <0.02%.

Advanced technology: High-pressure grinding rollers (HPGR) can improve grinding efficiency and reduce energy consumption by 20-30%. Multi-stage flotation (such as roughing-cleaning-scavenging) further reduces impurities (such as Si, Fe, Cu).

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Roasting:

Process flow: Molybdenum concentrate is roasted at 600-700°C in a rotary kiln or multi-hearth furnace, and MoS_2 is oxidized to molybdenum trioxide (MoO_3), the reaction is: $2MoS_2 + 7O_2 \rightarrow 2MoO_3 + 4SO_2$.

Process parameters:
Oxygen concentration: 20-25%, to avoid excessive oxidation and volatilization of molybdenum.
Roasting time: 4-8 hours, ensuring sulfur content <0.1%.
Tail gas treatment: Wet desulfurization ($Ca(OH)_2$ solution) is used to remove SO_2, meeting emission standards (such as China GB 28662).

Equipment: Rotary kiln (1-3 m in diameter, 10-20 m in length) equipped with precise temperature control system (±10°C) to improve roasting efficiency.

Chemical purification:

Ammonia dissolution: MoO_3 reacts with aqueous ammonia (concentration 10-15%) to form ammonium molybdate solution, which is then filtered to remove insoluble impurities (such as SiO_2 and Fe_2O_3), which are then calcined (500-600°C) to generate MoO_3 (purity>99.9%).
Refining:
Electron beam melting: melt MoO_3 at a vacuum degree <10^{-5} Pa and a temperature >3000°C to remove volatile impurities (such as S and P).
Molybdenum metal with a purity of ≥99.95% is obtained through multiple purification at local high temperature (>2600°C).

Environmental protection and recycling:

The waste liquid is treated by neutralization and precipitation to recover ammonium molybdate (recovery rate>80%).
The exhaust gas is discharged after desulfurization and dust removal, and the SO_2 concentration is <50 mg/m³, which complies with EU REACH regulations.

5.1.2 Molybdenum powder quality requirements

Molybdenum powder is the core raw material for the preparation of molybdenum crucibles. Its purity, particle size, morphology and fluidity directly affect the density and performance of the crucible.

Purity:
Standard: Ordinary molybdenum crucibles require molybdenum powder purity ≥ 99.95%, and high-end applications (such as sapphire crystal growth) require ≥ 99.99%.
Impurity Limits:
of molybdenum carbide (Mo_2C) at high temperatures.
Oxygen (O): <0.005%, to avoid sintering defects.
Nitrogen (N): <0.003%, reduces grain boundary embrittlement.

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Metal impurities (Fe, Si, Al): <0.001%, ensuring melt purity.

Detection method:
Inductively coupled plasma mass spectrometry (ICP-MS): Detects metal impurities with an accuracy of <0.1 ppm.
Oxygen and nitrogen analyzer: measures O and N content with an accuracy of <0.001%.
Carbon and sulfur analyzer: measures C and S content with an accuracy of <0.005%.

Particle size and morphology:
Particle size range: 1-10 μm, average particle size 3-5 μm. Fine particle size improves sintering activity, and uniform particle size distribution (D50 / D90 <2) ensures billet consistency.
Morphology: Nearly spherical or polyhedral particles, surface area 2-5 m²/g, avoid rod-shaped or flaky particles (poor fluidity).
Production technology:
Plasma atomization: produces spherical molybdenum powder with fluidity <25 s/ 50g.
Spray drying: Control particle size distribution, D50 deviation <0.5 μm.

Fluidity and apparent density:
Apparent density: 1.0-2.5 g/cm³, preferably above 2.0 g/cm³ to improve pressing efficiency.
Fluidity: Hall flow rate <30 s/ 50g, ensuring uniform filling of the mold.
Test methods: ASTM B213 (flowability test), ASTM B212 (apparent density test).

Production process:
Hydrogen reduction: MoO_3 is reduced to molybdenum powder in a hydrogen flow (purity 99.999%) at 900-1100°C. The process is divided into two stages:
Low temperature reduction (600-800°C): generate MoO_2 and control the oxygen content.
High temperature reduction (900-1100°C): generates molybdenum powder and refines the particle size.

Parameter optimization:
Hydrogen flow rate: 0.5-2 m³/h, to ensure adequate reduction.
Reduction time: 6-12 hours, controlled particle size <5 μm.

5.1.3 Doping and alloying

Doping and alloying improve the high temperature strength, creep resistance and corrosion resistance of molybdenum crucible by adding trace elements or metals.

Doping elements:
Cerium oxide (CeO_2): 0.5-2 wt %, refines grains (<30 μm), and increases tensile strength at 1700°C (>300 MPa).
Lanthanum oxide (La_2O_3): 0.5-1 wt %, enhances toughness and thermal shock resistance, and extends cycle life.

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Yttrium oxide (Y_2O_3): 0.5-1 wt %, improves oxidation resistance and corrosion resistance.
Titanium carbide (TiC): 0.1-0.5 wt %, for enhanced hardness (>300 HV) and wear resistance.

Doping method:
Dry mixing: Molybdenum powder and dopant are mixed using a high energy ball mill (200-400 rpm, 2-4 hours).
Wet mixing: Homogeneous composite powders were prepared by spray drying (inlet temperature 200 °C, outlet temperature 80 °C).

Alloying:
Mo-W alloy: contains 10-30% tungsten (www.tungsten.com.cn), the melting point is increased to 2800°C, suitable for ultra-high temperature applications.
Mo-Re alloy: contains 5-25% rhenium, which improves room temperature toughness and high temperature strength.
Mo-Zr alloy: contains 0.5-2% zirconium, enhances corrosion resistance, and is suitable for rare earth smelting.

Alloying method:
Co-reduction: MoO_3 and WO_3 are co-reduced in hydrogen, and the reduction temperature is controlled (1000-1200°C).
Mechanical alloying: High-energy ball milling mixes molybdenum powder and alloying elements, with a ball-to-material ratio of 10:1, for 4-8 hours.

Performance improvements:
-doped molybdenum crucible at 1700°C is reduced to 10^{-6} / s, and the service life is extended by 50%.
Mo-W alloy crucible still maintains a tensile strength of >200 MPa at 2000°C.

Detection:
Scanning electron microscopy (SEM) combined with energy dispersive spectroscopy (EDS) confirmed the uniformity of doping element distribution.
X-ray diffraction (XRD) is used to analyze the phase composition to ensure that no impurities are generated.

5.1.4 Raw material testing

Strict raw material testing ensures that the quality of molybdenum powder and dopants meets the requirements for crucible manufacturing.

Chemical composition analysis:
ICP -MS: Detection of metal impurities such as Fe, Si, Al, etc., with a detection limit of <0.05 ppm.
Oxygen and nitrogen analyzer: measures O and N content with an accuracy of <0.001%.
Carbon and sulfur analyzer: measures C and S content with an accuracy of <0.005%.

Physical performance test:
Laser particle size analyzer: measure particle size distribution, D10, D50, D90 deviation <0.5 μm.
Hall flow meter: Test fluidity, accuracy ±0.5 s.
Apparent density meter: measures the bulk density with an accuracy of ±0.01 g/cm³.

Microstructure observation:
SEM: Analyze the morphology of molybdenum powder, magnification 1000-5000 times.
Transmission electron microscopy (TEM): Observe the nanoscale particle structure and confirm the absence of crystal defects.
ARD: Detect the crystal structure and confirm that the molybdenum powder is a body-centered cubic (BCC) structure.

Standards and specifications:
It complies with ASTM B386 (Molybdenum and Molybdenum Alloy Standard) and GB/T 3462 (China Molybdenum Material Standard).
ISO 17025 certified laboratories ensure testing reliability.

5.2 Metallurgical process
The metallurgical process converts molybdenum powder into high-density billet to form the initial structure of the molybdenum crucible, covering technologies such as pressing and sintering, forging and rolling, spinning and stretching.

5.2.1 Pressing and sintering
Molybdenum crucible blanks through powder molding and high-temperature densification.

5.2.1.1 Isostatic pressing
Process Overview:
Cold Isostatic Pressing (CIP) uses high-pressure liquid (oil or water) to apply isotropic pressure to molybdenum powder to prepare high-density billets.
Pressure: 100-300 MPa, preferably 200 MPa.
Holding time: 5-10 minutes, depending on the size of the blank.
Green body density: 6.0-7.0 g/cm³ (60-70% theoretical density), providing a uniform structure for sintering.

equipment:
Isostatic press: pressure range 50-400 MPa, equipped with high-pressure pump (power 50-200 kW).
Mould: Flexible mould (such as rubber or polyurethane), pressure resistance >300 MPa, shape according to crucible design (cylindrical or conical).
The mold design takes into account the sintering shrinkage (15-20%) to ensure the final dimensional accuracy (±0.5 mm).

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Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

Molybdenum crucibles are made of high-purity molybdenum powder through isostatic pressing, high-temperature sintering and precision machining. They have excellent high-temperature strength, corrosion resistance and dimensional stability, making them widely used in sapphire crystal growth, rare earth smelting, glass industry, vacuum coating and high-temperature heat treatment.

2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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

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Process Optimization:
Molybdenum powder pretreatment: vacuum degassing (200-300°C, vacuum degree <10^{-2} Pa) to remove adsorbed gas and reduce oxygen content <0.005%.
Binder: Adding polyvinyl alcohol (PVA, 0.5-1 wt %) or polyethylene glycol (PEG, 0.3-0.8 wt %) can improve the strength of the blank and needs to volatilize before sintering (400-600°C).
Mould filling: Vibration filling (frequency 50-100 Hz) ensures uniform distribution of molybdenum powder with density deviation <2%.
Case: China Tungsten Online's isostatic pressing process improves the density uniformity of the billet by 15% through bidirectional vibration filling.

Quality Control:
Ultrasonic testing: Confirm that the blank has no internal cracks or delamination.
Density measurement: Buoyancy method is used to test the density of the blank, with an accuracy of ±0.01 g/cm³.

5.2.1.2 Sintering furnace and atmosphere
Sintering process:
Temperature: 1800-2200°C, step-by-step heating:
Low temperature (<1200°C): remove moisture, binder and gas, heating rate 5-10°C/min.
Medium temperature (1200-1600°C): particle surface activation, neck formation, heating rate 3-5°C/min.
High temperature (1600-2200°C): grain growth, densification, and heat preservation for 4-8 hours.

Final density: 9.8-10.2 g/cm³ (>95% theoretical density), porosity <1%.
Shrinkage rate: 15-20%, dimensional deviation (±0.2 mm) needs to be controlled through mold design and process optimization.

Sintering atmosphere:
Vacuum sintering:
Vacuum degree: <10^{-3} Pa, preferably <10^{-4} Pa.
Advantages: Prevent oxidation, reduce impurity contamination, suitable for high-purity crucibles.
Equipment: Equipped with a condenser to collect volatile impurities (such as S, P).

Hydrogen sintering:
Hydrogen purity: 99.999%, flow rate 0.5-2 m³/h.
Advantages: Reduces trace oxides, oxygen content drops to <0.003%.
Note: The carbon content in the furnace must be controlled to <0.01% to avoid carbonization.

Atmosphere monitoring: Use a mass spectrometer to detect O_2, N_2 and CO content in real time to ensure < 10 ppm.

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Equipment:
Vacuum sintering furnace:
Heating element: molybdenum or tungsten wire, power 100-500 kW.
Furnace: Molybdenum or tungsten lined, size 0.5-2 m diameter.
Temperature control accuracy: ±5°C, equipped with infrared thermometer.

Hydrogen sintering furnace:
Equipped with gas purification system (molecular sieve + palladium catalyst), hydrogen dew point <-70°C.
Safety system: explosion-proof valve and hydrogen leak detector.

Quality Control:
Density test: Archimedes method is used to measure the density of sintered blanks with an accuracy of ±0.01 g/cm³.
Microstructure analysis: SEM observation of grain size (20-50 μm) and pore distribution.
Nondestructive testing: X-ray testing confirms there are no internal cracks or inclusions.

5.2.2 Forging and rolling
Forging and rolling eliminate pores, refine grains, and improve billet density and mechanical properties through high-temperature plastic deformation.
5.2.2.1 Hot forging and cold forging

Hot Forging:
Temperature: 1200-1600°C, preferably 1400°C, carried out in hydrogen (99.999%) or argon atmosphere.
Process:
Equipment: hydraulic forging machine (pressure 1000-5000 tons) or hammer forging machine (frequency 50-100 times/min).
Deformation: 10-20% per pass, total deformation 30-50%.
Mold: Molybdenum or high temperature alloy, surface coated with MoS_2 (www.tungsten-disulfide.com) lubricant.

Advantages:
Density increased to >99.5% theoretical density.
The grain size is refined to <50 μm and the tensile strength is >800 MPa.
Inducing texture (such as <110> orientation) to improve thermal shock resistance.

Note:
Control the forging speed (<0.1 m/s) to avoid cracks.
Billet
Cold Forging:
Temperature: Room temperature or <400°C, used for precision forging small crucibles or thin-

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walled parts.
Process:
Equipment: High-precision forging machine (pressure 500-2000 tons).
Deformation: <10%, <2% per pass.

Limitations: Molybdenum is brittle at room temperature and requires controlled strain rate (<0.01 s^{-1}) to avoid cracks.
Application: Production of small crucibles with wall thickness <2 mm and surface roughness Ra<0.8 μm.

Quality Control:
Ultrasonic testing: Confirm that there are no internal cracks or delamination.
Hardness test: Vickers hardness (HV) 200-300, confirming the processing strengthening effect.

5.2.2.2 Rolling process
Process Overview:
Rolling processes sintered or forged billets into molybdenum plates or foils for welding or spinning crucibles.
Equipment: Four-roll or multi-roll mill, roll surface material is ceramic or tungsten alloy, wear resistance> 1000 hours.

Hot Rolled:
Temperature: 1000-1400°C, preferably 1200°C, in hydrogen or vacuum environment.
Process parameters:
Deformation per pass: 10-20%, total deformation >80%.
Rolling speed: 0.5-1 m/s, roller surface pressure 100-500 MPa.
Lubricant: Graphite or MoS_2 coating, friction coefficient <0.1.

Advantages:
The density is close to the theoretical value (>99.8%).
Forming <110> texture, tensile strength>900 MPa.

Note:
Intermediate annealing (800-1000°C, 1-2 hours) to relieve stress.
Control the roller surface temperature (<200°C) to avoid adhesion.

Cold Rolling:
Temperature: Room temperature or <200°C, used to produce thin molybdenum sheets (thickness 0.1-1 mm).
Process parameters:
Deformation per pass: 5-10%, total deformation <50%.
Rolling speed: 1-2 m/s, surface roughness Ra<0.8 μm.

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Note:
Multiple annealing (600-800°C, 30 minutes) is required to eliminate work hardening.
Surface cleaning removes lubricant residues.
Quality Control:
Surface inspection: Roughness measured by laser microscope, Ra<0.5 μm.
Thickness measurement: Ultrasonic thickness gauge, accuracy ±0.01 mm.
Texture analysis: Electron backscatter diffraction (EBSD) confirms grain orientation.

5.2.3 Spinning and stretching

Spinning and stretching forming are used to prepare thin-walled or complex-shaped molybdenum crucibles through plastic deformation, which are suitable for mass production of small and medium-sized crucibles.

5.2.3.1 Spinning Die

Process Overview:
Spinning is done by spinning a molybdenum plate and applying local pressure to form the crucible at a temperature of 800-1200°C.
Equipment: CNC spinning machine, power 50-200 kW, rotation speed 100-600 rpm.
Mould:
Material: high temperature alloy (such as Inconel) or ceramic (SiC), wear life >1000 times.
Design: Corner radius > 2 mm to avoid stress concentration; wall thickness 1-5 mm, dimensional tolerance ±0.1 mm.
Surface treatment: Coating with MoS_2 or ZrO_2 to reduce friction.

Process parameters:
Feed rate: 0.5-2 mm/s, preferably 1 mm/s.
Pressure: 10-50 kN, adjusted according to wall thickness.
Lubricant: Graphite suspension or MoS_2 coating, friction coefficient < 0.1.
Heating method: induction heating or flame heating, temperature control accuracy ±10°C.

Advantages:
Wall thickness uniformity ±0.1 mm, surface roughness Ra<0.8 μm.
High production efficiency, single piece molding time <10 minutes.

Quality Control:
Laser distance meter: real-time monitoring of wall thickness, accuracy ±0.05 mm.
Surface inspection: Optical microscope confirms no scratches or cracks.

5.2.3.2 Stretching temperature and lubrication

Stretching process:
molybdenum plate is stretched into a crucible shape through a die at a temperature of 600-1000°C, preferably 800°C.

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Equipment: Hydraulic stretching machine, pressure 100-500 tons.
Process parameters:
Tensile rate: 0.1-0.5 mm/s, deformation <30%.
Mold corner radius: >3 mm, to reduce stress concentration.

Mould: high temperature alloy or ceramic, surface polished to Ra<0.5 μm.

lubricating:
Lubricant: graphite suspension (concentration 5-10%) or MoS_2 powder, coating thickness 10-50 μm.
Application method: spray or brush, friction coefficient <0.1.
Cleaning: After stretching, use ultrasonic cleaning (40 kHz) to remove lubricants and avoid contamination.

Quality Control:
Wall thickness measurement: ultrasonic thickness gauge, accuracy ±0.01 mm.
Surface inspection: SEM analyzes surface defects and confirms that there are no microcracks.

5.3 Processing and finishing

Machining and finishing processes ensure the dimensional accuracy, surface quality and high temperature performance of molybdenum crucibles, including turning, milling, welding, surface treatment and heat treatment.

5.3.1 Turning and milling

Turning and milling are used to process the inner and outer surfaces of molybdenum crucibles to meet high precision and high surface quality requirements.

5.3.1.1 CNC machining

Process Overview:
CNC lathe: for machining inner and outer cylindrical surfaces, suitable for crucibles with a diameter of 50-500 mm.
CNC milling machines: for machining complex geometries such as crucible bottoms or flanges.
Knife:
Cemented carbide (WC-Co): hardness >90 HRA, suitable for rough machining.
Diamond-coated tools: hardness >5000 HV, suitable for finishing.

Cutting data:
Rough machining: cutting speed 20-30 m/min, feed rate 0.1-0.2 mm/r, cutting depth 0.5-2 mm.
Finishing: cutting speed 40-50 m/min, feed rate 0.05-0.1 mm/r, cutting depth 0.1-0.5 mm.

Cooling and lubrication:
Dry cutting: avoid liquid contamination, suitable for high purity crucibles.
Minimal lubrication (MQL): Use compressed air + trace oil mist (<0.1 mL/min) to reduce tool wear.

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Tool life: Carbide tools>100 minutes, diamond tools>500 minutes.

Equipment:
Five-axis CNC lathe: machining accuracy ±0.005 mm, equipped with laser tool setting system.
Machining center: integrated turning and milling compound functions, suitable for crucibles with complex shapes.

Quality Control:
Coordinate Measuring Machine (CMM): measures dimensional tolerances with an accuracy of ±0.002 mm.
Laser scanner: Check roundness and coaxiality, deviation < 0.01 mm.

5.3.1.2 Precision and roughness

Accuracy requirements:
Diameter tolerance: large crucible ±0.05 mm, small crucible ±0.01 mm.
Wall thickness uniformity: ±0.1 mm, ensuring uniform thermal field.
Roundness: <0.02 mm, to prevent thermal stress concentration.
Coaxiality: <0.01 mm, meeting the requirements of crystal growth.

Surface roughness:
Inner surface: Ra<0.8 μm, reducing melt adhesion.
External surface: Ra<1.6 μm, reducing the risk of cracks.

Detection method:
Surface roughness tester: accuracy ±0.01 μm.
Laser microscope: 3D morphology analysis, magnification 1000 times.

5.3.2 Welding technology

Welding is used to prepare large or complex-shaped molybdenum crucibles, and weld strength, sealing and high-temperature performance must be ensured.

5.3.2.1 Electron beam welding

Process Overview:
Electron beam welding (EBW) is carried out in a vacuum chamber with a vacuum degree of <10^{-4} Pa, using a high-energy electron beam (energy 10^{-15} J) to melt the molybdenum sheet.
Welding parameters:
Voltage: 60-100 kV, preferably 80 kV.
Current: 50-200 mA, adjusted according to board thickness.
Welding speed: 0.5-2 m/min, preferably 1 m/min.
Welding seam depth: 5-10 mm, suitable for crucibles with wall thickness of 3-8 mm.

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Advantages:
The weld is pure, free of oxygen contamination, and the oxygen content is <0.002%.
The heat affected zone (HAZ) is <0.5 mm and the grain growth are <10 μm.
The weld strength reaches 90-95% of the parent material.

Process Optimization:
Surface pretreatment: pickling (10% HNO_3 solution) + ultrasonic cleaning (40 kHz) to remove oxides, surface roughness Ra < 0.5 μm.
Positioning accuracy: laser alignment system, deviation <0.05 mm.
Post-processing: weld polishing (Ra<0.8 μm) to eliminate stress concentration.

Quality Control:
X-ray flaw detection: detect pores and cracks, with defect size less than 0.1 mm.
Tensile test: weld tensile strength>600 MPa.
Helium mass spectrometer leak detection: confirm the tightness, the leak rate is $<10^{-9}$ Pa · m^3 /s.

5.3.2.2 Laser welding and brazing
Laser welding:
Equipment: Fiber laser (power 2-5 kW) or Nd:YAG laser (pulse energy 0.1-1 J).
Process parameters:
Pulse width: 0.5-2 ms, frequency 10-50 Hz.
Welding speed: 1-3 m/min, weld width 0.5-2 mm.
Shielding gas: argon (99.999%), flow rate 10-20 L/min.

Advantages:
High precision, suitable for crucibles with wall thickness < 2 mm.
Heat affected zone <0.3 mm, reducing grain growth.

Note:
The surface is cleaned to Ra<0.5 μm to remove oil, dirt and oxides.
Controlling the laser focus (deviation < 0.1 mm) ensures a uniform weld.

Brazing:
Solder: Silver-based solder (Ag-Cu, melting point 780-850℃) or molybdenum -based solder (Mo-Ni, melting point 1200℃).
Process parameters:
Brazing temperature: 800-1200℃, holding time 5-10 minutes.
Atmosphere: vacuum ($<10^{-3}$ Pa) or hydrogen (99.999%).

Advantages: Suitable for crucibles with complex shapes, joint strength >400 MPa.
Note: The solder needs to be evenly applied (thickness 0.1-0.3 mm) to avoid excessive penetration.

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Quality Control:
Ultrasonic testing: Confirm that the weld has no porosity or lack of fusion.
Microhardness test: Weld hardness 200-250 HV.
SEM analysis: Observe the weld microstructure, grain size <20 μm.

5.3.3 Surface treatment

Surface treatment improves the oxidation resistance, corrosion resistance and surface quality of molybdenum crucibles and prolongs their service life.

5.3.3.1 Cleaning and polishing

Cleaning:
Ultrasonic cleaning:
Frequency: 40-80 kHz, power 1-5 kW.
Cleaning solution: deionized water + neutral detergent (pH 6-8), temperature 50-70°C.
Time: 10-20 minutes, depending on the degree of pollution.

Pickling:
Solution: 10% HNO_3 or 5 % HCl, soak for 5-10 minutes.
Post-treatment: deionized water rinse + vacuum drying (100°C, $<10^{-2}$ Pa).

Quality Control:
Surface analysis: X-ray photoelectron spectroscopy (XPS) confirmed the absence of residual oxides.
Cleanliness test: Particle counter, particles <100 particles/cm² (>0.5 μm).

Polishing:
Mechanical polishing:
Abrasive: Alumina (particle size 0.5-5 μm) or diamond suspension (particle size 0.1-1 μm).
Equipment: Automatic polishing machine, speed 500-1000 rpm, pressure 10-50 kPa.
Surface roughness: Ra <0.5 μm, preferably <0.3 μm.

Electrochemical polishing:
Electrolyte: phosphoric acid (50%) + sulfuric acid (30%) + water, temperature 40-60°C.
Current density: 0.5-2 A/cm², time 5-15 minutes.
Advantages: Remove microscopic defects and improve corrosion resistance.

Quality Control:
Surface roughness tester: measure Ra, accuracy ±0.01 μm.
Laser microscope: Analyze the surface morphology and confirm that there are no scratches.

5.3.3.2 Anti-oxidation coating

Coating Type:
Molybdenum silicide ($MoSi_2$) :

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Thickness: 50-200 μm, bonding strength >50 MPa.
A SiO_2 protective layer is formed at 1700°C, and the anti-oxidation life is >1000 hours.

Zirconia (ZrO_2):
Thickness: 100-300 μm, thermal reflectivity >80%.
Improves oxidation resistance and thermal efficiency, suitable for crystal growth.

Alumina (Al_2O_3) :
Thickness: 50-150 μm, excellent corrosion resistance, suitable for rare earth smelting.

Coating process:
Chemical Vapor Deposition (CVD):
Temperature: 1000-1200°C, atmosphere: $SiCl_4$ + H_2.
Deposition rate: 0.5-2 μm/h, coating uniformity ±5 μm.

Plasma spraying:
Power: 30-100 kW, spraying speed 100-400 m/s.
Gas: Ar+H_2, flow rate 50-100 L/min.
Coating porosity: <2%, bonding strength> 60 MPa.

Physical Vapor Deposition (PVD):
Temperature: 400-600°C, vacuum degree $<10^{-3}$ Pa.
Deposition rate: 0.1-0.5 μm/min, suitable for thin coatings (<50 μm).

Quality Control:
Coating thickness: ultrasonic thickness gauge, accuracy ±1 μm.
Bond strength: tensile test, in accordance with ASTM C633 standard.
Microstructure: SEM+EDS analysis of coating composition and interface.

5.3.4 Heat treatment and annealing

Heat treatment and annealing are used to control grain structure, relieve processing stresses and improve high temperature properties.

5.3.4.1 Grain Control

Process Overview:
Temperature: 1200-1600°C, preferably 1400°C.
Insulation time: 1-4 hours, depending on the size of the crucible.
Atmosphere: Hydrogen (99.999%) or vacuum ($<10^{-3}$ Pa).
Target: Grain size 20-50 μm, optimized strength and creep resistance.

Process Optimization:
Heating rate: 5-10°C/min, avoid thermal stress.

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Cooling rate: >50°C/min, inhibiting grain growth.
Doping: CeO_2 or La_2O_3 pins grain boundaries, grain size deviation <10 μm .

Quality Control:
Optical microscope: measure grain size with an accuracy of ±1 μm.
BEDS: Analyze grain orientation and confirm that the <110> texture ratio is >60%.

5.3.4.2 Stress relief

Process Overview:
Temperature: 800-1000°C, preferably 900°C.
Insulation time: 2-6 hours, depending on wall thickness.
Atmosphere: vacuum ($<10^{-3}$ Pa) or argon (99.999%).
Target: Residual stress <50 MPa, reduce crack risk.

Process Optimization:
Slow cooling (<5°C/min) to 500°C to avoid secondary stress.
Multi-stage annealing: 800°C (2 hours) + 600°C (1 hour) to optimize stress distribution.

Quality Control:
X-ray stress analyzer: measures residual stress with an accuracy of ±5 MPa.
Ultrasonic testing: Confirm that there are no internal cracks and the defect size is <0.1 mm.

5.4 Production Equipment and Automation

Advanced production equipment and automation technology improve the manufacturing efficiency, quality consistency and production safety of molybdenum crucibles.

5.4.1 Key Equipment

5.4.1.1 Vacuum sintering furnace

Specification:
Maximum temperature: 2300°C, temperature control accuracy ±5°C.
Vacuum degree: $<10^{-4}$ Pa, equipped with molecular pump and mechanical pump.
Power: 100-500 kW, furnace size 0.5-2 m in diameter.
Heating element: molybdenum or tungsten wire, life span>5000 hours.

Function:
Multi-stage temperature control: supports low temperature (<1200°C), medium temperature (1200-1600°C), and high temperature (1600-2200°C) sintering.
Atmosphere control: integrated mass spectrometer, O_2 content <10 ppm.
Data logging: Real-time monitoring of temperature, pressure and gas flow.

Security System:
Over temperature protection: automatic power off, threshold 2350°C.

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Vacuum leak detection: alarm threshold $>10^{-3}$ Pa.

5.4.1.2 Spinning machines and lathes

Spinning machine:
Power: 50-200 kW, rotation speed 100-600 rpm.
Control system: CNC, machining accuracy ±0.05 mm.
Mould: high temperature alloy or ceramic, wear-resistant life> 1000 times.
Function: Supports the molding of thin-walled crucibles (wall thickness 1-5 mm), and the molding time is <10 minutes.

CNC Lathe:
Type: five-axis linkage, processing diameter 0.1-1 m.
Tool: Diamond coating, cutting speed 30-60 m/min.
Precision: dimensional tolerance ±0.005 mm, roundness <0.01 mm.
Function: Support internal and external surface finishing, surface roughness Ra<0.5 μm.

5.4.1.3 Surface treatment equipment

Ultrasonic cleaning machine:
Frequency: 40-80 kHz, power 1-5 kW.
Cleaning tank: multi-tank design (cleaning, rinsing, drying), capacity 50-200 L.
Function: Remove oxides, oil and particles, cleanliness <100 particles/cm².
Plasma spraying equipment:
Power: 30-100 kW, spraying speed 100-400 m/s.
Gas: $Ar+H_2$, flow rate 50-100 L/min.
Robot arm: six-axis linkage, coating thickness uniformity ±5 μm.
Function: Produce $MoSi_2$ and ZrO_2 coatings with bonding strength >60 MPa.

Electrochemical polishing equipment:
Electrolyte: phosphoric acid + sulfuric acid, current density 0.5-2 A/cm².
Function: Improve surface finish (Ra<0.3 μm) and corrosion resistance.

5.4.2 Automation and intelligence

Automation technology:
Robotic system:
Loading and unloading robot: used for molybdenum powder filling, blank handling and finished product packaging, with a load of 50-200 kg.
Welding robot: equipped with visual recognition system, welding accuracy ±0.05 mm.

CNC system:
Integrated CAD/CAM software optimizes processing paths and reduces processing time by 10-15%.
Support G code programming and compatible with crucibles of complex shapes.

Online monitoring:
Infrared thermometer: monitor sintering temperature, accuracy ±2°C.
Pressure sensor: detects isostatic pressing pressure with an accuracy of ±0.1 MPa.
Laser scanner: real-time measurement of crucible dimensions with an accuracy of ±0.01 mm.

Intelligent:
Industry 4.0:
Internet of Things (IoT): Devices are connected and upload temperature, pressure and production data in real time.
Big data analysis: Optimize process parameters and reduce scrap rate to <1.5%.

Artificial Intelligence (AI):
Predictive maintenance: Predict equipment failures based on vibration and temperature data, reducing downtime by 20%.
Process optimization: The AI model adjusted the sintering temperature and pressure, increasing the density by 0.5%.

Digital Twin:
Virtually model the crucible production process and simulate sintering, forging and machining.
Optimize mold design and achieve shrinkage prediction accuracy of ±0.1%.

5.4.3 Clean room requirements
The clean room ensures that the molybdenum crucible manufacturing process is pollution-free and meets the needs of high-purity applications.

Cleanliness level:
ISO 5 (Class 100): Particle concentration <100 particles/m³ (particle size ≥0.5 μm).
ISO 7 (10,000): For non-critical processes, particle concentration <10,000 particles/m³.

Environmental Control:
Temperature: 20-25°C, fluctuation ±1°C.
Humidity: 40-60%, fluctuation ±5%.
Positive pressure: >10 Pa, to prevent external particles from entering.

Equipment and measures:
High efficiency filter (HEPA): filtration efficiency>99.97%, replacement cycle 6-12 months.
Air shower: Inlet wind speed> 20 m/s, removes particles on the surface of people.
Dust-free floor: Epoxy resin coating, surface resistance 10^6 -10^9 Ω .

Personnel protection:
Wear cleanroom clothing (polyester), mask, gloves and shoe covers.
Training: ISO 14644 cleanroom operating specifications.

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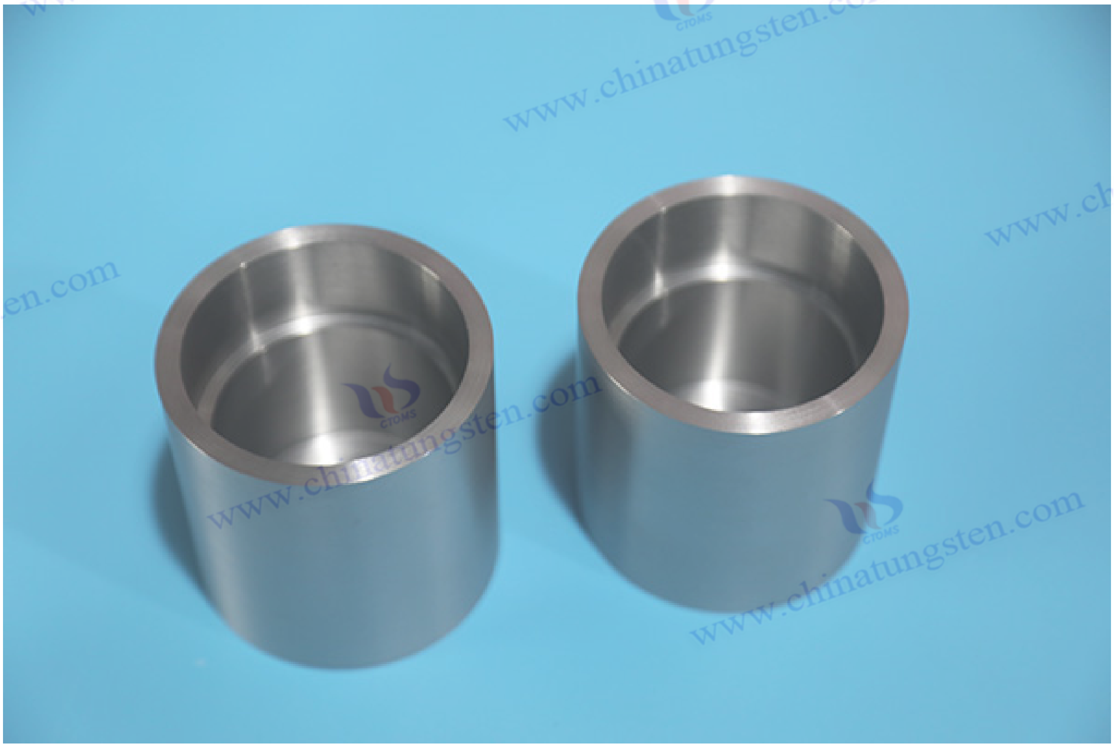
Detection method:
Particle counter: real-time monitoring of particles, accuracy ±10 particles/m³.
Microbiological sampling: weekly testing, colony count <1 CFU/m³.
Surface cleanliness: Contact particle test, particles <50 particles/cm².



CTIA GROUP LTD Molybdenum Crucible

Chapter 6 Molybdenum Crucible Quality Control and Inspection

Molybdenum crucibles are key links to ensure their stable performance and reliability in high-temperature, high-corrosion environments (such as sapphire crystal growth, rare earth smelting, and semiconductor manufacturing). Molybdenum crucibles must meet the requirements of high purity, high density, excellent mechanical properties, and corrosion resistance. Any minor defects may lead to major failures. This chapter discusses the quality control and inspection technology of molybdenum crucibles in detail, covering online inspection, performance testing, and failure analysis, and provides comprehensive technical details and methodology with reference to the practices of leading global companies, industry standards, and academic research.

6.1 Online Detection

Online inspection monitors product quality in real time during the molybdenum crucible manufacturing process to ensure dimensional accuracy, surface quality and microstructural compliance. These technologies minimize production interruptions and improve efficiency through non-contact or rapid inspection methods.

6.1.1 Dimensions and accuracy

the molybdenum crucible directly affects its thermal field uniformity and mechanical stability in a high-temperature environment. Online dimensional detection ensures that the geometry, wall thickness and roundness of the crucible meet the design requirements.

Detection method:

Laser ranging and scanning:

Use a high-precision laser rangefinder or 3D laser scanner to measure the outer diameter, inner diameter, wall thickness and height of the crucible in real time.

The laser scanning system generates a 3D model of the crucible from point cloud data and detects roundness, coaxiality and surface flatness.

Advantages: non-contact, fast measurement, suitable for large crucibles (diameter > 300 mm).

Ultrasonic thickness measurement:

Ultrasonic thickness gauges measure crucible wall thickness by emitting high-frequency sound waves (5-10 MHz) and are particularly suitable for thin-walled crucibles (<5 mm).

Online integration in CNC lathes or spinning machines provides real-time feedback of wall thickness data and guides processing adjustments.

Advantages: High precision, suitable for complex geometries.

Coordinate Measuring Machine (CMM):

Online CMM measures the critical dimensions of the crucible (such as flange diameter, bottom radius) using a contact probe.

Equipped with automatic tool changing system, supports multi-point measurement, suitable for mass production.

Advantages: High repeatability, suitable for high-precision crucibles (tolerance < 0.01 mm).

Detection parameters:

Diameter tolerance: Large crucibles require micron tolerances; small crucibles require sub-micron tolerances.

Wall thickness uniformity: Deviations must be controlled within a very small range to ensure uniform thermal field.

Roundness and coaxiality: The roundness deviation needs to be extremely low, and the coaxiality needs to meet the strict requirements of the crystal growth equipment.

Height and flatness: The height tolerance is in micron level, and the bottom flatness needs to avoid thermal stress concentration.

Process Integration:

The online detection system is connected to the CNC processing equipment through the Industrial Internet of Things (IoT), and the dimensional data is uploaded to the central control system in real time.

Feedback mechanism: If dimensional deviations are detected, the system automatically adjusts

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processing parameters (such as cutting depth, spinning pressure).
Monitor dimensional trends and predict potential defects through statistical process control (SPC).

Quality Standards:
Conforms to ASTM B386 (Molybdenum and Molybdenum Alloy Standard) and GB/T 3462 (China Molybdenum Material Standard).
The ISO 9001 quality management system requires that online testing equipment be calibrated regularly with an accuracy deviation of <1%.

Practical Application:
In sapphire crystal growth, the dimensional accuracy of the molybdenum crucible directly affects the crystal quality. HC Starck Solutions' online laser scanning system ensures that the crucible diameter tolerance is extremely small, meeting the requirements of the Czochralski method.

6.1.2 Surface defects
Surface defects (such as scratches, cracks, oxide layers) may become the starting point for crack propagation at high temperatures or cause melt contamination. Online surface inspection ensures the surface finish and integrity of the crucible.

Detection method:
Optical microscopy and image analysis:
A high-resolution optical microscope (magnification 50-1000x) equipped with a CCD camera captures images of the crucible surface in real time.
Image processing software identifies scratches, pits and micro-cracks through edge detection and grayscale analysis.
Advantages: High sensitivity, suitable for inner surface detection.

Laser scattering detection:
The laser beam (wavelength 532 nm) irradiates the crucible surface, and the scattered light signal reflects the surface defects (such as roughness and cracks).
Equipped with a photomultiplier tube (PMT) to collect scattered light and generate a defect distribution map.
Advantages: Non-contact, suitable for fast scanning of large crucibles (>500 mm).

Eddy current testing:
The crucible surface is scanned by an eddy current probe (frequency 1-10 MHz) to detect near-surface cracks and inclusions.
Suitable for welding crucibles in the weld area to identify micro cracks and pores.
Advantages: High sensitivity, suitable for internal defects of metals.

Detection parameters:
Surface roughness: The inner surface needs to have a very low roughness (Ra<0.8 μm), and the

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outer surface is slightly loose (Ra<1.6 μm).
Cracks and scratches: The length of cracks must be controlled below the micron level, and the depth of scratches must be extremely shallow.
Oxide layer and contamination: There should be no oxide residue on the surface, and the particle contamination should be very low (<100 particles/cm², particle size>0.5 μm).

Process Integration:
The online surface inspection system is linked with polishing, cleaning and coating equipment to provide real-time feedback of defect data.
Automatic sorting: Unqualified crucibles are sent to the rework area by a robotic arm, and qualified ones enter the next process.
Data traceability: The surface inspection data of each crucible is stored in the cloud to support quality traceability.

Quality Standards:
Complies with ISO 4287 (surface roughness standard) and ASTM E407 (metal surface testing standard).
The semiconductor industry requires surface cleanliness to comply with SEMI standards (such as SEMI F21).

Practical Application:
In the production of semiconductor silicon single crystals, surface defects of molybdenum crucibles may contaminate silicon melt. Chinatungsten Online's online laser scattering system ensures that there are no micro cracks on the inner surface to meet high purity requirements.

6.2 Performance Testing
Performance testing evaluates the high temperature strength, corrosion resistance and long-term stability of molybdenum crucibles under actual use conditions to ensure that they meet the needs of specific applications (such as high temperature environments of 1700-2050°C).

6.2.1 High temperature strength
High temperature strength is the key performance of molybdenum crucible to maintain structural integrity and anti-deformation ability in high temperature environment (such as sapphire crystal growth, rare earth smelting).

Test method:
High temperature tensile test:
It is carried out in a vacuum or inert atmosphere (argon or hydrogen) furnace at a temperature range of 1400-1800°C.
Measure tensile strength, yield strength and elongation by applying a constant stress using a high temperature tensile machine equipped with molybdenum or tungsten grips.
Test standard: ASTM E21 (High temperature tensile test specification).

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Advantages: Simulate the actual high temperature stress environment and evaluate the mechanical properties of the crucible.

High temperature creep test:
A constant stress (50-200 MPa) was applied at 1700-2000°C, and the creep rate and deformation were measured.
Equipment: High temperature creep testing machine equipped with laser displacement sensor (accuracy ±0.001 mm).
Test standard: ASTM E139 (creep test specification).
Advantages: Evaluate the stability of crucibles during long-term high-temperature operation.

Hardness test:
The hardness of the crucible at room temperature and high temperature (1000-1500°C) was measured using a high temperature Vickers hardness tester (load 1-10 kg).
Test standard: ASTM E92 (Vickers hardness test specification).
Advantages: Rapid evaluation of material strengthening effects (e.g. doping or heat treatment).

Test parameters:
Tensile strength: Sufficient strength must be maintained at high temperatures (>100 MPa at 1700°C), and doped crucibles have higher strength.
Creep rate: needs to be extremely low to ensure no significant deformation during long-term operation.
Hardness: High temperature hardness needs to be maintained at a high level (>150 HV), reflecting the material's ability to resist wear.

Process feedback:
Test results guide raw material selection (e.g. doping elements) and process optimization (e.g. heat treatment temperature).
If the strength is insufficient, the sintering temperature, forging deformation or doping ratio can be adjusted.
Data is stored in the quality management system to support performance traceability.

Quality Standards:
Conforms to ISO 6892-2 (elevated temperature metal tensile testing) and ASTM E139 (creep testing).
The sapphire crystal growth industry requires that the crucible remain free of deformation at 2050°C, and rare earth smelting requires long-term stability at 1700°C.

Practical Application:
During the growth of sapphire crystals, the molybdenum crucible needs to withstand high temperatures of 2050°C and mechanical stress. China Tungsten Online's high temperature tensile test ensures that the crucible is crack-free under extreme conditions.

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Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

Molybdenum crucibles are made of high-purity molybdenum powder through isostatic pressing, high-temperature sintering and precision machining. They have excellent high-temperature strength, corrosion resistance and dimensional stability, making them widely used in sapphire crystal growth, rare earth smelting, glass industry, vacuum coating and high-temperature heat treatment.

2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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6.2.2 Corrosion resistance

Corrosion resistance determines the durability of molybdenum crucibles in molten metals (such as rare earth metals), oxides or high-temperature atmospheres, especially in rare earth smelting and precious metal purification.

Test method:

Static corrosion test:

Immerse the molybdenum crucible sample in a molten medium (such as molten neodymium, alumina) at a temperature of 1400-1800°C and keep it warm for several hours to several days.

Measure wall thickness loss, surface erosion depth and mass loss.

Test standard: ASTM G31 (corrosion test specification).

Advantages: Simulate the actual use environment and evaluate the corrosion resistance of the crucible.

Dynamic corrosion testing:

The dynamic contact (such as stirring or flowing) between the crucible and the melt is simulated in a high temperature furnace at a temperature of 1500-1700°C.

The relative motion between the sample and the melt is controlled using a rotating immersion device to measure the corrosion rate.

Advantages: Closer to the actual working conditions of rare earth smelting.

Electrochemical corrosion test:

Measure the electrochemical behavior of crucibles (e.g. corrosion potential, polarization resistance) in high temperature molten salt or acid solutions.

Equipment: High temperature electrochemical workstation, temperature 800-1200°C.

Advantages: Quantification of corrosion mechanisms, suitable for coating crucibles.

Test parameters:

Wall thickness loss: needs to be extremely low (micrometer level/100 hours) to ensure the life of the crucible.

Surface erosion: The surface should be kept smooth without obvious pitting or peeling.

Mass loss: needs to be extremely small, reflecting the chemical stability of the crucible.

Coating performance: Anti-corrosion coatings (such as $MoSi_2$) must not peel off and have high bonding strength.

Process feedback:

Corrosion test results guide the selection of doping elements (such as CeO_2, La_2O_3) and coating process optimization.

If the corrosion rate is too high, the coating thickness can be increased or the sintering process can be adjusted to increase the crucible density.

The data are used to build a corrosion database to predict the life of crucibles in different environments.

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Quality Standards:
Conforms to ASTM G31 (corrosion testing) and ISO 11846 (high temperature corrosion testing).
Rare earth smelting requires that the crucible has a life of >1000 hours in molten neodymium at 1700°C, and the semiconductor industry requires no pollution.

Practical Application:
In the production of NdFeB magnets, molybdenum crucibles need to resist corrosion from molten neodymium. Chinatungsten Online's static corrosion test ensures the corrosion resistance of doped crucibles and extends their service life.

6.3 Failure Analysis

Failure analysis identifies the failure causes and optimizes the manufacturing process and use conditions by studying the cracks, deformation, fatigue and life attenuation of molybdenum crucibles.

6.3.1 Cracks and deformation

Cracks and deformation are common failure modes of molybdenum crucibles at high temperatures or thermal cycles, which may be caused by thermal stress, mechanical stress or material defects.

Analytical methods:
Macroscopic observation:
Crack location, length and morphology (surface crack or through-crack) are recorded using a high-resolution camera or stereo microscope.
Deformation measurements (e.g. crucible diameter change, wall thickness thinning) are performed using a laser scanner.

Microscopic analysis:
Scanning electron microscopy (SEM) was used to observe the crack morphology (intergranular fracture or ductile fracture) at a magnification of 1000-10,000 times.
Energy dispersive spectrometry (EDS) detects the chemical composition of the crack area to confirm whether embrittlement is caused by impurities (such as O, C).

Finite Element Analysis (FEA):
A thermal-mechanical coupling model of the crucible was established to simulate the stress distribution and deformation behavior at high temperatures.
Input parameters: thermal expansion coefficient of molybdenum (4.8×10^{-6} /K), thermal conductivity (138 W/(m·K)), and tensile strength.
Advantages: Predict crack initiation points and optimize crucible design.

Failure reason:
Thermal stress: Rapid temperature rise and fall (e.g. >10°C/min) causes thermal stress concentration and induces cracks.

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Mechanical stress: Impact forces during loading or unloading exceed the strength of the crucible.
Material defects: sintering pores, grain boundary impurities or welding pores reduce the toughness of the crucible.
Process problems: Uneven wall thickness or improper heat treatment leading to stress concentration.

Improvement measures:
Optimize thermal cycling: control the heating and cooling rates (<5°C/min) to reduce thermal stress.
Improve material quality: Use high-purity molybdenum powder (>99.95%) and doping elements (such as CeO_2) to refine the grains.
Improved processing: ensuring uniformity of wall thickness (deviation < 0.1 mm) and surface roughness (Ra < 0.8 μm).

Practical Application:
During sapphire crystal growth, cracks in the molybdenum crucible can lead to melt leakage.

6.3.2 Fatigue and lifespan

Fatigue failure and life attenuation are the main problems of molybdenum crucibles in repeated thermal cycles or long-term high-temperature operation, affecting their recycling capacity and economy.

Analytical methods:
Thermal Cycle Test:
Simulate actual use conditions (such as 1500-1700℃, 100-500 thermal cycles) to observe the formation and growth of fatigue cracks.
Equipment: High temperature thermal cycle furnace equipped with laser displacement sensors to record deformations.
Test standard: ISO 1893 (thermal shock test for refractory materials).

Fatigue fracture analysis:
The fracture morphology was observed using SEM to distinguish fatigue cracks (smooth striations) from transient fracture areas (dimples).
Electron backscatter diffraction (EBSD) analysis of crack propagation paths confirmed the effect of grain orientation on fatigue.

Lifespan prediction model:
Crucible life is predicted based on Miner's cumulative damage theory combined with thermal cycle and creep data.
Input parameters: number of thermal cycles, temperature gradient, stress level.
Advantage: Guides crucible maintenance and replacement cycles.

Failure reason:
Thermal fatigue: Repeated thermal cycles lead to the growth of microcracks, which eventually form

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macrocracks.
Creep: Long-term high temperature stress causes slow deformation, reducing the strength of the crucible.
Surface deterioration: Oxidation or corrosion causes surface defects that accelerate fatigue cracks.
Design defects: uneven wall thickness or sharp geometric corners causing stress concentration.

Improvement measures:
Enhanced material properties: Doping with oxides (such as La_2O_3) improves toughness and fatigue resistance.
Optimize design: increase corner radius (>2 mm) to reduce stress concentration.
Surface protection: Apply anti-oxidation coating (such as $MoSi_2$) to extend fatigue life.
Process improvement: Control grain size (<50 μm) and heat treatment parameters to reduce creep rate.

CTIA GROUP LTD Molybdenum Crucible

Chapter 8 Transportation and Storage of Molybdenum Crucible

As a high-value, high-temperature resistant industrial component, the transportation and storage of molybdenum crucibles are crucial to maintaining their physical integrity and chemical stability. Improper packaging, transportation or storage may cause surface scratches, oxidation, contamination or deformation, thus affecting their performance in high-end applications such as crystal growth, rare earth smelting, and semiconductor manufacturing. This chapter discusses in detail the transportation and storage specifications of molybdenum crucibles, covering packaging

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requirements, shock and moisture-proof measures, storage environment and conditions, inventory management and quality tracking, and provides comprehensive technical guidance with reference to global industry standards and best practices.

8.1 Packaging requirements

Molybdenum crucibles must ensure that they are protected from mechanical damage, chemical contamination and environmental impact during transportation and storage, while being easy to handle and identify.

Packaging Materials:

Inner Packing:

Use high-purity polyethylene (PE) or polypropylene (PP) film to wrap the crucible to prevent the surface from contacting air or particles and keep it clean.

Lined with high-density foam or bubble film, it provides cushioning protection and reduces the impact of vibration and shock.

It is recommended to use vacuum sealed bags to remove internal air to prevent oxidation and moisture absorption, especially for long-term storage.

Outer Packaging:

Use hardwood boxes (in compliance with ISPM 15 international phytosanitary standards) or aluminum alloy boxes, which are strong enough to withstand stacking and transportation pressure.

The interior of the wooden box is filled with shock-absorbing materials (such as polyurethane foam or pearl cotton) to ensure that the crucible is fixed without shaking.

The surface of the outer packaging is sprayed with waterproof paint or covered with a moisture-proof film to prevent moisture from penetrating.

Supplementary Materials:

Use ceramic or polytetrafluoroethylene (PTFE) gaskets to isolate the crucible from the packaging material to avoid scratches caused by metal contact.

Equipped with a desiccant (such as silica gel or molecular sieve) and placed in the inner packaging to control humidity to prevent corrosion.

Use dust-free labels and sealing tape to ensure no additional contamination during the packaging process.

Packaging design:

Size matching: The size of the packaging box is customized according to the specifications of the crucible, and the internal space fits the shape of the crucible tightly to ensure that it is fixed and has no room for movement.

Load-bearing capacity: The packaging box design must support multi-layer stacking and be suitable for long-distance transportation and warehousing needs.

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Logo and label:

The outer packaging is marked with warning signs such as "fragile", "moisture-proof", and "handle with care". The fonts are clear and visible and comply with ISO 780 (packaging marking standard).

Comes with a product label containing the crucible model, size, batch number, production date, net weight and supplier information, using a waterproof, wear-resistant label (such as PVC or PET).

Provide a packing list and quality certificate, seal them in a transparent plastic bag and stick them on the outside of the packaging box.

Traceability: The packaging box is printed with a QR code or comes with an RFID tag, which is linked to the production and quality data of the crucible and supports digital tracking.

Packaging process:

Cleaning: Before packaging, wipe the crucible with a dust-free cloth dipped in high-purity ethanol to confirm that there are no particles, oil stains or fingerprints, and the surface cleanliness meets the requirements of the semiconductor industry.

Packaging: Inner packaging is done in a clean room, using dust-free gloves and non-metallic tools.

Fixing: The crucible is placed in a custom foam mold, filled with shock absorbing material, and ensured that there are no gaps. The outer packaging box is sealed with stainless steel bolts or high-strength tape.

Inspection: Visual inspection after packaging to confirm that there is no looseness or damage. Vibration test if necessary to simulate transportation conditions to ensure the safety of the crucible.

Quality Standards:

The packaging must comply with ISO 3394 (transport packaging dimensions) and ASTM D4169 (transport packaging performance test).

The semiconductor industry requires packaging materials to be free of volatile organic compounds (VOCs) and comply with SEMI E170 (clean packaging standard).

The packaging process must be carried out under the ISO 9001 quality management system to ensure consistency and reliability.

Practical Application:

In the sapphire crystal growth industry, vacuum-sealed packaging of molybdenum crucibles prevents oxidation during transportation and ensures that the surface is free of contamination.

In rare earth smelting, hard wooden boxes and foam liners protect large crucibles and reduce the risk of deformation during transportation.

8.2 Shock and moisture resistance

Anti-vibration and moisture-proof measures are the core requirements for the transportation and storage of molybdenum crucibles, aiming to prevent mechanical damage and chemical deterioration and ensure that the performance of the crucible is not affected.

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2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

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Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
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100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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Anti-shock measures:

Cushioning material:

Use high-density polyurethane foam or pearl cotton to fill the inside of the packaging box to provide sufficient shock-absorbing capacity to absorb vibration and impact during transportation.

For small crucibles, air cushion film can be used to provide additional protection, suitable for lightweight packaging.

Large crucibles require custom foam molds that precisely match the shape of the crucible to ensure a tight fit and prevent movement.

Packing box design:

The outer packaging box is made of multi-layer plywood or aluminum alloy, which has high impact resistance and is suitable for long-distance transportation.

Shock-absorbing springs or rubber pads are installed inside to reduce vibration transmission and protect the crucible from external impact.

The bottom of the packaging box is equipped with an anti-skid pad to increase friction and prevent sliding during transportation.

Transport protection:

The transport vehicles are equipped with air bag suspension or hydraulic shock absorption system to reduce the impact of road vibration on the crucible.

The crucible packaging box is fixed on a standard transport pallet and reinforced with high-strength nylon or steel straps to ensure stability.

Avoid sudden acceleration, sudden braking or severe bumps during transportation. It is recommended to use a professional logistics company that is familiar with the transportation regulations for fragile goods.

Moisture-proof measures:

Sealed Packaging:

The inner packaging uses a vacuum sealed bag or a high barrier film (such as aluminum-plastic composite film) to prevent moisture from entering and keep the crucible surface dry.

The inside of the outer packaging box is coated with a moisture-proof agent or covered with a moisture-proof film to enhance the waterproof performance.

Desiccant:

Place silica gel or molecular sieve desiccant in the inner packaging to absorb residual moisture and keep the relative humidity extremely low.

Desiccant should be checked and replaced regularly, especially during long-term storage or in areas of high humidity.

Transportation environment:

The transport vehicles are equipped with moisture-proof facilities (such as sealed cargo holds or dehumidification equipment) to avoid rain or high humidity environments.

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Temperature-controlled transportation (temperature 20-25°C, humidity <40%) is recommended, especially during cross-regional or sea transportation.

Inspection and monitoring:
After packaging, use a humidity indicator card (accuracy ±5%) to check the humidity of the inner packaging to confirm that no moisture has penetrated.
During transportation, a temperature and humidity recorder is installed to monitor environmental conditions in real time and sound an alarm when abnormalities occur.

Quality Standards:
Anti-vibration measures must pass ASTM D4169 vibration and shock tests to ensure that the crucible is not damaged during transportation.
The moisture-proof performance complies with ISO 2233 (package moisture-proof test), and the packaging box remains dry even in a high humidity environment.
The transportation process must comply with IATA (International Air Transport Association) or IMDG (International Maritime Dangerous Goods) standards to ensure safety.

Practical Application:
In the semiconductor industry, the shockproof packaging of molybdenum crucibles ensures that there are no micro cracks during transportation and maintains high precision requirements.
In the purification of precious metals, moisture-proof packaging prevents oxidation of the crucible surface and ensures cleanliness before use.

8.3 Storage environment and conditions

molybdenum crucibles must strictly control temperature, humidity, cleanliness and chemical stability to prevent oxidation, contamination or performance degradation.

Temperature and humidity:
Temperature control:
The storage environment should maintain a constant temperature (20-25°C) to avoid temperature fluctuations that may cause thermal stress or condensation.
Use air conditioning or temperature control equipment to control temperature deviation within a very small range.

Humidity Control:
The relative humidity is kept <40%, preferably <20%, to prevent the surface of the molybdenum crucible from absorbing moisture or oxidation.
Equipped with industrial dehumidifier or drying cabinet, humidity monitoring accuracy is ±2%.
In areas of high humidity, it is recommended to use a sealed storage box with a desiccant inside.

Monitor:
Install a temperature and humidity recorder to record environmental data in real time and trigger an

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alarm when an abnormality occurs.

Check storage areas regularly to verify there are no water leaks or condensation.

Cleanliness:

Environmental requirements:

The storage area must reach ISO 7 or higher cleanliness level with extremely low particle concentration to prevent dust from contaminating the crucible surface.

The floor is coated with epoxy resin, which has appropriate surface resistance and reduces static adsorption of particles.

Protective measures:

The crucible should be stored in a sealed packaging box or dust-free cabinet and equipped with a dust cover or protective cover.

When entering the storage area, you need to wear dust-free clothing, masks and gloves and comply with ISO 14644 clean room operation specifications.

Cleaning and maintenance:

Clean storage areas regularly, using a dust-free vacuum or damp cloth to remove particles from floors and shelves.

Avoid using volatile chemicals in storage areas to prevent gas contamination.

Chemical stability:

Avoid corrosive gases:

storage environment must be free of acidic gases (such as HCl, SO_2) or oxidizing gases (such as O_3) , and the oxygen content must be controlled at an extremely low level.

Use an air purifier or activated carbon filter to remove potential pollutants.

Material Isolation:

The crucible is isolated from metal shelves or tools. It is recommended to use ceramic or plastic trays to avoid contact corrosion.

It is prohibited to store crucibles together with other chemically active materials (such as acids and alkalis) to prevent cross contamination.

Storage layout:

Shelf design:

Use dust-free stainless steel or plastic shelves with flat surface and corrosion resistance.

The shelves are of moderate height (<2 m), easy to load and unload, and are equipped with anti-tipping devices.

Stacking specification:

The packaging boxes should be stacked in a single layer to avoid deformation due to heavy pressure, and the stacking height should not exceed the load-bearing capacity of the packaging boxes.

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There should be enough space (>10 cm) between each box to facilitate ventilation and inspection.

Identity Management:
The storage area is divided into sections by batch and model, and the crucible specifications and storage date are marked.
Use barcodes or RFID tags to quickly identify crucible information.

Quality Standards:
The storage environment must comply with ISO 14644 (clean room standard) and ASTM E2352 (high temperature material storage specification).
The semiconductor industry requires extremely low particle concentrations in storage areas and chemical contaminants < 1 ppb.

Practical Application:
In silicon single crystal production, the clean storage environment of the molybdenum crucible prevents surface contamination and meets high purity requirements.
In the melting of aerospace high-temperature alloys, constant temperature and low humidity storage prolongs the life of the crucible and reduces the risk of oxidation.

8.4 Inventory Management and Quality Tracking

Effective inventory management and quality tracking ensure that the storage status of molybdenum crucibles is controllable and the quality is traceable, meeting production needs and customer requirements.

Inventory Management:
Storage by category:
Crucibles are stored in different areas according to their model, size, material (such as pure molybdenum, doped molybdenum) and purpose (such as crystal growth, rare earth smelting).
Use an electronic inventory management system to record the batch number, storage time and storage location of each crucible.

First In First Out (FIFO):
Follow the first-in-first-out principle and give priority to the crucibles that were stored earlier to prevent performance degradation due to long-term storage.
Perform regular inventory checks (every 3-6 months) to update inventory status and remove expired or damaged crucibles.

Quantity Control:
Set reasonable inventory levels based on production plans and demand forecasts to avoid backlogs or shortages.
Equipped with an automated inventory system to quickly update inventory data through barcode or RFID scanning.

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Quality Tracking:

Data Record:

Each crucible comes with a quality file, which records the production process parameters (such as sintering temperature, doping ratio), test results (such as purity, density) and packaging information.

Use cloud computing platforms to store quality data, supporting remote access and multi-party sharing.

Regular inspection:

Sample stored crucibles every 6-12 months to check surface condition (scratches, oxidation), packaging integrity and humidity levels.

Use an optical microscope (magnification 50-200 times) to detect surface defects, and XPS to analyze the chemical composition to confirm that there is no contamination.

Traceability:

Each crucible is assigned a unique identification code (QR code or RFID) that is linked to the entire process data of production, transportation and storage.

When quality problems occur, they can be traced back to specific batches and process links to quickly locate the causes.

Feedback Mechanism:

Collect customer feedback and record the performance of crucibles in actual applications (such as lifespan and corrosion resistance).

Analyze feedback data, optimize storage conditions and packaging design, and improve product quality.

Digital Management:

Inventory Management System:

Integrate with ERP (Enterprise Resource Planning) or WMS (Warehouse Management System) to monitor inventory status in real time and automatically generate inbound, outbound and inventory reports.

Supports mobile operation, making it convenient for on-site managers to quickly query and update data.

Internet of Things (IoT):

The storage area is equipped with temperature and humidity sensors and RFID readers to upload environmental data to the cloud in real time.

When an abnormality occurs (such as excessive humidity or temperature fluctuation), the system will automatically alarm and prompt management personnel to take measures.

Data Analysis:

Use big data analytics to predict crucible storage life and optimize inventory turnover.

Establish a quality database to analyze the impact of long-term storage on crucible performance and

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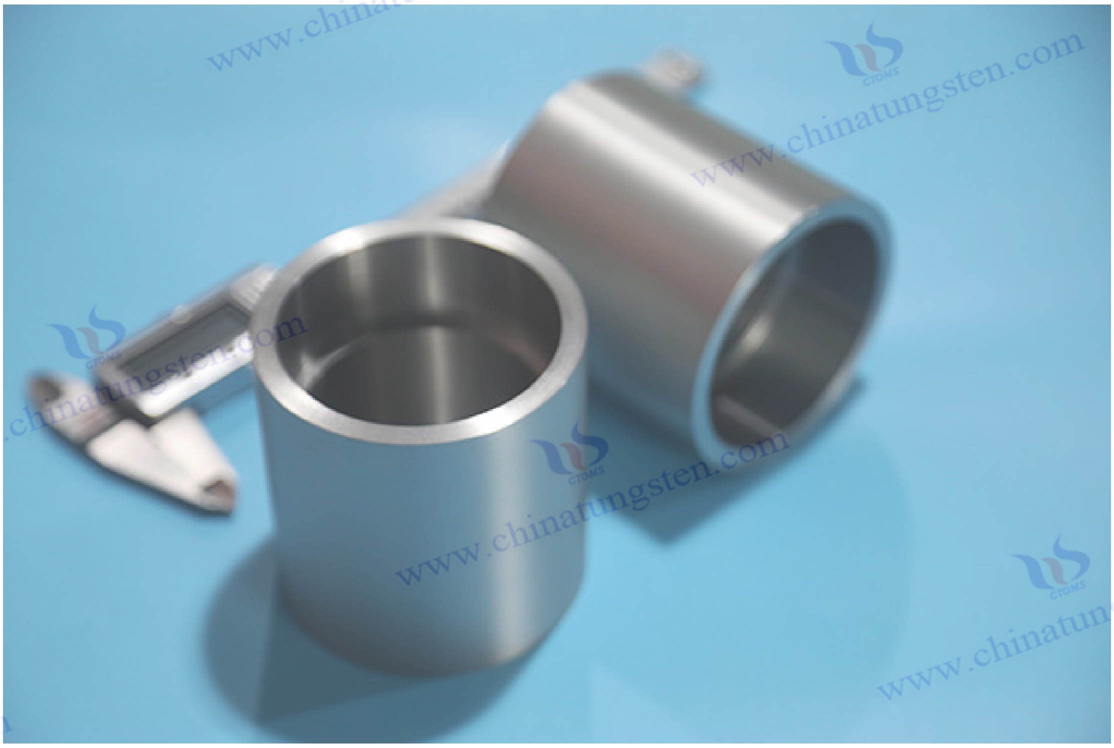
provide guidance for improvements.

Quality Standards:
Inventory management must comply with ISO 9001 (quality management system) and ISO 28000 (supply chain security management).
Quality tracking must meet ASTM B386 (molybdenum material standard) and SEMI E170 (clean packaging standard).
Traceability is in compliance with ISO 8000 (data quality standard), ensuring data integrity and accuracy.

Practical Application:
In the rare earth smelting industry, digital inventory management ensures rapid supply of molybdenum crucibles and reduces production interruptions.
In the semiconductor industry, the quality tracking system ensures that the crucible is contaminant-free from storage to use, meeting high purity requirements.



CTIA GROUP LTD Molybdenum Crucible

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Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

Molybdenum crucibles are made of high-purity molybdenum powder through isostatic pressing, high-temperature sintering and precision machining. They have excellent high-temperature strength, corrosion resistance and dimensional stability, making them widely used in sapphire crystal growth, rare earth smelting, glass industry, vacuum coating and high-temperature heat treatment.

2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

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Chapter 9 Sustainability and Recycling of Molybdenum Crucibles

Molybdenum crucibles are indispensable in high-end industries such as crystal growth, rare earth smelting, and semiconductor manufacturing, but their production and use involve high energy consumption, resource consumption, and potential environmental impacts. With the global emphasis on sustainable development, the manufacture, recovery, and recycling of molybdenum crucibles have become the focus of industry attention. This chapter discusses the sustainability and recycling of molybdenum crucibles in detail, covering energy conservation and emission reduction, waste recycling technology, recycling economic and environmental benefits, green manufacturing trends and practices, and provides comprehensive technical and strategic guidance with reference to global industry standards, academic research, and best practices.

9.1 Energy Saving and Emission Reduction

Molybdenum crucibles involve high energy consumption processes (such as roasting, sintering, forging), which places higher demands on energy efficiency and emission control. Energy saving and emission reduction are the key to achieving sustainable production.

Energy saving measures:

Process Optimization:

Use high-efficiency roasting equipment (such as multi-chamber furnaces or rotary kilns) to improve energy utilization through precise temperature control and heat recovery systems.

Use a high-temperature vacuum sintering furnace equipped with heat pipes or radiation shielding to reduce heat loss.

Optimize forging and spinning processes, reduce repeated heating and processing steps, and shorten production cycles.

Equipment Upgrade:

Introduce variable frequency motors and intelligent control systems to dynamically adjust equipment power and reduce standby energy consumption.

Use induction heating instead of resistance heating to improve heating efficiency and reduce power consumption.

Equipped with an energy management system to monitor production energy consumption in real time, identify and eliminate energy waste.

Renewable Energy:

Integrate solar, wind or geothermal energy into production facilities to reduce dependence on fossil fuels.

Give priority to green electricity suppliers and ensure that energy sources meet low-carbon standards.

Emission reduction strategies:

Waste gas treatment: produced during the roasting process is treated by wet desulfurization and converted into calcium sulfate by-product.

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Volatile organic compounds (VOCs) from sintering and thermal processing are removed using activated carbon adsorption or catalytic combustion technology.
Equipped with high-efficiency dust collectors (such as bag filters or electrostatic dust collectors) to capture dust particles and prevent air pollution.

Wastewater Management:
The acidic wastewater generated by chemical purification and surface treatment is treated by neutralization, precipitation and filtration to recover useful substances such as ammonium molybdate.
Use a closed-loop water system to reduce water consumption and wastewater discharge.

Carbon Footprint Control:
molybdenum crucibles from raw material extraction to manufacturing are analyzed through life cycle assessment (LCA) to identify key emission reduction points.
Optimize supply chains and choose low-carbon transportation methods (such as rail or electric trucks) to reduce logistics emissions.
Implement carbon neutrality programs, such as carbon offsetting or reforestation, to offset carbon emissions in production.

Monitoring and reporting:
Install an energy consumption monitoring system to record the energy consumption of each process and generate energy saving reports.
Equipped with emission monitoring equipment to detect SO_2, NOx and particulate matter concentrations in real time to ensure compliance with emission standards.
Submit environmental reports regularly and comply with ISO 14001 (Environmental Management System) and local environmental regulations.

Quality Standards:
Energy-saving measures must comply with ISO 50001 (Energy Management System) to ensure continuous improvement of energy efficiency.
Emission reductions must comply with EU REACH regulations and China GB 28662 (non-ferrous metal industry emission standards).
Carbon footprint assessment refers to ISO 14067 (product carbon footprint standard).

Practical Application:
In the sapphire crystal growth industry, heat recovery systems in high-efficiency sintering furnaces significantly reduce energy consumption and improve production sustainability.
In rare earth smelting, waste gas treatment technology reduces SO_2 emissions and improves the environmental quality around the factory.

9.2 Waste Recycling Technology
The waste materials (such as scraps, waste crucibles, and powder) generated during the production

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and use of molybdenum crucibles are valuable resources. Advanced recycling technologies can be used to recycle resources and reduce costs and environmental impacts.

Waste classification:

Production waste:

It includes molybdenum powder, sintering residues, forging scraps and machining chips, which come from non-qualified products or waste materials in the production process.

Features: high purity, low impurity content, suitable for direct recovery.

Post-consumer waste:

Includes scrapped crucibles, surface coating flakes and melt residues, which come from used crucibles.

Features: May contain melt contaminants (such as alumina, rare earth metals) and require pretreatment.

Category management:

Store waste materials according to their source, composition and degree of contamination, using sealed containers and clear labels.

Equipped with dedicated recycling areas to avoid cross contamination of waste materials with the production environment.

Recycling technology:

Physical Recycling:

Mechanical separation: Use crushers and vibrating screens to separate the molybdenum matrix and surface coating (such as $MoSi_2$) in the spent crucible and recover high-purity molybdenum fragments.

Magnetic separation and flotation: Remove impurities such as iron and silicon from waste materials and improve molybdenum recovery rate.

Screening and grinding: Grind the recovered molybdenum fragments into powder with particle size controlled at micron level, which is suitable for re-sintering.

Chemical recycling:

The molybdenum compounds in the waste to produce ammonium molybdate solution, which is filtered to remove insoluble impurities (such as SiO_2).

Ammonia dissolution: Molybdenum oxide (MoO_3) reacts with ammonia water to generate high-purity ammonium molybdate, which is then crystallized and calcined to recover molybdenum powder.

Molybdenum is extracted from waste liquid by electrolysis, which is suitable for recovering low-concentration molybdenum solution.

Metallurgical Recovery:

Molybdenum materials in a vacuum or hydrogen atmosphere to remove volatile impurities and

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produce high-purity molybdenum ingots.
Plasma Refining: Using a plasma arc to melt the scrap further purifies the molybdenum to produce extremely pure molybdenum metal.
Regional smelting: Through local high temperature and multiple purification, it is suitable for the production of semiconductor-grade molybdenum materials.

Recycling process optimization:
Pretreatment: High temperature cleaning (1000-1200℃, vacuum or hydrogen atmosphere) of used waste to remove melt residues and coatings.
Automation: Introduce automated sorting equipment (such as X-ray sorters) to improve waste sorting efficiency and purity.
Closed-loop system: The recycling process is integrated with the production process, and the recovered molybdenum powder is directly used in the manufacture of new crucibles, reducing resource waste.

Quality Control:
Recycled molybdenum powder needs to be tested for purity (>99.95%), particle size (micron level) and impurity content (C, O, N <0.01%).
Using ICP -MS (Inductively Coupled Plasma Mass Spectrometry).
Recycled materials must pass performance tests (such as density and hardness) to ensure that they meet ASTM B386 standards.

Quality Standards:
Recycling technologies need to comply with ISO 14040 (life cycle assessment) and ISO 14044 (environmental management).
Waste disposal must comply with the EU WEEE Directive (Waste Electrical and Electronic Equipment) and China's Law on the Prevention and Control of Environmental Pollution by Solid Waste.
The recycling rate target reaches a high level to reduce resource waste.

Practical Application:
In the semiconductor industry, chemical recycling technology of waste molybdenum crucibles produces high-purity molybdenum powder to meet the needs of silicon single crystal production.
In precious metal purification, metallurgical recycling technology converts waste crucibles into molybdenum ingots, reducing production costs.

9.3 Economic and environmental benefits of recycling
Recycling molybdenum crucible waste not only reduces resource consumption and production costs, but also brings significant environmental and social benefits, and promotes the development of the circular economy.

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Economic Benefits:

Cost Savings:

Recycling molybdenum waste is much lower than extracting new molybdenum from molybdenite, saving the cost of purchasing raw materials.

Closed-loop recycling systems reduce waste handling and disposal costs and optimize supply chain efficiency.

Resource efficiency:

Recycling reduces the demand for molybdenum ore mining and extends the service life of rare metal resources.

Recycled molybdenum powder can be directly used in production, shortening the manufacturing cycle and increasing production capacity.

Market competitiveness:

Offering sustainable products attracts environmentally conscious customers and strengthens your brand image.

Comply with green procurement standards and open up high-end markets (such as semiconductors and aerospace).

Environmental benefits:

Resource Protection:

Reduce molybdenum mining, reduce land destruction, tailings accumulation and ecological impact.

Recycling reduces dependence on rare metals and protects non-renewable resources.

Pollution reduction:

The recycling process consumes less energy than primary molybdenum production and reduces emissions of CO_2, SO_2 and other pollutants.

Proper waste disposal avoids soil and water pollution and improves environmental quality.

Energy saving:

recycled molybdenum is much lower than that of primary molybdenum refining, which reduces the carbon footprint of production.

Efficient recovery technologies such as plasma refining further reduce energy consumption.

Social Benefits:

Career Opportunities:

The recovery and recycling industry creates jobs and covers waste collection, sorting and processing.

Promote green technology research and development and attract highly skilled talents.

Community Impact:

Reduce the interference of mining on local communities and improve the quality of life of residents.

Green production enhances the corporate social responsibility (CSR) image and gains community

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support.

Circular Economy Model:

Closed-loop supply chain:

Establish a closed-loop system from production to recycling and reuse to maximize the value of resources.

Collaborate with suppliers and customers to build a waste recycling network to ensure a stable supply.

Policy support:

Use government subsidies and tax incentives to encourage companies to invest in recycling technology and green manufacturing.

Participate in circular economy pilot projects and share best practices.

Digital Management:

Use blockchain technology to track the life cycle of molybdenum crucibles to ensure that the recycling process is transparent and traceable.

Implement data analysis to optimize recycling efficiency and resource allocation.

Quality Standards:

Recycling must comply with ISO 14021 (environmental labelling and declarations) and ISO 14064 (greenhouse gas accounting).

The economic benefit assessment refers to the UNEP (United Nations Environment Programme) circular economy guidelines.

Environmental benefits need to be quantified through LCA (Life Cycle Assessment) in accordance with ISO 14040 standards.

Practical Application:

In the rare earth smelting industry, recycling of waste molybdenum crucibles reduces production costs while reducing tailings emissions.

In aerospace high-temperature alloy manufacturing, recycling molybdenum crucibles supports a green supply chain and meets the industry's sustainability goals.

9.4 Green Manufacturing Trends and Practices

Green manufacturing is the future direction for the molybdenum crucible industry to achieve sustainable development, covering technological innovation, intelligent production and ecological design, and promoting the industry's transformation towards low-carbon and environmentally friendly.

Technological innovation:

Low energy consumption process:

Develop plasma atomization technology to produce high-purity molybdenum powder and reduce

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the energy consumption of reduction and grinding.
Use laser-assisted processing instead of traditional cutting to reduce energy consumption and waste generation.

Clean production:
Use solvent-free surface treatment technologies (such as plasma spraying) to reduce chemical usage and waste discharge.
Develop water-based cleaning agents to replace acidic cleaning solutions and reduce environmental risks.

Green Materials:
Research and develop molybdenum -based composite materials (such as Mo-Re alloy) to improve the durability of crucibles and extend their service life.
Use recyclable packaging materials, such as biodegradable plastics, to reduce packaging waste.

Intelligent production:
Industry 4.0:
Introducing the Internet of Things (IoT) and sensors to monitor energy consumption, emissions and waste generation during production in real time.
Use artificial intelligence (IDEALIZED AI) to optimize process parameters and reduce resource waste.

Digital Twin:
Establish a virtual model of the molybdenum crucible production process, simulate the energy-saving and emission reduction effects, and guide process improvements.
Predict equipment maintenance needs to reduce downtime and energy waste.

automation:
Deploy robots and automated assembly lines to improve production efficiency and reduce waste in manual operations.
Use intelligent sorting equipment to optimize the waste recycling process and improve the recycling rate.

Eco-design:
Product Design:
Modular molybdenum crucible design is easy to disassemble and recycle, reducing waste.
Optimize crucible geometry to reduce material usage while maintaining performance.

Lifecycle Management:
The environmental impact of crucibles from production to recycling is evaluated through LCA , and low-carbon processes are preferred.
Design recyclable crucibles to support multiple recycling and remanufacturing.

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Green Certification:

Apply for ISO 14001 certification to prove that the production process complies with environmental management standards.

Obtain EPD (Environmental Product Declaration) to show customers the environmental performance of the crucible.

Industry Practice:

Collaboration and Sharing:

Cooperate with upstream and downstream enterprises to establish a molybdenum waste recycling network and share recycling facilities and data.

Participate in industry alliances, such as the International Molybdenum Association, to promote green manufacturing best practices.

Policy drivers:

In response to global carbon neutrality goals (such as the EU's 2050 carbon neutrality plan), develop a corporate carbon reduction roadmap.

Take advantage of government green manufacturing subsidies and invest in energy-saving equipment and recycling technologies.

Consumer Education:

Acceptance of sustainable molybdenum crucibles by promoting green product advantages.

Provide recycling instructions to encourage customers to return used crucibles to the supplier.

Quality Standards:

Green manufacturing must comply with ISO 14001 (environmental management system) and ISO 50001 (energy management system).

Technological innovation refers to IEC 62474 (material declaration standard) to ensure that the materials are environmentally friendly.

Ecodesign needs to follow ISO 14006 (Ecodesign Guidelines).

Practical Application:

In the semiconductor industry, intelligent production and eco-design reduce the carbon footprint of molybdenum crucible manufacturing and meet green supply chain requirements.

In sapphire crystal growth, low-energy consumption processes and waste recycling technologies reduce production costs and improve environmental benefits.

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Chapter 10 Molybdenum Crucible Technical Challenges and Future Development

Molybdenum crucibles play an irreplaceable role in high-end fields such as sapphire crystal growth, rare earth smelting, semiconductor manufacturing, aerospace, etc. due to their high melting point (2623°C), excellent high temperature resistance and corrosion resistance. However, with the complexity of application scenarios and the improvement of performance requirements, the manufacture and use of molybdenum crucibles face multiple technical challenges, including anti-oxidation performance, complex shape manufacturing and cost control. At the same time, the rapid development of new materials, new technologies, intelligent production and green manufacturing has opened up broad prospects for the future of molybdenum crucibles. This chapter discusses in detail the technical challenges and future development directions of molybdenum crucibles, covering technical challenges, new materials and technologies, intelligent and green manufacturing, and future trends. It refers to global academic research, industry standards and cutting-edge practices to provide comprehensive technical analysis and strategic outlook.

10.1 Technical Challenges

Molybdenum crucibles need to cope with the challenges brought by high temperature, corrosion and complex process environment. The following analysis is carried out from three aspects: anti-oxidation performance, complex shape manufacturing and cost control.

10.1.1 Antioxidant properties

Molybdenum easily reacts with oxygen at high temperatures (>600°C) to form volatile molybdenum

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oxide (MoO_3), which leads to crucible surface degradation, wall thickness loss and performance degradation. This problem is particularly prominent in non-vacuum or non-inert atmosphere environments.

Challenge Description:

Oxidation mechanism: Molybdenum forms MoO_3 in a high-temperature oxidizing environment , which volatilizes and leaves pores, resulting in surface roughness and reduced strength. In the growth of sapphire crystals, trace amounts of oxygen may cause the crucible surface to peel off and contaminate the melt.

Difficulty of atmosphere control: Even in vacuum ($<10^{-3}$ Pa) or high-purity inert atmosphere (argon, oxygen content <10 ppm), trace oxygen infiltration is still difficult to completely avoid, especially in large furnaces or long-term operation.

Coating limitations: Current anti-oxidation coatings (such as $MoSi_2$ and ZrO_2) may peel off or crack at extremely high temperatures (>1800°C), reducing the protective effect. The bonding strength and thermal expansion coefficient matching between the coating and the substrate need to be further optimized.

Application scenarios: In rare earth smelting or precious metal purification, the crucible may be exposed to complex atmospheres (such as those containing trace amounts of oxidizing gases), and higher anti-oxidation performance is required.

Technical Difficulties:

Develop an oxidation-resistant coating that can withstand ultra-high temperatures (>2000°C) while maintaining good bonding between the coating and the molybdenum substrate.
Improve the intrinsic oxidation resistance of molybdenum materials and reduce oxidation sensitivity through doping or alloying.
Design efficient atmosphere control systems to precisely control oxygen content and gas flow to adapt to dynamic production environments.
Balance antioxidant performance with cost to ensure solutions are suitable for large-scale production.

Coping strategies:

Surface modification: Use plasma spraying or chemical vapor deposition (CVD) to prepare multilayer composite coatings (such as $MoSi_2/Al_2O_3$) to improve oxidation resistance and thermal stability.

Doping technology: Doping with rare earth oxides (such as La_2O_3 and CeO_2) can refine the molybdenum grains, enhance the grain boundary stability and slow down the oxidation rate.

Atmosphere Optimization: Develop an intelligent atmosphere control system that integrates a mass spectrometer and oxygen sensor to adjust the gas composition in real time to keep the oxygen content extremely low.

Test verification: Establish a high temperature oxidation test platform to simulate actual use conditions (1700-2050℃, oxygen-containing atmosphere) and evaluate the anti-oxidation life of coatings and materials.

Practical Application:
In the growth of sapphire crystals, the composite coated molybdenum crucible can effectively resist the erosion of trace oxygen and extend its service life.
In high-temperature alloy smelting, molybdenum -doped crucibles reduce oxidation losses and lower the risk of melt contamination.

10.1.2 Complex Shape Manufacturing

Modern industry has increasingly higher requirements on the geometric shape and dimensional accuracy of molybdenum crucibles, such as thin walls, large diameters, and special-shaped structures. The manufacture of crucibles with complex shapes faces multiple technical obstacles.

Challenge Description:
Material properties: Molybdenum 's high hardness and low ductility (high brittleness at room temperature) make it difficult to process, especially when manufacturing thin-walled (<5 mm) or complex-shaped (such as conical, trapezoidal) crucibles, which are prone to cracks or deformation.

Forming technology: Traditional spinning, forging and welding processes are difficult to meet high precision and complex geometry requirements, and it is difficult to ensure uniformity of wall thickness and surface finish.

Dimensional accuracy: Large crucibles (diameter > 500 mm) require micron-level tolerances that are difficult to reliably achieve with existing processing equipment and mold designs.

Application requirements: The semiconductor industry requires ultra-thin-wall crucibles (<3 mm) to optimize thermal field uniformity, and the aerospace industry requires special-shaped crucibles to adapt to specific melting processes.

Technical Difficulties:
Improve the machinability of molybdenum materials and reduce the tendency to crack during high temperature processing.
Develop high-precision molding technology to meet the manufacturing needs of complex shapes and thin-walled structures.
Optimize mold design and processing paths to ensure uniform wall thickness and surface quality.
Balance manufacturing precision and production efficiency to meet mass production needs.

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Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

Molybdenum crucibles are made of high-purity molybdenum powder through isostatic pressing, high-temperature sintering and precision machining. They have excellent high-temperature strength, corrosion resistance and dimensional stability, making them widely used in sapphire crystal growth, rare earth smelting, glass industry, vacuum coating and high-temperature heat treatment.

2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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

Website: www.molybdenum.com.cn

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Coping strategies:

Additive Manufacturing: Explore 3D printing technologies such as Laser Powder Bed Fusion (LPBF) or Electron Beam Melting (EBM) to directly form complex crucible shapes and reduce subsequent processing.

Hot Isostatic Pressing (HIP): HIP technology is used to improve crucible density and uniformity, reduce molding defects, and is suitable for thin-walled structures.

Precision Spinning: Develop CNC spinning equipment equipped with a real-time monitoring system to control wall thickness deviation and surface roughness.

Mold optimization: Design multi-stage progressive molds and combine finite element analysis (FEA) to simulate the molding process and optimize stress distribution and material flow.

Practical Application:

In the silicon single crystal Czochralski method, 3D printed molybdenum crucibles achieve complex thermal field design and improve crystal quality.

In the melting of aerospace high-temperature alloys, precision spinning technology is used to manufacture special-shaped crucibles to meet customized needs.

10.1.3 Cost Control

Molybdenum crucibles keep their production costs high, limiting their widespread application in some fields. Especially in the highly competitive market, cost control becomes a key challenge.

Challenge Description:

Raw material cost: High-purity molybdenum (>99.95%) is expensive, and doping elements (such as CeO_2, La_2O_3) and anti-oxidation coatings further increase the cost.

Manufacturing costs: High energy consumption processes (such as vacuum sintering, plasma spraying) and complex processing (such as precision spinning) lead to high production costs.

Recycling cost: The recycling of waste crucibles involves chemical treatment and metallurgical purification, which is a complex process with high energy consumption.

Market Competition: Low-cost alternative materials (such as graphite, ceramics) have price advantages in certain applications, squeezing the molybdenum crucible market share.

Technical Difficulties:

Reduce procurement costs of high purity molybdenum and doping materials while maintaining performance.

Optimize production processes, reduce energy consumption and waste, and improve resource utilization.

Develop efficient recycling technologies to reduce waste disposal costs and increase recycling rates.

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molybdenum crucible products suitable for the mid- and low-end markets.

Coping strategies:
Raw material optimization: Explore low-cost molybdenum sources (such as recycled molybdenum waste) or alternative doping elements (such as ZrO_2 instead of rare earth oxides) to reduce raw material costs.

Process improvement: Use efficient sintering technology (such as microwave sintering) to shorten heating time and reduce energy consumption. Optimize processing paths and reduce waste generation.

Large-scale production: Build automated production lines to improve production efficiency and spread unit costs.

Recycling and Integration: Establish a closed-loop recycling system to directly convert waste crucibles into high-purity molybdenum powder, reducing recycling costs.

Practical Application:
In rare earth smelting, automated production lines and waste recycling reduce the production cost of molybdenum crucibles and improve market competitiveness.
In the purification of precious metals, process optimization reduces energy consumption and meets the cost needs of small and medium-sized enterprises.

10.2 New Materials and Technologies

The introduction of new materials and technologies has made it possible to improve the performance and expand the application of molybdenum crucibles. The following will be discussed from three aspects: molybdenum-based composite materials, nanostructures and alternative materials.

10.2.1 Molybdenum -based composite materials

Molybdenum -based composite materials improve the mechanical properties, corrosion resistance and oxidation resistance of crucibles by adding strengthening phases or functional phases.

Material Design:
Molybdenum -rare earth composite materials: doped with La_2O_3 , CeO_2 or Y_2O_3 , refined grains (<50 μm), improved high temperature strength and creep resistance, suitable for sapphire crystal growth (2050°C).

Molybdenum - ceramic composites: Adding SiC , Al_2O_3 or ZrO_2 particles enhances hardness and wear resistance and prolongs the life of the crucible in corrosive melts (such as rare earth metals) .

Molybdenum -metal composites: alloyed with tungsten (Mo-W) or rhenium (Mo-Re) to improve toughness and thermal shock resistance, suitable for high-temperature melting in aerospace.

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Manufacturing Technology:

Powder Metallurgy: Composite crucibles are prepared by high temperature sintering and hot pressing to ensure uniform phase distribution.

Plasma spraying: Preparation of composite coatings (such as $MoSi_2/ZrO_2$) to improve surface oxidation resistance and corrosion resistance.

Mechanical alloying: Use high energy ball milling to dope strengthening phases and optimize the material microstructure.

Performance advantages:

The high temperature strength is improved and the creep resistance is better than pure molybdenum.

Oxidation resistance is enhanced and coating life is extended.

Improved corrosion resistance, suitable for a variety of melt environments.

Practical Application:

In the semiconductor industry, Mo-Re composite crucibles improve thermal cycle stability and meet the needs of silicon single crystal production.

In rare earth smelting, Mo-SiC composite crucibles can resist the erosion of molten neodymium and extend their service life.

10.2.2 Nanostructures

Nanostructured molybdenum materials significantly improve the mechanical properties and high-temperature stability of crucibles by controlling grain size and interface characteristics.

Nanocrystalline Molybdenum:

Preparation method: Nano-scale molybdenum powder (particle size <100 nm) is produced by plasma atomization or chemical vapor deposition (CVD) and sintered into crucibles by hot pressing.

Improved performance: Nanocrystalline structure (grains <100 nm) increases grain boundary density, improves strength and toughness, and reduces high temperature creep.

Challenge: Nanocrystalline materials may experience grain growth at ultra-high temperatures (>2000°C), and grain boundaries need to be stabilized by doping.

Nano coating:

Technology: Nanoscale anti-oxidation coatings (such as Al_2O_3, Si_3N_4, thickness 10-100 nm) are prepared using atomic layer deposition (ALD) or magnetron sputtering.

Advantages: The nano coating is dense and uniform, the thermal expansion coefficient matches that of the molybdenum substrate, and significantly improves oxidation and corrosion resistance.

Application: To extend the service life of crucibles in oxygen-containing atmospheres and reduce melt contamination.

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Nanocomposites:
Design: Introduce nanoparticles (such as ZrO_2, SiC) as the second phase to enhance the mechanical properties and thermal stability of the Mo matrix.

Fabrication: Prepared by mechanical alloying and hot isostatic pressing (HIP) to achieve uniform dispersion of nanoparticles.

Performance: Improve the crack growth resistance and extend the crucible fatigue life.

Practical Application:
In the growth of sapphire crystals, nanocrystalline molybdenum crucibles reduce thermal stress cracks and improve crystal quality.
In aerospace, nano-coated crucibles resist high-temperature oxidation and meet the needs of extreme environments.

10.2.3 Alternative Materials

Although molybdenum crucibles offer excellent performance, in some applications alternative materials may offer better cost performance or specific performance advantages.

Tungsten (W):
Features: Higher melting point (3422°C), better corrosion resistance than molybdenum, suitable for ultra-high temperature environment (>2200°C).
Limitations: High density (19.25 g/cm^3), difficult to process, more expensive than molybdenum.
Application: Aerospace high temperature alloy melting, partially replacing molybdenum crucible.

Ceramic Materials:
Types: Alumina (Al_2O_3), Zirconium Oxide (ZrO_2), Boron Nitride (BN).
Features: High chemical stability, strong corrosion resistance, low cost, but limited high temperature strength (<2000°C).
Application: Low- to medium-end rare earth smelting or precious metal purification, replacing some molybdenum crucibles.

Graphite:
Features: low cost, easy processing, high thermal conductivity, but easy to oxidize and need to be used in vacuum or inert atmosphere.
Application: Low-cost silicon smelting, partial replacement of molybdenum crucible.
Improvement: Graphite is coated with SiC or BN layer to improve oxidation resistance and corrosion resistance.

Composite materials:
Design: Tungsten-ceramic composite or graphite- molybdenum composite, combining the advantages of both.

Advantages: Balances high temperature performance and cost to suit specific applications.
Applications: High temperature alloy manufacturing and crystal growth.

Practical Application:
In the purification of precious metals, zirconia crucibles serve as a low-cost alternative to meet the needs of small and medium-sized enterprises.
In aerospace, tungsten crucibles are used for ultra-high temperature melting to make up for the temperature limitation of molybdenum crucibles.

10.3 Intelligent and Green Manufacturing
Intelligent and green manufacturing are the key directions for the molybdenum crucible industry to cope with technological challenges and sustainable development. The following will be discussed from three aspects: intelligent monitoring, energy saving and environmental protection, and waste recycling.

10.3.1 Intelligent Monitoring
Molybdenum crucible production and use through sensors, the Internet of Things (IoT) and artificial intelligence (AI).

Production monitoring:
Sensor network: Deploy temperature, pressure and vibration sensors in sintering furnaces, spinning machines and coating equipment to collect process parameters in real time.

Data analysis: Use AI algorithms to analyze sensor data, predict equipment failures, and optimize process parameters (such as sintering temperature and spinning speed).

Digital Twin: Build a virtual model of the crucible production process to simulate thermal fields, stress distribution, and material flow to guide process improvements.

Usage monitoring:
High temperature monitoring: Install infrared thermometers and thermocouples in the crystal growth or melting furnace to monitor the crucible temperature distribution in real time and control the deviation within a very small range.

Atmosphere Control: Use a mass spectrometer and oxygen sensor to monitor the gas composition in the furnace and automatically adjust the argon or hydrogen flow to keep the oxygen content extremely low.

Life prediction: Analyze the crucible's thermal cycle data through machine learning to predict crack occurrence and life attenuation, and optimize maintenance cycles.

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Quality traceability:

Blockchain technology: records the entire life cycle data of the crucible from production to use to ensure quality traceability.

QR code /RFID: Each crucible is equipped with a unique identification, which is linked to the production, testing and usage records to facilitate fault analysis.

Practical Application:

In the semiconductor industry, intelligent monitoring systems ensure uniform thermal fields in molybdenum crucibles during silicon single crystal production, reducing defects.

In rare earth smelting, digital twin technology optimizes crucible design and extends service life.

10.3.2 Energy saving and environmental protection

Molybdenum crucible production through energy-saving technologies and environmental protection measures.

Energy-saving technology:

Efficient heating: Use microwave sintering or induction heating instead of traditional resistance heating to improve energy utilization.

Heat recovery: Heat pipes or heat exchangers are installed in the sintering furnace to recover waste heat for preheating or plant heating.

Intelligent control: Deploy variable frequency motors and energy management systems to dynamically adjust equipment power and reduce standby energy consumption.

Environmental protection measures:

SO_2 produced by roasting is converted into by-products through wet desulfurization, and volatile organic compounds (VOCs) are removed using catalytic combustion.

Recycled after neutralization and filtration, reducing water resource consumption.

Low-carbon energy: Integrate solar or wind power to reduce the carbon footprint of production and give priority to green electricity suppliers.

Lifecycle Management:

LCA analysis: Evaluate the environmental impact of crucibles from raw material extraction to recycling and optimize low-carbon processes.

Green Certification: Apply for ISO 14001 (Environmental Management System) and ISO 50001 (Energy Management System) certification to demonstrate environmental commitment.

Carbon neutrality: Achieve carbon neutrality in production through carbon offsetting or afforestation, in response to the global 2050 carbon neutrality target.

Practical Application:

In sapphire crystal growth, the heat recovery system reduces the energy consumption of the sintering furnace and improves production sustainability.

In the manufacturing of aerospace high-temperature alloys, exhaust gas treatment technology

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reduces SO_2 emissions and improves environmental quality.

10.3.3 Waste Recycling

Efficient waste recycling technology is the core of green manufacturing, supporting resource recycling and cost savings.

Recycling process:

Classification: Store production waste (scraps, powder) and post-use waste (waste crucibles, coating residues) separately to avoid cross contamination.

Physical recovery: Use crushing, screening and magnetic separation to separate the molybdenum matrix and impurities, and recover high-purity molybdenum fragments.

Chemical recovery: Ammonium molybdate is extracted from the waste by acid leaching and ammonia dissolution, and calcined to produce high-purity molybdenum powder.

Metallurgical Recovery: Use vacuum melting or plasma refining to purify waste molybdenum and produce high-purity molybdenum ingots.

Technological innovation:

Automated sorting: Introducing X-ray sorters and robots to improve waste sorting efficiency and purity.

Closed loop system: Recycled molybdenum powder is directly used in new crucible production, reducing resource waste.

Low-energy recycling: Develop electrochemical recycling technology to reduce energy consumption and pollution in waste liquid treatment.

Quality Control:

Recycled molybdenum powder needs to be tested for purity and impurity content, which must comply with ASTM B386 standards.

using ICP -MS ensures that the recycled material is suitable for high-end applications.

the equivalence of the recycled material to virgin molybdenum.

Practical Application:

In the semiconductor industry, waste crucibles are recycled to produce high-purity molybdenum powder to meet the needs of silicon single crystal production.

In rare earth smelting, closed-loop recycling systems reduce waste disposal costs and improve resource efficiency.

10.4 Future Trends

Molybdenum crucibles will revolve around high-performance design, cross-field applications and adaptability to extreme environments, driving industry technological innovation and market expansion.

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10.4.1 High-performance design

High-performance molybdenum crucibles will meet more demanding application requirements through material innovation, structural optimization and intelligent design.

Material Upgrade:

Develop ultra-high purity molybdenum (>99.999%) and new composite materials (such as Mo-W-Re) to improve high temperature strength and corrosion resistance.

Introducing self-healing coatings (such as nano-composite coatings containing ZrO_2) to automatically repair microcracks at high temperatures and extend service life.

Structural optimization:

Design thin-walled (<2 mm) and large-diameter (>600 mm) crucibles to optimize thermal field uniformity and reduce material consumption.

Develop modular crucibles that can be easily disassembled and recycled, supporting a circular economy.

Intelligent design:

Embed sensors (such as temperature and stress sensors) in the crucible wall to monitor the operating status in real time and predict failure risks.

Use digital twin technology to optimize crucible geometry and balance thermal conductivity and mechanical properties.

Practical Application:

In next-generation semiconductor manufacturing, ultra-high purity molybdenum crucibles support more advanced wafer production processes.

In high temperature alloy manufacturing, self-healing coated crucibles extend life and reduce maintenance costs.

10.4.2 Cross-domain applications

Molybdenum crucibles will expand from traditional fields to emerging industries to meet diversified needs.

New Energy:

In the manufacture of perovskite solar cells, molybdenum crucibles are used in high-temperature evaporation or melting processes to support efficient cell production.

In nuclear fusion reactors, molybdenum crucibles are used to melt high-temperature plasma confinement materials.

Biopharmaceuticals:

In the manufacture of high-end medical devices, molybdenum crucibles are used to purify biocompatible metals such as titanium alloys.

In pharmaceutical synthesis, molybdenum crucibles support high-temperature chemical reactions

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and ensure high purity.

3D Printing:

In metal 3D printing, molybdenum crucibles are used to melt high-melting-point alloy powders to meet the needs of the aerospace and automotive industries.

Develop special molybdenum crucibles to support continuous printing and large-scale production.

Practical Application:

In nuclear fusion research, molybdenum crucibles support high-temperature material testing and contribute to the development of clean energy.

In the 3D printing industry, molybdenum crucibles improve the quality of alloy powders and meet the needs of precision manufacturing.

10.4.3 Extreme Environments

Molybdenum crucibles will adapt to more extreme working environments, such as ultra-high temperature, strong corrosion and complex atmosphere.

Ultra-high temperature:

Molybdenum -based composite crucibles with a temperature resistance of >2500°C to meet the melting needs of ultra- high temperature alloys in aerospace.

Use multi-layer nano-coatings (such as Si_3N_4 / ZrO_2) to improve oxidation resistance and thermal stability.

Strong corrosion:

Design crucibles that are resistant to corrosion by rare earth metals and molten salts for use in new energy batteries and the chemical industry.

The introduction of molybdenum -ceramic composite materials enhance chemical stability and prolongs service life.

Complex atmosphere:

Develop crucibles that are suitable for oxygen-containing, sulfur-containing or halogen-containing atmospheres to meet special smelting needs.

Use intelligent atmosphere control system to dynamically adjust gas composition and protect the crucible surface.

Practical Application:

In aerospace, ultra-high temperature resistant molybdenum crucibles support the research and development of new propulsion materials.

In the chemical industry, corrosion-resistant crucibles improve the efficiency of molten salt reactions and reduce production risks.

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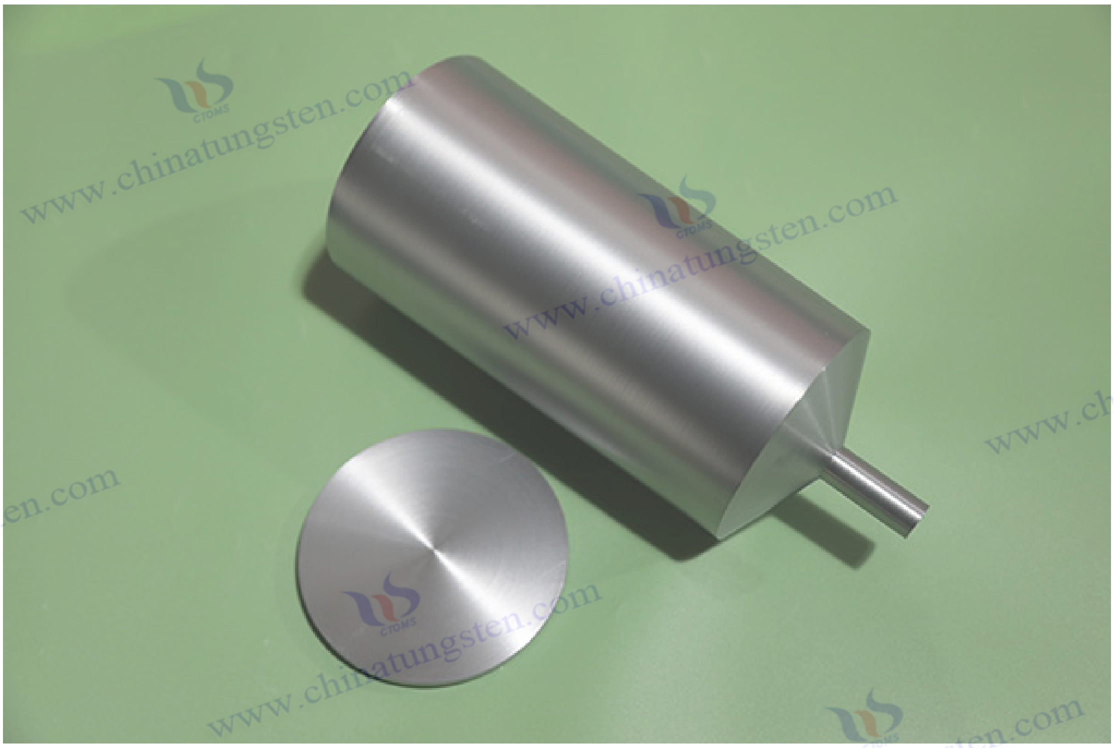

CTIA GROUP LTD Molybdenum Crucible

Chapter 11 Molybdenum Crucible Standards and Specifications

Molybdenum crucibles rely on strict standards and specifications to ensure material consistency, manufacturing accuracy and safety of use. This chapter discusses in detail the national standards (GB), international standards (ISO), American standards (ANSI) and other international and industry standards related to molybdenum crucibles, and analyzes the requirements for standard implementation and certification, covering production, testing, quality certification and export compliance, referring to global authoritative standards and industry practices, and providing comprehensive technical guidance.

11.1 National Standards (GB)

China's national standard (GB/T) provides detailed specifications for materials, tests and equipment for molybdenum crucibles and is widely used in domestic production and applications.

11.1.1 GB/T Molybdenum Material Standard

GB/T standard specifies the chemical composition, mechanical properties, processing properties and application requirements of molybdenum and molybdenum alloys, and is the basis for the manufacture of molybdenum crucibles.

Main criteria:

GB/T 3462-2017 Molybdenum bars and rods:

Content: Specifies the chemical composition (such as Mo ≥ 99.95%), dimensional tolerance, surface

quality and mechanical properties of molybdenum bars and rods.
Suitability: Raw materials used to make crucibles, ensuring high purity and consistency.
Requirements: The surface of the molybdenum bar shall be free of cracks, oxide scale or inclusions, the tolerance shall be controlled at the micron level, and it shall be suitable for spinning or forging.

GB/T 3876-2017 Molybdenum and molybdenum alloy plates, strips and foils:
Content: Standardize the thickness, width, surface roughness and mechanical properties (such as tensile strength and elongation) of molybdenum plates.
Applicability: Used for welding or spinning crucibles, especially suitable for thin-walled crucibles.
Requirements: The surface roughness of the plate Ra <1.6 μm, the thickness deviation is extremely small, meeting the high-precision requirements.

GB/T 4182-2017 Molybdenum powder:
Content: Specifies the particle size, purity, bulk density and flow properties of molybdenum powder.
Applicability: Used for preparing crucible blanks by powder metallurgy to ensure high density of sintered crucibles.
Requirements: Molybdenum powder purity> 99.95%, extremely low oxygen content, uniform particle size.

Key requirements:
Chemical composition: Molybdenum crucible materials must be of high purity, and the content of impurities (such as Fe, Ni, C, O) must be strictly controlled to prevent performance degradation at high temperatures.
Mechanical properties: High temperature tensile strength and ductility must meet the requirements of the crystal growth or smelting environment.
Surface quality: The inner and outer surfaces of the crucible should be smooth and free of defects (such as scratches and pores) to avoid contamination of the melt.

Practical Application:
In sapphire crystal growth, GB/T 3462 ensures the high purity of molybdenum rods and meets the high temperature requirements of 2050°C.
In rare earth smelting, molybdenum plates in accordance with GB/T 3876 are used to weld crucibles to ensure the quality of the weld.

11.1.2 Testing and Evaluation

GB/T standard provides detailed methods for performance testing and quality evaluation of molybdenum crucibles to ensure that the products meet the design and application requirements.

Test Method:
Chemical composition analysis: Inductively coupled plasma mass spectrometry (ICP -MS) or X-ray fluorescence spectroscopy (XRF) is used to detect molybdenum purity and impurity content with extremely high accuracy.

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Mechanical properties test:
Tensile test (GB/T 228.1): Measures tensile strength, yield strength and elongation at room temperature and high temperature (1000-1500°C).
Hardness test (GB/T 231.1): Use Vickers hardness tester to evaluate the hardness of crucible material, reflecting the grain refinement effect.

Microstructure Analysis: Use Scanning Electron Microscopy (SEM) and Electron Backscatter Diffraction (EBSD) to examine grain size and defects (e.g. pores, inclusions).
Surface quality inspection: Use an optical microscope or laser scattering instrument to inspect surface roughness (Ra) and defects (such as scratches and cracks).

Evaluation criteria:
Dimensional accuracy: The tolerances of crucible diameter, height and wall thickness must meet the design requirements, and the deviation must be controlled at the micron level.
Performance consistency: The mechanical properties and chemical composition of batches of crucibles must be highly consistent, with minimal batch differences.
High temperature stability: The creep resistance and corrosion resistance of the crucible are tested at 1700-2050°C to ensure long-term use without failure.

Quality Control:
Implement statistical process control (SPC) to monitor key parameters in the production process (such as sintering temperature and spinning pressure).
Each batch of crucibles must be accompanied by a test report recording the chemical composition, mechanical properties and surface quality data.
Defective products must be isolated and analyzed to prevent them from entering the market.

Practical Application:
In semiconductor silicon single crystal production, the GB/T test method ensures that the crucible surface is defect-free and meets high purity requirements.
In the melting of aerospace high-temperature alloys, high-temperature tensile tests verify the creep resistance of crucibles.

11.1.3 Equipment Specifications

The GB/T standard sets clear requirements for molybdenum crucible manufacturing and testing equipment to ensure the reliability and consistency of the production process.

Manufacturing Equipment:
Sintering furnace: The vacuum sintering furnace must have high temperature (>2000°C) and low pressure ($<10^{-3}$ Pa) capabilities and be equipped with a precise temperature control system (±5°C).
Spinning machine: CNC spinning machine needs to support micron-level precision processing and be equipped with a real-time monitoring system to control the uniformity of wall thickness.
Welding equipment: TIG welding or electron beam welding equipment is required to ensure that the

weld is free of pores and has high bonding strength.

Testing equipment:
Dimensional inspection: Using a laser rangefinder or a coordinate measuring machine (CMM), the diameter, height and wall thickness of the crucible are measured with extremely high precision.
Surface inspection: Equipped with high-resolution optical microscope and laser scattering instrument to detect surface roughness and micro cracks.
Nondestructive testing: Use ultrasonic testing instrument or eddy current flaw detector to check the internal defects of crucible (such as inclusions, pores).

Equipment maintenance:
The equipment is calibrated regularly to meet the requirements of GB/T 10067 (Electrical Equipment Specifications) with extremely small accuracy deviations.
Equipped with environmental control systems (such as clean rooms, ISO 7 grade) to prevent contamination during equipment operation.
Record equipment operation logs, analyze fault causes, and optimize maintenance cycles.

Practical Application:
In the production of rare earth smelting crucibles, CNC spinning machines ensure uniform wall thickness and meet GB/T standards.
In crystal growth equipment, ultrasonic testing verifies that the crucible has no internal defects, improving reliability.

11.2 International Standards (ISO)

ISO standards provide globally uniform specifications for performance testing, environmental management and quality control of molybdenum crucibles, and are widely used in international trade and high-end applications.

11.2.1 ISO 6892 tensile test

The ISO 6892 series of standards specify the tensile test methods for metallic materials and is applicable to the evaluation of the mechanical properties of molybdenum crucibles.

Standard content:
ISO 6892-1: Room temperature tensile testing, specifies specimen preparation, test speed and data recording methods.
ISO 6892-2: High temperature tensile test (1000-1500℃), suitable for the performance test of molybdenum crucible in high temperature environment.
ISO 6892-3: Low temperature tensile test to evaluate the toughness of molybdenum under specific conditions.

Test requirements:
Sample preparation: The molybdenum crucible material is processed into a standard sample (such

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as a cylinder or plate) with no surface defects.
Test conditions: High temperature tests must be carried out in a vacuum or inert atmosphere to prevent oxidation, with a temperature control accuracy of ±5°C.
Measurement parameters: tensile strength, yield strength, elongation and reduction of area with high data repeatability.

Applicability:
Used to verify the mechanical stability of molybdenum crucibles in high temperature melting (such as 2050°C).
Ensure that the mechanical properties of doped molybdenum crucibles (such as Mo-La_2O_3) are better than pure molybdenum.

Practical Application:
In sapphire crystal growth, the ISO 6892-2 test ensures that the crucible does not deform at high temperatures.
In the melting of aerospace high-temperature alloys, tensile tests verify the creep resistance of crucibles.

11.2.2 ISO 14001 Environmental Management

ISO 14001 provides an environmental management system framework for molybdenum crucible production, aiming to reduce environmental impact and promote sustainable development.

Standard content:
Define environmental policies, objectives and plans, and identify environmental impacts in production (such as energy consumption, waste gas, waste water).
It is required to establish environmental performance indicators and regularly review and improve the management system.
Emphasize compliance and adherence to local and international environmental regulations.

Implementation requirements:
Energy management: Optimize sintering and forging processes, reduce energy consumption, and use renewable energy (such as solar energy).
Waste treatment: Recycling of molybdenum waste, treatment of roasting waste gas (such as SO_2) and chemical waste liquid to ensure zero pollution discharge.
Environmental monitoring: Install exhaust gas and wastewater monitoring equipment to record emission data in real time and comply with emission standards.
Staff training: Improve staff environmental awareness and ensure operations comply with ISO 14001 requirements.

Applicability:
Enhance the green image of molybdenum crucible manufacturers and meet the environmental protection requirements of high-end customers (such as the semiconductor industry).

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Support export market and comply with EU REACH and RoHS regulations.

Practical Application:
In rare earth smelting, ISO 14001 guides waste gas treatment to reduce SO_2 emissions.
In the semiconductor industry, environmental management systems ensure that the production process is pollution-free and meets clean room requirements.

11.2.3 ISO 3452 Nondestructive Testing

ISO 3452 specifies the penetrant testing (PT) method for detecting microcracks and defects on the surface of molybdenum crucibles.

Standard content:
Specify the selection of penetrants, developers and cleaning agents, as well as the testing procedures and environmental conditions.
Including sensitivity levels (1-4), suitable for crucibles with different precision requirements.
It is required that the inspectors undergo professional training and comply with ISO 9712 (certification of non-destructive testing personnel).

Testing process:
Surface preparation: The crucible surface is cleaned to be free of oil, scale and roughness Ra < 0.8 μm.
Penetrant application: Apply high- sensitivity penetrant, with a penetration time of 5-30 minutes to cover micro-cracks.
Imaging and observation: Use developer to show defects, and combine with ultraviolet light or white light to check crack location and morphology.
Result evaluation: The crucible is qualified based on the defect size and distribution. If the crack length is extremely small, it needs to be repaired.

Applicability:
Used to detect the weld quality of welding crucibles and prevent crack propagation at high temperatures.
Ensure that there are no micro cracks on the surface of the spinning crucible to meet the cleanliness requirements of the semiconductor industry.

Practical Application:
In silicon single crystal production, ISO 3452 testing ensures that the crucible surface is free of defects to prevent contamination of the silicon melt.
In aerospace, penetrant testing verifies the integrity of welds on large crucibles.

11.3 American Standard (American Standard)

American standards (ASTM, ASME) provide high-precision specifications for materials, tests and equipment for molybdenum crucibles and are widely used in the international market.

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Molybdenum Crucible Introduction

1. Overview of Molybdenum Crucible

Molybdenum crucibles are made of high-purity molybdenum powder through isostatic pressing, high-temperature sintering and precision machining. They have excellent high-temperature strength, corrosion resistance and dimensional stability, making them widely used in sapphire crystal growth, rare earth smelting, glass industry, vacuum coating and high-temperature heat treatment.

2. Advantages of Molybdenum Crucible

Advantages	Description
High temperature resistance	Maintains strength and structural stability up to 1800°C
High purity	Pure materials to avoid impurities contaminating the material or the reaction process
Thermal shock resistance	Low thermal expansion coefficient, not prone to cracking or deformation during heating/cooling
Corrosion resistance	Resistant to corrosion by acids, alkalis, molten metals and glass
Non-magnetic	Diamagnetic material, suitable for magnetron sputtering and high magnetic field equipment
Flexible processing	Supports precision machining of different shapes (cylindrical, square, covered structure, etc.) and sizes

3. Application Fields of Molybdenum Crucible

Application Industry	Usage
Sapphire Industry	As a raw material container in crystal growth furnace
Rare earth and precious metal smelting	Melting active metals such as neodymium, tantalum, platinum, etc. at high temperatures
Vacuum heat treatment	Used in vacuum sintering, annealing and other heat treatment reactors
Coating industry	As evaporation container for target or precursor
Scientific research experiments	Chemical high temperature reaction, high purity material preparation

4. Specifications of Molybdenum Crucible from CTIA GROUP LTD (Customizable)

Outer Diameter (mm)	Height (mm)	Wall Thickness (mm)	Volume (mL)	Remark
50	50	3.0	~100	Commonly used for experimental melting
100	100	5.0	~785	Common Sizes of Sapphire Crystals
150	200	8.0	~3534	Industrial furnace large capacity model
Note: Special forms such as threads and caps can be customized according to customer needs.				

5. Purchasing Information

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

Website: www.molybdenum.com.cn

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11.3.1 ASTM B386 Molybdenum Alloy

ASTM B386 is the international authoritative standard for molybdenum and molybdenum alloys, covering the material requirements for crucible manufacturing.

Standard content:

Specifies the chemical composition, mechanical properties and processing properties of molybdenum and molybdenum alloys (Mo, Mo-La_2O_3, Mo-W).

Includes specifications for plates, bars, foils and forgings suitable for spinning, welding and forging crucibles.

The molybdenum purity is required to be >99.95%, and the content of impurities (such as Fe, Ni, and C) is extremely low.

Key requirements:

Chemical composition: Molybdenum materials must be verified for purity through spectral analysis to ensure high temperature stability.

Mechanical properties: Specified tensile strength, yield strength and elongation to meet high temperature (1700-2050℃) requirements.

Surface quality: The material surface has no cracks, inclusions or oxide layers, suitable for high-precision processing.

Dimensional tolerance: The thickness and diameter tolerances of plates and bars are controlled in micron level.

Applicability:

Used to manufacture high-performance molybdenum crucibles that meet the stringent requirements of the sapphire crystal growth and semiconductor industries.

Guide material selection and performance optimization of doped molybdenum crucibles (such as Mo- CeO_2).

Practical Application:

In sapphire crystal growth, ASTM B386 ensures the high purity and mechanical properties of molybdenum plates.

In rare earth smelting, standard specification molybdenum rods are used for forging crucibles to ensure corrosion resistance.

11.3.2 ASTM E384 Hardness Test

ASTM E384 specifies Vickers and Knoop hardness test methods for evaluating the hardness and microstructure of molybdenum crucible materials.

Standard content:

Specifies the load (0.1-10 kg), indenter type (diamond pyramid) and measurement method for hardness testing.

Includes room temperature and high temperature (1000℃) test conditions, suitable for performance

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evaluation of molybdenum crucibles.

The test surface is required to be flat, with a roughness Ra<0.5 μm and extremely high measurement repeatability.

Testing process:

Sample preparation: The molybdenum crucible material is polished to a mirror surface and cleaned to remove oil and particles.

Hardness measurement: Use a Vickers hardness tester to apply a constant load, measure the diagonal length of the indentation, and calculate the hardness value.

Result analysis: Compare the hardness values in different areas to evaluate the grain refinement effect and material homogeneity.

Applicability:

Used to verify the effect of doping or heat treatment on the hardness of molybdenum crucible and reflect the wear resistance.

Guide the optimization of crucible manufacturing process, such as sintering temperature and forging deformation.

Practical Application:

In the semiconductor industry, ASTM E384 testing ensures the high hardness of molybdenum crucibles to meet long-term use requirements.

In high temperature alloy melting, hardness test verifies the anti-deformation performance of the crucible.

11.3.3 ASME High Temperature Vessels

ASME standards provide specifications for the design, manufacture and testing of high temperature vessels (such as crucibles) and are suitable for use in molybdenum crucibles under pressure or high temperature environments.

Standard content:

ASME BPVC Section VIII: Pressure vessel design and fabrication, specifies material selection, stress analysis, and safety factors.

ASME B31.3: Process piping specification applicable to furnace systems where crucibles are located.

ASME PTC 19.3: High temperature performance test to evaluate the stability of crucibles under extreme conditions.

Key requirements:

Material selection: Molybdenum crucible must comply with ASTM B386 , high temperature resistance and corrosion resistance.

Design Verification: Finite Element Analysis (FEA) was used to simulate the stress distribution of the crucible under high temperature (>2000°C) and thermal cycling.

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Safety Test: Pressure test and thermal shock test are carried out to ensure that the crucible has no cracks or deformation.

Applicability:
Molybdenum crucibles for use in the aerospace and nuclear industries ensure safety and reliability.
Provide guidance for the design of large crucibles (diameter > 500 mm) to meet complex thermal field requirements.

Practical Application:
In aerospace high temperature alloy melting, ASME standards ensure the safe operation of crucibles.
In nuclear fusion research, standard crucible designs support high-temperature material testing.

11.4 Other International and Industry Standards

In addition to the national standard, ISO and American standard, other international and industry standards provide supplementary specifications for molybdenum crucibles, which are suitable for specific markets and applications.

11.4.1 JIS G 0571

Japanese Industrial Standard (JIS G 0571) specifies the corrosion test methods for stainless steel and heat-resistant alloys, which is partially applicable to the corrosion resistance evaluation of molybdenum crucibles.

Standard content:
Specifies immersion tests and electrochemical test methods to evaluate the performance of materials in corrosive environments.
These include acidic solutions (such as HNO_3), molten metals (such as neodymium), and high temperature atmosphere testing.

Applicability:
Used to test the corrosion resistance of molybdenum crucibles in rare earth smelting, especially in molten rare earth metal environments.
the performance verification of anti-corrosion coatings such as $MoSi_2$.

Implementation requirements:
The test environment needs to simulate actual usage conditions (such as 1700°C, molten neodymium).
Measure wall thickness loss, surface erosion depth and mass loss to assess crucible life.

Practical Application:
In NdFeB magnet production, the JIS G 0571 test ensures the corrosion resistance of molybdenum crucibles.
In precious metal purification, the standard verifies the stability of the crucible in an acidic

environment.

11.4.2 DIN EN 10228

The German standard DIN EN 10228 regulates the non-destructive testing of metal products and is applicable to the internal and surface quality control of molybdenum crucibles.

Standard content:

Including ultrasonic testing (UT), magnetic particle testing (MT) and eddy current testing (ET) methods.

Specify acceptance criteria for defects such as crack length and pore size.

Testing requirements:

Ultrasonic testing: Use a high-frequency probe (5-10 MHz) to check for inclusions and pores inside the crucible with extremely high sensitivity.

Eddy Current Testing: Detects surface and sub-surface cracks, suitable for welding crucibles.

Magnetic particle testing: To detect surface micro cracks, it must be carried out under magnetized conditions.

Applicability:

For quality control of large molybdenum crucibles (diameter > 300 mm) to ensure there are no internal defects.

Meets the high reliability requirements of the aerospace and nuclear industries.

Practical Application:

In the melting of aerospace high-temperature alloys, DIN EN 10228 ensures that the crucibles are free of internal defects.

In the semiconductor industry, eddy current testing verifies crucible surface quality and prevents melt contamination.

11.4.3 GOST 17431

The Russian standard GOST 17431 specifies the properties and test methods of heat-resistant alloys and is suitable for the application of molybdenum crucibles in high temperature environments.

Standard content:

Specifies the chemical composition, mechanical properties and high temperature stability of heat-resistant alloys.

Includes elevated temperature tensile, creep and fatigue test methods.

Test requirements:

High temperature tensile: Test tensile strength and elongation at 1400-1800°C.

Creep test: Measures the rate of deformation of a crucible at high temperature (1700°C) and constant stress.

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Fatigue Testing: Simulates thermal cycling conditions to evaluate the fatigue life of crucibles.

Applicability:
molybdenum crucibles for the Russian market, meeting the needs of the aerospace and energy industries.
Guide the performance optimization of doped molybdenum crucibles.

Practical Application:
In nuclear fusion research, the GOST 17431 test ensures the creep resistance of molybdenum crucibles.
In high temperature alloy melting, the standard verifies the fatigue life of the crucible.

11.5 Standard Implementation and Certification

The implementation and certification of standards are key to ensuring the quality and market competitiveness of molybdenum crucibles, covering production, testing, quality certification and export compliance.

11.5.1 Production and testing

Standard implementation requires that specifications be integrated into production and testing processes to ensure product consistency and reliability.

Production Implementation:
Process control: Select high purity molybdenum materials according to GB/T 3462 and ASTM B386 , and strictly control the sintering temperature (>2000°C) and spinning pressure.
Equipment calibration: Manufacturing equipment (such as sintering furnaces, spinning machines) needs to be calibrated regularly in accordance with GB/T 10067 or ISO 10012 (measurement management system).
Environmental Control: Production is carried out in a clean room (ISO 7) to prevent particle contamination and comply with SEMI E170.

Testing implementation:
Performance Testing: Tensile and hardness tests are performed according to ISO 6892 and ASTM E384 to verify the mechanical properties of the crucible.
Non-destructive testing: Penetrant and ultrasonic testing using ISO 3452 and DIN EN 10228 ensures surface and internal defects are free.
Data Records: Each batch of crucibles comes with a test report recording chemical composition, dimensional accuracy and performance data to support quality traceability.

Quality Management:
Implement ISO 9001 quality management system to ensure standardization of production and testing processes.
Use Statistical Process Control (SPC) to monitor key parameters and reduce non-conformance rates.

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Practical Application:
In the semiconductor industry, standardized production and testing ensure the high purity and consistency of molybdenum crucibles.
In aerospace, non-destructive testing ensures the reliability of crucibles and meets stringent requirements.

11.5.2 Quality Certification

Quality certification is a key step to prove that molybdenum crucibles meet standards and enhance market confidence.

Certification Type:
ISO 9001: Quality management certification that proves the company's production and service capabilities.
ISO 14001: Environmental management certification, demonstrating commitment to green production.
AS 9100: Aerospace quality management certification for molybdenum crucibles used in aerospace applications.
Nadcap: Specialty process certification covering non-destructive testing and heat treatment.

Certification process:
Document preparation: Prepare quality manuals, procedure documents and standard operating procedures (SOPs) in compliance with certification requirements.
Internal Audit: Conduct internal audits to identify and correct non-conformities.
Third-party audit: On-site audits are conducted by certification bodies (such as SGS and TÜV) to verify the implementation of standards.
Continuous Improvement: Regularly review and update the quality management system to ensure ongoing compliance.

Practical Application:
In sapphire crystal growth, ISO 9001 certification increases customer confidence in the quality of crucibles.
In aerospace, AS9100 certification ensures that crucibles meet stringent industry standards.

11.5.3 Export Compliance

The export of molybdenum crucibles must comply with the standards and regulations of the target market to ensure that the products enter the international market smoothly.

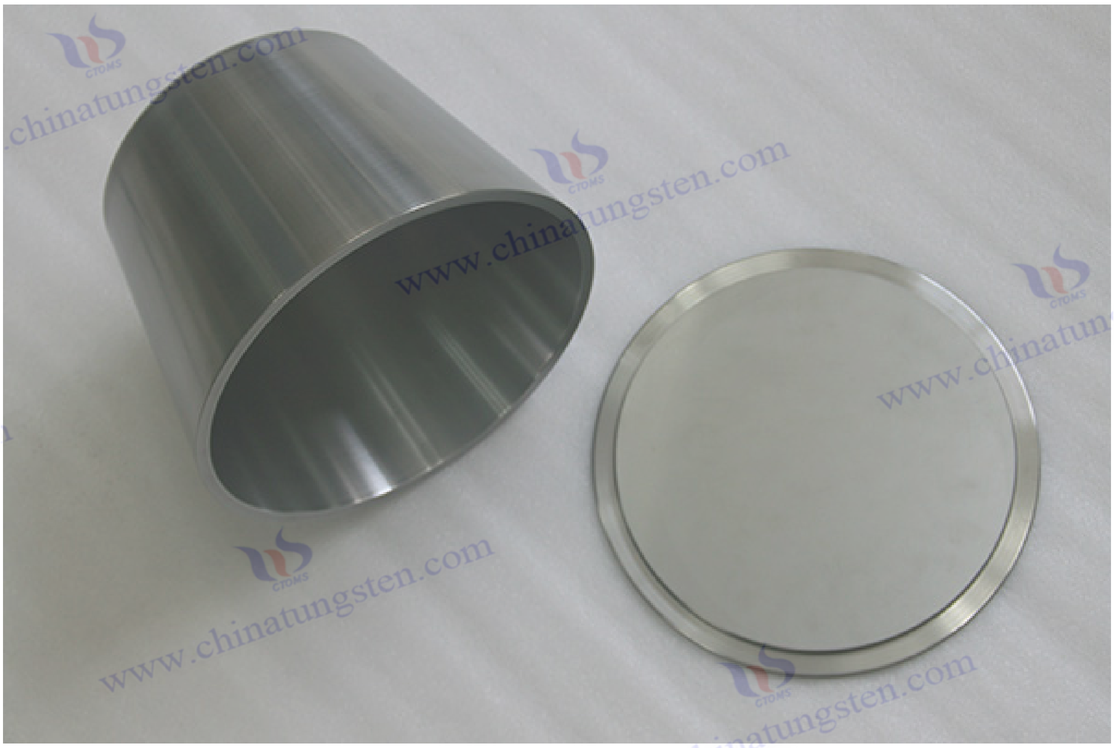
Compliance Requirements:
EU Market: Comply with REACH (Registration, Evaluation and Authorization of Chemicals) and RoHS (Restriction of Hazardous Substances) directives to ensure that the materials are free of hazardous substances.
US market: Comply with ASTM B386 and ASME standards, provide quality certificates and test

reports.
Japanese market: Complies with JIS G 0571 to ensure the crucible's corrosion resistance.
Russian market: Comply with GOST 17431 and provide high temperature performance data.

Certification and Documentation:
Provide a quality certificate in accordance with ISO 8000 (data quality) containing chemical composition, performance data and test results.
Apply for CE marking (EU) or UL certification (US) to prove product safety and compliance.
Prepare export manifests, commercial invoices and certificates of origin to meet international trade requirements.

Risk Management:
Monitor updates to international standards and adjust production and testing processes in a timely manner.
Work with local agents or certification bodies to ensure that products meet target market requirements.
Establish an export compliance team to handle customs and regulatory issues.

Practical Application:
In the semiconductor industry exported to Europe, REACH compliance ensures that molybdenum crucibles are free of harmful substances and can enter the market smoothly.
In the aerospace market exported to the United States, ASTM B386 certification improves product competitiveness.



CTIA GROUP LTD Molybdenum Crucible

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Appendix

A. Glossary

Antioxidation Coating: A protective layer applied to the surface of the molybdenum crucible to prevent oxidation at high temperatures and extend the life of the crucible.

Closed-Loop Recycling: The recycling process of recycling waste molybdenum crucibles and converting them into new crucible materials to reduce resource waste.

Czochralski Method: A method of growing single crystals (such as silicon and sapphire) by crystal pulling technology, which requires the use of a high-purity molybdenum crucible to hold the melt.

Plasma Spraying: A surface modification technology that uses high-temperature plasma to spray oxidation-resistant or corrosion-resistant materials onto the surface of a molybdenum crucible.

High-Temperature Creep: The slow deformation of molybdenum crucibles under high temperature (>1500°C) and stress may lead to performance degradation.

Cleanroom: A controlled environment that controls particulate matter and contamination, used for packaging and storage of molybdenum crucibles, in accordance with ISO 14644 standards.

Grain Refinement: Reducing the grain size of molybdenum materials by doping or heat treatment to improve strength and toughness.

Mechanical Properties: The properties of a material under stress, such as tensile strength, hardness, and elongation, affect the high temperature stability of the molybdenum crucible.

Nanostructure: Molybdenum materials with grain or coating size at the nanoscale (<100 nm) have excellent mechanical properties and oxidation resistance.

Hot Isostatic Pressing (HIP): A technique for molding molybdenum crucibles under high temperature and pressure to improve density and uniformity and reduce internal defects.

Thermal Field Uniformity: The consistency of temperature distribution of the crucible in a high-temperature furnace affects the quality of crystal growth.

Sintering: The process of solidifying molybdenum powder into crucible blanks by high temperature heating, usually carried out in a vacuum or hydrogen atmosphere.

Non-destructive Testing (NDT): A method of detecting defects without destroying the crucible structure, such as ultrasonic testing and penetrant testing.

Circular Economy: An economic model that maximizes the value of resources through recycling and reuse, applied to molybdenum crucible waste management.

Spinning: A technique for processing molybdenum plates into crucibles by rotating molds and pressure, which is suitable for thin-walled and complex-shaped crucibles.

Sintering Furnace: Equipment that heats molybdenum powder at low pressure ($<10^{-3}$ Pa) to make high-density crucibles.

Doping: Adding trace elements to molybdenum to improve mechanical properties or oxidation resistance.

Quality Traceability: A method of tracking the quality of molybdenum crucibles by recording production, inspection and usage data to support failure analysis.

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