Encyclopedia of Molybdenum Wire for Lighting

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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 Wire for Lighting Introduction

1. Overview of Molybdenum Wire for Lighting

As one of the core materials in modern lighting technology, molybdenum wire is widely used in various light sources including incandescent lamps, halogen lamps, fluorescent lamps, and gas discharge lamps, due to its high melting point, high strength, excellent corrosion resistance, and superior electrical conductivity. It is an irreplaceable and critical component in the lighting industry.

2. Typical Applications of Molybdenum Wire for Lighting

Residential and Commercial Lighting: Used in incandescent and halogen lamps to provide warm light and long service life.

Automotive Lighting: Functions as electrodes in HID and xenon lamps, offering high brightness and vibration resistance.

Specialty Lighting: Utilized in projection lamps, ultraviolet (UV) lamps, and infrared (IR) lamps to meet high-temperature and high-precision requirements in medical, industrial, and scientific applications.

Emerging Fields: Serves as conductive leads for LED lamps and supports for phosphors in laser lighting, aligning with future lighting technology development.

3. Basic Data of Molybdenum Wire for Lighting (Reference)

Parameter	Pure Mo Wire	Mo-La Wire	Mo-Re Wire
Mo Content	≥99.95%	≥99.0%	52.5%–86.0%
Diameter Range	0.03–3.2 mm	0.03–1.5 mm	0.03–1.0 mm
Tolerance	±0.002 mm	±0.002 mm	±0.002 mm
Tensile Strength (Room Temp)	800–1200 MPa	900–1400 MPa	1000–1500 MPa
Tensile Strength (at 1500°C)	150–300 MPa	200–400 MPa	250–450 MPa
Elongation at Break	10%–25%	12%–20%	15%–25%
Electrical Resistivity (20°C)	5.5×10^{-8} Ω·m	6.0×10^{-8} Ω·m	6.5×10^{-8} Ω·m
Main Applications	Incandescent, Halogen	Halogen, Auto Headlights	HID, Projection Lamps

4. Procurement Information

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Chapter 1 Introduction

1.1 Definition and overview of molybdenum wire

1.1.1 Chemical composition and physical properties of molybdenum wire

Molybdenum wire is an elongated metal material with molybdenum metal as the main component, molybdenum (chemical symbol Mo, atomic number 42) is a refractory metal, because of its unique physical and chemical properties are widely used in industrial products in high temperature environments. Molybdenum wire is usually produced in a high-purity form with extremely high purity, ensuring its consistent performance. Some molybdenum wires are doped with trace elements such as lanthanum or rhenium to enhance specific properties to suit the needs of different application scenarios. The crystal structure of molybdenum is body-centered cubic, which gives molybdenum wire excellent mechanical strength and resistance to deformation at high temperatures, allowing it to withstand extreme operating conditions.

Molybdenum wire has an extremely high melting point, which is sufficient to cope with the high temperature environments in lighting devices. Its high density gives the material solid physical properties, while its thermal and electrical conductivity performance is excellent, giving it an advantage in electrical applications. Molybdenum wire has good chemical stability at room temperature and can resist the erosion of acids, alkalis and other chemicals, but when exposed to air at high temperatures, it is easy to react with oxygen to form oxides, so vacuum or inert gas (such as argon or nitrogen) environment protection is usually required in lamps and lanterns to prevent oxidation reactions from damaging material properties.

The thermal expansion characteristics of molybdenum wire are one of the important factors for its application in the lighting field. Its coefficient of thermal expansion is highly matched to certain glass materials, such as borosilicate glass, which makes molybdenum wire an ideal choice in glass-to-metal sealing processes in luminaire manufacturing, ensuring airtightness and structural stability. In addition, the surface properties of molybdenum wire have a significant impact on its properties. Through electrolytic polishing or chemical cleaning, the surface of the molybdenum wire can achieve a high finish, reducing the unevenness during arc discharge, thereby improving the stability and optical performance of the luminaire. Doped molybdenum wire (e.g. molybdenum lanthanum wire or molybdenum rhenium wire) by adding rare earths or other elements, the creep resistance and recrystallization temperature of the material at high temperatures are significantly improved, making it more suitable for demanding lighting application scenarios.

1.1.2 The core function of molybdenum wire in the field of lighting

The application of molybdenum wire in the lighting field covers a variety of key functions, including filament support, electrode material, sealing components, and support for halogen cycling, etc., which are detailed below:

Filament support: In incandescent and halogen lamps, molybdenum filament is often used as a structural material to support tungsten filament. Tungsten filament is prone to deformation or sag when working at high temperatures, while molybdenum filament, with its excellent high-temperature strength and creep resistance, can firmly support the filament and maintain its geometry, thus ensuring the luminous efficiency and service life of the lamp. This support function is particularly important in high-temperature environments, where the filament may be close to the melting point for long periods of time.

Electrode material: In gas discharge lamps (e.g., high-intensity discharge lamps, fluorescent lamps), molybdenum wire acts as the electrode material, which is responsible for guiding the arc and transmitting current. Its high conductivity and resistance to arc corrosion allow it to withstand the impact of instantaneous high voltage and high temperature arcs, maintaining the integrity of the electrode structure. For example, in high-pressure sodium or metal halide lamps, the molybdenum wire electrode needs to operate stably under extreme conditions to ensure that the luminaire is lit and continues to emit light.

Sealing components: Molybdenum wire matches the coefficient of thermal expansion of glass, making it the material of choice for glass-to-metal sealing in luminaire manufacturing. The sealing components need to ensure the airtightness inside the luminaire and prevent inert gas leakage or outside air infiltration, thereby protecting the environment inside the lamp and extending the service life. The chemical stability of the molybdenum wire allows it to resist corrosion in the high-temperature gas environment inside the lamp, ensuring long-term reliability of the sealing part.

Halogen cycle assistance: In halogen lamps, molybdenum filaments are involved in the halogen cycle process together with halogen gases (such as iodine or bromine) in the lamp. The halogen cycle deposits the evaporated tungsten back into the filament through a chemical reaction, significantly extending filament life while increasing luminous efficiency. The chemical resistance of molybdenum wire ensures that it is not attacked in halogen environments, thus maintaining the stability of the cyclic process and supporting the high performance of halogen lamps.

The versatility of molybdenum wire makes it an indispensable role in both traditional lighting (e.g., incandescent lamps, halogen lamps) and specialty lighting (e.g., automotive lamps, stage lamps, medical lamps). Its potential in emerging lighting technologies, such as high-power discharge lamps, is also becoming an important pillar of the modern lighting industry.

1.1.3 Comparison of molybdenum wire with other metal materials

The unique advantages of molybdenum wire in lighting can be demonstrated by a detailed comparison with commonly used metal materials such as tungsten, copper, nickel and platinum:

Contrast with tungsten: Tungsten is the material of choice for incandescent filaments due to its extremely high melting point, which makes it suitable for direct use as a light-emitting element. The luminous efficiency of tungsten at high temperature is better than that of molybdenum, but its thermal expansion coefficient is slightly less compatible with that of glass, and it is easy to recrystallize at high temperature, resulting in embrittlement of the material. In contrast, molybdenum wire has better creep resistance and structural stability at high temperatures, making it particularly suitable as a filament support or electrode material. In addition, molybdenum's raw material cost and processing difficulty are lower than tungsten, making it more economical and widely used in scenarios that require high-temperature stability and sealing functions.

Contrast to copper: Copper has extremely high electrical conductivity and good ductility, but its low melting point makes it unable to withstand the high temperatures found in lighting devices. In addition, the coefficient of thermal expansion of copper is quite different from that of glass, making it unsuitable for glass-to-metal sealing. Molybdenum wire's high-temperature stability and compatibility with glass make it far superior to copper in luminaire manufacturing, especially in applications that require high temperature resistance and air tightness.

Comparison with nickel: Nickel is used as an electrode material in some low-power lamps due to its corrosion resistance and processability. However, nickel has a low melting point and insufficient strength at high temperatures to meet the demanding requirements of high-intensity discharge or halogen lamps. The excellent properties of molybdenum wire in high-temperature arc and chemically corrosive environments make it a more suitable material for high-performance lighting applications.

Contrast with platinum: Platinum is occasionally used in high-end specialty lamps due to its high chemical stability and oxidation resistance. However, platinum has a lower melting point than molybdenum and its extremely high cost, limiting its large-scale application in industry. Molybdenum wire offers a good balance between performance and cost, making it suitable for a wide range of lighting and high-temperature applications.

In summary, molybdenum wire occupies a unique position in the lighting field due to its combination of high-temperature performance, sealing ability, chemical stability and cost-effectiveness, especially in applications that require high-temperature stability and hermetically sealed connection.

1.2 History and development of molybdenum wire

1.2.1 Discovery and early industrial application of molybdenum

The discovery of molybdenum dates back to the end of the 18th century. In 1778, the Swedish chemist Carl Wilhelm Scherer isolated molybdenum acid from molybdenite through chemical experiments, laying the foundation for molybdenum research. In 1781, Peter Jacob Hiyem successfully prepared molybdenum metal by reducing molybdenum acid, marking the official discovery of molybdenum. At the end of the 19th century, with the advancement of metallurgical technology, molybdenum began to enter the industrial field, initially mainly used in the manufacture of steel alloys to enhance the strength, heat resistance and corrosion resistance of steel. At the beginning of the 20th century, the refractory properties of molybdenum were gradually recognized, and its high melting point and high-temperature strength led to its application in high-temperature industries, such as electric furnace heating elements and vacuum equipment.

In the field of lighting, the application of molybdenum began with the development of incandescent lamps at the end of the 19th century. Early incandescent lamps used carbon filament or platinum filament as filament, but the carbon filament had a short life, and the cost of platinum filament was high, making it difficult to meet the needs of large-scale production. Molybdenum has been tried for filament support and electrode materials due to its high melting point and good mechanical properties, especially in vacuum or inert gas environments. At the beginning of the 20th century, molybdenum wire began to be used in the sealing parts of incandescent lamps, because it matched the thermal expansion of glass better than other metals, and significantly improved the airtightness and reliability of lamps.

1.2.2 The evolution of molybdenum wire in lighting technology

The application of molybdenum wire in lighting technology has undergone several stages of evolution with the development of luminaire technology:

The era of incandescent lamps (late 19th to early 20th centuries): The invention of incandescent lamps drove the early application of molybdenum wire. When Thomas Edison and others developed incandescent lamps, they faced the problem of selecting filament support and sealing materials. Molybdenum wire was used to support tungsten filaments and form hermetically sealed joints due to its high-temperature strength and compatibility with glass. In the 1900s, the drawing process of molybdenum wire gradually matured, producing finer and more uniform molybdenum wire, which met the precision manufacturing needs of incandescent lamps.

The rise of halogen lamps (mid-20th century): In the 1950s, the invention of halogen lamps put forward higher requirements for molybdenum wire. Halogen lamps operate at extremely high temperatures and are filled with chemically active halogen gases. Molybdenum wire is an ideal choice for electrodes and support materials due to its high temperature and chemical resistance. Doped molybdenum wire (e.g. molybdenum lanthanum wire) was developed during this period to further improve the high-temperature performance.

Gas discharge lamps and specialty lighting (late 20th century): With the popularity of high-intensity discharge lamps (HID), fluorescent lamps and specialty lighting (e.g., automotive lamps, projection lamps), the application range of molybdenum wire has been further expanded. Its stability in arc discharge environments and the reliability of its sealing to glass make it the material of choice for gas discharge lamp electrodes and sealing components.

Modern lighting technology (21st century): Although LED lighting is gradually replacing traditional luminaires, molybdenum wire is still indispensable in the stock market of high-power specialty lighting (e.g. stage lights, medical lamps) and traditional luminaires. In addition, the application potential of molybdenum wire in vacuum electronic devices, aerospace high-temperature components and other fields has been further explored, showing its cross-field adaptability.

1.2.3 Key technological breakthroughs and milestones

The wide application of molybdenum wire in the field of lighting is due to the following key technological breakthroughs:

Maturity of powder metallurgy technology: At the beginning of the 20th century, the progress of powder metallurgy technology made it possible to produce high-purity molybdenum wire on a large scale. By pressing, sintering and forging the molybdenum powder into a blank, it provides a high-quality raw material for the subsequent drawing process.

Improvement of the wire drawing process: In the 1920s, the optimization of multi-pass wire drawing technology and die design led to a significant reduction in the diameter of molybdenum wire, which was able to produce micron-sized filaments to meet the needs of precision lamps. The introduction of annealing process improves the ductility and toughness of molybdenum wire, and reduces the fracture rate during processing.

Development of doping technology: In the 1950s, the high temperature creep resistance and recrystallization temperature of molybdenum wire were significantly improved by doping elements such as lanthanum oxide or rhenium. For example, molybdenum lanthanum wire has a recrystallization temperature of hundreds of degrees Celsius higher than pure molybdenum wire, allowing it to be used under more demanding conditions.

Advances in surface treatment technology: In the 1980s, the application of electrolytic polishing and chemical cleaning technology significantly improved the surface finish of molybdenum wire, reduced inhomogeneity in arc discharge, and extended the service life of luminaires.

The introduction of automated production: At the beginning of the 21st century, the wide application of automated production lines has improved the consistency and efficiency of molybdenum wire production, reduced production costs, and further enhanced the competitiveness of molybdenum wire in the global market.

These technological breakthroughs not only promote the application of molybdenum wire in the lighting field, but also lay the foundation for its expansion in other high-temperature industrial fields.

1.3 The importance of molybdenum wire in the modern lighting industry

1.3.1 Performance comparison between molybdenum wire and traditional tungsten wire

Molybdenum wire and tungsten wire are the two most commonly used high-temperature metal materials in the lighting industry. The following is a detailed comparison from multiple aspects:

High temperature performance: The melting point of tungsten is higher than that of molybdenum, making it more suitable as a luminous filament for incandescent lamps and directly withstand high-temperature luminescent tasks. However, molybdenum has better creep resistance and structural stability at high temperatures, making it suitable as a support material or electrode, especially in scenarios where long-term shape retention is required.

Thermal expansion characteristics: The coefficient of thermal expansion of molybdenum is highly matched with sealing materials such as borosilicate glass, which can form a reliable hermetic seal. Tungsten's coefficient of thermal expansion is slightly less compatible with glass, and additional transition materials are often required for sealing, adding to the manufacturing complexity.

Chemical stability: In the halogen gas environment of halogen lamps, the corrosion resistance of molybdenum wire is better than that of tungsten, which can effectively resist the chemical attack of halogen gas, support the halogen cycle process, and prolong the life of the lamp.

Cost and processability: Molybdenum has lower raw material and processing costs than tungsten, and its drawing and forming processes are relatively simple, making it suitable for large-scale production. Tungsten is difficult to process, especially in the production of ultrafine wires, and the yield is low.

Electrical properties: The resistivity of tungsten and molybdenum is similar, but molybdenum has better arc stability in gas discharge lamps, and is suitable as an electrode material to withstand the impact of instantaneous high voltage and high temperature arc.

In summary, molybdenum wire and tungsten wire form a complementary relationship in lighting devices, molybdenum wire is widely used in support, electrode and sealing functions due to its excellent sealing performance, chemical stability and economy, while tungsten wire is mainly used for light-emitting filament.

1.3.2 The strategic position of molybdenum wire in high-efficiency lighting

High-efficiency lighting (e.g., halogen lamps, high-intensity discharge lamps) puts forward higher requirements for the high-temperature performance, chemical stability and electrical properties of materials, and molybdenum wire has shown its strategic position in the following aspects:

A key role in halogen lamps: Halogen lamps achieve higher luminous efficiency and longer life through halogen cycling. As an electrode and support material, molybdenum wire needs to withstand high temperature and chemical attack of halogen gas, and its excellent corrosion resistance and high temperature strength ensure the stable operation of the lamp, providing key support for the high efficiency of halogen lamp.

Application of high-intensity discharge lamps: In high-intensity discharge lamps such as metal halide lamps and high-pressure sodium lamps, molybdenum wire, as an electrode material, needs to withstand instantaneous high voltage and extreme high temperature arc environment. Its arc stability and high-temperature resistance make it an irreplaceable material, ensuring a quick start-up and continuous luminescence of the luminaire.

Reliability in specialty lighting: In automotive headlamps, projection lamps and stage lighting, luminaires need to operate stably in complex environments such as vibration and high temperatures. The high reliability of the molybdenum wire and the ability to seal with glass ensure the durability and performance stability of the luminaire.

Support energy saving and environmental protection: The high efficiency and long life characteristics of molybdenum wire support the design of energy-saving lamps and lanterns, which meet the requirements of the modern lighting industry for energy efficiency and environmental protection. Its production and use process also meets strict environmental standards, such as the European Union's RoHS directive.

The strategic position of molybdenum wire is reflected in its ability to promote the development of lighting technology in the direction of high performance, long life and energy saving, especially in the transformation of traditional lighting to high-efficiency lighting.

1.3.3 The role of molybdenum wire in energy-saving lamps

Energy-saving luminaires (e.g. halogen lamps, compact fluorescent lamps, high-intensity discharge lamps) are the mainstream of modern lighting, and molybdenum wire plays a key role in it:

Halogen lamps: Molybdenum filaments extend filament life and reduce energy consumption by supporting halogen cycles. The reliability of molybdenum filament is key to achieving this advantage due to the significant proportion of luminous efficiency of halogen lamps compared to conventional incandescent lamps, ensuring stable operation of luminaires in high temperature and chemical attack environments.

Compact fluorescent lamps: In compact fluorescent lamps, molybdenum wire acts as an electrode material and is responsible for initiating and maintaining the fluorescent discharge. Its high conductivity and resistance to arc corrosion ensure fast start-up and long-term stability of the luminaires, meeting the requirements for high efficiency in energy-efficient lighting.

High-intensity discharge lamps: The luminous efficiency of high-intensity discharge lamps far exceeds that of traditional incandescent lamps, and they are the representative of high-efficiency lighting. As an electrode and sealing material, molybdenum wire supports the operation of lamps in high temperature and high pressure environments, and significantly improves energy efficiency.

Environmental protection characteristics: The production and use of molybdenum wire comply with strict environmental protection regulations, do not contain lead, mercury and other harmful substances, and meet the requirements of green lighting. Its high durability also reduces the frequency of luminaire replacement, reducing resource consumption and waste generation.

The application of molybdenum wire in energy-saving lamps and lanterns promotes the miniaturization, high performance and environmental protection of lamps and lanterns, and meets the needs of modern society for low-carbon and sustainable development.

1.4 Research and application status of molybdenum wire

1.4.1 Research progress of molybdenum wire technology at home and abroad

Globally, the research on molybdenum wire technology mainly focuses on the following directions:

Doping technology: domestic and foreign research institutions are committed to the development of new doped molybdenum wires, by adding rare earth elements (such as lanthanum, cerium, yttrium) or precious metals (such as rhenium) to improve high temperature creep resistance and oxidation resistance. For example, the high-performance molybdenum lanthanum wire developed by the Institute of Metal Research of the Chinese Academy of Sciences has a significantly higher recrystallization temperature and is suitable for more demanding high-temperature environments. Research in Europe and the United States has focused on the development of molybdenum-rhenium alloys to improve ductility and oxidation resistance.

Production process optimization: Companies in Germany and Austria have significantly improved the surface quality and production consistency of molybdenum wire by introducing intelligent manufacturing technology and precision wire drawing equipment. Chinese companies have made breakthroughs in powder metallurgy and wire drawing processes, optimizing production efficiency and reducing costs.

Nanoscale molybdenum wire: With the rise of nanotechnology, some research institutions have explored the preparation of nanoscale molybdenum wire for high-precision electronic devices and new lighting technologies. The strength and conductivity of nano-molybdenum wire are expected to be further improved, providing the possibility for next-generation lighting technology.

Green manufacturing: Research in Europe and Japan focuses on environmentally friendly production technologies, such as reducing energy consumption and exhaust emissions in the sintering process. China is also promoting the low-carbon production of molybdenum wire, developing waste recycling technology and green processes, and responding to the global environmental protection trend.

1.4.2 Global Market Size and Application Distribution

According to industry analysis, the global molybdenum wire market has maintained steady growth in recent years, and the lighting field is one of its main application scenarios. The growth of the market size is mainly driven by the following factors:

Regional distribution: China is the world's largest producer of molybdenum wire, with rich molybdenum ore resources and mature processing technology, accounting for a significant share of global production. Europe (Germany, Austria) and the United States have technological advantages in the production of high-end doped molybdenum wires, focusing on high value-added products.

Application distribution: In the field of lighting, halogen lamps and high-intensity discharge lamps are the main application scenarios of molybdenum wire, occupying a large market share of molybdenum wire for lighting. Other applications include specialty lighting (e.g., automotive lights, medical lights) and vacuum electronics (e.g., X-ray tubes).

Market Drivers: The growing demand for high-efficiency lighting, the rapid expansion of the automotive lighting market, and the use of specialty lighting in the aerospace and medical sectors are driving the continued growth of the molybdenum wire market. The global emphasis on energy-efficient and eco-friendly lighting has also further promoted the application of molybdenum wire.

1.4.3 Technical bottlenecks and future challenges

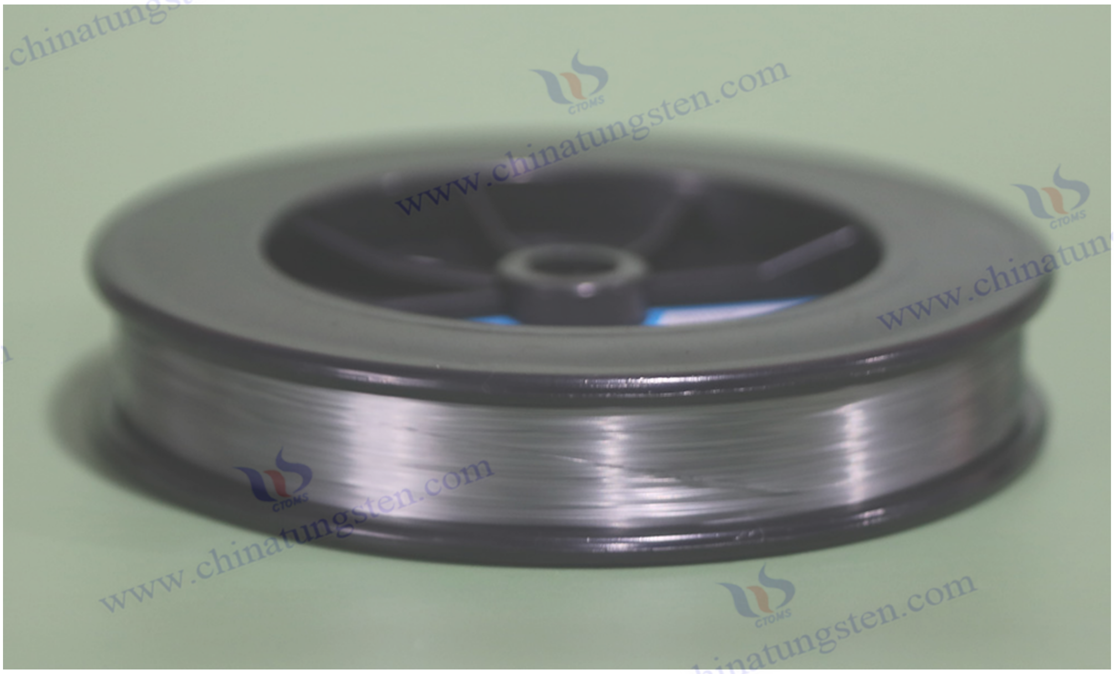
Although molybdenum wire is widely used in the lighting field, it still faces the following technical bottlenecks and challenges:

High-temperature oxidation problem: Molybdenum wire is easily oxidized in high-temperature air, which limits its application in non-vacuum or non-inert gas environments. The development of anti-oxidation coatings or new doped materials is the focus of future research to further broaden their application scenarios.

Difficulty in the production of ultra-fine molybdenum wire: The production of ultra-fine molybdenum wire (diameter less than 0.02 mm) requires extremely high process accuracy and low yield, resulting in an increase in cost. Improving production consistency and reducing costs are important challenges for the industry.

Competition in LED lighting: The popularity of LED lamps has significantly reduced the demand for traditional lamps (such as incandescent lamps and halogen lamps), and the market share of molybdenum wire in the lighting field has been affected to a certain extent. Developing applications of molybdenum wire in LED-related high-temperature components or emerging fields is key to meeting this challenge.

Environmental protection and sustainability: Energy consumption and waste disposal in the production of molybdenum wire are subject to increasingly stringent environmental regulations (e.g. RoHS and REACH directives in the European Union). The development of green manufacturing technology and waste recycling system has become an important development direction of the industry.



molybdenum wire for lighting from CTIA

Chapter 2 Classification of Molybdenum Wire for Lighting

As a key material in the lighting industry, Molybdenum wire for lighting has diversified properties and application scenarios due to different chemical compositions, uses and physical specifications. According to the chemical composition, molybdenum wire can be divided into pure molybdenum wire, molybdenum lanthanum wire, molybdenum rhenium wire and other doped molybdenum wire; According to the application, it is divided into incandescent lamp, halogen lamp, fluorescent lamp and gas discharge lamp and molybdenum wire for special lamp; According to the specifications, it is divided into different diameter ranges, surface treatment types and wire shapes. This chapter will provide a comprehensive and detailed analysis of the characteristics, preparation processes, application scenarios, technical challenges, and market status of each classification, combined with global research and industrial practices.

2.1 Classification by chemical composition

The chemical composition of molybdenum wire is the core factor that determines its physical, chemical, mechanical and electrical properties. By doping different elements in a molybdenum matrix or maintaining high purity, molybdenum wire can meet diverse needs from low-cost incandescent lamps to high-performance specialty lamps. The following is a detailed introduction to the characteristics, production process and application of pure molybdenum wire, molybdenum lanthanum wire, molybdenum rhenium wire and other doped molybdenum wires.

2.1.1 Pure molybdenum wire

Pure molybdenum wire refers to molybdenum wire with a molybdenum content of ≥ 99.95%, without adding any doping elements, and is the most basic and widely used type of Molybdenum wire for lighting. Its high purity and excellent physicochemical properties make it the material of choice for conventional lighting devices.

Chemical composition and purity: Pure molybdenum wire is based on high-purity molybdenum, and the total content of impurities (such as iron, nickel, carbon, oxygen, silicon, etc.) is usually controlled below 0.05%, and can be as low as 0.01% in some high-demand applications. High purity is achieved by hydrogen reduction of ammonium molybdate (AMT) or molybdenum trioxide (MoO_3) to prepare molybdenum powder. Strict control of impurities on the conductivity of molybdenum wire (resistivity about 5.5×10^{-8} Ω·m) and corrosion resistance are crucial. For example, too high oxygen levels can lead to accelerated oxidation at high temperatures, resulting in volatile MoO_3 and affecting the life of the luminaire.

Physical properties: Pure molybdenum wire has a high melting point (2623°C), high density (10.2 g/cm³) and low coefficient of thermal expansion (4.8×10^{-6}/K). Its thermal conductivity (138 W/m·K) is better than that of tungsten (174 W/m·K), making it suitable for thermal and electrical conductivity. The body-centered cubic (BCC) crystal structure of molybdenum wire gives it excellent mechanical strength, but it is prone to recrystallization at high temperatures (>1000°C), resulting in grain growth and embrittlement.

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Molybdenum Wire for Lighting Introduction

1. Overview of Molybdenum Wire for Lighting

As one of the core materials in modern lighting technology, molybdenum wire is widely used in various light sources including incandescent lamps, halogen lamps, fluorescent lamps, and gas discharge lamps, due to its high melting point, high strength, excellent corrosion resistance, and superior electrical conductivity. It is an irreplaceable and critical component in the lighting industry.

2. Typical Applications of Molybdenum Wire for Lighting

Residential and Commercial Lighting: Used in incandescent and halogen lamps to provide warm light and long service life.

Automotive Lighting: Functions as electrodes in HID and xenon lamps, offering high brightness and vibration resistance.

Specialty Lighting: Utilized in projection lamps, ultraviolet (UV) lamps, and infrared (IR) lamps to meet high-temperature and high-precision requirements in medical, industrial, and scientific applications.

Emerging Fields: Serves as conductive leads for LED lamps and supports for phosphors in laser lighting, aligning with future lighting technology development.

3. Basic Data of Molybdenum Wire for Lighting (Reference)

Parameter	Pure Mo Wire	Mo-La Wire	Mo-Re Wire
Mo Content	≥99.95%	≥99.0%	52.5%–86.0%
Diameter Range	0.03–3.2 mm	0.03–1.5 mm	0.03–1.0 mm
Tolerance	±0.002 mm	±0.002 mm	±0.002 mm
Tensile Strength (Room Temp)	800–1200 MPa	900–1400 MPa	1000–1500 MPa
Tensile Strength (at 1500°C)	150–300 MPa	200–400 MPa	250–450 MPa
Elongation at Break	10%–25%	12%–20%	15%–25%
Electrical Resistivity (20°C)	5.5×10^{-8} Ω·m	6.0×10^{-8} Ω·m	6.5×10^{-8} Ω·m
Main Applications	Incandescent, Halogen	Halogen, Auto Headlights	HID, Projection Lamps

4. Procurement Information

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Mechanical properties: At room temperature, the tensile strength of pure molybdenum wire is 800-1000 MPa, and the elongation at break is about 5%-10%. At high temperatures (1500°C), the tensile strength drops to 200-300 MPa, and the creep resistance is weak, which limits its application in extremely high temperature environments. The ductility of molybdenum wire allows it to be processed into ultrafine wires with diameters as low as 0.01 mm by multi-pass drawing.

Chemical stability: Pure molybdenum wire has good corrosion resistance to acids, alkalis and water at room temperature, but it will oxidize rapidly when exposed to air at high temperature (>600°C) to form MoO_3. Therefore, pure Molybdenum wire for lighting is usually used in a vacuum or inert gas (e.g., argon, nitrogen) environment to avoid oxidation losses.

Preparation process:
Raw material preparation: high-purity molybdenum powder (particle size 1-5 μm) is prepared by reducing ammonium molybdate or molybdenum trioxide by hydrogen. Impurities such as oxygen and carbon in the powder need to be strictly controlled.
Powder metallurgy: Molybdenum powder is pressed into a billet by cold isostatic pressing (CIP) and sintered (1800-2000°C) in a vacuum or hydrogen atmosphere to form a dense molybdenum billet.
Hot working: The blank is hot-forged, hot-rolled or rotary forging to form molybdenum rods with a diameter reduced to 1-5 mm.
Wire drawing: The molybdenum rod is stretched to the target diameter using a diamond die and a lubricant such as graphite emulsion by means of multiple passes (10-20 passes). Intermediate annealing (800-1200°C) is performed during the drawing process to eliminate work hardening.
Surface treatment: Depending on the application requirements, the oxide layer (black molybdenum wire) can be retained or cleaned molybdenum wire can be made by pickling and electrolytic polishing.

Application scenario: Pure molybdenum wire is mainly used for filament support filaments and sealing electrodes in low-power incandescent lamps (40-100 W), because it is highly matched to the thermal expansion coefficient of borosilicate glass (difference $<0.5\times10^{-6}$/K), which can form a reliable hermetically sealed bond. In addition, pure molybdenum wire is also used as an electrode material for fluorescent lamps and is responsible for initiating discharge. It is cost-effective and suitable for large-scale production.

Market and technology status: The production technology of pure molybdenum wire has been highly mature in the world, and China accounts for more than 60% of the global output.

Advantages and Limitations:
Advantages: Low cost (about $1-2/kg, depending on specifications), excellent processing performance, suitable for low-cost lighting devices. The production process of pure molybdenum wire is simple, and the yield is high (>95%).

Limitations: Poor creep and oxidation resistance at high temperatures limit its application in high-

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power halogen or gas discharge lamps. In > 1500°C environment, the lifetime of pure molybdenum wire is usually less than 1000 hours.

Technical challenges: Improving the high-temperature performance of pure molybdenum wire requires an optimized annealing process or surface passivation to reduce grain growth and oxidation losses. In the future, the development of low-cost anti-oxidation coatings may be a breakthrough direction.

2.1.2 Molybdenum lanthanum wire

Molybdenum lanthanum wire is made by doping lanthanum oxide (La_2O_3, content 0.3%-1.0%) in molybdenum matrix, which is widely used in high-end lighting devices because of its excellent high-temperature performance and creep resistance.

Chemical composition: Molybdenum lanthanum wire is based on high-purity molybdenum (≥99.5%) and doped with lanthanum oxide particles (particle size 10-100 nm). Lanthanum oxide is distributed in the form of a diffuse phase at the molybdenum grain boundary, which inhibits grain growth and dislocation slip through the pinning effect. Impurities (e.g. iron, carbon) should be controlled below 0.03% to avoid performance deterioration.

Physical properties: The melting point of molybdenum lanthanum wire is close to that of pure molybdenum (about 2620 °C), but the recrystallization temperature is significantly increased to 1800-2000 °C (1400-1600 °C for pure molybdenum wire). Its coefficient of thermal expansion (4.8×10^{-6}/K) and thermal conductivity (about 135 W/m·K) are comparable to those of pure molybdenum wire, but the oxidation resistance is slightly improved, because lanthanum oxide particles can slow down oxygen diffusion.

Mechanical properties: The tensile strength of molybdenum lanthanum wire at high temperature (2000°C) is 300-500 MPa, and the creep resistance is 2-3 times higher than that of pure molybdenum wire. Its elongation at break is 8%-12% at room temperature, and it still maintains a certain toughness at high temperature. The pinning effect of lanthanum oxide makes molybdenum lanthanum wire more fatigue resistant during thermal cycling.

Chemical stability: Molybdenum lanthanum wire performs well in halogen gas environments (such as iodine, bromine) and is better chemically resistant than pure molybdenum wire. In vacuum or inert gases, its oxidation resistance can support a luminaire life of > 2000 hours.

Preparation process:

Doping preparation: Ensure uniform distribution of lanthanum oxide by wet doping (mixing lanthanum oxide solution with molybdenum powder) or spray drying. The doping ratio needs to be precisely controlled (0.3%-1.0%), too high can lead to embrittlement of the material.

Powder metallurgy: doped molybdenum powder is pressed into a blank and sintered in a hydrogen atmosphere (1900-2100 °C) to form a uniform diffuse phase structure.

Hot working and wire drawing: The blank is formed by multi-pass wire drawing after hot forging

and hot rolling. Several annealing (900-1300°C) are required during the drawing process to maintain ductility. The choice of mold and lubricant is critical to surface quality.
Surface treatment: It is usually made into cleaned molybdenum wire, and the oxide layer is removed by electrolytic polishing to improve arc stability and corrosion resistance.

Application scenario: Molybdenum lanthanum wire is widely used as an electrode and support material for halogen lamps and high-intensity discharge lamps (HID). For example, in automotive headlights, molybdenum lanthanum wire can withstand high temperatures (>2500°C) and vibration, ensuring a lamp life of more than 2000 hours. Its electrode application in metal halide lamps also significantly improves discharge stability.

Market and technical status: Molybdenum lanthanum wire accounts for about 30% of the market for lamp molybdenum wire. Through technology introduction and independent research and development, China has realized the large-scale production of molybdenum lanthanum wire, which is exported to Europe and North America. The global market is growing at an annual rate of about 5% and is driven by the demand for automotive lighting.

Advantages and Limitations:
Advantages: Creep resistance and oxidation resistance at high temperature are significantly better than pure molybdenum wire, suitable for high-performance lamps. The service life can reach 2-3 times that of pure molybdenum wire.
Limitations: The doping process increases the production cost (about 3-5 USD/kg), and the uniform distribution of lanthanum oxide places high demands on equipment and processes. Improper doping may result in particle agglomeration and reduced performance.

Technical challenges: Optimizing doping uniformity and reducing costs are the main directions. The preparation and dispersion technology of nanoscale lanthanum oxide particles is the focus of future research and development.

2.1.3 Molybdenum rhenium wire

Molybdenum rhenium wire is an alloy wire made by doping rhenium (Re) in a molybdenum matrix, which has unique advantages in special lighting with its excellent ductility and oxidation resistance.

Chemical composition: molybdenum rhenium wire is based on molybdenum and doped with rhenium metal to form a solid solution. The addition of rhenium improves the crystal structure of molybdenum and reduces the brittleness at low temperatures. Impurities (such as oxygen and nitrogen) should be controlled below 0.02% to ensure stable performance.

Physical properties: The melting point of molybdenum rhenium wire is slightly lower than that of pure molybdenum (about 2600 °C), because the melting point of rhenium (3186 °C) is slightly lower. Its coefficient of thermal expansion (4.9×10^{-6}/K) and thermal conductivity (about 130 W/m·K) are similar to those of pure molybdenum, but the oxidation resistance is significantly improved, and the oxidation rate is reduced by about 30% at high temperatures.

Mechanical properties: The tensile strength of molybdenum rhenium wire at room temperature is 900-1200 MPa, and the elongation at break is 15%-20%, which is much higher than that of pure molybdenum wire (5%-10%). At 2000°C, the tensile strength is 300-400 MPa, and the fatigue resistance is better than that of molybdenum lanthanum wire, which is suitable for frequent thermal cycling environments.

Chemical stability: Molybdenum rhenium wire performs well in halogen gas and vacuum environment, and its chemical corrosion resistance is better than that of pure molybdenum wire and molybdenum lanthanum wire. Its antioxidant properties are due to the protective oxide layer formed by rhenium, which slows down the volatilization of MoO_3.

Preparation process:
Doping preparation: Rhenium powder is mixed with molybdenum powder by mechanical mixing or chemical co-precipitation, which needs to be operated under vacuum or inert atmosphere to prevent rhenium oxidation.
Powder metallurgy: doped powder pressed into a blank and sintered under hydrogen or vacuum (1900-2100°C). The sintering temperature needs to be precisely controlled to avoid rhenium volatilization.
Hot working and wire drawing: The blank is formed by precision wire drawing after hot forging and hot rolling. Low temperature annealing (700-1000°C) is required during the wire drawing process to maintain toughness.
Surface treatment: cleaned molybdenum wire is mostly used, and the surface finish is improved by electrolytic polishing or chemical cleaning.

Application scenario: Molybdenum rhenium wire is mainly used for special lamps, such as projection lamps, stage lights, medical ultraviolet lamps and aviation lights. Its high ductility is suitable for complex electrode shape designs (e.g. spiral or curved electrodes), and its oxidation resistance extends the life of the luminaire (up to more than 3000 hours).

Market and technology status: molybdenum rhenium wire accounts for about 10% of the molybdenum wire market for lamps. China has achieved small-scale production through technology introduction in recent years, but the scarcity and high price of rhenium limit the market size.

Advantages and Limitations:
Advantages: Ductility and oxidation resistance are better than pure molybdenum wire and molybdenum lanthanum wire, suitable for complex shapes and extreme environments. High toughness and strong resistance to thermal cycling.
Limitations: The high cost of rhenium makes the price of molybdenum rhenium wire about 3-5 times that of pure molybdenum wire, which limits large-scale application. The doping ratio needs to be precisely controlled, as too high can lead to softening of the material.

Technical challenges: Reducing the amount of rhenium or developing alternative elements (e.g. ruthenium, osmium) is key to cost optimization. Improving doping uniformity and production efficiency is also the way forward.

2.1.4 Other doped molybdenum wires

In addition to molybdenum lanthanum wire and molybdenum rhenium wire, other doped molybdenum wires include molybdenum wires doped with tungsten, yttrium, cerium or multi-element composite doped wires, optimized for specific high-end applications.

Molybdenum tungsten wire:

Characteristics: Molybdenum wire doped with tungsten (W, content 1%-10%) combines the sealing properties of molybdenum with the high melting point of tungsten (3422°C). Its tensile strength can reach 600 MPa at 2000°C, making it suitable for high-power luminaires.

Application: Electrodes and support materials for high-power incandescent lamps and metal halide lamps.

Limitations: Poor ductility (elongation at break <5%), high processing difficulty, and the cost is about 2 times that of pure molybdenum wire.

Molybdenum yttrium wire:

Characteristics: doped with yttrium oxide (Y_2O_3, content 0.5%-2%), recrystallization temperature up to 1900 °C, excellent oxidation resistance and creep resistance.

Application: Used in aerospace special lamps (such as navigation lights) and high-temperature infrared lamps.

Limitations: The doping process of yttrium oxide is complex, and the yield is low (about 80%).

Molybdenum and cerium wire:

Characteristics: Doped cerium oxide (CeO_2, content 0.3%-1%), strong arc corrosion resistance, suitable for high-frequency discharge environment.

Application: used for ultraviolet lamps and medical light sources.

Limitations: Higher cost and narrow market application.

Multi-element doped molybdenum wire:

Characteristics: such as composite molybdenum wire doped with lanthanum, rhenium and yttrium, which combines high temperature strength, ductility and oxidation resistance.

Applications: Used in extreme environments such as high-pressure discharge lamps and scientific light sources.

Limitations: The preparation process is complex, the cost is high, and it is limited to small batch production.

Preparation process: similar to molybdenum lanthanum wire, it needs to be uniformed by wet doping or spray drying, the sintering temperature is 1900-2200 °C, and high-precision molds and multi-pass annealing are required for wire drawing.

Market and technical status: Other doped molybdenum wire accounts for 5% of the market for lamp molybdenum wire, which is mainly produced by foreign enterprises. China has made some progress in the field of molybdenum yttrium wire and molybdenum and cerium wire, but the technology still needs to be broken through.

Advantages and Limitations:
Benefits: Performance optimized for specific needs for high-end applications.
Limitations: high cost, small market size, complex production technology.

Technical challenges: The development of low-cost doping elements and simplified processes are key. The application of nanoscale doping technology is expected to further improve performance.

2.2 Classification by use

According to its functions and application scenarios in different types of lamps, Molybdenum wire for lighting can be divided into incandescent lamps, halogen lamps, fluorescent lamps and gas discharge lamps, and molybdenum wires for special lamps. Each application has different performance requirements for molybdenum wire, involving high temperature stability, corrosion resistance, electrical properties and processability.

2.2.1 Molybdenum wire for incandescent lamps

Molybdenum wire for incandescent lamps is mainly used for filament support and glass-to-metal sealing, and is the most common molybdenum wire application in traditional lighting.

Function and function: In incandescent lamps, molybdenum wire is mainly used as a support wire to fix tungsten filament to prevent it from sagging or breaking at high temperature (2500-3000°C); As a sealing electrode, an electric current is introduced into the bulb and a hermetic connection is formed with the glass, ensuring that vacuum or inert gases (such as argon, nitrogen) in the lamp do not leak.

Performance Requirements:
High temperature stability: It needs to withstand the working temperature of more than 2000 °C, and the tensile strength is maintained at more than 200 MPa at high temperature.
Thermal expansion matching: The coefficient of thermal expansion should be highly matched with borosilicate glass ($4.3\text{-}5.0\times10^{-6}$/K), and the difference should be $< 0.5\times10^{-6}$/K.
Conductivity: Resistivity should be low (about 5.5×10^{-8} Ω·m) to ensure the efficiency of current transmission.
Surface quality: Cleaned molybdenum wire is usually used, and the surface roughness of Ra<0.5 μm is used to reduce arc instability.

Application characteristics: Incandescent lamps have a low luminous efficiency (10-15 lm/W) and a lifespan of about 1000 hours, mainly used in home lighting, decorative lighting (such as retro bulbs) and low-cost scenes. Molybdenum wire needs to work in a vacuum or inert gas environment to prevent oxidation.

Preparation process:
Raw material selection: high-purity molybdenum powder (≥99.95%) is used to prepare it by hydrogen reduction.
Forming & Drawing: Molybdenum wires with a diameter of 0.1-0.5 mm are made by powder metallurgy and multi-pass drawing. Several annealing (800-1200°C) are required during the drawing process to maintain ductility.
Surface treatment: Cleaned molybdenum wire is usually made by electrolytic polishing or pickling (HNO_3-HF mixture) to ensure adhesion to glass and arc stability.

Market status: The incandescent lamp market has shrunk due to the popularity of LED lighting, but it still accounts for about 10% of the global lighting market, and the amount of molybdenum wire accounts for about 20% of the lamp molybdenum wire. The main markets are concentrated in developing countries such as Southeast Asia and Africa, and China is the main supplier.

Advantages and Limitations:
Advantages: mature technology, low cost (about 1 USD/kg), suitable for large-scale production. Pure molybdenum wire has excellent sealing performance and high yield (>95%).
Limitations: Poor creep resistance at high temperatures, short life, not suitable for high-power or long-life lamps.

Technical challenges: Improving the high-temperature performance and life of molybdenum wire, and developing low-cost anti-oxidation coatings to extend the service life of incandescent lamps.

2.2.2 Molybdenum wire for halogen lamps
Molybdenum wire for halogen lamps is a key material in high-end lighting applications, where it is widely used for electrodes, supports and seals, where it is subjected to high temperatures and chemical attack by halogen gases.

Function and function: In halogen lamps, molybdenum wire is used as an electrode to guide the current and start the arc, as a support wire to fix the tungsten filament, and as a sealing material to ensure air tightness. The halogen cycle involves the reaction of halogen gases (e.g., iodine, bromine) with the evaporated tungsten to deposit the tungsten back into the filament, extending its life.

Performance Requirements:
High temperature performance: The operating temperature can reach 3000°C, and the tensile strength > 300 MPa and excellent creep resistance are required.
Chemical resistance: It needs to resist the attack of halogen gas, and the surface needs to be resistant to high-temperature chemical reactions.
Arc stability: high surface finish (Ra<0.3 μm) and low resistivity ensure uniform arc.
Thermal expansion matching: Matched with quartz glass (coefficient of thermal expansion 0.5-1.0×10^{-6}/K) or borosilicate glass.

Application characteristics: Halogen lamps have a luminous efficiency of 20-30 lm/W and a life span of 2000-4000 hours, which are widely used in automotive headlights, stage lighting and household high-end lighting. Molybdenum wire is subject to a combination of high temperatures, thermal cycling and chemical corrosion.

Preparation process:
Raw material selection: doped molybdenum powder (such as lanthanum oxide doped, content 0.3%-1.0%) is mostly used to improve high temperature performance.
Forming & Drawing: Molybdenum wire with a diameter of 0.05-0.3 mm is made by powder metallurgy, hot forging and multi-pass wire drawing. The annealing temperature (900-1300°C) needs to be precisely controlled to optimize the grain structure.
Surface treatment: cleaned molybdenum wire is made by electrolytic polishing or chemical cleaning, and some high-end applications require the deposition of anti-corrosion coatings (such as $MoSi_2$).

Market status: Halogen lamps account for 15% of the global lighting market, and the amount of molybdenum wire accounts for more than 30% of the molybdenum wire used in lamps. Automotive lighting is the main driver, with stable demand expected from 2025 to 2030. China, Europe, and Japan are the main markets.

Advantages and Limitations:
Advantages: The high-temperature performance and corrosion resistance of molybdenum lanthanum wire meet the needs of halogen lamps, with long life and stable performance.
Limitations: Oxidation at high temperatures still needs to be solved by inert gas protection, and the doping process increases the cost.

Technical challenge: To develop halogen-resistant surface coatings and low-cost doping technologies to improve the life of molybdenum wire in extreme environments.

2.2.3 Molybdenum wire for fluorescent lamps and gas discharge lamps

Molybdenum wire for fluorescent lamps and gas discharge lamps (e.g., high-intensity discharge lamps, HIDs) is mainly used as an electrode and sealing material, and needs to withstand high voltages and arc temperatures.

Function and function: In fluorescent lamps, molybdenum wire acts as an electrode to initiate and maintain fluorescent discharge; In HID lamps (e.g. metal halide lamps, high-pressure sodium lamps), molybdenum wire is used as an electrode to withstand transient high voltages (>10 kV) and arc temperatures (up to 6000°C), while acting as a sealing material to ensure hermeticity.

Performance Requirements:
Electrical properties: High conductivity (resistivity< 6×10^{-8} Ω·· m) and arc corrosion resistance to ensure discharge stability.
High temperature performance: The structure needs to be intact at the high temperature of the arc, and the tensile strength > 300 MPa.
Chemical stability: It needs to resist the chemical attack of high-pressure gases (such as mercury

vapor, sodium vapor) in the lamp.
Thermal expansion matching: Matched with borosilicate glass or quartz glass.

Application characteristics: The luminous efficiency of fluorescent lamps is 50-100 lm/W, and HID lamps are 100-150 lm/W, which are widely used in commercial lighting (office, shopping mall), road lighting and industrial lighting. Molybdenum wire needs to be resistant to high-frequency discharge and chemical corrosion.

Preparation process:
Raw material selection: molybdenum lanthanum wire or molybdenum rhenium wire is mostly used, and the doping ratio is 0.3%-2% to improve the arc corrosion resistance.
Forming and drawing: Molybdenum wire with a diameter of 0.03-0.2 mm is made by precision drawing, which needs to be annealed at low temperature (700-1000°C) to maintain toughness.
Surface treatment: electrolytic polishing or passivation treatment, and some molybdenum wires for HID lamps need to be deposited with anti-corrosion coatings.

Market status: The fluorescent lamp market is shrinking due to LED competition, HID lamps still account for 20% of the market share in outdoor lighting, and the amount of molybdenum wire accounts for 25% of the molybdenum wire used in lamps. GE Lighting in the United States and NVC Lighting in China are the main users.

Advantages and Limitations:
Advantages: The high performance of molybdenum lanthanum wire and molybdenum rhenium wire meets the needs of high-efficiency lighting and has strong arc stability.
Limitations: The service life in the high-frequency discharge environment needs to be further improved, and the surface treatment cost is high.

Technical challenge: Developing arc-resistant coatings and optimizing electrode designs to improve discharge efficiency and lifetime.

2.2.4 Molybdenum wire for special lamps (ultraviolet lamps, infrared lamps, etc.)

Molybdenum wire for specialty lamps is designed for specific spectral or extreme environments in medical, scientific, aerospace and industrial applications.

Function and function: In the ultraviolet lamp, the molybdenum wire is used as an electrode to initiate the ultraviolet discharge; In infrared lamps, molybdenum wires are subjected to high-temperature radiation as a support or electrode; In medical lamps (e.g. surgical lights) or aviation lamps, molybdenum wires need to meet the requirements of high reliability and complex shapes.

Performance Requirements:
Arc corrosion resistance: It needs to resist high-frequency discharge and mercury vapor corrosion.
High temperature stability: the working temperature can reach more than 2000°C, and the tensile strength > 300 MPa.

Ductility: Complex electrode shapes (e.g., spiral, bending) need to be supported.
Surface quality: A high finish is required to ensure spectral purity.

Application features: UV lamps are used for sterilization and medical treatment, infrared lamps are used for heating and industrial processing, and aviation lamps need high reliability. Molybdenum wire needs to resist complex chemical environments and high-temperature radiation.

Preparation process:
Raw material selection: molybdenum rhenium wire or molybdenum yttrium wire is mostly used, and the doping ratio is 0.5%-2%.
Forming and drawing: Molybdenum wire with a diameter of 0.02-0.1 mm is made by ultra-precision drawing, which requires low-temperature annealing and high-end molding.
Surface treatment: CVD or PVD for anti-oxidation coating (e.g. Al_2O_3, $MoSi_2$).

Market status: The market size of special lamps is small (accounting for 5% of the global lighting market), but the added value is high, and the amount of molybdenum wire accounts for 10% of the molybdenum wire used in lamps.

Advantages and Limitations:
Advantages: High performance meets professional needs and long life (up to 5000 hours).
Limitations: High cost (about $10/kg), customized production required.

Technical challenge: Expanding the range of applications for specialty lamps by developing low-cost coating and complex shape processing technologies.

2.3 Classification by specification

The specifications of Molybdenum wire for lighting are classified according to the diameter range, surface treatment type and wire morphology, which directly affects its performance and application.

2.3.1 Diameter range and tolerance

The diameter and tolerance of molybdenum wire are the core parameters of its specifications, which determine its electrical, mechanical and processing properties.

Diameter Range:
Ultra-fine molybdenum wire (0.01-0.05 mm): used for high-precision special lamps (e.g. UV lamps, medical lamps) that require high ductility and surface finish. High resistivity (approx. 6×10^{-8} Ω·m), suitable for high voltage electrodes.
Fine molybdenum wire (0.05-0.2 mm): electrode or support wire for halogen, HID and fluorescent lamps, accounting for more than 60% of the market.
Medium-coarse molybdenum wire (0.2-0.5 mm): support wire and sealing material for incandescent lamps with high mechanical strength.
Coarse molybdenum wire (0.5-2.0 mm): Structural components for high-power luminaires (e.g. industrial infrared lamps).

Tolerance requirements: According to GB/T 4191-2015 and ASTM B387, the tolerance of ultra-fine molybdenum wire is ±0.001 mm, fine molybdenum wire is ±0.002 mm, and coarse molybdenum wire is ±0.01 mm. Tolerance control is achieved by laser micrometry and in-line inspection.

Influencing factors: the smaller the diameter, the higher the resistivity, suitable for the electrode; The larger the diameter, the higher the strength and is suitable for support. Tolerance accuracy affects sealing reliability and arc stability.

Preparation process: ultra-fine molybdenum wire needs 20-30 times of drawing, using diamond mold and low temperature annealing (700-900 °C). Coarse molybdenum wire requires a high-strength mold and high-temperature annealing (1000-1200°C).

Market status: Fine molybdenum wire (0.05-0.2 mm) is in the greatest demand, and China has achieved high-precision production through the introduction of German equipment.

Technical challenge: Increasing the yield of ultra-fine molybdenum wire (currently about 85%) and reducing the cost of tolerance control.

2.3.2 Surface treatment type (black molybdenum wire, cleaned molybdenum wire, coated molybdenum wire)

The type of surface treatment has a significant impact on the electrical properties, corrosion resistance and application scenarios of molybdenum wire.

Black molybdenum wire:

Characteristics: The surface has a black oxide layer (MoO_2 or MoO_3) and a roughness of Ra 0.5-2.0 μm. The oxide layer enhances adhesion to glass.

Preparation process: After drawing, annealing (800-1000°C) under air or low vacuum to form an oxide layer.

Application: Support filament and low-cost sealing for incandescent lamps, accounting for 20% of the market.

Advantages and limitations: low cost, but poor arc stability, not suitable for high-performance luminaires.

Cleaned molybdenum wire:

Characteristics: Removal of the oxide layer by electrolytic polishing or pickling, smooth surface (Ra 0.1-0.5 μm), excellent conductivity and corrosion resistance.

Preparation process: HNO_3-HF mixed solution pickling or NaOH solution electrolytic polishing, environmental protection waste liquid treatment.

Application: Electrodes and seals for halogen, HID and specialty lamps, accounting for 70% of the market.

Advantages and limitations: Excellent performance and long life, but high processing costs.

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Coated molybdenum wire:
Properties: Deposit oxidation- or corrosion-resistant coatings (e.g. Al_2O_3, $MoSi_2$) with a thickness of 0.1-1.0 μm.
Preparation process: CVD or PVD technology is adopted, vacuum environment and high-precision equipment are required.
Application: Used in extreme environments such as ultraviolet lamps and infrared lamps, accounting for 5% of the market.
Advantages and limitations: The life is extended by 2-3 times, but the cost is high (about 10 USD/kg).

Market status: Cleaned molybdenum wire is the mainstream, and coated molybdenum wire is growing rapidly in the European and American markets.
Technical challenge: Development of low-cost coating technology and environmentally friendly surface treatment processes.

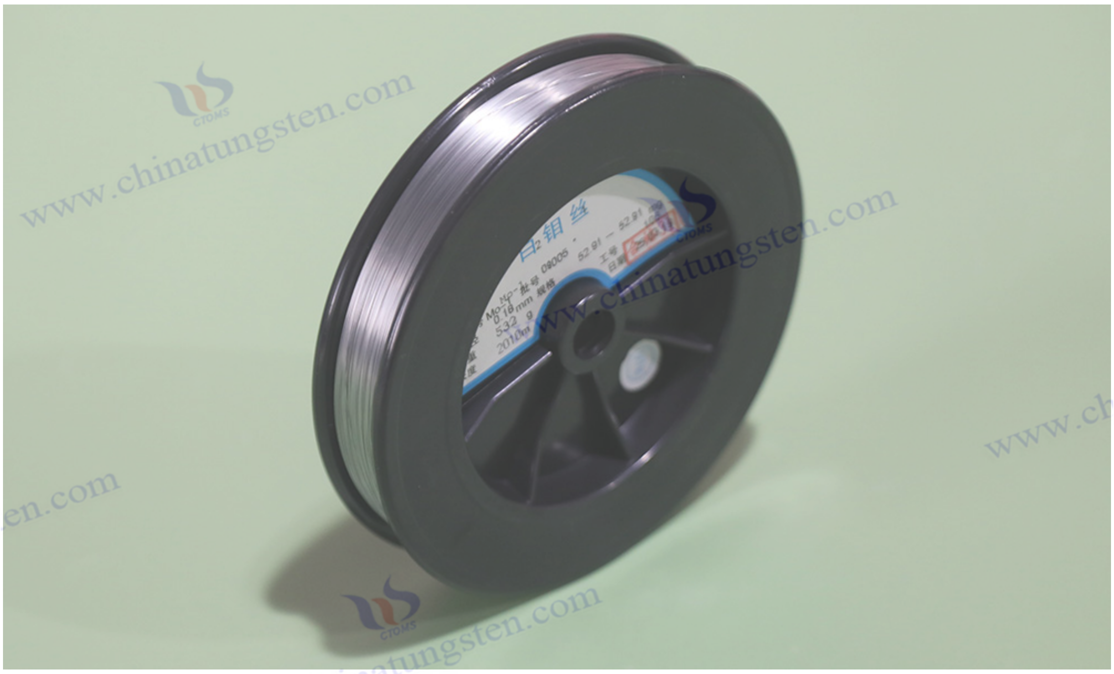
2.3.3 Wire form (straight wire, coiled wire, cut wire)
The wire shape affects the way molybdenum wire is processed, transported and applied.

Straight wire:
Characteristics: Fixed length (10-100 cm), suitable for automated assembly.
Preparation process: After drawing, it is cut by a high-precision cutting machine, and the incision needs to be smooth and burr-free.
Application: Used for support filament and sealing of incandescent lamps and halogen lamps, accounting for 30% of the market.
Advantages and limitations: The installation efficiency is high, but the transportation is easy to deform.

Coiling:
Characteristics: Wound on reels, the length can reach several kilometers, suitable for continuous processing.
Preparation process: After drawing, it is wound by the winder, and the tension needs to be controlled.
application: For large-scale lamp production, accounting for 50% of the market.
Advantages and limitations: Easy to store and transport, requires unwinding equipment.

Cutting wire:
Characteristics: Short length (1-10 mm) for precision assembly.
Preparation process: high-precision cutting to ensure length consistency.
Application: Complex electrodes for specialty lamps, accounting for 10% of the market.
Advantages and limitations: suitable for customization, low production efficiency.

Market status: coiled wire is the mainstream, and straight wire and cut wire are mostly used in high-end applications.
Technical challenge: Improving the accuracy of the cut wire and reducing the transportation cost of the straight wire.



molybdenum wire for lighting from CTIA

Chapter 3 Characteristics of Molybdenum Wire for Lighting

The characteristics of Molybdenum wire for lighting are the key to its application in the lighting field, covering physical, chemical, mechanical, electrical, optical and related Material Safety Data Sheet (MSDS) information. This chapter explores these characteristics in detail, analyzes their impact on the performance of lighting devices, and provides a comprehensive technical description based on global research and industry practices.

3.1 Physical characteristics of molybdenum wire for lighting

The physical properties of Molybdenum wire for lighting determine its performance in high temperature, high pressure and complex environments, mainly including density and melting point, thermal expansion coefficient and temperature dependence, thermal conductivity and electrical conductivity. These properties directly affect the structural stability, thermal management ability and electrical performance of molybdenum wire in luminaires.

3.1.1 Density and melting point of molybdenum wire for lighting

With a density of 10.2 g/cm³, molybdenum wire is a high-density metallic material, only slightly lower than tungsten (19.25 g/cm³). This density gives the molybdenum wire a high mass stability, allowing it to withstand mechanical stress and vibration in the support structure or electrodes of the luminaire. For example, in automotive headlights, molybdenum wire needs to resist the vibration of the vehicle while driving, and the moderately dense molybdenum wire can provide sufficient strength without increasing the difficulty of lamp design due to excessive weight.

Molybdenum wire has a melting point of 2623 °C (2896 K), which is one of its core advantages as a refractory metal, second only to tungsten (3422 °C) and rhenium (3186 °C). This high melting point allows molybdenum filament to operate stably in incandescent lamps (filament temperature up to 2500°C), halogen lamps (filament temperature up to 3000°C) and high-intensity gas discharge lamps (HID, arc center temperature up to 6000°C) without melting or significant deformation. In practical applications, molybdenum wire usually operates at temperatures well below its melting point (1000-2000°C) to avoid softening of the material as it approaches its melting point. Molybdenum wire has a slightly lower melting point than tungsten, but its processing costs are lower and its creep resistance below 2000°C makes it ideal for filament support and sealing materials.

The density and melting point of molybdenum wire are also closely related to its crystal structure. Molybdenum's body-centered cubic (BCC) crystal structure remains stable at high temperatures, and small changes in the lattice constant, which expands slightly with increasing temperature, ensure its structural integrity during thermal cycling. In production, the density of the molybdenum wire is controlled by the sintering process of high-purity molybdenum powder (purity ≥99.95%), and the melting point is further optimized by doping trace elements such as lanthanum oxide to increase the recrystallization temperature (from about 1400°C to over 1800°C).

3.1.2 Thermal expansion coefficient and temperature dependence of molybdenum wire for lighting

The coefficient of thermal expansion of molybdenum wire is 4.8×10^{-6}/K (in the range of 20-1000°C), which is highly compatible with borosilicate glass (about $4.5\text{-}5.0\times10^{-6}$/K). This property makes molybdenum wire the material of choice for glass-to-metal sealing of lamps, ensuring that the molybdenum wire and glass will not cause stress cracks due to the difference in thermal expansion when operating at high temperatures (e.g., the temperature of the sealing part in halogen lamps can reach 600-800°C). In contrast, tungsten has a slightly lower coefficient of thermal expansion (4.5×10^{-6}/K) and may require additional transition material, while copper (16.5×10^{-6}/K) does not match the thermal expansion of glass and cannot be used for sealing.

The coefficient of thermal expansion of molybdenum wire increases slightly with increasing temperature, e.g. up to 5.2×10^{-6} at 1500°C/K。 This temperature dependence is a special consideration in luminaire design, especially in halogen or HID lamps with frequent thermal cycles. In order to reduce the effect of thermal expansion, molybdenum wire is often doped with lanthanum oxide or rhenium to optimize the crystal structure and reduce the lattice expansion at high temperatures. In addition, the coefficient of thermal expansion of molybdenum wire is closely related to surface treatment, and cleaned molybdenum wire (electrolytically polished) expands more uniformly at high temperatures than black molybdenum wire (with an oxide layer on the surface) because it has fewer surface defects.

In practical applications, the matching of the coefficient of thermal expansion directly affects the airtightness and service life of the luminaire. For example, in high-pressure sodium lamps, the molybdenum wire seal is subjected to a cyclic temperature change of 500-700°C, and a mismatch in the coefficient of thermal expansion can lead to glass cracks or gas leaks. Therefore, precise thermal expansion tests (e.g. dilatometer measurements) and glass composition optimization are

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required in production to ensure the reliability of the seal.

3.1.3 Thermal conductivity and conductivity analysis of molybdenum wire for lighting

The thermal conductivity of molybdenum wire is 138 W/m·K (20°C), which is moderately high among metals, lower than copper (401 W/m·K) but higher than tungsten (173 W/m·K). The high thermal conductivity allows the molybdenum wire to quickly transfer the heat generated during luminaire operation from hot areas (e.g., near arcs or filaments) to low temperature areas (e.g., sealing sites), thereby reducing the risk of local overheating and protecting the luminaire structure. For example, in halogen lamps, molybdenum wire needs to be used as a support wire to effectively dissipate the heat of the filament to avoid overheating of the glass seal (> 800°C may cause the glass to soften).

The conductivity of molybdenum wire is about 1.8×10^7 S/m (resistivity 5.5×10^{-8} Ω·). m), which performs well in high-temperature metals, slightly below copper (5.9×10^7 S/m) but close to tungsten (1.9×10^7 S/m). Its electrical conductivity ensures that the molybdenum wire can efficiently transmit current in the electrode or conductive component, reducing energy loss. In gas discharge lamps, molybdenum wire electrodes are subjected to high voltages (hundreds to thousands of volts) and instantaneous high currents (several amperes), and high conductivity can reduce Joule heating and extend electrode life.

The temperature dependence of thermal conductivity and electrical conductivity is a key factor in the design. With increasing temperature, the thermal conductivity of molybdenum wire decreases slightly (about 120 W/m·K at 1000°C) and increases the resistivity (about 2.0×10^{-7} Ω·· at 1000°C). m）。 Doped molybdenum wires, such as molybdenum lanthanum wires, can slow down the decline in conductivity at high temperatures by optimizing the crystal structure. For example, molybdenum wire doped with 1% lanthanum oxide has a resistivity of about 10% lower than pure molybdenum wire at 1500°C. In production, thermal conductivity and electrical conductivity are optimized by controlling the purity, grain size, and surface finish of the molybdenum wire.

3.2 Chemical characteristics of molybdenum wire for lighting

The chemical properties of Molybdenum wire for lighting determine its stability and life in the complex chemical environment of lamps (such as halogen gas, high temperature vacuum), mainly including oxidation resistance, corrosion resistance and interaction with inert gas and vacuum environment.

3.2.1 Oxidation resistance and high temperature stability of molybdenum wire for lighting

Molybdenum wire has good oxidation resistance at room temperature, and a thin oxide protective layer (MoO_2) can be formed on its surface to prevent further oxidation. However, when exposed to air at high temperatures (>600°C), molybdenum filaments rapidly to form molybdenum trioxide (MoO_3), which is volatile, resulting in material loss and performance degradation. In lighting applications, luminaires are often operated in a vacuum or in an inert gas (e.g., argon, nitrogen) to avoid oxidation. For example, incandescent lamps are filled with argon gas and a small amount of halogen gas to protect the molybdenum wire from oxidation.

In order to improve the antioxidant performance, doped molybdenum wire (such as molybdenum lanthanum wire, molybdenum rhenium wire) is widely used. The addition of lanthanum oxide slows down the diffusion of molybdenum atoms at high temperature by pinning grain boundaries and delays the occurrence of oxidation reaction. Due to the solution strengthening effect of rhenium, molybdenum rhenium wire can form a more stable surface oxide layer above 1000°C and slow down the volatilization of MoO_3. Studies have shown that the oxidation rate of molybdenum wire doped with 1% lanthanum oxide in air at 1200°C is about 30% lower than that of pure molybdenum wire. In addition, surface coating technologies, such as alumina or molybdenum silicide coatings, further enhance oxidation resistance and are suitable for special luminaires.

In terms of high-temperature stability, the recrystallization temperature of molybdenum wire (about 1400°C for pure molybdenum) is a key indicator. Recrystallization leads to grain growth and embrittlement of the material, reducing mechanical strength. Doped molybdenum wire significantly extends the service life at high temperatures by increasing the recrystallization temperature (up to 1800°C for molybdenum lanthanum wire and about 1700°C for molybdenum rhenium wire). In halogen lamps, molybdenum wire needs to operate at 1500-2000°C for a long time, and the excellent high temperature stability of doped molybdenum wire ensures its structural integrity.

3.2.2 Corrosion resistance of molybdenum wire for lighting

The corrosion resistance of molybdenum wire in lamps is mainly reflected in its resistance to halogen gases (such as iodine, bromine), mercury vapor and other chemicals. In halogen lamps, the molybdenum wire is in direct contact with the halogen gas and needs to resist chemical attack at high temperatures (1000-1500°C). Molybdenum's chemical stability allows it to perform well in iodine or bromine environments without the formation of volatile compounds or significant corrosion. In contrast, tungsten is prone to the formation of volatile halides (e.g., WBr_6) in halogen environments, resulting in filament loss.

In gas-discharge lamps, such as high-pressure mercury lamps or metal halide lamps, the molybdenum wire electrode needs to resist mercury vapor and metal halide (e.g., sodium iodide). The results show that molybdenum wire can maintain surface integrity in mercury vapor (500-800°C) with a corrosion rate of less than 0.01 $mg/cm^2 \cdot h$. Doped molybdenum wire, such as molybdenum lanthanum wire, further improves corrosion resistance by forming a stable surface structure. For example, molybdenum wire doped with lanthanum oxide can reduce corrosion losses by about 20% in a sodium iodide environment.

Corrosion resistance is also related to the surface treatment of molybdenum wire. Cleaned molybdenum wire (electrolytically polished) has few surface defects and a lower corrosion rate than black molybdenum wire (with an oxide layer on the surface). In production, molybdenum wire is often used to remove surface oxides by pickling (HNO_3-HF mixture) or electrolytic polishing (NaOH solution) to improve corrosion resistance. In addition, coated molybdenum wires, such as molybdenum silicide coatings, perform well in extremely corrosive environments such as mercury vapor in UV lamps, but at a higher cost.

CTIA GROUP LTD
Molybdenum Wire for Lighting Introduction

1. Overview of Molybdenum Wire for Lighting

As one of the core materials in modern lighting technology, molybdenum wire is widely used in various light sources including incandescent lamps, halogen lamps, fluorescent lamps, and gas discharge lamps, due to its high melting point, high strength, excellent corrosion resistance, and superior electrical conductivity. It is an irreplaceable and critical component in the lighting industry.

2. Typical Applications of Molybdenum Wire for Lighting

Residential and Commercial Lighting: Used in incandescent and halogen lamps to provide warm light and long service life.

Automotive Lighting: Functions as electrodes in HID and xenon lamps, offering high brightness and vibration resistance.

Specialty Lighting: Utilized in projection lamps, ultraviolet (UV) lamps, and infrared (IR) lamps to meet high-temperature and high-precision requirements in medical, industrial, and scientific applications.

Emerging Fields: Serves as conductive leads for LED lamps and supports for phosphors in laser lighting, aligning with future lighting technology development.

3. Basic Data of Molybdenum Wire for Lighting (Reference)

Parameter	Pure Mo Wire	Mo-La Wire	Mo-Re Wire
Mo Content	≥99.95%	≥99.0%	52.5%–86.0%
Diameter Range	0.03–3.2 mm	0.03–1.5 mm	0.03–1.0 mm
Tolerance	±0.002 mm	±0.002 mm	±0.002 mm
Tensile Strength (Room Temp)	800–1200 MPa	900–1400 MPa	1000–1500 MPa
Tensile Strength (at 1500°C)	150–300 MPa	200–400 MPa	250–450 MPa
Elongation at Break	10%–25%	12%–20%	15%–25%
Electrical Resistivity (20°C)	5.5×10^{-8} Ω·m	6.0×10^{-8} Ω·m	6.5×10^{-8} Ω·m
Main Applications	Incandescent, Halogen	Halogen, Auto Headlights	HID, Projection Lamps

4. Procurement Information

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Website: www.molybdenum.com.cn

3.2.3 Interaction between molybdenum wire for lighting and inert gas and vacuum environment

Molybdenum wire for lighting is usually operated in a vacuum or inert gas (e.g., argon, nitrogen, krypton) to avoid oxidation and prolong life. In a vacuum environment (e.g. inside an incandescent lamp, the pressure is <10^{-3} Pa), the chemical stability of molybdenum wire is extremely high, there is almost no reaction with gases, and the surface remains stable. The vacuum environment also reduces heat convection losses, so that the heat of the molybdenum wire is mainly dissipated through heat conduction and radiation, which contributes to the energy efficiency of the lamp.

In an inert gas environment (such as a halogen lamp, filled with argon and a small amount of halogen gas, pressure 0.1-1 MPa), molybdenum wire has no obvious chemical reaction with argon or nitrogen, but may have weak surface adsorption or chemical bonding with halogen gas at high temperatures. Studies have shown that molybdenum filament can form a thin layer of molybdenum iodide (MoI_3) on the surface of iodine-containing argon gas (1200°C), but the compound decomposes rapidly at high temperatures without affecting the performance of lamps. Doped molybdenum wires, such as molybdenum lanthanum wires, can reduce this adsorption effect by optimizing the surface structure.

In gas discharge lamps, the molybdenum wire electrode interacts with complex gas mixtures (mercury vapor, metal halides, inert gases). The high chemical stability of molybdenum wire ensures that it does not undergo significant chemical degradation in these environments, but arcing may cause surface microstructural changes such as grain boundary corrosion. For this reason, the stability of molybdenum wire is often enhanced by surface passivation or doping technology in production.

3.3 Mechanical characteristics of molybdenum wire for lighting

The mechanical properties of Molybdenum wire for lighting directly affect its structural stability and durability in lamps, including tensile strength and creep properties, ductility and toughness, fatigue resistance and fracture resistance at high temperatures. These properties are particularly important in high-temperature, thermal cycling, and mechanical vibration environments.

3.3.1 High temperature tensile strength and creep properties of molybdenum wire for lighting

The tensile strength of molybdenum wire is 800-1000 MPa at room temperature, but it will decrease significantly at high temperature (>1000°C). For example, the tensile strength of pure molybdenum wire at 1500°C is about 200 MPa. The doped molybdenum wire significantly improves the high-temperature strength through grain boundary strengthening, and the molybdenum lanthanum wire can reach 300-500 MPa at 1500°C, and the molybdenum-rhenium wire is about 250-400 MPa. This high strength allows molybdenum wire to act as a filament support material to withstand high-temperature loads in incandescent or halogen lamps.

Creep performance is a key indicator of molybdenum wire for long-term operation at high temperatures. Creep refers to the process by which a material slowly deforms under sustained stress, which can lead to failure of the filament support or deformation of the electrode. Pure molybdenum wire is prone to creep above 1200°C with a creep rate of about 10^{-5} s^{-1} (at 100 MPa stress). Doped molybdenum wire significantly reduces the creep rate by pinning grain boundary dislocations, for example, molybdenum wire doped with 1% lanthanum oxide has a creep rate more than 50% lower than that of pure molybdenum wire at 1500°C. Due to the solid solution strengthening effect of rhenium, the creep performance of molybdenum rhenium wire is also better than that of pure molybdenum wire.

In halogen lamps, the molybdenum wire support is subjected to thermal cycling (rapid ramp-up from room temperature to 1500°C), and the tensile strength and creep resistance at high temperatures directly determine the lamp life. The creep resistance of molybdenum wire is improved in production by optimizing the grain size (typically 10-50 μm) and the doping process.

3.3.2 Ductility and toughness of molybdenum wire for lighting

The ductility of molybdenum wire refers to its ability to plastically deform when stretched, and the elongation at break of pure molybdenum wire is 10%-15% at room temperature. Doped molybdenum wire (such as molybdenum rhenium wire) significantly improves ductility by solution strengthening, and the elongation at break can reach 20%-25%. The high ductility makes the molybdenum wire not easy to break during the drawing and forming process, and is suitable for manufacturing electrodes or support structures with complex shapes.

Toughness reflects the ability of molybdenum wire to absorb impact energy and prevent brittle fracture. In luminaires, molybdenum wires are subjected to vibration (e.g., automotive lamps) or thermal shock (e.g., frequent switching of halogen lamps). At high temperature (>1000°C), pure molybdenum wire becomes brittle due to recrystallization, and the toughness decreases. The molybdenum lanthanum wire is strengthened by the dispersion of lanthanum oxide particles, which maintains the high-temperature toughness, and the fracture toughness (K_IC) is about 10 $MPa \cdot m^{1/2}$ at 1500°C, which is higher than that of pure molybdenum wire of 7 $MPa \cdot m^{1/2}$. Molybdenum rhenium wire has better toughness and is suitable for high vibration environments.
In production, the optimization of ductility and toughness depends on the annealing temperature (800-1200°C) and the uniform distribution of doping elements in the drawing process. Ultra-fine molybdenum wire (<0.05 mm diameter) requires higher ductility and requires low-temperature annealing and precision molding.

3.3.3 Fatigue resistance and fracture resistance of molybdenum wire for lighting

The fatigue resistance reflects the durability of the molybdenum wire under cyclic stress. In automotive headlamps or stage lights, molybdenum wires are subjected to frequent thermal cycling and mechanical vibrations, which can lead to fatigue cracks. The fatigue life of pure molybdenum wire is shorter at high temperature (about 10^4 cycles, 100 MPa stress), while the fatigue life of doped molybdenum wire (such as molybdenum lanthanum wire) can be increased to more than 10^5 cycles through grain boundary strengthening.

The fracture resistance is closely related to the grain size and surface defects of molybdenum wire. Fine grains (10-20 μm) disperse stress concentrations and improve fracture resistance. Due to its high surface finish (Ra<0.5 μm) and few crack initiation points, cleaned molybdenum wire has better fracture resistance than black molybdenum wire (Ra 0.5-2.0 μm). In production, surface polishing and defect detection (e.g. ultrasonic flaw detection) are key to improving fracture resistance.

In HID lamps, molybdenum wire electrodes need to resist the stress concentration caused by arc impact, and doped molybdenum wire (such as molybdenum rhenium wire) can effectively reduce the risk of fracture due to its high toughness and fatigue resistance.

3.4 Electrical characteristics of molybdenum wire for lighting

The electrical properties of Molybdenum wire for lighting determine its performance as an electrode or conductive component, including resistivity and temperature coefficient, current carrying capacity, and arc stability.

3.4.1 Resistivity and temperature coefficient of molybdenum wire for lighting

The resistivity of molybdenum wire is 5.5×10^{-8} Ω··at 20°C m, slightly higher than copper (1.68×10^{-8} Ω·m) but close to tungsten (5.6×10^{-8} Ω·m)。 The resistivity increases with temperature and is about 2.0×10^{-7} Ω··at 1000°C m, up to 4.0×10^{-7} Ω··at 2000°C m。 The temperature coefficient (TCR) of the resistivity is 0.0045 K^{-1} (20-1000°C), indicating that its conductivity decreases rapidly with increasing temperature.

Doped molybdenum wire can reduce high-temperature resistivity by optimizing the crystal structure. For example, molybdenum wire doped with 1% lanthanum oxide has a resistivity of about 10% lower than pure molybdenum wire at 1500°C because the lanthanum oxide particles reduce grain boundary scattering. Due to the solid solution effect of rhenium, the resistivity of molybdenum rhenium wire is slightly higher (about 6.0×10^{-8} Ω·m at 20°C), but its temperature coefficient is more stable, suitable for high-frequency discharge environments.

In luminaires, resistivity has a direct impact on energy loss and heat generation. Low resistivity molybdenum wire reduces Joule heating and improves luminaire efficiency. In HID lamps, the resistivity of the molybdenum wire electrodes needs to be precisely controlled to ensure the stability of arc start-up.

3.4.2 Current carrying capacity of molybdenum wire for lighting

The current carrying capacity of a molybdenum wire depends on its diameter, material purity, and operating temperature. A pure molybdenum wire with a diameter of 0.1 mm can carry a current of about 10 A at 20 °C and drop to about 5 A at 1000 °C. Doped molybdenum wire (such as molybdenum lanthanum wire) has a slightly better current carrying capacity due to its higher strength at high temperatures, and can carry 4-6 A (0.1 mm diameter) at 1500°C.

In gas discharge lamps, the molybdenum wire electrodes are subjected to instantaneous high currents (10-100 A for a few milliseconds), requiring high conductivity and thermal shock resistance. Due to its excellent ductility and toughness, molybdenum rhenium wire can withstand repeated current shocks without breakage. In production, the optimization of current carrying capacity needs to be achieved by increasing the grain size and reducing surface defects.

3.4.3 Arc stability of molybdenum wire for lighting

Arc stability is a key property of molybdenum wire as an electrode material, especially in HID lamps and fluorescent lamps. The high melting point and arc corrosion resistance of molybdenum wire allow it to maintain structural integrity at high arc temperatures (>4000°C). Due to the high surface finish (Ra<0.5 μm), cleaned molybdenum wire can reduce local overheating and spatter during arc discharge and improve stability.

Doped molybdenum wire (e.g., molybdenum lanthanum wire, molybdenum rhenium wire) reduces grain boundary corrosion caused by arcing by optimizing the surface microstructure. For example, lanthanum oxide-doped molybdenum wire has an arc stability of about 20% higher than pure molybdenum wire in high-frequency discharge (10-100 kHz). In production, arc stability is often tested by simulating luminaire operating conditions, such as high-voltage impulse tests, to ensure the long-term reliability of the electrodes.

3.5 Optical properties of molybdenum wire for lighting

The optical properties of Molybdenum wire for lighting affect its radiation efficiency and light output quality in lamps, mainly including surface finish and reflectivity, high-temperature radiation characteristics and the influence of surface oxidation on optical properties.

3.5.1 Surface finish and reflectivity of molybdenum wire for lighting

The surface finish of molybdenum wire directly affects its reflectivity and the uniformity of arc discharge. By electrolytic polishing or chemical cleaning, the surface roughness of cleaned molybdenum wire can reach Ra 0.1-0.5 μm, and the reflectance (visible light range) is about 60%-70%. Due to the surface oxide layer (MoO_2), the roughness of black molybdenum wire is high (Ra 0.5-2.0 μm), and the reflectivity is only 30%-40%.

High-finish molybdenum wire improves the uniformity of light output in halogen and HID lamps and reduces local overheating caused by surface defects. In projection lamps, the reflectivity of molybdenum wire affects the focusing effect of light, and high reflectivity of cleaned molybdenum wire can improve light utilization. In production, the control of surface finish needs to be achieved by precision polishing equipment and online inspection.

3.5.2 High-temperature radiation characteristics and spectral analysis of molybdenum wire for lighting

The radiation properties of molybdenum wire at high temperatures are closely related to its performance as an electrode or support material. At 1500-2000°C, the radiation spectrum of molybdenum wire is mainly concentrated in the infrared and near-infrared regions (wavelength 0.7-2.5 μm), and the visible light (0.4-0.7 μm) is relatively low. This gives it an advantage in infrared lamps, but mainly as an auxiliary material in white light illumination.

Doped molybdenum wires, such as molybdenum lanthanum wires, can slightly increase the radiation efficiency in the visible region by optimizing the crystal structure. For example, a molybdenum wire doped with 1% lanthanum oxide has a radiation power about 10% higher at 2000°C than a pure molybdenum wire. Spectral analysis shows that the radiation peak of molybdenum wire moves to short wavelength with the increase of temperature, which conforms to Planck's blackbody radiation law. In practice, the radiation characteristics of molybdenum filament need to be co-optimized with the filament (typically tungsten) to achieve the desired light output.

3.5.3 Effect of surface oxidation of molybdenum wire for lighting on optical properties

Surface oxidation has a significant effect on the optical properties of molybdenum wire. The oxide layer (MoO_2 or MoO_3) of black molybdenum wire absorbs part of the visible and infrared light, reducing the reflectivity and radiation efficiency. In halogen lamps, the evaporation of the oxide layer can lead to the deposition of the inner wall of the bulb, reducing the efficiency of light output. By removing the oxide layer, cleaned molybdenum wire significantly improves the optical performance, and the reflectivity and radiation efficiency are better than those of black molybdenum wire.

At high temperature (>1000°C), a small amount of oxidation may occur on the surface of molybdenum wire, which affects the spectral characteristics. Doped molybdenum wire (e.g., molybdenum lanthanum wire) slows down the oxidation process and maintains the stability of optical properties by forming a stable surface structure. Coated molybdenum wires, such as alumina coatings, provide further protection against surface oxidation and are suitable for high-performance specialty lamps.

3.6 Molybdenum Wire for Lighting MSDS from CTIA GROUP LTD

Material Safety Data Sheets (MSDS) provide guidance for the safe use, storage, and transportation of Molybdenum wire for lighting. The following are the main contents of MSDS of molybdenum wire for lighting from CTIA:

Part I: Chemical Names

Chemical name: molybdenum wire
CAS No.:7439-98-7
Molecular Formula: Mo
Molecular Weight: 99.95

Part II: Composition/Composition Information

Content 99.3%~99.95% molybdenum

Part III: Overview of Hazards

Health hazards: This product is non-irritating to the eyes and skin.
Explosion hazard: This product is non-flammable and non-irritating.

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Part IV: First Aid Measures

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

Part V: Fire Protection Measures

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

Part VI: Emergency Handling of Spills

Emergency treatment: Isolate the leakage contaminated area and restrict access. Cut off the source of fire. Emergency responders are advised to wear dust masks (full face masks) and protective clothing. Avoid dust, sweep it up carefully, put it in a bag and transfer it to a safe place. If there is a large amount of leakage, cover it with plastic cloth or canvas. Collect and recycle or transport to a waste disposal site for disposal.

Part VII: Handling, Handling and Storage

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

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

Part VIII: Exposure Control/Personal Protection

China MAC (mg/m3): 6
USSR MAC (mg/m3): 6
TLVTN:ACGIH 1mg/m3

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CTIAQCD -MA-E/P 2018- 2024V
sales@chinatungsten.com

TLVWN:ACGIH 3mg/m3
Monitoring method: potassium thiocyanide-titanium chloride spectroluminescence method
Engineering control: the production process is dust-free and fully ventilated.
Respiratory protection: When the dust concentration in the air exceeds the standard, a self-priming filtering dust mask must be worn. In the event of an emergency evacuation, air breathing apparatus should be worn.
Eye protection: Wear chemical safety glasses.
Body protection: Wear anti-poison penetration overalls.
Hand protection: Wear rubber gloves.

Part IX: Physicochemical properties

Main ingredient: Pure
Appearance and properties: solid, metallic bright white; Blank, black finish
Melting Point (°C): 2620
Boiling point (°C): 5560
Relative density (water = 1): 9.4~10.2 (20 °C)
Vapor density (air = 1): No data
Saturation vapor pressure (kPa): no data available
Heat of combustion (kj/mol): no data
Critical temperature (°C): No data available
Critical pressure (MPa): No data available
Logarithm of water partition coefficient: no data
Flash point (°C): No data available
Ignition temperature (°C): No data
Explosion Limit % (V/V): No data
Lower explosion limit % (V/V): No data
Solubility: soluble in nitric acid, hydrofluoric acid
Main uses: used in the production of molds, molybdenum wires, electronic parts, etc

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

Part 11:

Acute toxicity: no data available
LC50: No data

Part XII: Ecological data

There is no data for this section

Part XIII: Disposal

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

Part XIV: Shipping Information

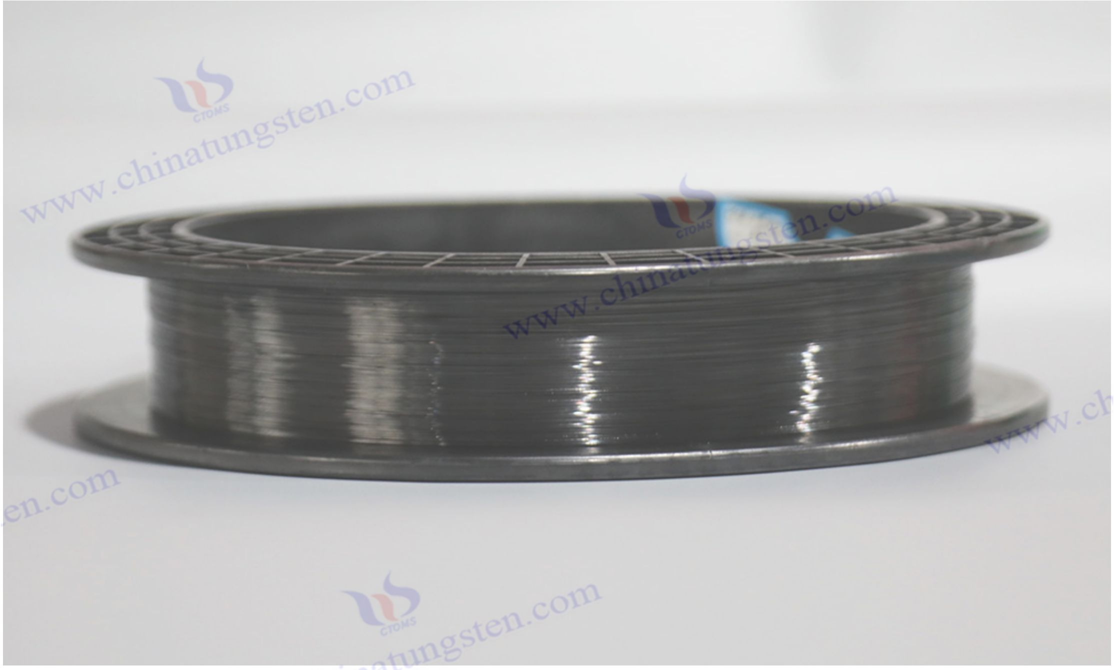
Dangerous goods number: no information
Packaging category: Z01
Precautions for transportation: The packaging should be complete when shipping, and the loading should be secure. During transportation, it is necessary to ensure that the container does not leak, collapse, fall, or damage. It is strictly forbidden to mix with oxidants, halogens, edible chemicals, etc. During transportation, it should be protected from exposure to sun, rain and high temperature. Vehicles should be thoroughly cleaned after transportation.

Part XV: Regulatory Information

Regulatory information: Regulations on the Safety Management of Dangerous Chemicals (promulgated by the State Council on February 17, 1987), Detailed Rules for the Implementation of the Regulations on the Safety Management of Dangerous Chemicals (Hua Lao Fa [1992] No. 677), Regulations on the Safe Use of Chemicals in the Workplace ([1996] Lao Bu Fa No. 423) and other laws and regulations, which have made corresponding provisions on the safe use, production, storage, transportation, loading and unloading of dangerous chemicals; The hygienic standard for tungsten in workshop air (GB 16229-1996) stipulates the maximum allowable concentration and detection method of this substance in workshop air.

Part XVI: Supplier Information

Supplier: CTIA GROUP LTD
Tel: 0592-5129696/5129595



molybdenum wire for lighting from CTIA

Chapter 4 Preparation and Production Technology of Molybdenum Wire for Lighting

The preparation of Molybdenum wire for lighting is a complex and precise process, involving multiple process links from raw material selection to final product, and its production technology and process optimization directly determine the quality and performance of molybdenum wire. This chapter will discuss in detail the preparation and production process of Molybdenum wire for lighting, including raw material selection and pretreatment, smelting and molding, wire drawing process, surface treatment technology, doping process, quality control and process optimization.

4.1 Raw material selection and pretreatment of molybdenum wire for lighting

The performance of Molybdenum wire for lighting is highly dependent on the quality of the raw material and the pretreatment process. Raw material selection and pretreatment are the first step in production, which directly affects the success rate of subsequent smelting, forming and wire drawing, as well as the performance of the final product. The following is a detailed analysis from three aspects: molybdenum powder purity and particle size control, doping material selection and proportion, and pretreatment process.

4.1.1 Molybdenum powder purity requirements (≥99.95%) and particle size control

The preparation of molybdenum wire is usually made of high-purity molybdenum powder, and the purity is required to reach more than 99.95% to ensure the chemical stability and electrical properties of molybdenum wire in a high-temperature environment. The content of impurities (e.g. iron, nickel, silicon, carbon, etc.) needs to be kept to a very low level (0.05% of total impurities< because even trace impurities can cause grain boundary corrosion or arc instability at high temperatures. For example, iron impurities above 0.01% may cause molybdenum filaments to react with halogen gases in halogen lamps to form volatile compounds and shorten the life of the lamp.

The preparation of molybdenum powder is usually obtained by refining molybdenite (MoS_2). The process consists of molybdenite roasting to produce molybdenum trioxide (MoO_3), followed by hydrogen reduction (two reductions in a tube furnace at 600-1000°C) to produce high-purity molybdenum powder. During the reduction process, the purity of hydrogen (≥99.999%) and the reduction temperature should be controlled to avoid oxygen residue. The reduced molybdenum powder needs to be chemically analyzed (e.g., ICP-OES) to confirm its purity and comply with ASTM B386 or GB/T 3462 standards.

Particle size control is a key part of raw material pretreatment. Molybdenum wire for lighting requires molybdenum powder with a particle size of 1-5 μm and uniform particle size distribution (D50 is about 2-3 μm). The fine and uniform particle size helps to increase the density of the sintered billet and reduce porosity and inclusions. If the particle size is too large (>10 μm), it will lead to uneven sintering and affect the mechanical strength of molybdenum wire. If the particle size is too small (<1 μm), it may increase the sintering shrinkage and lead to cracking of the blank. Particle size control is achieved by airflow classification or vibrating screening, and common equipment includes airflow classifiers and ultrasonic sieves. In addition, the morphology of molybdenum powder is crucial for subsequent compaction and sintering effect, and spherical powder can be prepared by plasma spheroidization technology.

4.1.2 Selection and ratio of doping materials (lanthanum, rhenium, etc.).

The selection and ratio of doped materials is the core link in the preparation of high-performance molybdenum wire (such as molybdenum lanthanum wire and molybdenum rhenium wire), which aims to improve the creep resistance, ductility and oxidation resistance at high temperature. Commonly doped materials include lanthanum oxide (La_2O_3), rhenium (Re), yttrium oxide (Y_2O_3) and cerium oxide (CeO_2).

Lanthanum oxide (La_2O_3): the most commonly used doped material, typically 0.3%-1.0% by mass. Lanthanum oxide is dispersed in a molybdenum matrix in the form of nanoscale particles (particle size 50-200 nm), which significantly increases the recrystallization temperature (from 1400 °C to 1800 °C) and creep resistance. Lanthanum oxide needs to be of high purity (≥ 99.99%) to avoid the influence of impurities (such as sulfur and phosphorus) on performance.

Rhenium (Re): Doped with rhenium (1%-5%) to form a solid solution of molybdenum rhenium, which improves ductility and oxidation resistance. Rhenium powder needs to be prepared by hydrogen reduction, and the purity is ≥ 99.98%. The high cost of rhenium (about 50-100 times that of molybdenum) makes it mostly used in high-end special lamps.

Yttrium oxide (Y_2O_3) and cerium oxide (CeO_2): used in special molybdenum wires with 0.5%-2% and 0.3%-1% content. Yttrium oxide improves arc corrosion resistance and is suitable for ultraviolet lamps; Cerium oxide enhances high temperature stability and is suitable for infrared lamps. Both require high purity (≥99.95%) and fine particle size (<100 nm).

Ratio control: The doping ratio needs to be precisely controlled, too high may lead to softening of the material or higher costs, too low will not significantly improve the performance. For example, when the lanthanum oxide content is 0.8%, the tensile strength of molybdenum wire can reach 400 MPa at 1500°C, which is 50% higher than that of pure molybdenum wire. The ratio is verified by electronic balance weighing and chemical analysis, and the error is controlled at ±0.01%.

The choice of doping material also needs to consider the chemical compatibility with the molybdenum matrix. For example, lanthanum oxide forms a stable dispersed phase with molybdenum at high temperatures, while rhenium improves the crystal structure through solution strengthening. In production, homogeneous distribution of doped materials is key, which is achieved through subsequent mixing processes.

4.1.3 Raw material pretreatment (cleaning, screening, mixing)

Raw material pretreatment includes washing, screening, and mixing to ensure consistent quality of molybdenum powder and doped materials.

Cleaning: Molybdenum powder may adsorb moisture, grease or oxides during the production process and need to be removed by chemical cleaning. The commonly used cleaning agent is dilute nitric acid (HNO_3, concentration 5%-10%) or sodium hydroxide (NaOH, concentration 2%-5%), and the cleaning temperature is controlled at 40-60°C for 5-10 minutes. After cleaning, it should be rinsed with deionized water and dried (vacuum drying at 100-150°C) to avoid residual impurities.

Sieving: Remove oversized or undersized particles by means of a vibrating screen or air classifier to ensure a particle size distribution of 1-5 µm. The screening equipment should be made of stainless steel or ceramic to avoid metal contamination. During the screening process, the particle size distribution curve should be monitored, and the D90/D10 ratio should be controlled at 2-3 to ensure uniformity.

Mixing: Doped molybdenum wire requires a uniform mixing of molybdenum powder with doped materials (such as lanthanum oxide). Wet mixing (e.g., ethanol or deionized water as a medium) or dry mixing (e.g., V-mixer) is commonly used. Wet mixing improves uniformity by ultrasonic dispersion, typically for 2-4 hours. After mixing, the composite powder is prepared by spray drying (inlet temperature 200-250°C) to ensure uniform distribution of doped particles.

The pretreatment process needs to be carried out in a clean environment (cleanliness class ISO 7) to avoid dust contamination. State-of-the-art pre-treatment equipment improves efficiency and consistency.

4.2 Smelting and forming of molybdenum wire for lighting

Smelting and forming is the core link of molybdenum wire preparation, which converts molybdenum powder into high-density blanks through powder metallurgy, sintering, hot pressing, forging and rolling, providing the basis for subsequent wire drawing.

4.2.1 Powder metallurgy process

Powder metallurgy is the main preparation method of Molybdenum wire for lighting, and the process includes powder pressing, sintering, thermal processing and forming. It has the advantage of precise control of material composition and microstructure, making it suitable for the production of high-performance molybdenum wire.

Powder pressing: The pretreated molybdenum powder or doped powder is loaded into a mold and pressed into a rod or plate blank under a hydraulic press. The pressing pressure is 100-200 MPa, and the mold material is high-strength steel or cemented carbide to avoid contamination. During the pressing process, the powder filling density (about 50%-60% theoretical density) needs to be controlled to ensure the uniformity of the blank.

Pre-sintering: The pressed billet is pre-sintered in a hydrogen atmosphere furnace (temperature 800-1000°C, holding for 2-4 hours) to remove moisture and volatile impurities and enhance the strength of the billet. Pre-sintering requires controlled hydrogen flow rate (1-2 m^3/h) and dew point (<-40°C) to avoid oxidation.

Process characteristics: Powder metallurgy can produce doped molybdenum wire (such as molybdenum lanthanum wire) with complex composition, and optimize the microstructure of the blank through precise control of pressing and sintering parameters. The world's leading company uses automated pressing equipment to improve production efficiency.

4.2.2 Vacuum sintering and high-temperature sintering technology

Sintering is a critical step in converting the pressed billet into a highly dense molybdenum billet and is usually carried out in a vacuum or hydrogen atmosphere to avoid oxidation.

Vacuum sintering: In a vacuum sintering furnace (vacuum degree $< 10^{-3}$ Pa), the temperature rises to 1800-2200 °C and is kept warm for 4-8 hours. The vacuum environment effectively removes residual oxygen and reduces porosity. After sintering, the density of the blank can reach 95%-98% theoretical density, and the grain size is controlled at 10-50 μm.

High-temperature sintering: For doped molybdenum wire (such as molybdenum lanthanum wire), high-temperature sintering (2300-2500°C, holding for 2-4 hours) in a hydrogen atmosphere is required. Hydrogen protection prevents the volatilization of lanthanum oxide or rhenium and ensures the stability of doped elements. The sintering furnace needs to be equipped with a tungsten or molybdenum heating element to withstand high temperatures.

Key parameters: sintering temperature, holding time and heating rate need to be precisely controlled. Excessive temperature (>2600°C) may cause excessive grain growth and reduce mechanical strength; Temperatures that are too low (<1800°C) will not achieve the desired density. The state-of-the-art sintering furnace achieves a temperature control accuracy of ±5°C.

Application implications: The highly dense sintered blank provides a good basis for mechanical properties for subsequent wire drawing, and is suitable for the manufacture of ultra-fine molybdenum wire (diameter <0.05 mm).

4.2.3 Hot pressing, forging and rolling processes

The sintered blank is further processed by hot pressing, forging and rolling to form a bar or plate suitable for wire drawing.

Hot pressing: In the hot press (pressure 50-100 MPa, temperature 1500-1800°C), the sintered blank is further compacted to eliminate microscorosity. The hot pressing is usually carried out in a vacuum or hydrogen atmosphere, and the density of the billet can reach more than 99%.

Forging: Hot-pressed blanks are processed into cylindrical or square bars by a multi-directional forging machine (forging temperature 1200-1600°C). Forging refines the grains (from 50 µm to 20-30 µm) and improves material toughness. The deformation rate (0.1-0.5 s^{-1}) needs to be controlled during the forging process to avoid cracking.

Rolling: Forged bars are rolled into bars or plates with a diameter of 5-10 mm by a hot rolling mill (temperature 1000-1400°C). Rolling requires the use of multiple passes of small deformation (10%-15% per deformation) to reduce stress concentration. The surface of the rolled bar needs to be polished to remove the oxide scale.

Process characteristics: The hot working process improves the mechanical properties and processability of the blank, and provides a high-quality substrate for subsequent wire drawing. Chinese enterprises have significantly improved the dimensional accuracy of bars by introducing German hot rolling equipment.

4.3 Drawing process of molybdenum wire for lighting

The wire drawing process is the process of stretching the molybdenum rod into a filament, which is the core technology for preparing the Molybdenum wire for lighting, which directly determines the dimensional accuracy, surface quality and mechanical properties of the wire.

4.3.1 Coarse drawing, fine drawing and ultra-fine drawing technology

The wire drawing process is divided into three stages: coarse drawing, fine drawing and ultra-fine drawing, and the size of the wire is gradually reduced according to the target diameter and application requirements.

Rough drawing: Rolled bars (diameter 5-10 mm) are stretched to a diameter of 0.5-2 mm. Multi-pass wire drawing machine (10%-20% diameter reduction per time) is used for rough drawing, and the mold material is cemented carbide or natural diamond. The drawing speed is 1-5 m/min and hot drawing is required at 600-800°C to improve ductility.

Fine drawing: Drawing the coarse wire to a diameter of 0.05-0.5 mm, suitable for incandescent, halogen and HID lamps. Fine drawing requires the use of high-precision dies (tolerances ± 0.001

mm) and the drawing speed is reduced to 0.5-2 m/min. Multiple annealing (800-1000°C) is required during the fine drawing process to eliminate work hardening.

Ultra-fine drawing: Stretching the wire to a diameter of 0.01-0.05 mm, suitable for special lamps (e.g. UV lamps). Ultra-fine wire drawing places extremely high demands on the die and lubricant, requiring a polycrystalline diamond die (hole diameter accuracy ± 0.0005 mm) and a drawing speed of < 0.5 m/min. The tensile strength of ultra-fine molybdenum wire can reach more than 1500 MPa, but it is easy to break, and the process parameters need to be strictly controlled.

Technical challenges: The yield of ultra-fine drawing is low (about 70%-80%), and fracture may occur due to surface defects or internal stresses in the wire. The state-of-the-art wire drawing machine improves yield through in-line tension control and defect detection.

4.3.2 Lubricant selection and mold design optimization

Lubricants and die design are key to the drawing process, which directly affects the surface quality of the wire and the drawing efficiency.

Lubricant selection: Graphite emulsion or molybdenum disulfide (MoS_2) lubricants are commonly used for rough and fine drawing, with high temperature stability and a low coefficient of friction (0.1-0.2). Ultrafine drawing requires the use of oil-based lubricants (e.g. polyethylene glycol-based lubricants) to reduce surface scratches. The lubricant needs to be changed regularly to prevent contamination by impurities.

Mold design: The drawing die needs to be made of high hardness materials (such as cemented carbide WC or polycrystalline diamond PCD). The hole diameter of the die needs to be machined precisely (tolerance± 0.001 mm), and the entry angle (8-12°) and the length of the reducer zone need to be optimized to reduce drawing stress. The surface of the mold needs to be polished (Ra<0.05 µm) to reduce friction and surface defects.

Optimization measures: Advanced tool design uses finite element analysis (FEA) to simulate the stress distribution during wire drawing and optimize the mold geometry. The lubrication system ensures uniform lubricant coverage through an automatic spraying device and improves drawing stability.

4.3.3 Intermediate annealing and final annealing processes

The annealing process is used to eliminate work hardening during the drawing process and restore the ductility and toughness of the molybdenum wire.

Intermediate annealing: carried out after every 2-3 passes of rough drawing and fine drawing, at a temperature of 800-1000 °C, holding for 10-30 seconds, usually in a hydrogen atmosphere furnace. Intermediate annealing reduces the internal stress of the wire by 50%-70% and maintains the grain size at 10-20 µm.

Final annealing: Carried out after drawing at a temperature of 900-1200°C and held for 5-15 seconds, with the aim of optimizing the mechanical properties and surface quality of the wire. The final annealing needs to control the cooling rate (10-50°C/s) to avoid excessive grain growth.

Process characteristics: The annealing furnace needs to be equipped with a precise temperature control system (accuracy ± 5°C), and the hydrogen gas flow rate is controlled at 0.5-1 m^3/h. The annealing temperature of doped molybdenum wire (e.g. molybdenum lanthanum wire) is slightly higher (1000-1300°C) to ensure the stability of the doped elements.

The annealing process is critical to the performance of molybdenum wire. Annealing temperatures that are too high may lead to recrystallization, reducing strength; Temperatures that are too low will not adequately relieve the stress. The advanced annealing equipment can realize online annealing and improve production efficiency.

4.4 Surface treatment technology of molybdenum wire for lighting

Surface treatment technology is the key to improving the surface quality, corrosion resistance and optical properties of molybdenum wire, covering chemical cleaning and electrolytic polishing, process differences between black and cleaned molybdenum wire, and surface coating technology.

4.4.1 Chemical cleaning and electropolishing

Chemical cleaning and electropolishing are used to remove oxides, greases, and drawing residues from the surface of molybdenum wire, improving surface finish and electrical properties.

Chemical cleaning: Wash with pickling solution (such as HNO_3-HF mixture, ratio 3:1, concentration 5%-10%) at 40-60°C for 1-3 minutes to remove the surface oxide layer (MoO_2 or MoO_3). After washing, rinse with deionized water and dry (100-150°C) to avoid residual acid. Chemical cleaning is suitable for the conversion of black molybdenum wire to cleaned molybdenum wire.

Electrolytic polishing: molybdenum wire is used as the anode in the electrolyte (such as NaOH solution, concentration 5%-10%), the current density is 0.5-2 A/cm^2, and the polishing time is 10-30 seconds. Electrolytic polishing reduces surface roughness to Ra 0.1-0.5 μm, improves reflectivity (60%-70%) and resistance to arc corrosion.

Process characteristics: low cost of chemical cleaning, suitable for large-scale production; Electrolytic polishing has higher accuracy and is suitable for high-end lamps (such as halogen lamps, HID lamps). Waste liquid treatment needs to comply with environmental standards (such as RoHS directive), and neutralization and sedimentation technology is used to treat acid and alkali waste liquid.

4.4.2 Process differences between black molybdenum wire and cleaned molybdenum wire

There are significant differences between black molybdenum wire and cleaned molybdenum wire in terms of surface treatment process and application scenarios.

Black molybdenum wire: retains a layer of oxide (MoO_2 or MoO_3) on the surface with a roughness of Ra 0.5-2.0 μm. After drawing, annealing (600-800 °C) in air or low vacuum (10-100 Pa) directly to form an oxide layer. Black molybdenum wire is suitable for support filaments or sealing materials for low-cost incandescent lamps, because the oxide layer enhances adhesion to glass, but the arc stability is poor.

Cleaned molybdenum wire: The oxide layer is removed by chemical cleaning or electrolytic polishing, and the surface is bright with a roughness of Ra 0.1-0.5 μm. The conductivity and arc corrosion resistance of cleaned molybdenum wire are better than those of black molybdenum wire, and it is suitable for electrodes of halogen lamps and HID lamps. Additional cleaning and polishing steps are required in production, which increases the cost by about 20%-30%.

Process differences: the production of black molybdenum wire omits the surface treatment step, and the process is simple; Cleaned molybdenum wire needs to be tightly controlled cleaning and polishing parameters to ensure that there are no residual defects on the surface. The production of cleaned molybdenum wire requires high-precision polishing equipment.

4.4.3 Surface coating technologies (e.g. anti-oxidation coatings)

Surface coating technology improves the performance of molybdenum wire in harsh environments by depositing oxidation- or corrosion-resistant coatings (e.g., alumina Al_2O_3, molybdenum silicide $MoSi_2$) on the surface.

Coating type: Alumina coating (thickness 0.1-1 μm) can improve oxidation resistance, suitable for infrared lamps; The molybdenum silicide coating (0.5-2 μm thick) enhances arc corrosion resistance and is suitable for UV lamps. Carbide coatings, such as Mo_2C, are used in extremely high temperature environments.

Preparation process: Chemical vapor deposition (CVD, temperature 800-1200 °C) or physical vapor deposition (PVD, temperature 500-800 °C) to deposit the coating. CVD is suitable for complex shapes of molybdenum wire, while PVD provides higher coating uniformity. The coating should be firmly bonded to the molybdenum matrix to avoid peeling.

Process characteristics: The coating process needs to be carried out in a vacuum or inert atmosphere, and the equipment cost is high (for example, the price of CVD furnace is about 2-3 times that of ordinary sintering furnace). The coating thickness is measured by scanning electron microscopy (SEM) and the adhesion is verified by tensile testing.

Application impact: Coated molybdenum wire can increase the oxidation temperature to more than 1500°C and extend the life of lamps by 20%-30%, but the cost is high, and the market application is limited to high-end special lamps.

4.5 Doping process of molybdenum wire for lighting

The doping process is a key technology to improve the high-temperature performance and durability of molybdenum wire, which involves the doping method, uniformity control and performance enhancement mechanism of lanthanum, rhenium and other elements.

4.5.1 Doping methods of lanthanum, rhenium and other elements

Doping methods mainly include wet doping, dry doping and chemical co-precipitation.

Wet doping: Molybdenum powder is mixed with a doped material (e.g. lanthanum oxide) in a liquid medium (e.g. ethanol or deionized water) and homogeneity is ensured by ultrasonic dispersion (frequency 20-40 kHz for 1-2 hours). After mixing, the compound powder is prepared by spray drying (inlet temperature 200-250 °C). Wet doping is suitable for lanthanum oxide and yttrium oxide, and has high uniformity, but the drying process needs to be controlled to avoid particle agglomeration.

Dry doping: molybdenum powder is dry mixed with doped materials by V-type or double cone mixer, and the mixing time is 4-8 hours. Dry doping is suitable for rhenium powder, because rhenium is easy to oxidize in liquid. The speed of the mixer (20-50 rpm) needs to be controlled to avoid powder stratification.

Chemical co-precipitation: doped powder is prepared by chemical reaction (such as lanthanum nitrate and ammonium molybdate co-precipitation), which is suitable for multi-element doping (such as lanthanum + yttrium). The pH value (6-8) and reaction temperature (50-80°C) need to be controlled for co-precipitation to ensure uniform distribution of doped elements.

Process characteristics: the wet-doping uniformity is the best, suitable for large-scale production; The dry doping equipment is simple and suitable for rhenium doping; Chemical co-precipitation has high precision, but high cost, and is suitable for special molybdenum wire.

4.5.2 Doping uniformity control

The doping uniformity directly affects the performance stability of molybdenum wire. Uniformity control includes the following measures:

Powder mixing: Using high-precision mixing equipment, the distribution of doped elements is verified by online sampling and X-ray fluorescence (XRF) analysis, and the deviation is controlled at ±0.01%.

Sintering process: The sintering temperature (1800-2500°C) and holding time (2-8 hours) need to be optimized to avoid volatilization or segregation of doping elements. For example, lanthanum oxide may partially decompose at > 2300°C, and the sintering atmosphere (hydrogen dew point <-40°C) needs to be controlled.

Detection technology: Scanning electron microscopy (SEM) combined with energy spectroscopy (EDS) was used to detect the distribution of doped particles, and the particle spacing was controlled at 0.5-2 μm. The tensile strength of molybdenum wire with high uniformity can be increased by

20%-30% at high temperature.

4.5.3 Mechanism of doping to enhance high-temperature performance

Doping improves the high-temperature performance of molybdenum wire through the following mechanisms:

Grain boundary strengthening: Lanthanum oxide, yttrium oxide, etc. are dispersed in the form of nanoparticles in the molybdenum grain boundary, pinned to the dislocation, and inhibited grain growth and creep. For example, molybdenum wire doped with 0.8% lanthanum oxide has a creep rate 50% lower at 1500°C than pure molybdenum wire.

Solution strengthening: Rhenium dissolves into the molybdenum lattice to form a solid solution, which reduces the density of crystal defects and improves ductility and oxidation resistance. The elongation at break of molybdenum wire doped with 3% rhenium is increased to 20% at 1200°C.

Surface stability: Doped elements can form a stable surface structure and inhibit oxide volatilization. For example, lanthanum oxide particles form a protective oxide layer at high temperatures, reducing the rate of MoO_3 formation.

4.6 Quality control and process optimization of molybdenum wire for lighting

Quality control and process optimization are key to ensuring consistent performance and productivity of molybdenum wire, including process parameter monitoring, defect control, and cost optimization.

4.6.1 On-line monitoring of process parameters

Online monitoring ensures the stability of the production process by detecting process parameters in real time.

Monitoring parameters: including sintering temperature (±5°C), drawing speed (±0.1 m/min), annealing temperature (±10°C), lubricant flow rate (±0.1 L/min). Real-time recording with sensors (e.g., thermocouples, laser velocimeters) and data acquisition systems.

Monitoring equipment: The advanced monitoring system can realize the automatic control of the whole process, and optimize the parameters through big data analysis. For example, the tension fluctuations during the drawing process are controlled at ±0.5 N.

Application impact: Online monitoring can reduce the failure rate to less than 1%, improve the dimensional accuracy and performance consistency of molybdenum wire, and meet the needs of high-end lamps.

4.6.2 Defect control (cracks, porosity, inclusions)

Defect control is key to improving the quality of molybdenum wire, and common defects include cracks, porosity, and inclusions.

Cracks: Caused by drawing stress or improper annealing. Control measures include optimization of the drawing die (inlet angle 8-12°), reduction of the drawing rate (<0.5 m/min for ultrafilament) and intermediate annealing (800-1000°C). Crack detection is done by ultrasonic flaw detection or microscopic inspection.

Porosity: caused by insufficient sintering or impurities of raw materials. Control measures include increasing the sintering temperature (2200-2500°C), extending the holding time (4-8 hours), and using high-purity hydrogen (dew point <-40°C). The porosity was detected by X-ray CT scanning, and the porosity was controlled at <0.5%.

Inclusions: caused by contamination or uneven doping of raw materials. Control measures include strict cleaning of raw materials (HNO_3 cleaning) and the use of wet doping. The detection of inclusions was carried out by energy spectroscopy (EDS), and the impurity content was controlled at <0.01%.

4.6.3 Productivity and cost optimization

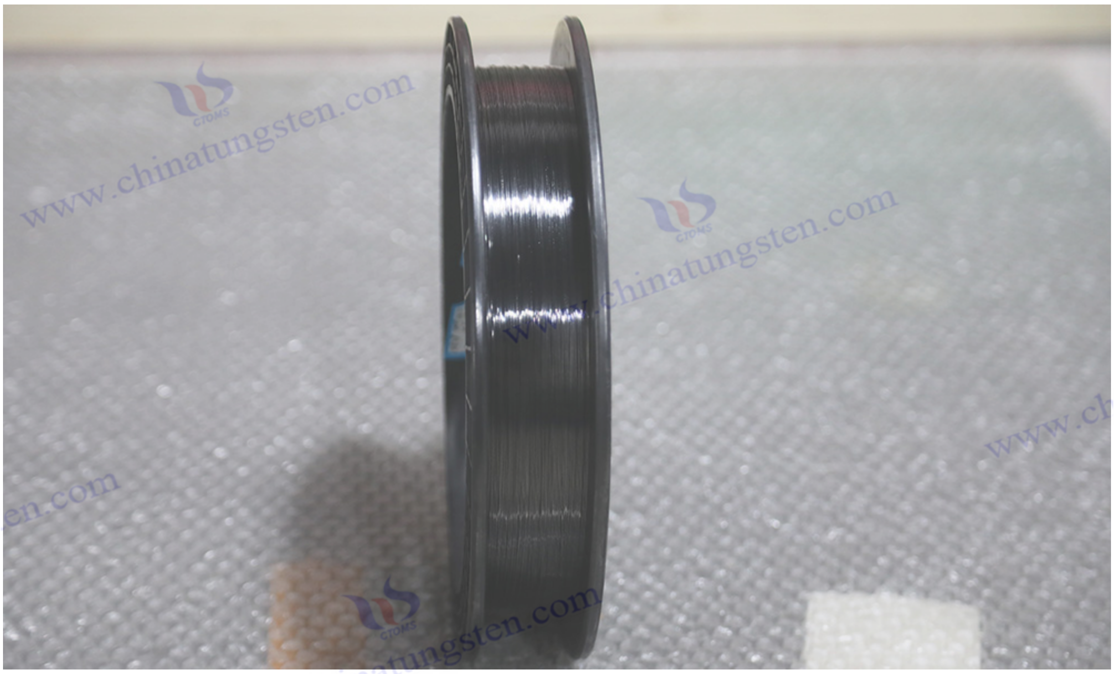
Production efficiency and cost optimization are the key to the competitiveness of the molybdenum wire industry.

Efficiency improvement: The continuous wire drawing machine (such as the German Niehoff equipment) is used to increase the wire drawing speed to 5-10 m/min, and the yield rate is increased to more than 90%. Automated sintering and annealing equipment can reduce production cycle times by up to 20%.

Cost optimization: Reduce raw material costs by recycling waste materials (e.g. broken wires) in the drawing process, with a scrap recovery rate of up to 30%. Optimised lubricant usage (10%-20% reduction) and energy consumption (15% reduction in sintering furnace energy consumption) further reduce costs.

Environmental protection measures: Waste liquid treatment systems (such as neutralization and sedimentation equipment) ensure compliance with RoHS and REACH regulations and reduce environmental protection costs. Green manufacturing technologies, such as low-energy sintering furnaces, can reduce energy consumption by 10%-15%.

Chinese enterprises have advantages in cost optimization, but they still need to learn from European and American companies in the process consistency of high-end doped molybdenum wire.



molybdenum wire for lighting from CTIA

Chapter 5 The Use of Molybdenum Wire for Lighting

Molybdenum wire for lighting plays a key role in a variety of lighting devices due to its excellent high-temperature performance, chemical stability and mechanical strength. This chapter will discuss in detail the specific applications of molybdenum wire in incandescent lamps, halogen lamps, gas discharge lamps, specialty lighting, and other related fields, and analyze its functions, performance requirements, and market status.

5.1 Incandescent lamps

Incandescent lamps were the first widely used lighting devices, and although their market has gradually shrunk due to the rise of LED lights, they are still widely used in decorative lighting, retro lamps and low-cost scenes. Molybdenum filament is mainly used as a filament support and conductive component in incandescent lamps, and has become an indispensable material due to its high temperature stability and thermal expansion compatibility with glass.

5.1.1 Filament support and conductive function

In incandescent lamps, the main function of molybdenum filament is to support the tungsten filament and act as a conductive electrode, ensuring stable current transmission and maintaining the geometry of the filament. Incandescent lamps work by heating tungsten filaments with an electric current to produce visible light, and molybdenum filaments need to maintain structural stability and electrical properties in this high-temperature environment.

Filament support: Tungsten filament is prone to softening or sagging at high temperatures, resulting in uneven light output or filament breakage. The molybdenum filament is used as a support material to hold the filament at a designated position on the inside of the bulb, usually in a spiral or U-shaped structure wound with tungsten filament. The high tensile strength of molybdenum wire ensures that it can withstand the weight and thermal stress of the filament. Pure molybdenum wire with a diameter of 0.1-0.5 mm is a common choice due to its low cost and good processability.

Conductive function: The molybdenum wire acts as an electrode to introduce the current from the external power supply into the inside of the bulb and connect with the tungsten filament. Its low resistivity reduces Joule heat loss and improves energy efficiency. The molybdenum wire also needs to be sealed with glass to form an airtight structure to prevent vacuum or inert gas leakage. Its coefficient of thermal expansion is matched to that of borosilicate glass, ensuring that the sealing area does not crack during thermal cycling.

Process characteristics: The molybdenum wire for incandescent lamp is mostly pure molybdenum wire, and the surface is usually black molybdenum wire, because the oxide layer can enhance the adhesion with the glass. In production, molybdenum wire is required through a precision drawing and cutting process to ensure consistent diameter tolerances and lengths. The automatic assembly equipment can accurately combine molybdenum wire with tungsten filament to improve production efficiency.

Application scenario: The power range of incandescent lamps is 15-1000 W, and molybdenum wire is mostly used in household bulbs, decorative lights and industrial lighting. Low-power bulbs require less performance from molybdenum wires, while high-power bulbs require thicker molybdenum wires to carry higher currents.

The application technology of molybdenum wire in incandescent lamps is mature, and the global market is dominated by China, India and Southeast Asia to meet the demand for low-cost lighting.

5.1.2 Stability and life in high temperature environment

The incandescent lamp works in a vacuum or low-pressure inert gas with an internal temperature of more than 2500°C, and the molybdenum wire needs to maintain mechanical and chemical stability at high temperatures to prolong the life of the lamp.

Mechanical stability: The tensile strength and creep resistance of molybdenum wire at high temperatures are key. The tensile strength of pure molybdenum wire at 1500°C is sufficient to support tungsten filament, but its creep rate may cause deformation of the support structure after long-term operation. In order to improve stability, doped molybdenum wire can be used for high-power incandescent lamps, which reduces the creep rate by more than 50% and is suitable for industrial luminaires above 1000 W.

Chemical stability: The incandescent lamp is in a vacuum or argon/nitrogen environment, and the molybdenum wire does not need to face oxidation problems, but it may react with residual oxygen or water vapor in trace amounts at high temperatures to generate volatile MoO_3. The bulb vauming process or gas purity needs to be strictly controlled in production to protect the molybdenum wire. The oxide layer of black molybdenum wire is stable in a vacuum environment and does not significantly affect the performance.

Life impact: The stability of molybdenum wire directly affects the life of incandescent lamps. Deformation or fracture of the support wire may cause the tungsten filament to shift, causing a short circuit or light decay. Failure of the hermetically sealed electrode can introduce air, resulting in rapid oxidation of the filament and molybdenum filament. Studies have shown that optimizing the surface quality of molybdenum wire and the sealing process can extend the life of the luminaire by 10%-20%.

Process optimization: Intermediate annealing in production improves the ductility of molybdenum wire and reduces the risk of embrittlement at high temperatures. Surface cleaning removes trace impurities and further improves chemical stability. Chinese companies ensure the reliability of molybdenum wire and the life of lamps and lanterns through automatic sealing equipment and online testing technology.

Although the market for molybdenum wire for incandescent lamps is gradually shrinking, its demand for decorative lighting is stable, and it is expected to still account for 15%-20% of the market for lamp molybdenum wire from 2025 to 2030.

5.2 Halogen lamps

Halogen lamps are widely used in automotive lighting, home lighting, and professional lighting to improve luminous efficiency and longevity through halogen cycling. Molybdenum wire is used as an electrode, support wire and sealing material in halogen lamps and is subject to higher temperatures and chemical environments.

5.2.1 The key role of molybdenum wire in the halogen cycle

The working principle of halogen lamp is to add a small amount of halogen gas to the bulb, which reacts with the evaporated tungsten atoms to form volatile tungsten halide, which prevents tungsten from being deposited on the inner wall of the bulb and makes tungsten back deposited on the filament to prolong the life of the filament. Molybdenum wire plays a key role in this cycle.

Electrode function: The molybdenum wire acts as an electrode to introduce the current into the tungsten filament, which needs to withstand high voltage and instantaneous high current. Its low resistivity and high conductivity ensure efficient current transmission and reduce energy loss. The molybdenum wire electrode also needs to be sealed to the glass to maintain a high-voltage environment inside the bulb.

Support function: The molybdenum wire supports the tungsten filament to prevent it from vibrating or sagging in high temperatures and halogen cycles. Molybdenum lanthanum wire with a diameter of 0.05-0.3 mm is preferred because its tensile strength and creep resistance at high temperatures are superior to that of pure molybdenum wire.

Halogen cycle support: Molybdenum wire is in direct contact with halogen gas and needs to be resistant to chemical corrosion. The halogen cycle creates a hot area near the inner wall of the bulb, and the surface of the molybdenum wire needs to be stable and not form volatile compounds with iodine or bromine. Studies have shown that molybdenum wire has a much better corrosion rate than tungsten in an iodine environment.

Process characteristics: The molybdenum wire for halogen lamp is mostly cleaned molybdenum wire, and the surface finish and corrosion resistance are improved by electrolytic polishing. The sealing process needs to be precisely controlled in production to ensure air tightness and halogen gas stability.

Application scenarios: Halogen lamps are widely used in automotive headlights, household spotlights and stage lighting. Automotive halogen lamps account for more than 50% of the halogen lamp market, and the reliability requirements for molybdenum wire are extremely high.

The stability and corrosion resistance of molybdenum wire in the halogen cycle make it the core material of halogen lamps, and the global market is dominated by Europe and China.

5.2.2 High temperature resistance and chemical corrosion resistance

The working temperature of halogen lamps is much higher than that of incandescent lamps, the filament temperature can reach 3000°C, the temperature of the sealing part is 600-800°C, and the molybdenum wire needs to have excellent high temperature resistance and chemical corrosion resistance.

High temperature resistance: Molybdenum wire needs to maintain mechanical strength and structural stability at 1500-2000°C. Due to the doping of lanthanum oxide, the recrystallization temperature of molybdenum lanthanum wire is increased to 1800 °C, and the tensile strength can reach 400 MPa at 1500 °C, and the creep rate is lower than that of pure molybdenum wire. In contrast, pure molybdenum wire is prone to deformation at 1500°C. The excellent performance of molybdenum lanthanum wire ensures the reliability of the filament support and electrode in long-term high-temperature operation.

Chemical resistance: Halogen gas is highly corrosive at high temperatures, and molybdenum wire needs to resist its erosion. The chemical stability of molybdenum allows it to form a stable surface structure in a halogen environment without the formation of volatile halides. Cleaned molybdenum wire has less surface defects, and the corrosion rate is about 30% lower than that of black molybdenum wire. Doped molybdenum wire further improves corrosion resistance by forming a corrosion-resistant surface layer.

Process optimization: Corrosion resistance is enhanced through surface passivation in production. Electropolishing reduces the surface roughness to Ra 0.2 μm, reducing the corrosion initiation point. The sealing process needs to control the glass composition to ensure that it matches the thermal expansion of the molybdenum wire.

Life effect: The high temperature resistance and corrosion resistance of molybdenum wire directly determine the life of halogen lamp. Studies have shown that the life of halogen lamps using molybdenum lanthanum wire can reach 4000 hours, which is 50% higher than that of pure molybdenum filament lamps. The optimization of surface quality and seal tightness can further extend the life by 10%-20%.

Molybdenum wire for halogen lamps accounts for more than 30% of the market for lamp molybdenum wire, and it is expected to maintain stable growth due to the demand for automotive lighting from 2025 to 2030.

5.3 Gas discharge lamps

Gas discharge lamps produce light through gas discharge, which have high luminous efficiency and long life, and are widely used in commercial, industrial, and outdoor lighting. Molybdenum wire is mainly used as an electrode and sealing material in gas discharge lamps, which needs to withstand high voltage, arc high temperature and complex chemical environment.

5.3.1 Molybdenum wire for high-intensity discharge lamps (HID).

High-intensity gas discharge lamps include metal halide lamps, high-pressure sodium lamps and xenon lamps with luminous efficiencies of 100-150 lm/W and are widely used in road lighting, stadiums and industrial plants. Molybdenum wire is used as an electrode and sealing material in HID lamps and needs to meet extremely high performance requirements.

Electrode function: HID lamp generates light through arc discharge, and the electrode needs to withstand high voltage and instantaneous high current. The high melting point and conductivity of molybdenum wire ensure that it does not melt or suffer significant losses at high arc temperatures. Molybdenum lanthanum wire or molybdenum rhenium wire with a diameter of 0.03-0.2 mm is preferred due to its excellent arc corrosion resistance and high temperature strength.

Sealing function: Molybdenum wire is sealed with ceramic or glass to maintain a high-pressure environment inside the bulb. Its coefficient of thermal expansion is similar to that of alumina ceramics and enables reliable sealing through transition materials. The sealing part needs to withstand the cyclic temperature change of 500-700°C, and the air tightness of the molybdenum wire directly affects the life of the lamp.

Performance requirements: HID lamp electrodes need to resist surface corrosion and sputtering caused by arcing. Due to the doping of lanthanum oxide, molybdenum lanthanum wire has an arc corrosion resistance rate 20% lower than that of pure molybdenum wire. The ductility of molybdenum rhenium wire makes it suitable for complex electrode shapes and improves arc stability.

Process characteristics: The molybdenum wire used for HID lamp is mostly cleaned molybdenum wire, which improves the surface finish and arc stability through electrolytic polishing. Precision wire drawing and high-temperature annealing are used in production to ensure wire consistency. The sealing process is carried out in an inert atmosphere, and the temperature gradient is controlled

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to avoid stress cracking.

Application scenarios: metal halide lamps are used for commercial lighting, high-pressure sodium lamps are used for road lighting, and xenon lamps are used for automotive headlights and projection equipment. HID lamps account for 70% of the gas discharge lamp market, and the amount of molybdenum wire used in lamps accounts for 25%.

5.3.2 Fluorescent lamp electrode materials

Fluorescent lamps excite phosphors to produce light through mercury vapor discharge, with a luminous efficiency of 50-100 lm/W, and are widely used in office, school, and home lighting. Molybdenum wire is mainly used as an electrode material in fluorescent lamps and is responsible for initiating and maintaining discharge.

Electrode function: Fluorescent lamp electrodes are subjected to low-voltage discharge, which is initiated by thermal electron emission. As the electrode substrate, molybdenum wire is usually coated with the emitting material to reduce the work function and improve the emission efficiency. Pure molybdenum wire or molybdenum lanthanum wire with a diameter of 0.05-0.2 mm is a common choice.

Performance requirements: Molybdenum wire needs to resist the chemical corrosion of mercury vapor and the thermal shock of the arc. The corrosion rate of pure molybdenum wire in mercury vapor meets the needs of fluorescent lamps. Molybdenum lanthanum wire is suitable for high-power fluorescent lamps due to its stronger resistance to arc corrosion.

Process characteristics: The molybdenum wire used in fluorescent lamps is mostly cleaned molybdenum wire, and the surface oxide is removed by chemical cleaning to ensure the adhesion of the emission coating. Electrode forming requires precision stamping or winding to control the electrode spacing to ensure discharge stability. The sealing process needs to be matched with borosilicate glass, and the sealing temperature is controlled at 600-700°C.

Application scenarios: Fluorescent lamps include straight tube fluorescent lamps, compact fluorescent lamps and ring fluorescent lamps. CFLs account for 50% of the fluorescent lamp market and are widely used in home lighting. Although LED lamps are gradually replacing fluorescent lamps, fluorescent lamps are still in demand in developing countries, and molybdenum wire accounts for 10% of lamp molybdenum wire.

Market Status: The fluorescent lamp market has shrunk due to environmental regulations, but its low cost advantage has allowed it to remain in Asia and Africa. China is a major producer of molybdenum wire for fluorescent lamps, which is exported to India and Southeast Asia.

Molybdenum wire for fluorescent lamps has a low technical threshold, but the quality of electrode coating and sealing needs to be strictly controlled to ensure start-up performance and longevity.

CTIA GROUP LTD
Molybdenum Wire for Lighting Introduction

1. Overview of Molybdenum Wire for Lighting

As one of the core materials in modern lighting technology, molybdenum wire is widely used in various light sources including incandescent lamps, halogen lamps, fluorescent lamps, and gas discharge lamps, due to its high melting point, high strength, excellent corrosion resistance, and superior electrical conductivity. It is an irreplaceable and critical component in the lighting industry.

2. Typical Applications of Molybdenum Wire for Lighting

Residential and Commercial Lighting: Used in incandescent and halogen lamps to provide warm light and long service life.

Automotive Lighting: Functions as electrodes in HID and xenon lamps, offering high brightness and vibration resistance.

Specialty Lighting: Utilized in projection lamps, ultraviolet (UV) lamps, and infrared (IR) lamps to meet high-temperature and high-precision requirements in medical, industrial, and scientific applications.

Emerging Fields: Serves as conductive leads for LED lamps and supports for phosphors in laser lighting, aligning with future lighting technology development.

3. Basic Data of Molybdenum Wire for Lighting (Reference)

Parameter	Pure Mo Wire	Mo-La Wire	Mo-Re Wire
Mo Content	≥99.95%	≥99.0%	52.5%–86.0%
Diameter Range	0.03–3.2 mm	0.03–1.5 mm	0.03–1.0 mm
Tolerance	±0.002 mm	±0.002 mm	±0.002 mm
Tensile Strength (Room Temp)	800–1200 MPa	900–1400 MPa	1000–1500 MPa
Tensile Strength (at 1500°C)	150–300 MPa	200–400 MPa	250–450 MPa
Elongation at Break	10%–25%	12%–20%	15%–25%
Electrical Resistivity (20°C)	5.5×10^{-8} Ω·m	6.0×10^{-8} Ω·m	6.5×10^{-8} Ω·m
Main Applications	Incandescent, Halogen	Halogen, Auto Headlights	HID, Projection Lamps

4. Procurement Information

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5.4 Special Lighting

Specialty lighting is designed for a specific spectrum, environment, or use, including automotive headlights, projection lights, stage lighting, UV lights, infrared lights, and medical lighting. Molybdenum wire needs to meet the requirements of high reliability, complex shapes and extreme environments in special lighting.

5.4.1 Headlamps and fog lamps

Automotive headlamps and fog lamps require high brightness, long life and vibration resistance, and molybdenum wires are mainly used for electrodes, support wires and sealing materials for halogen lamps and xenon lamps.

Function: In halogen headlamps, the molybdenum wire acts as an electrode and support wire, withstands a voltage of 12-24 V and a current of 5-10 A, supporting the tungsten filament. In xenon lamps, the molybdenum wire acts as an electrode and is subjected to a starting voltage of 20-30 kV and a high arc temperature. Molybdenum wire also needs to be sealed with glass or ceramic to maintain a high-pressure environment.

Performance requirements: Automotive lamps need to resist vibration and thermal cycling. Molybdenum lanthanum wire and molybdenum rhenium wire are suitable for automotive lamps due to their excellent strength and ductility at high temperatures. Arc corrosion resistance and surface finish are critical to arc stability.

Process characteristics: The molybdenum wire used for automobile lamps is mostly cleaned molybdenum wire, which improves the corrosion resistance through electrolytic polishing. The electrodes need to be precisely molded to a tolerance of ±0.005 mm. The sealing process requires the use of automated equipment to ensure airtightness and consistency.

Application scenario: Halogen headlamps account for 60% of the automotive lighting market, and xenon lamps account for 20%, mainly used in high-end models. Fog lamps use halogen lamps more often because they need to penetrate the fog. Global automotive production drives the demand for molybdenum wire, accounting for 20% of the molybdenum wire used in lamps.
Market status: Europe and China are the main markets, and Chinese companies occupy the low-end market through cost advantages.

5.4.2 Projection lamps, stage lighting and photographic lights

Projection lamps, stage lighting and photographic lamps require high brightness, precise beam and long life, and molybdenum wire is mainly used as electrodes and support materials for HID lamps and halogen lamps.

Function: In projection lamps, molybdenum wire acts as a HID lamp electrode, subjected to a start-up voltage of 10-20 kV and a high arc temperature. Stage lighting and photographic lights mostly use halogen lamps or xenon lamps, and molybdenum wires are used as support wires and electrodes to support tungsten filaments or guide arcs. Molybdenum lanthanum wire or molybdenum-rhenium wire with a diameter of 0.05-0.2 mm is a common choice.

Performance requirements: high arc stability and thermal shock resistance are required. Molybdenum rhenium wire is suitable for complex electrode shapes due to its excellent ductility. The surface finish reduces arc spatter and improves light output efficiency.

Process characteristics: Molybdenum wire for projection lamp needs ultra-fine wire drawing and surface passivation treatment to enhance corrosion resistance. Molybdenum wire for stage lights needs to be annealed at high temperature to improve creep resistance. The sealing process needs to be matched with high-purity alumina ceramics, and the temperature is controlled at 800-1000°C.

Application scenarios: projection lamps are used for educational and commercial displays, stage lighting is used for theaters and concerts, and photography lights are used for film and television shooting. The global professional lighting market size is driving the demand for molybdenum wire, accounting for 10% of the molybdenum wire used in lamps.

Market status: foreign companies are the main suppliers, and Chinese companies are competitive in the low-end market.

5.4.3 Ultraviolet lamps, infrared lamps and medical lighting

Ultraviolet, infrared, and medical lighting are specific to a specific spectrum or application, and molybdenum filaments need to meet high chemical stability and complex environmental requirements.

Ultraviolet lamp: used for sterilization, curing and water treatment, molybdenum wire is used as an electrode to withstand mercury vapor discharge. Molybdenum yttrium wire or molybdenum cerium wire is preferred due to its strong resistance to mercury corrosion. The surface coating can further increase the service life.

Infrared lamp: used for heating and industrial drying, molybdenum wire as a support wire or electrode, withstand high temperature of 2000-2500°C. Molybdenum lanthanum wire is suitable for infrared lamps due to its excellent creep resistance. The surface finish improves the efficiency of radiation.

Medical lighting: such as surgical and dental lamps, using halogen lamps or HID lamps, molybdenum wire as electrodes and support wires, requires high reliability and accurate light output. The ductility of molybdenum rhenium wire makes it suitable for complex electrode designs.

Process characteristics: molybdenum wire for ultraviolet lamp needs precision wire drawing and surface passivation, molybdenum wire for infrared lamp needs high temperature annealing, and molybdenum wire for medical lamp needs strict defect detection. The sealing process needs to be matched with special glass, and the temperature is controlled at 900-1100°C.

Application scenarios: UV lamps are used in hospitals and water treatment, infrared lamps are used for industrial heating, and medical lighting is used in operating rooms. The special lighting market has high added value, and the amount of molybdenum wire accounts for 10% of the molybdenum wire used in lamps.

Market status: foreign companies are the main suppliers, and Chinese companies are gradually rising in the field of molybdenum wire for ultraviolet lamps.

5.5 Other areas of application

In addition to lighting, molybdenum wire also has important applications in vacuum electronics, EDM and high-temperature furnaces, demonstrating its versatility.

5.5.1 Vacuum electronics (tubes, X-ray tubes)

Vacuum electronics use the movement of electrons in a vacuum to achieve signal amplification or imaging, and molybdenum wire is used as an electrode, gate, or support material.

Function: In electron tubes, molybdenum wire acts as a cathode or gate to withstand high temperatures and electron bombardment. In an X-ray tube, the molybdenum wire acts as a target support or electrode and is subjected to high voltages and arcs. Molybdenum lanthanum wire or molybdenum-rhenium wire with a diameter of 0.05-0.2 mm is a common choice.

Performance requirements: high conductivity, arc corrosion resistance and high temperature stability are required. Molybdenum rhenium wire is suitable for complex gate structures due to its excellent ductility. The surface finish reduces the non-uniformity of electron emission.

Process characteristics: ultra-fine wire drawing and electrolytic polishing are required, and the sealing process is matched with special glass. The vacuum degree needs to be strictly controlled in production to avoid impurity contamination.

Application scenarios: Tubes are used in hi-fi and radar, and X-ray tubes are used in medical imaging and industrial inspection. The market size of vacuum electronic devices is small, and the amount of molybdenum wire accounts for 5% of the total market.

5.5.2 Molybdenum wire for electrical discharge machining (EDM).

EDM ablates materials through EDM, and molybdenum wire is used as an electrode wire, which is widely used in mold making and precision machining.

Function: Molybdenum wire acts as a discharge electrode in EDM, with a diameter of 0.1-0.3 mm, and is subjected to high-frequency pulse current. Its high melting point and tensile strength ensure that the electrode does not melt or break.

Performance requirements: high conductivity and arc corrosion resistance are required. Pure molybdenum wire is the main choice due to its low cost. The surface finish improves discharge stability.

Process characteristics: precision wire drawing and annealing are required to ensure the consistency of the wire. Continuous wire drawing machine is used in production to improve efficiency.

Application scenario: EDM is used in aerospace, automotive mold and medical device manufacturing. Molybdenum wire accounts for 30% of the EDM electrode wire market, and China is the main producer.

5.5.3 High-temperature furnace heating elements and thermocouples

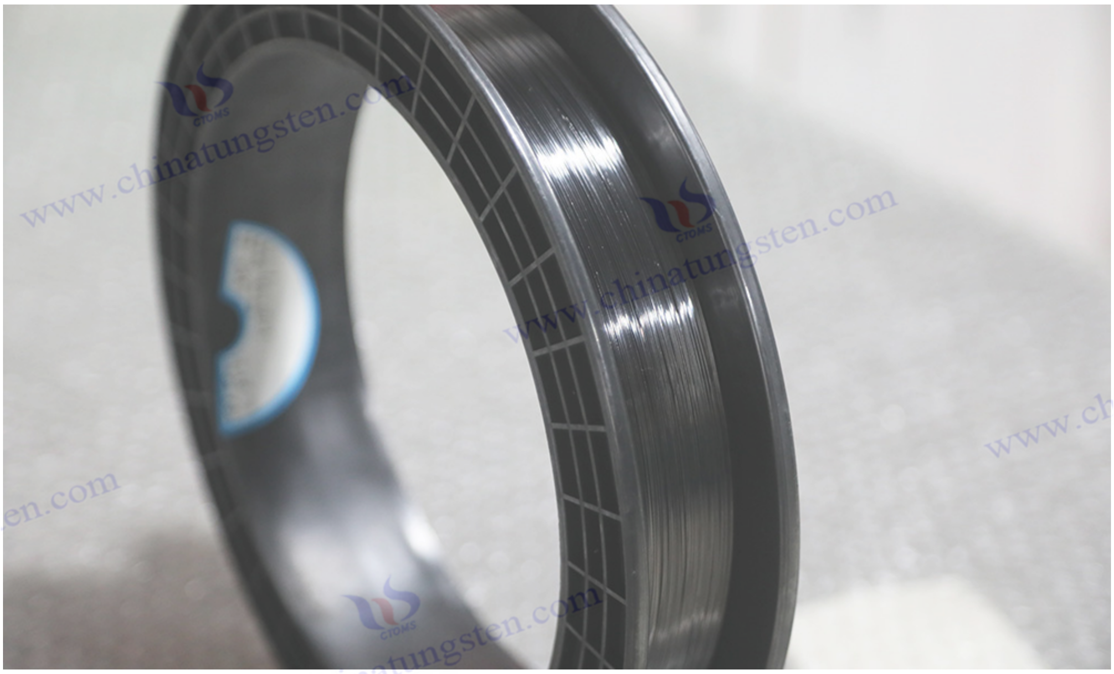
Molybdenum wire is used in high-temperature furnaces as heating elements or thermocouple sheaths to withstand extreme high temperatures.

Function: As a heating element, molybdenum wire generates high temperatures through Joule heating, which requires high resistivity and high temperature resistance. As a thermocouple protective sheath, molybdenum wire protects the thermocouple from corrosion. Pure molybdenum wire or molybdenum lanthanum wire with a diameter of 0.5-2.0 mm is a common choice.

Performance requirements: oxidation resistance and creep resistance are required. The creep rate of molybdenum lanthanum wire at 1800°C is lower than that of pure molybdenum wire, which is suitable for long-term operation.

Process characteristics: coarse wire drawing and high-temperature annealing are required, and the surface can be coated with an anti-oxidation layer. Grain size needs to be controlled during production.

Application scenarios: High-temperature furnaces are used for sintering and heat treatment of materials, and thermocouples are used for temperature measurement. Molybdenum wire is used in this field to account for 5% of the total market.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Chapter 6 Production Equipment for Molybdenum Wire for Lighting

The production of Molybdenum wire for lighting is a high-precision, high-tech process, involving multiple links from raw material processing to finished product testing, relying on advanced special equipment. This chapter will discuss in detail the various types of equipment required for the production of Molybdenum wire for lighting, including raw material handling equipment, smelting and molding equipment, wire drawing equipment, surface treatment equipment, and inspection and quality control equipment. Each section will provide an in-depth analysis of the equipment's functions, technical parameters, process characteristics and role in the production of Molybdenum wire for lighting, and provide a comprehensive technical explanation in combination with the world's leading equipment suppliers and industrial practices to meet the lighting industry's demand for high-performance molybdenum wire production equipment.

6.1 Molybdenum wire raw material processing equipment for lamps

Raw material processing is the first step in the production of Molybdenum wire for lighting, which involves molybdenum powder grinding, screening, mixing of doped materials and purification of raw materials, which directly affects the success rate of the subsequent process and the quality of molybdenum wire. The following is a detailed analysis from three aspects: grinding and screening, doping mixing and purification equipment.

6.1.1 Molybdenum powder grinding and screening equipment

The particle size and morphology of molybdenum powder are crucial to the density of the sintered blank and the performance of the molybdenum wire, and the grinding and screening equipment is used to prepare high-purity molybdenum powder with uniform particle size (particle size 1-5 μm, purity ≥ 99.95%).

Grinding equipment: Commonly used equipment includes planetary ball mills and jet mills. Planetary ball mills (e.g. the German Fritsch Pulverisette series) grind coarse molybdenum powder (particle size 10-50 μm) to 1-5 μm with a grinding time of 2-6 hours and a speed of 200-400 rpm by means of a high-speed rotating grinding ball (made of zirconia or cemented carbide). Jet mills (such as NETZSCH Jet Mill in Germany) use high-speed air flow (pressure 0.5-1 MPa) to collide and crush, which is suitable for the production of spherical or near-spherical molybdenum powder to improve sintering performance. The grinding process is carried out in an inert atmosphere (e.g. argon) or in a vacuum to avoid oxidation.

Screening equipment: vibrating screening machine and air classifier are used to control the particle size distribution of molybdenum powder. Vibrating sieving machines (e.g., Retsch AS 200 in Germany) separate powders of different particle sizes through multi-layer screens (pore size 1-10 μm), and the screening efficiency can reach more than 95%. An air classifier (such as Hosokawa Alpine, Germany) can accurately control the D50 at 2-3 μm and the D90/D10 ratio at 2-3 to ensure particle size uniformity through air separation. The equipment should be lined with stainless steel or ceramic to avoid metal contamination.

Process characteristics: The grinding equipment needs to be equipped with a cooling system (water cooling or liquid nitrogen freezing) to control the grinding temperature (<50 °C) to prevent molybdenum powder oxidation or agglomeration. The screening equipment needs to be equipped with an online particle size analyzer (such as a laser particle size analyzer) to monitor the particle size distribution in real time. Advanced grinding and screening equipment can increase the powder yield to more than 98%.

Application impact: Uniform molybdenum powder particle size and spherical morphology can increase the density of the sintered blank (95%-98%), reduce porosity and inclusions, and provide high-quality raw materials for subsequent wire drawing.

6.1.2 Dopane mixing and homogenization equipment

The uniform distribution of doped materials (e.g., lanthanum oxide, rhenium) is the key to the preparation of high-performance molybdenum wires (e.g., molybdenum, molybdenum-rhenium wires), and mixing and homogenization equipment is used to ensure the uniformity of doped elements.

Mixing equipment: ultrasonic disperser and planetary mixer are commonly used for wet mixing. The ultrasonic disperser (such as Hielscher UP400St in the United States) disperses molybdenum powder and doped materials (such as lanthanum oxide, particle size 50-200 nm) in a liquid medium (such as ethanol) through high-frequency vibration (20-40 kHz), and the mixing time is 1-2 hours, and the uniformity deviation is <0.01%. Planetary mixers (e.g. EIRICH RV02 from Germany) achieve wet or dry mixing by multi-directional mixing (50-100 rpm) and are suitable for large-scale production. The dry mixing adopts V-type or double cone mixer (such as the product of China Nantong Mixing Equipment Factory), and the mixing time is 4-8 hours, which is suitable for rhenium powder doping.

Homogenization equipment: Spray dryer (such as German Büchi B-290) is used for powder drying after wet mixing, with an inlet temperature of 200-250 °C and an outlet temperature of 80-100 °C, to prepare a homogeneous composite powder. Spray drying can avoid the agglomeration of doped particles, and the particle spacing is controlled to 0.5-2 μm.

Process characteristics: The mixing equipment needs to be operated in a clean environment (ISO 7 class) to prevent dust pollution. The ultrasonic disperser is suitable for small batches of high-precision doping, and the spray dryer is suitable for large-scale production. The homogenization equipment needs to be equipped with an in-line sampling system to verify doping uniformity by X-ray fluorescence (XRF) analysis.

Application Impact: Uniform doping distribution can improve the tensile strength and creep resistance of molybdenum wire at high temperature (20%-30% at 1500°C).

6.1.3 Raw material purification equipment

Raw material purification equipment is used to remove impurities (such as iron, silicon, oxygen) in molybdenum powder to ensure that the purity reaches more than 99.95%.

Hydrogen Reduction Furnace: Tubular hydrogen reduction furnaces (such as the equipment of Zhuzhou Cemented Carbide Plant in China) are used to reduce molybdenum trioxide (MoO_3) to high-purity molybdenum powder. The reduction temperature is 600-1000 °C, the hydrogen purity ≥ 99.999%, the dew point <-40 °C, and the reduction time is 4-8 hours. The equipment needs to be equipped with a multi-stage heating zone to control the temperature gradient (±5°C) and avoid oxygen residue.

Chemical cleaning equipment: pickling tank (made of corrosion-resistant PTFE) is used to remove oxides and grease on the surface of molybdenum powder, the commonly used cleaning agent is dilute nitric acid (HNO_3, concentration 5%-10%) or sodium hydroxide (NaOH, concentration 2%-5%), cleaning temperature 40-60 °C, time 5-10 minutes. After washing, rinse with deionized water and vacuum dry (100-150°C).

Process characteristics: The hydrogen reduction furnace needs to be equipped with an exhaust gas treatment system (such as an absorption tower) to treat unreacted hydrogen and oxide gas, which meets the requirements of environmental protection. Chemical cleaning equipment is required to be equipped with a waste disposal system (neutralizing sedimentation) to ensure compliance with the RoHS Directive. The purification equipment can reduce the impurity content to less than 0.01%.

Application impact: High purity molybdenum powder can reduce inclusions in sintered blanks and improve the chemical stability and electrical properties of molybdenum wire.

6.2 Molybdenum wire smelting and forming equipment for lamps

Smelting and forming equipment is used to convert molybdenum powder into a high-density blank that provides the basis for subsequent wire drawing, involving vacuum sintering, hot pressing, forging and rolling processes.

6.2.1 Vacuum sintering furnace and atmosphere protection furnace

The sintering furnace is the core equipment for the preparation of high-density molybdenum blanks, which is divided into vacuum sintering furnace and atmosphere protection furnace.

Vacuum sintering furnace: such as the VIGA series of ALD Vacuum Technologies in Germany, the working vacuum degree is $<10^{-3}$ Pa, the temperature is 1800-2200 °C, and the holding time is 4-8 hours. Molybdenum or tungsten heating elements are used in the furnace, which are resistant to high temperatures and do not pollute the blanks. After sintering, the density of the blank can reach 95%-98%, and the grain size is 10-50 μm. The equipment needs to be equipped with a high-precision temperature control system (±5°C) and a vacuum pump (mechanical pump + diffusion pump) to ensure an oxygen-free environment.

Atmosphere protection furnace: such as the hydrogen sintering furnace of Chenhua Electric Furnace in Shanghai, China, with a working temperature of 2300-2500°C, a hydrogen gas flow rate of 1-2 m^3/h, and a dew point of <-40°C, suitable for sintering doped molybdenum wire (such as molybdenum lanthanum wire). Molybdenum shielding is used in the furnace to reduce heat radiation loss. Atmosphere protection prevents the volatilization of doping elements and ensures stable performance.

Process characteristics: vacuum sintering is suitable for pure molybdenum blanks, and atmosphere protection furnace is suitable for doped molybdenum wire. Both are required to be equipped with an exhaust gas treatment system to treat hydrogen or volatile oxides. The advanced sintering furnace realizes automatic operation through PLC control to reduce manual errors.

Application Impact: High density blanks reduce the risk of cracks and wire breakage during the wire drawing process and improve yield.

6.2.2 Hot press and multi-directional forging equipment

Hot pressing and forging equipment is used to further compact the sintered blank, eliminate porosity and improve mechanical properties.

Heat press: such as the heat press of Sodick in Japan, the working pressure is 50-100 MPa, the temperature is 1500-1800 °C, and the vacuum degree is $<10^{-2}$ Pa. The equipment adopts a hydraulic system, and the pressure control accuracy is ± 0.1 MPa, which is suitable for the production of high-density blanks (>99%). The hot press needs to be equipped with molybdenum or graphite molds, which are resistant to high temperatures and do not pollute the blank.

Multi-directional forging equipment: such as the multi-directional forging machine of the German SMS Group, the forging temperature is 1200-1600°C, and the deformation rate is 0.1-0.5 s^{-1}. The machine refines the grains (from 50 μm to 20-30 μm) and improves the toughness of the billet through multi-axis collaborative forging. After forging, the surface of the blank needs to be polished to remove the oxide scale.

Process characteristics: The hot press is suitable for small-size blanks (diameter < 50 mm), and multi-directional forging is suitable for large-size bars (diameter 50-100 mm). The equipment needs to be equipped with a cooling system (water-cooled or air-cooled) to control the billet temperature gradient (±10°C). The automatic control system can improve the production efficiency by 10%-15%.

Application impact: Hot pressing and forging can significantly improve the tensile strength of the blank (20% increase at room temperature) and processability, providing the basis for ultra-fine wire drawing.

6.2.3 Precision rolling mills

Precision rolling mills are used to process forged blanks into bars or plates with a diameter of 5-10 mm, suitable for subsequent wire drawing.

Equipment type: such as the precision rolling mill of Kocks in Germany, the working temperature is 1000-1400°C, and the rolling speed is 1-5 m/s. The machine is multi-pass rolling (10%-15% deformation per time) and is equipped with carbide rolls (hardness HRC 80-90) to ensure dimensional accuracy (tolerance±0.01 mm).

Process characteristics: The rolling mill needs to be equipped with a heating system (induction heating or resistance heating) to maintain the high-temperature ductility of the billet. Surface polishing devices (e.g. belt polishers) are used to remove oxide scale, and the roughness is controlled at Ra 1-2 μm. The automated rolling line can achieve continuous production and increase efficiency by 20%.

Application Impact: Precision rolling improves the dimensional consistency and surface quality of the bar and reduces drawing die wear.

6.3 Wire drawing equipment for molybdenum wire for lighting

The wire drawing equipment is the core equipment for stretching molybdenum rod into filament, which involves multi-pass wire drawing, die design, lubrication system and annealing process, which directly determines the dimensional accuracy and mechanical properties of molybdenum wire.

6.3.1 Multi-pass wire drawing machine and continuous wire drawing equipment

The wire drawing machine is used to stretch the bar into molybdenum wire with a diameter of 0.01-2 mm, which is divided into multi-pass wire drawing machine and continuous wire drawing machine.

Multi-pass drawing machine: such as the German Niehoff MMH series, suitable for rough drawing (0.5-2 mm diameter) and fine drawing (0.05-0.5 mm). The equipment is equipped with multiple sets of wire drawing dies (5-20 passes), each time the diameter is reduced by 10%-20%, and the drawing speed is 1-5 m/min. The wire drawing machine uses a servo motor to control the tension (±0.5 N) to ensure the uniformity of the wire.

Continuous drawing equipment: such as the continuous drawing line from Frigerio in Italy, suitable for ultra-fine drawing (diameter 0.01-0.05 mm). The machine integrates multi-pass drawing, annealing and winding at speeds of 0.1-0.5 m/min and tolerances ± 0.001 mm. Continuous drawing can increase production efficiency by up to 30%.

Process characteristics: The wire drawing machine needs to be equipped with online tension detection and broken wire alarm system to prevent wire breakage. Ultra-fine wire drawing needs to be carried out in a constant temperature environment (20-25°C) to reduce the effect of thermal expansion. The equipment has a high degree of automation, which can reduce manual intervention.

Application impact: The continuous wire drawing equipment is suitable for large-scale production, with a yield of more than 90%, and is suitable for molybdenum wire for halogen lamps and HID lamps.

6.3.2 High-precision molds and lubrication systems

The die and lubrication system are at the heart of the drawing process, which directly affects the surface quality and dimensional accuracy of the molybdenum wire.

High-precision mold: Tungsten carbide (WC) or polycrystalline diamond (PCD) material is used, such as PCD mold from Sumitomo in Japan. The tool hole tolerance ± 0.001 mm, the entry angle is 8-12°, and the length of the reducer zone is optimized to reduce drawing stress. The aperture accuracy of the ultra-fine drawing die is ±0.0005 mm, and the surface roughness is Ra<0.05 μm.

Lubrication system: automatic spraying device (such as German Schumag system) is used to spray graphite emulsion or molybdenum disulfide (MoS_2) lubricant, with a friction coefficient of 0.1-0.2. Oil-based lubricants (e.g. polyethylene glycol) are used for ultrafine wire drawing, and the flow rate is controlled at 0.1-0.5 L/min. The lubrication system needs to be equipped with a filtration device to prevent contamination by impurities.

Process characteristics: The mold needs to be polished and replaced regularly (after drawing every 100-200 km) to ensure the surface finish. The lubrication system ensures uniform coverage with closed-loop control and reduces surface scratches. Finite element analysis (FEA) is used to optimize the die design and improve drawing stability.

Application Impact: High-precision tooling and lubrication systems can reduce the surface defect rate of molybdenum wire to less than 0.5%, which is suitable for high-performance lamps such as automotive headlights.

6.3.3 Annealing furnace and temperature control system

The annealing furnace is used to eliminate work hardening during the drawing process and restore the ductility and toughness of the molybdenum wire.

Annealing furnace: such as the continuous annealing furnace of Koyo in Japan, the working temperature is 800-1300 °C, the hydrogen flow rate is 0.5-1 m^3/h, and the dew point is <-40 °C. Molybdenum or tungsten heating elements are used in the furnace, and the temperature control accuracy is ± 5°C. Intermediate annealing (800-1000°C, holding for 10-30 seconds) is used for rough and fine drawing, and final annealing (900-1200°C, holding for 5-15 seconds) is used to optimize performance.

Temperature control system: PID controller and thermocouple (such as K-type thermocouple, accuracy ± 1°C) are used to monitor the temperature in the furnace in real time. The cooling system (water-cooled or air-cooled) controls the cooling rate (10-50°C/s) to avoid overgrowth of the grains.

Process characteristics: The annealing furnace needs to be equipped with an online atmosphere monitoring system to ensure the purity of hydrogen. The continuous annealing furnace can realize the continuous passage of wire, increasing the efficiency by 20%. Doped molybdenum wire (such as molybdenum lanthanum wire) requires a higher annealing temperature (1000-1300°C) to ensure the stability of the doped elements.

Application impact: The precise annealing process can increase the elongation at break of molybdenum wire to 15%-20%, reduce the risk of wire breakage, and is suitable for the production of ultra-fine molybdenum wire.

6.4 Surface treatment equipment for molybdenum wire for lighting

Surface treatment equipment is used to improve the surface finish, corrosion resistance, and optical properties of molybdenum wire, including electrolytic polishing, chemical cleaning, and surface coating deposition.

6.4.1 Electrolytic polishing and chemical cleaning equipment

Electrolytic polishing and chemical cleaning equipment is used to remove oxides, grease and drawing residues from the surface of molybdenum wire to prepare cleaned molybdenum wire.

Electrolytic polishing equipment: such as the German KAMMERER electrolytic polishing machine, using NaOH electrolyte (concentration 5%-10%), current density of 0.5-2 A/cm^2, polishing time of 10-30 seconds. The equipment is equipped with stainless steel electrodes and a circulating filtration system to ensure the purity of the electrolyte. After polishing, the surface roughness of the molybdenum wire reaches Ra 0.1-0.5 μm, and the reflectivity is increased to 60%-70%.

Chemical cleaning equipment: For example, the pickling tank of Nantong Cleaning Equipment Factory in China uses HNO_3-HF mixture (ratio 3:1, concentration 5%-10%), cleaning temperature 40-60 °C, time 1-3 minutes. The equipment is equipped with PTFE lining and waste liquid treatment system (neutralization and precipitation), which meets environmental protection requirements.

Process characteristics: electrolytic polishing is suitable for high-end molybdenum wire (such as HID lamp), and chemical cleaning is suitable for large-scale production. Both need to be equipped with a deionized water rinsing and vacuum drying system (100-150°C) to prevent residual contamination. The waste disposal system ensures compliance with the RoHS directive.

Application impact: The surface treatment equipment can improve the arc corrosion resistance and conductivity of molybdenum wire, and extend the life of the lamp by 10%-20%.

6.4.2 Surface coating deposition equipment

Surface coating equipment is used to deposit anti-oxidation or corrosion-resistant coatings (e.g., alumina Al_2O_3, molybdenum silicide $MoSi_2$) to improve the performance of molybdenum wire in harsh environments.

CVD equipment: such as CVD furnace of Applied Materials in the United States, with a working temperature of 800-1200°C and a vacuum of $<10^{-2}$ Pa. It is used for depositing alumina (0.1-1 μm thickness) or molybdenum silicide coatings (0.5-2 μm) at a deposition rate of 0.1-0.5 μm/min. The equipment is equipped with a gas control system (precise control of the flow rate of CH_4, SiH_4, etc.).

PVD equipment: such as magnetron sputtering equipment from Leybold in Germany, with a working temperature of 500-800°C, suitable for high uniformity coating deposition. The sputtering target is high-purity molybdenum or aluminum, and the deposition rate is 0.05-0.2 μm/min. PVD equipment is suitable for molybdenum wires with complex shapes.
Process characteristics: CVD is suitable for thick coatings, PVD is suitable for thin coatings and high uniformity. The equipment needs to be equipped with an on-line thickness monitoring system (e.g., quartz crystal oscillator) to ensure consistent coating thickness. The coating adhesion is verified by tensile test (spalling stress > 50 MPa).

Application impact: The coating equipment can increase the oxidation temperature of molybdenum wire to more than 1500°C, which is suitable for infrared lamps and ultraviolet lamps, and extends the life by 20%-30%.

6.4.3 Surface quality testing equipment

Surface quality inspection equipment is used to evaluate the roughness, defects, and coating quality of molybdenum wire.

Surface roughness tester: such as Mitutoyo SJ-410 in Japan, the measuring range is Ra 0.01-10 μm, and the accuracy is ± 0.001 μm. It is used to inspect the surface quality of cleaned molybdenum wire (Ra 0.1-0.5 μm) and black molybdenum wire (Ra 0.5-2.0 μm).

Laser microscope: such as the German Zeiss LSM 800, magnification 100-1000x, for the detection of surface scratches, cracks and oxide residues. The device is equipped with a 3D imaging function to analyze the surface topography.

Process characteristics: The testing equipment needs to be integrated with the online monitoring system of the production line to feedback the surface quality data in real time. Automated inspection

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can increase inspection efficiency by up to 50%.

Application Impact: Surface quality inspection can reduce the failure rate to less than 0.5%, ensuring the arc stability and optical performance of molybdenum wire in luminaires.

6.5 Testing and quality control equipment for molybdenum wire for lighting

Inspection and quality control equipment is used to evaluate the microstructure, mechanical properties, chemical composition and environmental adaptability of molybdenum wire to ensure that the product meets lighting industry standards.

6.5.1 Microscopes (optical, electronic) and surface analyzers

Microscopes and surface analyzers are used to analyze the microstructure and surface properties of molybdenum wires.

Optical microscope: such as the Japanese Olympus BX53M, magnification 50-1000x, for the observation of grain size (10-50 μm) and surface defects (such as cracks, porosity). The equipment is equipped with image analysis software to automatically count the grain distribution.

Scanning electron microscopy (SEM): e.g., FEI Quanta 650 in the United States, equipped with energy spectroscopy (EDS), for the analysis of doped element distribution (e.g., lanthanum oxide particle spacing 0.5-2 μm) and surface corrosion topography. With a resolution of up to 1 nm, it is suitable for ultra-fine molybdenum wire inspection.

Surface analyzers: such as XPS (X-ray photoelectron spectroscopy) from Bruker, Germany, for the analysis of surface oxide composition (e.g. MoO_2, MoO_3) and coating chemistry. The detection depth is 1-10 nm, and the accuracy is ± 0.1 eV.

Process characteristics: The microscope needs to be equipped with sample preparation equipment (such as ion polishing machine) to ensure a smooth surface. SEM and XPS are run in ultra-high vacuum ($<10^{-6}$ Pa) with a detection time of 10-30 minutes.

Application impact: Microscopic analysis can optimize the grain structure and doping uniformity of molybdenum wire, improve high-temperature performance and corrosion resistance.

6.5.2 Tensile testing machines and hardness testers

Tensile testing machines and hardness testers are used to evaluate the mechanical properties of molybdenum wires.

Tensile testing machine: such as the American Instron 5982, the test range is 0-100 kN, and the accuracy is ±0.5%. It is used to measure the tensile strength (800-1000 MPa at room temperature, 200-400 MPa at 1500°C) and elongation at break (10%-25%) of molybdenum wire. The device can simulate high temperature environments (up to 2000°C).

Hardness tester: such as German Zwick Vickers hardness tester, the test range is HV 0.1-1000, and the accuracy is ± 0.5 HV. It is used to evaluate the surface hardness of molybdenum wire (approx. HV 200-250 for pure molybdenum wire and HV 250-300 for doped molybdenum wire).

Process characteristics: the tensile test needs to be equipped with high-temperature fixtures and atmosphere protection devices (hydrogen or argon), and the hardness test needs to control the indentation depth (<0.01 mm). Automated testing systems can increase efficiency by up to 20%.

Application Impact: The mechanical properties test ensures the mechanical stability and fatigue resistance of the molybdenum wire in the luminaire and meets the requirements of halogen and HID lamps.

6.5.3 Composition analyzers (ICP, XRF)

Composition analyzers are used to detect the chemical composition and impurity content of molybdenum wires.

ICP-OES: such as PerkinElmer Optima 8300 in the United States, with a detection limit of 0.01 ppm, for the analysis of impurities (e.g., Fe, Si, C) in molybdenum powder and molybdenum wire. The detection time is 5-10 minutes, and the accuracy ± 0.1%.

XRF: e.g., German Bruker S8 Tiger, detection range 0.01%-100%, used to analyze the content and distribution of doping elements (e.g., La, Re). The equipment is equipped with non-destructive testing function and is suitable for online monitoring.

Process characteristics: ICP needs to be dissolved in the sample (HNO_3-HF solution), XRF is non-destructive detection, suitable for finished product analysis. Both require regular calibration to ensure detection accuracy.

Application impact: Composition analysis can control the impurity content below 0.01% to ensure the chemical stability and electrical performance of molybdenum wire.

6.5.4 Environmental simulation test equipment

Environmental simulation test equipment is used to evaluate the performance of molybdenum wire in high-temperature, corrosive, and arc environments.

High temperature test furnace: such as the high temperature furnace of Nabertherm in Germany, the temperature range is 500-2000 °C, and the accuracy is ± 5 °C, which is used to simulate the working environment of lamps and lanterns (such as halogen lamps 1500 °C). Argon or halogen gas can be introduced into the furnace to test for oxidation resistance and corrosion resistance.

Arc test equipment: such as the arc simulator of Shanghai Electro-Optical Research Institute in China, with a voltage of 1-30 kV and a current of 0.1-100 A, which is used to test the arc stability of molybdenum wire. The device is equipped with a high-speed camera that records arc shifts (<0.1

mm).

Process characteristics: The environmental simulation equipment needs to be equipped with a data acquisition system to record temperature, current and corrosion rate. The test cycle is 1-100 hours, simulating the lamp life (1000-20,000 hours).

Application Impact: Environmental testing verifies the reliability and longevity of molybdenum wire in real-world applications, ensuring that HID and UV lamp requirements are met.

molybdenum wire for lighting from CTIA

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Molybdenum Wire for Lighting Introduction

1. Overview of Molybdenum Wire for Lighting

As one of the core materials in modern lighting technology, molybdenum wire is widely used in various light sources including incandescent lamps, halogen lamps, fluorescent lamps, and gas discharge lamps, due to its high melting point, high strength, excellent corrosion resistance, and superior electrical conductivity. It is an irreplaceable and critical component in the lighting industry.

2. Typical Applications of Molybdenum Wire for Lighting

Residential and Commercial Lighting: Used in incandescent and halogen lamps to provide warm light and long service life.

Automotive Lighting: Functions as electrodes in HID and xenon lamps, offering high brightness and vibration resistance.

Specialty Lighting: Utilized in projection lamps, ultraviolet (UV) lamps, and infrared (IR) lamps to meet high-temperature and high-precision requirements in medical, industrial, and scientific applications.

Emerging Fields: Serves as conductive leads for LED lamps and supports for phosphors in laser lighting, aligning with future lighting technology development.

3. Basic Data of Molybdenum Wire for Lighting (Reference)

Parameter	Pure Mo Wire	Mo-La Wire	Mo-Re Wire
Mo Content	≥99.95%	≥99.0%	52.5%–86.0%
Diameter Range	0.03–3.2 mm	0.03–1.5 mm	0.03–1.0 mm
Tolerance	±0.002 mm	±0.002 mm	±0.002 mm
Tensile Strength (Room Temp)	800–1200 MPa	900–1400 MPa	1000–1500 MPa
Tensile Strength (at 1500°C)	150–300 MPa	200–400 MPa	250–450 MPa
Elongation at Break	10%–25%	12%–20%	15%–25%
Electrical Resistivity (20°C)	5.5×10^{-8} Ω·m	6.0×10^{-8} Ω·m	6.5×10^{-8} Ω·m
Main Applications	Incandescent, Halogen	Halogen, Auto Headlights	HID, Projection Lamps

4. Procurement Information

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Chapter 7 Domestic and Foreign Standards for Molybdenum Wire for Lighting

As an important material in the lighting industry, Molybdenum wire for lighting has a direct impact on the reliability and life of lamps and lanterns. In order to ensure product consistency and market competitiveness, a series of standards have been formulated at home and abroad, covering the chemical composition, dimensional accuracy, mechanical properties and environmental protection requirements of molybdenum wire. This chapter will discuss in detail the domestic standards, international standards, comparison and conversion between standards, environmental regulations, and industry and enterprise specifications of Molybdenum wire for lighting, and provide a comprehensive technical analysis to meet the needs of the lighting industry for standardized production in combination with specific standard content and application scenarios.

7.1 Domestic standards for molybdenum wire for lighting

As the world's largest producer of molybdenum wire, China has formulated a number of national standards (GB/T) to regulate the production and application of molybdenum wire. These standards specify in detail the raw materials, processing, properties and testing methods of Molybdenum wire for lighting, and are suitable for applications such as incandescent lamps, halogen lamps, and gas discharge lamps.

7.1.1 GB/T 3462-2017

GB/T 3462-2017 is China's national standard for molybdenum bars and molybdenum slabs, which is suitable for the production of Molybdenum wire for lighting and provides a basis for the subsequent wire drawing process.

Scope of application: The standard stipulates the chemical composition, size, surface quality and mechanical properties of molybdenum bars and molybdenum slabs, which is suitable for sintering, forging and rolling blanks, and is indirectly used in the production of Molybdenum wire for lighting.

Technical Requirements:
Chemical composition: molybdenum content ≥ 99.95%, total impurities (such as Fe, Ni, Si) < 0.05%.
Doped molybdenum (e.g., molybdenum-lanthanum) requires a clear doping element content (e.g., La_2O_3 0.3%-1.0%).
Dimensional accuracy: molybdenum bar diameter 5-100 mm, tolerance ± 0.05 mm; The thickness of the slab is 2-50 mm, and the tolerance ± 0.1 mm.
Surface quality: no cracks, oxide scale, roughness Ra≤3.2 μm.
Mechanical properties: tensile strength (room temperature) ≥ 600 MPa, elongation at break ≥10%.

Detection method: The chemical composition is analyzed by ICP-OES (Inductively Coupled Plasma Spectroscopy), the dimensions are detected by micrometer or laser rangefinder, and the surface quality is checked by visual and microscopic inspection.

Application impact: Molybdenum wire blanks for lamps need high density (≥95% theoretical density) and uniform microstructure, GB/T 3462-2017 ensures the quality of the blank and reduces the risk of fracture in the wire drawing process.

7.1.2 GB/T 4191-2015

GB/T 4191-2015 directly addresses the performance and specifications of molybdenum wire, and is suitable for the production and acceptance of Molybdenum wire for lighting.

Scope of application: The standard covers pure molybdenum wire and doped molybdenum wire (such as molybdenum lanthanum wire, molybdenum rhenium wire) for incandescent lamps, halogen lamps, gas discharge lamps, etc.

Technical Requirements:

Chemical composition: The molybdenum content of pure molybdenum wire ≥ 99.95%, and the doped molybdenum wire needs to be marked with the proportion of doped elements (such as Re 1%-5%).

Size range: diameter 0.01-2 mm, tolerances ± 0.002 mm (ultra-fine) to ±0.01 mm (coarse).

Surface quality: Ra≤0.5 μm roughness of cleaned molybdenum wire, Ra≤2.0 μm of black molybdenum wire, no cracks, scratches or oxide residues.

Mechanical properties: tensile strength at room temperature 800-1200 MPa, high temperature (1500°C) tensile strength ≥ 200 MPa, elongation at break 10%-20%.

Testing method: The dimensional accuracy is measured by a laser caliper, the mechanical properties are measured by a tensile testing machine, and the surface quality is detected by an optical microscope and a roughness meter.

Application impact: The standard ensures the mechanical stability and electrical properties of molybdenum wire in high-temperature environments, and is suitable for the high requirements of halogen and HID lamps.

7.1.3 GB/T 4182-2000

GB/T 4182-2000 stipulates the chemical composition analysis method of molybdenum and molybdenum alloys to ensure the purity of the raw materials and finished products of Molybdenum wire for lighting.

Scope of application: The standard is applicable to the chemical composition testing of molybdenum powder, molybdenum bar and molybdenum wire, including the main elements (Mo) and impurities (Fe, Ni, Si, C, O, etc.).

Analytical Methods:

ICP-OES: Detection of impurity elements, sensitivity of 0.01 ppm, suitable for the analysis of Fe, Ni, Si and other trace elements.

Gas analyzer: detect O, N, H content, accuracy ± 0.001%, to ensure that the oxygen content < 0.005%.

Gravimetric method and titration method: determination of molybdenum content with an error of ±

0.01%.

Process characteristics: The analysis was performed in a clean environment (ISO class 7) and the sample preparation was acid-soluble (HNO_3-HF mixture). The standard requires the instrument to be calibrated regularly to ensure consistent testing.

Application impact: High-precision chemical analysis ensures the chemical stability of molybdenum wire and prevents grain boundary corrosion caused by impurities at high temperatures. The standard is widely used by China's non-ferrous metal testing institutions.

7.1.4 Other relevant national standards

In addition to the above standards, China has also formulated other standards related to Molybdenum wire for lighting:

GB/T 3461-2017 "Molybdenum Powder": specifies the particle size (1-5 μm), purity (≥99.95%) and morphology (spherical or nearly spherical) of molybdenum powder, which is suitable for molybdenum wire raw materials for lamps.
GB/T 17792-1999 "Inspection methods for molybdenum and molybdenum alloy processed products": testing methods covering size, surface quality and mechanical properties, such as ultrasonic flaw detection and X-ray inspection.
YS/T 357-2006 "Doped Molybdenum Strip": For doped molybdenum (such as molybdenum, lanthanum, molybdenum-rhenium) blanks, the content and distribution uniformity of doped elements are specified.

Application impact: These standards supplement the requirements of GB/T 3462 and GB/T 4191 to form a complete standardization system to ensure the quality control of molybdenum wire from raw materials to finished products. Chinese companies can enhance the competitiveness of their products by following a combination of multiple standards.

7.2 International standards for molybdenum wire for lighting

International standards provide a unified specification for the global trade and application of Molybdenum wire for lighting, covering the United States (ASTM), the International Organization for Standardization (ISO) and Japan (JIS) and other standard systems.

7.2.1 ASTM B387 Standard Specification for Molybdenum and Molybdenum Alloy Rods, Bars, and Wires

ASTM B387 is a standard for molybdenum and molybdenum alloys developed by the American Society for Testing and Materials, which is widely used in the international market.

Scope of application: The standard covers rods, strips and wires of molybdenum and molybdenum alloys (pure molybdenum, molybdenum lanthanum, molybdenum-rhenium) for lighting, electronics and high-temperature applications.

Technical Requirements:

Chemical composition: Molybdenum content ≥ 99.95%, impurities (such as Fe<0.01%, Si <0.005%) are strictly controlled. For doping molybdenum, the doping ratio (e.g., La_2O_3 0.3%-1.0%) should be specified.

Dimensional accuracy: wire diameter 0.01-3 mm, tolerance ± 0.002 mm (ultra-fine wire) to ± 0.015 mm (thick wire).

Mechanical properties: tensile strength at room temperature 700-1100 MPa, high temperature (1500°C) tensile strength ≥ 150 MPa, elongation at break 10%-25%.

Surface quality: Ra ≤0.4 μm for cleaned molybdenum wire, Ra ≤ 2.5 μm for black molybdenum wire, no cracks or oxides.

Detection method: The chemical composition adopts ICP-MS, the size is tested by the laser caliper, the mechanical properties are tested by the tensile testing machine, and the surface quality is tested by SEM.

Application Implications: ASTM B387 is widely adopted by European and American luminaire manufacturers to ensure the reliability of molybdenum wire in halogen and HID lamps. The high requirements of standards have promoted the technological upgrading of Chinese enterprises.

7.2.2 ISO 22447 Molybdenum and molybdenum alloy articles

ISO 22447 is a standard for molybdenum products developed by the International Organization for Standardization and is applicable to the global market.

Scope of application: The standard covers molybdenum wire, rod, plate and other products, and is suitable for lighting, aerospace and electronics industries.

Technical Requirements:

Chemical composition: molybdenum content ≥ 99.95%, total impurity content < 0.05%. Doped molybdenum (e.g., molybdenum-rhenium) requires clear elemental proportions and uniformity.

Size range: wire diameter 0.02-2 mm, tolerance ± 0.003 mm.

Mechanical properties: tensile strength at room temperature 750-1200 MPa, high temperature (1500°C) tensile strength ≥ 200 MPa.

Surface quality: no cracks and porosity on the surface, roughness Ra≤0.5 μm (cleaned molybdenum wire).

Detection method: The chemical composition is XRF or ICP-OES, the size is passed by laser caliper, and the surface quality is passed by optical microscope.

Application implications: ISO 22447 is internationally applicable and suitable for export-oriented companies, ensuring that products meet the requirements of the global luminaire market.

7.2.3 JIS H 4461

JIS H 4461 is a Japanese industrial standard for the performance and production requirements of molybdenum wire and molybdenum rod.

Scope of application: The standard applies to pure molybdenum wire and doped molybdenum wire for lighting and electronic devices.

Technical Requirements:
Chemical composition: molybdenum content ≥ 99.95%, impurities (such as Fe, Ni) < 0.01%.
Dimensional accuracy: wire diameter 0.01-2 mm, tolerance ± 0.002 mm (ultra-fine).
Mechanical properties: tensile strength at room temperature 800-1100 MPa, elongation at break 10%-20%.
Surface quality: Ra ≤ 0.4 μm for cleaned molybdenum wire and 2.0 μm for black molybdenum ≤.

Detection method: The chemical composition adopts ICP-OES, the size passes through the laser caliper, and the mechanical properties pass through the tensile testing machine.

Application impact: JIS H 4461 is widely used by Japanese lighting companies, especially for molybdenum wire for projection lamps and automotive headlights. The Japanese market has strict requirements for dimensional accuracy and surface quality, which has driven the development of high-precision wire drawing technology.

7.2.4 Other ISO standards

Other international standards also have guidance for the production and application of Molybdenum wire for lighting:

DIN EN 10204 (Germany): Specifies the requirements for quality certification and inspection documentation of molybdenum wire, which applies to products exported to the European market.
IEC 60357: International Electrotechnical Commission standard for performance requirements for molybdenum wire for halogen and gas discharge lamps, such as arc corrosion resistance and sealing reliability.
ASTM E3171: Chemical Analysis Methods for Molybdenum and Molybdenum Alloys, Supplementing the Requirements of ASTM B387.

Application impact: These standards provide a technical basis for the international trade of molybdenum wire and promote the standardization of the global supply chain. European and Japanese companies ensure the competitiveness of their products in high-end markets such as automotive lighting by following a combination of multiple standards.

7.3 Comparison and conversion between different standards of molybdenum wire for lighting

The difference between domestic and foreign standards may affect the international trade and application of Molybdenum wire for lighting, and mutual recognition should be achieved through the comparison and conversion of technical parameters.

7.3.1 Comparison of technical parameters of domestic and foreign standards (purity, size, performance)

The following is a comparison of the parameters of the main criteria:

Purity:

GB/T 4191-2015: Molybdenum content ≥99.95%, impurities <0.05%.

ASTM B387: Molybdenum content ≥99.95%, Fe <0.01%, Si <0.005%.

ISO 22447: Molybdenum content ≥99.95%, impurities <0.05%.

JIS H 4461: Molybdenum content ≥99.95%, Fe, Ni <0.01%.

Analysis: The purity requirements of domestic and foreign standards are consistent, and ASTM B387 is more stringent for specific impurities (such as Fe, Si), which is suitable for high-end lamps (such as HID lamps).

Dimensional accuracy:

GB/T 4191-2015: diameter 0.01-2 mm, tolerance ± 0.002 mm (ultra-fine).

ASTM B387: Diameter 0.01-3 mm, tolerances ± 0.002 mm (ultra-fine) to ±0.015 mm (coarse).

ISO 22447: Diameter 0.02-2 mm, tolerance ± 0.003 mm.

JIS H 4461: diameter 0.01-2 mm, tolerance ± 0.002 mm.

Analysis: JIS H 4461 and GB/T 4191 have higher tolerance requirements for ultra-fine filaments and are suitable for projection lamps and UV lamps. ASTM B387 covers a wider range of diameters to accommodate a wide range of applications.

Mechanical Properties:

GB/T 4191-2015: Tensile strength at room temperature 800-1200 MPa, high temperature (1500°C) ≥ 200 MPa.

ASTM B387: 700-1100 MPa at room temperature, ≥150 MPa at high temperature.

ISO 22447: 750-1200 MPa at room temperature, ≥200 MPa at high temperature.

JIS H 4461: 800-1100 MPa at room temperature.

Analysis: GB/T 4191 and ISO 22447 require higher high-temperature performance and are suitable for halogen and HID lamps. ASTM B387 has a wider performance range and is suitable for a variety of application scenarios.

7.3.2 Standard conversion methods (e.g. tolerances, units of mechanical properties)

Tolerance conversion: domestic and foreign standards are in millimeters (mm), and the tolerances are directly compared. The coarse wire tolerance of ASTM B387 (±0.015 mm) can meet the ±0.01 mm requirements of GB/T 4191 with high-precision wire drawing equipment.

Conversion of mechanical properties units: tensile strength is expressed in MPa, and elongation at break is expressed in percentage (%), which is consistent with domestic and foreign standards. The high temperature test temperature (1500°C) needs to be calibrated uniformly to ensure that the test conditions are consistent.

Chemical Composition Conversion: Impurity content is expressed as a percentage by mass (%) or ppm, 1% = 10,000 ppm. GB/T 4182 and ASTM E3171 are compatible with each other, and ICP-OES results can be directly compared.

Process characteristics: The accuracy of the testing equipment (e.g., laser caliper accuracy ±0.001 mm) and calibration standards need to be considered in the conversion. Small differences between standards can be compensated for by process optimization, such as annealing temperature adjustments.

7.3.3 Analysis of mutual recognition between international standards and domestic standards

Mutual recognition: GB/T 4191-2015 is highly compatible with ASTM B387 and ISO 22447 in terms of purity, size and mechanical properties, and the mutual recognition is more than 90%. JIS H 4461 requires additional polishing processes due to the stricter requirements for surface quality.

Differences: ASTM B387 has stricter requirements for specific impurities (e.g., Fe) and requires high-purity raw materials. GB/T 4191 has higher requirements for ultra-fine wire tolerances and requires precision wire drawing equipment. The versatility of ISO 22447 makes it more acceptable to the global market.

Application impact: Chinese companies can expand export markets (e.g., Europe, the United States) by meeting both GB/T and ASTM/ISO standards. Mutual recognition analysis helps to optimize production processes and reduce certification costs. Plansee in Austria and H.C. Starck in the United States have passed multi-standard certification to ensure that the products are universally applicable.

7.4 Environmental protection and RoHS regulations of molybdenum wire for lighting

Environmental regulations have put forward strict requirements for the production and application of Molybdenum wire for lighting, involving heavy metal control, exhaust emissions and green manufacturing.

7.4.1 RoHS Directive (EU 2011/65/EU) requirements for molybdenum wire materials

The RoHS Directive (Restriction of Hazardous Substances) restricts hazardous substances in electrical and electronic products, and applies to Molybdenum wire for lighting and lamps and lanterns.

Requirements: Molybdenum wire needs to limit 6 harmful substances such as lead (Pb), mercury (Hg), cadmium (Cd), etc., with a content of < 0.1% (1000 ppm) and cadmium < 0.01% (100 ppm). Molybdenum wire impurities (such as Fe, Ni) need to be tested by ICP-OES to ensure compliance with RoHS requirements.

Process impact: high-purity molybdenum powder (≥99.95%) needs to be used in production to avoid raw material pollution. Chemical cleaning (HNO_3-HF) and electropolishing (NaOH) require a waste disposal system to prevent heavy metal emissions.

Application impact: RoHS-compliant molybdenum wire can enter the EU market and is widely used in halogen lamps and HID lamps. European luminaire manufacturers, such as Philips, require suppliers to provide a RoHS compliance certificate.

7.4.2 China RoHS (Measures for the Control of Pollution from Electronic Information Products)

China RoHS (GB/T 26572-2011) is China's standard for restricting hazardous substances in electronic products, similar to EU RoHS.

Requirements: Limit 6 kinds of hazardous substances, and the content requirements are consistent with EU RoHS. Molybdenum wire needs to provide a hazardous substance test report, indicating the environmental protection use period (usually 10-50 years).
Process impact: Manufacturers need to establish a hazardous substance management system and use XRF or ICP-MS to detect raw materials and finished products. Waste gas and waste liquid need to be treated by absorption tower and neutralization and precipitation, in accordance with GB 25466-2010 (emission standard).
Application impact: China's RoHS has promoted the green transformation of the domestic lighting market, and molybdenum wire suppliers need to provide compliance certificates to meet the needs of domestic and commercial lighting.

7.4.3 Environmental compliance in the production of molybdenum wire (heavy metals, exhaust emissions)

Heavy metal control: The cleaning solution (HNO_3-HF) and electrolyte (NaOH) in the production of molybdenum wire may contain trace amounts of heavy metals (such as Cr and Ni), which need to be precipitated and filtered, and the discharge concentration is < 0.1 mg/L, in line with GB 8978-1996 (sewage discharge standard).
Exhaust gas emission: The hydrogen reduction and sintering process produces a small amount of oxide gas (such as MoO_3), which needs to be treated by the tail gas absorption tower (lye absorption), and the emission concentration is < 0.05 mg/m³, which meets GB 16297-1996 (air pollutant emission standard).
Process characteristics: enterprises need to be equipped with environmental protection equipment (such as waste liquid neutralization system, tail gas treatment tower), which increases production costs by about 5%-10%. Automated monitoring systems detect emission parameters in real-time to ensure compliance.
Application impact: Environmental compliance is a necessary condition for entering the European and American markets, and Chinese companies (such as Jinduicheng Molybdenum) have enhanced their international competitiveness through environmental certification.

7.4.4 Green manufacturing and sustainable development requirements

Green manufacturing: Adopt low-energy equipment (such as energy-saving sintering furnaces, which reduces energy consumption by 15%) and waste recycling technology (recycling rate of up to 30%) to reduce resource consumption. Spray drying and continuous wire drawing equipment can increase production efficiency by 10%-20%.
Sustainability: Promote the transformation of molybdenum wire production to a circular economy, such as recycling drawing broken wire and sintering waste, and reduce raw material costs. Green manufacturing certifications, such as ISO 14001, become a competitive advantage.
Application impact: Green manufacturing meets the sustainability requirements of global customers and drives the growth of Chinese companies' share in high-end markets such as automotive lighting.

7.5 Industry standards and enterprise specifications for molybdenum wire for lighting

In addition to national standards and international standards, industry associations and internal enterprise specifications further refine the requirements for Molybdenum wire for lighting.

CTIA GROUP LTD
Molybdenum Wire for Lighting Introduction

1. Overview of Molybdenum Wire for Lighting

As one of the core materials in modern lighting technology, molybdenum wire is widely used in various light sources including incandescent lamps, halogen lamps, fluorescent lamps, and gas discharge lamps, due to its high melting point, high strength, excellent corrosion resistance, and superior electrical conductivity. It is an irreplaceable and critical component in the lighting industry.

2. Typical Applications of Molybdenum Wire for Lighting

Residential and Commercial Lighting: Used in incandescent and halogen lamps to provide warm light and long service life.

Automotive Lighting: Functions as electrodes in HID and xenon lamps, offering high brightness and vibration resistance.

Specialty Lighting: Utilized in projection lamps, ultraviolet (UV) lamps, and infrared (IR) lamps to meet high-temperature and high-precision requirements in medical, industrial, and scientific applications.

Emerging Fields: Serves as conductive leads for LED lamps and supports for phosphors in laser lighting, aligning with future lighting technology development.

3. Basic Data of Molybdenum Wire for Lighting (Reference)

Parameter	Pure Mo Wire	Mo-La Wire	Mo-Re Wire
Mo Content	≥99.95%	≥99.0%	52.5%–86.0%
Diameter Range	0.03–3.2 mm	0.03–1.5 mm	0.03–1.0 mm
Tolerance	±0.002 mm	±0.002 mm	±0.002 mm
Tensile Strength (Room Temp)	800–1200 MPa	900–1400 MPa	1000–1500 MPa
Tensile Strength (at 1500°C)	150–300 MPa	200–400 MPa	250–450 MPa
Elongation at Break	10%–25%	12%–20%	15%–25%
Electrical Resistivity (20°C)	5.5×10^{-8} Ω·m	6.0×10^{-8} Ω·m	6.5×10^{-8} Ω·m
Main Applications	Incandescent, Halogen	Halogen, Auto Headlights	HID, Projection Lamps

4. Procurement Information

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7.5.1 China Nonferrous Metals Industry Association Standards

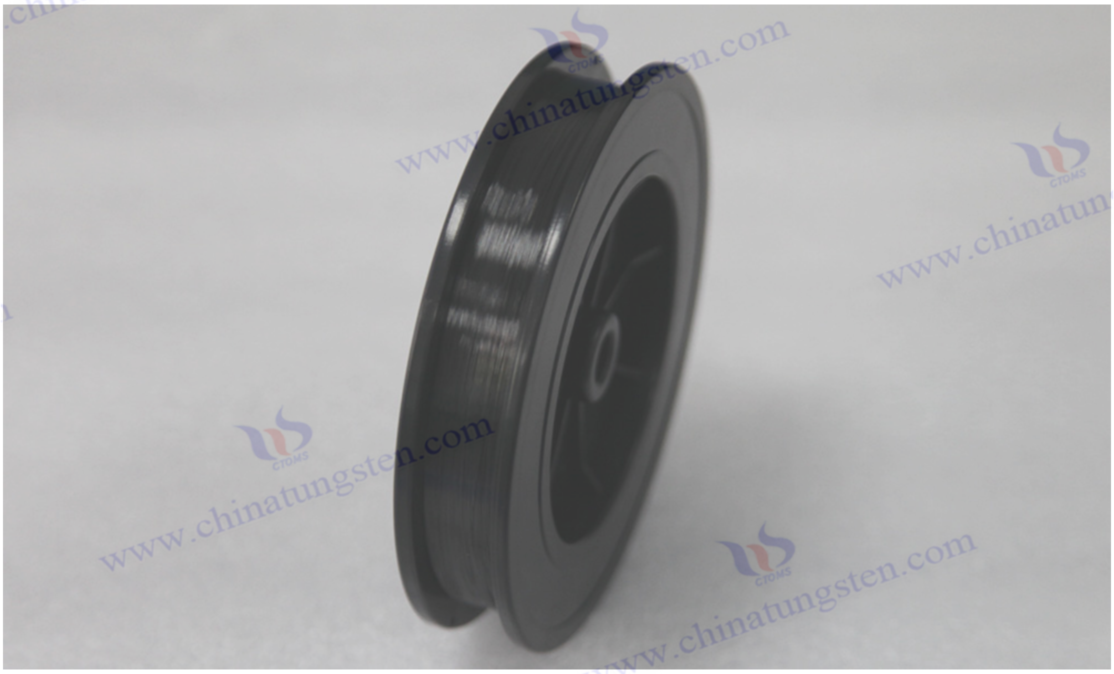
The China Nonferrous Metals Industry Association (YS/T standard) has formulated a number of molybdenum and molybdenum alloy standards, supplementing the national standards.

YS/T 357-2006 "Doped Molybdenum Strip": stipulates the chemical composition, size and properties of doped molybdenum (such as molybdenum, lanthanum, molybdenum-rhenium), and the uniformity deviation of doped elements <0.01%.
YS/T 659-2007 "Molybdenum Wire Test Method": specifies the XRF analysis and high temperature mechanical test method of doped molybdenum wire, which is suitable for lamp molybdenum wire.
Application impact: The YS/T standard pays more attention to the performance of doped molybdenum wires, and is suitable for halogen lamps and HID lamps. Chinese companies (e.g., Xiamen Honglu) optimize the doping process through the YS/T standard to increase the added value of their products.

7.5.2 Internal Specifications for the Lighting Industry

Internal specifications for the lighting industry are developed by luminaire manufacturers and industry associations for specific applications of molybdenum wire.

China Lighting Society specification: The corrosion resistance (corrosion rate < 0.005 mg/cm²·h) and arc stability (offset < 0.1 mm) of molybdenum wire in halogen lamps are required.
The International Institute of Illumination (CIE) specification specifies high-temperature tensile strength (1500°C≥200 MPa) and surface roughness (Ra≤0.4 μm) for molybdenum wire for HID lamps.
Application Implications: Industry norms have driven the custom production of molybdenum wire in specific luminaires, such as molybdenum lanthanum wire for automotive headlamps, which need to meet more stringent vibration resistance requirements.



molybdenum wire for lighting from CTIA

Chapter 8 Detection Technology of Molybdenum Wire for Lighting

The performance of Molybdenum wire for lighting directly affects the reliability, life and efficiency of lighting devices, and its detection technology covers many aspects such as chemical composition, physical properties, surface quality, high temperature performance, electrical properties and non-destructive testing. This chapter will discuss in detail the various detection technologies of Molybdenum wire for lighting, analyze the detection methods, equipment functions, accuracy and application scenarios, and provide a comprehensive technical explanation based on advanced technology practices at home and abroad.

8.1 Chemical composition testing of molybdenum wire for lighting

Chemical composition testing is used to determine the purity (≥99.95%) and impurities (such as Fe, Ni, Si) content of molybdenum wire, to ensure its chemical stability and electrical properties, and to meet the requirements of the high-temperature environment of lamps.

8.1.1 X-ray fluorescence analysis (XRF)

X-ray fluorescence analysis is a rapid, non-destructive method for component detection of finished molybdenum wire and raw materials.

Principle: X-rays excite the atoms on the surface of the sample to produce characteristic fluorescence, and the element content is determined by spectral analysis.
Device function: The detection range of the device is 0.01%-100%, the sensitivity is 0.01 ppm, and the analysis time is 1-5 minutes.
Technical Parameters:
Detected elements: molybdenum (Mo), iron (Fe), nickel (Ni), silicon (Si), etc. The content deviation of doped elements (such as La, Re) is <0.01%.
Sample requirements: The surface of the molybdenum wire should be clean, no oxides, and the sample diameter should be 0.01-2 mm.
Accuracy: ±0.01% (high concentration elements), ± 0.001% (trace elements).

Process characteristics: XRF is non-destructive testing and suitable for on-line quality control. The equipment needs to be calibrated regularly and standard samples are used to ensure accuracy. The testing environment should be clean (ISO class 7) to avoid dust interference.

Application impact: XRF is widely used to detect the doping uniformity of molybdenum wire for halogen lamps and HID lamps, ensuring corrosion resistance and high temperature stability, with a detection efficiency of 98%.

8.1.2 Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)

ICP-OES is a highly sensitive method for component analysis that is suitable for the detection of trace impurities.

Principle: After the sample is dissolved, it is excited by plasma, and a specific wavelength spectrum

is emitted to analyze the element content.
Equipment function: The detection limit of the device is 0.001 ppm, and the analysis time is 5-10 minutes.
Technical Parameters:
Detection elements: Fe, Ni, Si, C, O, etc., detection range 0.001-1000 ppm.
Sample preparation: Molybdenum wire should be dissolved with HNO_3-HF mixture (ratio 3:1) at a temperature of 60-80°C.
Accuracy: ±0.1% (main element), ± 0.001% (trace element).

Process characteristics: ICP-OES needs to be destroyed by the sample, which is suitable for laboratory analysis. The equipment is equipped with high-purity argon gas (≥99.999%) to avoid background interference. The waste liquid needs to be neutralized and treated to meet the sewage discharge standards.

Application impact: ICP-OES is used to detect the oxygen content (<0.005%) in molybdenum wire, ensure the chemical stability of incandescent lamps and halogen lamps, and control the impurity content below 0.01%.

8.1.3 Atomic Absorption Spectroscopy (AAS)

AAS is used to detect trace amounts of specific elements and is suitable for heavy metal impurities in molybdenum wire.

Principle: After atomization, the sample absorbs a specific wavelength of light, and the absorption intensity is analyzed to determine the element content.
Device features: The device has a detection limit of 0.01 ppm and an analysis time of 3-5 minutes/element.
Technical Parameters:
Detection elements: Fe, Ni, Cr, Pb, etc., detection range 0.01-100 ppm.
Sample preparation: Molybdenum wire dissolved in HNO_3-HCl mixture (ratio 1:3) at 50-70 °C.
Accuracy: ±0.05% (trace elements).

Process characteristics: AAS is a single element analysis, suitable for targeted detection (e.g., Pb<0.01% to comply with RoHS). The equipment needs to be equipped with a hollow cathode lamp and replaced regularly. Waste liquid disposal must meet environmental protection requirements.

Application Implications: AAS is used to verify the RoHS compliance of molybdenum wire and meet the requirements of the EU market for molybdenum wire for automotive headlights.

8.2 Testing of physical properties of molybdenum wire for lighting

Physical property testing evaluates the size, density, and mechanical properties of molybdenum wire to ensure that it meets the mechanical and structural requirements of the luminaire.

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Molybdenum Wire for Lighting Introduction

1. Overview of Molybdenum Wire for Lighting

As one of the core materials in modern lighting technology, molybdenum wire is widely used in various light sources including incandescent lamps, halogen lamps, fluorescent lamps, and gas discharge lamps, due to its high melting point, high strength, excellent corrosion resistance, and superior electrical conductivity. It is an irreplaceable and critical component in the lighting industry.

2. Typical Applications of Molybdenum Wire for Lighting

Residential and Commercial Lighting: Used in incandescent and halogen lamps to provide warm light and long service life.

Automotive Lighting: Functions as electrodes in HID and xenon lamps, offering high brightness and vibration resistance.

Specialty Lighting: Utilized in projection lamps, ultraviolet (UV) lamps, and infrared (IR) lamps to meet high-temperature and high-precision requirements in medical, industrial, and scientific applications.

Emerging Fields: Serves as conductive leads for LED lamps and supports for phosphors in laser lighting, aligning with future lighting technology development.

3. Basic Data of Molybdenum Wire for Lighting (Reference)

Parameter	Pure Mo Wire	Mo-La Wire	Mo-Re Wire
Mo Content	≥99.95%	≥99.0%	52.5%–86.0%
Diameter Range	0.03–3.2 mm	0.03–1.5 mm	0.03–1.0 mm
Tolerance	±0.002 mm	±0.002 mm	±0.002 mm
Tensile Strength (Room Temp)	800–1200 MPa	900–1400 MPa	1000–1500 MPa
Tensile Strength (at 1500°C)	150–300 MPa	200–400 MPa	250–450 MPa
Elongation at Break	10%–25%	12%–20%	15%–25%
Electrical Resistivity (20°C)	5.5×10^{-8} Ω·m	6.0×10^{-8} Ω·m	6.5×10^{-8} Ω·m
Main Applications	Incandescent, Halogen	Halogen, Auto Headlights	HID, Projection Lamps

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8.2.1 Dimensional and tolerance measurement (laser micrometry, microscopy)

Size and tolerance directly affect the electrical properties and sealing reliability of molybdenum wire.

Laser Micrometer:
Device function: measuring range 0.005-2 mm, accuracy ± 0.0001 mm.
Principle: The laser beam scans the molybdenum wire and calculates the diameter and roundness.
Technical parameters: tolerance control ± 0.002 mm (ultra-fine wire), measuring speed 1-10 m/min, suitable for in-line inspection.
Process characteristics: The equipment needs a constant temperature environment (20-25 °C) to avoid thermal expansion error. The in-line micrometer can be integrated with the wire drawing machine to monitor diameter consistency in real time.

Optical Microscopy:
Device function: magnification 50-1000 times, accuracy ± 0.001 mm.
Principle: Molybdenum wire diameter and surface topography are measured by high-resolution imaging.
Technical parameters: suitable for off-line inspection, measuring range 0.01-2 mm, tolerance verification ± 0.002 mm.
Process characteristics: sample cutting and polishing, detection time 5-10 minutes. The image analysis software automatically calculates the size distribution.

Application impact: Laser micrometer is used for production control of ultra-fine molybdenum wire (0.01-0.05 mm diameter), and microscope is used for R&D and failure analysis, meeting GB/T 4191-2015 and ASTM B387 standards.

8.2.2 Density testing and quality analysis

The density test evaluates the density of the molybdenum wire, which indirectly reflects the porosity and inclusion content.

Equipment function: Based on Archimedes' principle, the accuracy ± 0.001 g/cm³.
Technical Parameters:
The theoretical density of molybdenum is 10.22 g/cm³, and the measured density is ≥ 9.8 g/cm³ (density ≥ 96%).
Sample requirements: molybdenum wire length 10-50 mm, clean surface.

Process characteristics: The test requires high-purity ethanol (density 0.789 g/cm³) as the immersion solution, and the temperature is controlled at 20°C. The equipment needs to be calibrated regularly and standard samples are used.
Application impact: High density molybdenum wire reduces stomatal volatilization at high temperatures, prolongs the life of halogen lamps and HID lamps.

8.2.3 Tensile strength, ductility and hardness testing

The mechanical properties test evaluates the mechanical stability of molybdenum wire at room temperature and high temperature.

Tensile test:
Device function: test range 0-100 kN, accuracy ± 0.5%.
Technical parameters: tensile strength at room temperature 800-1200 MPa, elongation at break 10%-25%; High temperature (1500°C) tensile strength 200-400 MPa.
Process characteristics: The high-temperature test needs to be equipped with a hydrogen protection furnace (dew point <-40°C), and the fixture material is molybdenum or tungsten. Test speed 0.1-1 mm/min.

Hardness Testing:
Device function: test range HV 0.1-1000, accuracy ± 0.5 HV.
Technical parameters: pure molybdenum wire HV 200-250, doped molybdenum wire HV 250-300, indentation depth < 0.01 mm.
Process characteristics: the surface of the sample needs to be polished, the test force is 0.1-0.5 N, and the holding time is 10 seconds.

Application Impact: Tensile and hardness testing ensures the mechanical reliability of molybdenum filament in filament supports and electrodes, meeting the requirements of automotive headlamps and projection lamps.

8.3 Surface quality inspection of molybdenum wire for lighting

The surface quality affects the arc stability, corrosion resistance, and optical properties of molybdenum wire, which need to be evaluated by microscopy and defect detection techniques.

8.3.1 Optical microscope and surface roughness testing

Optical microscopes and roughness meters are used to evaluate the surface topography and finish of molybdenum wires.

Optical Microscopy:
Device function: magnification 50-1000x, accuracy ± 0.001 μm.
Technical parameters: Detection of scratches, cracks and oxides with an image resolution of 0.1 μm.
Process characteristics: sample polishing is required, equipped with image analysis software, and the number of defects is automatically counted. The detection time is 5-10 minutes.

Surface Roughness Tester:
Device function: measuring range Ra 0.01-10 μm, accuracy ± 0.001 μm.
Technical parameters: cleaned molybdenum wire Ra 0.1-0.5 μm, black molybdenum wire Ra 0.5-2.0 μm.
Process characteristics: contact probe measurement, probe radius 2 μm, moving speed 0.5 mm/s. In-line inspection can be integrated with polishing equipment.

Application impact: High finish molybdenum wire (Ra<0.4 μm) improves arc stability, suitable for HID lamps and UV lamps, and controls the surface defect rate < 0.5%.

8.3.2 Scanning electron microscopy (SEM) and energy spectroscopy (EDS)

SEM and EDS are used for high-resolution surface topography and composition analysis.

WITHOUT:
Device features: resolution 1 nm, magnification 100-100,000x.
Technical parameters: detection of surface cracks, porosity and corrosion topography, suitable for ultra-fine molybdenum wire (diameter 0.01-0.05 mm).
Process characteristics: Vacuum environment ($<10^{-6}$ Pa) is required, and conductive coating (e.g., carbon film) is required on the sample surface. 3D imaging capabilities to analyze surface topography.

EDS：
Technical parameters: detection of doped elements (e.g., La, Re) distribution, accuracy ± 0.1%, detection depth 1-2 μm.
Process characteristics: integrated with SEM to analyze doping uniformity (particle spacing 0.5-2 μm). Detection time 10-20 minutes.

Application implications: SEM-EDS is used for failure analysis (e.g., halogen lamp electrode corrosion), to optimize the doping process, and to improve the performance of molybdenum lanthanum wire.

8.3.3 Surface defect detection technology

Surface defect detection technology is used to identify microscopic cracks and inclusions.

Laser Scanning Microscope:
Device features: resolution 0.1 μm, 3D imaging depth 10-100 μm.
Technical parameters: Detection of scratches, cracks and oxides, defect size > 0.5 μm.
Process characteristics: non-contact detection, suitable for online quality control. The detection speed is 1-5 m/min.

Automated Vision Systems:
Device features: Equipped with high-resolution CCD camera with a resolution of 0.01 μm.
Technical parameters: The detection surface defect rate is <0.5%, which is suitable for large-scale production.
Process features: integrated with wire drawing, real-time feedback of defect location, efficiency increased by 50%.

Application impact: Defect detection technology reduces the failure rate, meets the strict requirements of projection lamps and automotive headlights, and the yield rate reaches 98%.

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Molybdenum Wire for Lighting Introduction

1. Overview of Molybdenum Wire for Lighting

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2. Typical Applications of Molybdenum Wire for Lighting

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Parameter	Pure Mo Wire	Mo-La Wire	Mo-Re Wire
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Diameter Range	0.03–3.2 mm	0.03–1.5 mm	0.03–1.0 mm
Tolerance	±0.002 mm	±0.002 mm	±0.002 mm
Tensile Strength (Room Temp)	800–1200 MPa	900–1400 MPa	1000–1500 MPa
Tensile Strength (at 1500°C)	150–300 MPa	200–400 MPa	250–450 MPa
Elongation at Break	10%–25%	12%–20%	15%–25%
Electrical Resistivity (20°C)	5.5×10^{-8} Ω·m	6.0×10^{-8} Ω·m	6.5×10^{-8} Ω·m
Main Applications	Incandescent, Halogen	Halogen, Auto Headlights	HID, Projection Lamps

4. Procurement Information

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8.4 High temperature performance test of molybdenum wire for lighting

The high-temperature performance test evaluates the stability of the molybdenum wire under the working environment (1500-3000°C) of the luminaire, covering oxidation resistance, thermal cycling and mechanical properties.

8.4.1 High temperature oxidation resistance and thermal stability test

The antioxidant test evaluates the chemical stability of molybdenum wire at high temperatures.

Equipment function: temperature range 500-2000°C, accuracy ±5°C.
Technical Parameters:
Test conditions: argon or hydrogen protection (dew point <-40°C), temperature 1500-1800°C, heat preservation 1-100 hours.
Index: Oxidative weight gain <0.01 mg/cm², no MoO_3 volatilization on the surface.
Process characteristics: It needs to be equipped with an exhaust gas treatment system (alkali absorption) to treat volatile oxides. The surface of the sample should be polished (Ra<0.5 μm) to reduce the oxidation initiation point.

Application impact: Antioxidant performance ensures the chemical stability of molybdenum wire in incandescent lamps and halogen lamps, and prolongs the life by 10%-20%.

8.4.2 Thermal cycling and creep resistance testing

Thermal cycling and creep resistance tests evaluate the stability of molybdenum wire under temperature changes and high temperatures over long periods of time.

Thermal Cycling Test:
Equipment function: temperature range -40°C to 800°C, cycle rate 10-20°C/min.
Technical parameters: 100-1000 cycles, detection of cracks and sealing failures.
Process characteristics: Simulate the switching process of lamps and lanterns, and test the thermal expansion matching of the sealing part (molybdenum wire-glass).

Creep Resistance Test:
Equipment function: temperature 1500-1800°C, stress 50-200 MPa.
Technical parameters: creep rate <10^{-6} s^{-1} (molybdenum lanthanum wire), test time 100-1000 hours.
Process characteristics: hydrogen protection is required, and the fixture material is molybdenum or tungsten. The creep rate is measured by a displacement sensor with an accuracy of ±0.001 mm.

Application impact: Thermal cycling test ensures the reliability of molybdenum wire in automotive headlamps, and creep resistance test optimizes doped molybdenum wire (such as molybdenum lanthanum wire) to extend the life of HID lamps.

8.4.3 High temperature mechanical property test

High-temperature mechanical tests evaluate the mechanical properties of molybdenum wire at the operating temperature of the luminaire.

Equipment function: temperature range 500-2000°C, accuracy ± 0.5%.
Technical Parameters:
Test conditions: 1500°C, hydrogen protection, tensile speed 0.1-1 mm/min.
Index: tensile strength 200-400 MPa, elongation at break 5%-15%.

Process characteristics: It needs to be equipped with high-temperature fixtures (molybdenum or tungsten material) and atmosphere control system (argon or hydrogen, purity ≥ 99.999%). The test data is recorded by strain gauge (accuracy ± 0.01%).

Application Impact: High-temperature mechanical properties test ensures the mechanical stability of molybdenum wire in halogen lamps and infrared lamps, and meets the requirements of ASTM B387 and GB/T 4191-2015.

8.5 Electrical performance test of molybdenum wire for lighting

The electrical performance test evaluates the conductivity and arc stability of the molybdenum wire, which affects the luminous efficiency and life of the luminaire.

8.5.1 Resistivity and conductivity testing

The resistivity test evaluates the electrical conductivity of the molybdenum wire.

Device function: Four-probe tester, measuring range 10^{-8}-10^{6} Ω·m, the accuracy ± 0.01%.
Technical Parameters:
Resistivity: Pure molybdenum wire 5.5×10^{-8} Ω·m (20 °C), doped molybdenum wire slightly higher (6-7×10^{-8} Ω·m)。
Test conditions: sample length 50-100 mm, current 1-10 mA.

Process characteristics: a constant temperature environment (20°C) is required, and the contact probe is made of gold or tungsten to avoid contact resistance. The test results are calculated by Ohm's law.
Application impact: Low resistivity molybdenum wire reduces Joule heat loss and improves the energy efficiency of incandescent and halogen lamps.

8.5.2 Temperature coefficient and arc stability analysis

The temperature coefficient and arc stability affect the performance of molybdenum wire in a high-temperature arc environment.

Temperature coefficient test:
Equipment function: temperature range 20-1500°C, accuracy ±0.1%.
Technical parameters: temperature coefficient of resistance of molybdenum wire 4.5×10^{-3}/°C (20-1000°C).
Process characteristics: The test needs hydrogen protection, and the sample is fixed in a ceramic fixture. Resistance as a function of temperature is measured by the four-probe method.

Arc Stability Test:

Device function: voltage 1-30 kV, current 0.1-100 A.
Technical parameters: arc offset < 0.1 mm, electrode corrosion rate < 0.01 $mg/cm^2 \cdot h$.
Process characteristics: Equipped with a high-speed camera (1000 fps) to record arc trajectory. The test simulates the working environment of HID lamp (6000°C arc center).

Application implications: Arc stability testing optimizes the surface quality of molybdenum wires (Ra<0.4 μm) and improves the luminous efficiency of HID and xenon lamps.

8.5.3 High temperature electrical performance test

High-temperature electrical tests evaluate the conductivity of molybdenum wire at the operating temperature of the luminaire.

Equipment function: semiconductor analyzer, temperature range 500-1500°C, accuracy ±0.01%.
Technical Parameters:
Resistivity: approx. 2.5×10^{-7} Ω··at 1500°C m。
Test conditions: Hydrogen protection, current 0.1-1 A.

Process characteristics: high temperature fixture (molybdenum or tungsten material) and atmosphere control system are required. The test data is analyzed by recording the resistance change in real time.
Application Impact: High-temperature electrical testing ensures the conductivity stability of molybdenum wire in halogen and projection lamps to meet JIS H 4461 requirements.

8.6 Non-destructive testing of molybdenum wire for lighting

Non-destructive testing (NDT) is used to evaluate the internal defects and structural integrity of molybdenum wires without affecting their performance in use.
8.6.1 Ultrasonic flaw detection technology
Ultrasonic flaw detection detects porosity and inclusions inside the molybdenum wire.

Device function: frequency 5-20 MHz, accuracy ± 0.01 mm.
Technical Parameters:
Detection range: diameter 0.05-2 mm, defect size > 0.01 mm.
Sensitivity: Detects stomata and inclusions, and the reflected signal intensity > 10%.

Process characteristics: requires water couplant, probe diameter 2-5 mm. The detection speed is 1-5 m/min, which is suitable for in-line inspection.
Application impact: Ultrasonic flaw detection improves the internal quality of molybdenum wire, reduces the risk of HID lamp electrode failure, and the defect detection rate reaches 95%.

8.6.2 X-ray flaw detection and CT scanning

X-ray flaw detection and CT scanning are used to detect tiny defects in the interior and surface of molybdenum wires.

X-ray flaw detection:
Device function: voltage 50-225 kV, resolution 1 μm.
Technical parameters: Crack detection, porosity, defect size> 0.005 mm.
Process characteristics: the sample needs to be rotated, and the imaging time is 5-10 minutes. Suitable for offline inspection.

CT scan:
Device function: resolution 0.5 μm, 3D reconstruction accuracy ± 0.001 mm.
Technical parameters: Detection of internal inclusions and grain boundary defects, suitable for ultra-fine molybdenum wire.
Process characteristics: high vacuum environment is required, and the scanning time is 10-30 minutes. 3D reconstruction to analyze defect distribution.

Application implications: X-ray and CT scans are used for high-end molybdenum wires (e.g. for projection lamps) to ensure no internal defects and improve reliability.

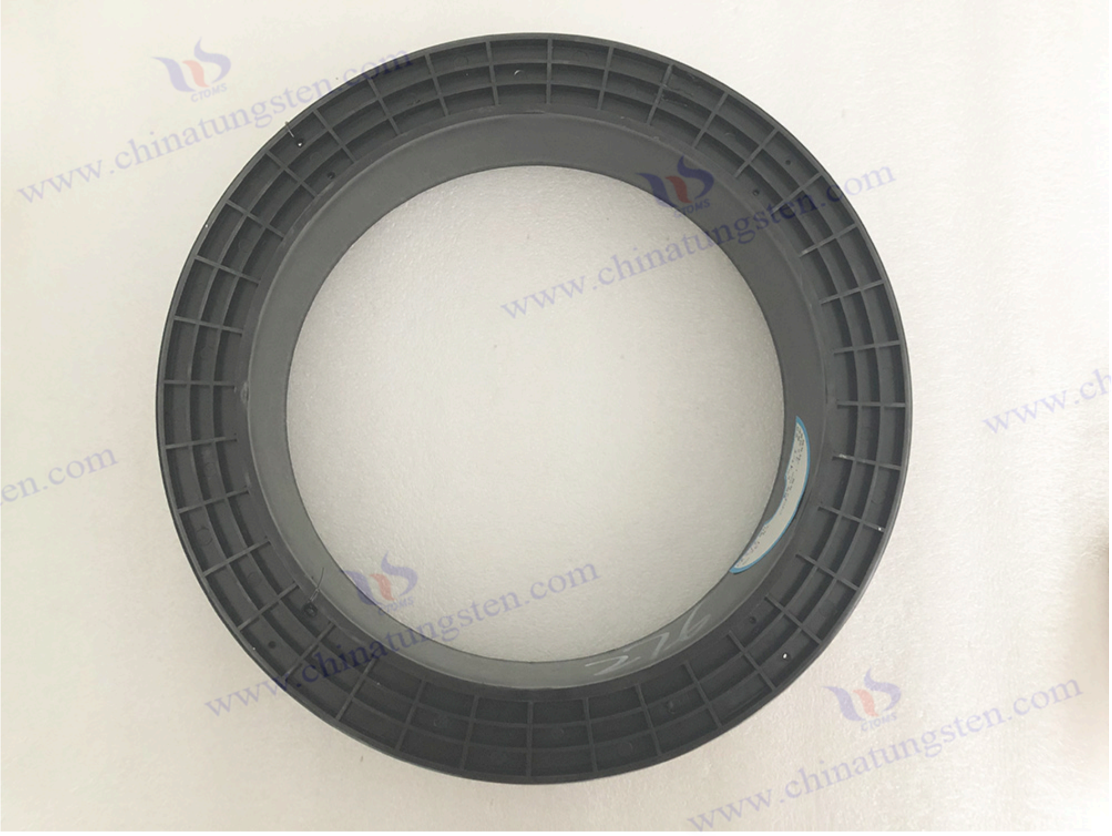
8.6.3 Magnetic particle testing and eddy current testing

Magnetic particle and eddy current testing is used for rapid screening of surface and near-surface defects.

Magnetic particle inspection:
Device function: magnetic field strength 0.1-1 T, sensitivity 0.01 mm.
Technical parameters: Detection of surface cracks and scratches, suitable for molybdenum wire with a diameter of >0.1 mm.
Process characteristics: magnetic powder suspension (fluorescent or non-fluorescent) is required, and the detection time is 1-3 minutes. Only for ferromagnetic inclusions.

Eddy current testing:
Device function: frequency 10 kHz-10 MHz, sensitivity 0.01 mm.
Technical parameters: detection of surface and near-surface cracks, suitable for in-line inspection, speed 1-10 m/min.
Process characteristics: The coil needs to be calibrated to detect non-conductive coating or oxide layer interference. The automation system increases efficiency by 50%.

Application implications: Eddy current testing is used for mass production, magnetic particle testing is used for failure analysis, ensuring the surface quality of molybdenum wire in automotive headlights.



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Chapter 9 The Future Development Trend of Molybdenum Wire for Lighting

As an important material in the lighting industry, Molybdenum wire for lighting is facing rapid changes in new material technology, production process upgrading, competition of alternative materials and market demand. This chapter will discuss the future development trend of Molybdenum wire for lighting in new doping technology, intelligent and green production process, research and development of alternative materials, and market and application expansion, and provide forward-looking analysis based on global technological progress and industry trends.

9.1 New Materials and Doping Technologies

Advances in new materials and doping technologies will improve the performance of Molybdenum wire for lighting to meet the needs of more demanding lighting applications, such as high temperature stability, corrosion resistance, and electrical properties.

9.1.1 Exploration of new doped elements (e.g. rare earths, precious metals).

Doping technology significantly improves the high-temperature strength, creep resistance and corrosion resistance of molybdenum wire by introducing rare earth or precious metal elements.

Technology trends: Research focuses on novel doped elements such as cerium (Ce), yttrium (Y), rhenium (Re) and platinum (Pt). Rare earth elements (e.g., CeO_2, doping 0.2%-1.0%) refine grains (grain size from 20 μm to 10 μm) and increase tensile strength (20% increase at 1500°C). Precious metals (e.g., Re, doping 1%-5%) enhance arc corrosion resistance, reduce the corrosion rate by 30%, and are suitable for high-intensity discharge lamps (HID).

Process characteristics: wet doping combined with spray drying technology to ensure uniform distribution of doped elements (deviation < 0.01%). High-temperature sintering (2000-2300°C) requires precise control of the atmosphere (hydrogen, dew point <-40°C) to avoid element volatilization.

Challenges and prospects: The cost of new doping elements is high (e.g., Re is 10 times that of molybdenum), and the doping amount needs to be optimized to balance performance and cost. In the next 5-10 years, rare earth doped molybdenum wire is expected to account for 20% of the market share in high-end automotive headlamps and projection lamps.

Application impact: The new doped molybdenum wire will extend the life of the lamp (30%-50%), and meet the needs of high-brightness and long-life lighting.

9.1.2 R&D and application of nanoscale molybdenum wire

Nanoscale molybdenum wire (<0.01 mm diameter) is optimized by nanostructure to improve mechanical and electrical properties.

Technology Trends: Preparation of molybdenum filaments with a diameter of 5-10 nm by nano-drawing technology and chemical vapor deposition (CVD). The nanostructure can improve the tensile strength (up to 1500 MPa at room temperature) and the elongation at break (15%). Surface nanoprocessing (e.g., deposition of Al_2O_3 coating, thickness 50-100 nm) enhances oxidation resistance, and oxidative weight gain < 0.005 mg/cm².

Process characteristics: ultra-high-precision wire drawing equipment (tolerance ± 0.0005 mm) and nano-scale molds (aperture accuracy ± 0.001 μm) are required. The annealing process (900-1100°C, hydrogen protection) optimizes grain size (<100 nm).

Challenges and prospects: The cost of nano wire drawing equipment is high, and the yield rate is low (about 70%). In the next 10 years, with the advancement of precision manufacturing technology, nano-scale molybdenum wire is expected to be used in miniaturized lamps (such as medical lighting), with an estimated market share of 10%.

Application Implications: Nanoscale molybdenum wire is suitable for high-precision illumination (e.g. laser projection) to improve arc stability and optical performance.

9.1.3 Composites and molybdenum-based alloys

Molybdenum matrix composites and alloys expand the range of applications for molybdenum wire by combining with other high-temperature materials.

Technology trends: Development of molybdenum-tungsten (Mo-W), molybdenum-ceramic (e.g., $Mo-ZrO_2$), and molybdenum-carbon nanotube (CNT) composites. Mo-W alloy (10%-30% W content) increases melting point (to 2800°C) and creep resistance (creep rate $<10^{-7}$ s^{-1}). $Mo-ZrO_2$ composites enhance oxidation resistance and are suitable for infrared lamps.

Process characteristics: powder metallurgy combined with plasma sintering (temperature 2000-2200 °C, pressure 50 MPa) to prepare composite blanks. Composites require precisely controlled phase distribution (deviation < 0.1 μm) to ensure uniformity of mechanical properties.

Challenges and prospects: Composites are difficult to process, and the cost increases by 20%-30%. In the next 5-10 years, Mo-W alloy is expected to replace part of pure molybdenum wire, accounting for 15% of the lamp molybdenum wire market.

Application impact: Composites improve the reliability of molybdenum wire in extreme environments (such as ultraviolet lamps, high-temperature furnaces) and meet the needs of special lighting.

9.2 Intelligent and green production process

Intelligent and green production processes will improve the production efficiency, quality consistency and environmental sustainability of Molybdenum wire for lighting.

9.2.1 Intelligent manufacturing and Industry 4.0 technologies

Smart manufacturing optimizes molybdenum wire production through automation, data analytics, and the Internet of Things (IoT).

Technology trends: Adoption of Industry 4.0 technologies such as online monitoring systems, artificial intelligence (AI) and big data analytics. The online laser caliper (accuracy±0.001 mm) monitors the diameter of the molybdenum wire in real time, and the AI algorithm predicts the risk of wire breakage (accuracy rate > 95%). The IIoT integrates drawing, annealing, and inspection equipment to automate the entire process.

Process features: The intelligent wire drawing machine controls the tension (±0.5 N) through the servo motor, which reduces the wire breakage rate by 10%. The digital twin technology simulates the sintering and wire drawing process, optimizes the process parameters (temperature, speed) and increases the yield rate to 98%.

Challenges and prospects: The initial investment of smart devices is high (accounting for about 30% of the total cost), but it can reduce labor costs by 20%. In the next 5 years, intelligent manufacturing is expected to be popularized in China's molybdenum wire enterprises, and the production efficiency will be increased by 15%-20%.

Application impact: Intelligent production ensures the dimensional consistency and performance stability of molybdenum wire, and meets the high-precision requirements of high-end lamps (such as HID lamps).

9.2.2 Green production processes and waste recycling

Green production reduces environmental impact through waste recycling and environmentally friendly processes.

Technology Trends: Development of closed-loop recycling systems for the recovery of brushed broken wires and sintered waste (30%-40% recovery). The chemical cleaning waste liquid is neutralized and precipitated, and the heavy metal discharge < 0.1 mg/L, which meets the sewage discharge standard. The exhaust gas treatment system (caustic absorption) controls oxide emissions < 0.05 mg/m³.

Process characteristics: The use of low-volatile lubricants (such as water-based lubricants) to reduce VOC emissions in the drawing process (50%). The waste is reproduced from molybdenum powder by hydrogen reduction (temperature 800-1000°C), reducing the cost by 10%.

Challenges and prospects: Recycling equipment requires a high initial investment, and recycling efficiency is limited by the purity of the waste. In the next 10 years, green production will become the industry standard, in line with RoHS and ISO 14001 requirements.

Application impact: Green technology enhances the environmental image of the enterprise and meets the compliance needs of the European and American markets (such as automotive lighting).

9.2.3 Energy Optimization and Low-Carbon Manufacturing

Low-carbon manufacturing reduces production costs and carbon emissions by optimizing energy consumption.

Technology trends: energy-efficient sintering furnaces (15% less energy consumption) and high-efficiency wire drawing machines (motor efficiency > 90%). Induction heating replaces resistance heating, and the heating efficiency is increased by 20%. Optimization of process parameters (e.g. 50°C reduction in annealing temperature) reduces energy consumption by 10%.

Process characteristics: The energy management system (EMS) monitors energy consumption in real time and optimizes production scheduling. The waste heat recovery system uses the waste heat of the sintering furnace to preheat the blank, saving energy by 5%-10%.

Challenges and prospects: Energy-saving equipment is expensive to upgrade, and it takes 5-7 years to recover the investment. In the next 10 years, low-carbon manufacturing will promote a 20% reduction in carbon emissions from molybdenum wire production, in line with the global carbon neutrality goal.

Application impact: Low-carbon manufacturing reduces production costs (about 5%), enhances market competitiveness, and meets the demand of the green lighting market.

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Molybdenum Wire for Lighting Introduction

1. Overview of Molybdenum Wire for Lighting

As one of the core materials in modern lighting technology, molybdenum wire is widely used in various light sources including incandescent lamps, halogen lamps, fluorescent lamps, and gas discharge lamps, due to its high melting point, high strength, excellent corrosion resistance, and superior electrical conductivity. It is an irreplaceable and critical component in the lighting industry.

2. Typical Applications of Molybdenum Wire for Lighting

Residential and Commercial Lighting: Used in incandescent and halogen lamps to provide warm light and long service life.

Automotive Lighting: Functions as electrodes in HID and xenon lamps, offering high brightness and vibration resistance.

Specialty Lighting: Utilized in projection lamps, ultraviolet (UV) lamps, and infrared (IR) lamps to meet high-temperature and high-precision requirements in medical, industrial, and scientific applications.

Emerging Fields: Serves as conductive leads for LED lamps and supports for phosphors in laser lighting, aligning with future lighting technology development.

3. Basic Data of Molybdenum Wire for Lighting (Reference)

Parameter	Pure Mo Wire	Mo-La Wire	Mo-Re Wire
Mo Content	≥99.95%	≥99.0%	52.5%–86.0%
Diameter Range	0.03–3.2 mm	0.03–1.5 mm	0.03–1.0 mm
Tolerance	±0.002 mm	±0.002 mm	±0.002 mm
Tensile Strength (Room Temp)	800–1200 MPa	900–1400 MPa	1000–1500 MPa
Tensile Strength (at 1500°C)	150–300 MPa	200–400 MPa	250–450 MPa
Elongation at Break	10%–25%	12%–20%	15%–25%
Electrical Resistivity (20°C)	5.5×10^{-8} Ω·m	6.0×10^{-8} Ω·m	6.5×10^{-8} Ω·m
Main Applications	Incandescent, Halogen	Halogen, Auto Headlights	HID, Projection Lamps

4. Procurement Information

Email: sales@chinatungsten.com
Phone: +86 592 5129595; 592 5129696
Website: www.molybdenum.com.cn

9.3 Alternative materials for molybdenum wire for lighting

With the advancement of lighting technology, alternative materials may partially replace molybdenum wire, but its unique properties still have advantages.

9.3.1 Tungsten-based materials and new alloys

Tungsten-based materials are seen as a potential alternative to molybdenum wire due to their high melting point and strength.

Technology Trend: Tungsten-rhenium (W-Re, 3%-10% Re) alloy to improve tensile strength (500 MPa at 1500°C) and arc corrosion resistance. Tungsten matrix composites (e.g., $W\text{-}ZrO_2$) enhance oxidation resistance and increase oxidative weight < 0.005 mg/cm².

Process characteristics: Tungsten-based materials require higher sintering temperature (2500-2800°C) and precision wire drawing equipment (tolerance± 0.001 mm). Surface coatings (e.g. Si_3N_4) improve chemical stability.

Challenges and prospects: The cost of tungsten-based materials is 2-3 times that of molybdenum, and it is difficult to process. In the next 5-10 years, W-Re alloy may account for 10% of the market share in high-end HID lamps, but molybdenum wire is still the mainstream due to cost advantages.

Application implications: Tungsten-based materials are suitable for ultra-high temperature applications (e.g. xenon lamps), but molybdenum wire is more economical in halogen and incandescent lamps.

9.3.2 Ceramics and carbon-based materials

Ceramics and carbon-based materials are attracting attention for their high-temperature stability and lightweight properties.

Technology Trends: Zirconia (ZrO_2) and silicon nitride (Si_3N_4) ceramics have excellent oxidation resistance (stable at 2000°C) and electrical insulation, making them suitable for luminaire support structures. Carbon nanotubes (CNTs) and graphene are used in electrodes due to their high conductivity (10^6 S/m) and strength (>1 GPa).

Process characteristics: ceramics need to be plasma sintered (1800-2000 °C), carbon-based materials are dedeposited by CVD (800-1200 °C). Ceramic processing requires high-precision molds, and carbon-based materials need to solve the problem of thermal expansion mismatch with glass sealing.

Challenges and prospects: Ceramics and carbon-based materials are costly (3-5 times more expensive than molybdenum) and have limited production scales. In the next 10-15 years, it may account for 5% of the market share in specialty lighting (such as ultraviolet lamps).

Application impact: Ceramic and carbon-based materials are suitable for high-precision miniature luminaires, but the dominance of molybdenum wire in traditional lighting is difficult to replace in the short term.

9.3.3 Emerging high-temperature conductive materials

Emerging conductive materials offer more possibilities for Molybdenum wire for lighting.

Technology trends: Metal matrix composites (e.g., TiC-Ni) and high-temperature superconductors (e.g., YBCO) have excellent electrical conductivity (resistivity< 10^{-8} Ω·m) and high temperature resistance (>2000°C). Two-dimensional materials, such as MoS_2 films, are attracting attention due to their high electrical conductivity and corrosion resistance.

Process characteristics: Emerging materials require advanced deposition technologies (such as PVD, ALD), and the thickness is controlled at 10-100 nm. The production needs to be ultra-clean environment (ISO class 5) to avoid contamination by impurities.

Challenges and prospects: Emerging material technologies are not yet mature, and the cost is 5-10 times that of molybdenum. In the next 15-20 years, breakthroughs may be achieved in the field of laser lighting and aerospace, accounting for <5% of the market.

Application impact: Emerging materials are suitable for cutting-edge applications, but molybdenum wire is still dominant due to mature process and cost advantages.

9.4 Market and Application Expansion

The application field and market demand of Molybdenum wire for lighting will expand with the changes in lighting technology and global market.

9.4.1 Potential applications in LED and laser illumination

Although LED and laser illumination reduce the need for traditional molybdenum wire, it still has potential in specific areas.

Technology trend: Molybdenum wire, as a conductive lead and heat dissipation substrate for LED lamps, requires high electrical conductivity (>10^7 S/m) and thermal conductivity (>130 W/m·K). In laser illumination, molybdenum wire is used to support phosphors or electrodes and is subjected to high energy densities (>10^4 W/cm²).

Process characteristics: Ultra-fine drawing (diameter <0.02 mm) and surface coating (Al_2O_3, thickness 50 nm) are required to improve heat dissipation and corrosion resistance. The sealing process needs to be matched to the sapphire substrate (coefficient of thermal expansion deviation < 10^{-6}/°C).

Challenges and prospects: The LED and laser lighting market is growing rapidly (10% annual growth), but the use of molybdenum wire accounts for 5% of the total market. Over the next 10 years, the demand for molybdenum wire in high-end LEDs (e.g. automotive lighting) and laser projection is expected to grow by 15%.

Application impact: The application of molybdenum wire in LED and laser lighting extends its market life and makes up for the shrinking of the traditional lighting market.

9.4.2 Expansion in the aerospace and high-temperature industries

The aerospace and high-temperature industries offer new applications for molybdenum wire.

Technology trends: Molybdenum wire is required in the aerospace industry as a high-temperature electrode (>2000°C) and sensor material, with a tensile strength of 1500 MPa (room temperature). High-temperature industries (e.g. plasma spraying, heat treatment furnaces) use molybdenum wire as a heating element and need creep resistance (creep rate < 10^{-7} s^{-1}).

Process characteristics: Molybdenum-rhenium alloy (5% Re) and surface coating (e.g. $MoSi_2$, thickness 1-2 μm) need to be developed. Production requires high-vacuum sintering (<10^{-3} Pa) and precision molding processes.

Challenges and prospects: The aerospace market has extremely high reliability requirements, and molybdenum wires need to be certified (e.g. AS9100). In the next 10 years, the demand in this field is expected to account for 10% of the molybdenum wire market.

Application impact: The aerospace and high-temperature industries are expanding the high value-added applications of molybdenum wire to compensate for the shrinking lighting market.

9.4.3 Global Market Demand and Emerging Market Analysis

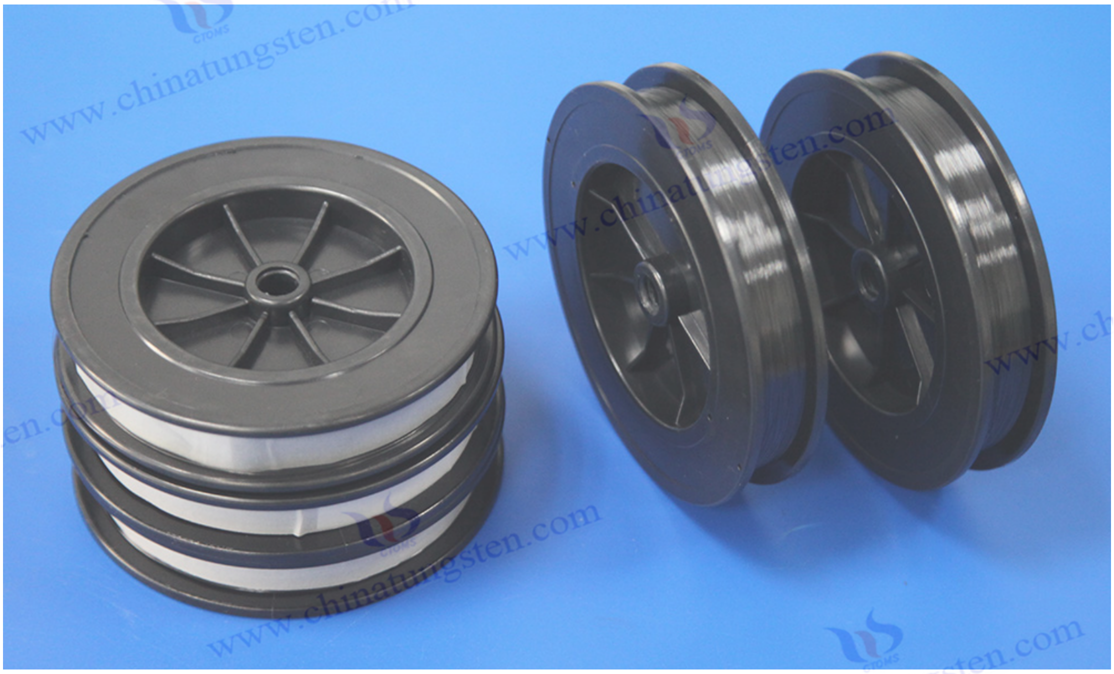
Changes in global market demand and the rise of new markets provide growth opportunities for molybdenum wire.

Technology Trends: The market for conventional lighting (e.g., halogen, HID) is still growing at an annual rate of 5%-7% in developing countries (e.g., India, Southeast Asia). Demand for high-end lighting (e.g., automotive headlamps, projection lamps) drove a 10% increase in doped molybdenum wire (molybdenum, lanthanum, molybdenum-rhenium). The global molybdenum wire market is expected to maintain an average annual growth rate of 3% from 2025 to 2030.

Market characteristics: China accounts for 70% of the world's molybdenum wire production, which is exported to Europe, North America and Asia. Emerging markets (e.g., Africa, Latin America) are expected to account for 15% of the global market due to increased demand for infrastructure construction.

Challenges and prospects: The European and American markets have strict environmental protection requirements (RoHS, REACH) and require green production processes. In the next 10 years, the demand for low-cost lighting in emerging markets will drive a 20% increase in molybdenum wire sales.

Application Impact: The growth of emerging markets and the expansion of high-end applications will ensure the continued competitiveness of molybdenum wire in the global lighting market.



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Appendix

A. Glossary

Molybdenum Wire: A slender metal wire with molybdenum as the main component, which is widely used in high-temperature lighting devices.

Pure Molybdenum Wire: Molybdenum wire with a purity of ≥99.95%, without adding doping elements.

Molybdenum Lanthanum Wire: Molybdenum wire doped with lanthanum oxide to enhance high-temperature strength and creep resistance.

Molybdenum Rhenium Wire: Molybdenum wire doped with rhenium element to improve ductility and oxidation resistance.

Black Molybdenum Wire: Molybdenum wire with a black oxide layer on the surface, unpolished.

Cleaned Molybdenum Wire: Molybdenum wire that has been polished or cleaned, with a bright surface.

Powder Metallurgy: The technology of preparing metal materials through powder pressing, sintering and other processes.

Wire Drawing Process: A processing method for stretching a metal blank through a die to form a filament.

High-temperature Strength: The tensile strength and deformation resistance of the material at high temperatures.

Oxidation Resistance: The ability of a material to resist oxidative corrosion at high temperatures.

Halogen Cycle: The process of extending the life of the filament through the chemical reaction of halogen gas with the filament in a halogen lamp.

X-ray Fluorescence (XRF): A detection technique that uses X-rays to excite a sample for elemental analysis.
Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES): A technique for elemental quantification by plasma excitation.
Scanning Electron Microscopy (SEM): A high-resolution microscope used to observe the surface topography of materials.
Resistivity: A measure of a material's ability to resist an electric current, measured in ohms-meters.
Coefficient of Thermal Expansion: The degree to which a material expands in volume as it increases with temperature.
RoHS: Restriction of Hazardous Substances.
Green Manufacturing: A production method with the goal of energy saving, environmental protection and low carbon.

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