

What Is Tungsten Copper Electrode

中钨智造科技有限公司

CTIA GROUP LTD

CTIA GROUP LTD

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

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INTRODUCTION TO CTIA GROUP

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

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

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

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



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Table of Contents

Chapter 1: Introduction

- 1.1 Definition of Tungsten Copper Electrode
- 1.2 Basic Characteristics of Tungsten Copper Electrode
- 1.3 Development History of Tungsten Copper Electrode

Chapter 2: Material Basics of Tungsten Copper Electrodes

- 2.1 Characteristics of Tungsten
- 2.2 Characteristics of Copper
- 2.3 Tungsten-Copper Composite Mechanism
 - 2.3.1 Physical Compatibility of Tungsten Copper Electrodes
 - 2.3.1.1 Structural Compatibility
 - 2.3.1.2 Thermal Compatibility
 - 2.3.2 Performance Synergy of Tungsten Copper Electrodes
 - 2.3.2.1 Synergy of Electrical and Thermal Conductivity
 - 2.3.2.2 Synergy Between High Temperature Resistance and Structural Stability
- 2.4 Key Raw Material Requirements for Tungsten Copper Electrodes
 - 2.4.1 Tungsten Powder Requirements
 - 2.4.2 Copper Powder Requirements
 - 2.4.3 Raw Material Pretreatment Standards

Chapter 3: Physical and Chemical Properties of Tungsten Copper Electrodes

- 3.1 Physical Properties of Tungsten Copper Electrodes
 - 3.1.1 Density of Tungsten Copper Electrode
 - 3.1.1.1 Density Calculation Method
 - 3.1.1.2 Relationship Between Density and Composition
 - 3.1.1.3 Impact of Density on Applications
 - 3.1.2 Thermal Properties of Tungsten Copper Electrodes
 - 3.1.2.1 Thermal Conductivity
 - 3.1.2.2 Coefficient of Thermal Expansion
 - 3.1.2.3 High Temperature Resistance
- 3.2 Functional Performance of Tungsten Copper Electrode
 - 3.2.1 Conductive Properties of Tungsten Copper Electrodes
 - 3.2.1.1 Conductivity
 - 3.2.1.2 Resistivity
 - 3.2.1.3 Current Carrying Capacity
 - 3.2.2 Arc Erosion Resistance of Tungsten Copper Electrodes
 - 3.2.2.1 Arc Erosion Mechanism
 - 3.2.2.2 Evaluation of Ablation Resistance
 - 3.2.2.3 Factors Affecting Ablation Resistance
- 3.3 Other Properties of Tungsten Copper Electrode

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- 3.3.1 Hardness of Tungsten Copper Electrode
- 3.3.2 Strength of Tungsten Copper Electrode
- 3.3.3 Toughness of Tungsten Copper Electrode
- 3.3.4 Wear Resistance of Tungsten Copper Electrode
- 3.3.5 Corrosion Resistance of Tungsten Copper Electrodes
- 3.3.6 Anti-Welding and Anti-Adhesion Properties of Tungsten Copper Electrodes
- 3.4 CTIA GROUP LTD Copper Tungsten Electrode MSDS

Chapter 4: Classification of Tungsten Copper Electrodes

- 4.1 Composition-Ratio Dominant Classification Tungsten Copper Electrode
 - 4.1.1 High Tungsten Content Electrodes (80%-95% Tungsten)
 - 4.1.2 Medium Tungsten Content Electrodes (50%-80% Tungsten)
 - 4.1.3 Low Tungsten Content Electrodes (20%-50% Tungsten)
- 4.2 Application Scenario-Oriented Classification of Tungsten Copper Electrodes
 - 4.2.1 Electrodes for EDM
 - 4.2.2 Electrodes for High Voltage Electrical Appliances
 - 4.2.3 Electrodes in Welding Field
 - 4.2.4 Special Electrodes for Aerospace and Military Applications
- 4.3 Classification of Morphological and Structural Characteristics of Tungsten Copper Electrodes
 - 4.3.1 Block Electrodes
 - 4.3.2 Rod Electrode
 - 4.3.3 Sheet Electrode
 - 4.3.4 Special-Shaped Electrodes
- 4.4 Performance-Driven Classification of Tungsten Copper Electrodes
 - 4.4.1 Highly Conductive Electrodes
 - 4.4.2 Arc Erosion Resistant Electrodes
 - 4.4.3 High-Strength Electrodes
 - 4.4.4 High Heat-Resistant Electrodes
- 4.5 Classification of Tungsten Copper Electrodes by Microstructure
 - 4.5.1 Uniformly Dispersed Electrodes
 - 4.5.2 Skeleton-Filled Electrodes
 - 4.5.3 Gradient Distribution Electrode
- 4.6 Classification of Tungsten Copper Electrodes by Macroscopic Physical Form
 - 4.6.1 Dense Electrode
 - 4.6.2 Porous Electrodes
 - 4.6.3 Composite Coating Electrodes

Chapter 5: Preparation Process of Tungsten Copper Electrode

- 5.1 Infiltration Process
 - 5.1.1 Tungsten Skeleton Prefabrication
 - 5.1.1.1 Tungsten Powder Molding
 - 5.1.1.2 Tungsten Skeleton Sintering

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- 5.1.1.3 Tungsten Skeleton Pore Control
- 5.1.2 Infiltration Control
 - 5.1.2.1 Copper Material Preparation
 - 5.1.2.2 Infiltration Temperature Control
 - 5.1.2.3 Infiltration Time Control
- 5.2 Post-Processing Technology
 - 5.2.1 Cutting
 - 5.2.2 Grinding
 - 5.2.3 Surface Treatment
 - 5.2.4 Dimensional Accuracy Control

Chapter 6: Application Scenarios of Tungsten Copper Electrodes

- 6.1 Application of Tungsten Copper Electrode in EDM
 - 6.1.1 Application in Mold Processing
 - 6.1.2 Application in the Processing of Difficult-to-Process Materials
 - 6.1.3 Advantages of Application in EDM
- 6.2 Application of Tungsten Copper Electrodes in High Voltage Electrical Appliances
 - 6.2.1 Application in High-Voltage Switches
 - 6.2.2 Application in Lightning Arresters
 - 6.2.3 Application Advantages in High-Voltage Electrical Appliances
- 6.3 Application of Tungsten Copper Electrodes in Welding and Brazing
 - 6.3.1 Applications in Resistance Welding
 - 6.3.2 Application in Brazing
 - 6.3.3 Application Advantages in Welding Field
- 6.4 Application of Tungsten Copper Electrodes in Aerospace and Military Industries
 - 6.4.1 Application in Rocket Engine Related Components
 - 6.4.2 Application in Guidance Components
 - 6.4.3 Application Advantages in the Aerospace and Military Industry

Chapter 7: Quality Control and Testing Standards for Tungsten Copper Electrodes

- 7.1 Detection of Key Indicators of Tungsten Copper Electrode
 - 7.1.1 Physical Properties Test of Tungsten Copper Electrode
 - 7.1.1.1 Density Testing Methods and Standards
 - 7.1.1.2 Thermal Performance Test Methods and Standards
 - 7.1.1.3 Conductivity Testing Methods and Standards
 - 7.1.2 Chemical Properties of Tungsten Copper Electrodes
 - 7.1.2.1 Composition Analysis Method
 - 7.1.2.2 Corrosion Resistance Test Method
 - 7.1.2.3 Impurity Content Testing Standards
 - 7.1.3 Mechanical Properties of Tungsten Copper Electrodes
 - 7.1.3.1 Hardness Testing Methods and Standards
 - 7.1.3.2 Strength Testing Methods and Standards

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7.1.3.3 Toughness Test Methods and Standards

7.2 Microstructure Inspection of Tungsten Copper Electrode

7.2.1 Metallographic Analysis

7.2.1.1 Metallographic Sample Preparation

7.2.1.2 Evaluation Criteria for Phase Distribution Uniformity

7.2.1.3 Grain Size Detection

7.2.2 Defect Detection of Tungsten Copper Electrodes

7.2.2.1 Porosity Detection Method and Permissible Range

7.2.2.2 Crack Detection Methods and Criteria

7.2.2.3 Inclusion Detection Methods and Control Standards

7.3 Industry Standards for Tungsten Copper Electrodes

7.3.1 Relevant Domestic Standards

7.3.1.1 Relevant Provisions of Chinese Standards

7.3.1.2 Industry Standard Requirements

7.3.2 Relevant International Standards

7.3.2.1 International Tungsten Copper Electrode Standards

7.3.2.2 Tungsten Copper Electrode Standards in Europe, America, Japan, South Korea, and Other Countries

Chapter 8: Tungsten Copper Electrode Market and Technology Trends

8.1 Analysis of the Industry Chain of Tungsten Copper Electrodes

8.1.1 Upstream Raw Material Supply

8.1.2 Midstream Manufacturing

8.1.3 Downstream Application Market

8.2 Technical Direction of Tungsten Copper Electrode

8.2.1 Preparation Process Optimization

8.2.2 Performance Improvement Path

8.2.3 Application Expansion Exploration

Appendix:

Tungsten Copper Electrode Glossary

References



CTIA GROUP LTD Copper Tungsten Electrode

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Tungsten-copper alloy electrodes Introduction

1. Overview of Tungsten-copper alloy electrodes

Tungsten-copper alloy electrodes are composite materials made primarily from high-purity tungsten powder and copper powder, produced through processes such as isostatic pressing and high-temperature sintering. They combine tungsten's high melting point and hardness with copper's electrical conductivity and ductility, offering characteristics such as high-temperature resistance, low thermal expansion, and resistance to arc erosion. These properties make them widely used in resistance welding, electrical discharge machining, high-voltage discharge tubes, and electronic device heat dissipation applications. CTIA GROUP LTD provides a variety of customized tungsten-copper electrode services, with products featuring excellent appearance and stable performance.

2. Typical Properties of Tungsten-copper alloy electrodes

Product Name	Chemical Composition (%)			Physical and Mechanical Properties			
	Cu	Total Impurities ≤	W	Density (g/cm³)	Hardness (HB)	Resistivity (MΩ·cm)	Tensile Strength (MPa)
Tungsten Copper (50)	50±2.0	0.5	Balance	11.85	115	3.2	—
Tungsten Copper (60)	40±2.0	0.5	Balance	12.75	140	3.7	—
Tungsten Copper (70)	30±2.0	0.5	Balance	13.8	175	4.1	790
Tungsten Copper (80)	20±2.0	0.5	Balance	15.15	220	5	980
Tungsten Copper (90)	10±2.0	0.5	Balance	16.75	260	6.5	1160

3. Applications of Tungsten-copper alloy electrodes

Resistance Welding Electrodes: Used as electrodes for spot welding or seam welding of low-carbon steel and coated steel plates.

Repair Welding Electrodes: Applied in cold stamping, bending, extrusion, and die-casting molds.

Electrical Discharge Machining (EDM) Electrodes: Used for mold discharge machining, or as molds and fixtures for projection welders, as well as molds or inlaid electrodes for heat-resistant steel.

High-Voltage Discharge Tube Electrodes: This electrode allows high-pressure flushing to remove eroded material from the tube body.

4. Purchasing Information

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Chapter 1: Introduction

1.1 Definition of Tungsten Copper Electrode

A tungsten-copper electrode is a composite electrode made of tungsten (W) and copper (Cu) via powder metallurgy or vacuum infiltration. Its definition encompasses its composition, preparation method, and functional properties in specific applications. Tungsten-copper electrodes typically use tungsten as the primary skeleton material and copper as the filler. The two metals are combined in varying proportions (e.g., WCu 70/30, WCu 80/20), resulting in a material with a high melting point, high-temperature resistance, and excellent electrical conductivity. Tungsten's high melting point of 3422°C gives the electrode exceptional thermal stability and resistance to arc erosion, while copper, with a melting point of 1083°C, possesses high electrical and thermal conductivity, ensuring efficient current transfer and rapid heat dissipation. The properties of this composite material make it widely used in applications such as electrical discharge machining (EDM), resistance welding, and electrical contacts. The definition of a tungsten-copper electrode also encompasses its microstructure. The electrodes are formed by mixing tungsten and copper powders through powder metallurgy, pressing, and sintering, or by infiltrating liquid copper into the porous tungsten skeleton through vacuum infiltration, resulting in a uniform phase distribution and low porosity.

In practical applications, the definition of tungsten-copper electrodes further expands to encompass their functional properties, such as their use as tool electrodes in electrospark machining (EDM) for removing workpiece material, or as electrodes in resistance welding, withstanding high currents and pressures. The ratio and preparation process can be tailored to specific needs. For example, electrodes with a high tungsten content are more suitable for wear and arc resistance, while electrodes with a high copper content optimize electrical conductivity. The definition of tungsten-copper electrodes also encompasses their differences from traditional single-metal electrodes. The advantage of composite materials lies in their balanced properties of tungsten and copper, overcoming the limitations of single materials, such as the low melting point of pure copper or the low electrical conductivity of pure tungsten. In recent years, with advances in manufacturing technology, the definition of tungsten-copper electrodes has gradually expanded to the fields of additive manufacturing and nanotechnology, exploring more refined microstructures and novel applications.

1.2 Basic characteristics of tungsten copper electrode

Tungsten-copper electrodes lie in their unique physical, mechanical, and electrical properties as a composite material, making them particularly suitable for a variety of applications. Firstly, electrical conductivity is a core characteristic of tungsten-copper electrodes. The high electrical conductivity of the copper phase (approximately 5.8×10^7 S/m) provides an efficient current transmission path. Although tungsten has a lower electrical conductivity (approximately 1.8×10^7 S/m), by optimizing the distribution of copper, the electrical conductivity of tungsten-copper electrodes can reach 80%-90% of that of traditional copper electrodes, meeting the requirements of EDM and welding. Thermal conductivity is another key characteristic. The combination of copper's thermal conductivity and

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tungsten's moderate thermal conductivity (approximately $174 \text{ W/m}\cdot\text{K}$) results in an alloy with a thermal conductivity between $180\text{-}220 \text{ W/m}\cdot\text{K}$, enabling rapid dissipation of heat generated during machining or welding, preventing localized overheating.

High-temperature resistance is a significant advantage of tungsten-copper electrodes. Tungsten's ultra-high melting point ensures stability in arcs and high-temperature environments. The copper phase, after melting, fills pores, further enhancing the material's thermal stability, making it suitable for extreme conditions up to 3000°C . Tungsten's high hardness (approximately 3430 HV) and wear resistance contribute to its resistance to arc erosion. This significantly reduces electrode surface ablation during EDM, extending its service life. Mechanical strength and hardness are also important characteristics. Tungsten-copper electrodes boast a compressive strength exceeding 1000 MPa and a hardness between 200 and 300 HV , enabling them to withstand high pressures and frequent mechanical action. Meanwhile, the copper phase provides toughness, reducing the risk of brittle fracture.

The low thermal expansion coefficient (approximately $6\text{-}8 \text{ ppm}/^{\circ}\text{C}$) is a unique advantage of tungsten copper electrodes. It matches silicon or ceramic substrates, reduces stress during thermal cycling, and is particularly suitable for microelectronic packaging. Corrosion resistance is achieved through the chemical stability of tungsten and the surface treatment of copper (such as nickel plating), making it suitable for humid or industrial environments. Microstructurally, the uniform phase distribution and low porosity (typically less than 1%) of the tungsten copper electrode ensure consistent performance. These basic characteristics together constitute the versatility of tungsten copper electrodes, enabling them to perform well in high-precision processing, electrical contact, and thermal management. In the future, with the development of nanotechnology and surface modification, these characteristics are expected to be further optimized.

1.3 Development History of Tungsten-Copper Electrode

Tungsten-copper electrodes reflect the historical evolution of materials science and industrial needs, with its origins dating back to the mid-20th century, with advances in powder metallurgy and the rapid development of the electrical industry. Initially, research and development of tungsten-copper electrodes began in the 1940s, driven by the unique properties of tungsten and copper in military and industrial applications. Early research focused on powder metallurgy processes, and in 1945, the American Society for Metals (ASM) first reported on the preparation of tungsten-copper composites, exploring their application in electrical contacts by mixing, pressing, and sintering tungsten and copper powders. Tungsten-copper electrodes at this stage were primarily used in low-end electrical equipment, with limited performance, high porosity, and room for improvement in conductivity and durability.

1950s to the 1970s, with the introduction of vacuum infiltration technology, the development of tungsten-copper electrodes entered a period of rapid growth. In 1955, Siemens successfully developed the vacuum infiltration method, infiltrating liquid copper into the sintered tungsten skeleton, significantly reducing porosity and improving the material's density and conductivity. This technological breakthrough enabled the application of tungsten-copper electrodes in electrical discharge machining (EDM), making

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them ideal for machining hard materials such as tungsten carbide. In the 1960s , Japanese and American companies such as Toshiba and General Electric further optimized the ratio and microstructure, resulting in WCu 70/30 and WCu 80/20 becoming industry standards, widely used in high-voltage switches and welding electrodes.

1980s to the 2000s , the application areas of tungsten-copper electrodes expanded to microelectronics and aerospace, driving innovations in preparation technology. In 1985, hot isostatic pressing (HIP) technology was introduced, which enhanced the uniformity and mechanical strength of the material, supporting the needs of high-precision processing. In the 1990s , the introduction of nano-tungsten powder increased the degree of grain refinement, improved wear resistance and arc erosion resistance. After 2000, with the rise of additive manufacturing and 3D printing technology, the preparation of tungsten-copper electrodes moved towards personalized customization, and electrodes with complex geometries became possible. In the 2020s , combined with artificial intelligence and material simulation, the research and development of tungsten-copper electrodes focused on functionally gradient materials and surface modification to meet the needs of 5G equipment and high-temperature sensors. By 2025, tungsten-copper electrodes have become core materials in high-performance processing and electronics, and their development history reflects the deep integration of technological innovation and application needs.



CTIA GROUP LTD Copper Tungsten Electrode

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Chapter 2: Material Basis of Tungsten-Copper Electrode

2.1 Characteristics of Tungsten

Tungsten, a key component of tungsten-copper electrodes, possesses properties that provide a unique foundation for high-performance applications. Tungsten is a high-melting-point metal, with a melting point of 3422°C, the highest of all known metals. This property enables it to maintain structural stability in extremely high-temperature environments, making it particularly suitable for withstanding the arc and high-temperature shocks encountered in electrical discharge machining (EDM) or resistance welding. Tungsten's density of 19.25 g/cm³ gives the electrode high mass and deformation resistance. Its compressive strength can exceed 1000 MPa, and its hardness is approximately 3430 HV, demonstrating excellent wear resistance and mechanical strength. These properties enable it to withstand frequent mechanical stress or arc erosion, extending the electrode's service life. While its thermal conductivity of approximately 174 W/ m·K is lower than that of copper, its high melting point compensates for this disadvantage, ensuring it retains its shape at high temperatures.

Tungsten's chemical stability is another outstanding characteristic. It is resistant to acid, alkali, and oxidizing environments, and is particularly resistant to significant corrosion on its surface in humid or industrial environments. This provides a guarantee for the application of tungsten-copper electrodes outdoors or in harsh conditions. However, tungsten has a relatively low electrical conductivity (approximately 1.8×10^{-7} S/m), which limits its use alone and requires compounding with other highly conductive materials. The thermal expansion coefficient is approximately 4.5 ppm/°C, which matches many ceramic or semiconductor materials, reducing stress during thermal cycling and providing an advantage in microelectronic packaging. Tungsten has poor machinability and must be prepared through powder metallurgy or high-temperature sintering, but its fine grain structure can improve performance through process optimization. In recent years, the introduction of nano-tungsten powder has further improved the uniformity and strength of tungsten, giving it greater potential for application in high-precision electrodes.

2.2 Characteristics of Copper

Copper, another key component of tungsten-copper electrodes, possesses properties that provide them with exceptional electrical and thermal performance. While copper's melting point of 1083°C is lower than that of tungsten, its high electrical and thermal conductivity make it an ideal material for efficient current transmission and heat dissipation. In tungsten-copper electrodes, the copper phase is incorporated into the tungsten skeleton through powder metallurgy or vacuum infiltration, forming a continuous conductive network that ensures stable current transmission during EDM or welding. With a density of 8.96 g/cm³, copper is lighter than tungsten, but its ductility and toughness provide additional mechanical flexibility, reducing the risk of brittle fracture under mechanical stress.

Copper's corrosion resistance is weak in its pure state and is easily affected by oxidation or sulfidation. However, in tungsten-copper composites, the chemical stability of tungsten provides protection, and the

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copper surface can be further coated with a coating (such as nickel or gold) to enhance its weather resistance. Copper has a relatively high coefficient of thermal expansion of approximately 17 ppm/°C, but by combining it with tungsten, it matches silicon or ceramic substrates, making it suitable for microelectronic applications. Copper has excellent machinability, facilitating precision cutting and forming, and supporting the manufacture of complex electrode shapes. However, copper's tendency to soften at high temperatures limits its use alone, requiring it to rely on tungsten for support. In recent years, higher-purity electrolytic copper has been widely adopted to reduce the impact of impurities on electrical and thermal conductivity. The properties of copper imbue tungsten-copper electrodes with high electrical and thermal conductivity, enabling them to perform well in electrical and thermal management applications.

2.3 Tungsten-copper composite mechanism

The tungsten-copper composite mechanism is key to understanding the fundamentals of tungsten-copper electrode performance, involving the interaction between tungsten and copper at the microscopic level and the optimization of the preparation process. Tungsten-copper composite materials are achieved through powder metallurgy or vacuum infiltration processes. The basic principle is to use the high melting point of tungsten as a skeleton and the low melting point of copper as a filling phase to form a complementary performance system. In powder metallurgy, tungsten powder and copper powder are mixed in a specific ratio, pressed into a blank, and then sintered at high temperature. The copper wets the tungsten particles in the liquid phase, filling the pores and forming a uniform composite structure. Vacuum infiltration first prepares a porous tungsten skeleton, which is then heated above the melting point of copper in a vacuum environment. Liquid copper infiltrates and fills the blank, enhancing the density of the material.

The core of the composite mechanism lies in the physical and chemical incompatibility of tungsten and copper. No significant compound forms between the two, and the interface is primarily mechanically bonded and partially diffused, minimizing phase transitions or the formation of brittle phases. The tungsten skeleton provides structural support and high-temperature resistance, while the copper phase forms a continuous network, optimizing electrical and thermal conductivity. In the microstructure, tungsten particles are typically distributed as irregular polygons, ranging in size from 5 to 20 microns. Copper fills the pores, and the porosity can be controlled below 1%. Heat treatment and pressure-assisted processes (such as hot isostatic pressing) further improve interfacial bonding and uniformity. The composite mechanism also involves thermal expansion matching. The low thermal expansion of tungsten is balanced with the high thermal expansion of copper through proportional adjustment, resulting in a thermal expansion coefficient of 6-8 ppm/°C, adaptable to a variety of substrates.

2.3.1 Physical compatibility of tungsten-copper electrodes

The physical compatibility of tungsten-copper electrodes is an important component of their composite mechanism, involving the coordination of tungsten and copper's thermal, mechanical, and electrical properties. First, thermal compatibility is reflected in the matching of the coefficient of thermal expansion

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(CTE). Tungsten has a CTE of 4.5 ppm/°C, while copper has a CTE of 17 ppm/°C. The difference is significant when used alone, but by adjusting the composite ratio (e.g., WCu 85/15), the final CTE can be controlled to 6-8 ppm/°C, close to that of silicon or ceramic substrates, reducing stress concentration during thermal cycling. This property is particularly important in microelectronic packaging and sensor applications to prevent package warping or fracture.

Mechanical compatibility is reflected in the balance between hardness and toughness. Tungsten has a hardness of up to 3430 HV, while copper has a hardness of only about 70 HV. Through compounding, the hardness of tungsten-copper electrodes is usually between 200-300 HV, combining wear resistance and ductility. The tungsten skeleton provides mechanical support, while the copper phase enhances toughness, absorbs impact energy, and prevents brittle fracture, especially in EDM, where electrode surface wear is reduced. Electrical compatibility is the core. The high conductivity of copper and the lower conductivity of tungsten (1.8×10^{-7} S/m) are coordinated through a continuous network of copper phases. The electrical conductivity is close to 80%-90% of pure copper, meeting the needs of high current transmission.

Physical compatibility also involves interfacial stability. There is no significant chemical reaction between tungsten and copper; the interface is primarily mechanically bonded and diffused, minimizing the formation of brittle phases and enhancing long-term stability. The vacuum infiltration process optimizes interfacial wetting, reduces unfilled pores, and improves density. Thermal conductivity also reflects compatibility, with the copper phase dominating heat conduction and the tungsten phase providing thermal stability. In the future, nanopowder or surface modification could further enhance compatibility and enable applications in more demanding environments, such as high-temperature sensors or 5G devices.

2.3.1.1 Structural compatibility

Tungsten-copper electrodes is a core component of their physical compatibility. This involves the geometric matching and interfacial stability of the tungsten and copper microstructures, directly impacting the electrode's mechanical properties and long-term reliability. Structural compatibility is primarily reflected in the coordination between the tungsten framework and the copper filler phase, achieved through powder metallurgy or vacuum infiltration processes. In powder metallurgy, tungsten powder (typically 5-20 microns in size) and copper powder are mixed in a specific ratio (e.g., WCu 70/30) and pressed into a green body. During sintering, the copper, in its liquid phase, wets the tungsten particles and fills the pores, forming a composite structure with tungsten as a continuous framework and copper as a dispersed phase. The vacuum infiltration process first creates a porous tungsten framework. The tungsten framework is then heated in a vacuum environment to above the melting point of copper (1083°C), allowing liquid copper to infiltrate and fill the pores. This significantly reduces porosity (typically below 1%) and enhances the material's density and consistency. The tungsten particles are distributed in an irregular polygonal pattern, with the copper filling the gaps uniformly. The interface is primarily mechanically interlocked and diffused, minimizing the risk of microcracks or delamination. Structural compatibility is also reflected in the uniformity of grain size and phase distribution. Fine grains,

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achieved through the introduction of nano-tungsten powder, enhance mechanical strength and wear resistance, achieving compressive strength exceeding 1000 MPa and a hardness between 200 and 300 HV. The continuous network of copper phases supports the integrity of the conductive path, reducing resistance variability. Microscopic analysis shows that the uniform phase distribution improves the overall stability of the electrode. In electrospark machining (EDM), structural uniformity reduces discharge variability, improving machining accuracy and surface quality. In microelectronic packaging, structural compatibility ensures a low-stress bond with silicon (CTE approximately 2.6 ppm/°C) or ceramic substrates, preventing warping or fracture during thermal cycling. Mechanical testing and scanning electron microscopy have demonstrated that interfacial bonding stability is key to structural compatibility, reducing failures caused by thermal or mechanical stresses.

Furthermore, the manufacturing process is crucial to structural compatibility. The hot isostatic pressing (HIP) process uses omnidirectional pressure at high temperatures to further compress pores, improve the interfacial bonding between tungsten and copper, and enhance the material's fatigue resistance. Ultrafine powders introduced by nanotechnology enhance grain boundary strength, making them suitable for high-precision electrodes. Optimizing structural compatibility also involves controlling powder particle size and adjusting sintering parameters. Future dynamic simulation and process innovations will further refine the grain distribution and reduce porosity to below 0.5%, enabling applications with complex geometries or high durability, such as aerospace components or 5G device electrodes.

2.3.1.2 Thermal compatibility

The thermal compatibility of tungsten-copper electrodes is a key component of their physical compatibility. This involves the coordination of thermal expansion and thermal conductivity between tungsten and copper, which impacts the electrode's stability and reliability during thermal cycling and high-temperature environments. The coefficient of thermal expansion (CTE) of tungsten is 4.5 ppm/°C, while that of copper is 17 ppm/°C. While the difference is significant when used alone, by adjusting the composite ratio, the CTE of tungsten-copper electrodes can be controlled to 6-8 ppm/°C. This value is similar to that of silicon (approximately 2.6 ppm/°C) or alumina ceramic (approximately 7 ppm/°C) substrates. This reduces stress concentration during thermal cycling, preventing package warping or fracture, and is particularly effective in microelectronic packaging and high-temperature sensor applications. Achieving thermal compatibility relies on optimizing the ratio of tungsten to copper. For example, an 85/15 WCu ratio performs well at high temperatures. Thermal simulations have verified its low-stress properties, with thermal expansion matching within 10% of the silicon substrate.

Thermal conductivity is another key focus of thermal compatibility. Copper has a thermal conductivity of approximately 400 W/m·K, higher than tungsten's 174 W/m·K. The thermal conductivity of a composite tungsten-copper electrode ranges from 180 to 220 W/m·K. The copper phase dominates heat conduction, while the tungsten phase provides thermal stability. In EDM, high thermal conductivity rapidly disperses discharge heat (instantaneously reaching temperatures of thousands of °C), preventing localized electrode overheating that could lead to deformation or burns in the workpiece and improving surface quality. In resistance welding, even heat distribution reduces the heat-affected zone (HAZ),

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enhancing the strength and durability of the weld joint. Thermal compatibility also involves melting point differences. Tungsten's melting point of 3422°C and copper's melting point of 1083°C are harmonized through liquid-phase sintering. The copper fills the tungsten skeleton at high temperatures, enhancing thermal stability. Experimental data shows that the thermal conductivity of WCu 70/30 supports stable operation at a current of 200A and a temperature of 300°C. The introduction of fine grains through nanotechnology further optimizes the heat conduction path, reducing thermal resistance by approximately 15%.

Thermal compatibility is also influenced by the microstructure. Low porosity and uniform phase distribution reduce scattering during heat conduction, while hot isostatic pressing (HIP) improves the thermal conductivity of the interface. Thermal fatigue testing shows that the deformation rate of tungsten-copper electrodes during thermal cycling from -50°C to 300°C is less than 0.1%, demonstrating their excellent thermal stability. In the future, through functional gradient design (where the tungsten content gradually decreases from the interior to the surface) or the introduction of intermediate phases (such as molybdenum), thermal compatibility can be further optimized to accommodate even higher temperature differences or complex thermal management requirements, such as in high-temperature pressure sensors or power equipment.

2.3.2 Performance synergy of tungsten-copper electrodes

The synergistic performance of tungsten-copper electrodes is the ultimate manifestation of their composite mechanism. This synergy involves the complementary effects of tungsten and copper in electrical conductivity, thermal conductivity, mechanical strength, and durability, collectively enhancing the electrode's overall performance in a variety of applications. This synergistic performance relies on optimized fabrication processes, such as powder metallurgy and vacuum infiltration, to ensure uniform distribution and interfacial stability between the tungsten skeleton and the copper filler. Tungsten's high melting point (3422°C) provides resistance to high temperatures and arc erosion, while copper's high electrical and thermal conductivity optimizes electrical and thermal management performance. The composite tungsten-copper electrode achieves a balance between a thermal expansion coefficient of 6-8 ppm/°C and a thermal conductivity of 180-220 W/ m·K, meeting the requirements of microelectronic packaging and high-temperature sensors. The low porosity and fine grain size of the microstructure enhance mechanical strength and wear resistance, resulting in a compressive strength exceeding 1000 MPa and a hardness between 200-300 HV.

2.3.2.1 Synergy of electrical and thermal conductivity

Tungsten-copper electrodes is a core manifestation of their synergistic performance. This synergy stems from the complementary electrical and thermal properties of tungsten and copper, directly enhancing the electrode's efficiency in EDM, welding, and microelectronics applications. The electrical conductivity is primarily provided by the copper phase, which boasts a high conductivity of 5.8×10^7 S/m, forming a continuous conductive network that ensures efficient current transmission. Despite the lower conductivity of tungsten in tungsten-copper electrodes, by optimizing the copper ratio (e.g., WCu

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70/30), the conductivity can reach 80%-90% of that of pure copper, meeting the high current demands of EDM and the low resistance requirements of welding. The uniform distribution of the copper phase within the microstructure reduces resistance unevenness and enhances discharge stability, particularly in precision machining applications such as micromolds. Experimental data demonstrates that WCu 70/30 achieves electrical conductivity close to that of pure copper under high current conditions, enabling high-precision and efficient machining.

The synergy of thermal conductivity is closely related to electrical conductivity. Copper has a thermal conductivity of approximately $400 \text{ W/m}\cdot\text{K}$, significantly higher than tungsten's $174 \text{ W/m}\cdot\text{K}$. The thermal conductivity of the composite tungsten-copper electrode ranges from 180 to $220 \text{ W/m}\cdot\text{K}$. The copper phase dominates heat transfer, while the tungsten phase provides thermal stability. In EDM, thermal conductivity quickly disperses discharge heat to the electrode's exterior, preventing localized overheating that could lead to deformation or burns in the workpiece. In resistance welding, heat distribution evenly reduces the heat-affected zone (HAZ), improving the strength and durability of the weld joint and keeping the HAZ within 0.1mm. Tungsten's high melting point (3422°C) ensures structural integrity under high-temperature arc conditions, while copper's low melting point (1083°C) enhances the continuity of the heat conduction path through liquid phase filling. The thermal conductivity of an 85/15 WCu ratio supports stable operation at 300°C .

This synergistic performance is also reflected in the combination of a low thermal expansion coefficient and thermal conductivity, which reduces thermal stress and improves long-term stability. Nanotechnology introduces fine grains (<5 microns), further optimizing the electrical and thermal conductivity network, reducing thermal resistance and electrical resistance by approximately 15% and 10%, respectively, making it suitable for high-power chip heat dissipation. In practical applications, the synergistic performance of tungsten-copper electrodes excels in high-voltage switch contacts and 5G equipment, such as maintaining conductive stability and thermal management efficiency at a current of 500A. In the future, by adjusting the tungsten-copper ratio, introducing an intermediate phase (such as molybdenum), or surface modification (such as silver plating), the synergistic effect can be enhanced to accommodate higher currents or complex thermal management requirements, such as in high-temperature sensors or power transmission equipment.

2.3.2.2 Synergy between high temperature resistance and structural stability

Tungsten-copper electrodes is a key manifestation of their performance synergy. This synergy stems from the complementary effects of tungsten and copper in high-temperature environments, ensuring the electrode's reliability and long-term service life under extreme conditions. Tungsten's high-temperature resistance is primarily provided by tungsten, which has a melting point of 3422°C , the highest of all metals. This property enables tungsten-copper electrodes to withstand arc shocks up to 3000°C during electrical discharge machining (EDM) or resistance welding without significant melting or deformation. In composite structures, tungsten serves as a skeletal material, forming a high-strength, thermally stable network that resists thermal stresses at high temperatures. In practical applications, such as machining high-hardness materials (such as tungsten steel) or high-current disconnection, tungsten's high-

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temperature resistance ensures the integrity of the electrode surface, reducing ablation and material loss.

The synergy of structural stability depends on copper filling and microstructure optimization. Copper has a melting point of 1083°C. During sintering or vacuum infiltration, it fills the tungsten skeleton in liquid form, enhancing the density of the material. The porosity is usually controlled below 1%. This low-porosity structure reduces the risk of microcracks during thermal cycling. The ductility of the copper phase further absorbs thermal stress and prevents brittle fracture. In the microstructure, the uniform distribution of tungsten particles and copper is achieved through powder metallurgy or hot isostatic pressing (HIP) processes. The fine grains improve fatigue resistance and the compressive strength can reach over 1000 MPa.

The synergy between high-temperature resistance and structural stability is also reflected in thermal expansion matching. The low thermal expansion coefficient of tungsten is proportionally adjusted to the high thermal expansion coefficient of copper, resulting in a composite CTE of 6-8 ppm/°C, close to that of silicon (2.6 ppm/°C) or ceramic substrates, reducing thermal stress concentration. In microelectronic packaging, this property prevents warping between the chip and electrodes; in high-temperature sensors, it supports long-term high-temperature operation. Surface treatments (such as nickel plating) further enhance oxidation resistance and extend service life in humid or industrial environments.

2.4 Requirements of key raw materials for tungsten copper electrodes

Raw material purity requirements

As a key material widely used in many high-end fields, the performance of tungsten-copper electrodes is closely related to the quality of the key raw materials used - tungsten powder and copper powder. High-purity raw materials are the cornerstone for ensuring the excellent performance of tungsten-copper electrodes. When preparing tungsten-copper electrodes, the purity of tungsten powder is usually required to reach more than 99.9%. Even in some application scenarios with extremely high requirements for electrode performance, such as ultra-precision electrospark machining, the purity needs to be higher. This is because the presence of impurities, even in trace amounts, may form defects inside the electrode and destroy the uniformity of the material's structure. For example, if the tungsten powder contains impurity elements such as iron and nickel, these impurities may react with tungsten and copper during high-temperature sintering to form brittle phases, reducing the strength and toughness of the electrode, making it prone to cracking or even breaking during use.

Similarly, the purity of copper powder is also crucial. The purity of high-quality copper powder should generally be no less than 99.95%. Impure copper powder may contain oxides, moisture or other impurities, which will seriously affect the conductivity and ductility of copper. In tungsten-copper electrodes, copper mainly contributes to good electrical and thermal conductivity. If the copper powder is impure, the electrical and thermal conductivity efficiency of the electrode will be greatly reduced. For example, when there is a lot of copper oxide in the copper powder, the resistivity of copper oxide is much higher than that of pure copper, which will significantly increase the resistance of the electrode, resulting

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in a decrease in the efficiency of converting electrical energy into thermal energy in applications such as electrospark machining. This not only affects the processing efficiency, but may also cause local overheating of the electrode and accelerate electrode loss.

Control of particle size and particle size distribution

In addition to purity, the particle size and distribution of tungsten and copper powders are also key factors affecting the performance of tungsten-copper electrodes. The particle size needs to be precisely selected based on the different preparation processes and final application scenarios. In the conventional powder metallurgy process for preparing tungsten-copper electrodes, the particle size of tungsten powder is generally controlled between 1 and 10 μm . Finer tungsten powder can increase the contact area between tungsten and copper, promote diffusion and fusion between elements during the sintering process, and facilitate the formation of a more uniform and dense microstructure, thereby improving the strength and hardness of the electrode, making it more suitable for processing high-hardness materials. However, overly fine tungsten powder can also bring some problems, such as poor fluidity, making it difficult to evenly distribute during the powder mixing and molding process, and easily leading to uneven density in the green body. While coarser tungsten powder has better fluidity, it will make the internal pores of the sintered electrode relatively larger, reducing the density and affecting the overall performance of the electrode.

Copper powder typically has a relatively fine particle size. This is because copper has a lower melting point, making it easier to fill the gaps between tungsten particles during the sintering process. Copper powder of the appropriate particle size ensures good wettability while forming a stable interface with tungsten. For example, in EDM electrodes, if the copper powder particle size is appropriate, when the electrode heats up locally during discharge, the copper can quickly conduct the heat away, preventing excessive wear of the electrode due to local overheating.

Furthermore, the uniformity of particle size distribution is also crucial. Ideally, both tungsten and copper powders should have a narrow particle size distribution range. If the particle size distribution is too wide, particles of different sizes can easily segregate during the mixing process, leading to uneven composition and performance of the final electrode material. For example, areas where large tungsten powder particles are concentrated may have high hardness but insufficient toughness, while areas where small particles are concentrated may lack density, resulting in performance shortcomings during use.

Comprehensive influence of raw material characteristics on electrode performance

The inherent properties of tungsten and copper play a decisive role in the performance of tungsten-copper electrodes. Tungsten's extremely high melting point (3410°C) and hardness endow tungsten-copper electrodes with excellent high-temperature and wear resistance. In high-temperature environments, such as when high-voltage discharge tube electrodes are in operation, where the instantaneous contact material temperature can reach thousands of degrees Celsius, tungsten maintains the electrode's basic shape and structural integrity, preventing softening and deformation due to high temperatures. Furthermore, its high

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hardness makes the electrode less susceptible to wear when machining high-hardness workpieces, such as in the EDM of carbide molds, ensuring machining accuracy.

Copper, with its excellent electrical and thermal conductivity, provides tungsten-copper electrodes with the advantages of rapid heat dissipation and efficient electrical conduction. During EDM, frequent discharges between the electrode and the workpiece generate a large amount of heat. Copper can quickly conduct this heat away, lowering the electrode temperature, reducing thermal deformation and thermal fatigue, and extending the electrode's service life. Good electrical conductivity ensures a stable discharge process and improves machining efficiency. When tungsten powder and copper powder are compounded in a certain ratio, the two complement and synergize to determine the performance of the tungsten-copper electrode. A suitable tungsten-copper ratio ensures an optimal balance between strength, hardness, electrical and thermal conductivity, and ablation resistance. For example, resistance welding electrodes generally require higher hardness and conductivity, and the tungsten content can be appropriately increased.

2.4.1 Tungsten powder requirements

Tungsten-copper electrodes are crucial for ensuring structural stability and performance during the composite process. These requirements involve purity, particle size, and morphology. Purity is paramount, requiring impurities below 0.1%, particularly those of oxygen, carbon, and iron. Excessive impurities can weaken grain boundaries and reduce conductivity, impacting electrode performance. International standards such as ASTM B702 stipulate that high-purity tungsten powder must be produced through hydrogen reduction or chemical precipitation, with an oxygen content below 0.05%. Particle size is another key parameter. Particle size typically ranges from 1 to 20 microns. Fine particles are introduced through nanotechnology to enhance grain uniformity and mechanical strength, while coarse particles (>20 microns) are used for rough electrode processing. The choice of particle size depends on the application. Morphology requires spherical or near-spherical tungsten powder to reduce porosity and increase sintered density. Scanning electron microscopy analysis shows that spherical powders have better flowability than irregular powders and improve filling efficiency by approximately 15%. Chemical stability requires that tungsten powder withstand acidic and alkaline environments to prevent oxidation during the preparation process, and the surface oxide layer thickness must be controlled below 10nm. Fluidity, as measured by the Hall effect flow rate method, is better than 20s/50g, ensuring uniform powder mixing. The bulk density of tungsten powder affects compaction and must be matched with copper powder to reduce the risk of delamination. Preparation processes such as plasma spheroidization or mechanical alloying can optimize particle size distribution. In the future, high-purity nano-tungsten powders can improve the microstructural consistency of electrodes, making them suitable for high-precision applications such as microelectronic packaging and 5G devices.

2.4.2 Copper powder requirements

Tungsten-copper electrodes focus on its conductivity and filling properties, ensuring the electrical and thermal management capabilities of the composite material. Purity is a core requirement. The impurity

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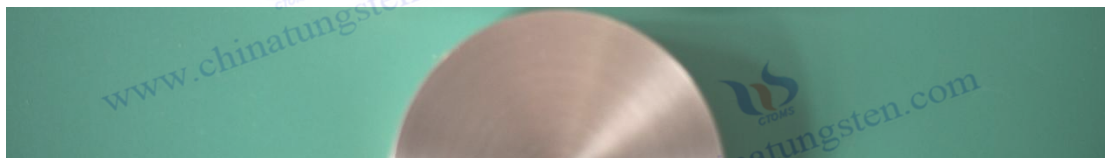
content of the copper powder must be less than 0.05%, and the oxygen content must be controlled below 0.03%. Excessive oxygen may lead to the formation of copper oxide, reducing conductivity and wettability. Electrolytic copper powder or atomized copper powder is prepared by atomizing high-purity electrolyte or inert gas and complies with ASTM B413 standards. The particle size is typically between 5 and 15 microns. Fine particle size improves filling efficiency, while coarse particle size is suitable for rapid sintering. It must be matched to the tungsten powder particle size, and the particle size ratio must be controlled between 1:2 and 1:3 to optimize phase distribution.

The copper powder must be spherical or nearly spherical in shape to minimize porosity and enhance fluidity. The Hall effect flow rate must be better than 15 s/50 g, the bulk density must be approximately 4-6 g/cm³, and the powder must be compacted in a coordinated manner with the tungsten powder. Chemical stability requires a surface oxide layer less than 5 nm thick to prevent pore formation during sintering. Surface treatment (such as organic coating) can enhance oxidation resistance. Electrical conductivity must approach that of pure copper (5.8×10^7 S/m), and thermal conductivity must be approximately 400 W/ m·K to support electrode performance. Preparation processes, such as water atomization or gas atomization, can influence powder properties. Future efforts, such as using ultrafine copper powders or alloying (e.g., Cu-Ag), can improve wettability and conductive stability, making them suitable for high-current applications.

2.4.3 Raw material pretreatment standards

Tungsten-copper electrodes are designed to ensure uniform powder mixing and controllable preparation processes, which directly impact the quality of the composite material. Drying is a critical step. Tungsten and copper powders must be dried in a vacuum or inert gas environment (such as argon) to prevent the formation of pores during sintering. Mixing uniformity is achieved using a ball mill or V-type mixer. The particle size distribution after mixing is controlled within $\pm 5\%$, and X-ray diffraction (XRD) verifies phase consistency.

Particle size classification is carried out by sieving, with the sieve size adjusted to the particle size requirements to remove oversized or ultrafine particles, and the standard deviation of the particle size distribution is less than 10%. Surface treatment includes deoxidation or coating, and the oxide layer is removed by hydrogen reduction. Powder flowability is tested using the Hall flow rate method, with a value better than 20s/50g, ensuring uniform pressing. Storage and transportation require sealed packaging, away from light and moisture, to prevent oxidation. Pretreatment standards must comply with ISO 13320 and ASTM B214. In the future, automated grading and real-time monitoring will improve pretreatment accuracy and optimize electrode performance.



CTIA GROUP LTD Copper Tungsten Electrode

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Tungsten-copper alloy electrodes Introduction

1. Overview of Tungsten-copper alloy electrodes

Tungsten-copper alloy electrodes are composite materials made primarily from high-purity tungsten powder and copper powder, produced through processes such as isostatic pressing and high-temperature sintering. They combine tungsten's high melting point and hardness with copper's electrical conductivity and ductility, offering characteristics such as high-temperature resistance, low thermal expansion, and resistance to arc erosion. These properties make them widely used in resistance welding, electrical discharge machining, high-voltage discharge tubes, and electronic device heat dissipation applications. CTIA GROUP LTD provides a variety of customized tungsten-copper electrode services, with products featuring excellent appearance and stable performance.

2. Typical Properties of Tungsten-copper alloy electrodes

Product Name	Chemical Composition (%)			Physical and Mechanical Properties			
	Cu	Total Impurities ≤	W	Density (g/cm³)	Hardness (HB)	Resistivity (MΩ·cm)	Tensile Strength (MPa)
Tungsten Copper (50)	50±2.0	0.5	Balance	11.85	115	3.2	—
Tungsten Copper (60)	40±2.0	0.5	Balance	12.75	140	3.7	—
Tungsten Copper (70)	30±2.0	0.5	Balance	13.8	175	4.1	790
Tungsten Copper (80)	20±2.0	0.5	Balance	15.15	220	5	980
Tungsten Copper (90)	10±2.0	0.5	Balance	16.75	260	6.5	1160

3. Applications of Tungsten-copper alloy electrodes

Resistance Welding Electrodes: Used as electrodes for spot welding or seam welding of low-carbon steel and coated steel plates.

Repair Welding Electrodes: Applied in cold stamping, bending, extrusion, and die-casting molds.

Electrical Discharge Machining (EDM) Electrodes: Used for mold discharge machining, or as molds and fixtures for projection welders, as well as molds or inlaid electrodes for heat-resistant steel.

High-Voltage Discharge Tube Electrodes: This electrode allows high-pressure flushing to remove eroded material from the tube body.

4. Purchasing Information

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Chapter 3: Physical and Chemical Properties of Tungsten-Copper Electrodes

The physical and chemical properties of tungsten-copper electrodes are derived from the synergistic effect of tungsten and copper, integrating the core advantages of the two metals. In terms of physical properties, its density increases with the increase of tungsten content, and remains at a high level overall; the melting point is maintained at a high level due to the high melting point characteristics of tungsten, which is far superior to pure copper, and can withstand instantaneous thermal shock in high-temperature environments without easily deforming. The electrical and thermal conductivity are outstanding, and it can efficiently conduct current and quickly dissipate the heat generated during work, effectively avoiding losses caused by local overheating. In terms of mechanical properties, it has moderate hardness and high compressive strength, while taking into account a certain degree of toughness, and is not easy to break when subjected to mechanical shock. In addition, its linear expansion coefficient is low and its thermal stability is excellent. Even in an environment with large temperature changes, the size can remain stable, making it suitable for precision machining scenarios with strict precision requirements.

3.1 Physical properties of tungsten copper electrode

Tungsten-copper electrodes, encompassing density, coefficient of thermal expansion, electrical conductivity, and thermal conductivity, form the foundation for their superior performance in a wide range of applications. These properties directly impact the electrode's stability and efficiency in EDM, welding, and microelectronic packaging. The physical properties of tungsten-copper electrodes stem from the combined properties of tungsten and copper: tungsten provides a high melting point and mechanical strength, while copper contributes high electrical and thermal conductivity. Optimizing the microstructure through powder metallurgy or vacuum infiltration processes results in a uniform phase distribution and low porosity. This combined performance enables tungsten-copper electrodes to maintain reliability under high temperatures, high currents, and complex environments.

3.1.1 Density of tungsten copper electrode

Tungsten-copper electrodes is an important indicator of their physical properties. It reflects the density and porosity inside the material and directly affects the mechanical strength, electrical conductivity, and thermal conductivity. The density characteristics are derived from the composite ratio of tungsten and copper and the optimization of the preparation process. The high density of tungsten and the lower density of copper are balanced through a specific ratio to form a composite material with specific mass and volume properties. The density determines the wear resistance and deformation resistance of the electrode during processing. In microelectronics applications, appropriate density helps to match the substrate and reduce stress concentration. Preparation processes such as powder metallurgy and vacuum infiltration significantly affect the uniformity of the final density by controlling the sintering temperature and pressure. Lower porosity usually corresponds to higher density values, enhancing the overall performance of the material.

Density measurement and control are crucial in the production of tungsten-copper electrodes, affecting

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their performance in practical applications, such as material removal rate in electrospark machining or thermal management efficiency in welding. Different application scenarios may require adjusting the tungsten-copper ratio to optimize density characteristics. For example, high-density electrodes are more suitable for scenarios requiring high durability, while lower-density electrodes may be used for lightweight designs. Phase distribution and compactness in the microstructure are key factors in density performance, and future research may further improve density controllability through new processes. This section will further explore density calculation methods and analyze their role in performance optimization.

3.1.1.1 Density calculation method

Density calculation is a scientific approach to determining the density of tungsten-copper electrodes. It involves both experimental measurements and theoretical derivations, aiming to accurately assess the material's internal compactness and porosity. A commonly used method is the Archimedean method, which measures the mass difference between the electrode in air and liquid and combines this with volume to calculate density. This method exploits the buoyancy of an object in a liquid. The dry mass of the electrode is first weighed, then immersed in a specific liquid (such as distilled water). The mass difference after immersion is measured, and the volume is indirectly calculated using the buoyancy formula. Density is then calculated as the ratio of mass to volume. This method is suitable for irregularly shaped electrode samples. It is important to ensure that the liquid does not chemically react with the material, and to control the temperature to minimize errors.

Another approach is theoretical calculation, which uses mixing rules to estimate the overall density of the composite material based on the volume fractions and respective densities of tungsten and copper. This method requires precise component ratio data and assumes that tungsten and copper do not undergo significant volume changes during the composite process. The density is a weighted average of the densities of the components. The calculation must account for the uniformity of phase distribution. Actual measured values may deviate from the theoretical values due to porosity or microscopic defects, requiring correction through microscopic analysis. Theoretical calculations are suitable for preliminary design and process optimization, but experimental results must be verified.

Additionally, X-ray tomography (XCT) or mercury penetration analysis can be used for nondestructive testing of electrode porosity and density distribution. These methods assess the density of the internal structure through image reconstruction or pressure penetration analysis and are suitable for electrodes with complex geometries. The choice of calculation method depends on the experimental conditions and accuracy requirements, and multiple methods are often combined to improve reliability.

3.1.1.2 Relationship between density and composition

The relationship between density and composition is the key to understanding the physical properties of tungsten-copper electrodes, reflecting the influence of the ratio of tungsten to copper on the density and mass distribution of the material. The density of tungsten-copper electrodes is mainly determined by the

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ratio of their components. Tungsten has a higher density than copper. An increase in tungsten content usually leads to an increase in overall density, while the lower density of copper plays a diluting role in high copper content ratios. The composition ratio is precisely controlled by powder metallurgy or vacuum infiltration processes. For example, in the common WCu 70/30 and WCu 80/20 ratios, the high density characteristics of tungsten dominate, while the filling effect of copper optimizes the uniformity of the microstructure. Composition changes directly affect the phase distribution. Tungsten provides structural support as a skeleton material, and copper fills the pores in the form of a liquid phase. Adjusting the ratio changes the porosity and density of the material, thereby affecting the density performance.

The compositional dependence of density is also closely related to the preparation process. In powder metallurgy, the particle size ratio and mixing uniformity of tungsten powder and copper powder determine the uniformity of component distribution. Sintering temperature and pressure further affect the wetting and filling effect of copper, affecting the final density. In vacuum infiltration, the porosity of the tungsten skeleton and the penetration depth of copper are directly related to the composition ratio. A high tungsten content may lead to insufficient pore filling and reduce density, while a high copper content enhances the filling efficiency. Microstructural analysis shows that slight changes in the composition ratio will lead to differences in the phase interface area, affecting the overall density of the material. In theory, the relationship between density and composition can be derived through a weighted average model, where the contribution of each component density is weighted by volume fraction, but the actual value is affected by porosity and interface bonding and needs to be verified in combination with experiments.

Furthermore, the relationship between composition and density is also affected by impurities and additives. Small amounts of impurities can alter interfacial properties and affect density stability. Different applications have different requirements for composition and density. For example, high-density electrodes are more suitable for wear-resistant applications, while low-density electrodes are used for lightweight designs.

3.1.1.3 Impact of density on applications

Density is one of the core performance parameters of tungsten-copper electrodes. Its level and distribution directly determine the applicability, stability and efficiency of the electrode in different application scenarios. Especially in high-end fields such as EDM, welding and microelectronics packaging, slight differences in density may cause significant fluctuations in performance, thereby affecting the overall process effect.

1. The relationship between density and mechanical properties and their application impact

Tungsten copper electrodes is positively correlated with their mechanical strength and wear resistance. High-density electrodes have extremely low internal porosity, and the tungsten particles and copper phases are tightly bonded to form a dense microstructure. This allows the material to evenly disperse stress when subjected to external force or high-temperature shock, making local fracture or deformation

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less likely to occur. This characteristic is particularly critical in EDM: high-frequency discharge between the electrode and the workpiece will generate instantaneous high temperature and mechanical shock. High-density electrodes, with their higher compressive strength and deformation resistance, can effectively withstand the impact force during the discharge process, reduce surface ablation marks, and reduce the risk of local collapse due to loose structure. For example, in the precision machining of high-strength materials such as mold steel, high-density tungsten copper electrodes can maintain stable shape accuracy and ensure a uniform discharge gap, thereby improving the surface finish and dimensional accuracy of the workpiece and extending the service life of a single electrode.

In contrast, low-density electrodes have more pores inside, which reduces the interface area between tungsten and copper, and reduces the overall wear resistance of the material. This type of electrode is more applicable in low-load, short-cycle processing tasks, such as EDM processing of small plastic parts, which has relatively low requirements for precision and durability, and the cost advantage of low-density electrodes can be reflected. However, in high-energy, long-term processing scenarios, the pores of low-density electrodes will become stress concentration points. As the processing time increases, microcracks are likely to form around the pores, eventually leading to electrode failure, increasing replacement frequency and production costs.

2. Impact of Density on Thermal Conductivity and Process Optimization

Density is the core factor affecting the thermal conductivity of tungsten copper electrodes. High density usually corresponds to better thermal conductivity efficiency. Inside the material, the copper phase serves as the main thermal conductor, and the continuity of its distribution directly depends on the material density: in high-density electrodes, the copper phase can more evenly fill the gaps between tungsten particles, forming a continuous thermal conductivity network, allowing the heat generated in the processing area (such as the instantaneous high temperature during electric spark discharge) to quickly diffuse into the interior of the electrode and be conducted out through the equipment fixture, thereby reducing the risk of local overheating. This efficient heat dissipation capability is crucial to processing accuracy - if heat accumulates on the electrode surface, it will cause a sudden rise in local temperature, which may not only melt or evaporate the surface material of the electrode, causing loss of electrode size, but also affect the discharge stability, resulting in defects such as burns and cracks on the workpiece surface. For example, in the precision processing of complex curved surfaces such as aircraft engine blades, the efficient heat dissipation characteristics of high-density tungsten copper electrodes can ensure temperature stability during long-term processing, maintain the consistency of discharge parameters, and ultimately achieve high-precision forming of the workpiece.

Low-density electrodes have discontinuous copper phase distribution, and the pores hinder heat conduction, forming a "thermal resistance zone" and reducing heat dissipation efficiency. In low-power processing scenarios, this defect may not be obvious, but in high-energy EDM (such as rough machining of large molds), heat accumulation will significantly increase electrode wear, forcing the process to reduce discharge energy to avoid overheating, indirectly reducing processing efficiency. Therefore, in applications with stringent heat dissipation requirements, high-density electrodes are a key choice for

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improving process stability.

3. Multiple Roles of Density in Welding Applications

In the field of welding, the density of tungsten copper electrodes directly determines the quality and efficiency of welding by affecting electrical conductivity and thermal management capabilities. High-density electrodes have a continuous distribution of copper phases and lower resistance values, which can provide a stable current transmission path for the welding process and reduce the "resistance heat" generated by excessive resistance. This extra heat not only wastes energy, but may also cause the electrode itself to overheat and deform, affecting the contact stability between the electrode and the workpiece. For example, in resistance spot welding of automobile bodies, high-density tungsten copper electrodes can maintain stable current output at high currents, ensuring heat concentration and nugget formation at the weld point, avoiding defects such as cold welds or weld penetrations. In continuous welding processes such as seam welding, their excellent electrical conductivity can also reduce current fluctuations and ensure the uniformity of the weld.

The relationship between density and electrode weight also impacts welding equipment. High-density electrodes are heavier and are suitable for fixed automated welding equipment—the robotic arms or fixtures of such equipment have strong load-bearing capacity, and counterweights can be adjusted to ensure precise contact between the electrode and the workpiece. However, in portable welding equipment (such as handheld spot welding guns), overly heavy electrodes increase the operator's workload. In this case, the lightweight advantage of low-density electrodes is more prominent. Their design must balance weight and performance, typically by optimizing the tungsten-copper ratio to reduce density while preserving the core electrical and thermal conductivity as much as possible.

Furthermore, the thermal cycling during welding places special demands on electrode density. High-density electrodes, due to their dense structure and more uniform thermal expansion, are less susceptible to cracking due to internal stress concentration during repeated heating and cooling, making them suitable for high-frequency welding scenarios (such as batch welding on home appliance production lines). Low-density electrodes, however, may experience surface peeling after long-term thermal cycling due to stress concentration around the pores, shortening their service life.

4. The relationship between density and reliability in microelectronic packaging

Microelectronics packaging places even more stringent demands on the density of tungsten-copper electrodes. The core requirement is to achieve thermal expansion matching and mechanical stability between the electrode and the substrate. In chip packaging, the electrodes must be tightly bonded to materials such as silicon wafers and ceramic substrates. However, different materials have different thermal expansion coefficients. If the electrode density is too high, its overall thermal expansion coefficient may deviate significantly from the substrate. During temperature cycling, significant stress will be generated at the interface between the electrode and the substrate. Long-term accumulation may lead to solder cracking, circuit breakage, and even package failure. Therefore, tungsten-copper electrodes

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for microelectronics packaging must precisely control density to adjust the thermal expansion coefficient to a range close to that of the substrate. Medium-to-high density designs are typically used—ensuring both structural density to support current transmission and mitigating thermal stress through optimized pore distribution (such as a small number of evenly distributed micropores) to ensure long-term reliability. At the same time, the mechanical stability of high-density electrodes is essential in microelectronics packaging. During chip packaging, electrodes must withstand the mechanical stresses of bonding, packaging, and other processes. The high compressive strength of high-density electrodes prevents deformation or breakage due to external forces, ensuring precise alignment between the electrodes and chip pins. However, low-density electrodes with uneven pore distribution may experience localized collapse under bonding pressure, affecting the stability of the electrical connection. For example, in the high-frequency packaging of 5G chips, even slight electrode deformation can lead to increased signal transmission loss.

5. Impact of Density on Manufacturing Cost and Scenario Adaptation

Density is also directly related to the manufacturing cost and processing difficulty of tungsten copper electrodes. The production of high-density electrodes requires higher sintering pressures, longer holding times, and even secondary pressurization processes to reduce internal porosity, which undoubtedly increases equipment energy consumption and production cycles. At the same time, the processing of high-density materials (such as precision grinding and wire cutting) is more difficult, and tool wear is faster, further pushing up manufacturing costs. However, in high-end application scenarios (such as the processing of precision components for aerospace engines), its performance advantages are sufficient to cover the cost increase. The losses caused by equipment failure or product scrapping are far higher than the cost of the electrode, and the durability of high-density electrodes becomes the preferred choice. The production process of low-density electrodes is relatively simple. Lower sintering pressures and shorter processing times can reduce costs, but its performance limitations make it more suitable for cost-sensitive scenarios that do not require extreme performance (such as welding low-end components for consumer electronics). In addition, specific industries have customized requirements for density: in order to reduce the overall weight, aerospace equipment tends to choose low-density tungsten-copper electrodes in non-core components, and retain the necessary strength while reducing weight through structural design; while the electrodes of nuclear power equipment require high-density design to resist material aging and corrosion in radiation environments and ensure long-term stable operation.

3.1.2 Thermal properties of tungsten copper electrodes

The thermal properties of tungsten-copper electrodes are an important component of their physical properties, covering thermal conductivity, thermal expansion coefficient, and high-temperature resistance, which directly affect the performance of the electrode in high-temperature environments and thermal cycles. Thermal conductivity is mainly provided by the copper phase. The high thermal conductivity of copper ensures that heat is quickly transferred from the processing or operating area to the outside, reducing local temperatures and preventing overheating, deformation, or damage to the workpiece. The moderate thermal conductivity of tungsten and the synergistic effect of the copper phase

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form the overall thermal management capabilities of the composite material, which is suitable for high heat load scenarios in EDM and welding. Thermal properties also include the thermal expansion coefficient. The low thermal expansion characteristics of tungsten and the high thermal expansion characteristics of copper are balanced by proportional adjustment. The thermal expansion coefficient of the composite matches that of a variety of substrates to reduce thermal stress.

High-temperature resistance is the core of thermal performance. Tungsten's high melting point imparts stability to the electrode at extremely high temperatures. The copper phase fills the pores in liquid form at high temperatures, enhancing thermal stability and making it suitable for arc environments. The low porosity and uniform phase distribution in the microstructure further optimize the heat conduction path, and the hot isostatic pressing process improves the thermal conductivity efficiency of the interface. Thermal fatigue testing shows that tungsten-copper electrodes maintain structural integrity over a wide temperature range, making them suitable for microelectronic packaging and sensor applications. In the future, functional gradient design or surface modification can further enhance thermal performance to accommodate even higher temperature differences or complex thermal management requirements.

3.1.2.1 Thermal conductivity

Thermal conductivity is the core indicator of the thermal performance of tungsten-copper electrodes. It reflects the material's ability to transfer heat and directly affects its performance in high-heat-load applications. Thermal conductivity is mainly provided by the copper phase. The high thermal conductivity of copper ensures that heat is quickly transferred from the processing area or operating area to the outside, preventing deformation or workpiece damage caused by local overheating. The moderate thermal conductivity of tungsten and the synergistic effect of the copper phase form the overall thermal management capability of the composite material, which is suitable for the heat dissipation needs of high-energy discharge in electrospark machining. During the preparation process, powder metallurgy or vacuum infiltration technology optimizes the heat conduction path by controlling the ratio of tungsten and copper and the sintering conditions. The low porosity and uniform phase distribution in the microstructure reduce thermal resistance and enhance thermal conductivity.

Thermal conductivity is also closely related to the electrode's microstructure and composition ratio. High copper content (e.g., WCu 70/30) generally corresponds to higher thermal conductivity. The continuous network of copper phases provides an efficient heat conduction channel, while the tungsten skeleton maintains structural stability at high temperatures. In welding applications, higher thermal conductivity ensures even heat distribution, reduces the heat-affected zone, and improves joint quality. In microelectronic packaging, thermal conductivity supports chip heat dissipation, reduces operating temperatures, and extends service life. The hot isostatic pressing (HIP) process optimizes interfacial bonding through omnidirectional pressure, further improving thermal conductivity efficiency. Thermal conductivity performance is also affected by environmental factors. For example, the softening of the copper phase at high temperatures may slightly reduce heat transfer capacity, but the supporting role of tungsten maintains overall stability. In practical applications, optimizing thermal conductivity depends on specific scenarios. For example, high-power processing requires electrodes with higher thermal

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conductivity, while lightweight designs may sacrifice some thermal conductivity to reduce density. Thermal conductivity testing is typically performed using laser flash or steady-state heat flow methods. Future improvements in thermal conductivity could be achieved through the introduction of nanotechnology or functional gradient design (e.g., increasing copper content from the inside out) to accommodate higher heat loads, such as in 5G devices or high-temperature sensors.

3.1.2.2 Thermal expansion coefficient

The coefficient of thermal expansion (CTE) is a crucial component of the thermal performance of tungsten-copper electrodes. It reflects the material's ability to change volume under temperature fluctuations and directly influences its compatibility with the substrate and thermal cycling stability. The CTE is primarily determined by the properties of tungsten and copper. The low CTE of tungsten (approximately 4.5 ppm/°C) and the high CTE of copper (approximately 17 ppm/°C) are balanced by adjusting the composite ratio. The CTE of tungsten-copper electrodes is typically controlled between 6-8 ppm/°C. This value is close to that of silicon (approximately 2.6 ppm/°C) or alumina ceramic (approximately 7 ppm/°C) substrates. This reduces stress concentration during thermal cycling, preventing package warping or fracture, making it particularly suitable for microelectronic packaging and sensor applications. Adjusting the CTE depends on the W/Cu ratio and the fabrication process. For example, an 85/15 W/Cu ratio exhibits excellent performance at high temperatures. Thermal simulations have verified its low stress characteristics, and the thermal expansion compatibility with the silicon substrate is within 10%. The uniform phase distribution and low porosity in the microstructure further minimize differential thermal expansion. The hot isostatic pressing process improves the thermal stability of the interface, reducing the risk of microcracking during thermal cycling. In EDM, a moderate thermal expansion coefficient ensures the electrode's ability to recover after high-energy discharge. In welding, thermal expansion matching reduces joint stress and improves durability. The thermal expansion coefficient is also affected by ambient temperature and long-term use. The softening of the copper phase at high temperatures may slightly increase expansion, but the support of the tungsten skeleton maintains overall stability.

3.1.2.3 High temperature resistance

High-temperature resistance is a prominent feature of the thermal properties of tungsten-copper electrodes. It reflects the material's structural stability and ability to maintain performance in extremely high-temperature environments, and directly determines its suitability for high-heat-load applications. This high-temperature resistance is primarily provided by tungsten, which has a melting point of 3422°C, the highest of all metals. This property enables tungsten-copper electrodes to maintain structural integrity during arc discharge or high-temperature welding, resisting melting or deformation. In the composite structure, tungsten acts as a skeleton material, forming a high-strength, thermally stable network. The copper phase fills the pores in liquid form at high temperatures, enhancing the material's overall thermal stability, making it suitable for EDM of high-hardness materials or disconnection operations in high-voltage switches. High-temperature resistance also depends on the microstructure and preparation process. Low porosity and uniform phase distribution are achieved through powder metallurgy or

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vacuum infiltration processes, reducing thermal stress concentration at high temperatures. Hot isostatic pressing (HIP) further optimizes interfacial bonding and improves thermal fatigue resistance. In EDM, high-temperature resistance reduces ablation on the electrode surface under high-energy discharges, extending service life. High-temperature resistance is also affected by the copper phase. Copper has a low melting point (1083°C) and may soften at extremely high temperatures, but the support of the tungsten skeleton maintains structural integrity. Surface treatments (such as nickel plating) further enhance oxidation resistance and extend service life in humid or industrial environments.

3.2 Functional performance of tungsten-copper electrode

Tungsten-copper electrodes is their core value in practical applications, encompassing electrical conductivity, arc erosion resistance, mechanical durability, and thermal management capabilities. These properties stem from the composite properties of tungsten and copper. By optimizing the preparation process and microstructure, tungsten-copper electrodes demonstrate multifunctionality in EDM, welding, and microelectronic packaging. Electrical conductivity is provided by the copper phase, ensuring efficient current transfer; arc erosion resistance is supported by tungsten's high melting point and hardness, reducing surface losses; mechanical durability is achieved through uniform phase distribution and low porosity, supporting high-load operation; and thermal management combines the thermal conductivity of copper with the stability of tungsten to optimize performance in high-temperature environments.

3.2.1 Conductive properties of tungsten-copper electrodes

Tungsten-copper electrodes is the core foundation for their functional value, directly determining their electrical efficiency and long-term reliability in fields such as EDM, welding, and microelectronics packaging. This unique performance stems from the synergistic effect of tungsten and copper: copper, a naturally conductive metal, forms a continuous current transmission network within the electrode, providing a low-resistance path for charge flow; while tungsten's high melting point and high strength form a robust framework, maintaining the electrode's structural stability under harsh operating conditions such as high temperature and mechanical stress, and preventing the copper phase from overheating or deformation, which could lead to a break in the conductive path. This combination of the two retains copper's conductive advantages while addressing the shortcomings of pure copper in strength and high-temperature resistance, making tungsten-copper electrodes an ideal choice for complex electrical environments.

Microstructural Basis of Electrical Conductivity

Tungsten-copper electrodes are closely related to their microstructure, with the core focus being the distribution of the copper phase and the bonding quality of the tungsten-copper interface. Through processes such as powder metallurgy or vacuum infiltration, the microstructure can be precisely controlled. Powder metallurgy involves mixing tungsten powder and copper powder in a certain proportion, pressing, and sintering them, so that the copper phase evenly fills the gaps between tungsten

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particles, forming a dense "tungsten skeleton-copper filler" structure. Vacuum infiltration involves infiltrating liquid copper into a pre-sintered tungsten skeleton at high temperatures, using capillary action to achieve a continuous distribution of the copper phase. Both processes share the goal of reducing internal porosity and interface defects. Porosity can block the current path, leading to a sudden increase in local resistance, while poor interface bonding can form "contact resistance," increasing the resistance to charge transfer. Therefore, low porosity and uniform phase distribution are prerequisites for high conductivity. They ensure uniform current conduction within the electrode, avoiding heat concentration or current fluctuations caused by local resistance differences.

Tungsten to copper is a key parameter for regulating electrical conductivity. The higher the copper content, the better the electrical conductivity in theory, because more copper phases can form a denser conductive network; but too high a copper content will weaken the supporting role of the tungsten skeleton, causing the electrode to soften and deform easily at high temperatures. In practical applications, it is necessary to balance the ratio of the two according to the needs of the scenario: for example, a higher copper content will be selected for scenarios that focus on conductive efficiency, while the proportion of tungsten will be appropriately increased for scenarios that need to take into account high-temperature stability. This ratio regulation is essentially to find a balance between "conductivity" and "structural stability" to adapt to the core needs of different working conditions.

Impact of conductive properties on application scenarios

In EDM, electrical conductivity directly affects machining accuracy and electrode life. During machining, high-frequency discharges are generated between the electrode and the workpiece to generate high-temperature molten material, and stable current transmission is a prerequisite for ensuring uniform discharge energy. Tungsten-copper electrodes with high conductivity can evenly distribute current density, avoiding the "over-discharge" phenomenon caused by excessive local resistance - that is, abnormally high temperatures caused by local current concentration, which can cause ablation of the electrode surface or defects such as pits and cracks on the workpiece surface. At the same time, excellent conductivity can reduce energy loss, convert more electrical energy into the heat energy required for machining, and improve machining efficiency; and stable current transmission can also reduce the "electrochemical corrosion" of the electrode, slow down the loss rate, and extend the single-use cycle.

In the field of welding, the quality of electrical conductivity directly determines the consistency of welding quality. Whether it is resistance spot welding or seam welding, the electrode needs to efficiently transmit current to the welding area, and melt the contact surface of the workpiece through resistance heat to form a molten core. Tungsten copper electrodes with high conductivity can ensure the stable output of current at the contact point between the electrode and the workpiece, avoiding uneven heat caused by resistance fluctuations - insufficient heat will cause cold welding, and excessive heat may penetrate the workpiece or cause the electrode to stick. In addition, during the welding process, the electrode itself will heat up due to resistance heat. If the conductivity is poor, the high temperature of the electrode may cause surface oxidation or deformation, further deteriorating the conductivity and forming a vicious cycle of "performance degradation-exacerbated overheating". The low resistance characteristics

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of high-conductivity electrodes can reduce self-heating and maintain long-term stable welding effects.

Microelectronic packaging has more sophisticated requirements for electrical conductivity. In the connection between the chip and the substrate, the tungsten copper electrode, as a conductive interconnect, needs to achieve low-resistance and stable circuit conduction to ensure the integrity of signal transmission. High-frequency, high-speed electronic signals are extremely sensitive to changes in resistance. Even small resistance fluctuations may cause signal delays or attenuation. Therefore, the tungsten copper electrodes used in microelectronic packaging must have extremely high conductivity consistency, and there must be no local high-resistance areas inside, otherwise it may become a "bottleneck" for signal transmission. At the same time, the temperature cycle in the packaging environment will cause the material to expand and contract. If the conductive performance is attenuated due to structural changes, it may cause poor circuit contact and even cause equipment failure. This requires the conductive performance of the electrode to remain stable during long-term use and not be significantly affected by environmental stress.

Correlation and significance of core conductive parameters

Conductivity, resistivity and current carrying capacity are the core parameters for measuring the conductive performance of tungsten copper electrodes. The three are interrelated and have different focuses. Conductivity reflects the ability of a material to conduct current. The higher the value, the better the conductivity; resistivity is the reciprocal of conductivity, which directly reflects the resistance to current transmission. In practical applications, these two parameters jointly determine the current intensity of the electrode at a specific voltage, which in turn affects the energy output efficiency. The current carrying capacity describes the maximum current that can continuously pass through the electrode without overheating or structural damage. It is not only related to the conductive performance, but also closely related to the heat dissipation capacity and high temperature resistance of the material - high conductivity can reduce Joule heat when current passes through, and the high temperature resistance of the tungsten skeleton provides structural support for carrying large currents.

Balancing these three parameters is crucial in tungsten-copper electrode design. For example, in high-current applications, both high conductivity (to minimize heat generation) and high current-carrying capacity (to avoid structural failure) must be maintained. In precision microelectronics, however, greater emphasis is placed on conductivity stability and uniformity to ensure accurate signal transmission. In-depth research and control of these parameters is both the foundation for optimizing tungsten-copper electrode performance and the technical guarantee for its adaptability to diverse high-end applications.

3.2.1.1 Conductivity

Conductivity is a fundamental indicator of the conductive properties of tungsten-copper electrodes, reflecting the material's ability to transfer charge and directly impacting its efficiency in electrical applications. Conductivity is primarily contributed by the copper phase, whose high conductivity ensures efficient current transmission within the electrode, forming a continuous conductive network. Tungsten's

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conductivity is lower than that of copper, but through optimized composite processes (such as a 70/30 WCu ratio), its conductivity can approach that of pure copper, meeting the high current demands of EDM and the low resistance requirements of welding. The uniform distribution of the copper phase within the microstructure reduces resistance variations and enhances discharge stability. This is particularly true in precision machining applications (such as micro-molds), where conductivity directly determines machining accuracy and surface quality.

Achieving high electrical conductivity depends on the manufacturing process. Powder metallurgy controls copper wetting and filling by sintering temperature and pressure. Vacuum infiltration optimizes the phase interface through liquid copper penetration, reducing porosity and minimizing scattering effects. Hot isostatic pressing (HIP) further enhances interfacial bonding and improves conductivity consistency. Conductivity is also affected by the composition ratio. High copper content (such as WCu 60/40) generally results in higher conductivity and is suitable for high-efficiency processing, while high tungsten content (such as WCu 90/10) performs well when wear resistance is prioritized. In practical applications, high electrical conductivity supports stable arc discharge, reduces energy loss, and extends electrode life. In the future, the introduction of nano-copper powder or surface modification (such as silver plating) can further improve conductivity to adapt to higher current or high-frequency applications such as 5G equipment and power transmission.

3.2.1.2 Resistivity

Resistivity is another important indicator of the conductive properties of tungsten-copper electrodes. It reflects the material's resistance to current flow and directly affects the efficiency of electrical energy transfer and heat generation. Resistivity is primarily determined by the composite properties of tungsten and copper. Copper's low resistivity provides an efficient current path, while tungsten's high resistivity can increase overall impedance at high ratios. By optimizing the ratio, the resistivity of tungsten-copper electrodes is effectively reduced to near the level of pure copper, making them suitable for applications requiring low energy loss. The low porosity and uniform phase distribution in the microstructure reduce electron scattering and enhance resistivity consistency, which is particularly prominent in long-distance current transmission. Controlling resistivity depends on the manufacturing process. Powder metallurgy optimizes copper phase continuity through precise mixing and sintering, while vacuum infiltration further reduces resistivity by filling pores with liquid copper. Heat treatment and pressure-assisted processes (such as HIP) improve material density and reduce the resistance increase caused by grain boundaries and defects. Resistivity is also affected by temperature and environment. The softening of the copper phase at high temperatures may slightly increase resistance, but the support of the tungsten skeleton maintains overall stability. In electrospark machining, low resistivity reduces thermal effects and improves surface quality. In welding, it reduces joint resistance and improves efficiency.

3.2.1.3 Current carrying capacity

Current carrying capacity is a key indicator of the conductive properties of tungsten-copper electrodes. It reflects the electrode's stability and durability under high current conditions and directly determines its

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suitability for high-load applications. Current carrying capacity is primarily supported by the high conductivity of the copper phase and the high melting point of tungsten. Copper provides an efficient current transmission path, while the skeletal structure of tungsten maintains stability under high-temperature arcs, preventing melting or deformation. Tungsten-copper electrodes, through optimized ratios (such as WCu 80/20), perform exceptionally well under high currents. The low porosity and uniform phase distribution in the microstructure reduce the risk of localized overheating and enhance current carrying capacity.

Achieving current-carrying capacity depends on the manufacturing process. Powder metallurgy optimizes the phase interface by controlling sintering temperature and pressure. Vacuum infiltration improves density through the infiltration of liquid copper. Hot isostatic pressing further enhances the material's mechanical strength and conductive stability. A high tungsten content (such as WCu 90/10) improves resistance to arc erosion, making it suitable for high-energy discharge applications, while a high copper content (such as WCu 60/40) optimizes low-resistance transmission. In EDM, a high current-carrying capacity supports large-volume material removal; in welding, it ensures joint quality and durability under high currents. In practical applications, current-carrying capacity is also affected by ambient temperature and heat dissipation conditions. Good thermal management (such as air or liquid cooling) can improve the current-carrying limit. Improving current-carrying capacity also depends on electrode design. Complex geometries require uniform current distribution, and surface treatment (such as plating) can enhance corrosion resistance and extend service life.

3.2.2 Arc erosion resistance of tungsten copper electrodes

A tungsten-copper electrode's performance, reflecting its durability and stability in high-energy arc discharge environments. This characteristic gives it significant advantages in fields such as electrical discharge machining (EDM), resistance welding, and high-voltage switching. Arc erosion resistance is primarily due to tungsten's high melting point and hardness, combined with copper's conductivity and filling properties. Microstructure optimization through powder metallurgy or vacuum infiltration processes, along with low porosity and uniform phase distribution, further enhances erosion resistance. Under the action of an arc, material evaporation or melting may occur on the electrode surface. Arc erosion resistance directly impacts machining accuracy, service life, and cost-effectiveness.

3.2.2.1 Arc erosion mechanism

The arc erosion mechanism is fundamental to understanding the arc erosion resistance of tungsten-copper electrodes. It involves the thermal effects and material loss caused by arc discharge on the material surface. Arc erosion begins with a discharge under high voltage or high current conditions, generating a high-temperature plasma (reaching thousands of °C). This instantaneous heating of the electrode surface causes localized melting or vaporization of the material. In tungsten-copper electrodes, the arc action first affects the copper phase. Due to its low melting point (1083°C), the liquid copper may evaporate or sputter at high temperatures, exposing the tungsten skeleton. Tungsten's high melting point (3422°C) ensures structural stability under arcing, but surface oxidation or micro-ablation may occur, forming pits

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or cracks. The erosion process also involves thermal stress. Rapid heating and cooling lead to stress concentrations within the material, which may trigger microcrack propagation.

The arc ablation mechanism is also affected by the microstructure. Low porosity reduces heat concentration points, and uniform phase distribution (such as WCu 70/30) optimizes heat conduction and reduces the risk of local overheating. The arc energy and discharge frequency also affect the degree of ablation. High-energy discharges exacerbate material loss, while low-frequency discharges may only cause minor surface damage. Ablation products such as metal vapor or oxides may deposit on the workpiece surface, affecting processing quality. Preparation processes such as hot isostatic pressing (HIP) enhance ablation resistance by increasing density and reducing vaporization points in the pores. In the future, by studying arc energy distribution and material phase transformations, the ablation mechanism can be further revealed and electrode design can be optimized.

3.2.2.2 Evaluation of ablation resistance

Erosion resistance evaluation is a scientific method for assessing the arc erosion resistance of tungsten-copper electrodes. It involves experimental testing and performance analysis to ensure the electrodes' reliability in practical applications. This evaluation is typically conducted through arc erosion tests, simulating high-energy discharge conditions and recording the electrode's surface mass loss, dimensional change, and surface morphology. The mass loss rate is a key indicator. Electrodes with high erosion resistance exhibit significantly lower mass loss than pure copper or graphite electrodes after prolonged discharges. An 80/20 WCu ratio performs exceptionally well at 200A. Dimensional change is measured using 3D scanning to assess the degree of wear along the electrode profile. A low wear rate indicates high erosion resistance. Surface morphology analysis utilizes a scanning electron microscope (SEM) to observe the microstructure after erosion, assessing pit depth, crack density, and oxide layer thickness. Uniform erosion marks reflect microstructural stability. Erosion resistance is also assessed through life testing, which records the electrode's performance degradation after a specified number of discharges. Highly durable electrodes maintain both conductivity and mechanical strength. International standards such as ISO 14132 and IEC 62271-102 provide testing guidelines, including arc withstand tests and thermal stability assessments. Experimental results show that electrodes with optimized fabrication processes (such as vacuum infiltration) can reduce the ablation rate by approximately 30%.

The evaluation of ablation resistance also takes into account the application scenario. In electrospark machining, ablation resistance directly affects the machining accuracy and workpiece surface quality; in welding, it reduces the frequency of electrode replacement.

3.2.2.3 Factors affecting ablation resistance

Factors influencing ablation resistance are key to optimizing the performance of tungsten-copper electrodes, encompassing aspects such as material composition, microstructure, and operating conditions. The composition ratio is the primary factor. A higher tungsten content (e.g., WCu 90/10) increases ablation resistance. Tungsten's high melting point and hardness protect against arc shock. While a high

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copper content (e.g., WCu 60/40) improves conductivity, it also reduces ablation resistance. A balance must be struck between durability and efficiency. Microstructure has a significant impact. Low porosity reduces heat concentration points, while a uniform phase distribution optimizes heat transfer. The hot isostatic pressing (HIP) process improves density and reduces ablation rates by approximately 15%.

The manufacturing process is crucial to ablation resistance. In powder metallurgy, sintering temperature and pressure control the wetting effect of copper. In vacuum infiltration, penetration depth affects interface stability. High-temperature treatment reduces defects. Surface treatments such as nickel plating or coatings enhance oxidation resistance and reduce arc-induced surface damage. Operating conditions include arc energy and discharge frequency. High-energy discharge (e.g., 500A) exacerbates ablation, while low-frequency discharge reduces losses. Environmental factors such as moisture or oxidizing atmospheres can accelerate surface degradation, necessitating optimized working conditions. Electrode design also affects ablation resistance. Complex geometries require uniform current distribution to minimize local overheating.

3.3 Other properties of tungsten copper electrode

Tungsten-copper electrodes are key factors in their unique advantages in various application scenarios, covering hardness, strength, toughness, wear resistance, corrosion resistance, as well as resistance to welding and adhesion. These properties are derived from the composite characteristics of tungsten and copper. The microstructure is optimized through powder metallurgy or vacuum infiltration processes to form a material with low porosity and high uniformity. Tungsten's high melting point, hardness, and chemical stability provide a foundation for high-temperature resistance and wear resistance, while copper's high electrical conductivity, ductility, and thermal conductivity enhance electrical properties and toughness. The combined performance of other properties directly affects the durability, efficiency, and reliability of the electrode in EDM, welding, and microelectronic packaging.

3.3.1 Hardness of tungsten copper electrode

A tungsten-copper electrode is a key indicator of its mechanical properties, reflecting its durability and resistance to deformation under high loads and abrasive conditions. This property is primarily provided by tungsten, whose high hardness dominates the composite material. Combined with the filling effect of copper, powder metallurgy or vacuum infiltration processes optimize the microstructure, resulting in a uniform phase distribution and low porosity. Hardness directly impacts the electrode's erosion resistance during EDM, its compressive strength during welding, and its surface stability in microelectronic packaging. High-hardness electrodes can withstand frequent mechanical stress or arc shock, extending their service life while maintaining machining accuracy. Achieving this hardness depends on the tungsten-to-copper ratio and the preparation process. Higher tungsten content (such as WCu 80/20 or WCu 90/10) results in higher hardness. The natural hardness of tungsten provides a foundation for wear resistance, while the ductility of copper fills pores during sintering, enhancing the overall density of the material. The fine grains in the microstructure, optimized through hot isostatic pressing (HIP), further increase the hardness and reduce surface wear. Hardness testing typically uses the Vickers or Rockwell

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hardness methods. The results reflect the material's surface resistance to indentation. Preparation processes, such as high-temperature sintering and pressure control, directly influence the uniformity of the hardness distribution. In practical applications, electrodes with higher hardness perform better when machining high-hardness materials, minimizing electrode deformation.

Hardness is also affected by environmental and usage conditions. While softening of the copper phase at high temperatures may slightly reduce hardness, the support provided by the tungsten skeleton maintains overall stability. Surface treatments such as polishing or coatings can further enhance surface hardness and corrosion resistance. In microelectronic packaging, hardness ensures close contact between electrodes and substrates, preventing mechanical damage.

3.3.2 Strength of tungsten copper electrode

A tungsten-copper electrode is a key indicator of its mechanical properties, reflecting its resistance to fracture and deformation under high pressure and mechanical stress. This characteristic is supported by the high compressive strength of tungsten and the toughness of copper. Microstructural optimization through powder metallurgy or vacuum infiltration processes results in a composite material with low porosity and high density. Strength directly impacts the electrode's impact resistance in EDM, its compressive strength in welding, and its structural stability in microelectronic packaging. High-strength electrodes can withstand the stresses of high-energy discharges or mechanical clamping, extending their service life and improving processing efficiency.

The achievement of strength depends on the ratio of tungsten to copper and the preparation process. High tungsten content (e.g., WCu 85/15) significantly improves compressive strength. The tungsten skeleton provides high-strength structural support, while the copper filling optimizes microstructural uniformity and reduces stress concentration. The low porosity and uniform phase distribution in the microstructure are enhanced through hot isostatic pressing (HIP). The fine grain size improves the material's fatigue resistance, and strength testing shows that compressive strength can reach a relatively high level. Preparation processes such as sintering temperature and pressure control directly influence the uniformity of strength distribution. Vacuum infiltration enhances interfacial bonding through the penetration of liquid copper.

Strength is also affected by operating conditions. Softening of the copper phase at high temperatures may slightly reduce strength, but the support of the tungsten skeleton maintains overall stability. In EDM, high-strength electrodes can withstand the impact of high-energy discharges and reduce deformation. In welding, they support joint formation under high pressure. In microelectronic packaging, strength ensures that electrodes do not fracture during thermal cycling, enhancing reliability. Surface treatments such as plating can improve corrosion resistance, indirectly supporting strength performance.

3.3.3 Toughness of tungsten copper electrode

A tungsten-copper electrode is a key aspect of its mechanical properties, reflecting its resistance to

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fracture and energy absorption under impact or stress. This property is primarily provided by copper, whose high ductility and toughness play a key role in composite materials. Combined with the hardness of tungsten, the microstructure is optimized through powder metallurgy or vacuum infiltration processes, resulting in a material with low porosity and high uniformity. Toughness directly affects the electrode's crack resistance in EDM, its impact resistance in welding, and its structural flexibility in microelectronic packaging. Highly tough electrodes can absorb mechanical or thermal stresses, reduce brittle fracture, and extend service life. This section will explore in detail the toughness properties of tungsten-copper electrodes and their role in practical applications.

Achieving toughness depends on the ratio of tungsten to copper and the preparation process. Higher copper content results in greater toughness. Copper's elongation at break provides energy absorption, while the tungsten skeleton maintains structural stability at high temperatures. The low porosity and uniform phase distribution in the microstructure are optimized through hot isostatic pressing. The fine grain size improves the material's resistance to crack propagation. Toughness testing shows that the material exhibits some plastic deformation under impact. Preparation processes such as sintering temperature and pressure control directly influence the uniformity of toughness distribution. Vacuum infiltration, through the penetration of liquid copper, improves interfacial bonding and reduces stress concentration points. Toughness is also affected by operating conditions. Softening of the copper phase at high temperatures enhances toughness, but excessive temperatures can lead to a decrease in strength. The support provided by the tungsten skeleton maintains overall balance. In electrospark machining, electrodes with high toughness can withstand the impact of high-energy discharges and reduce crack formation. In welding, they absorb thermal stresses and improve joint durability. In microelectronic packaging, toughness prevents brittle fracture during thermal cycling, enhancing reliability. Surface treatments such as polishing can reduce surface defects and indirectly support toughness.

3.3.4 Wear resistance of tungsten copper electrode

Tungsten-copper electrodes is a key aspect of their mechanical properties, reflecting their resistance to wear and surface stability under repeated friction or high-load conditions. This characteristic is primarily provided by tungsten, whose high hardness and wear resistance dominate the composite material. Combined with the filling effect of copper, the microstructure is optimized through powder metallurgy or vacuum infiltration processes, resulting in a material with low porosity and high uniformity. Wear resistance directly impacts the electrode's long-term service life in EDM, its resistance to contact wear in welding, and its surface integrity in microelectronic packaging. Highly wear-resistant electrodes can withstand mechanical friction or arc shock, reducing material loss and maintaining machining accuracy.

Wear resistance depends on the ratio of tungsten to copper and the preparation process. Higher tungsten contents (such as WCu 80/20 or WCu 90/10) result in greater wear resistance. The natural hardness of tungsten provides the material with a wear-resistant foundation, while the ductility of copper fills pores during sintering, enhancing the density of the microstructure. The fine grains in the microstructure are optimized through the hot isostatic pressing (HIP) process, further improving wear resistance and reducing surface wear and erosion. Wear resistance testing typically uses friction and wear tests or arc

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ablation tests to measure changes in surface roughness and mass loss rates. Preparation processes such as high-temperature sintering and pressure control directly affect the uniformity of wear resistance distribution. In practical applications, electrodes with high wear resistance perform exceptionally well when machining high-hardness materials (such as tungsten steel), reducing electrode deformation and replacement frequency.

Wear resistance is also affected by operating conditions. Softening of the copper phase at high temperatures may slightly reduce wear resistance, but the tungsten support maintains overall stability. Surface treatments such as polishing or coatings (e.g., CrN) can further enhance surface wear resistance and corrosion resistance. In microelectronic packaging, wear resistance ensures that electrodes maintain surface quality during repeated assembly and prevents mechanical damage.

3.3.5 Corrosion resistance of tungsten copper electrodes

Tungsten-copper electrodes is a key performance characteristic of their environmental adaptability, reflecting their resistance to chemical attack and long-term stability in humid, acidic, alkaline, or industrial environments. This characteristic is primarily provided by the chemical stability of tungsten, combined with the surface protection of copper, and the optimization of the microstructure through powder metallurgy or vacuum infiltration processes, resulting in a low-porosity and highly uniform material. Corrosion resistance directly affects the electrode's workpiece surface quality in EDM, its oxidation resistance in welding, and its reliability in microelectronic packaging. Electrodes with high corrosion resistance can resist environmental erosion, reduce surface degradation, and extend their service life. This section will discuss in detail the corrosion resistance characteristics of tungsten-copper electrodes and their application performance.

Achieving corrosion resistance depends on the ratio of tungsten to copper and the preparation process. Higher tungsten contents (such as WCu 85/15) result in greater corrosion resistance. Tungsten's natural chemical stability provides the material with a foundation for acid and alkali resistance, while copper's ductility fills pores during sintering , reducing corrosion paths. The low porosity in the microstructure, optimized through hot isostatic pressing (HIP), reduces channels for corrosive media to penetrate, and the fine grain size enhances the material's crack resistance. Corrosion resistance testing typically involves salt spray or acid immersion tests, measuring surface corrosion rate and mass loss. Preparation processes such as vacuum infiltration improve interface density through the infiltration of liquid copper, enhancing corrosion resistance. In practical applications, electrodes with high corrosion resistance excel when processing chemically active materials (such as titanium-containing alloys), reducing workpiece contamination.

Corrosion resistance is also affected by operating conditions. Humid or oxidizing atmospheres can accelerate the corrosion of the copper phase, but the support of the tungsten skeleton and surface treatments (such as nickel or gold plating) significantly improve overall stability. In microelectronic packaging, corrosion resistance ensures that electrodes do not oxidize in humid environments, enhancing reliability.

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3.3.6 Anti-welding and anti-adhesion properties of tungsten copper electrodes

Tungsten-copper electrodes are key properties in welding applications. They reflect the electrode's ability to resist adhesion to the joining materials under high heat and pressure, as well as the cleanliness of the surface after welding. This characteristic is primarily supported by the high-temperature resistance of tungsten and the surface properties of copper. Microstructure optimization through powder metallurgy or vacuum infiltration processes results in a low-porosity and highly uniform material. Welding and adhesion resistance affect the electrode's efficiency in resistance welding, surface quality in spot welding, and replacement frequency over long-term use. Electrodes with high adhesion resistance can reduce slag adhesion, improve weld joint quality, and extend weld life.

Achieving both soldering and adhesion resistance depends on the ratio of tungsten to copper and the preparation process. Higher tungsten contents (e.g., WCu 80/20) result in stronger adhesion resistance. Tungsten's high melting point and hardness reduce adhesion during molten solder, while copper's thermal conductivity optimizes thermal management during sintering and reduces surface residue. The low porosity in the microstructure, optimized through hot isostatic pressing (HIP), reduces channels for slag penetration, while the fine grain size enhances the material's resistance to deformation. Adhesion resistance is typically tested using a welding cycle test, measuring slag adhesion area and surface cleanliness. Preparation processes such as vacuum infiltration improve interface density through liquid copper infiltration, enhancing adhesion resistance. In practice, electrodes with high adhesion resistance excel in spot or seam welding, reducing cleaning frequency.

Soldering and adhesion resistance are also affected by operating conditions. The softening of the copper phase at high temperatures can increase the risk of adhesion, but the support and surface treatment of the tungsten skeleton significantly enhance overall performance. In resistance welding, adhesion resistance ensures smooth separation of the electrode from the workpiece, improving joint quality. In microelectronic packaging, soldering resistance supports multiple soldering operations without residue.

3.4 CTIA GROUP LTD Copper Tungsten Electrode MSDS

Tungsten copper electrode is a metal composite material with tungsten and copper as the core components. It is made through powder metallurgy, vacuum infiltration and other processes. It has the excellent properties of both tungsten and copper and is widely used in the industrial field.

From a material perspective, tungsten's high melting point (3410°C) and high strength provide the electrode with excellent high-temperature resistance and structural stability, allowing it to maintain its shape and resist deformation in harsh environments such as high temperature and high pressure. Copper's high electrical and thermal conductivity, on the other hand, allows the electrode to efficiently transmit and dissipate heat, quickly dissipating heat generated during operation and preventing localized overheating and performance degradation. This "strong tungsten, superior copper" combination allows the tungsten-copper electrode to overcome the shortcomings of pure tungsten's poor electrical and thermal conductivity while also compensating for pure copper's lack of high-temperature strength,

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resulting in unique performance advantages.

Tungsten-copper electrodes can be flexibly adjusted based on the application scenario. Common ratios include WCu70/30 and WCu80/20. A higher copper content improves electrical and thermal conductivity, making it suitable for applications requiring high electrical performance. A higher tungsten content improves heat resistance and mechanical strength, making it more suitable for high-temperature, high-stress working environments. Adjusting the ratio allows for precise performance matching.

From the perspective of application fields, tungsten copper electrodes play a key role in multiple high-end industrial scenarios: in electrospark machining, as a discharge electrode, it can accurately process high-strength materials such as mold steel and cemented carbide with its stable conductivity and ablation resistance, ensuring the surface accuracy of the workpiece; in the field of welding, especially resistance welding and arc welding, its efficient electrical and thermal conductivity can ensure the stable transmission of welding current, reduce heat loss, and improve the quality of solder joints; in microelectronic packaging, due to its good electrical conductivity and thermal expansion coefficient matching the substrate, it can be used as an interconnection electrode to ensure reliable connection between the chip and the substrate, and enhance the stability of electronic equipment; in addition, in aerospace, national defense and other fields, it is also often used in high-temperature arc contacts, high-voltage switches and other components to meet performance requirements under extreme working conditions.

Hazard Overview: This product is a solid metal composite material, inherently non-toxic. No toxic substances are released during normal storage and use. Since it does not exist in powder form, there is no risk of dust inhalation and it is not explosive or flammable. Under extreme temperatures (e.g., exceeding the melting point of copper, 1083°C), the copper phase may melt, but this process does not produce toxic gases. Avoid burns from high-temperature contact.

Firefighting measures: This product is non-flammable and non-explosive. At high temperatures, it undergoes only physical changes (such as copper melting) and does not release toxic gases. In the event of a fire, no special firefighting measures are required for this product; standard firefighting measures will suffice. When extinguishing a fire, be careful to avoid contact with hot molten materials, which can cause burns.

Leakage Emergency Response: The product is in solid form and poses no risk of leakage. If it breaks or is damaged by external forces, simply collect the fragments; no special protective measures are required. The fragments can be recycled or treated as standard industrial waste, ensuring environmental safety.

Handling and Storage: No special protective equipment is required during handling; wearing industrial gloves is sufficient to prevent surface scratches. Store in a dry, well-ventilated environment away from corrosive substances such as strong acids and bases to prevent corrosion of the metal surface. No sealing or special isolation is required; simply keep dry when storing with other industrial materials.

Exposure Controls and Personal Protection: No special respiratory protection or dust control measures

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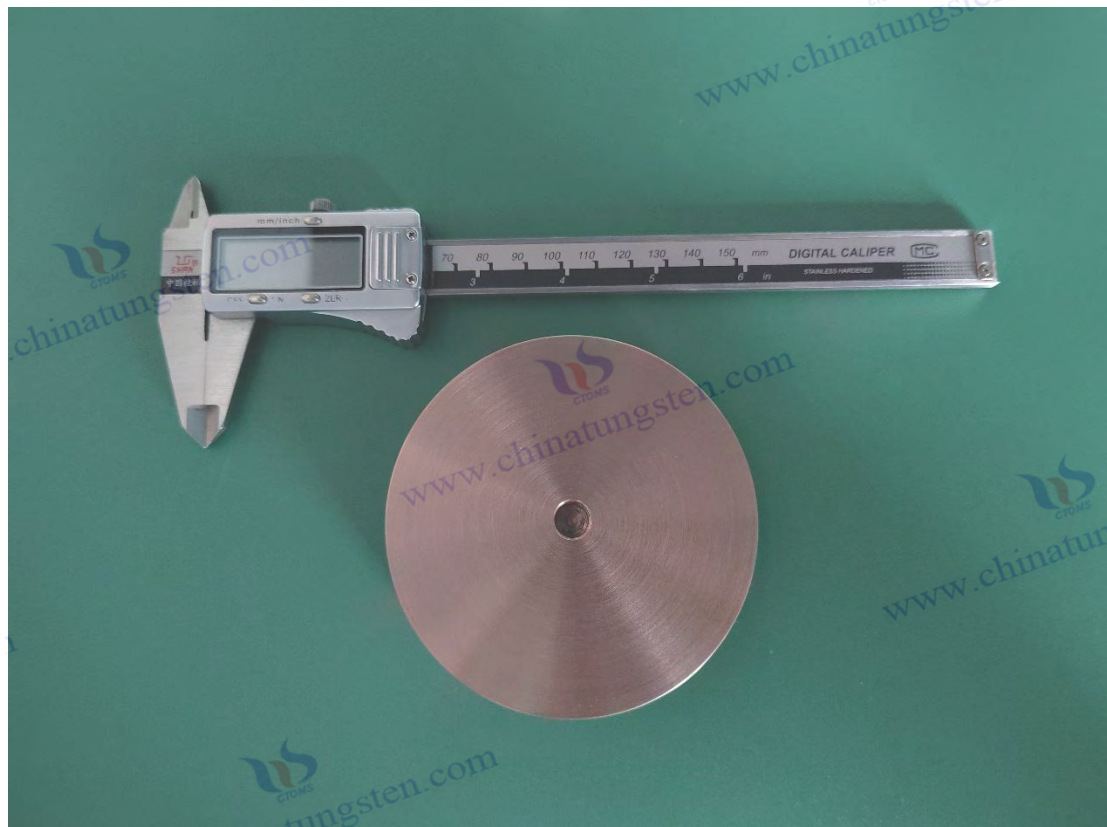
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are required (due to the absence of powder). It is recommended to wear ordinary industrial gloves during operation to prevent injuries from friction with hard surfaces; heat-insulating gloves are required when working with high temperatures.

Disposal: Discarded electrodes can be recycled as metal scrap and processed by professional recycling agencies to extract the tungsten and copper for further processing. Unrecyclable materials are treated as general industrial solid waste and do not pollute soil or water.

Transportation Information: There are no special restrictions during transportation, and no hazardous material labeling is required. Just keep the packaging intact and avoid deformation caused by severe collisions. It can be shipped in the same batch as other non-corrosive industrial products.

Regulatory Information: This product complies with the Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste, the Regulations on the Safety Management of Hazardous Chemicals, and other relevant laws and regulations. It is not a hazardous chemical or toxic substance, and its production, sales, and transportation all comply with national industrial material standards.



CTIA GROUP LTD Copper Tungsten Electrode

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Chapter 4: Classification of Tungsten-Copper Electrodes

Tungsten-copper electrodes can be classified according to different standards. Common methods include composition ratio, application scenarios and molding processes. According to the ratio of tungsten to copper content, they can be divided into high-tungsten type and high-copper type. The high-tungsten type has a high tungsten content, better high-temperature resistance and hardness, and is suitable for high-temperature and high-stress scenarios; the high-copper type (such as WCu60/40, WCu70/30) has a high copper content and more outstanding electrical and thermal conductivity, and is suitable for working conditions with high electrical efficiency requirements. According to the application field, there are mainly EDM electrodes, welding electrodes, microelectronic packaging electrodes, etc. EDM electrodes need to have both ablation resistance and conductivity, welding electrodes focus on current stability, and microelectronic packaging electrodes have strict requirements on dimensional accuracy and thermal matching.

4.1 Composition ratio-dominated classification of tungsten copper electrodes

The composition ratio-dominated classification of tungsten-copper electrodes is a grouping method of electrodes based on the ratio of tungsten and copper content. This classification method directly affects the physical, mechanical and electrical properties of the electrodes and meets the needs of different application scenarios. Tungsten-copper electrodes are prepared by powder metallurgy or vacuum infiltration process. Tungsten provides high melting point, high temperature resistance and wear resistance, and copper contributes high electrical conductivity and thermal conductivity. The adjustment of the ratio determines the comprehensive performance of the electrode. The difference in composition ratio is mainly reflected in the level of tungsten content. It is divided into three categories: high tungsten content, medium tungsten content and low tungsten content. Each type of electrode is optimized for specific purposes, such as electrospark machining, resistance welding or microelectronics packaging. The classification basis also takes into account the influence of microstructure and preparation process. Low porosity and uniform phase distribution are common characteristics of various types of electrodes.

4.1.1 High Tungsten Content Electrodes (80%-95% Tungsten)

Tungsten-copper electrodes primarily composed of tungsten, with the copper content typically ranging from 5% to 20%. These electrodes possess exceptional high-temperature resistance and arc erosion resistance due to tungsten's high melting point (3422°C) and hardness (approximately 3430 HV). Through a powder metallurgy process, tungsten powder is mixed and pressed with a small amount of copper powder. After sintering, the copper fills the pores in the liquid phase, forming a dense tungsten skeleton structure. The low porosity enhances material stability. A vacuum infiltration process further optimizes copper penetration and improves interfacial bonding, enabling high-tungsten-content electrodes to maintain structural integrity even under extreme conditions.

The characteristics of high tungsten content electrodes make them outstanding in electrospark machining (EDM), and are particularly suitable for machining high-hardness materials. The high wear resistance of

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tungsten reduces electrode surface loss and extends service life. In resistance welding, high tungsten content supports high-current disconnection operations, and its resistance to arc erosion is significantly better than that of low-tungsten electrodes, reducing slag adhesion. The fine grains in the microstructure are optimized through the hot isostatic pressing process, and the compressive strength can reach a certain high level, making it suitable for high-energy discharge scenarios. However, the electrical and thermal conductivity of high-tungsten content electrodes are weak, and the low copper ratio limits the current transmission efficiency, so they need to be used in conjunction with heat dissipation design.

Applications also include aerospace components and high-voltage switches. The high-tungsten content of electrodes allows for high-temperature resistance exceeding 3000°C, and surface treatments such as nickel plating further enhance oxidation resistance. During the manufacturing process, the tungsten powder purity must be controlled above 99.9%, with a particle size between 5 and 15 microns to ensure consistent performance.

4.1.2 Medium Tungsten Content Electrodes (50%-80% Tungsten)

Medium-tungsten-content electrodes are a balanced type of tungsten-copper electrode, with a copper content ranging from 20% to 50%. These electrodes offer a good compromise between high-temperature resistance and electrical conductivity. Produced through powder metallurgy or vacuum infiltration, their microstructure exhibits a uniform tungsten skeleton and copper phase network. During sintering, copper in liquid form fills the pores between tungsten particles. The low porosity and fine grain size are optimized through hot isostatic pressing, enhancing the material's mechanical strength and electrical properties. The increased copper content improves both electrical and thermal conductivity, making medium-tungsten-content electrodes versatile in a variety of applications.

Medium-tungsten electrodes are widely used in electrical discharge machining (EDM), suitable for precision machining of medium-hardness materials. The wear resistance of tungsten combined with the conductivity of copper reduces electrode loss and improves machining efficiency. In resistance welding, medium-tungsten electrodes support medium current operation and offer superior thermal management capabilities compared to high-tungsten electrodes, reducing the heat-affected zone and improving joint quality. Microelectronics packaging is another important application, where their thermal expansion coefficient matches that of silicon or ceramic substrates, reducing thermal cycling stress and enhancing reliability. The performance of medium-tungsten electrodes is also influenced by the ratio and processing. For example, a 70/30 WCu ratio balances durability and efficiency, while a 60/40 WCu ratio favors conductivity. At high temperatures, the softening of the copper phase may slightly affect stability, but the tungsten skeleton provides support. Surface treatments such as polishing or plating can enhance corrosion resistance and extend service life.

4.1.3 Low Tungsten Content Electrodes (20%-50% Tungsten)

Low-tungsten electrodes (20%-50% tungsten) are primarily copper-based tungsten-copper electrodes, with copper content ranging from 50% to 80%. These electrodes exhibit excellent electrical and thermal

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management properties due to copper's high electrical conductivity (5.8×10^7 S/m) and thermal conductivity (approximately $400 \text{ W/m}\cdot\text{K}$). Through a powder metallurgy process, tungsten powder is mixed with a high proportion of copper powder. After sintering, the copper forms a continuous network. The low porosity and uniform phase distribution are optimized through hot isostatic pressing, enhancing the overall material performance. A vacuum infiltration process, through the infiltration of liquid copper, further improves the integrity of the conductive path, enabling low-tungsten electrodes to excel in high-efficiency conduction.

Electrodes with low tungsten content are mainly used in scenarios that require high electrical and thermal conductivity, such as spot welding or seam welding in resistance welding. The high performance of copper reduces the resistance thermal effect and improves the quality of the joint. In electrospark machining, electrodes with low tungsten content are suitable for rough machining of low-hardness materials. The ductility of copper supports rapid heat dispersion and reduces local overheating. In microelectronic packaging, the thermal expansion coefficient matches the substrate, and the high thermal conductivity of copper supports chip heat dissipation and extends service life. However, the high temperature resistance and arc erosion resistance of low-tungsten content electrodes are weak, and the low tungsten ratio limits their stability under extreme conditions. They need to be used in combination with heat dissipation or low-energy discharge.

During the manufacturing process, the copper powder purity must be controlled above 99.9%, with a particle size between 5 and 15 microns. The tungsten powder particle size is slightly larger to optimize filling. Surface treatments such as gold plating can enhance corrosion resistance and extend service life in humid environments.

4.2 Application Scenario-Oriented Classification of Tungsten-Copper Electrodes

The application scenario-oriented classification of tungsten copper electrodes is a grouping method of electrodes based on specific usage environments and functional requirements. This classification method emphasizes the targeted design and performance optimization of electrodes in different industrial fields. Tungsten copper electrodes are prepared by powder metallurgy or vacuum infiltration process. The high melting point and hardness of tungsten are combined with the high electrical conductivity and thermal conductivity of copper. The ratio and microstructure are adjusted according to the application scenario to form a material with low porosity and high uniformity. The classification basis includes electric discharge machining, high-voltage electrical appliances and welding fields. Each type of electrode is optimized for specific process and performance requirements, such as arc erosion resistance, electrical conductivity efficiency or thermal management capabilities.

4.2.1 Electrodes for EDM

Electrodes specifically designed for EDM (Electro-Discharge Machining) are tungsten-copper electrodes, specifically designed for arc erosion resistance, mechanical strength, and machining precision. These electrodes typically utilize a high tungsten content (such as WCu 80/20 or WCu 90/10).

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Tungsten powder is mixed with a small amount of copper powder through a powder metallurgy process. After sintering, the copper fills the pores in the liquid phase, forming a dense tungsten skeleton structure. The low porosity enhances resistance to high-temperature shock. A vacuum infiltration process further optimizes copper penetration and improves interfacial bonding, ensuring electrode stability during high-energy discharges. The fine grains in the microstructure are optimized through hot isostatic pressing (HIP), enhancing compressive strength and wear resistance.

The primary advantage of electrodes designed for EDM lies in their resistance to arc erosion. Tungsten's high melting point (3422°C) and hardness (approximately 3430 HV) withstand the thousands of°C discharge temperatures, reducing surface wear and making it suitable for machining high-hardness materials such as tungsten carbide and titanium alloys. Machining precision is guaranteed, with surface roughness controlled to the micron level. The fine grain structure supports the formation of complex geometries. In practical applications, the electrodes can withstand high-energy discharges, extending their service life and reducing replacement frequency.

However, low copper content can limit electrical and thermal conductivity, necessitating a heat dissipation design to prevent local overheating. Surface treatments such as polishing can improve surface quality, making them suitable for precision mold manufacturing.

4.2.2 Electrodes for high-voltage electrical appliances

tungsten-copper electrodes designed specifically for high-voltage switches and electrical contacts , emphasizing high-temperature resistance, arc erosion resistance, and conductive stability. These electrodes typically utilize a medium-to-high tungsten content ratio (such as WCu 70/30 or WCu 85/15) and are produced through a powder metallurgy process. Tungsten powder is mixed with copper powder and sintered, with the copper filling the pores in the liquid phase, forming a uniform phase network. The low porosity enhances the material's arc resistance. A vacuum infiltration process optimizes copper penetration, and hot isostatic pressing (HIP) further improves interfacial bonding, ensuring the electrode maintains reliability during high-voltage disconnection. The fine grains in the microstructure support high compressive strength, making it suitable for frequent mechanical action.

The properties of electrodes for high-voltage electrical appliances make them excellent performers in high-voltage switches. Tungsten's high melting point (3422°C) protects against arc heat, and its arc-erosion resistance reduces surface erosion and extends service life. Copper's high conductivity ensures efficient current transmission, making it suitable for high-current disconnection scenarios. Its thermal expansion coefficient matches the substrate, reducing thermal cycling stress. Optimized microstructure reduces resistance variability and supports stable electrical performance. In practical applications, the electrodes can withstand frequent switching operations, reducing failure rates and are widely used in power equipment and industrial control systems.

During the manufacturing process, the particle size ratio of tungsten powder to copper powder must be controlled between 1:2 and 1:3 to ensure uniform phase distribution. Surface treatments such as nickel

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plating can enhance oxidation resistance and adaptability to humid or industrial environments. In the future, by adjusting the composition ratio or introducing interphases (such as molybdenum), arc resistance and electrical conductivity can be further improved to meet higher voltage or complex electrical requirements, such as in smart grid equipment.

4.2.3 Electrodes in welding field

Tungsten-copper electrodes designed specifically for resistance welding, emphasizing electrical conductivity, thermal conductivity, and anti-sticking properties. These electrodes typically utilize a low-to-medium tungsten content (such as WCu 60/40 or WCu 70/30). Tungsten powder is mixed with a high percentage of copper powder through a powder metallurgy process. After sintering, the copper forms a continuous network. The low porosity is optimized through hot isostatic pressing, enhancing thermal management and electrical performance. The vacuum infiltration process improves the integrity of the conductive path through liquid copper penetration. The fine grains in the microstructure support compressive strength and toughness, making them suitable for high-pressure welding environments.

The primary advantages of electrodes in welding lie in their electrical and thermal conductivity. Copper's high electrical conductivity (5.8×10^7 S/m) and thermal conductivity (approximately 400 W/m·K) reduce resistive heating effects, improve joint quality, and evenly distribute heat, reducing the heat-affected zone (HAZ), making it suitable for spot or seam welding. Tungsten's high-temperature resistance (3422°C) provides structural support, and its anti-sticking properties are further optimized through surface treatments (such as polishing), which reduces slag adhesion and extends electrode life. In practical applications, the electrodes can withstand moderate currents, supporting efficient welding and are widely used in automotive manufacturing and electronics assembly.

During the manufacturing process, copper powder purity must exceed 99.9%, with a particle size between 5 and 15 microns. Tungsten powder particles should be slightly larger to optimize filling. High operating temperatures, such as high temperatures, can cause the copper phase to soften, necessitating integrated heat dissipation design. In the future, the introduction of nano-copper powder or multi-phase designs could further enhance conductivity and anti-adhesion properties, enabling applications requiring higher efficiency or complex welding, such as lightweight structural parts.

4.2.4 Special electrodes for aerospace and military applications

Tungsten-copper electrodes designed specifically for the aerospace and military sectors, emphasizing high-temperature resistance, mechanical strength, and reliability in extreme environments. These electrodes typically utilize a high tungsten content and are manufactured through powder metallurgy or vacuum infiltration. Tungsten powder is mixed with a small amount of copper powder and then sintered. The copper fills the pores in liquid form, forming a robust tungsten skeleton structure. During the manufacturing process, the microstructure is optimized through hot isostatic pressing (HIP), resulting in low porosity and a uniform phase distribution, ensuring the electrode's stability under high stress or high temperature conditions. The addition of copper optimizes electrical conductivity and thermal

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management , enabling its adaptation to complex operating environments.

The main applications of special electrodes in the aerospace and military industries include thermal protection systems for spacecraft and electrical contacts for military equipment. Tungsten's high melting point provides excellent high-temperature resistance, making it suitable for withstanding high-energy shocks or extreme thermal loads. The mechanical strength of the electrode supports high-precision processing and long-term use, and the uniformity of the microstructure reduces stress concentration and enhances fatigue resistance. In the military field, electrodes are often used in key components of high-performance radar or weapon systems, which need to withstand severe vibrations and corrosive environments. Surface treatments such as plating further enhance weather resistance. The preparation process focuses on raw material purity and particle size control to ensure consistent performance. The use scenario also requires the electrode to have excellent arc erosion resistance and thermal stability. The thermal conductivity of copper helps to quickly disperse heat and reduce the risk of local overheating.

4.3 Classification of tungsten-copper electrodes by morphological and structural characteristics

Tungsten-copper electrodes are the core basis for their adaptability to different application scenarios, encompassing multiple dimensions such as geometry, microstructure, and macromorphology. These characteristics directly impact the electrode's installation adaptability, performance efficiency, and processing compatibility. Therefore, classification by morphological and structural characteristics is one of the most intuitive methods for industrial selection.

4.3.1 Block Electrode

Block electrodes are tungsten-copper electrodes designed in a block-like form , suitable for applications requiring large-area contact or high-strength support. These electrodes are manufactured using a powder metallurgy process, where tungsten and copper powders are mixed in a specific ratio and then pressed into shape. During sintering, the copper fills the pores in the liquid phase, forming a dense microstructure. Hot isostatic pressing further optimizes the uniformity and low porosity of the block electrodes, ensuring the material's stability under mechanical loading. The block design facilitates machining and allows for cutting or forming into different sizes as needed, adapting to diverse application requirements.

The characteristics of the block electrode make it outstanding in EDM, suitable for processing large workpieces or complex geometries, and the large contact area provides stable discharge conditions. The uniform phase distribution in the microstructure enhances the resistance to arc erosion, the hardness of tungsten supports long-term use, and the conductivity of copper optimizes current transmission. During the preparation process, the mixing uniformity of raw materials and the control of sintering parameters directly affect the performance of the block electrode, and surface treatment such as polishing can improve processing accuracy. In the field of welding, the block electrode can be used as a mold or support to withstand high pressure and thermal cycles. In the future, the mechanical properties and application range of the block electrode can be further improved by adjusting the pressing process or introducing a multi-phase design.

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4.3.2 Rod Electrode

Rod electrodes are tungsten-copper electrodes designed in a rod-like form , suitable for applications requiring precise positioning or delicate machining. These electrodes are manufactured using powder metallurgy or vacuum infiltration processes. Tungsten and copper powders are mixed and pressed into a rod shape . During sintering, the copper fills the pores, creating a slender, dense structure. Hot isostatic pressing optimizes the rod electrode's microstructure, resulting in low porosity and uniform phase distribution, ensuring material stability during high-precision operations. The rod design facilitates installation and guidance, making it particularly suitable for applications requiring deep hole machining or working in confined spaces.

Rod electrodes excel in EDM (Electrodischarge Machining) and are suitable for fine machining or micro-component manufacturing. Their slender shape supports high-precision discharge, while the wear resistance of tungsten reduces electrode wear. The copper phase in the microstructure provides electrical and thermal conductivity, supporting stable current transfer and thermal management. In microelectronic packaging, the shape of rod electrodes facilitates alignment with the substrate, matching thermal expansion and reducing stress concentration. During fabrication, the length and diameter ratio of rod electrodes must be controlled to ensure mechanical strength and processability. Surface treatments such as grinding can improve surface quality.

4.3.3 Sheet Electrode

Sheet electrodes are tungsten-copper electrodes designed in the form of thin sheets , suitable for applications requiring large-area contact or uniform discharge. These electrodes are manufactured using a powder metallurgy process, where tungsten and copper powders are mixed in a specific ratio and pressed into a thin sheet. During sintering, the copper fills the pores in liquid form, forming a dense microstructure. Hot isostatic pressing further optimizes the uniformity and low porosity of the sheet electrodes, ensuring the material's stability under mechanical loading and thermal cycling. The sheet design provides a large surface area, facilitating close contact with the workpiece or substrate, and is suitable for processing requirements requiring uniform heat distribution or high current transmission.

Sheet electrodes perform outstandingly in EDM and are suitable for processing flat workpieces or scenarios requiring large-area discharges. The thin sheet structure supports efficient arc distribution, and tungsten's wear resistance and arc erosion resistance reduce surface loss and extend service life. The copper phase in the microstructure provides electrical and thermal conductivity, ensuring stable current transmission and heat dispersion, reducing the risk of local overheating. In the field of welding, sheet electrodes can be used as electrode plates or heat sinks, withstanding high pressure and thermal cycles, and improving joint quality. During the preparation process, the pressing process needs to control the uniformity of thickness. The mixing uniformity of raw materials and sintering parameters directly affect the performance of the sheet electrode. Surface treatment such as grinding or polishing can improve contact accuracy. Applications also include microelectronics packaging and thermal management. The thin design of the sheet electrode facilitates bonding to the chip or substrate, and thermal expansion

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matching reduces stress concentration and enhances reliability. The sheet electrode's flexibility allows it to adapt to complex geometries, but care must be taken during the fabrication process to avoid sheet deformation.

4.3.4 Special-shaped electrodes

Special-shaped electrodes are the most complex type of tungsten-copper electrodes. Their form is completely customized according to the functional requirements of specific application scenarios, breaking through the limitations of regular shapes such as blocks and rods, and encompassing a variety of non-standard structures such as special-shaped surfaces, stepped shapes, porous shapes, hollow grids, and composite surfaces. The design of this type of electrode must be deeply integrated with the operating parameters, assembly space, and performance objectives of the end product. From initial modeling to final formation, multiple rounds of simulation verification are required, and extremely high processing precision is required. Any slight deviation can directly affect the stability of downstream processes or the performance indicators of the final product.

In terms of morphological design, the core of special-shaped electrodes lies in "function orientation". For example, for the complex cavity processing of automobile cover molds, special-shaped tungsten copper electrodes need to completely replicate the curved surface contours of the cavity, including details such as fillets, deep grooves, slopes, and even simulate the draft angle when the workpiece is formed. This "mirror-image replication" morphological design can ensure that the discharge gap is uniform during electrospark machining, and ultimately ensure the surface finish and assembly accuracy of automobile covers. In the processing of the flame tube of the aircraft engine combustion chamber, special-shaped electrodes are often designed as curved structures with dense microgrooves. These microgrooves correspond one-to-one to the cooling channels of the flame tube. The channels formed by discharge machining must meet strict dimensional consistency, otherwise it will cause uneven local cooling and cause thermal fatigue failure during engine operation.

Stepped special-shaped electrodes are widely used in multi-station processing scenarios, and their different step sections correspond to different processing depths or precision requirements. For example, in the integrated processing of the mobile phone middle frame, the first section of the stepped electrode is used for rough processing to remove a large amount of material, the second section achieves fine trimming by reducing the diameter, and the third section completes the rounding through the arc transition at the end. This "one-time clamping, multi-step forming" design can reduce the number of tool changes, improve processing efficiency, and avoid positioning errors caused by multiple clamping. The height difference and diameter difference of the steps need to be accurately calculated based on the material hardness and processing allowance. If there is a deviation in the size of a certain step, it may cause the cumulative error of the size of subsequent processing to exceed the standard.

The design of porous, shaped electrodes focuses on balancing efficient heat dissipation with lightweight design. In the stator manufacturing of new energy vehicle motors, the electrodes require honeycomb-like through-holes. These holes not only reduce electrode weight but also allow internal airflow to quickly

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dissipate heat generated by discharge, preventing thermal deformation that could affect machining accuracy. In the processing of heat exchanger components for nuclear power equipment, the through-holes of porous, shaped electrodes must perfectly match the tube bundle holes of the heat exchanger. Failure to do so will result in uneven gaps during subsequent tube assembly, affecting heat transfer efficiency.

The forming process of special-shaped electrodes plays a decisive role in the morphological accuracy. The wire cutting process can achieve two-dimensional cutting of complex contours and is suitable for flat special-shaped structures; the electrospark forming process can process three-dimensional curved surfaces, reproduce complex shapes through the synchronous movement of the electrode and the workpiece, and ensure surface finish. For porous special-shaped electrodes with internal channels, it is also necessary to combine deep hole drilling, laser drilling and other processes to ensure the verticality and penetration of the holes. During the processing, the morphological error needs to be detected in real time by precision measuring equipment. Once a certain feature dimension is found to be out of tolerance, the processing parameters need to be adjusted immediately, otherwise the entire electrode will be scrapped. This extreme pursuit of precision makes the manufacturing cost of special-shaped electrodes much higher than that of regular-shaped electrodes, but it also makes them an indispensable key component in the field of high-end manufacturing.

4.4 Performance indicator driven classification of tungsten copper electrodes

Performance-driven classification of tungsten-copper electrodes groups electrodes based on specific performance requirements, emphasizing the optimization of key indicators such as conductivity, high-temperature resistance, or mechanical strength. This classification method designs specialized electrodes for different performance requirements by adjusting the tungsten and copper ratios and the preparation process. The microstructure of tungsten-copper electrodes is optimized through powder metallurgy or vacuum infiltration processes, exhibiting low porosity and uniform phase distribution. Hot isostatic pressing further enhances performance consistency. Classification criteria include high conductivity, high-temperature resistance, or high mechanical strength, with each type of electrode excelling in specific applications.

4.4.1 Highly conductive electrodes

High-conductivity electrodes are tungsten-copper electrodes designed for efficient current transmission, emphasizing optimal conductivity and resistivity. These electrodes typically utilize a low tungsten content. Tungsten powder is mixed with a high proportion of copper powder via a powder metallurgy process, and the copper forms a continuous conductive network upon sintering. The microstructure is optimized through hot isostatic pressing (HIP) to achieve low porosity and a uniform phase distribution. The high conductivity of copper (near pure copper levels) ensures efficient current transmission. A vacuum infiltration process further enhances the integrity of the conductive path through the infiltration of liquid copper, enabling high-conductivity electrodes to excel in electrical applications. The primary applications of highly conductive electrodes include resistance welding and microelectronic packaging.

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Copper's high conductivity supports stable current transmission, reduces resistance heating effects, and improves joint quality and circuit connection efficiency. In resistance welding, the electrodes can withstand moderate currents, evenly distribute heat, and reduce the heat-affected zone, making them suitable for spot welding or seam welding operations. In microelectronic packaging, the low resistivity of highly conductive electrodes supports efficient signal transmission, while copper's thermal conductivity aids chip heat dissipation and enhances reliability. The uniform copper phase network in the microstructure reduces electron scattering. The copper powder purity in the preparation process must be high, and the particle size must be controlled within a certain range to ensure consistent performance.

Operating conditions such as high temperatures can soften the copper phase, affecting conductive stability. Heat dissipation design or surface treatment (such as gold plating) is required to maintain performance. Surface treatment can also improve corrosion resistance and extend service life in humid environments. Highly conductive electrodes demonstrate superior performance in high-frequency or high-current scenarios and are widely used in electronic equipment and automotive manufacturing.

4.4.2 Arc erosion resistant electrodes

Tungsten-copper electrodes designed specifically for high-energy arc environments, emphasizing arc-erosion resistance and surface stability. These electrodes typically utilize a high tungsten content. Tungsten powder is mixed with a small amount of copper powder through a powder metallurgy process. After sintering, the copper fills the pores in the liquid phase, forming a strong tungsten skeleton structure. The microstructure is optimized through hot isostatic pressing (HIP) to exhibit low porosity and uniform phase distribution. Tungsten's high melting point and hardness provide excellent arc resistance. A vacuum infiltration process, through the infiltration of liquid copper, further enhances interfacial bonding, ensuring the electrode's durability during repeated discharges.

The main applications of arc erosion-resistant electrodes include electrospark machining and high-voltage switches. The high melting point of tungsten resists high-temperature arcs of thousands of degrees, reduces surface melting or evaporation, and extends service life. In electrospark machining, the electrode can process high-hardness materials, reduce erosion losses, and maintain machining accuracy. In high-voltage switches, the arc resistance of the electrode supports frequent current disconnection and reduces surface damage. The uniform tungsten phase network in the microstructure reduces thermal stress concentration, and surface treatments such as polishing or plating can further enhance oxidation resistance and adapt to industrial environments. In the preparation process, the purity of tungsten powder must reach a high level, and the particle size must be controlled within a certain range to ensure performance consistency. Usage scenarios also include special applications that require high-energy discharge. The thermal conductivity of copper assists in heat dispersion and reduces the risk of local overheating.

4.4.3 High-strength electrodes

Tungsten-copper electrodes designed specifically for high mechanical stress environments, emphasizing

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compressive strength and deformation resistance. These electrodes typically utilize a medium-to-high tungsten content (such as WCu 85/15 or WCu 70/30) and are produced through a powder metallurgy process. Tungsten and copper powders are mixed and compacted, and the copper fills the pores during sintering, creating a dense microstructure. Hot isostatic pressing optimizes interfacial bonding, resulting in a microstructure with low porosity and a uniform phase distribution. The tungsten skeleton provides high compressive resistance. A vacuum infiltration process, through the infiltration of liquid copper, further enhances the overall strength of the material, making it suitable for high-load operation.

Key applications for high-strength electrodes include bulk material removal in electrospark machining (EDM) and high-pressure welding. Tungsten's high hardness provides resistance to mechanical shock, while copper's ductility optimizes stress distribution and reduces crack formation. In microelectronic packaging, high-strength electrodes withstand the stresses of thermal cycling and mechanical clamping, enhancing reliability. The fine grains in their microstructure improve fatigue resistance. The particle size ratio of tungsten and copper powders must be matched during the manufacturing process to ensure uniform phase distribution. Surface treatments such as grinding can enhance wear resistance and extend service life.

Operating conditions such as high temperatures can affect the stability of the copper phase, necessitating a heat dissipation design to maintain performance. High-strength electrodes excel in high-stress environments and are widely used in aerospace components and industrial molds.

4.4.4 High heat-resistant electrodes

Tungsten-copper electrodes designed specifically for extreme high-temperature environments, emphasizing high-temperature stability and thermal management capabilities. These electrodes typically utilize a high tungsten content (such as WCu 90/10 or WCu 85/15) and are produced through a powder metallurgy process. Tungsten powder is mixed with a small amount of copper powder. After sintering, the copper fills the pores in the liquid phase, forming a strong tungsten skeleton structure. The microstructure is optimized through hot isostatic pressing (HIP) to achieve low porosity and uniform phase distribution. The high melting point of tungsten provides excellent thermal stability. A vacuum infiltration process, infiltrating liquid copper, enhances the integrity of the heat conduction path, ensuring the electrode maintains performance at high temperatures.

The main applications of high-heat-resistant electrodes include high-temperature sensors and aerospace thermal protection systems. The high melting point of tungsten supports high-temperature environments of thousands of degrees, and the thermal conductivity of copper assists in heat dispersion, reducing the risk of local overheating. In microelectronic packaging, the thermal stability of the electrode ensures the reliability of the chip during high-temperature operation, and thermal expansion matching reduces stress concentration. The uniform tungsten phase network in the microstructure reduces thermal fatigue, and surface treatments such as nickel plating can improve oxidation resistance and adapt to humid or industrial environments. In the preparation process, the purity of tungsten powder must reach a high level, and the particle size must be controlled within a certain range to ensure consistent thermal performance.

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Usage scenarios also include special applications that require high heat loads. The copper phase may soften at high temperatures, but the tungsten skeleton provides support.

4.5 Classification of Tungsten-Copper Electrodes by Microstructure

The microstructure is determined by the preparation process and reflects the distribution state and bonding mode of the tungsten-copper two phases. It is mainly divided into uniform dispersion type, skeleton filling type and gradient distribution type. Different structures have a significant impact on the electrical conductivity, thermal conductivity and mechanical properties of the electrode.

4.5.1 Uniformly dispersed electrodes

Uniformly dispersed electrodes are the most microstructurally balanced type of tungsten-copper electrodes. Their core characteristic lies in the highly uniform distribution of tungsten particles and copper phases. In this structure, tiny tungsten particles are evenly embedded in the copper matrix in a discrete form. There is neither localized agglomeration of tungsten particles nor segregation and aggregation of copper phases. The interface between the two phases is tightly bonded through high-temperature sintering in a powder metallurgy process, presenting a microscopic morphology of "you in me, me in you." This structure breaks the limitations of the properties of a single metal, allowing tungsten's high-temperature resistance to synergize with copper's electrical and thermal conductivity, while also avoiding performance shortcomings caused by uneven component distribution.

The key to achieving this uniform dispersion structure lies in the precise control of the preparation process. First, the tungsten powder and copper powder need to be deeply processed through a ball milling mixing process, so that the two powders are fully in contact and refined under the action of mechanical force to form a mixed powder with uniform composition; then the mixed powder is pressed into a blank through a uniform pressing process to ensure that the pressure is evenly transmitted to all parts of the blank to avoid local density differences; finally, in the sintering stage, the temperature and holding time are precisely controlled to promote the diffusion and fusion of tungsten and copper at the interface to form a stable bonding state. The entire process must strictly avoid the mixing of impurities or fluctuations in process parameters, otherwise the uniformity may be destroyed - for example, insufficient ball milling time will lead to uneven mixing of powders, and too low a sintering temperature will affect the interface bonding strength, which will leave defects in the microstructure.

The core advantage of the electrode given by the uniform dispersion structure is the consistency of performance. At the macro level, the conductivity, thermal conductivity, hardness and other indicators of the electrode remain stable in different areas and will not fluctuate significantly due to changes in position. This characteristic makes it outstanding in scenarios with strict requirements on performance uniformity, such as the field of precision EDM: when the electrode and the workpiece perform high-frequency discharge, the uniform microstructure can ensure that the current density is evenly distributed on the electrode surface, avoiding the concentration of discharge energy due to local resistance differences, thereby reducing the unevenness or burn marks on the workpiece surface and ensuring the consistency

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of the finish of the machined surface. Even in long-term continuous processing, this uniformity can maintain the stability of the discharge parameters and reduce process deviations caused by fluctuations in electrode performance.

In high-frequency welding applications, the advantages of uniformly dispersed electrodes are also significant. During the welding process, the electrode needs to stably transmit high-frequency current to the weld area and achieve material fusion through resistance heat. If the electrode microstructure is uneven, local high-resistance areas will generate excessive heat, causing the weld to overburn or even stick; while low-resistance areas may not have enough heat, resulting in a cold weld. The uniformly dispersed structure ensures that the current is evenly distributed during the transmission process through a continuous and uniform copper phase conductive network, so that the heat at the weld remains stable, ensuring that the molten core is fully formed while avoiding overheating damage. At the same time, the evenly distributed tungsten particles can provide consistent mechanical support for the electrode, preventing local deformation during repeated pressure contact and extending the service life of the electrode. Thermal management benefits of this structure cannot be ignored. In high-power electronic devices, tungsten-copper electrodes often serve as heat sinks. The uniform thermal conductivity network quickly and evenly diffuses heat from hot spots throughout the electrode, dissipating it through the heat sink, thus preventing localized heat accumulation and device performance degradation. Even in environments with drastic temperature fluctuations, the uniform microstructure reduces internal stress caused by differential thermal expansion, lowering the risk of electrode cracking.

4.5.2 Skeleton-filled Electrodes

The skeleton-filled electrode is a tungsten-copper composite material that achieves synergistic performance through a unique structural design. Its core feature is the formation of an interpenetrating network structure of "tungsten skeleton-copper filling." In this structure, tungsten forms the supporting body of the electrode in the form of a continuous skeleton, much like the steel frame in a building, providing a solid structural foundation for the entire structure; while the copper phase fully fills the pores of the tungsten skeleton, forming a continuous conductive path. The two components not only maintain their respective performance advantages, but also achieve functional synergy through structural complementarity. This design breaks the performance limitations of a single metal material, allowing the electrode to simultaneously possess the composite properties of high strength, high temperature resistance, and high electrical and thermal conductivity.

The key to preparing skeleton-filled electrodes lies in the precise control of the vacuum infiltration process, which is divided into two core stages. The first is the prefabrication of the tungsten skeleton: after the tungsten powder is mixed according to a specific formula, it is pressed into shape through a mold, and then sintered at high temperature to form a porous skeleton with a certain porosity. During the sintering process, the tungsten particles are firmly connected by diffusion welding, constructing a continuous three-dimensional network, and the pores inside the skeleton reserve space for the subsequent filling of the copper phase. At this time, the tungsten skeleton already has high mechanical strength and high temperature resistance, but its conductivity is poor, which needs to be compensated by subsequent

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steps .

The second stage is copper phase infiltration : the prefabricated tungsten skeleton is placed in a vacuum environment, copper material is laid around it and heated to above the melting point of copper. Under the combined action of high temperature and vacuum conditions, solid copper is converted into liquid, and with the help of capillary action and gravity penetration, it is evenly filled along the pores of the tungsten skeleton until all gaps are filled. The role of the vacuum environment is crucial. It can prevent air from mixing in to form bubbles and ensure that the copper phase forms a continuous and uninterrupted conductive network in the pores. After cooling, the tungsten skeleton and the copper phase form a tightly integrated interpenetrating structure - the tungsten skeleton provides anti-deformation ability and high-temperature support, and the copper phase is responsible for current transmission and heat dissipation. The two complement each other and give the electrode excellent comprehensive performance .

The performance advantages of skeleton-filled electrodes are particularly evident in high-temperature and high-pressure applications. The continuous structure of its tungsten skeleton gives it mechanical strength and high-temperature resistance far exceeding that of pure copper. Even in extreme temperature environments, it can maintain structural stability and is not easily softened or deformed. The copper phase filling ensures excellent electrical and thermal conductivity, quickly dissipating heat away from high-temperature areas and avoiding performance degradation caused by local overheating. This characteristic makes it an ideal choice for extreme working conditions in aerospace, nuclear energy, and other fields .

In rocket engine nozzle electrode applications, skeleton-filled electrodes demonstrate unique advantages. As a key component of the rocket propulsion system, the nozzle must withstand the continuous erosion of high-temperature gas during operation, while also requiring ignition and flame control through electrodes. At this point, the tungsten skeleton, with its extremely high melting point and structural strength, resists the high-temperature erosion of the gas, preventing the electrode from melting or deforming due to the high temperature. The copper phase filled in the skeleton rapidly dissipates the large amount of heat generated by the gas erosion through a continuous path, avoiding structural failure caused by localized overheating. This synergistic mechanism of "tungsten resists ablation and copper conducts heat" ensures the long-term stable operation of the nozzle electrode in extreme environments .

Skeleton-filled electrodes also play an important role in high-temperature electrode components of nuclear energy equipment. When a nuclear reactor is in operation, the internal environment is not only extremely hot, but also accompanied by high pressure and radiation, which places stringent demands on the stability of the material. In such scenarios, the tungsten skeleton serves as the main structural body, which can resist creep and corrosion under long-term high temperatures and maintain the dimensional stability of the electrode; while the copper phase ensures the conductivity of the electrode under high current, while conducting the heat in the reactor to the cooling system in a timely manner to prevent safety risks caused by heat accumulation. In addition, since both tungsten and copper have good radiation stability, electrodes with this structure can also maintain stable performance in a radiation environment, avoiding functional degradation caused by material aging .

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In the application of electrodes in industrial electric arc furnaces, the advantages of skeleton-filled electrodes are also very obvious. When the electric arc furnace is working, the high-temperature arc generated between the electrode and the charge is extremely hot, and the electrode needs to withstand frequent mechanical shock and thermal shock. At this time, the high strength characteristics of the tungsten skeleton can prevent the electrode from breaking under the impact, and its high temperature resistance can resist the direct burning of the arc; the high conductivity of the copper phase ensures the stable generation of the arc, while quickly dissipating the arc heat, avoiding the loss of the electrode end due to overheating. Compared with other types of electrodes, skeleton-filled electrodes show longer service life and more stable working performance under such high-frequency and high-intensity working conditions .

In short, the skeleton-filled electrode achieves a perfect balance between mechanical and functional properties through the structural design of "tungsten skeleton support-copper phase function". Its performance is particularly outstanding under extreme environments such as high temperature and high pressure, making it an indispensable key material in the high-end industrial field.

4.5.3 Gradient distribution electrode

The gradient distribution electrode is a highly targeted structural design in tungsten-copper composites . Its core feature is a continuously varying distribution of the tungsten-to-copper ratio across the electrode's cross-section. From one end of the electrode to the other, the tungsten content may gradually increase while the copper content decreases, or vice versa, resulting in a microstructure with a smooth performance transition. This design breaks away from the uniform distribution of components in traditional composite materials. By carefully controlling the composition gradient, different regions of the electrode prioritize the performance advantages of either tungsten or copper, while the buffering effect of the transition region prevents interfacial stress problems caused by sudden performance changes.

In terms of performance, the gradient distribution electrode exhibits significant "regional functionalization" characteristics. The high tungsten content area has excellent high temperature resistance and wear resistance due to the high melting point and high strength of tungsten, and can maintain structural stability in extremely high temperature environments; while the high copper content area relies on the high electrical and thermal conductivity of copper to achieve efficient current transmission and heat dissipation. More importantly, the composition of the intermediate transition area changes slowly, so that the two properties are smoothly connected at the junction. There is neither a cliff-like drop in electrical conductivity due to a sudden increase in tungsten content, nor a sharp decrease in high temperature resistance due to a sudden increase in copper content. This gradual change in performance effectively solves the common stress concentration problem when connecting heterogeneous materials, and greatly improves the reliability of the electrode under complex working conditions.

The process of preparing gradient-distributed electrodes is extremely technically challenging and requires precise control of the composition distribution. Common preparation methods include layered

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powder metallurgy and gradient sintering: the layered powder metallurgy method is to lay mixed powders of different tungsten-copper ratios in layers according to the designed gradient order, and achieve a continuous transition of the composition through one-time pressing and sintering. The composition difference of each layer of powder needs to be precisely controlled to ensure the smoothness of the transition area; the gradient sintering method is to guide the tungsten or copper to diffuse in a directional manner inside the material by regulating the temperature field or atmosphere field during the sintering process, thereby forming a natural composition gradient. Regardless of which method is used, it is necessary to use advanced simulation technology to pre-design the composition distribution curve, and to ensure that the actual distribution is consistent with the design through precise process parameter control. Any slight deviation may lead to a performance mutation in the transition area.

thermal structural components within the aerospace industry . For example, when a spacecraft reenters the atmosphere from space, the surface of the reentry capsule experiences intense friction with the atmosphere, generating extremely high temperatures. This requires the capsule's surface material to possess excellent high-temperature resistance and oxidation resistance. Meanwhile, the precision instruments within the capsule are extremely temperature-sensitive and require an efficient heat dissipation system to maintain a suitable operating temperature. In this scenario, gradient-distributed electrodes serve as a key component connecting the capsule's surface with the internal heat dissipation system. The outer end, facing the capsule, is designed with a high tungsten content, providing high-temperature resistance to withstand the intense re-entry heat, preventing surface melting or oxidation. The inner end, facing the capsule, is constructed with a high copper content, utilizing its excellent thermal conductivity to quickly transfer heat absorbed by the surface to the internal heat sink, preventing heat dissipation to the instruments within. The transition zone provides a smooth transition in performance, dissipating the significant stresses caused by the internal and external temperature differences and material property differences, preventing cracking or detachment of the electrode during repeated thermal cycling.

Gradient-distributed electrodes also play an irreplaceable role in the combustion chamber components of high-speed aircraft engines. The interior of the combustion chamber is exposed to high temperature and pressure during operation. The high-temperature airflow generated by the fuel combustion creates a strong scouring effect on the chamber walls, requiring the side exposed to the high temperature to possess extremely high heat resistance and scouring resistance. Meanwhile, the exterior of the combustion chamber needs to be connected to the cooling system to promptly dissipate heat to prevent the overall temperature from overheating, which in turn requires the exterior material to possess good thermal conductivity. The gradient-distributed electrode, through the rational design of the tungsten-to-copper ratio gradient, exhibits high tungsten properties on the inside of the combustion chamber to resist high-temperature scouring, while the high copper properties on the outside ensure heat dissipation efficiency. The intermediate transition region resolves performance conflicts and stress contradictions between the inside and outside, ensuring the combustion chamber maintains structural integrity and stable performance during long-term, high-frequency operation.

Furthermore, gradient-distributed electrodes also exhibit unique advantages in heat dissipation electrodes

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for high-power semiconductor devices. When a semiconductor device is operating, a large amount of heat is generated in the core area of the chip, requiring the electrode to have efficient thermal conductivity to dissipate the heat. The portion of the electrode connected to the external circuit requires good electrical conductivity to reduce signal transmission losses. By designing a gradual distribution of copper content from the chip contact end to the circuit connection end, the electrode can simultaneously meet the dual requirements of efficient heat dissipation and low-resistance electrical conductivity, while avoiding the problems of insufficient heat dissipation or poor electrical conductivity caused by the performance limitations of a single material.

4.6 Classification of Tungsten-Copper Electrodes by Macroscopic Physical Form

The macroscopic physical morphology mainly focuses on the surface state, density and composite mode of the electrode, which is divided into dense type, porous type and composite coating type to meet different functional requirements.

4.6.1 Dense Electrode

Dense electrodes are the most widely used basic category of tungsten-copper electrodes. Their core feature is their extremely low internal porosity. The tungsten particles and copper phases are tightly bonded to form a continuous and dense microstructure, resulting in a smooth and flat surface. This structure not only gives the electrode excellent overall performance, but also enables it to perform stably and reliably in a variety of industrial scenarios, making it a fundamental material choice in the field of precision manufacturing.

The key to achieving this dense structure lies in advanced preparation processes, with high-pressure sintering and hot isostatic pressing being the most commonly used technical approaches. High-pressure sintering applies continuous high pressure to the tungsten-copper mixed powder under high temperature, forcing the particles to fully contact, diffuse, and fuse, eliminating the pores formed between the particles. Hot isostatic pressing goes a step further, applying uniform pressure in all directions to the blank through a fluid medium under high temperature conditions, completely compacting the tiny pores inside the material and ultimately forming a nearly defect-free dense structure. The core goals of both processes are the same: through the synergistic effect of pressure and temperature, the physical barriers between particles are broken down, achieving a close bond between the tungsten-copper two phases and laying the structural foundation for the high performance of the electrode.

The performance advantage of dense electrodes stems from their structural integrity. First, the low porosity ensures that the copper phase forms a continuous and uninterrupted conductive network. The current will not produce local resistance mutations due to pore obstruction during transmission, and the conductive performance is stable and efficient. At the same time, the tightly integrated microstructure provides a smooth path for heat conduction, so that the heat generated during processing or work can be quickly diffused, avoiding performance degradation caused by local overheating. Secondly, the dense structure gives the electrode higher mechanical strength and deformation resistance. When subjected to

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mechanical pressure or thermal stress, it is not easy to crack or break, and can maintain a stable shape for a long time, extending its service life. In addition, the smooth and flat surface reduces resistance fluctuations when in contact with the workpiece, and also reduces the possibility of impurities adhering during processing, which is conducive to improving process stability.

In the field of EDM, the advantages of dense electrodes are particularly obvious. EDM relies on high-frequency discharge between the electrode and the workpiece to achieve material removal. The structural density of the electrode directly affects the uniformity of the discharge energy distribution. If there are pores inside the electrode, local energy concentration may occur during the discharge process, resulting in irregular ablation marks on the surface of the workpiece, affecting the processing accuracy; the uniform structure of the dense electrode can ensure the stable release of discharge energy and keep the surface roughness of the workpiece consistent. It is especially suitable for scenarios with strict precision requirements such as mold manufacturing. For example, in the processing of precision gear molds, dense electrodes can accurately replicate the tooth profile of the gear through stable discharge performance, ensure the dimensional accuracy and surface quality of the mold, and provide reliable guarantees for the subsequent mass production of gears.

In resistance welding applications, dense electrodes also play an irreplaceable role. During the welding process, the electrode needs to transmit current through close contact with the workpiece while also withstanding a certain amount of pressure. The low porosity of the dense electrode avoids the "void effect" in current transmission—that is, the interruption of the current path or the sudden increase in resistance caused by pores. It ensures that the current flows evenly through the welding area, so that the heat at the weld point is generated stably, and the consistency of the weld nugget formation is guaranteed. In the welding of automotive transmission gears, this stability is crucial: the strength of the gear weld directly affects the overall performance of the transmission. The dense electrode can ensure the uniform strength of each weld point through stable current transmission and pressure tolerance, avoiding the risk of gear failure due to local welding defects.

In the field of microelectronics packaging, dense electrodes are also widely used. Microelectronic devices have extremely high requirements for the dimensional accuracy and performance stability of electrodes. The smooth surface and uniform structure of dense electrodes can ensure good contact with the chip or substrate, reduce contact resistance, and improve signal transmission efficiency. At the same time, their excellent thermal conductivity can quickly dissipate the heat generated by the chip during operation, preventing device performance degradation due to excessive temperature. For example, in the packaging of smartphone chips, dense tungsten-copper electrodes serve as a dual medium for electrical conduction and heat dissipation, ensuring stable transmission of electrical signals while effectively controlling chip temperature, providing support for high-performance operation of the device.

4.6.2 Porous Electrodes

Porous electrodes are a type of tungsten-copper electrode with special structural characteristics. They are distributed with a large number of regular or irregular pores. These pores are not material defects, but

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structural features actively formed through process design. Unlike dense electrodes that pursue low porosity, the pore distribution and proportion of porous electrodes are core design parameters. By regulating parameters such as pressure, temperature, and holding time during the sintering process, the morphology and density of the pores can be precisely controlled, ultimately forming a special material with both functional and structural properties. This design allows the electrode to maintain the basic properties of tungsten-copper composite materials while obtaining unique advantages such as lightweight and high specific surface area, thus adapting to the needs of specific scenarios .

The key to the process of preparing porous electrodes lies in the reverse regulation of the sintering process. Conventional densification processes promote particle fusion through high pressure and long-term heat preservation, while the formation of porous structures requires appropriately reducing the sintering pressure and shortening the heat preservation time, so that the tungsten powder and copper powder form a skeleton structure in an incompletely densified state, and the gaps between the particles are retained as pores. In addition, the formation of regular pores can be assisted by adding pore-forming agents: volatile or soluble substances are added to the mixed powder. During the sintering process, these substances evaporate or are subsequently dissolved and removed, leaving behind pore channels of a preset shape. Regardless of the method, precise control of process parameters is required to ensure that the pore distribution is uniform and consistent with the design expectations, avoiding performance shortcomings caused by local pore concentration .

The core advantage of the porous structure that gives the electrode is reflected in the balance between lightweight and heat dissipation efficiency. The presence of a large number of pores significantly reduces the overall density of the material, and the weight is greatly reduced compared to dense electrodes of the same volume, which is crucial for scenarios where the load of the device needs to be controlled. At the same time, the complex channel network formed by the pores greatly increases the specific surface area of the electrode. When heat is conducted through the material, the larger surface area can accelerate heat exchange with the surrounding environment, and combined with the air circulation that may be formed in the pores, the heat dissipation efficiency is improved. This combination of "light weight + high heat dissipation" makes porous electrodes irreplaceable in scenarios such as mobile devices and aerospace components that are sensitive to weight and have high heat dissipation requirements .

In the application of commutation electrodes for drone motors, the advantages of porous electrodes are fully demonstrated. The endurance of drones is directly related to the weight of the equipment. Lightweight design is the key to improving endurance. As the motor is a core component, weight optimization of its electrodes is particularly important. The porous tungsten copper electrode reduces weight through its internal pore structure, while at the same time ensuring stable current transmission during commutation due to the high conductivity of the copper phase . More importantly, drone motors generate a lot of heat when running at high speeds. If the heat is not dissipated in time, it may cause the motor to overheat and fail. The high specific surface area of the porous structure can quickly dissipate heat into the air. Combined with the heat dissipation design of the motor housing, it forms an efficient heat dissipation system to ensure that the motor maintains stable performance during long-term flight . In the field of electrolytic machining, the pore structure of porous electrodes plays a unique role in

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medium storage and transmission. Electrolytic machining achieves electrochemical dissolution of materials through the electrolyte between the electrode and the workpiece. Traditional electrodes require external pipes to continuously transport electrolyte, while the internal pores of porous electrodes can directly serve as electrolyte storage and channels, slowly releasing electrolyte during the machining process to ensure that the machining area is always moist and achieve continuous cooling and lubrication. This design simplifies the piping system of the machining equipment and is particularly suitable for electrolytic machining of complex surfaces or deep cavities - when the electrode penetrates into a narrow space, the electrolyte released from the pores can act precisely on the machining area, avoiding the problem of uneven electrolyte distribution caused by external transportation, and improving machining accuracy and surface quality .

Among the electrode components of fuel cells, porous tungsten-copper electrodes also show special value. Fuel cells need to use electrodes to achieve catalytic reactions between fuel and oxidant while conducting the generated current. This requires the electrodes to have both good electrical conductivity and sufficient contact area for the reaction. The pore structure of the porous electrode provides space for gas diffusion and reaction, and the high conductivity of the tungsten -copper composite material ensures the rapid transmission of electrons. By optimizing the pore size and distribution, the reaction efficiency and conductivity can be balanced, allowing the fuel cell to maintain stable operation while outputting high power. In addition, the porous structure has good toughness, which can buffer the volume changes during battery operation and extend the service life of the electrode .

It is worth noting that the design of porous electrodes requires adjusting pore parameters according to specific application scenarios. Excessively large pores may reduce structural strength, while too small pores may affect heat dissipation or dielectric transmission efficiency. Therefore, the pore morphology, distribution uniformity, and proportion must be repeatedly verified through simulation and experimentation. Although this customized structural design increases the difficulty of preparation, it also allows porous electrodes to meet special needs that conventional electrodes cannot meet, making them one of the most versatile categories in the tungsten-copper electrode family.

4.6.3 Composite coating electrodes

Composite coating electrodes are a special category of tungsten-copper electrodes that achieve performance breakthroughs through functional superposition. Its core design concept is to composite one or more functional coatings on the surface of a tungsten-copper substrate , leveraging the synergistic performance of the coating and substrate to compensate for the performance shortcomings of a single material. The choice of coating material is extremely flexible, and different materials such as silver, nickel, diamond, and ceramic can be selected according to application requirements. Through electroplating, vapor deposition, thermal spraying and other processes, a close bond with the substrate is achieved, ultimately forming a composite structure of "tungsten-copper substrate providing structural support + surface coating optimizing specific functions." This design not only retains the core advantages of tungsten-copper materials, such as high strength and high electrical and thermal conductivity, but also gives the electrode a new performance dimension through the coating, greatly expanding its application

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scenarios .

The key to preparing composite coating electrodes lies in the quality of the bonding between the coating and the substrate, and different process paths have different focuses. The electroplating process is suitable for preparing metal coatings. Through electrolysis, metal ions are uniformly deposited on the surface of the tungsten-copper substrate to form a dense coating. Its advantages are controllable coating thickness and strong bonding with the substrate. It is particularly suitable for the preparation of conductive metal coatings such as silver and nickel. The vapor deposition method vaporizes the coating material in a vacuum environment and deposits it into a film on the substrate surface. It can prepare thin layers with nanometer-level precision. It is suitable for non-metallic coatings such as diamond and ceramics, and can accurately control the composition and structure of the coating. The thermal spraying process heats the coating material to a molten or semi-molten state and sprays it onto the substrate surface through a high-speed airflow to form a coating. It is suitable for preparing thick coatings or large-area coverage and is widely used in wear-resistant and high-temperature resistant coatings. Regardless of the process used, the substrate surface must be pretreated (such as polishing, cleaning, and activation) to ensure that there are no impurities or oxide layers between the coating and the substrate. Otherwise, the coating may fall off or performance degradation may occur .

The performance advantage of composite-coated electrodes lies in their targeted functional enhancements. The tungsten-copper matrix , as the supporting body, provides stable mechanical strength, electrical and thermal conductivity, and structural stability, ensuring the electrode maintains its shape and basic performance during use. The surface coating optimizes performance for specific needs, such as reducing contact resistance, enhancing wear resistance, and improving oxidation resistance, enabling the electrode to surpass the performance of pure tungsten-copper materials in specific scenarios . This "basic guarantee + functional enhancement" model allows the electrode to adapt to the comprehensive requirements of complex working conditions while achieving the ultimate level in key performance indicators .

In connector applications for high-frequency communication equipment, silver-plated composite coating electrodes perform outstandingly. High-frequency signal transmission is extremely sensitive to contact resistance, and even tiny resistance fluctuations can cause signal attenuation or distortion. The tungsten-copper substrate has good conductivity, and the surface silver coating can further reduce the contact resistance, because silver is one of the most conductive metals, and its surface is not easily oxidized, and it can maintain low resistance characteristics for a long time. When the electrode is used as a connector, the silver plating layer can ensure efficient transmission of the signal at the contact interface, reduce reflection and loss, and is especially suitable for scenarios with strict requirements on signal quality, such as satellite communications and 5G base stations. At the same time, the high strength of the tungsten-copper substrate ensures that the connector does not deform during the plugging and unplugging process, avoiding poor contact due to loose structure .

Composite electrodes coated with diamond coatings on the surface show unique value in the field of high-hardness material processing. In the EDM of materials such as mold steel and cemented carbide ,

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the electrodes need to frequently withstand high-temperature discharge shocks and mechanical friction. After long-term use, the surface of pure tungsten-copper electrodes is prone to wear or ablation, resulting in a decrease in processing accuracy. With its extremely high hardness and wear resistance, the diamond coating can form a protective barrier on the electrode surface to resist mechanical wear and high-temperature erosion during the processing process, significantly extending the service life of the electrode. At the same time, the excellent thermal conductivity of diamond can assist the electrode in quickly dissipating heat and avoid coating failure caused by local overheating. This dual advantage of "wear resistance + heat dissipation" makes this type of electrode very popular in fields such as precision mold processing and aircraft engine blade manufacturing .

In high-temperature anti-oxidation scenarios, composite electrodes with nickel coatings or ceramic coatings play a key role. For example, in the arc furnace electrodes of the metallurgical industry, the electrodes need to work continuously in a high-temperature oxidizing environment. An oxide layer is easily formed on the surface of pure tungsten-copper materials , resulting in a decrease in electrical conductivity. Nickel coatings can form a dense oxide film at high temperatures, preventing oxygen from further corroding the substrate and protecting the conductive network of the electrode from being destroyed; ceramic coatings (such as alumina and zirconia) have higher high-temperature resistance and oxidation resistance, and are suitable for higher-temperature working conditions. They prevent the substrate from contacting corrosive media through physical isolation. This type of composite electrode not only maintains the high electrical and thermal conductivity of tungsten copper , but also has the high-temperature resistance and oxidation resistance of the coating, greatly expanding the application boundaries of tungsten-copper materials in high-temperature industries .

In addition, composite coating technology can also achieve multifunctional integration. For example, in precision electrodes of medical devices, composite biocompatible coatings (such as titanium alloy coatings) can be used to ensure that tungsten copper electrodes have excellent electrical conductivity while avoiding adverse reactions when in contact with human tissue, meeting the special requirements of minimally invasive surgical instruments. This functional customization achieved through coatings allows composite coating electrodes to meet various unconventional needs, making them the category with the most innovative potential in the tungsten copper electrode family.

It is worth noting that the thickness and uniformity of the coating have a significant impact on electrode performance. A coating that is too thick may cause excessive internal stress, leading to cracking or falling off; a coating that is too thin will not provide effective protection or functional enhancement. Therefore, the coating process parameters need to be precisely controlled according to the coating material and substrate characteristics, and early simulation and later testing are required to ensure that the coating performance meets the standards. Although this refined manufacturing requirement increases production costs, it also enables composite coating electrodes to create irreplaceable value in the field of high-end manufacturing.

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Tungsten-copper alloy electrodes Introduction

1. Overview of Tungsten-copper alloy electrodes

Tungsten-copper alloy electrodes are composite materials made primarily from high-purity tungsten powder and copper powder, produced through processes such as isostatic pressing and high-temperature sintering. They combine tungsten's high melting point and hardness with copper's electrical conductivity and ductility, offering characteristics such as high-temperature resistance, low thermal expansion, and resistance to arc erosion. These properties make them widely used in resistance welding, electrical discharge machining, high-voltage discharge tubes, and electronic device heat dissipation applications. CTIA GROUP LTD provides a variety of customized tungsten-copper electrode services, with products featuring excellent appearance and stable performance.

2. Typical Properties of Tungsten-copper alloy electrodes

Product Name	Chemical Composition (%)			Physical and Mechanical Properties			
	Cu	Total Impurities ≤	W	Density (g/cm³)	Hardness (HB)	Resistivity (MΩ·cm)	Tensile Strength (MPa)
Tungsten Copper (50)	50±2.0	0.5	Balance	11.85	115	3.2	—
Tungsten Copper (60)	40±2.0	0.5	Balance	12.75	140	3.7	—
Tungsten Copper (70)	30±2.0	0.5	Balance	13.8	175	4.1	790
Tungsten Copper (80)	20±2.0	0.5	Balance	15.15	220	5	980
Tungsten Copper (90)	10±2.0	0.5	Balance	16.75	260	6.5	1160

3. Applications of Tungsten-copper alloy electrodes

Resistance Welding Electrodes: Used as electrodes for spot welding or seam welding of low-carbon steel and coated steel plates.

Repair Welding Electrodes: Applied in cold stamping, bending, extrusion, and die-casting molds.

Electrical Discharge Machining (EDM) Electrodes: Used for mold discharge machining, or as molds and fixtures for projection welders, as well as molds or inlaid electrodes for heat-resistant steel.

High-Voltage Discharge Tube Electrodes: This electrode allows high-pressure flushing to remove eroded material from the tube body.

4. Purchasing Information

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Chapter 5: Preparation Technology of Tungsten-Copper Electrode

5.1 Infiltration process

The infiltration process is the core technology in the preparation of tungsten-copper electrodes. By infiltrating liquid copper into a porous tungsten skeleton, a composite material with excellent performance is prepared. This process includes two main stages: the prefabrication of the tungsten skeleton and the infiltration of copper, aiming to achieve low porosity and uniform phase distribution. The infiltration process is based on powder metallurgy, combined with a vacuum or inert atmosphere environment to ensure the high density and stability of the material. During the preparation process, the forming, sintering and pore control of tungsten powder are key steps, which directly affect the mechanical strength, conductivity and durability of the final electrode. The optimization of process parameters, such as temperature, pressure and time, significantly determines the microstructure and performance of the electrode.

5.1.1 Tungsten skeleton prefabrication

Tungsten skeleton prefabrication is the first step in the infiltration process, aiming to create a porous tungsten structure that provides a foundation for subsequent copper infiltration. During this stage, a skeleton structure with a certain strength is constructed through the molding, sintering, and porosity control of tungsten powder. The quality of the tungsten skeleton directly affects the copper filling effect and the performance of the final electrode. The preparation process requires precise control of raw material purity, particle size, and process parameters. Porosity and uniformity in the microstructure are key to successful prefabrication. Hot isostatic pressing is often used to optimize the density and stability of the skeleton. Tungsten skeleton prefabrication lays the foundation for the infiltration process, ensuring that the electrode has good mechanical properties during subsequent processing.

5.1.1.1 Tungsten powder molding

Tungsten powder molding is a fundamental step in the prefabrication of tungsten skeletons. By pressing the tungsten powder into a specific shape, it prepares the body for subsequent sintering and infiltration. This process typically utilizes cold pressing or isostatic pressing techniques, placing high-purity tungsten powder in a mold and mechanically forming a preliminary green body. During the molding process, the particle size and morphology of the tungsten powder must be consistent. Spherical or near-spherical powders help improve filling efficiency and green body uniformity. Mixing uniformity is achieved through ball milling or V-type mixers, ensuring that the powder distribution is free of significant stratification. Molding pressure and mold design directly affect the density and porosity distribution of the green body. Appropriate pressure can reduce internal defects.

formed green body must possess a certain mechanical strength to support subsequent high-temperature sintering. Surface treatments such as pre-pressing can further improve green body stability. Humidity must be controlled during the process to prevent moisture absorption by the powder, which can lead to a

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decrease in forming quality. Tungsten powder forming is the starting point of the entire preparation process, and its quality determines the smooth progress of subsequent steps.

5.1.1.2 Tungsten skeleton sintering

Tungsten skeleton sintering is a key step in transforming a tungsten powder green body into a porous skeleton. High-temperature treatment enhances the green body's strength and stability. This process is typically performed under vacuum or a hydrogen atmosphere. The sintering temperature is tailored to the characteristics of the tungsten powder, promoting neck growth and bonding between particles. Initially, the tungsten powder particles form initial connections through diffusion and recrystallization. As the temperature rises, the microstructure gradually densifies, and a porous structure begins to form. The sintering time and heating rate must be precisely controlled to avoid excessive heating that can cause cracking or overheating. The sintering process also involves atmosphere control. A reducing hydrogen environment removes the surface oxide layer and improves interparticle bonding. Hot isostatic pressing (HIP) can further optimize sintering, enhancing the uniformity and strength of the skeleton through omnidirectional pressure. The sintered tungsten skeleton should possess sufficient mechanical strength and appropriate porosity to provide channels for copper infiltration. Adjustment of process parameters influences the skeleton's microstructure. Future efforts, including dynamic simulation and multi-stage sintering techniques, will improve sintering efficiency and skeleton quality to meet the demands of high-precision electrodes.

5.1.1.3 Tungsten skeleton pore control

the tungsten skeleton's porosity is a critical step in ensuring successful infiltration. The goal is to adjust the skeleton's porosity and pore size distribution to create optimal conditions for copper infiltration. This process is achieved through molding pressure, sintering conditions, and the use of additives. Porosity directly impacts copper filling efficiency and the final electrode's performance. During the molding stage, adjusting pressure can alter the initial density of the green body. Lower pressures retain more pores, while higher pressures reduce the number of pores. During sintering, controlling temperature and time influences pore closure and connection. Appropriate sintering parameters maintain an open-pore structure. Additives such as organic binders or pore formers can assist in pore control. After sintering, the additives are removed through pyrolysis to form a uniform pore network. Microstructural analysis shows that uniform pore size distribution is the core of pore control. Excessively large or uneven pores may lead to insufficient copper penetration. The hot isostatic pressing process optimizes the pore structure through omnidirectional pressure, reducing the proportion of closed pores and improving penetration efficiency. Pore control also needs to consider the subsequent wettability of copper. Surface treatment can improve the interfacial bonding between the tungsten skeleton and liquid copper.

5.1.2 Infiltration control

Infiltration control is the decisive stage of the infiltration process, aiming to produce high-performance tungsten-copper electrodes by precisely managing the copper infiltration process. This stage includes

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three key steps: copper material preparation, infiltration temperature control, and infiltration time control, ensuring that the liquid copper fully fills the pores of the tungsten skeleton to form a uniform composite structure. Infiltration control directly affects the pore filling rate, interfacial bonding strength, and the density of the final electrode. Low porosity and uniform phase distribution in the microstructure are the core of quality assurance. A vacuum or inert atmosphere environment further optimizes the infiltration effect, and hot isostatic pressing can help improve material stability. Optimization of infiltration control provides reliable performance support for the application of electrodes in electrospark machining, welding, and microelectronics packaging.

5.1.2.1 Copper material preparation

Copper material preparation is a fundamental step in infiltration control, aiming to provide high-quality copper raw materials and establish conditions for the infiltration of liquid copper. This process typically involves the selection, purification, and pretreatment of copper powder or copper blocks to ensure good fluidity and wettability at high temperatures. The purity of the copper material is a key factor. High-purity electrolytic copper or atomized copper is selected to reduce the content of impurities such as oxygen and sulfur to avoid the formation of pores or defects during the infiltration process. The copper material can be in powder or lump form according to process requirements. The powder form facilitates uniform distribution, while the lump form is suitable for large-scale infiltration. The particle size or block size must match the porosity of the tungsten skeleton.

Pretreatment includes drying and surface cleaning. The copper material is dried in a vacuum or inert gas environment to remove surface moisture and oxide layers, improving interfacial bonding with the tungsten framework. Mechanical stirring or ball milling is used to achieve uniform mixing, ensuring consistent distribution of the copper material during infiltration. Preparation of the copper material also requires consideration of its melting point. Appropriate preheating can improve infiltration efficiency. During the preparation process, environmental control is implemented to prevent oxidation and ensure copper material quality.

5.1.2.2 Infiltration temperature control

Controlling the infiltration temperature is a key step in infiltration control, ensuring that copper effectively penetrates the tungsten skeleton while in a liquid state, while avoiding material damage caused by excessive heat. This process is typically performed in a vacuum furnace or in an inert atmosphere. The temperature is set above the melting point of copper to achieve a liquid phase, allowing the copper to fully wet and fill the pores. Precise temperature control is crucial. Too low a temperature may prevent the copper from fully melting, while too high a temperature may cause localized melting of the tungsten skeleton or grain growth, affecting the microstructure. The heating rate must be adjusted gradually to avoid cracking caused by concentrated thermal stress.

Temperature control also involves atmosphere management. A vacuum environment reduces oxidation reactions, and inert gases such as argon further protect the material. Hot isostatic pressing can assist with

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temperature control, enhancing copper penetration and improving filling efficiency through omnidirectional pressure. The stability of the infiltration temperature directly affects the quality of interfacial bonding. Excessive temperature fluctuations may cause copper overflow or uneven distribution. The temperature distribution within the furnace must be monitored during the process to ensure consistency across all parts. In the future, the introduction of intelligent temperature control systems or multi-stage heating technology will further optimize infiltration temperature control, improving electrode density and performance consistency.

5.1.2.3 Infiltration time control

Infiltration time is a key parameter in infiltration control, ensuring that the liquid copper fully penetrates the tungsten skeleton and forms a stable composite structure. This process is determined by the porosity of the tungsten skeleton, the amount of copper material, and the temperature. Too short a time may result in incomplete filling, while too long a time may cause excessive copper flow or skeleton deformation. During the initial infiltration phase, the copper needs sufficient time to wet the tungsten surface and penetrate deep pores. Afterward, time control focuses on the solidification process to avoid copper overflow and pore formation.

Time control also needs to be coordinated with temperature and pressure. Hot isostatic pressing (HIP) can shorten infiltration time and accelerate copper flow through omnidirectional pressure. In the process, the infiltration time is typically set in stages: an initial stage to ensure infiltration, a stabilization stage to promote bonding, and a cooling stage to solidify the structure. Microstructural analysis shows that appropriate infiltration time can reduce unfilled pores and improve interfacial bonding. Environmental stability and equipment performance directly impact the effectiveness of time control. In the future, real-time monitoring or dynamic adjustment technologies will be used to optimize infiltration time and enhance electrode uniformity and durability.

5.2 Post-processing technology

Post-processing is the final stage in the preparation of tungsten-copper electrodes. It aims to optimize the electrode's geometry, surface quality, and functional performance through cutting, grinding, surface treatment, and dimensional accuracy control. This stage is performed after the infiltration process to ensure that the electrode meets the requirements of the specific application. Post-processing of tungsten-copper electrodes utilizes the high hardness of tungsten and the ductility of copper to adjust the microstructure and improve durability through machining and surface modification techniques. Precise control of process parameters is critical, involving tool selection, processing environment, and quality inspection, which directly affects the performance of the electrode in EDM, welding, or microelectronic packaging.

5.2.1 Cutting

Cutting is the initial step in post-machining, removing excess material to shape the tungsten-copper

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electrode . This process typically involves turning or milling, using carbide or diamond tools to remove the infiltrated rough blank. Tungsten's high hardness requires tools with high wear resistance, while copper's ductility requires controlled cutting speeds and feeds to prevent sticking or tearing. Cutting is suitable for complex electrode shapes, such as rods or blocks. Coolant usage must be ensured during the process to minimize heat buildup and surface damage. The cutting process involves multiple steps, with roughing to remove excess material and finishing to achieve contour accuracy, gradually approaching the design dimensions. Low porosity in the microstructure supports uniform cutting of the material, and electrodes optimized by the hot isostatic pressing process exhibit good mechanical stability. Surface roughness must be inspected after cutting to ensure smooth processing in subsequent steps. Environmental control, such as dust control, can prevent dust contamination. Future advancements in CNC machine tools or laser-assisted cutting could improve processing efficiency and the accuracy of complex shapes, meeting the demands of high-precision electrodes.

5.2.2 Grinding

Grinding is a delicate post-processing step that uses abrasive tools to remove chip residue and improve the surface finish and geometric accuracy of tungsten-copper electrodes. This process typically utilizes diamond grinding wheels or silicon carbide tools to precisely grind the tungsten's high hardness. The ductility of copper requires lubrication to prevent excessive wear. Grinding is suitable for improving the contact surface quality of the electrode, particularly in applications such as electrospark machining (EDM) or microelectronics packaging where high flatness is required. The uniform phase distribution in the microstructure supports stable grinding results. The grinding process consists of two stages: rough grinding to remove chip marks and fine grinding to achieve a mirror-like finish. Grinding pressure and speed must be adjusted during the process to prevent thermal cracking or surface burns. Coolant is used to reduce temperatures and protect material properties. Electrodes optimized for hot isostatic pressing exhibit excellent wear resistance. Surface defects, such as microcracks or pits, are inspected after grinding to ensure quality meets standards.

5.2.3 Surface treatment

Surface treatment is a post-process optimization step that enhances the surface properties of tungsten-copper electrodes, such as corrosion resistance, oxidation resistance, and adhesion resistance, through chemical or physical methods. This process includes polishing, plating, or coating techniques to modify the high hardness of tungsten and the chemical activity of copper . Polishing removes surface microscopic defects, nickel or gold plating enhances weather resistance, and coatings such as titanium nitride improve wear resistance. Low porosity in the microstructure supports uniform surface treatment.

The surface treatment process should be tailored to the application scenario. For EDM electrodes, polishing may be preferred to improve discharge stability, while for welding electrodes, coating may be required to reduce slag adhesion. Temperature and time must be controlled to avoid affecting the internal structure. Optimized hot isostatic pressing (HIP) processes enhance electrode surface adhesion. Environmental controls, such as an inert atmosphere, can reduce oxidation. Surface adhesion and

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durability should be tested after treatment.

5.2.4 Dimensional accuracy control

Dimensional accuracy control is the final step in post-processing, ensuring that the tungsten-copper electrode meets design specifications through measurement and adjustment. This process utilizes coordinate measuring machines or optical inspection equipment to check the length, width, and geometric tolerances of the electrode, fine-tuning it to account for the high hardness of tungsten and the ductility of copper. After cutting and grinding, the electrode undergoes finishing, controlling dimensional deviations to the micron level and ensuring uniformity in the microstructure to support high-precision machining.

Dimensional accuracy control involves multiple inspections and corrections. After initial testing reveals deviations, they are corrected through fine grinding or local cutting. Electrodes optimized for hot isostatic pressing exhibit excellent dimensional stability. Environmental factors such as temperature fluctuations must be considered, as they affect material thermal expansion, necessitating constant temperature operation. Inspection data is recorded to ensure batch consistency. In the future, intelligent inspection systems or 3D scanning technology will enable real-time precision control to meet the demands of high-precision electrodes or complex structural components.



CTIA GROUP LTD Copper Tungsten Electrode

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Chapter 6: Application Scenarios of Tungsten-Copper Electrodes

Tungsten-copper electrodes are widely used in electrical discharge machining (EDM) due to their excellent electrical conductivity, high-temperature resistance, arc erosion resistance, and good machinability. In precision mold manufacturing, they are used for forming complex cavities and fine structures due to their low loss and high machining accuracy, making them particularly suitable for machining carbide molds. For difficult-to-machine materials such as titanium alloys and high-temperature alloys in the aerospace industry, they can withstand the high temperatures generated by high-frequency discharge, ensuring the surface quality and dimensional accuracy of precision parts.

Tungsten-copper electrodes also play a key role in welding, cutting, and electrical switching. In resistance welding, they reduce electrode wear and ensure stable weld strength, making them suitable for industries such as automotive manufacturing and home appliance production. In plasma cutting, they withstand high-temperature erosion, improving cutting efficiency and cut quality. Furthermore, as contact components in high-voltage circuit breakers, relays, and other equipment, their resistance to arc erosion and fusion welding ensures the safe and stable operation of power systems and electrical control equipment.

Tungsten-copper electrodes also have important applications in defense, aerospace, and specialized fields. In missile guidance systems, their stability ensures proper functioning in extreme environments. In spacecraft power systems, they withstand the harsh environment of space, ensuring efficient and safe energy transmission. In nuclear testing equipment and medical devices, their radiation resistance, electrical conductivity, and biocompatibility help improve the accuracy of test data and the safety of treatment processes, respectively. With technological advancements, their potential applications will continue to expand.

6.1 Application of tungsten copper electrodes in EDM

Tungsten-copper electrodes in electrical discharge machining (EDM) is one of its key applications. Due to its unique material properties, this technology is widely used in precision manufacturing. Electrospark machining (EDM) removes material through arc discharge, and tungsten-copper electrodes are ideal tools due to tungsten's high melting point and hardness combined with copper's high conductivity. Fabrication processes such as powder metallurgy or vacuum infiltration ensure low porosity and uniform phase distribution in the electrodes, while hot isostatic pressing further optimizes their microstructure, enhancing durability and stability. The advantages of tungsten-copper electrodes in mold and die machining, machining difficult-to-machine materials, and EDM demonstrate their critical role in the manufacture of high-precision and complex parts.

6.1.1 Application in mold processing

Tungsten-copper electrodes in mold processing demonstrates their importance in high-precision manufacturing, particularly in EDM machining of complex molds. Mold manufacturing requires precise

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geometry and smooth surfaces, and tungsten-copper electrodes meet this requirement through their high hardness and resistance to arc erosion. During manufacturing, the electrodes typically utilize a medium-to-high tungsten content (such as WCu 70/30 or WCu 80/20). Powder metallurgy creates a dense microstructure, and hot isostatic pressing optimizes their compressive strength and surface stability. The electrode's low porosity ensures stable discharge performance, while copper's high conductivity supports efficient current transfer, reducing processing time.

In mold processing, tungsten copper electrodes are particularly suitable for the fine processing of stamping molds, plastic molds and forging molds. The wear resistance of the electrode allows it to maintain its shape integrity during repeated discharges and reduce loss. The uniform phase distribution in the microstructure supports the forming of complex contours, such as deep ribs or small holes, and the processing accuracy can reach the micron level. Surface treatment such as polishing further improves the contact quality of the electrode and improves the surface finish of the mold. In production, the electrode can process high-hardness steel or alloy steel to meet the manufacturing needs of automotive parts and electronic component molds. Usage scenarios also include multi-electrode collaborative processing, and the toughness of the tungsten copper electrode supports multiple adjustments and installations.

Environmental control, such as the use of coolant, reduces thermal effects and extends electrode life, while post-processing processes such as grinding ensure dimensional accuracy. In the future, the introduction of functional gradient design or nanotechnology can further improve the durability and processing efficiency of tungsten copper electrodes in mold processing, meeting the needs of more complex or demanding mold manufacturing, such as aerospace components.

6.1.2 Application in the processing of difficult-to-process materials

Tungsten-copper electrodes in the machining of difficult-to-machine materials has demonstrated their superior performance under extreme conditions, making them particularly suitable for processing materials with high hardness or high melting points. Difficult-to-machine materials such as tungsten steel, titanium alloys, and ceramics are difficult to cut using traditional methods due to their strong mechanical properties, making electrospark machining (EDM) the preferred technology. Tungsten-copper electrodes, due to their high-temperature resistance and resistance to arc erosion, have become a core tool. During the manufacturing process, the electrodes are made of a high tungsten content (e.g., WCu 90/10), with a vacuum infiltration process forming a strong tungsten skeleton. Hot isostatic pressing (HIP) optimizes the microstructure, resulting in low porosity and a uniform phase distribution. The high electrical conductivity of copper supports efficient discharge.

When machining difficult-to-machine materials, tungsten-copper electrodes can withstand high-energy discharges. Tungsten's high melting point (over 3000°C) protects against arc temperatures and reduces surface wear, making them suitable for machining materials such as tungsten carbide and titanium alloys. The fine grains in their microstructure support high-precision machining, while the electrodes' wear resistance ensures long-term shape stability, making them suitable for forming complex geometries such as turbine blades or medical implants. Surface treatments such as coatings enhance oxidation resistance

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and improve performance in humid environments, while post-machining processes such as cutting and grinding optimize geometric accuracy.

Usage scenarios also include the aerospace and defense industries. The mechanical strength of tungsten-copper electrodes supports high-load processing, and the use of coolant reduces the risk of thermal cracking and extends the life of the electrode.

6.1.3 Advantages of Application in EDM

Tungsten-copper electrodes in EDM (Electrodischarge Machining) stem from their material's composite properties and optimized manufacturing process, enabling them to excel in high-precision and efficient production. EDM relies on the electrode's arc erosion resistance, electrical conductivity, and thermal management capabilities. Tungsten-copper electrodes, with their high tungsten content (such as WCu 80/20), offer high-temperature resistance. Tungsten's hardness protects against discharge shock, while copper's high electrical conductivity (nearing that of pure copper) ensures stable current transmission. Powder metallurgy creates a low-porosity microstructure, while hot isostatic pressing enhances interfacial bonding. Surface treatments such as polishing improve discharge consistency.

The application advantages are primarily reflected in durability. The arc erosion resistance of tungsten-copper electrodes reduces surface loss, extends service life, and reduces production costs, especially in high-energy discharge scenarios. Secondly, the combination of electrical and thermal conductivity optimizes processing efficiency. Heat dispersion in the copper phase reduces local overheating, improving workpiece surface quality and making it suitable for the manufacture of precision molds and micro-components. Thirdly, the mechanical strength and toughness support the processing of complex shapes, and the low porosity of the electrodes reduces the risk of cracks, making them suitable for forming deep holes or fine structures.

Application scenarios include the automotive industry and electronic manufacturing. The thermal expansion matching of tungsten-copper electrodes reduces stress between the workpiece and the workpiece, and coolant and environmental control further enhance stability.

6.2 Application of tungsten-copper electrodes in high-voltage electrical appliances

Tungsten-copper electrodes in high-voltage electrical equipment demonstrate their superior performance under extreme electrical conditions and is used in scenarios requiring high durability and stability. Tungsten's high melting point and hardness, combined with copper's high electrical and thermal conductivity, make it an ideal material for equipment such as high-voltage switches and lightning arresters. Preparation processes such as powder metallurgy or vacuum infiltration ensure the electrode's low porosity and uniform microstructure, while hot isostatic pressing further optimizes its arc resistance and mechanical strength. The application of tungsten-copper electrodes in high-voltage electrical equipment meets the needs of power transmission, industrial control, and defense equipment, and its performance advantages are particularly prominent in high-voltage and high-current environments.

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6.2.1 Application in high-voltage switches

Tungsten-copper electrodes in high-voltage switchgear is a key manifestation of their application in high-voltage electrical equipment, particularly suitable for applications requiring frequent disconnection of high currents. High-voltage switchgear is used for circuit control and protection in power systems. Tungsten-copper electrodes utilize a medium-to-high tungsten content (such as WCu 70/30 or WCu 85/15). Tungsten powder is mixed with copper powder through a powder metallurgy process. After sintering, the copper fills the pores in the liquid phase, forming a dense microstructure. Hot isostatic pressing optimizes interfacial bonding, while the low porosity in the microstructure enhances resistance to arc erosion. The high electrical conductivity of copper supports efficient current transmission.

In high-voltage switchgear, the high-temperature resistance of tungsten-copper electrodes is a key advantage. Tungsten's high melting point withstands arc discharge temperatures of thousands of degrees Celsius, reducing surface melting or wear and tear, and extending service life. The electrodes' arc resistance supports frequent switching operations, while copper's thermal conductivity aids heat dissipation, reducing the risk of localized overheating and improving electrical stability. The uniform phase distribution in the microstructure reduces stress concentration, and surface treatments such as nickel plating enhance oxidation resistance, making them suitable for humid or industrial environments. During the manufacturing process, tungsten powder must be of high purity and particle size control to ensure consistent performance.

Applications include power substations and industrial power distribution systems. Tungsten copper electrodes can withstand high voltage disconnection, reducing failure rates. Post-processing processes such as grinding can optimize contact surface quality.

6.2.2 Application in lightning arresters

Tungsten-copper electrodes in lightning arresters demonstrates their unique value in lightning protection, particularly suited for absorbing and dispersing high-energy lightning strikes. Arrester electrodes, used to protect electrical equipment from overvoltage damage, utilize a high tungsten content (e.g., WCu 80/20) and are produced through a vacuum infiltration process. Tungsten powder forms a solid skeleton, while copper infiltrates the material via liquid infiltration, resulting in a low-porosity and uniform microstructure. Hot isostatic pressing enhances the material's impact resistance and stability, while copper's high conductivity supports rapid current discharge.

In lightning arresters, the high-temperature resistance of tungsten-copper electrodes is a core advantage. Tungsten's high melting point protects against the high-temperature arc at the moment of a lightning strike, reducing material loss and extending service life. The electrodes' resistance to arc erosion ensures they maintain performance after multiple lightning strikes, while copper's thermal conductivity quickly dissipates heat, preventing equipment damage from overheating. The fine grains in their microstructure provide high mechanical strength, while surface treatments such as plating enhance corrosion resistance and adaptability to outdoor environments. During the manufacturing process, uniform mixing of raw

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materials and controlled pore size directly impact penetration efficiency. Application scenarios include high-voltage transmission lines and communication base stations. Tungsten-copper electrodes can effectively absorb lightning currents, and post-processing processes such as cutting and polishing optimize geometric accuracy.

6.2.3 Application Advantages in High-Voltage Electrical Appliances

Tungsten-copper electrodes in high-voltage electrical equipment stem from their material's composite properties and optimized fabrication process, enabling them to perform exceptionally well in high-voltage and high-current environments. High-voltage electrical equipment requires electrodes with arc erosion resistance, electrical conductivity, and thermal stability. Tungsten-copper electrodes, with their high tungsten content, offer high-temperature resistance, while tungsten's hardness provides resistance to arc shock, and copper's high electrical conductivity (nearing that of pure copper) ensures efficient current transmission. Powder metallurgy creates a low-porosity microstructure, while hot isostatic pressing strengthens interfacial bonding. Surface treatments such as plating enhance weather resistance. The advantages of tungsten-copper electrodes primarily lie in their arc erosion resistance. The arc resistance of tungsten-copper electrodes reduces surface wear and extends service life, particularly in the frequent operation of high-voltage switches and lightning arresters. Secondly, their combined electrical and thermal conductivity optimizes electrical performance. Heat dissipation within the copper phase reduces local overheating, improving equipment stability and making them suitable for high-current disconnection or lightning protection. Thirdly, their mechanical strength and corrosion resistance support operation in challenging environments. The uniformity of the microstructure reduces the risk of cracking, and surface treatment enhances durability. Application scenarios include power systems and industrial equipment. The thermal expansion matching of tungsten copper electrodes reduces stress with the substrate, and cooling systems and environmental control further enhance performance.

6.3 Application of tungsten copper electrodes in welding and brazing

Tungsten copper electrodes in welding and brazing demonstrates their unique performance in high-heat and high-current environments, and is widely used in industrial scenarios requiring efficient connections and reliable joints. The high melting point and hardness of tungsten combined with the high electrical and thermal conductivity of copper make it an ideal tool for resistance welding and brazing. Preparation processes such as powder metallurgy or vacuum infiltration ensure the low porosity and uniform microstructure of the electrode, and the hot isostatic pressing process further optimizes its thermal fatigue resistance and surface stability. The application of tungsten copper electrodes in the welding field meets the needs of industries such as automotive manufacturing, electronic assembly, and metal processing. Its performance advantages are particularly prominent in high-strength connections and complex working conditions.

6.3.1 Application in resistance welding

Tungsten-copper electrodes in resistance welding demonstrates their critical role in efficiently joining

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metal parts, making them particularly suitable for processes such as spot welding and seam welding. Resistance welding achieves metal fusion through the use of electric current and pressure. Tungsten-copper electrodes utilize a low-to-medium tungsten content. Tungsten powder is mixed with a high proportion of copper powder through a powder metallurgy process. After sintering, the copper forms a continuous conductive network. Hot isostatic pressing optimizes the microstructure, ensuring low porosity and uniform phase distribution. Copper's high conductivity provides a stable current path, while tungsten's high-temperature resistance supports electrode stability under high-heat conditions. Surface treatments such as polishing reduce weld slag adhesion.

In resistance welding, tungsten copper electrodes are mainly used for spot welding of automotive body panels or electronic components. The thermal conductivity of the electrode quickly disperses heat, reduces the heat-affected zone, and improves the quality of the joint. Tungsten's resistance to arc erosion ensures that the electrode maintains its shape during repeated welding, extending its service life, and is particularly suitable for high-frequency operation. The uniform copper phase network in the microstructure supports efficient current transmission, and the toughness of the electrode allows multiple adjustments and installations to accommodate workpieces of different thicknesses. In the preparation process, the mixing uniformity of the raw materials and the sintering parameters directly affect the performance of the electrode, and post-processing processes such as grinding optimize the contact surface. Usage scenarios include automotive manufacturing and home appliance production. The anti-adhesion properties of tungsten copper electrodes reduce the frequency of cleaning, and the cooling system enhances thermal management capabilities.

6.3.2 Application in brazing

Tungsten-copper electrodes in brazing demonstrates their unique value in low-heat-input joining, making them particularly suitable for joining precision metals and ceramics. Brazing achieves this by melting a filler. Tungsten-copper electrodes are prepared using a vacuum infiltration process with a medium tungsten content. Tungsten powder forms the skeleton, while copper infiltrates the filler via liquid phase infiltration. Hot isostatic pressing optimizes the microstructure, ensuring low porosity and uniform phase distribution. Copper's high electrical and thermal conductivity supports stable heating, while tungsten's high-temperature resistance prevents electrode deformation. Surface treatments such as plating enhance corrosion resistance.

In brazing, tungsten-copper electrodes are used to connect electronic components or aerospace parts. The electrode's thermal management capabilities evenly distribute heat, reduce thermal stress in the joint, and improve joint strength. Tungsten's hardness allows the electrode to maintain its shape at high temperatures, and its uniformity in the microstructure ensures consistent heating, making it particularly suitable for micro-welding or multi-layer structures. During the fabrication process, pore control and copper wettability directly influence penetration effectiveness, while post-processing steps such as cutting and polishing optimize electrode geometry. Applications include microelectronics packaging and aerospace manufacturing. The thermal expansion matching of tungsten-copper electrodes reduces stress with the substrate, and environmental controls such as an inert atmosphere prevent oxidation.

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6.3.3 Application advantages in welding field

Tungsten-copper electrodes in welding stem from their composite material properties and optimized manufacturing process, enabling them to excel in high-heat and high-current environments. Welding requires electrodes to possess electrical conductivity, thermal conductivity, and durability. Tungsten-copper electrodes provide this electrical conductivity through a low to medium tungsten content. Copper's high conductivity ensures efficient current transfer, while tungsten's high melting point provides resistance to high-temperature shock. Powder metallurgy creates a low-porosity microstructure, while hot isostatic pressing enhances interfacial bonding. Surface treatments such as plating enhance weather resistance.

The application advantages are first reflected in electrical and thermal conductivity. The copper phase network of the tungsten-copper electrode reduces the effect of resistive heating, improves joint quality, and evenly distributes heat, reducing the heat-affected zone, making it particularly suitable for high-frequency welding. Secondly, high-temperature resistance and arc erosion resistance extend service life. The hardness of tungsten supports repeated operation, reduces surface loss, and adapts to complex working conditions. Thirdly, anti-adhesion and mechanical strength support use in multiple scenarios. The toughness in the microstructure reduces the risk of cracks, and the surface treatment reduces the adhesion of welding slag.

Application scenarios include the automotive industry and electronics manufacturing. The thermal management capabilities of tungsten copper electrodes enhance welding efficiency, and cooling systems and environmental controls further optimize performance.

6.4 Application of Tungsten-Copper Electrodes in Aerospace and Military Industries

Tungsten-copper electrodes in the aerospace and military sectors demonstrates their superior performance in extreme environments and is widely used in critical components requiring high durability and reliability. Tungsten's high melting point and hardness, combined with copper's high electrical and thermal conductivity, make it an ideal material for rocket engines and guidance components. Preparation processes such as powder metallurgy or vacuum infiltration ensure the electrodes' low porosity and uniform microstructure, while hot isostatic pressing further optimizes their thermal fatigue resistance and mechanical strength. The application of tungsten-copper electrodes in the aerospace and military sectors meets the needs of deep space exploration, missile technology, and defense equipment, and their performance advantages are particularly prominent under conditions of high heat and high stress.

6.4.1 Application in rocket engine related components

Tungsten-copper electrodes in rocket engine components demonstrates their unique value in high-temperature and high-pressure environments, making them particularly suitable for the manufacture of propulsion systems and combustion chambers. Rocket engines must maintain stability under extreme thermal loads. Tungsten-copper electrodes are manufactured using a high tungsten content through a

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vacuum infiltration process. Tungsten powder forms a solid skeleton, while copper infiltrates the material via liquid infiltration. Hot isostatic pressing optimizes the microstructure, ensuring low porosity and uniform phase distribution. Copper's high electrical and thermal conductivity supports efficient thermal management, while tungsten's high-temperature resistance prevents melting. Surface treatments such as plating enhance corrosion resistance.

In rocket engines, tungsten-copper electrodes are used in nozzles or combustion chamber linings. Their high-temperature resistance protects against high-temperature gas flow, maintaining structural integrity. Their uniformity in the microstructure ensures even heat distribution and reduces thermal stress. Tungsten's hardness supports long-term use, while copper's thermal conductivity aids heat dissipation, extending component life and making them particularly suitable for high-thrust engines. During the manufacturing process, porosity control and raw material purity directly influence penetration efficiency. Post-processing techniques such as cutting and grinding optimize geometric accuracy and accommodate complex shapes. Usage scenarios include space launches and deep space exploration. The mechanical strength of tungsten copper electrodes supports high-pressure environments, and environmental controls such as inert atmospheres prevent oxidation.

6.4.2 Application in guidance components

Tungsten-copper electrodes in guidance components demonstrates their critical role in precision control and vibration resistance, making them particularly suitable for the manufacture of radar antennas and navigation systems. Guidance components require high precision and reliability. Tungsten-copper electrodes are manufactured using a powder metallurgy process with a medium tungsten content. Tungsten powder is mixed with copper powder and sintered to form a conductive network. Hot isostatic pressing optimizes the microstructure, ensuring low porosity and uniform phase distribution. Copper's high conductivity supports signal transmission, while tungsten's hardness enhances vibration resistance. Surface treatments such as polishing enhance contact quality.

In guidance components, tungsten-copper electrodes are used as electrical contacts or heat sinks. The electrodes' thermal conductivity evenly distributes heat, reducing overheating in electronic components. Their toughness in the microstructure provides resistance to mechanical shock, making them particularly suitable for high-speed aircraft. Tungsten's wear resistance ensures long-term stability, while copper's conductivity optimizes signal quality and adapts to complex electromagnetic environments. During the manufacturing process, raw material mixing and sintering parameters directly influence electrode performance, while post-processing steps such as grinding ensure dimensional accuracy. Usage scenarios include missile guidance and satellite navigation. The thermal expansion matching of tungsten copper electrodes reduces stress with the substrate, and environmental control such as dust prevention treatment enhances reliability.

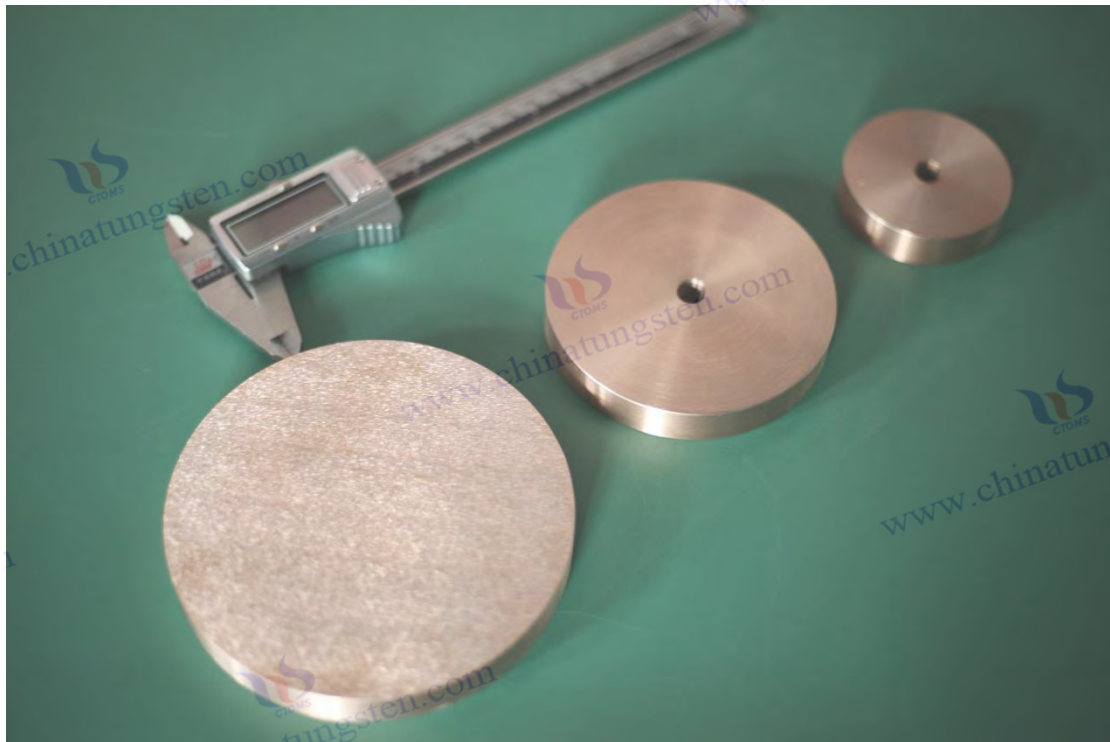
6.4.3 Application Advantages in Aerospace and Military Industries

Tungsten-copper electrodes in aerospace and military applications stem from their material's composite

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properties and optimized fabrication process, enabling them to excel in high-heat, high-stress environments. Aerospace and military applications require electrodes with high-temperature resistance, electrical conductivity, and mechanical strength. Tungsten-copper electrodes utilize a high tungsten content to provide heat resistance, while tungsten's hardness provides resistance to extreme conditions, and copper's high electrical conductivity ensures efficient current or signal transmission. Powder metallurgy creates a low-porosity microstructure, while hot isostatic pressing enhances interfacial bonding. Surface treatments such as plating enhance weather resistance.

The application advantages are first reflected in high temperature resistance. The heat resistance of tungsten copper electrodes supports the stable operation of rocket engines and guidance components in high-temperature environments, reduces material loss, and extends service life. Secondly, the combination of electrical conductivity and thermal conductivity optimizes performance. The heat dispersion of the copper phase reduces local overheating, improves the efficiency of electronic components or signal transmission, and is particularly suitable for high-precision applications. Thirdly, mechanical strength and vibration resistance support complex working conditions, the toughness in the microstructure reduces the risk of cracks, and surface treatment enhances durability. Usage scenarios include space launches and defense equipment. The thermal management capabilities of tungsten copper electrodes enhance component reliability, and environmental control and cooling systems further optimize performance.



CTIA GROUP LTD Copper Tungsten Electrode

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Chapter 7: Quality Control and Testing Standards for Tungsten-Copper Electrodes

Tungsten-copper electrodes is a rigorous process throughout the entire production process, from raw material screening to finished product processing. The purity, particle size, and uniformity of the tungsten and copper powders must be verified during the raw material process to prevent excessive impurities from affecting the electrode's electrical conductivity and high-temperature resistance. During the forming and sintering process, the pressing density, sintering temperature, and holding time must be controlled to ensure a dense internal structure, free of significant pores or cracks, and minimize the risk of wear during use. Furthermore, during the machining phase, dimensional accuracy and surface roughness must be monitored, particularly for electrodes used in precision EDM.

In terms of testing standards, tungsten-copper electrodes must undergo multiple performance tests to verify their quality. Physically, density, hardness, and conductivity are tested to ensure they meet the basic performance requirements of the application scenario. Structural integrity is inspected using a metallographic microscope or ultrasonic testing, and internal defects that affect strength are strictly prohibited. In special scenarios, arc erosion resistance testing and high-temperature stability testing are also required to simulate the wear and tear experienced in actual operating conditions. ASTM standards are often referenced internationally, while GB/T specifications are used domestically. Some high-end applications also employ customized standards to meet more stringent requirements.

7.1 Detection of key indicators of tungsten copper electrode

Tungsten-copper electrodes is crucial for ensuring their performance and reliability, encompassing aspects such as physical, thermal, and electrical conductivity. Through scientific testing methods and standardized processes, manufacturers can verify that the electrodes meet specific application requirements. Tungsten-copper electrodes are produced through powder metallurgy or vacuum infiltration processes, and their microstructure and composition distribution directly impact performance. Hot isostatic pressing further optimizes their consistency. The testing process involves a variety of instruments and environmental controls to assess the electrode's density, thermal conductivity, and electrical properties—all crucial in fields such as electrical discharge machining, high-voltage electrical equipment, and welding. In the future, advancements in testing technology will lead to even more refined quality control.

7.1.1 Physical properties test of tungsten copper electrode

Tungsten-copper electrodes is central to quality control, assessing their density, structural integrity, and mechanical properties to provide a foundation for subsequent applications. Physical properties reflect the quality of electrode preparation and microstructural characteristics. The high hardness of tungsten combined with the ductility of copper makes testing challenging. Testing is typically conducted in a laboratory setting using specialized equipment and standardized procedures, encompassing multiple parameters such as density, porosity, and surface morphology. Electrodes optimized for hot isostatic pressing exhibit high physical stability, and these test results guide process improvements, ensuring

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electrode reliability in high-load or high-temperature environments.

7.1.1.1 Density testing methods and standards

Density testing methods and standards are the starting point for physical property testing of tungsten-copper electrodes. They aim to measure the electrode's mass per unit volume, reflecting its compactness and pore distribution. Density directly affects the electrode's mechanical strength and conductivity. Testing typically employs the Archimedean method or the displacement method, calculating the density by immersing the electrode in a liquid and measuring the change in weight. The Archimedean method requires a clean electrode surface to prevent residual liquid from affecting the results. Temperature and humidity must be controlled during operation to ensure consistent measurements. The displacement method, achieved through precise weighing and liquid displacement, is suitable for electrodes with complex shapes and requires a high-precision balance.

The standardized testing process includes sample preparation and multi-point measurement. Samples are randomly selected from different batches, and representative areas are cut to assess uniformity. The testing environment must be stable to avoid external interference. Test results are correlated with process parameters such as sintering temperature and pressure. Quality control personnel establish density ranges based on industry standards. Electrodes outside these ranges require tracing back to the production process and adjusting powder mixing or infiltration conditions. Surface treatments such as polishing can assist with density testing and reduce the impact of surface defects.

7.1.1.2 Thermal performance test methods and standards

Thermal performance testing methods and standards are key to evaluating the thermal management capabilities of tungsten-copper electrodes. These tests measure their thermal conductivity and thermal expansion characteristics. Thermal performance directly impacts the electrode's stability and heat dissipation efficiency in high-temperature environments. Testing is typically performed using either a heat flow meter or laser flash method. The heat flow meter method measures heat transfer using a heat flow sensor and is suitable for evaluating the thermal conductivity of bulk electrodes, requiring constant temperature operation. The laser flash method heats the sample surface with a brief pulse and measures the thermal diffusion time. It is suitable for thin sheets or delicate components and requires highly sensitive equipment.

The standardized testing process includes sample preparation and environmental control. Samples must be polished to a flat surface to prevent surface roughness from affecting measurements. The testing environment must simulate actual operating conditions, such as high temperatures, and multi-point measurements ensure representative data. Thermal performance results are correlated with microstructure. Electrodes optimized for hot isostatic pressing exhibit good thermal stability, and test data guides process adjustments. Quality control personnel set thermal performance thresholds based on industry standards. Electrodes outside these thresholds require optimization of copper content or porosity distribution.

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7.1.1.3 Conductivity testing methods and standards

Conductivity testing methods and standards are central to evaluating the electrical properties of tungsten-copper electrodes. They measure their resistivity and conductivity to ensure efficient current transfer. Conductivity directly impacts the electrode's performance in EDM (Electro-Discharge Machining) or high-voltage electrical applications. Testing typically utilizes either the four-probe or bridge method. The four-probe method minimizes the effects of contact resistance by contacting the sample at multiple electrode points, making it suitable for high-precision measurements and requiring constant current operation. The bridge method compares resistance values using a bridge circuit and is suitable for complex electrode shapes, requiring highly sensitive instrumentation.

The standardized testing process includes sample preparation and environmental control. Samples must be cut to standard dimensions to prevent geometrical influences on the results. The testing environment must be shielded from electromagnetic interference, and the temperature and humidity must be kept stable. Multi-point measurement ensures conductivity consistency. Conductivity results are closely related to microstructure and copper content. Electrodes optimized through hot isostatic pressing (HIP) exhibit good conductivity uniformity, and test data guides ratio adjustments.

7.1.2 Chemical performance test of tungsten copper electrode

Tungsten-copper electrodes is a crucial component of quality control. It assesses their composition distribution, corrosion resistance, and impurity content to ensure the electrode's chemical stability and service life in various environments. Chemical properties directly impact the electrode's oxidation resistance, corrosion resistance, and long-term reliability. Testing is typically conducted under laboratory conditions, utilizing advanced analytical techniques and standardized operating procedures. Tungsten's high chemical stability and copper's active properties allow for diverse testing procedures. Electrodes optimized for hot isostatic pressing exhibit excellent chemical uniformity. Test results guide raw material selection and process improvements.

7.1.2.1 Component analysis method

Composition analysis methods are the basis for testing the chemical properties of tungsten-copper electrodes. They aim to determine the ratio of tungsten to copper, as well as the content of other trace elements, to ensure that the ratio meets design requirements. This process typically utilizes spectroscopic analysis or chemical titration. Spectroscopic analysis methods such as X-ray fluorescence spectroscopy (XRF) or inductively coupled plasma optical emission spectroscopy (ICP-OES) identify elemental composition through the spectral signatures emitted by the sample and are suitable for rapid testing. Chemical titration methods precisely determine the tungsten and copper content through the reaction of a standard solution with the sample, requiring high-precision titration equipment.

The standardized testing process includes sample preparation and multi-point sampling. Samples need to be cut from different parts of the electrode and crushed into a uniform powder to ensure

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representativeness. The humidity of the testing environment needs to be controlled to avoid oxidation or moisture absorption of the sample, and operators need to follow safety regulations when handling chemical reagents. The results of the composition analysis are related to the preparation process. For example, the powder mixing uniformity and infiltration conditions directly affect the final ratio. Quality control personnel set the composition range according to the product specifications. Electrodes that exceed the range need to trace the raw material batch or adjust the process parameters. Surface treatment such as polishing can reduce the impact of surface contamination. In the future, the efficiency and accuracy of composition detection can be improved by introducing portable spectrometers or automated analysis systems.

7.1.2.2 Corrosion resistance test method

Corrosion resistance testing methods are key to evaluating the chemical stability of tungsten-copper electrodes in acidic, alkaline, or humid environments, aiming to ensure their long-term performance in industrial applications. This process typically involves a salt spray test or immersion test. The salt spray test simulates a corrosive atmospheric environment and observes changes on the electrode surface. This test must be conducted in a dedicated salt spray chamber. The immersion test, on the other hand, places the electrode in a specific corrosive solution, such as dilute sulfuric acid or sodium chloride solution, and regularly checks the degree of surface corrosion and mass loss. This test requires constant temperature equipment.

The standardized testing process includes sample preparation and environmental control. Samples must be polished to a consistent surface to prevent initial defects from affecting the results. The testing cycle is set according to application requirements, and multiple groups of samples are tested in parallel to verify consistency. Corrosion resistance results are related to microstructure and surface treatment. Electrodes optimized by the hot isostatic pressing process show good corrosion resistance uniformity. Test data guides the plating or coating process. Quality control personnel evaluate corrosion rates according to industry standards. Electrodes that fall outside the range require optimization of copper content or introduction of corrosion resistance treatment.

7.1.2.3 Impurity content testing standards

Impurity content testing standards are key to ensuring the chemical purity of tungsten copper electrodes. They aim to identify and control the effects of oxygen, sulfur, or other trace elements to prevent them from adversely affecting performance. This process typically utilizes combustion or mass spectrometry. The combustion method decomposes the sample at high temperatures and measures the amount of oxygen or nitrogen released, requiring an infrared absorption spectrometer. Mass spectrometry analyzes elemental composition by ionizing the sample and is suitable for detecting trace impurities, requiring a high-resolution mass spectrometer.

The standardized testing process includes sample preparation and environmental control. Samples are randomly selected from different batches, crushed, and dried to remove surface moisture. The testing

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environment must be free of external contamination, and operators must follow safety regulations when handling high-temperature equipment. Impurity content results are related to raw material purity and the preparation environment. Electrodes optimized for hot isostatic pressing exhibit low impurity levels. Test data guides raw material screening and process optimization. Quality control personnel set impurity thresholds based on industry standards. Electrodes that exceed this range require adjustment of powder purity or the introduction of purification steps.

7.1.3 Mechanical properties test of tungsten copper electrode

Tungsten-copper electrodes is a crucial component of quality control, evaluating their hardness, strength, and toughness to ensure their reliability under high loads or impact. Mechanical properties reflect the electrode's resistance to deformation, fracture, and energy absorption. Testing is typically conducted in a laboratory setting using specialized equipment and standardized procedures. The high hardness of tungsten and the ductility of copper allow for diverse testing procedures. Electrodes optimized for hot isostatic pressing exhibit excellent mechanical uniformity, and these test results provide guidance for process improvements and application selection.

7.1.3.1 Hardness testing methods and standards

Hardness testing methods and standards are fundamental to the mechanical performance testing of tungsten-copper electrodes. They aim to measure their surface resistance to indentation and wear, ensuring the durability of the electrode during processing or use. This process typically utilizes either the Vickers or Rockwell hardness methods. The Vickers method involves pressing a diamond indenter into the sample surface and observing the geometry of the indentation. This method is suitable for testing hard materials and requires a high-precision microscope. The Rockwell method measures the depth of indenter penetration to rapidly assess changes in hardness. It is suitable for large-scale testing and requires the use of a standard testing machine.

The standardized testing process includes sample preparation and multi-point measurement. Samples need to be cut from different parts of the electrode and polished to a flat surface to avoid initial defects affecting the results. The testing environment needs to control temperature and humidity to prevent interference from thermal expansion or surface oxidation. Operators need to follow safety regulations to operate the equipment. The hardness results are related to the microstructure and tungsten content. The electrodes after optimization of the hot isostatic pressing process show good hardness uniformity, and the test data guides the ratio adjustment. Quality control personnel set the hardness range according to industry standards. Electrodes outside the range need to optimize the sintering or post-processing process. Surface treatment such as grinding can assist hardness testing. In the future, the introduction of automated hardness testers or image analysis can improve detection efficiency and accuracy.

7.1.3.2 Strength testing methods and standards

Strength testing methods and standards are key to evaluating the compressive and tensile strength of

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tungsten-copper electrodes , ensuring their stability under high mechanical stress. This process typically involves compression testing or tensile testing. Compression testing measures the sample's deformation limit by applying pressure and is suitable for block electrodes, requiring a universal testing machine. Tensile testing assesses tensile strength by applying a tensile force until fracture, suitable for rod-shaped or sheet-shaped electrodes and requiring the use of specialized fixtures.

The standardized testing process includes sample preparation and environmental control. Samples must be machined to standard dimensions to ensure consistent geometry, and incisions must be smooth to avoid stress concentration. The testing environment must maintain a constant temperature to prevent temperature fluctuations from affecting material properties, and multi-point measurements are used to verify uniformity. Strength results are related to the microstructure and preparation process. Electrodes optimized for hot isostatic pressing (HIP) exhibit high compressive stability, and test data guides adjustments to pressure and sintering parameters. Quality control personnel set strength thresholds based on industry standards. Electrodes outside this range require optimization of powder particle size or infiltration conditions.

7.1.3.3 Toughness test methods and standards

Toughness testing methods and standards are key to evaluating the fracture resistance and energy absorption capabilities of tungsten-copper electrodes , aiming to ensure their reliability during shock or thermal cycling. This process typically involves impact testing or fracture toughness testing. Impact testing involves striking a sample with a pendulum and measuring the absorbed energy. This is suitable for assessing impact resistance and requires a standard pendulum machine. Fracture toughness testing, on the other hand, involves loading a pre-created crack and analyzing its propagation behavior. This is suitable for testing precision components and requires high-precision loading equipment.

The standardized testing process includes sample preparation and environmental control. Samples must be machined to the specified shape, pre-cracks must meet standard requirements, and the surface must be polished to reduce initial defects. The testing environment must be stable to prevent vibration or temperature fluctuations from affecting the results. Multiple groups of samples are tested in parallel to ensure representativeness. Toughness results are related to microstructure and copper content . Electrodes optimized by the hot isostatic pressing process show good toughness uniformity. Test data guides phase distribution adjustments.

7.2 Microstructure inspection of tungsten copper electrode

Microstructural testing of tungsten-copper electrodes is a crucial step in quality control, aimed at evaluating the effectiveness of the manufacturing process and material properties by analyzing their internal structural characteristics. Microstructure directly impacts the electrode's mechanical strength, conductivity, and durability. Testing is typically performed in a laboratory setting using advanced microscopy techniques and standardized operating procedures. Tungsten-copper electrodes are manufactured through powder metallurgy or vacuum infiltration processes. Their microstructure consists

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of a tungsten skeleton and copper phase distribution. Hot isostatic pressing further optimizes their uniformity and density. The inspection process involves metallographic analysis, phase distribution uniformity evaluation, and grain size measurement—all crucial indicators in fields such as electrical discharge machining, high-voltage electrical equipment, and welding.

7.2.1 Metallographic analysis

Metallographic analysis is the core of microstructural testing for tungsten-copper electrodes, aiming to assess material quality and consistency by observing internal structural features. This process uses microscopic techniques, typically optical microscopy or scanning electron microscopy (SEM), to reveal the electrode's phase structure, pore distribution, and interfacial bonding. Metallographic analysis helps identify defects in the manufacturing process, such as unfilled pores or phase separation. Electrodes optimized for hot isostatic pressing exhibit excellent structural uniformity. The results guide process adjustments to ensure stable electrode performance under high loads or high temperatures.

7.2.1.1 Metallographic sample preparation

Metallographic sample preparation is a fundamental step in metallographic analysis, aiming to obtain a smooth cross-section suitable for microscopic observation through sample processing. This process typically includes multiple stages: cutting, grinding, and polishing. Cutting uses a metallographic cutter to slice the electrode into thin slices, and appropriate cutting tools must be selected to avoid material damage. Grinding uses sandpaper of varying grits to gradually remove surface roughness, controlling pressure and direction to ensure a smooth cross-section. Polishing uses diamond suspension or alumina polishing paste to further improve surface finish and must be performed in a dust-free environment to prevent contamination.

Sample preparation also involves etching the cross-section using appropriate chemical reagents to highlight the phase structure of tungsten and copper. Etching time and reagent concentration are adjusted according to the material properties. Electrodes optimized for hot isostatic pressing (HIP) require special attention to surface protection to avoid excessive corrosion that could affect observation. Environmental control, such as temperature and humidity, is crucial during preparation, and samples must be stored dry to prevent oxidation. Quality control personnel verify preparation quality according to industry standards; defects such as scratches or cracks can distort analysis.

7.2.1.2 Evaluation criteria for phase distribution uniformity

Phase uniformity evaluation is a key step in metallographic analysis, aiming to assess the distribution of tungsten and copper within the electrode to ensure consistent performance. This process involves observing cross-sectional images with a microscope and analyzing the uniformity of the phase structure using image processing software. Quantitative evaluation is typically performed using either a grid method or a point counting method. The grid method divides the cross section into multiple regions and calculates the phase ratios in each region. The point counting method calculates the distribution density

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of tungsten and copper through random sampling , using a high-resolution imaging system.

The standardized evaluation process includes sample selection and multi-point analysis. Samples need to be selected from different batches and locations to ensure representativeness, and the analysis needs to cover multiple areas of the cross section to verify uniformity. Electrodes optimized by the hot isostatic pressing process exhibit better phase distribution. The test results are related to the infiltration process and powder mixing. Defects such as local enrichment or voids may affect performance. Quality control personnel set uniformity thresholds based on industry standards. Electrodes that exceed the range need to adjust the raw material particle size or sintering conditions. Environmental control, such as avoiding vibration, ensures clear images. In the future, the accuracy and comprehensiveness of phase distribution evaluation can be improved by introducing artificial intelligence analysis or three-dimensional imaging technology .

7.2.1.3 Grain size detection

Grain size testing is a crucial component of metallographic analysis, aimed at measuring the size of tungsten and copper grains and assessing their impact on electrode performance. This process involves observing the etched cross-section with a microscope, using either the standard line intercept method or automated image analysis. The standard line intercept method uses random straight lines to plot grain cross-sections, while the automated image analysis method uses software to identify grain boundaries, requiring a high-magnification microscope.

The standardized inspection process includes sample preparation and multi-area measurement. The samples need to be polished and etched to ensure that the grain boundaries are clearly visible. The measurement needs to cover different parts of the cross section to evaluate the uniformity. The grain size of the electrode after optimization of the hot isostatic pressing process is more consistent. The test results are closely related to the sintering temperature and time. Excessively large or uneven grains may reduce performance. Quality control personnel set the grain size range according to industry standards. Electrodes that exceed the range need to optimize the sintering parameters or introduce refinement technology. Environmental control, such as constant temperature, avoids the influence of thermal expansion. In the future, the accuracy and real-time performance of grain size detection can be improved by introducing nano-scale microscopes or dynamic imaging technology.

7.2.2 Defect Detection of Tungsten-Copper Electrodes

Tungsten-copper electrodes is a key component of microstructural inspection, aimed at identifying and evaluating defects such as pores, cracks, and inclusions to ensure electrode quality and reliability. Defects can lead to reduced performance or shortened service life. Testing is typically performed under laboratory conditions, using non-destructive or destructive testing methods combined with standardized determination procedures. Preparation processes for tungsten-copper electrodes, such as powder metallurgy or vacuum infiltration, can introduce defects. Hot isostatic pressing (HIP) reduces these defects by optimizing the microstructure. Test results guide process improvements, ensuring stable

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electrode performance under high loads or extreme environments.

7.2.2.1 Porosity detection method and allowable range

Porosity detection methods and tolerances are fundamental to defect detection in tungsten-copper electrodes. They aim to identify internal voids and assess their impact on material properties. Porosity can form during sintering or infiltration, affecting the electrode's density and conductivity. Detection is typically performed using X-ray or ultrasonic testing. X-ray testing uses transmission imaging to visualize the distribution of internal pores. It is suitable for complex electrodes and requires a high-resolution imaging system. Ultrasonic testing analyzes internal voids through sound wave reflection and is suitable for large electrodes, requiring specialized probes and signal processing equipment.

The standardized testing process includes sample preparation and multi-angle scanning. The sample surface must be clean to reduce interference, and the test covers different parts of the electrode to ensure comprehensiveness. Electrodes optimized for hot isostatic pressing (HIP) exhibit less porosity. Test results are related to the preparation process, such as powder particle size and infiltration conditions, which directly influence pore formation. Quality control personnel set the permissible porosity range based on industry standards. Electrodes exceeding this range require adjustment of the sintering temperature or introduction of vacuum treatment.

7.2.2.2 Crack detection methods and criteria

Crack detection methods and criteria are key to assessing the risk of internal fracture in tungsten-copper electrodes. They aim to identify defects caused by thermal or mechanical stress. Cracks can develop during sintering, cooling, or post-processing, affecting the electrode's mechanical strength and service life. Detection is typically performed using penetrant testing or magnetic particle testing. Penetrant testing reveals surface cracks through dye penetration and is suitable for complex geometries, requiring surface cleaning. Magnetic particle testing, which uses a magnetic field and magnetic particles to reveal internal cracks, is suitable for ferromagnetic materials and requires magnetization equipment.

The standardized testing process includes sample pretreatment and multi-point inspection. Surface contamination must be removed, and critical electrode areas must be inspected to verify integrity. Electrodes optimized for hot isostatic pressing (HIP) exhibit fewer cracks. Test results are correlated with cooling rate and pressure conditions, and defects such as microcracks may require magnification. Quality control personnel set crack determination criteria based on industry standards. Electrodes exceeding these criteria require optimization of the sintering process or the introduction of stress relief treatment.

7.2.2.3 Inclusion detection methods and control standards

Inclusion detection methods and control standards are key to ensuring the purity of tungsten-copper electrodes. They aim to identify foreign matter introduced into the raw materials or during the preparation process. Inclusions may include oxides or unfused powder, which affect the electrode's

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conductivity and corrosion resistance. Detection is typically performed using spectral analysis or electron microscopy. Spectroscopic analysis detects inclusion elements by analyzing the spectral signature emitted by the sample. It is suitable for rapid screening and requires highly sensitive instrumentation. Electron microscopy, on the other hand, analyzes inclusion morphology through high-magnification imaging and is suitable for detailed analysis. It requires the use of an energy dispersive spectrometer.

The standardized testing process includes sample preparation and multi-area analysis. The samples need to be sliced and polished to a flat surface, and the test needs to cover different parts of the electrode to ensure representativeness. The electrode has fewer inclusions after the hot isostatic pressing process is optimized. The test results are related to the purity of the raw materials and the uniformity of the mixture. Defects such as local foreign matter may require further cross-sectional analysis. Quality control personnel set inclusion control standards according to industry standards. Electrodes that exceed the range need to adjust the powder source or introduce a filtration process. Environmental control such as dust prevention treatment avoids secondary pollution. In the future, the real-time and accuracy of inclusion detection can be improved by introducing online monitoring or automated detection technology.

7.3 Industry Standards for Tungsten-Copper Electrodes

Tungsten-copper electrodes are crucial for ensuring consistent quality and performance, encompassing the entire production, testing, and application process. Developed by relevant authoritative organizations, these standards, combined with the manufacturing process and application requirements of tungsten-copper electrodes, guide manufacturers and users in achieving technical specifications and safety assurance. Tungsten-copper electrodes are produced through powder metallurgy or vacuum infiltration processes, and their microstructure and performance must meet industry requirements. Hot isostatic pressing further optimizes their consistency. Industry standards encompass relevant domestic standards and specific requirements, covering material composition, performance indicators, and defect control, providing technical support for fields such as electrical discharge machining (EDM), high-voltage electrical equipment, and welding.

7.3.1 Relevant domestic standards

Relevant domestic standards provide a unified technical framework for the production and application of tungsten-copper electrodes, reflecting China's latest advancements in materials science and industrial manufacturing. These standards, jointly developed by the National Standardization Administration of China and industry associations, cover the preparation, testing, and use of electrodes, aiming to enhance product quality and international competitiveness. Tungsten-copper electrode preparation processes, such as powder metallurgy and vacuum infiltration, must comply with these standards. Electrodes optimized through hot isostatic pressing (HIP) must undergo testing to verify their compliance.

7.3.1.1 Relevant provisions of Chinese standards

Chinese standards, primarily issued by the Standardization Administration of China, provide a specific

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legal and technical basis for the quality control and application of tungsten-copper electrodes . These regulations, including national standards such as "Copper-Tungsten and Silver-Tungsten Electrical Contacts" and "Defect Detection Methods for Copper-Tungsten Electrical Contacts," address composition requirements, performance indicators, and defect detection specifications. The manufacturing process must ensure that the tungsten-to- copper ratio meets the standards. Testing encompasses physical, chemical, and mechanical properties, and electrodes optimized through hot isostatic pressing must undergo microstructural testing. The standards require manufacturers to establish a quality management system, regularly test raw materials and finished products, and ensure that surface treatments, such as coatings, meet corrosion resistance requirements.

These regulations apply to the field of electrical alloys, emphasizing the stability of electrodes in high-voltage electrical equipment and electrical discharge machining, and encouraging companies to adopt advanced processes to reduce defects. Industry associations such as the National Technical Committee for Standardization of Electrical Alloys are responsible for drafting the standards. Key organizations include the Guilin Electrical Science Research Institute and Wenzhou Hongfeng Electrical Alloy Co., Ltd., representing China's technological strength. The standards also require clear product labeling and accompanying safety instructions to ensure compatibility with diverse application scenarios.

7.3.1.2 Industry standard requirements

Industry standards provide detailed technical specifications for specific applications of tungsten-copper electrodes , primarily developed by the Ministry of Industry and Information Technology or relevant industry associations. These requirements, including industry standards such as "Tungsten-Copper Alloy Plate," focus on material properties, processing techniques, and operating conditions, guiding companies in producing electrodes that meet market demand. The preparation process requires controlled powder particle size and sintering parameters. Electrodes optimized through hot isostatic pressing must meet strength and conductivity requirements. Post-processing processes such as cutting and grinding must ensure geometric accuracy.

Industry standards require electrodes to resist arc erosion in EDM, ensure efficient thermal conductivity in welding, and maintain high-temperature resistance in high-voltage electrical equipment. Testing must cover microstructure, defects, and performance indicators, and manufacturers must establish a batch inspection system to record process parameters and test results. The standards also encourage green production, reduce waste emissions, and comply with environmental protection requirements. The participation of relevant organizations such as Guilin Jinge Electrical and Electronic Materials Technology Co., Ltd. in the standard's development reflects the industry's technological level.

7.3.2 Relevant international standards

International standards provide a unified technical framework for the global application of tungsten-copper electrodes , reflecting the collaboration and consensus among different countries and regions in materials science and industrial manufacturing. These standards are developed by organizations such as

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the International Organization for Standardization (ISO) or independently issued by major industrialized nations such as Europe, the United States, Japan, and South Korea based on their own needs and development levels. They aim to promote international trade and technological exchange. Tungsten-copper electrode manufacturing processes, such as powder metallurgy and vacuum infiltration, must comply with these standards. Electrodes optimized through hot isostatic pressing (HIP) processes must undergo testing to verify their international compatibility. International standards cover composition requirements, performance testing, and application specifications, providing guidance to multinational companies and ensuring consistent quality and reliability in global markets.

7.3.2.1 International Tungsten-Copper Electrode Standards

International tungsten-copper electrode standards are primarily developed by the International Organization for Standardization (ISO), aiming to establish unified specifications for the global production and application of tungsten-copper electrodes. These standards integrate the properties of tungsten-copper materials with the diverse requirements of various industrial applications, covering the entire process from raw material selection to final product testing. ISO standards are often based on extensive international collaboration and incorporate technical expertise from countries such as Europe, the United States, Japan, and South Korea, ensuring global applicability. Tungsten-copper electrodes are produced through powder metallurgy or vacuum infiltration processes. Their microstructure and properties must conform to ISO-specified composition ratios and physical properties. Electrodes optimized through hot isostatic pressing (HIP) must undergo rigorous performance testing to meet international requirements. ISO standards related to tungsten-copper electrodes primarily address material preparation, performance evaluation, and quality control. For example, the standards specify that the tungsten-copper ratio must be adjusted based on the application to balance conductivity, high-temperature resistance, and mechanical strength. During the production process, powder particle size, sintering conditions, and infiltration techniques must be precisely controlled to ensure low porosity and uniform phase distribution in the electrode. In terms of testing, ISO standards require a comprehensive assessment of the electrode's density, conductivity, hardness, and corrosion resistance, using advanced non-destructive testing techniques such as X-ray or ultrasonic testing to identify internal defects. The hot isostatic pressing process plays a key role in improving material density and performance consistency, and test results must be compared with internationally recognized performance thresholds.

These standards are particularly applicable to fields such as electrical discharge machining, high-voltage electrical equipment, and welding, emphasizing the stability and durability of electrodes under extreme conditions. ISO standards also encourage the use of environmentally friendly processes, reduce waste emissions during production, and adapt to global trends in sustainable development.

7.3.2.2 Tungsten-copper electrode standards in Europe, America, Japan, South Korea, and other countries

Tungsten-copper electrode standards in Europe, the United States, Japan, South Korea, and other countries reflect the unique characteristics of each region's industrial technology development and

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application needs. These standards are developed by their respective national standardization bodies and reflect different technical traditions and market orientations. US standards are primarily issued by the American Welding Society (AWS) and the American Society for Testing and Materials (ASTM), European standards are developed by the European Committee for Standardization (CEN), Japanese standards are issued by the Japan Industrial Standards Committee (JISC), and South Korean standards refer to Japanese standards while incorporating local needs. These standards provide detailed guidance for the preparation, testing, and application of tungsten-copper electrodes. Electrodes optimized through hot isostatic pressing (HIP) must meet the performance specifications specified by each region.

In the United States, the AWS standard focuses on the application of tungsten-copper electrodes in TIG welding and electrospark machining, and specifies the composition, geometry and surface treatment requirements of the electrodes. The ASTM standard focuses more on the mechanical properties and durability of the material, and is suitable for the aerospace and defense fields. The preparation process must ensure the uniform distribution of tungsten and copper, and the testing covers hardness, conductivity and arc erosion resistance. Electrodes optimized by the hot isostatic pressing process must pass multiple batches of testing. Europe's CEN standard emphasizes environmental protection and safety, covers the use of electrodes in high-voltage electrical appliances, focuses on thermal conductivity and corrosion resistance testing, and the preparation process requires the use of low-pollution technology. Testing methods include metallographic analysis and non-destructive testing. Electrodes optimized by the hot isostatic pressing process must meet unified market access requirements.

Japan's JIS standards, known for their high precision and process control, are particularly suitable for the electronics and automotive industries. They specify the microstructure and surface quality of electrodes, require the use of precision equipment for preparation, and testing includes grain size and defect analysis. Hot isostatic pressing (HIP) is crucial in improving material consistency, and test results must be compared with Japan's high standards. South Korea's standards are heavily influenced by Japan and, in line with local manufacturing needs, focus on electrode performance in welding and battery manufacturing. The preparation process requires optimized powder mixing and sintering conditions, and testing covers conductivity and strength. Electrodes optimized for HIP need to adapt to a fast-paced production environment.

The differences between these standards reflect the technological advantages and application priorities of each region. The United States prioritizes practicality, Europe emphasizes environmental protection, Japan emphasizes precision, and South Korea prioritizes efficiency. Multinational companies must select applicable standards based on their target markets. Optimizing the hot isostatic pressing process offers the potential to meet multiple standards. In the future, with global technological integration, these standards are likely to converge further, particularly in the fields of intelligent manufacturing and new energy. The standards for tungsten-copper electrodes will become even more international.

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CTIA GROUP LTD

Tungsten-copper alloy electrodes Introduction

1. Overview of Tungsten-copper alloy electrodes

Tungsten-copper alloy electrodes are composite materials made primarily from high-purity tungsten powder and copper powder, produced through processes such as isostatic pressing and high-temperature sintering. They combine tungsten's high melting point and hardness with copper's electrical conductivity and ductility, offering characteristics such as high-temperature resistance, low thermal expansion, and resistance to arc erosion. These properties make them widely used in resistance welding, electrical discharge machining, high-voltage discharge tubes, and electronic device heat dissipation applications. CTIA GROUP LTD provides a variety of customized tungsten-copper electrode services, with products featuring excellent appearance and stable performance.

2. Typical Properties of Tungsten-copper alloy electrodes

Product Name	Chemical Composition (%)			Physical and Mechanical Properties			
	Cu	Total Impurities ≤	W	Density (g/cm³)	Hardness (HB)	Resistivity (MΩ·cm)	Tensile Strength (MPa)
Tungsten Copper (50)	50±2.0	0.5	Balance	11.85	115	3.2	—
Tungsten Copper (60)	40±2.0	0.5	Balance	12.75	140	3.7	—
Tungsten Copper (70)	30±2.0	0.5	Balance	13.8	175	4.1	790
Tungsten Copper (80)	20±2.0	0.5	Balance	15.15	220	5	980
Tungsten Copper (90)	10±2.0	0.5	Balance	16.75	260	6.5	1160

3. Applications of Tungsten-copper alloy electrodes

Resistance Welding Electrodes: Used as electrodes for spot welding or seam welding of low-carbon steel and coated steel plates.

Repair Welding Electrodes: Applied in cold stamping, bending, extrusion, and die-casting molds.

Electrical Discharge Machining (EDM) Electrodes: Used for mold discharge machining, or as molds and fixtures for projection welders, as well as molds or inlaid electrodes for heat-resistant steel.

High-Voltage Discharge Tube Electrodes: This electrode allows high-pressure flushing to remove eroded material from the tube body.

4. Purchasing Information

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Chapter 8: Tungsten Copper Electrode Market and Technology Trends

8.1 Analysis of the Industrial Chain of Tungsten-Copper Electrodes

The tungsten-copper electrode industry chain is key to understanding its market development and technological advancement, encompassing the entire process from raw material acquisition to final product manufacturing. This analysis reveals the interdependence between each link in the industry chain, providing an important basis for optimizing production efficiency and market competitiveness. Tungsten-copper electrodes are manufactured through powder metallurgy or vacuum infiltration processes. Their performance depends on the quality of upstream raw materials and the refinement of midstream manufacturing processes. Hot isostatic pressing plays a significant role in improving product consistency. Each stage of the industry chain is influenced by technological innovation, market demand, and the policy environment. In the future, as global industrial upgrading continues, the coordinated development of the industry chain will further promote the application and expansion of tungsten-copper electrodes.

8.1.1 Upstream Raw Material Supply

Upstream raw material supply is the foundation of the tungsten-copper electrode industry chain, involving tungsten mining and copper processing, providing high-quality raw materials for subsequent production. This link directly determines the purity of the electrode's composition and performance stability. Tungsten ore, the primary raw material source, is typically obtained through underground or open-pit mining and requires beneficiation and purification to obtain high-purity tungsten powder. Copper is derived from the smelting of copper ore or the recycling of scrap copper, which is processed into copper powder or bulk materials suitable for powder metallurgy. The reliability of raw material supply depends on the distribution of mineral resources and mining technology. Multiple regions around the world are involved, forming a complex supply network.

The raw material preparation process requires strict quality control. The particle size, purity, and morphology of tungsten and copper powders must be carefully screened to ensure mixing uniformity and smooth subsequent processing. Suppliers need to work closely with downstream manufacturers to promptly adjust supply strategies to address market demand fluctuations. Environmental factors, such as the ecological impact of mineral mining, are also receiving attention, prompting the industry to move towards sustainable mining and resource recovery. The hot isostatic pressing process requires higher raw material purity, prompting upstream companies to continuously improve their purification technology and process levels.

8.1.2 Midstream Manufacturing

Midstream production and manufacturing is the core link of the tungsten-copper electrode industry chain, responsible for processing the raw materials provided by the upstream into finished products that meet application requirements. This stage includes multiple processes such as powder mixing, molding, sintering and infiltration, and is completed using powder metallurgy or vacuum infiltration technology.

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The production process requires precise control of process parameters such as temperature, pressure and atmosphere to ensure the microstructural density and uniformity of phase distribution of the electrode. The hot isostatic pressing process plays a key role in this stage, optimizing material properties through omnidirectional pressure, reducing defects and improving product consistency. Manufacturing companies are usually equipped with advanced equipment and professional technical teams to meet the customized needs of different application scenarios.

Manufacturing also involves post-processing, such as cutting, grinding, and surface treatment, to refine the electrode's geometry and surface quality. These operations require high-precision tools and rigorous quality inspections to ensure that products meet industry standards. The manufacturing process is driven by technological innovation, with new technologies such as near-net-shape shaping and the use of nanopowders emerging in recent years to improve efficiency and reduce costs. Changing market demands also drive flexible adjustments to production lines, such as those tailored to the specific requirements of the aerospace or electronics industries.

8.1.3 Downstream Application Market

The downstream application market is the terminal link in the tungsten-copper electrode industry chain, encompassing the practical use of electrodes in multiple high-tech fields, reflecting their performance advantages and market demand. This stage includes industries such as electrical discharge machining, high-voltage electrical equipment, welding and brazing, and aerospace and military applications. Tungsten-copper electrodes are widely favored for their high-temperature resistance, electrical conductivity, and mechanical strength. Preparation processes such as powder metallurgy and vacuum infiltration ensure that the electrode's microstructure and performance meet diverse needs. Electrodes optimized through hot isostatic pressing exhibit greater stability and durability in downstream applications. Changes in market demand are directly driving the expansion of the downstream market and product innovation.

In the field of electrospray machining, tungsten-copper electrodes are widely used in mold manufacturing and processing difficult-to-machine materials, especially in the automotive and electronics industries, where their high-precision machining capabilities are favored. Companies customize the shape and performance of electrodes according to customer needs, and post-processing processes such as grinding and polishing further enhance product quality. The high-voltage electrical appliance market utilizes the arc erosion resistance of tungsten-copper electrodes, primarily serving power transmission and industrial control equipment. Manufacturers must ensure the reliability of electrodes in high-voltage environments. The welding and brazing fields rely on the thermal conductivity and anti-adhesion properties of electrodes and are widely used in automotive assembly and microelectronics packaging. Market demand drives the flexible adjustment of production lines.

The aerospace and military sectors are another key pillar of the downstream market. Tungsten-copper electrodes are used in rocket engines and guidance components, requiring them to meet performance requirements in extreme environments. Industry-wide technical collaboration and R&D investment are

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driving manufacturers to develop high-performance products. Electrodes optimized through hot isostatic pressing (HIP) processes excel in these applications. Market trends are also influenced by policy support and environmental regulations, with green manufacturing and recyclability becoming key trends.

8.2 Technical Direction of Tungsten-Copper Electrodes

Tungsten-copper electrodes are key to driving performance improvements and market expansion, focusing on optimization of manufacturing processes, development of new materials, and intelligent applications. This focus aims to meet increasingly complex industrial demands by combining the latest manufacturing technologies with advances in materials science to enhance electrode efficiency and durability. Tungsten-copper electrodes are manufactured through powder metallurgy or vacuum infiltration processes. Optimizing their microstructure and properties is at the core of technological development, with hot isostatic pressing playing a significant role in improving product quality. These technological advancements, driven by market trends and supported by research investment, will enhance the competitiveness of electrodes in high-end applications.

8.2.1 Preparation process optimization

Process optimization is a core area of development for tungsten-copper electrode technology. It aims to enhance electrode performance, reduce costs, and improve production efficiency by improving existing processes. This process encompasses multiple steps, including powder preparation, forming, sintering, and infiltration. It utilizes powder metallurgy or vacuum infiltration techniques as the foundation, with hot isostatic pressing (HIP) as the key optimization tool. The goal of process optimization is to reduce defects, improve microstructural uniformity, and enhance material density to meet the stringent requirements of fields such as electrical discharge machining (EDM), high-voltage electrical equipment, and aerospace and military applications.

Powder preparation is the starting point for optimization. By improving ball milling technology and atomization processes, the particle size consistency and purity of tungsten and copper powders are enhanced to ensure uniformity during the mixing process. Near-net-shape technology is introduced in the forming stage to reduce the amount of subsequent processing. The pressing pressure and mold design are optimized to increase the density of the green body. Optimization of the sintering process focuses on temperature control and atmosphere management. Porosity and oxidation are reduced through multi-stage heating and vacuum environment. Hot isostatic pressing further enhances the sintering effect. Optimization of the infiltration stage ensures the perfect fusion of the tungsten skeleton and the copper phase by adjusting the wettability and infiltration time of copper, reducing unfilled areas.

Optimizing post-processing processes is equally important. Improvements in cutting and grinding techniques have enhanced the geometric accuracy and surface quality of electrodes, while advances in surface treatments such as plating and coating have enhanced corrosion resistance and durability. Implementation of process optimization requires advanced equipment, such as automated production lines and real-time monitoring systems, to reduce human error. In the future, manufacturing process

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optimization will incorporate artificial intelligence and simulation technologies to predict optimal process parameters and develop functionally graded materials or nanostructured electrodes to meet the demands of higher precision and extreme environments, thereby promoting the application of tungsten-copper electrodes in emerging markets.

8.2.2 Performance Improvement Path

Performance enhancement is the core goal of tungsten-copper electrode technology development, aiming to enhance its high-temperature resistance, electrical conductivity, mechanical strength, and durability through material improvements and process innovations. This approach encompasses composition optimization, microstructure control, and surface modification, seeking breakthroughs to meet the needs of fields such as electrical discharge machining, high-voltage electrical equipment, and aerospace and military applications. Tungsten-copper electrodes are manufactured using powder metallurgy or vacuum infiltration processes. Their performance depends on the ratio of tungsten to copper and the precise control of the manufacturing process. Hot isostatic pressing plays a key role in improving material consistency and stability.

Composition optimization is an important way to improve performance. By adjusting the ratio of tungsten and copper, conductivity or heat resistance can be enhanced for specific application scenarios. For example, increasing the copper content can improve conductivity and is suitable for welding applications, while increasing the tungsten ratio enhances high-temperature resistance and is suitable for rocket engine components. Microstructure regulation can be achieved by introducing nanopowders or multiphase materials to refine the grain size, reduce pores and defects, and hot isostatic pressing processes to further optimize the bonding force of the interface and improve the overall mechanical strength. Surface modification technologies such as plating or coating introduce corrosion-resistant or antioxidant materials to extend the service life of electrodes in humid or highly corrosive environments.

Furthermore, performance improvement relies on detection and feedback mechanisms. Through metallographic analysis and defect detection, weak links that affect performance can be identified and process parameters adjusted for continuous improvement. The R&D team collaborates with manufacturers to explore the use of alloying or composite materials, introducing interphase elements to enhance toughness. Advances in thermal management technology also support performance improvements by optimizing the heat conduction path in electrodes to reduce the risk of localized overheating.

8.2.3 Application Expansion Exploration

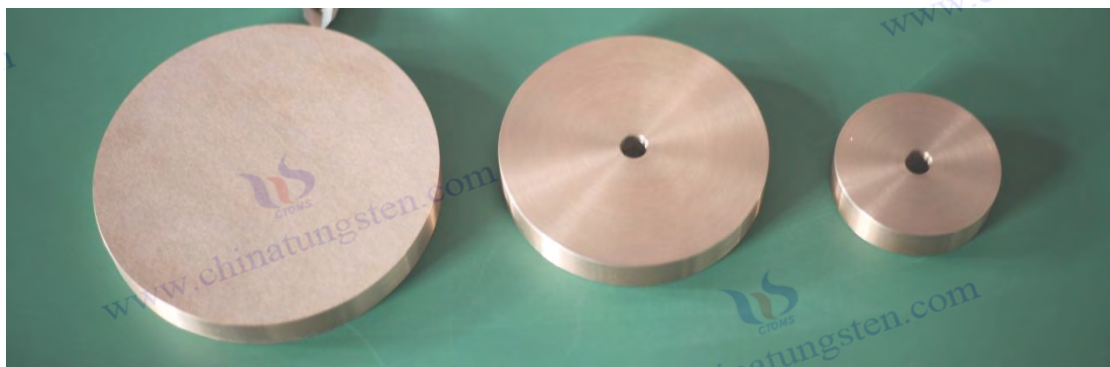
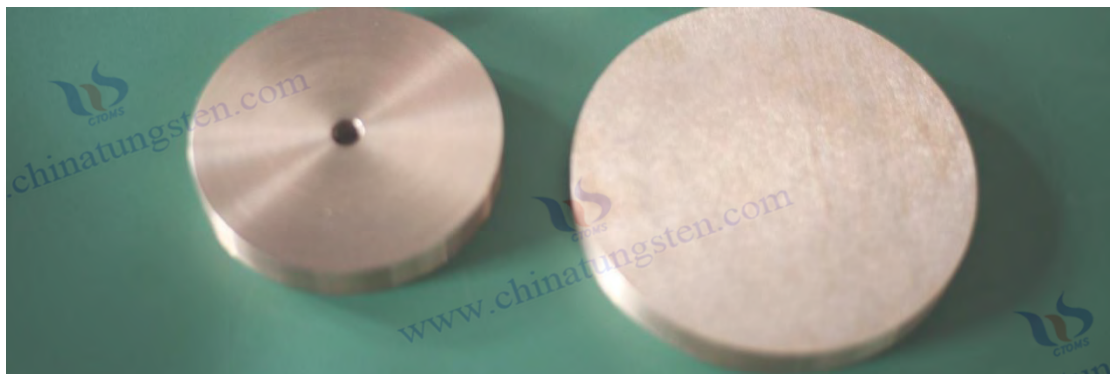
Application expansion and exploration are at the forefront of tungsten-copper electrode technology development, aiming to explore new market segments through innovative utilization of its unique properties. This exploration encompasses emerging industries such as new energy, medical devices, and intelligent manufacturing, exploring new application scenarios based on the high-temperature resistance, electrical conductivity, and mechanical strength of tungsten-copper electrodes. Tungsten-copper

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electrodes are manufactured through powder metallurgy or vacuum infiltration processes. The optimized microstructure and properties provide a foundation for expanded applications, while hot isostatic pressing enhances their adaptability to complex environments. Diversified market demands and technological advancements will drive tungsten-copper electrodes into more high-value sectors.

The new energy sector is a key area for application expansion. Tungsten-copper electrodes can be used as connectors for electric vehicle batteries or electrical contacts for charging equipment, where their conductivity and heat resistance support efficient energy transmission. The medical device sector is exploring applications in precision surgical instruments or imaging equipment, where the electrodes' high-precision machining capabilities and stability meet the demands of miniaturization. Intelligent manufacturing is focusing on their potential in robotic joints or sensors, where the mechanical strength and vibration resistance of tungsten-copper electrodes are well-suited for highly dynamic environments. Technological collaboration and R&D investment within the industry are driving manufacturers to develop customized products to meet the unique requirements of these emerging markets.

Application expansion also involves supporting process innovation. Through functional gradient design or nanotechnology, electrodes with multifunctional properties can be fabricated to meet the needs of diverse industries. The introduction of post-processing techniques such as laser etching and 3D printing has enhanced the geometric complexity and production flexibility of electrodes. Market research and user feedback are crucial foundations for exploration, and manufacturers need to collaborate with downstream companies to verify the feasibility of new applications.



CTIA GROUP LTD Copper Tungsten Electrode

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Appendix:

Tungsten Copper Electrode Glossary

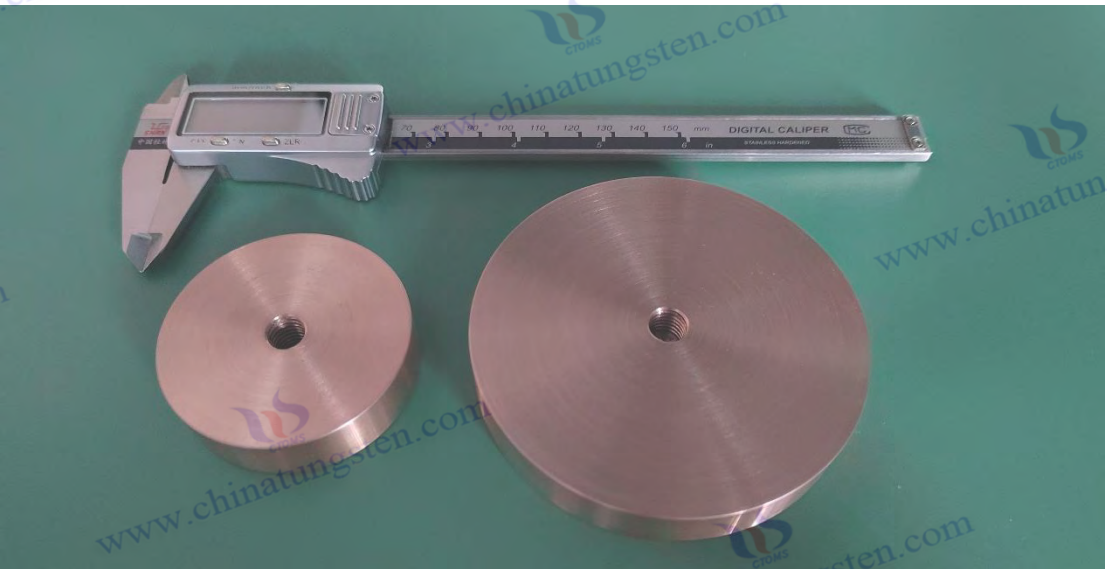
the term	definition
Tungsten copper electrode	of tungsten and copper in a specific ratio, combines tungsten's high melting point, high-temperature resistance, and hardness with copper's high electrical conductivity, thermal conductivity, and ductility. It is widely used in fields such as electrical discharge machining (EDM), high-voltage electrical equipment, welding and brazing, and aerospace and military applications. Its performance is optimized through powder metallurgy or vacuum infiltration processes, and hot isostatic pressing further enhances its microstructural consistency and durability.
Powder Metallurgy	producing tungsten-copper electrodes by mixing tungsten powder and copper powder, pressing them into a compact shape, and then sintering them at high temperatures . This process ensures material uniformity, reduces porosity, and achieves the desired mechanical and electrical properties by controlling sintering parameters. It is one of the mainstream technologies in tungsten-copper electrode production.
Vacuum infiltration	process for manufacturing tungsten-copper electrodes by infiltrating liquid copper into a prefabricated porous tungsten skeleton in a vacuum environment . This method involves melting copper at high temperatures and filling the pores of the tungsten skeleton, optimizing the material's density and phase distribution. This method is particularly suitable for electrodes requiring high conductivity and high-temperature resistance.
Hot isostatic pressing	A process that uses high temperature and isobaric gas to apply omnidirectional pressure to tungsten copper electrodes . This process eliminates internal defects, improves material density, and enhances performance consistency. It is widely used to enhance the mechanical strength and thermal stability of electrodes.
microstructure	The internal microstructural characteristics of tungsten-copper electrodes , including the tungsten skeleton, copper phase distribution , grain size, and porosity, directly affect their conductivity, mechanical strength, and durability. Microstructural quality can be assessed through metallographic analysis and defect detection, and hot isostatic pressing (HIP) has a significant effect on optimizing this microstructural quality.
EDM	A machining technology that uses arc discharge to remove material from a workpiece surface . Tungsten copper electrodes are widely used as tool electrodes. Their advantage lies in their ability to machine high-hardness materials, such as die steel and titanium alloys. The key properties of tungsten copper electrodes are their arc erosion resistance and electrical conductivity.
High-voltage electrical	In the field of electrical equipment involving high voltage and current, tungsten copper electrodes are used in switches, lightning arresters and other components.

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appliances	Relying on their arc erosion resistance and conductive stability, they ensure reliable operation in high-energy environments.
resistance welding	A welding method that achieves metal connection through electric current heating and pressure. Tungsten copper electrode provides electrical and thermal conductivity as an electrode. Its anti-adhesion and high temperature resistance make it perform well in spot welding and seam welding.
Aerospace and military industry	Including the fields of spacecraft and military equipment manufacturing, tungsten copper electrodes are used in rocket engine nozzles, guidance components, etc., and need to meet extreme high temperature, mechanical stress and reliability requirements. Its heat resistance and mechanical strength are its core advantages.
Post-processing	Tungsten copper electrodes are cut, ground, polished, and surface treated to optimize their geometry, surface quality, and functional performance. This process ensures that the electrodes meet the needs of specific applications, such as high-precision machining or resistance to corrosive environments.
Component Analysis	of tungsten and copper and the content of trace elements in tungsten-copper electrodes are detected by chemical or spectral methods to evaluate the purity of raw materials and the effect of preparation process to ensure that the electrode performance meets the design requirements.
Defect Detection	identifying and evaluating defects such as pores, cracks, and inclusions within tungsten copper electrodes , including X-ray testing and metallographic analysis, aim to improve product quality and service life.
Industry Standards	Specifications developed by national or international organizations, such as ISO standards and Chinese national standards, define the composition, performance, and testing requirements of tungsten copper electrodes, ensuring consistent quality across global markets.



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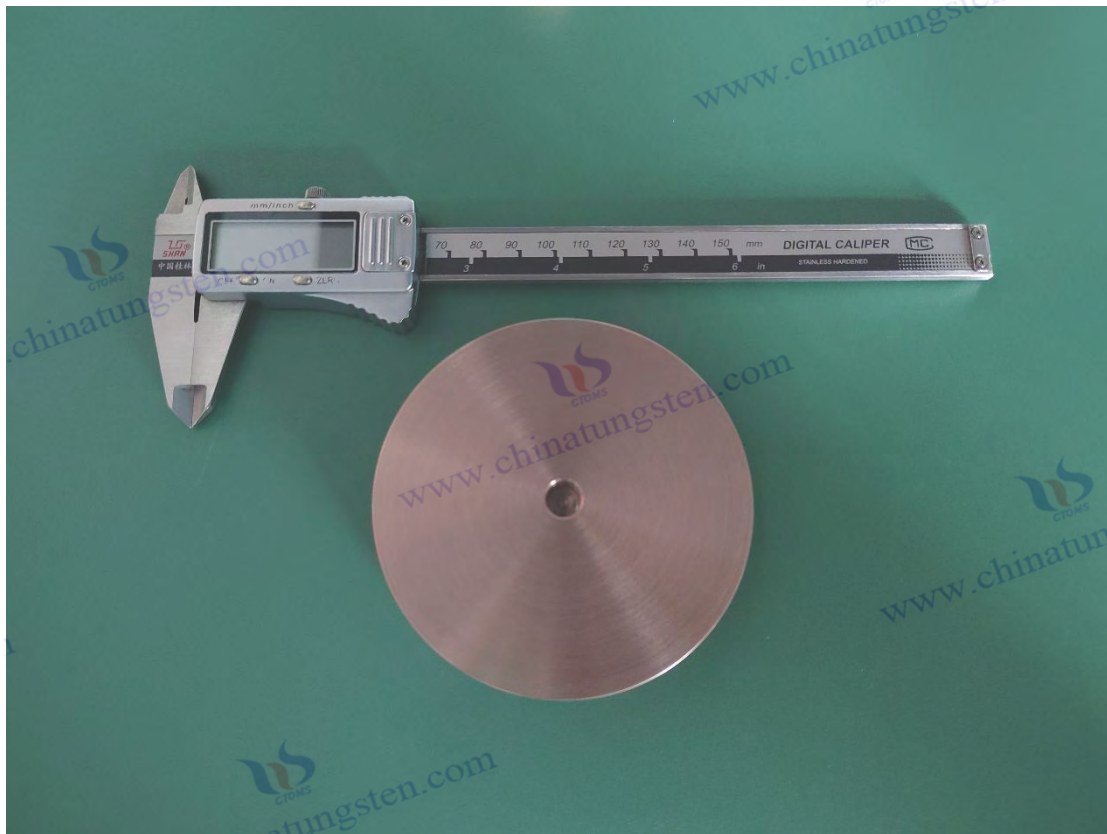
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