中国光伏行业
金刚线用钨丝市场研究

MARKET RESEARCH OF TUNGSTEN WIRE FOR DIAMOND WIRE SAWS IN CHINA'S PHOTOVOLTAIC INDUSTRY

DR. HANNS

XIAMEN CHINA, JUL.01,2022
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中钨在线® 中钨智造®
中国厦门 2022.07.01
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ISO 9001-2015 认证号码:00122Q31380R3S/3502
标准文件版本号 CTOXMQCD-MA-E/P 2022 版
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BRIEF INTRODUCTION TO THE AUTHOR

As the 1st E-commerce company of Tungsten (W), Molybdenum (Mo), Rare Earth (RE) in China, China Tungsten Online Manu. & Sales (CTOMS) was founded in 1997 based on China's the 1st and top tungsten website www.chinatungsten.com. As its specialized design, professional manufacturing, excellent service and powerful information database, CTOMS is not only the most authoritative information source of Chinese and English information of W Mo and RE products globally, but also the best comprehensive application solution provider of W, Mo and RE, both chemical materials and machined products, such as tungsten oxide, metal, cemented carbide and heavy alloys.

CTOMS has been created more than 1 million web pages and WeChat information message of W, Mo and RE news, price and market research, analysis. The web news.chinatungsten.com, www.ctia.com.cn are the world's top index websites of tungsten which have received 1 billion visits from 1997.

The major business of CTOMS is to complete product design, R & D with customers and provide customers with processing and integration services. In the past 2 decades, it has provided more than 100,000 different types of W, Mo & RE products to more than 10,000 customers all over the world. Years experience and technology accumulation have laid a foundation for promoting the flexible and intelligent manufacturing of customized products.

The professional research articles and reports of CTOMS are written by Dr. Hanns and its marketing team. Dr. Hanns is an expert of the main market and technical research of CTOMS has been engaged in e-commerce and international trade of tungsten and molybdenum products, production and manufacturing of cemented carbide and high specific gravity tungsten alloy since the early 1990s. He is a well-known expert in e-commerce, tungsten product design, processing and Market Research of tungsten and molybdenum products in the industry with more than 30 years of experience.

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Chapter 1: Basic Concept of Solar Energy, Photovoltaic and Tungsten Wire

Chapter 1

Basic Concept of Solar Energy, Photovoltaic (PV) & Tungsten Wire

The 2021 edition of "China Potovoltaic Industry Development Roadmap", edited by experts at the China Photovoltaic Industry Association (CPIA) and CCID Thinktank Institute of Integrated Circuits, was released on February 23, 2022, under the guidance of the Ministry of Industry and Information Technology of the People's Republic of China. Basic on authoritative statistics and basic thinking of the article, China Tungsten Online provides an overview of the background of the development of tungsten wire for main body of diamond wire in China, i.e., the extremely rapid development of China's photovoltaic (PV) industry in recent years and its worldwide position.

Solar panels of solar cells

The photovoltaic industry chain includes six major segments. The upstream incorporates phase of silicon material, silicon wafer, including silicon material, silicon ingot, monocrystalline silicon stick and slicing; midstream covers the phase of cell, cell components, including cell, cell components; downstream application systems contain centralized and distributed photovoltaic power station, etc. The industry chain in the PV market shows a pyramid-shaped structure, that is, from a global perspective, the number of companies involved in the six segments increased sharply in sequence.

China's PV manufacturing industry holds first place in the world, with grid-connected PV power generation capacity reaching 306 million kilowatts in 2021, ranking first in the world for seven consecutive years. China's related new energy industry chain is fully benefited amid the context of carbon reduction and carbon neutrality target, overlaid with the gradually eased PV upstream supply chain and demand tension, PV industry continued

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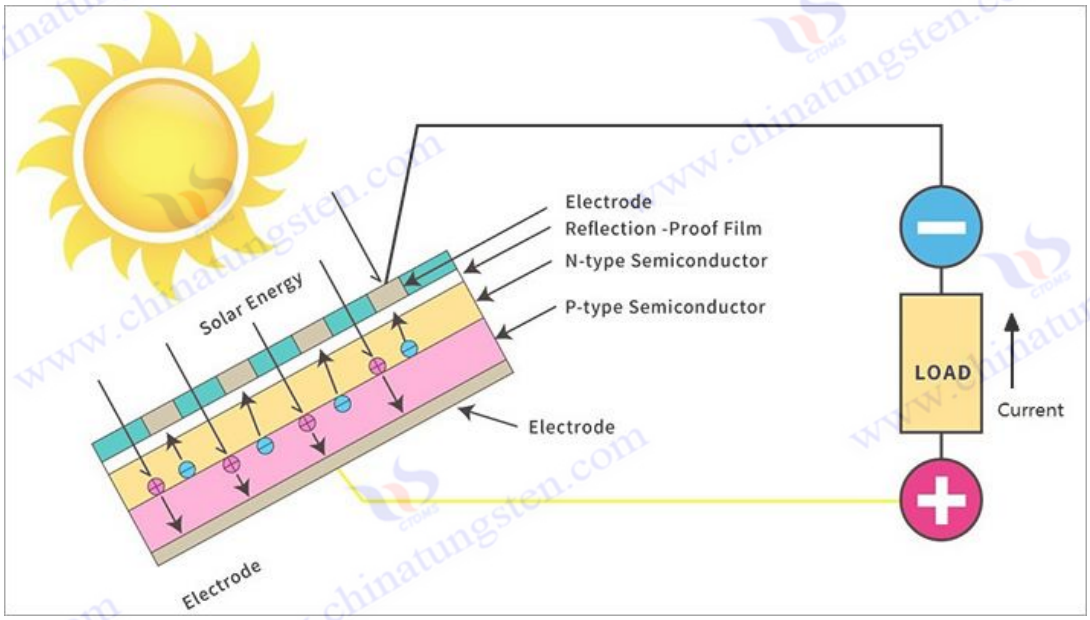
upward.

According to incomplete statistics, in the first half of 2022, China's new PV installation scale exceeded expectations and the end demand is robust. Since 2022, the policy for supporting PV industry introduced continuously, PV is a significant part of the new energy infrastructure, large base centralized power plants and distributed photovoltaic projects together to promote the industry. In a promising future, new installed capacity is expected to continue to improve, the industry chain boom will be maintained for quite a long time. With the mounting price of energy costs amid the conflict between Russia and Ukraine, upstream silicon material prices will remain high due to the tremendous market demand, which in turn provides investment incentives and profit margins to improve technology, save silicon materials and improve efficiency.

This chapter gives a brief explanation of the three major industries and four materials involved in this research. In principle, the research covers photovoltaic batteries/solar batteries, silicon materials, diamond wire (diamond wire saw, carbon steel wire saw), and tungsten wire. And the involves three industries namely are the silicon wafer cutting industry in PV industry, diamond wire manufacturing, and the tungsten wire processing in the tungsten industry.

1. Solar Batteries



Photovoltaic Effect

The PV industry is a novel type of industry derived from the combination of semiconductor technology and new energy. Among the various renewable energy sources, solar energy with its significant advantages of clean, safe, and inexhaustible, becoming the fastest growing renewable energy. Vigorous development of PV industry, is of great significance to adjust the energy structure, promote energy production and consumption revolution, as

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well as boost the construction of ecological civilization. China has listed PV industry as one of the national strategic emerging industries, and under the dual role of industrial policy guidance and market demand, China's PV industry has achieved rapid development and has become one of the few domestic industries that could participate in international competition and achieve a leading edge. West major developed countries are also taking the development and utilization of solar energy as a long-term plan for the energy revolution, and the PV industry is increasingly becoming another exploding development industry in the international arena following the IT and microelectronics industries.

Photovoltaic effect (PV Effect) is a process by which light excitation causes a semiconductor material to generate electron-hole pairs and form an electrical potential for P-N junction and separation. Solar battery uses the PV effect of the semiconductor materials to convert solar energy into electricity. Solar battery is mainly connected in series connection and parallel connection to produce the required voltage and current. The battery is divided into two types: space-based solar power and ground-mounted solar panels. The main requirements for space-based are light weight, high conversion efficiency, and radiation resistance, etc.; and the ground-mounted one requires high conversion efficiency and low cost. Solar power products have been widely applied in communications, lighting, traffic signals, beacon lights, home appliances, cathode protection, remote control instruments, water pumps, consumer goods (such as calculators, electronic watches), etc. Monocrystalline silicon solar batteries and gallium arsenide solar batteries are also used as power sources for artificial satellites.

Efficiency and production of major solar cells worldwidely

Types	Maximum lab Efficiency %	Product Efficiency %	Productization level
Monocrystalline silicon solar battery	24	14～15.5	mass production
Polycrystalline silicon solar battery	18.6	11～15	mass production
Amorphous silicon thin film solar battery	14.5	5～8	mass production
Cu-In-Tin thin film solar battery	18.8		testing work on trial
CdTe thin film solar battery	15.8	5～10	small scale production
AsGa solar battery	25.7	20	small scale production
InP solar battery	21.9	(for space)	N/A
Concentrator silicon solar battery	28.2	15～18	small scale production
GaAs/GaSb tandem solar battery	35.8		N/A

Materials used for solar batteries include monocrystalline silicon, polycrystalline silicon (see semiconductor silicon materials), gallium arsenide monocrystal, indium phosphide monocrystal, gallium antimonide monocrystal, and amorphous silicon film (see amorphous semiconductor materials), copper indium tin (see compound semiconductor materials), cadmium telluride film, and cadmium sulfide film.

2. Silicon Photovoltaic Materials

Silicon (Si) is the most important elemental semiconductor material, including polycrystalline silicon, monocrystalline silicon, silicon wafer, silicon epitaxy wafer, and amorphous silicon film, etc., which can be used directly or indirectly to prepare semiconductor devices. Si is a group IV element in the periodic table and exists in the earth's crust mainly in the form of silica and silicates. Si has an atomic weight of 28.05 and a density of 2.329 g/cm^3 at 25°C. It has a gray metallic luster, is brittle, with a hardness of 6.5 Mohs, which is slightly lower than that of quartz, the melting point is 1410°C with a volume shrinkage of 9.5% at the melting point. Si is available in crystalline and amorphous forms. Monocrystalline silicon hosts a dielectric coefficient of 11.7 at room temperature and a high refractive index of light (n=3.42), with a large reflection loss, which can be greatly improved by applying reflective film.

Si exists in three forms: amorphous, polycrystalline and monocrystalline. Compared to monocrystalline silicon, polycrystalline silicon has no fixed crystal orientation, its structural integrity is poor, and most devices are made from monocrystalline silicon. Monocrystalline silicon stick made by methods such as hydrogen reduction or thermal decomposition of silane are mainly used for producing monocrystalline silicon.

Polycrystalline silicon ingots with slice (www.ne21.com)

2.1 Crystalline Silicon Materials

Silicon ores (SiO2) are reducted to 95% to 99% purity of metallurgical grade under high temperature, and be changed to silicon halide or hydride, then purified to produce high purity of silicon polycrystalline silicon. Since most semiconductor devices use high-integrity

monocrystalline silicon, polycrystalline silicon must be remanufactured, and about 90% of the industry uses **Czochralski Method (直拉硅单晶的方法).** Czochralski monocrystalline silicon is mainly used for integrated circuits and transistors. The technical requirements for Czochralski mothod are rigorous, and they are self-contained monocrystalline silicon for integrated circuits. The main use of float zone silicon is for producing power electronics and, in the case of very pure float zone silicon, in radiation detectors. Monocrystalline silicon ingots should be sliced, grounded or polished for device production, and some devices require a silicon epitaxial layer on the polished wafer, called a silicon epitaxial wafer.

2.2 Polycrystalline Silicon

Polycrystalline silicone for solar battery is prepared by the ingot casting method, with directional coating and casting. The directional coating method involves melting silicon in a crucible and then gradually cooling the crucible from a hot field or passing a cold source from the bottom to create temperature gradient so that the solid-liquid interface moves upward from the bottom of the crucible to form an ingot. The casting method involves pouring the melted silicon from the crucible into a mold to form an ingot, which is then cut into silicon wafers for solar battery, generally, the wafer size is 100x100 mm and an average grain size is millimeters. There are also methods to grow silicon strips directly from molten silicon solution by jump slicing process to reduce costs.

In recent years, monocrystalline silicon films grown by chemical vapor deposition (CVD) have been widely used. It hosts some unique properties. Non-doped polycrystalline silicon owns a resistivity of 106 to 107 Ω.cm, and semi-insulated polycrystalline silicon hosts a resistivity as high as 010 to 1011 Ω.cm. The resistivity of polycrystalline silicon is higher than that of monocrystalline silicon, and the presence of intergranular boundaries reduces the carrier concentration, decreases its mobility, and increases the impurity diffusion coefficient. Polycrystalline silicon films are widely used in integrated circuits as dielectric isolation between devices, slot-fill support bodies, and semi-insulating polycrystalline silicon could be used as passivation films to improve stability and reliability of devices. In MOS circuits, doped polycrystalline silicon used as the gate could improve the integration than using aluminum, in addition to the use of polycrystalline silicon to produce low-cost solar cells, etc.

2.3 Monocrystalline Silicon

Monocrystalline silicon is produced through multiple reduction and purification processes, which is an ultra-high purity Si with a certain resistivity and perfect lattice. It is an important substrate for the preparation of semiconductor wafers. Monocrystalline silicon production generally uses Czochralski method and float zone method to further purify and dope the monocrystalline after distillation and reduction purification. Float zone monocrystalline silicons are more likely to be used in space, while ground applications tends to use Czochralski monocrystalline silicon. People preferred to use monocrystalline silicon wastes or low-grade polycrystalline silicon for saving cost, they generally are pulled into resistivity

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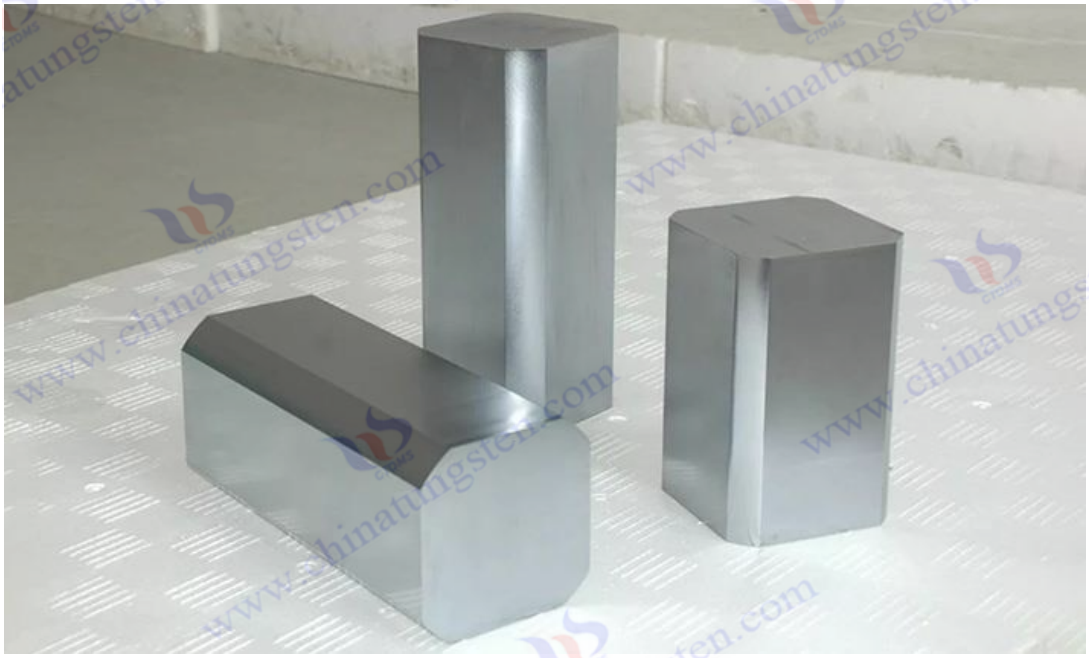
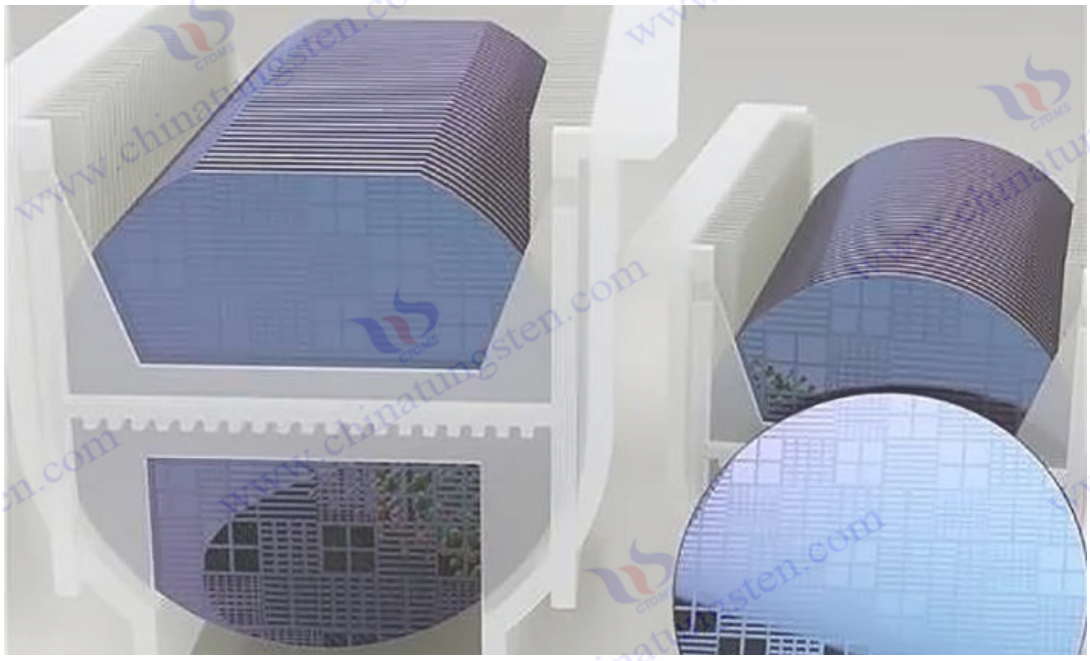
of 0.5 ~ 5Ω-cm monocrystalline silicon, and then are sliced.



Monocrystalline silicon rods (National Business Daily)

2.4 Semiconductor Silicon

Semiconductor Silicon is the most important elemental semiconductor material, including polycrystalline silicon, monocrystalline silicon, silicon wafer, silicon epitaxial wafer, and amorphous silicon film, etc., which can be used to prepare semiconductor devices directly or indirectly.



Semiconductor optoelectronic devices

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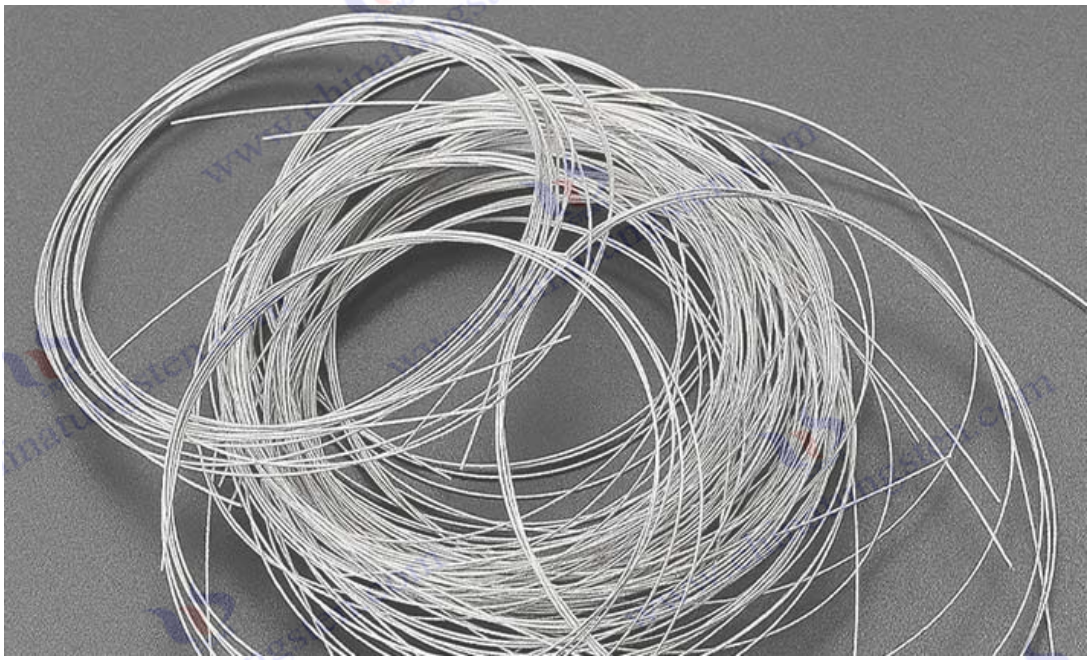
3. Wire Saw

Highly hard and brittle materials are characterized by high hardness, high brittleness, and difficult in processing, as well as easy fracture during processing. Before the 1980s, highly hard and brittle materials were generally cut with circular saws coated with diamond micro-powder. With the rapid development of the PV and semiconductor industries, the problems of large kerf and material loss of circular saw cutting are gradually emerging, and trickier problem is to overcome is the limitation of cutting size of highly hard and brittle materials. There are several factors make it hard to reduce the production costs of traditional circular saw cutting means.



Wire saw, rope saw material

Varying from the traditional steel cutting, saw blade cutting and inside/outside circular saw blade cutting, wire saw belongs to the flexible tool which refers to the principle of rope saw for cutting wood, also known as rope saw.

In terms of sawing characteristics, it can be described as sawing of curved or irregular shapes. For sawing objects, saw wire could carry out sawing of hard and brittle materials such as stone, glass, fiber fabric, etc. It is also applied to slicing and processing of precision materials such as crystalline silicon and semiconductors, which is an efficient and precise sawing tool. According to means of motion, wire saws can be divided into: linear wire saw and circular wire saw. Linear wire saw, also known as reciprocating wire saws, which therefore require frequent changes in direction during the sawing process. Circular wire saw, also known as one-way wire saw, the begin and the end of the wire are connected into a ring, in the role of the tensioning mechanism and guide wheel to achieve continuous movement in one direction. The principle of coated diamond abrasive wire saw substrate is

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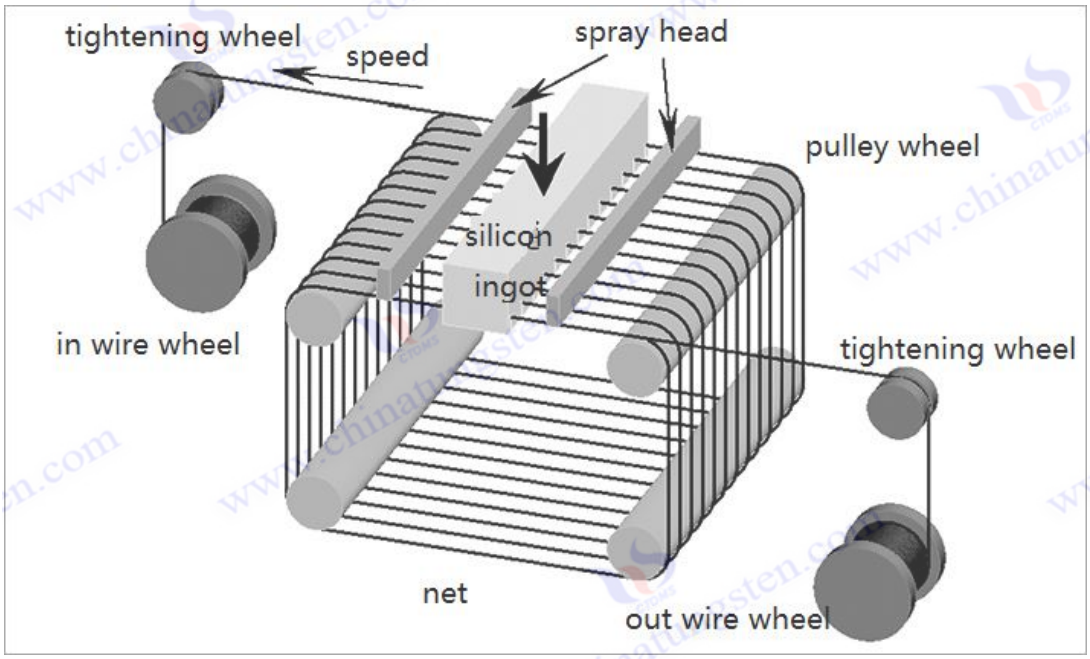
mainly based on small diameter and high strength, often using metal wire as the substrate, such as piano steel wire, ordinary steel wire, carbon steel wire, stainless steel wire and other different wire saw, also known as "base wire". According to the substrate of base wire, initial stage of coated diamond abrasive wire saw is mainly based on carbon steel diamond wire. Since 2019, major wire saw manufacturers, such as Yangling Metron New Material Co. and major PV slice manufacturers, such as LONGi Green Energy Technology Co. initiated experimenting with diamond wire saws using tungsten substrates. Globally, Japan's Panasonic began testing tungsten base wire for diamond wire saw earlier than China.

3.1 Free Abrasive Wire Saw

According to the ore, fiberboard and other hard and brittle materials for sawing processing technology, the development of abrasive grain and saw wires for free abrasive grain wire saws. The abrasive particles are stored in a swimming pool ejected by an abrasive nozzle and are thus carried into the cutting area by a saw line moving at a certain speed, while the abrasive particles act vertically on the machined surface in the form of an abrasive process. The slicing/sawing process is accomplished by removing the material by rolling and embedding the abrasive grains, thereby creating deep surface cracks on the cutting surface. However, due to the inherent defects of the cutting device and mechanism of the free abrasive wire saw, in sawing process, the surface quality and damage is not easy to control. There are potential problems, such as residual stress, kerf loss, abrasive slurry recycling and slurry pollution. Thus, free abrasive wire saw slicing processing brittle materials owns the disadvantages of long sawing time, low cutting efficiency and serious environmental pollution.



Free abrasive multi-wire cutting schematic (Engineering Science 2012-14:11)

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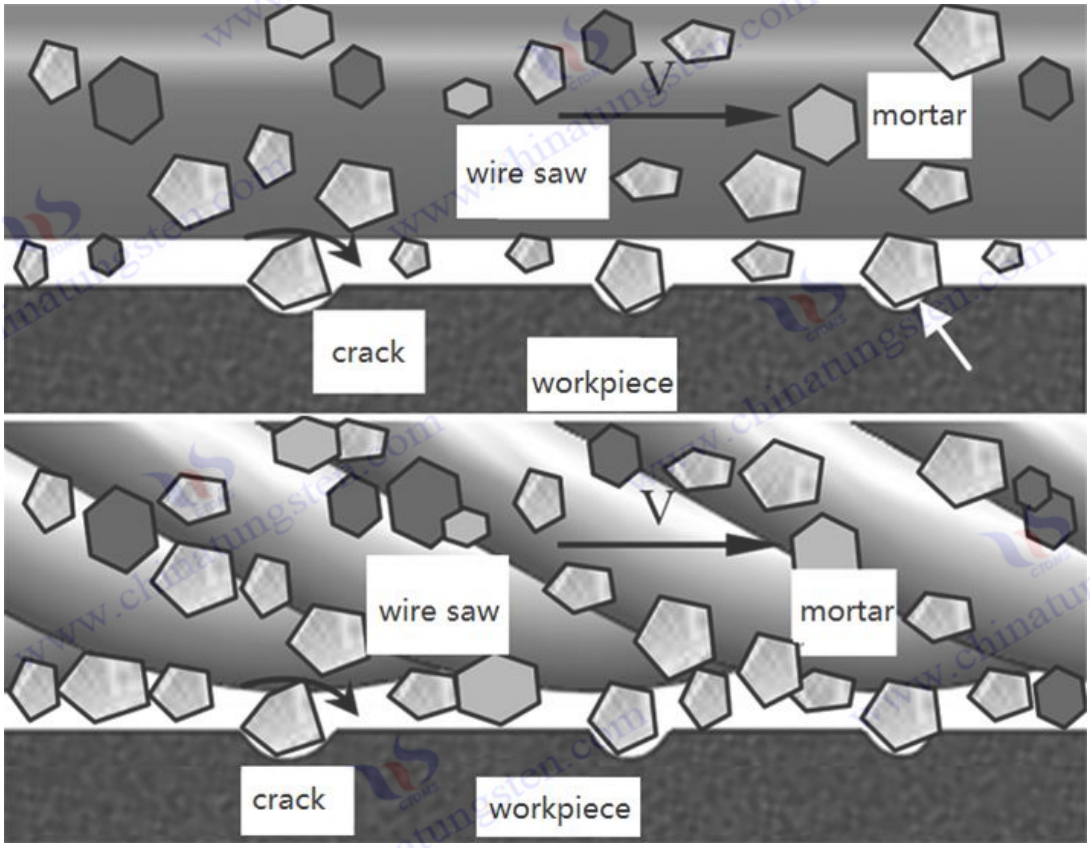
Since the mid-1990s, free abrasive wire saw cutting with narrow kerf, mean cutting thickness and low warpage has been gradually popularized. Free abrasive wire mortar cutting uses carbon steel wire as the basic cutting body, supplemented by high hardness abrasives, such as silicon carbide with a Mohs hardness of 9.5 as the cutting-edge material. The main steel wire drives the cutting fluid and the mortar mixed with silicon carbide to rub in high-speed motion, and uses the abrasive effect of silicon carbide to achieve cutting effect.

Free abrasive wire mortar cutting is stable in cutting field, and is widely used in silicon wafer cutting in the PV and semiconductor industries. Although the efficiency and quality of mortar cutting is much higher than circular saw cutting, the processing efficiency still needs to be improved, as the efficiency is even lower for materials with higher hardness, such as carbide. The environmental problem of constantly filled and discharged process waste is becoming increasingly serious and difficult to avoid and eliminate.



Single-strand wire (above), multi-strand wire of free abrasive wire saw cutting schematic (Engineering Science 2012-14:11)

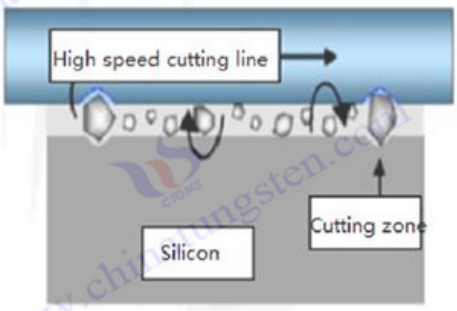
3.2 Coated Abrasive Wire Saw

Since 2015 coated abrasive diamon wire saw cutting technology steps into the cutting field, it replaces the mortar cutting production mode rapidly, and becoming the mainstream cutting process for crystalline silicon slices in PV industry. The coated abrasive wire saw is a

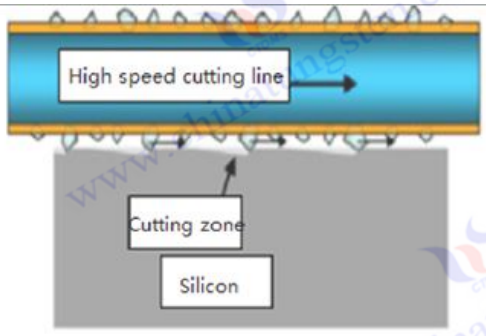
type of wire saw in which the abrasive grains are coated on the substrate of the wire so that they can move at the same speed as the wire for cutting. In present, coated abrasive wire saw is the dominant mean for cutting brittle and hard materials.

The coated abrasive wire saw is eco-friendly, clean, high processing accuracy, and low kerf loss, etc. compared to the free abrasive wire saw. It is suitable for sawing and processing of crystalline silicon, semiconductors, and other precision materials. Coated abrasive wire saw technology has gradually evolved from the initial pocket saw and bead saw to special technology for abrasive grains by welding methods, resin coating methods, and electroplating methods.

Coated abrasive wire saw cutting owns several advantages over free mortar wire saw cutting:
(1) Coated abrasive diamond wire hosts greater strength and longer service life, and significantly reducing the cost per unit of wire consumption.
(2) Fewer wire changes, finer wire diameter, improved utilization of the cutting material, and significantly reducing cutting losses.
(3) High strength, diamond coating improves cutting speed, the cutting efficiency could be increased by moderately increasing the tension of dimond wire.
(4) Coated diamond wire saw significantly reduces the loss of free abrasive mortar silicon carbide and mortar waste disposal.



Traditional mortar cutting schematic diagram



New diamond wire cutting schematic diagram

Items	Free mortar abrasive wire saw cutting	Coated diamond abrasive wire saw cutting
Cutting attrition	Abrasive particle attrition is approximately 60μm	Dimond particle attrition is approximately 20μm
	Make cutting silicon material for example,in same wire diameter, diamond cutting loss is lower than mortar cutting,per unit of silicon output is increased by about 20%，and thinnest diameter of mortar cutting wire is 80μm.	
Cutting speed	Mortar wire cutting speed is about 580-900m/min.	Dimond wire cutting speed is above 2000 m/min.
	Diamond wire cutting speed is about 2-3 times of mortar cutting	
Loss of accesspries	It's hard to handle with the PEG suspensions.	Water-based cutting fluids, easy to handle.
	Diamond wire cutting process is more eco-friendly.	

Coated mortar abrasive wire saw cutting VS free mortar abrasive wire saw cutting

(Source: prospectus of Gaoce)

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3.3 Resin-Bonded Coated Abrasive Wire Saw

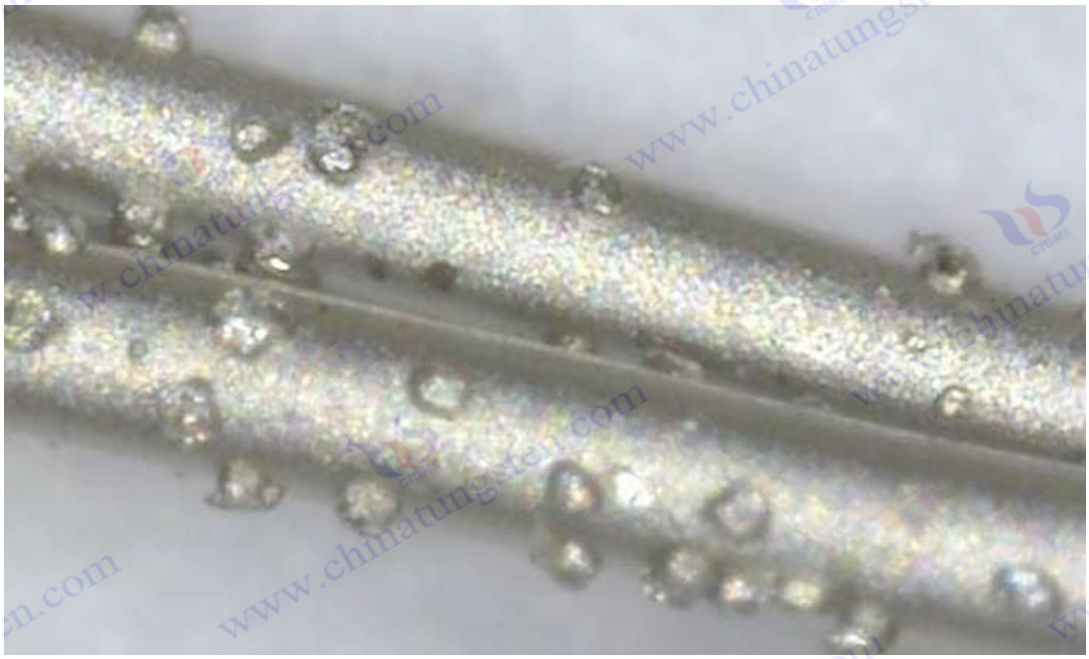
Resin-bonded coated abrasive wire saws use resin coating and curing process. Tis process is simple, low manufacturing costs, better surface quality, and eco-friendly. While, the inherent problems of the wire saws are weak abrasive curing, low holding strength, low wear resistance, low heat resistance, and relatively low service life.

3.4 Electroplated Coated Abrasive Wire Saw

Electroplated coated abrasive wire saw is a linear superhard material tool made by depositing a layer of metal wire with electroplating that can simultaneously solidify abrasive.

In the case of diamond plated wire saws, selected size of diamond abrasive grains are added to the plating solution during processing. When the metal ions in the plating solution are cathodically reduced to metal, such as Ni or Ni-Co alloy, etc. deposited on the substrate, the diamond particles are coated into the plating layer, thus, forming a linear super hard wire saw material. The metal coating is a bonding agent between the substrate and the diamond abrasive, and the uncoated part of the diamond abrasive is used for cutting.

3.5 Diamond Wire Saw



Electroplated coated abrasive wire saw

No matter resin-bonded or electroplated abrasive wire saw, it differs from processing of the wire saw. If the abrasive material using diamond (artificial) particles and particulates, regardless of carbon steel wire or tungsten wire for base material, both of them are called

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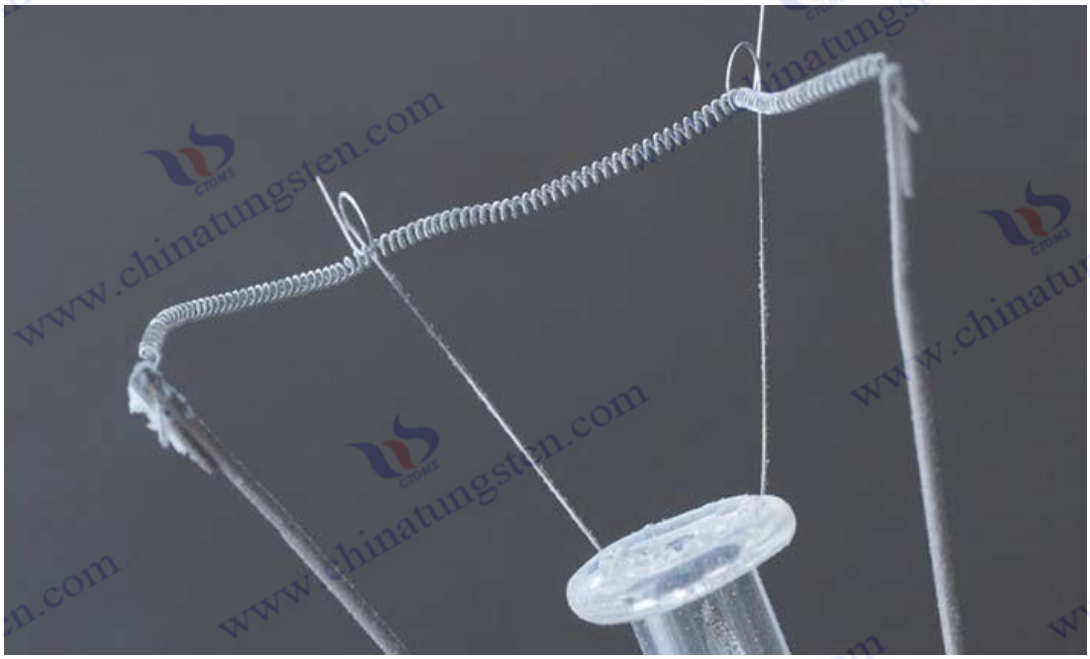
diamond wire saw. Diamond wire saw is a technology for precision, narrow-slit cutting of hard and brittle materials. Due to the the advantages of fast cutting speed, low cost of consumables, and environmental friendliness, coated abrasive diamond wire saws are widely used in the cutting and processing of silicon materials for semiconductors and solar batteries.

The advantages of electroplated coated abrasive dimond wire saws are:
(1) Less cutting, bright cutting surface, neat sawing and high output rate, it is suitable for processing hard and brittle materials such as gemstones and crystals.
(2) High cutting speed, adapting to reciprocating cutting with high-speed start and sharp pause, high efficiency, energy saving, low noise and eco-friendly.
(3) Processing materials are not limited by size and shape, and it enables surface machining and grinding and dressing of small holes.

4. Tungsten wire

4.1 Tungsten wire

Tungsten is a high atomic number material with properties of high density, high melting point, high hardness, low coefficient of thermal expansion, corrosion resistance, oxidation resistance, high temperature resistance, and thermal conductivity. It has been widely used in the fields of aerospace, electronic information, metallurgy and chemical industry.



Spiral tungsten filament for traditional incandescent lamp

Tungsten wire is formed by cold rolling, hot rolling, extrusion and spin-forging processes of tungsten or tungsten alloy, which owns higher strength and toughness, and it has become one of the most promising candidates for the cutting industry. Tungsten wire is made of

metal tungsten bar or doped tungsten bar after draping, forging, and continuous re-drawing. Tungsten wire was invented mainly to solve the problem of traditional incandescent light emitters, but also applied in cutting, heat generation, electrical conductivity and other applications due to its benign hardness and strength. Since its introduction in 1903, most tungsten filaments have been used to make filaments for incandescent, tungsten halogen lamps and electrodes for gas discharge lamps, with a few used as heating materials for high-temperature furnaces, heaters for electron tubes, and reinforcement for composite materials.

4.2 Tungsten-based Wire (Tungsten Core Wire)

In recent years, with the trend of thin wafer cutting in PV industry, tungsten wire has been of great interest due to its finer diameter and better flexibility than traditional saw wire. Since this year, Changsha Dialine New Material, Xiamen Tungsten, Xiamen Tungsten Co. and other industry leaders have been promoting the technical reform and expansion project of tungsten wire for PV, which is intended to capture development prospects of PV industry, semiconductor industry and other areas.

4.3 Tungsten-Based Wire of China Tungsten Online

At the end of 2021, China Tungsten Online (CTOMS) and its team up with industry partners who hold many years of tungsten wire production capacity to conduct testing and research on the suitability of the tungsten-based wire for diamond wire saw. Meanwhile, CTOMS keeps cooperating with diamond wire processors to test the performance of tungsten steel diamond wire saw, and has achieved good test results. Therefore, CTOMS warmly welcomes all walks of life to jointly carry out various means of cooperation.

Spiral tungsten filament of traditional incandescent lamp

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The traditional tungsten wire information has been uploaded to Tungsten Wire's web. Parts of the tungsten-based diamond wire saws' information and markets price will be listed on our news web. Any requirements and willingness for cooperation, please feel free to contact us! zhenghua@ctia.com.cn

For more information about tungsten, tungsten wire and its properties, please visit China Tungsten Industry Association's (CTIA) web site, or subscribe our official account of Wechat "中钨在线（Chinatungsten）" for getting the latest market information and prices of tungsten and molybdenum materials daily.

In the meantime, China Tungsten will also keep tracking the tungsten-based diamond wire saw and PV cutting information actively and focusing on the information of CTIA GROUP, China Tungsten and Hightech Materials Co., Ltd., and Xiamen Tungsten Co., Ltd. as well as the market price of tungsten-based dimond wire saw.

Chapter Ⅰ of the **"Market Research of Tungsten Wire for Diamond Wire Saws in China's Photovoltaic Industry"** provides an overview of the main concepts involved tungsten-based diamond wire in the PV industry. It kicks off the Chapter Ⅱ for keeping up unfolding the overview of the PV industry and the trend of demand for diamond wire.

The **"Market Research of Tungsten Wire for Diamond Wire Saws in China's Photovoltaic Industry"** is large-scale professional research on tungsten industry initiated by China Tungsten Online. in the first half of 2022. The content covers history, technology, cost and price factors of tungsten-based wire for diamond wire in PV industry.

The research will be updated in our official account "中钨在线（Chinatungsten）" in Wechat. Stay noticed!

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