

# **IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> COATED TITANIUM ANODE BASED ON GRAPHENE DOPING AND PROGRAMMED TEMPERATURE SINTERING SYNERGISTICALLY ENHANCED AND ITS PREPARATION METHOD**

## **TECHNICAL FIELD**

The technical field of the present invention belongs to the technical field of electrode material preparation, specifically relates to the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode and its preparation method based on the combined enhancement of graphene doping and programmed temperature sintering, applicable to the manufacturing field of industrial electrodes such as electrolytic copper foil, chlor-alkali industry, electrolytic water and wastewater treatment.

## **BACKGROUND TECHNOLOGY**

With the rapid development of the electronics industry, new energy and environmental protection fields, electrochemical technology is increasingly being applied in metal electrolysis, energy conversion and storage, environmental governance, etc. Electrolytic copper foil is a key base material for high-end electronic products such as lithium-ion batteries and printed circuit boards (PCBS), and its production process places extremely high demands on the electrochemical performance and service life of anode materials. In an electrolytic environment with strong acidity and high current density, anode materials need to have excellent electrical conductivity, high catalytic activity and outstanding corrosion resistance.

Traditionally, lead alloy anodes have been used in the electrolytic copper foil industry, but due to problems such as low electrocatalytic efficiency, corrosion susceptibility, short lifespan and heavy metal pollution, they have gradually been replaced by titanium anodes coated with precious metal oxides, which have better performance. The titanium substrate, which has good mechanical strength, corrosion resistance and electrical conductivity, is an ideal anode substrate. Among them, the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> composite oxide coating, due to its high catalytic activity and good stability, has become an important choice for anodes in the oxygen evolution reaction (OER), and is widely used in electrolytic copper foil, chlor-alkali industry, water electrolysis for hydrogen production, and other fields.

However, IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anodes still face two major challenges: first, iridium (Ir) as a precious metal is scarce and costly, and there is an urgent need to reduce its usage while ensuring performance; The second challenge is that during long-term high-load operation, the coating is prone to problems such as reduced activity and structural degradation, resulting in limited-service life. In recent years, researchers have attempted to introduce carbon materials such as graphene into electrode coatings, taking advantage of their high specific surface area, excellent electrical conductivity and chemical stability to enhance electron transport efficiency, improve coating structure and increase the utilization rate of active sites. But the uniformity of graphene dispersion in the coating and its compatibility with metal oxides have limited its practical application.

On the other hand, the sintering process has a decisive influence on the microstructure and performance of the coating. Conventional sintering at a constant temperature can cause stress concentration, grain coarsening and crack propagation within the coating, thereby reducing the bonding strength and electrochemical stability of the coating. Programmed temperature sintering, by controlling the temperature gradient, helps achieve more uniform crystal phase transformation and stress release, and is expected to form dense composite coating structures with abundant active sites.

As a result, graphene modification and programmed temperature sintering processes have not been effectively combined in existing technologies to achieve a synergistic improvement in the overall performance of IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anodes. In response to the above problems, the present invention proposes a method for preparing titanium anode coatings by combining graphene addition with programmed temperature sintering.

## **INVENTIVE CONTENT**

The present invention aims to provide an IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode characterized by high activity, long service life, and reduced cost. This is achieved through a synergistic innovation that combines optimized graphene incorporation with a programmed temperature sintering process, addressing the growing demand for high-performance electrode materials in advanced electrochemical industries. The present invention provides an IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode based on synergistic enhancement of graphene doping and programmed temperature sintering and its preparation method, using the following technical solution:

An IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode based on graphene doping and programmed temperature sintering synergistic enhancement and its preparation method, characterized in that it comprises the following steps:

S1. Take TaCl<sub>5</sub> and dissolve it in A mixture of ethanol and isopropanol to obtain coating solution A;

S2. Dissolve H<sub>2</sub>IrCl<sub>6</sub>·6H<sub>2</sub>O and TaCl<sub>5</sub> in a mixture of ethanol and isopropanol to obtain coating solution B;

S3. Take the graphene dispersion and add it to the coating solution B prepared in step S2 to obtain coating solution C.

S4. Apply the coating solution A prepared from step S1 evenly on the surface of the titanium plate, dry and bake it, then apply part of the coating solution C prepared from step S3, dry and bake it, continue to apply part of the coating solution C prepared from step S3, and repeat the process of air-drying, sintering and coating until the coating solution C is used up to obtain the titanium anode coating.

Preferably, it also includes pretreatment of the titanium plate in step S4. The titanium plate is sandblasted with alumina particles, then ultrasonically treated in an alkaline cleaning solution at 75-90 °C for 15-30 min, then acid-etched in a 30% hydrochloric acid solution at 75-90 °C for 15-30 min, ultrasonically cleaned with ionized water and dried for later use.

Preferably, the volume ratio of ethanol to isopropanol in steps S1 and S2 is 1:1.

Preferably, the molar ratio of H<sub>2</sub>IrCl<sub>6</sub>·6H<sub>2</sub>O to TaCl<sub>5</sub> in step S2 is 7:3.

Preferably, the iridium content in the titanium anode coating prepared in step S4 is 26 g/m<sup>2</sup>.

Preferably, the graphene content in the titanium anode coating prepared in step S4 is 0.2-0.8 mg/mL.

Preferably, the titanium plate in step S4 is a TA2 titanium plate;

The size of the alumina particles is 14-16 μm;

During the sandblasting process, the spray gun head and the titanium plate are at a 45° Angle.

Preferably, the sintering temperature in step S4 can be any of 480 °C, 500 °C, 200-480 °C, or 200-500 °C programmed temperature.

Preferably, the rate of programmed temperature rise is 5 °C /min.

On the other hand, the present invention also provides an IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> titanium anode coating prepared by the above-mentioned method.

By introducing an appropriate amount of graphene and the synergistic effect of the programmed temperature sintering process, the invention has achieved a significant improvement in the overall performance of the titanium anode coating, which is manifested in the following beneficial effects:

1. Graphene doping effectively constructs a three-dimensional conductive network, significantly improving the electron transport efficiency of the coating. At a preferred content of 0.2-0.8 mg/mL (preferably 0.6 mg/mL), the coating exhibits lower charge transfer resistance, greater double-layer capacitance and electrochemical active area, thereby significantly reducing the overpotential of the oxygen evolution reaction. Enhanced electrocatalytic activity.

2. The programmed temperature sintering process (200-500 °C, heating rate 5 °C /min) optimizes the microstructure of the coating, promotes uniform crystal phase transformation and internal stress release, enhances the compactness of the coating and the bonding strength with the titanium substrate, thereby significantly improving its resistance to electrolyte penetration and structural stability.

3. Under the condition of a relatively low dosage of the precious metal iridium (26 g/m<sup>2</sup>), a coordinated breakthrough in electrochemical performance and service life was achieved. Enhanced life tests showed that the optimized anode had a life of over 1,100 hours, far better than traditional temperature-controlled sintered samples, significantly reducing reliance on scarce precious metal resources.

4. The method has clear, stable and controllable process parameters and good prospects for industrial promotion. Combined with the established solution concentration system and quantitative coating parameters, it provides a high-performance, long-life electrode solution for high-demand electrochemical scenarios such as electrolytic copper foil and chlor-alkali industry.

## **ILLUSTRATIVE FIGURE**

Figure 1 shows the polarization curve of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Example 1-4;

Figure 2 shows the cyclic voltammetry curve of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Example 1-4;

Figure 3 shows the cyclic volt-ampere charge (q\*) of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Example 1-4;

Figure 4 shows the Nyquist diagram of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Example 1-4;

Figure 5 shows the results of the enhanced life experiment of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Example 1-4;

Figure 6 shows the polarization curves of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Examples 3 and 5-7;

Figure 7 shows the cyclic voltammetry curve of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Example 3 and Example 5-7;

Figure 8 shows the cyclic voltammetry of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Example 3 and Example 5-7;

Figure 9 shows the Nyquist diagram of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Examples 3 and 5-7;

Figure 10 shows the results of the enhanced life experiment of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Examples 3 and 5-7.

## **SPECIFIC IMPLEMENTATION METHODS**

The following provides further details of the invention in combination with embodiments and test examples.

In order to achieve controllability and reproducibility of coating performance, the proportions and amounts of key raw materials in the following embodiments have been optimized. Unless otherwise specified, the preparation of each solution follows the following benchmark parameters:

Coating solution A: The concentration of TaCl<sub>5</sub> in a mixed solvent of ethanol and isopropanol (volume ratio 1:1) is 0.1 g/mL.

Coating solution B: The total concentration of H<sub>2</sub>IrCl<sub>6</sub>·6H<sub>2</sub>O to TaCl<sub>5</sub> (molar ratio 7:3) in the mixed solvent is 0.2 g/mL.

Coating Solution C: Made by mixing solution B with graphene dispersion in a volume ratio of 15:1 to ensure the target content of graphene in the final coating.

Application volume: The application volume of coating solution A is controlled at 10 μL/cm<sup>2</sup>; The single application of intermediate layer solution C is controlled at 30 μL/cm<sup>2</sup>. By controlling the number of applications, the iridium content of the coating was ultimately stabilized at 26 g/m<sup>2</sup>, and the coating thickness was approximately 15 μm.

## Examples

### Example 1

A method for preparing a titanium anode coating, including the following steps:

S1. Accurately weigh 1.0 g of  $\text{TaCl}_5$  and dissolve it in 10 mL of A 1:1 mixture of ethanol and isopropanol solution, stir thoroughly until completely dissolved to obtain coating solution A;

S2. Accurately weigh 1.42 g  $\text{H}_2\text{IrCl}_6 \cdot 6\text{H}_2\text{O}$  and 0.29 g of  $\text{TaCl}_5$  (molar ratio 7:3), dissolve them in 8.5 mL of ethanol and isopropanol mixture at a volume ratio of 1:1, stir thoroughly until completely dissolved to obtain coating solution B;

S3. Measure 0.5 mL of graphene dispersion with a graphene content of 0.2 mg/mL and slowly add it to 7.5 mL of coating solution B prepared in step S2 with continuous stirring to obtain coating solution C;

S4. Take a TA2 titanium plate with dimensions of 10 cm×10 cm×2 cm. Use 14-16  $\mu\text{m}$  alumina particles to sandblast the TA2 titanium plate. The spray gun head should be at a 45° Angle to the sample to remove the surface passivation oxide layer. Then, place it in an 80 °C alkaline cleaning solution for ultrasonic treatment for 20 minutes to remove the oil stains on the titanium substrate surface. The treated TA2 titanium plate was then acid-etched for 20 minutes in 30% hydrochloric acid solution at 80 °C to enhance the bonding strength between the coating and the substrate, and finally ultrasonically washed with ionized water.

S5 Apply the coating solution A obtained in step S1 evenly to the surface of the pre-treated titanium plate at a controlled amount of approximately 1.0 mL (i.e. 10  $\mu\text{L}/\text{cm}^2$ ). After air-drying with a blower, sintering at a constant temperature of 500 °C for 25 minutes. Subsequently, the coating solution C obtained in step S3 was applied at an amount of approximately 3.0 mL (i.e. 30  $\mu\text{L}/\text{cm}^2$ ) per application, air-dried with a blower, and then sintered at 500 °C for 25 min. Repeat this "coating - air-drying - sintering" process a total of 10 times until the coating solution C is exhausted, and the titanium anode coating is finally produced. The iridium content of the coating was measured to be 26 g/m<sup>2</sup>, with an average thickness of about 15  $\mu\text{m}$ .

### Example 2

A method for preparing a titanium anode coating in which, unlike in Example 1, the graphene dispersion in step S3 has a graphene content of 0.4 mg/mL, and the remaining steps are the same as in Example 1.

### Example 3

A method for preparing a titanium anode coating in which, unlike Example 1, the graphene dispersion in step S3 contains 0.6 mg/mL of graphene, and the rest of the steps are the same as in Example 1.

### Example 4

A method for preparing a titanium anode coating in which, unlike Example 1, the graphene dispersion in step S3 has a graphene content of 0.8 mg/mL, and the remaining steps are the same as in Example 1.

### Example 5

A method for preparing a titanium anode coating, in which, unlike Example 3, the sintering temperature of coating solution A and coating solution C in step S5 is programmed to 200-500 °C, and then sintered at a rate of 5 °C /min to 500 °C for 25 min.

### Embodiment 6

A method for preparing a titanium anode coating, with a sintering temperature of 480 °C for coating solution A and coating solution C in step S5, unlike in Example 3.

### Example 7

A method for preparing a titanium anode coating, in which, unlike Example 3, the sintering temperature of coating solution A and coating solution C in step S5 is programmed at 200-480 °C, followed by sintering at 480 °C at a rate of 5 °C /min for 25 min.

### Test Case

#### Test Case 1

The IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anodes prepared in Examples 1-4 were subjected to electrochemical test analysis using the Gamry interface1010E electrochemical workstation. The electrochemical analysis was performed using a three-electrode system, with a platinum sheet electrode as the counter electrode, a saturated calomel electrode as the reference electrode, an IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode test sample as the working electrode, and 1 mol/L sulfuric acid aqueous solution as the electrolyte. The test sample was connected to a copper wire as the working electrode, encapsulated in resin to expose the coating to be tested, with a test area of 1cm<sup>2</sup>.

The test conditions were: scanning at a rate of 10 mV/s over a potential range of 0.2 V to 1.8 V to plot the polarization curve; cyclic voltammetry was performed at a scanning rate of 20 mV/s over a potential range of 0.16V to 1.16V; impedance condition tests were conducted in the frequency range of 100,000 Hz to 0.01 Hz, using a 1.35 V DC voltage signal for EIS measurements.

With reference to Figure 1, the electrochemical performance of the anode was significantly enhanced when the addition of graphene was increased from 0.2 mg/mL to 0.6 mg/mL, as the high conductivity of graphene promoted rapid electron transport and effective exposure of the active site, thereby enhancing the electrocatalytic performance. When the addition of graphene is further increased to 0.8 mg/mL, the electrochemical performance shows a downward trend, possibly because the excessive graphene may occupy the contact area of the active material IrO<sub>2</sub> in the coating, reducing the effective contact area between the electrolyte and the active site on the active material IrO<sub>2</sub>, thereby affecting the overall electrochemical activity of the anode.

With reference to Figure 2, when the addition of graphene was 0.6 mg/mL, the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode had the largest area enclosed by the cyclic voltammetry curve, with the best electrochemical activity and charge capacity.

With reference to Figure 3, the anode had the highest  $q^*$  value when graphene was added at 0.6 mg/mL. In contrast, the anode  $q^*$  values decreased when graphene was added at 0.2 mg/mL and 0.4 mg/mL, while the anode  $q^*$  value was the lowest when graphene was added at 0.8 mg/mL. These results suggest that a moderate addition of graphene can significantly improve the electrochemical performance of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode, but an excessive addition can have adverse effects.

Refer to Figure 4 and Table 1, where  $R_s$  in Table 1 represents the solution resistance,  $R_{ct}$  represents the charge transfer resistance between the coated titanium anode and the electrolyte solution, and  $Q_{dl}$  represents the double-layer capacitance. As the graphene content increases, the value of the charge transfer resistance ( $R_{ct}$ ) decreases accordingly, reaching a minimum at a graphene content of 0.6 mg/mL, indicating that at this content, graphene provides the best path for charge transfer, thereby reducing the resistance. However, when the graphene content was further increased to 0.8 mg/mL, the value of the charge transfer resistance ( $R_{ct}$ ) rose again. The excessive graphene content would reduce the number of surface-active sites of the coated titanium anode, which is consistent with the results of the cyclic volt-ampere quantity  $q^*$ .

Table 1 Fitting impedance parameters of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode in Example 1-4

Graphene content	R <sub>s</sub> (Ω·cm <sup>2</sup> )	R <sub>ct</sub> (Ω·cm <sup>2</sup> )	Q <sub>dl</sub> (Ω <sup>-1</sup> ·cm <sup>-2</sup> ·s <sup>-n</sup> )	n
0.2 G	2.29	3.74	0.04719	0.86003
0.4 G	3.15	3.54	0.05016	0.87911
0.6 G	2.23	2.92	0.06321	0.84056
0.8 G	2.61	4.48	0.03366	0.86307

#### Test Case 2

Test the electrode life of the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode prepared in Examples 1-4.

In 1 mol/L sulfuric acid solution at A temperature of 50 °C and a high current density of 4 A/cm<sup>2</sup>, with the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode as the anode and industrial pure titanium as the cathode, the 1 mol/L sulfuric acid solution was electrolyzed by a continuous direct current power supply, and the cell voltage change was recorded and replenished every 12 hours. The experiment was conducted by setting A fixed current parameter of 4 A through a DC regulated power supply, and the electrolytic cell was continuously heated and held in a constant temperature water bath. When the cell voltage rose sharply by 5 V due to a sudden drop in conductivity caused by coating failure, the anode life was determined to be terminated.

With reference to Figure 5, a moderate amount of graphene content can significantly improve the stability and service life of the coating, while too low or too high graphene content will reduce the performance of the coating, among which 0.6 mg/mL of graphene concentration is the best.

#### Test Case 3

Electrochemical test analysis was performed on the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anodes prepared in Examples 3, 5-7 using a Gamry interface 1010E electrochemical workstation, using the same method as in Example 1.

With reference to Figure 6, the curve of Example 5 (programmed temperature rise of 200-500 °C) is on the far left, indicating that the sample prepared in Example 5 has the highest oxygen evolution reaction (OER) activity. This means that at the same current density, Example 5 requires the lowest oxygen evolution overpotential, indicating that it requires the least energy input to drive the oxygen evolution reaction, has the highest energy efficiency, and has the best catalytic activity.

Referring to Figure 7-8, the 200-480 °C programmed temperature and 200-500 °C programmed temperature samples show a more symmetrical shape in the cyclic voltammetry curve, indicating better reversibility in the REDOX process and less charge transfer resistance. In addition, the 200-500 °C programmed temperature sample had the highest  $q^*$  value, indicating that it could store and release more charge in the electrochemical reaction.

With reference to Figure 9 and Table 2, 200-500 °C programmed temperature sintering process, the coating has the lowest  $R_{ct}$  value and the highest  $Q_{dl}$  value, with the least charge transfer resistance and the strongest charge storage capacity. Programmed temperature sintering process has a significant advantage in the electrochemical performance of  $\text{IrO}_2\text{-Ta}_2\text{O}_5$  coated titanium anodes.

Table 2 Fitting impedance parameters of the  $\text{IrO}_2\text{-Ta}_2\text{O}_5$  coated titanium anode in Examples 3, 5-7

Sintering Process	$R_s$ ( $\Omega \cdot \text{cm}^2$ )	$R_{ct}$ ( $\Omega \cdot \text{cm}^2$ )	$Q_{dl}$ ( $\Omega^{-1} \cdot \text{cm}^{-2} \cdot \text{s}^{-n}$ )	n
480°C	2.68	6.19	0.03759	0.87976
200-480°C	2.83	5.37	0.03144	0.83503
500°C	3.14	5.94	0.03024	0.87457
200-500°C	2.75	2.51	0.05639	0.86730

#### Test Case 4

Test the electrode life of the  $\text{IrO}_2\text{-Ta}_2\text{O}_5$  coated titanium anode prepared in Examples 1-4 using the same method as in Example 2.

With reference to Figure 10, the coating sintered at a constant temperature showed the failure feature of a sharp increase in voltage within 800 h, while the coated titanium anode sintered by the 200-500 °C programmed temperature process had a lifespan of more than 1100 h, and the cell voltage maintained a steady and slow increase for more than 1100 h, demonstrating excellent stability. The failure point of the voltage surge occurs only at the end. This proves that the coating prepared by the optimized process has unparalleled structural integrity and corrosion resistance. Programmed temperature sintering effectively releases internal stress, forming a coating structure that binds more firmly, denser and more uniform to the titanium substrate, greatly delaying the penetration and erosion of the acidic electrolyte into the coating, as well as the attack on the substrate.

The conductive network was constructed by doping graphene in the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode, which greatly enhanced the conductivity of the coated titanium anode. Programmed temperature sintering was used to effectively enhance the bonding strength between the coating and the titanium substrate and the resistance to acid medium penetration. It is expected in the existing technology that graphene will be incorporated into the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode to enhance conductivity, but it is unpredictable that an appropriate amount of graphene (0.6 mg/mL) will significantly increase the electrocatalytic activity of the coating, reduce the charge transfer resistance, enhance the double-layer capacitance, and exhibit the best electrochemical performance. It is unpredictable that the performance will first be optimized and then deteriorate with the increase of graphene content. In the existing technology, the use of programmed temperature sintering for extreme microstructure, electrochemical performance and service life is expected, but it is unexpected that the 200-500 °C programmed temperature sintered coating shows the best oxygen evolution reactivity, the highest electrochemical activity and charge storage capacity, while having the lowest charge transfer resistance.

It should be noted that the above embodiments are only used to illustrate the technical solution of the invention and not to limit it. Although the invention has been described in detail with reference to the preferred embodiments, it should be understood by those skilled in the art that the technical solution of the invention can be modified or replaced equivalents without departing from the spirit and scope of the invention, which should be covered within the scope of the invention.

This application relates to an IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode and its preparation method based on the synergistic enhancement of graphene doping and programmed temperature sintering, belonging to the technical field of electrode material preparation. The method involves doping graphene in the IrO<sub>2</sub>-Ta<sub>2</sub>O<sub>5</sub> coated titanium anode, controlling the graphene content to 0.2-0.8 mg/mL, preferably 0.6 mg/mL, with an iridium content of 26 g/m<sup>2</sup>, and using a 200-500 °C programmed temperature sintering process. By optimizing the graphene dispersion and sintering process, the electrical conductivity, electrocatalytic activity and structural stability of the coating were significantly enhanced. Experimental results show that the coating has lower charge transfer resistance, higher double-layer capacitance and oxygen evolution reactivity, and the coating hardening life exceeds 1100 hours, which is much higher than that of traditional titanium anode coatings. The invention is applicable to high-demand electrochemical scenarios such as electrolytic copper foil and chlor-alkali industry, and has good prospects for industrial promotion.