euspen's 18th International Conference & Exhibition, Venice, IT, 2018
www.euspen.eu

Electrochemical polishing of tungsten mold

Fang Wang [1] and Hui Deng [1,*]

[1]Department of Mechanical and Energy Engineering, Southern University of Science and Technology. No. 1088, Xueyuan Road, Shenzhen, Guangdong 518055, China

dengh@sustc.edu.cn

Abstract

Owing to its high melting temperature, low coefficient of thermal expansion and acceptable hardness, tungsten alloy has been considered as a very promising mold material for replacement of tungsten carbide for glass lens moulding. For removal of subsurface damage and improvement of surface roughness, polishing is an indispensable step in the manufacturing process of tungsten alloy molds. However, damage-free and highly efficient polishing of tungsten has not been realized yet. In this study, we report the abrasive-free polishing of tungsten alloy using electrochemical polishing (ECP) and apply this process to realize the highly efficient and high quality polishing of tungsten. After 30 min of ECP, the surface Ra roughness has been drastically reduced from 881.4 nm to 35.8 nm and the top surface, slope surface and bottom surface have all been polished. Meanwhile, it has been confirmed that the form accuracy has not been affected demonstrating that ECP is an effective approach for polishing of tungsten molds.

Electrochemical polishing, electrochemical etching, damage-free, noncontact polishing

1. Introduction

Tungsten, due to its good electric conductivity, low coefficient of thermal expansion and high melting point which is the highest of all metals, has been widely used in various fields such as wiring material in fabrication of integrated circuits and manufacturing of the scan electron microscopy (SEM) filaments or nozzles.

In recent years, a new application of tungsten is to be used as the mold material for glass moulding. At present, most of the optical lens are made from ultra-precision molds made of sintered tungsten carbide (WC), or chemical vapor deposition-silicon carbide (CVD-SiC). WC and SiC have many excellent physical, mechanical and chemical properties making them the best material to fabricate the ultra-precision molds of optical lens. Nevertheless, these hard and stable materials are difficult to machine using traditional processing methods like cutting, grinding and polishing. On this account, tungsten which is hard enough and could be machined by commercial carbide tool, has been proposed to replace the WC and SiC as the mold material.

For the removal of subsurface damage and improvement of the surface quality, polishing is a key step in the fabrication process of the tungsten molds. The chemical machine polishing (CMP) method has been widely used to polish tungsten [1], but the large amount of consumption of slurry and the low polishing efficiency makes it an expensive process. Compared with CMP, electrochemical polishing (ECP), a highly efficient, slurry-free and damage-free [2] technique, is a more effective method for planarization of conductive materials.

In this paper, ECP has been applied to polish a tungsten mold and the experiments regarding the surface morphology, roughness and form accuracy have been demonstrated.

2. Experiment of tungsten polishing

Figure 1 shows the schematic of the experimental setup used in the experiment. The setup mainly contains a PMMA beaker, a counter electrode, a conductive spring, a power source and an insulator base. The NaOH solution (5wt%) was used as electrolyte and the tungsten alloy as working electrode being totally immersed into the solution. To selectively polish the top surface, the cylindrical surface are covered by silicone grease to protect the side face from etching. The bottom of the tungsten is fixed to the Polymethyl methacrylate (PMMA) beaker tightly with the paraffin which also prevent the leakage of the solution. The counter electrode, a platinum wire (Φ1x 37mm), was partly immersed into the solution, and connected to the cathode of the power source by wire. The PMMA beaker working as the container to perform the etching was located on the top of the base. The conductive spring was used to connect the tungsten and a compression state was needed to ensure the circuit was closed.

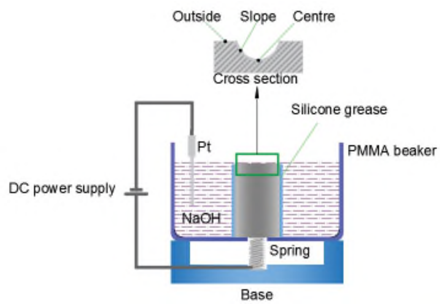

Figure 1. The schematic of the experimental setup used in the experiment.

KEITHLEY 2280S provided electric current to perform electrochemical etching. After anodic etching, samples were rinsed in water and dried by blowing N_2.

The ECP of the tungsten is a process of electrochemical etching and it is based on the simultaneous anodic oxidation and dissolution. The electrochemical reactions occurring on the platinum wire (cathode) and tungsten (anode) can be expressed as follows:

Cathode:

$$6H_2O + 6e^- \rightarrow 3H_2\,(g) + 6OH^- \quad (1)$$

Anode:

$$W\,(s) + 6OH^- \rightarrow WO_3\,(s) + 3H_2O + 6e^- \quad (2)$$

$$WO_3\,(s) + 2OH^- \rightarrow WO_4^{2-} + H_2O \quad (3)$$

On the mold surface, WO_3 is obtained by the oxidation of the tungsten as Eq. (2). The WO_3 generated reacts with the electrolyte (NaOH) and gets dissolved as Eq. (3).

Before and after ECP, the surface roughness and profiles were measured by a stylus profilometer and the surface morphology was measured by SEM.

3. Results and analysis

According to the two-step ECP process [3] the roughness of the polished surface will deteriorated under current driven mode, however at the potential driven mode the roughness is improved drastically. A higher potential value will result a higher quality surface.

In our experiment, after 30 min etching all of the outside surface, slope surface and the centre surface of the contour of the tungsten were polished. Figure2 shows the change of surface morphology during the ECP process of the tungsten. It is apparently that before etching the surface was rather rough and the damage marks caused by the diamond grinding wheel can be observed clearly. After the process of etching, the grinding marks were completely removed and ultra-smooth surface was obtained. The final surface is featureless without any sign of irregular etching. Moreover, the grand boundaries can be seen clearly on the polished surface which means that the surface is not only precise smooth but also free of damage.

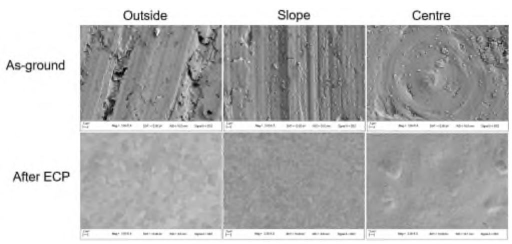

Figure 2. SEM images of tungsten surface

The Ra roughness value of the outside surface decreased from 264.1 nm to 61.13 nm; the distance between the peak and the depression cut down from 1.44 μm to 0.23 μm. In the slope surface, the Ra roughness of the grind surface is 150.5 nm, however after polishing the value reduced to 57.73 nm. The Rz roughness also saw a significant drop falling from 0.7 μm to 0.22 μm. The centre surface achieved the best quality after the process of etching compared with the outside and slope surface. The initial Ra roughness value of the grind centre surface is 180.15 μm, after etching the value declined to 40.5 μm. The gap between the peak and the depression narrowed over the process of polishing dropping from 0.74 μm to 0.15 μm.

Many hypotheses have been put forward to explain the flatting mechanism, among which the viscous film theory proposed by Jacquet [4] is most widely accepted. According to his theory, the dissolution products accumulate near the anode forming a viscous film layer and the layer increases the electrical resistance, as a result the current of the system is limited. As the thickness of the film layer over the peak area is thinner than that over the depression area, which results a higher current density over the peak, a levelling effect can be expected.

Except from the high polishing accuracy, the ECP although has the ability to preserve the original shape of the substrate. The traditional polishing approach or the CMP method both would leave a curve side at the border edge of the outside and the slope surface due to the diameter of tool or the abrasive. However, the form of the border edge could be well preserved during the ECP period as there is no mechanical removal and no need to use abrasive. Figure 3 shows the shape of the border edge using ECP method and the traditional polishing method.

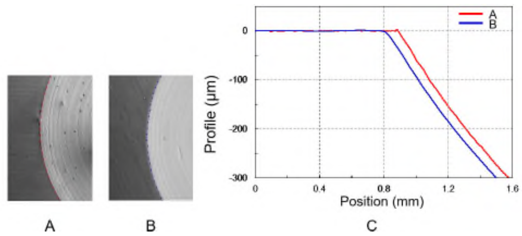

Figure 3. The shape of the border edge using ECP (A), the traditional polishing method (B) and the comparison of the two methods (C)

4. Conclusions

The electrochemical polishing was used to etch the tungsten. After 30 min polishing, all of the outside, slope and centre surface were polished with ultra-smooth surface obtained. Moreover, the shape of the tungsten was well preserved with a high form accuracy. As the accuracy of products produced by molding is determined by the ultra-precision mold, the polishing step is of great concern. How to further improve the polishing efficiency and acquire high quality mold is an ever issue to be solved.

Reference

1. Seo, Y. J., Kim, N. H., & Lee, W. S. 2006 Chemical mechanical polishing and electrochemical characteristics of tungsten using mixed oxidizers with hydrogen peroxide and ferric nitrate *Materials Letters*. **60** 1192-1197

2. Zhan, D., Han, L., Zhang, J., He, Q., Tian, Z. W., & Tian, Z. Q. 2017 Electrochemical micro/nano-machining: principles and practices *Chemical Society Reviews*. **46** 1526

3. Deng, H., Huang, R., Liu, K., & Zhang, X. 2017 Abrasive-free polishing of tungsten alloy using electrochemical etching *Electrochemistry Communications*. **82** 80-84

4. Landolt, D. 1987 Fundamental aspects of electropolishing *Electrochimica Acta*. **32** 1-11