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Effect of electrodeposition conditions on replication accuracy of electroforming

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Abstract

Electroforming is an accurate replication technique which provides an inverse shape of a master. In this study, the electrodeposition process using nickel sulfamate solution under room temperature condition, which is usually conducted at 40 °C to 60 °C, is developed to achieve nanometer-level accurate figure replication. Under ideal electrodeposition conditions, both maintaining the electrolyte composition and eliminating non-uniform deformation caused by the internal stress in the nickel layer have to be realized. First, anodic conditions were investigated by potentiostatic analysis while changing the anodic material. Just as well as conventional processes, a sulfur containing nickel anode dissolved without passivation at room temperature. Second, internal stress in the electrodeposited layer was measured to optimize cathodic conditions. The stress was monitored by a Shack-Hartmann wave-front sensor through measuring the curvature of a test plate in the electrolyte directly. Effects of agitation on replication performance were also examined. Replication experiment was conducted under the influence of solution agitation and the figure accuracy was compared to that obtained under a static condition. Finally, applying the optimized conditions, an advanced replication experiment was conducted. An ellipsoidal-shaped mandrel with figure accuracy of less than 100 nm (PV) in both circumferential and longitudinal direction was used as a master. The replicated figure was measured using a roundness measuring instrument and a wave-front measuring method. The results showed the replication accuracy of 100 nm order in the area of several square centimetres.

Keywords: electroforming, highly accurate replication, internal stress

1. Introduction

Electroforming is a replication process and applied for precision mould, LIGA process and high precision optics. Electrodeposition condition has largely not changed for several decades: it is conducted in nickel sulfamate solution that is circulating in the electrolytic cell while it is kept at 40 °C to 60 °C. The figure replication accuracy of electroforming via this process is still at the several hundred nanometre level [1], and few studies on figure replication accuracy have been conducted. Following a previous study [2], we expected the room temperature electrodeposition process to perform figure replication at 100 nm level accuracy due to the absence of thermal deformation. However, more detailed research into the electrodeposition condition was needed.

In this study, the electrodeposition conditions using nickel sulfamate solution under room temperature are investigated in terms of maintaining the electrolyte composition and improving figure replication accuracy of electroforming. First, the anode material and the anodic current density were determined by potentiostatic analysis. Second, cathodic condition was determined in terms of internal stress measurement. The effect of electrolyte agitation on the replication accuracy was also examined. Finally, applying the optimized conditions, a replication experiment using an ellipsoidal shaped master was conducted.

2. Anodic conditions

The polarization curves were obtained at room temperature in 2.8 mol/L nickel sulfamate solution as shown in Fig. 1. For this, (y1) a rolled nickel sheet, (y2) a high purity electrolytic nickel plate and (y3) a 0.01 % to 0.02 % sulfur containing nickel plate, which is widely used as anodic material in conventional processes, were used as anodes. Fig. 2 shows the sulfur containing nickel anode surface (a) before and (b) after electrolysis at a current density of 0.1 mA cm^{-2} for 130 hours. It can be seen that, just like under conventional electrodeposition conditions, the anode can dissolve without passivation during the room temperature electrodeposition.

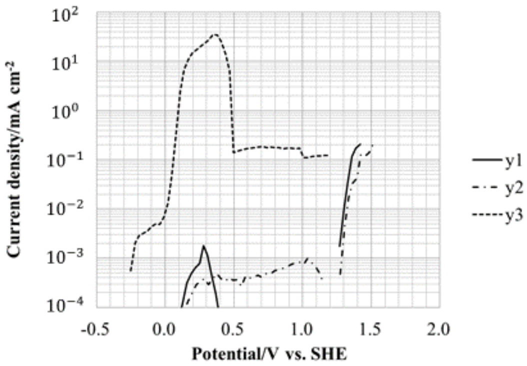
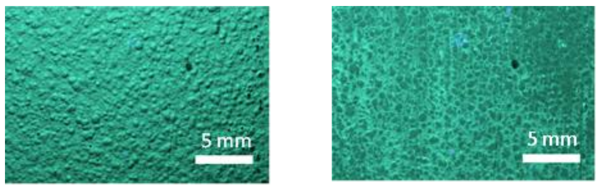


Figure 1. Anodic polarization curves.

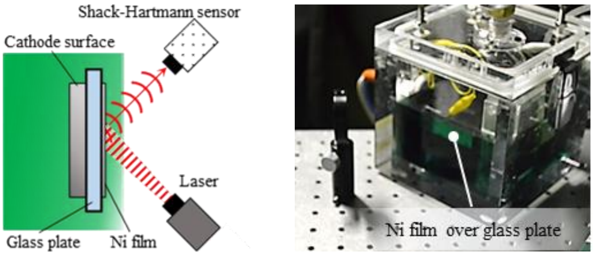


(a) **(b)**

Figure 2. Microscopic images of anodic surface.

3. Internal stress measurement

The internal stress of electrodeposited metal was measured using the apparatus [3] shown in Fig. 3. Nickel films were formed on both sides of a glass plate by evaporation. One side reflects the laser beam while on the other nickel is electrodeposited and the internal stress is generated. The wave-front of the reflected bean is distorted because of the deformation of the glass plate and measured by a Shack-Hartmann sensor. The results indicated that a current density of several mA/cm^{-2} is suitable for highly accurate replication at room temperature.



(a) (b)

Figure 3. Schematic and photograph of experimental apparatus.

4. Effect of agitation

To examine the effects of electrolyte agitation on replication accuracy, figure replication experiments were conducted. As shown in Fig. 4, the electrolyte was gently agitated by a magnetic stirrer. A truncated cone mandrel with a circularity of about 200 nm was used as a master.

Fig. 5 (a) shows the circularity of the internal surface of the resulting sample. For comparison, that of another sample electroformed from the same master under the static condition is shown in Fig. 5 (b). This suggests that the non-uniform flow distribution over the cathodic surface induced the non-uniform internal stress distribution, consequently inducing deformation.

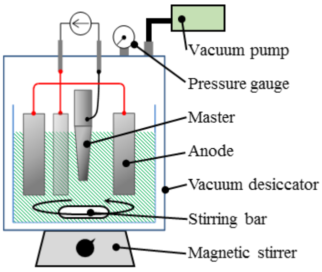
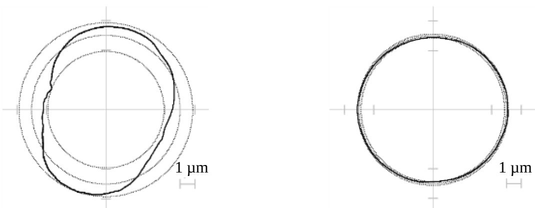


Figure 4. Experimental apparatus.



(a) (b)

Figure 5. Circularity comparison.

5. Replication experiment

5.1. Ellipsoidal mirror

To estimate the replication performance, an ellipsoidal mirror was electroformed using a master mandrel having figure accuracy of 60 nm (PV). An x-ray ellipsoidal mirror is a focusing optical device [4] whose internal surface reflects x-rays and is suitable for application of electroforming. Because it has a small diameter, as shown in Fig. 6, and requires nanometer-level figure accuracy in its internal surface, it cannot be fabricated without replication methods. In addition, a shape measuring method for ellipsoidal mirrors is established[4)] because of its optical characteristics. This means the replication accuracy of the electroforming process can be estimated properly.

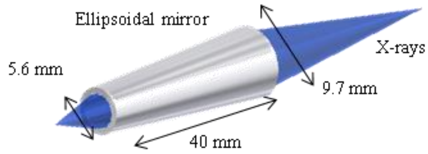


Figure 6. Ellipsoidal mirror

5.2. Circularity measurement

Fig. 7 shows the circularity of the internal surface of the mirror. It was measured at (a) 2 mm, (b) 6 mm, (c) 10 mm and (d) 18 mm distance from the larger opening. The accuracy in the circumferential direction was approximately 100 nm.

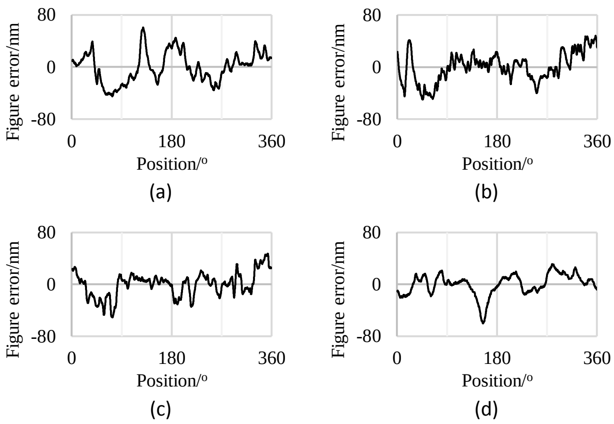


Figure 7. Circularity of internal surface of ellipsoidal mirror**.**

5.3. Wave-front measurement

The shape of the whole internal surface was measured by wave-front measuring method [5]. The figure error in the longitudinal direction was in 100 nm level over a length of 30 mm.

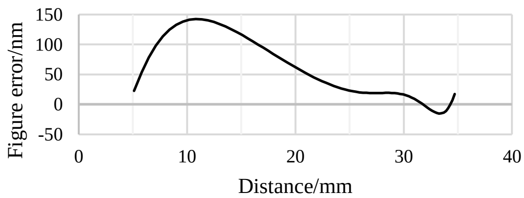


Figure 8. Profile in longitudinal direction.

6. Conclusion

The effect of electrodeposition conditions on the replication accuracy of electroforming was investigated. In room temperature electroforming, a current density of several mA cm^{-2} is suitable for highly accurate replication. In addition, non-uniform flow distribution caused by electrolyte agitation probably induces deformation in electroformed products. It is possible to perform 100 nm level accurate figure replication applying the static electrodeposition condition at room temperature.

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