Microcomposite electroforming for LIGA technology

M.-C. Chou, H. Yang, S.-H. Yeh

Abstract Effective methods to improve hardness and thickness uniformity in electroforming for the LIGA process to produce metallic microstructures are described. The result shows the internal stress of Ni-Co alloy deposit can be well tuned between 2 to −2 kg/mm² by adding a stress release agent into the electroplating bath. A secondary cathode is applied to improve the thickness uniformity in electroforming without loss plating rate at the center of the features.

1 Introduction

The demanded products with characters of high precision, high density, and profundity are necessary for the next century. Conventional machining processes faced the limitations of tiny features, complex geometry, and precision enhancement. The general conventional processes for machining metals can be described as follows. A sharp-edge tool of hard material is moved through a softer workpiece. The harder and sharper the cutting tool, the smaller the force required to make the cut. But other factors must be considered, such as lubrication and cutting edge. The tool point has to be strong enough to withstand the forces to which it is subjected, and the material of the tool must be resistant to abrasion as a result of rubbing across the workpiece. The work done against friction and plastically deforming the workpiece causes the temperature of the tool point and workpiece to rise. The increased temperature usually helps in plastic deforming the workpiece, and also tends to increase the deformation and wear of the tool [1]. These deformations and tool wear result in low precision of products. Microfabrication with deep X-ray lithography (DXRL), also known as LIGA (German acronym for Lithografe, Galvanoforung, Abformung), is a sequence of X-ray lithography, electroforming, and injection molding steps [2] for fabricating microstructures with high aspect ratios. The LIGA technique surpasses the possibilities of conventional precision machining, especially in mass production and precision of replication.

Ni electroforming has been fully developed for LIGA technology, but its hardness is just about Hv200. This confines the LIGA technology to fabricate soft metallic microstructures (e.g. the molding inserts for molding plastic microstructures). Electroforming with high hardness and low internal stress is required for the mold inserts fabrication by using the LIGA process. Traditional Cr electroplating, Ni-P, Ni-Co alloy plating [3–5], and other composite electroplating [6–8] with high strength as well as hardness are considered to be applied. The Cr plating using CrO₃ electrolyte is a toxic process and the deposit is brittle. The high internal stress on Ni-P alloy plating has been proven unfeasible for electroforming. Ni-Co electroforming with excellent hardness is noticed for fabricating microstructures. In many applications, such as the micromotors, the molding inserts for molding ceramic microstructures and the micro mechanical forming tools (e.g. integrated micropunches for IC leadframe), the microstructures require higher hardness to improve the wear-resistance and lifetime.

Due to microstructures fabricated by the LIGA process with high aspect ratio and large structural height, conventional grinding process may result in the destruction of electroformed microstructures. This study performed the NiCo/SiC microcomposite electroforming with low internal stress (~0 kg/mm²) and high hardness (>HV600). On the other hand, the deposited metal distribution is naturally a concave shape over the whole area of the plating base proved by experiments. The edge thickness of the plating area is usually twice or higher than the center of the plating area. This is required a post machining process to planarize the metallic molds. We also explored a method to improve thickness uniformity of electroformed microstructures on the substrate and reduce the machining quantity.

2 Experiment

As an integrated micropunch for IC leadframe, the hardness should be much higher than Hv500. Therefore,
Ni electroforming does not meet this requirement. One possible way is co-deposition of metal or alloy with ceramic particles. The objective of this experiment directly focuses on Ni-Co electroforming by changing the ratio of nickel sulfamate and cobalt sulfamate to enhance the deposit hardness.

The electrolyte composition and operating conditions are listed as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni concentration</td>
<td>70 g/l</td>
</tr>
<tr>
<td>Cobalt concentration</td>
<td>1–20% (w/o)</td>
</tr>
<tr>
<td>Boric acid</td>
<td>30–40 g/l</td>
</tr>
<tr>
<td>Current density</td>
<td>1–10 ASD</td>
</tr>
<tr>
<td>pH</td>
<td>4.0 ± 0.5</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>55 ± 1</td>
</tr>
<tr>
<td>Agitation</td>
<td>Magnetic stirrer</td>
</tr>
</tbody>
</table>

The pH value is adjusted by boric acid and nickel sulfamate. Specimens are stainless steel with thickness 0.3 mm and area 50 cm². Two anodes are used: cobalt plate and type S nickel plate within a titanium basket. Microhardness measurement is performed at the MVK-C1 microhardness test loading 50 gf. The composition of nickel and cobalt in the deposit is analyzed by an inductive coupled plasma spectrometer (ICP-OES). The deposit is dissolved by nitric acid before doing analysis. The internal stress is measured by using Yamaoto’s spiral contact-meter.

3 Result and discussion

3.1 Current density effect on Co content in deposition

Co content in the deposit increases with Co ion concentration in the electrolyte when keep the same current density. The result is shown in Fig. 1. The Co ion concentration is varied from 3 to 16%, Co content in the deposit is proportional to the ion concentration. It shows the amount of Co has a positive relation to its ion concentration.

However, the applied current density has an inverse relation to the amount of Co content when keeping a constant Co ion concentration in the solution as shown in Fig. 2. This relation shows the Co deposition efficiency is lower than Ni deposition.

3.2 Operating conditions effect on the deposit

The grain size increases with current density in nickel electroforming as shown in Fig. 3a–c. Special for at 10 ASD in Fig. 3c, mountains generated on SEM micrograph. If adding 6% Co concentration in the nickel electrolyte, the deposited surface do not have significant difference when varying current density shown in Fig. 3d–f. It can be concluded that Co can enhance the grain refinement in the deposition.

3.3 Internal stress and hardness in the deposit

The internal stress and hardness increase with the amount of Co in the deposit shown in Figs. 4 and 5. The maximum internal stress and hardness occur at 26–28% of Co content without adding any additive. It’s a parabolic curve along with Co content in the deposit. This is a conflict between internal stress and hardness in the Ni-Co electroforming. It’s necessary to add additives to reduce internal stress and raise hardness. The optimum solution is adding 0.5% stress reducer in the electrolyte, the deposit have its hardness higher than Hv500 as shown in Fig. 6.

3.4 Improvement of thickness uniformity

A secondary cathode is applied to improve the thickness uniformity in electroforming as shown in Fig. 7. The secondary cathode is placed at a specific distance from the primary cathode when electroforming. This spacing is limited to less than 2.5 mm; large spacing will not have any effect on thickness uniformity improvement. Two power supplies are used; one is for the primary cathode and the other one is for the secondary electrode. Both electroforming cathodes share with the same anode. The applied current density for the secondary cathode is same as the primary cathode. The objective of the secondary cathode is to reduce local ion concentration of the “double layer” surface plating area, thus reducing the growth rate on the edges of the deposited mold.