Manufacturing of Metal Micro Pillar with High Aspect Ratio using Negative-type Resin Mold

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The nickel micro pillars with high aspect ratio were manufactured using the negative-type resin mold. The resin master model was plated by nickel after the sputtering of gold, and was sublimated to take the products out. The pillar of 47.5 µm in diameter and 300 µm in height was produced by letting the bottom of the negative shape to be the cathode of the electroplating. The aspect ratio more than 8 was found to be achievable. The micromolding method will expand the producible size and shape of the metal micro products.

Keywords: micromolding, stereo lithography, photocurable resin, nickel electroplating

1. Introduction

The micromachine has been used in various fields today. Most of them are manufactured by the combination of plane structures made by the semiconductor lithography techniques. This manufacturing method has problems such as the difficulty in fabrication of the three-dimensional thick structure and the limitation of component materials to the semiconductor. The technique of the electrical discharge machining has been progressed to manufacture minute products. In this method, metal is melted little by little to manufacture the products, and therefore, the producible shape and size are limited by the precision of melting. The stereo lithography has been studied to manufacture complicated three-dimensional minute structure of resin [1-5]. This method is a kind of the lamination molding. The photocurable resin are irradiated by the scanning laser beam to manufacture the three-dimensional model. The movable structure with the precision lower than 100 nm can be realized if the two-photon absorption phenomena are used. However, the component materials of the products are limited to the resin.

We have proposed the micromolding method to manufacture the minute products of metal or metal compounds [6, 7]. In this method, at first, the resin master model manufactured by the stereo lithography is plated by metal or metal compound. In general, electroless plating is used since the resin does not have the electric conductivity. Then, extra of the plating is removed by, for example, electrolysis grinding [8]. Finally the resin master model is sublimated to take the product out. The products manufactured by the micromolding method can have the properties peculiar to metals or metal compounds, such as magnetism, rigidity, elasticity, wear resistance and conductivity, as well as high environmental tolerance [9, 10]. Using the positive-type master model, whose external shape is the same as that of...
the product design, we manufactured the microcapsule which was a kind of the magnetic micromachine, and also manufactured the micro fastener which enabled the removable conductive joint of electric parts [11, 12]. With the positive-type model, designed shape is realized as the internal shape of the products. On the other hand, using the negative-type master model having the intaglio of designed product shape, the external shape of the products agrees with the designed shape [13]. However, the products with high aspect ratio have not been yet manufactured with the negative-type master model since it is difficult to plate the deep inside of the mold.

In this study, we developed the process to manufacture the products with high aspect ratio by the micromolding method using the negative-type master model. The nickel pillar of less than 50 µm in diameter with the aspect ratio of more than 6 was produced by the electroplating to the inside of the negative shape.

2. Experiments

Figure 1 schematically shows two procedures of the micromolding method with the negative-type master model in this study. In the first procedure (the overall cathode process) shown in Fig. 1(a), the resin master model having the non-through hole with the depth same as product height is used. Conductive metal such as gold is sputtered to the face to be plated. Next, electroplating is given to fill the hole with metal. Finally the master model is sublimated to take the metal product out. In the second procedure (the bottom-end cathode process), the master model has a through hole. To manufacture the pillar, the master model having the thickness same as the pillar height is used. It is preferable to expand the top of the hole for the sputtering to the inner area. The metal is thicken by the first electroplating after the metal sputtering. Then, top and bottom of the sample is reversed and the second electroplating is done to fill the through hole until the plated metal overflows. The extra of the metal is grinded off and the resin master model is sublimated to take the product out. By the overall cathode process, the external shape of the products will follow the master model completely, but it may be difficult to plate the bottom of the hole when its aspect ratio is too large. By the bottom-end cathode process, the hole will be filled from the bottom to the top even when its aspect ratio is very large. However the master model cannot determine the shape of the tip completely.

The resin master model was fabricated using the regulation surface method, that is a kind of the sheet-lamination molding [14]. Focused laser beam was scanned onto the bottom of the glass container to cure resin inside. The advantage of this method is its high fabrication accuracy. Since the curing point is on the bottom of the glass container, the processed surface is not influenced by the movement of the air. The columnar hole was prepared for the manufacturing of the pillar with high aspect ratio. Figure 2 shows schematic of the negative-type master model in cross section and scanning electron microscope (SEM) observation of the opening of the hole. The photocurable resin was acrylic. The master models having the several holes of a = 45 µm and b = 90 µm were used
in the overall cathode process. The master models having the several holes of \( c = 40, 60, 80, 100 \, \mu m \) and \( d = 400 \, \mu m \) were used in the bottom-end cathode process. The holes were expanded to 200 \( \mu m \) at one end. These values are in design, and error of our resin modeling is several micro meters. Since the resin is not completely transparent, the internal size of the master model cannot be evaluated exactly.

![Figure 2 Schematics of the negative-type master models in cross section and SEM images of the opening of the holes: (a) for the overall cathode process and (b) for the bottom-end cathode process.](image)

In the electroplating, the coated enamel line was attached to the 150-nm sputtered gold layer by the silver paste. Anode was a nickel plate, and cathode of the resin master model was installed taking care of the directions. The bath of the electroplating was so-called ‘Watt Bath’, where 12.0 g of \( \text{NiSO}_4 \cdot 6\text{H}_2\text{O} \), 2.25 g of \( \text{NiCl}_2 \cdot 6\text{H}_2\text{O} \), 1.5 g of \( \text{H}_2\text{BO}_3 \) were dissolved in 50 ml of ion exchanged water. pH was controlled to 2.0 by HCl. Temperature of the bath was 45 °C. Just before the plating in the bath, the master model was degassed by decompression. The current density was approximately 0.5 mA/mm\(^2\). The plated samples were heated with the activated carbon in the vacuum furnace for the sublimation to prevent oxidation, and were washed by ethanol and ion-exchanged water afterwards. The heat treatment was done typically at 700 °C for 90 minutes.

**Figure 3** SEM images of the nickel pillars made by the overall cathode process with various plating time. The diameter of the pillars was 45

3. **Results and Discussions**

The nickel pillar was manufactured by the overall cathode process. We regulated the electric current in the electroplating to weaken the disturbance by the hydrogen gas generated on the resin surface. After the optimization, samples were plated for various time. SEM images of the samples after the sublimation of the master models are shown in Fig. 3. The height of the pillar rises in the order from (a) to (d), indicating the process of hole filling by the plating. The diameter of the manufactured micro pillar was almost the same as that of the master model. However, we found that 72 \( \mu m \) was the limit of the height of the pillar (Fig. 3(d)). The value is approximately 20% shorter than the hole depth. As a result, the maximum aspect ratio was 1.6 by the overall cathode process.

Two reasons are considerable for the limit of height. One is that the insufficient coating of the sputtering restricted the growth of the plating film in the deep part of the hole. The other is that the entrance was closed before
plating reached the deep part. By comparing four pictures of Fig. 3, plating seems to begin in the neighborhood of the entrance of the hole and to get thick as well as long. We expect that an electric line of force gathers at the sharp shape near the entrance. Even if some deep parts were plated, they were probably washed away after the heat-treatment. Anyway, the upper limit of the aspect ratio of the part does not depend on how much the plating occurs at the bottom but depends on how much the plating film grows towards the bottom before the entrance is closed.

Next we investigated the bottom-end cathode process. It was found that the amount of the first plating is very important to produce the tall pillar. Figure 4 shows SEM images of samples after the master model sublimation when the amount of the first plating was insufficient. The diameter of all pillars was 100 µm. In this case, we saw that the second plating film grew along the side wall of the hole. Unlike the case of the overall cathode process, the pillar was able to increase its height since the plating must progress from the deep part of the hole. The cavity was left inside, and the shape became cylindrical. We think that the cavity may be filled up partially when the plating is continued. Detailed observation revealed that the surface of the pillar reflected shape of the master model well as shown in the inset of Fig. 4(c). The trace of the sheet-lamination molding on the master model was copied even at the top of the pillar.

In Fig. 5, the result when the amount of the first plating was appropriate is shown. The diameter of all the pillar was 100 µm. When the bottom of the hole was occupied by the first plating, the second plating completely filled the negative-type master model. The second plating penetrated to the top of the hole and produced the mushroom-formed projection outside the hole. The trace of the sheet-lamination molding appeared well on the surface. The result suggests that the product may copy well the shape of the hole even if the part of the hole swells out or gets narrow to some extent.

The pillars with the smaller diameter were produced with the bottom-end cathode
process. Figure 6(a) shows the optical microscope image of the master model having six holes where plated nickel overflowed. We can see that the plated metal protrudes from all six holes into the mushroom form. The amount of the protrusion is not completely the same, but this is the limit of homogeneity in our current plating process. We scraped away the protruded part by hand grinding and sublimated the resin master model.

Figure 6(b) shows the SEM image of the pillars with the smallest diameter. Residual resin after the sublimation was left around the pillars, that would be completely removed by enough heat-treatment such as at 720 °C for 90 minutes. The diameter of the pillar was 47.5 µm, that is expected to be the same as the diameter of the holes of the master model since the trace of the sheet-lamination molding appeared. The height of the pillar varied. This is because the hand grinding was not homogeneous and some part of the master model was removed with the mushroom-formed protrusion. The best pillar had the height of 300 µm and the aspect ratio was approximately 6.3. If the grinding is done ideally, the height will be 400 µm. This corresponds to the aspect ratio of 8.4. The result suggests that the bottom-end cathode process is able to produce the micro pillars having the aspect ratio of more than 8 with the diameter less than 50 µm. It is left for the future study to research the electrolytic grinding to remove precisely the extra part of the plated nickel and to apply the complicated shape of the negative-type master model to the molding process.

4. Conclusion

We investigated the micromolding method to produce the metal micro products with high aspect ratio using the negative-type resin master model. By letting the whole inside of the master model to be the cathode, we manufactured the nickel micro pillar of 45 µm in diameter and 72 µm in height. The aspect ratio of the pillar was 1.6. By letting the bottom end of the master model to be the cathode, we manufactured the nickel micro pillar of 47.5 µm in diameter and 300 µm in height. The aspect ratio of 8 or more was shown to be achievable with this method. Our new method will expand the producible size and shape of the metal micro products.

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References


