Development of a selective electroforming process for micro-sized probe tips used in LCD inspection machines

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Abstract. A probe station is an inspection apparatus that automatically transfers liquid crystal display (LCD) panels and separates defective LCD products using a micro-probe unit. However, as the number of pixels increases in LCD screens, the size of the inspecting probe unit has to decrease. There are many limits to the conventional methodology when it comes to fabricating micro-sized probes. In this study, a selective electroforming process was developed and a micro-probe tip was fabricated using this process. Selective electroforming is a high-precision fabricating process where a non-conductive barrier layer is deposited on a conductive wafer and the conductive parts are electroformed using only Ni. Finally, using the selective electroforming process, the micro-sized probe was fabricated with a shape error of less than 0.1%.

1. Introduction

A probe station is an apparatus that checks and separates defective samples of thin film transistor–liquid crystal display (TFT-LCD) panels at the inspection stage. Currently, the size of LCD panels is increasing, along with the resolution of the display; simultaneously, inspection stations are becoming bigger and more probe tips are needed. In addition, the probe tip requires a finer pitch and high dimensional accuracy to result in zero defects. In particular, the probe unit is a core part of the probe station, and consists of components such as a tip, alignment guide, printed circuit board (PCB), metal contactor, as shown in Figure 1 and Figure 2 [1].

LCD defect inspection is carried out by applying a current to the assembly of the LCD package of the color filter and the TFT glass, and checking defects by determining whether or not the TFT cell activates the light. The TFT electrodes and probe tips match one to one, so there needs to be the same number of probe tips as TFT electrodes. The probe unit requires conductance, position alignment, and tip strength for high accuracy and reliability. Conventional metal contactors in the micro-probe unit are manufactured using processes such as micro-machining, micro-electrical discharge machining (micro-EDM), laser micro-machining, chemical etching processes.[2] However, the pitch of the metal contactor patterns in the probe unit is becoming finer, so requiring greater dimensional accuracy to correspond to the high pixel density screens in LCDs; thus, conventional manufacturing processes for
probe tips have reached their limits. With conventional methods such as micro-EDM, laser machining is used to make the machining burrs and chemical etching is then used to produce an isotropic form, so the required precision cannot be achieved.

In the present study, a selective electroforming process was developed based on ultraviolet (UV) lithography, and the electroforming process was applied to the manufacture of probe tips. To draw a selective region, a negative photoresist was coated on an STS316 substrate and a metal contactor was fabricated through an exposure, development, and electroforming process [3, 4].

2. Experiment

2.1. Design and structural analysis
Depending on the shape of the probe, there are various types of tip, with the blade type being generally used. The tip in the probe unit has a two-dimensional geometry, and therefore has many merits with regard to processes such as machining and etching. The blade-type probe consists of a ceramic guide,
Figure 4. Tip design and target dimensions.

PCB, tip, body, and housing, as shown in Figure 2. The tip’s role is to apply the current to the TFT cell in the probe station.

Figure 3 is a schematic representation of the principle of LCD inspection in the probe station.

Figure 4 shows the tip design. As a design guide, the tip should have high conductivity, strength, and reliability. In addition, X and Y deviations must be under 2 μm and the thickness deviation must be under 1 μm to avoid interference with the side walls.

2.2. Selective electroforming process and tip fabrication

Conventionally, the tip of the probe unit is fabricated by the normal chemical etching process used in the field of PCB making in order to save costs, and this process is based on metal substrates such as Cu, Be-Cu, and Be-Ni. However, there are limits to dimensional accuracy, such as shape errors due to undercutting and porous surfaces due to the isotropic etching characteristics and machining burrs in the system. In addition, the repeatability for re-fabrication is very low because it is difficult to maintain a constant concentration or mixing ratio of chemical components in every process. Thus, in this study, a selective electroforming process was investigated. Selective electroforming uses a photolithography process, with which the advanced polymer structure is formed. On a conductive substrate, the tips are fabricated by forming polymer structures using a photoresist and electroforming from the substrate bottom to the structure surface using nickel. This nickel substrate can be utilized over 5 times as a master mold. While building the metal structures on the substrate with nickel, the current density and processing time are the main factors in the electroforming process [1,2,5].

To form a micro-probe tip structure on the substrate (STS316L), spin coating was carried out uniformly on the cleaned substrate with the photoresist. For the photolithography, an SU8-2025 photoresist and PM-acetate developer from MicroChem Corporation were used. For the spin coating and baking, a HANA200D coater from Won Corporation and a hot plate were used, respectively. For exposure, a PC-500MFN UV lamp from Ushio Inc. was used, which discharges 365 nm I-line UV light every second.

Because the thickness of the tip has been decided, the speed of spin coating is a critical parameter in this step. After pretreatment by the Hexamethyldisilazane process (HMDS process) to improve the quality of the substrate surface, a polymer tip structure that was 25 mm in height was obtained at 1750 rpm (Table 1).

By exposing the photoresist-coated substrate to UV light through a probe tip patterned mask, the master structure was transferred and the substrate of the tip structure was formed after development. The photoresist was soft baked for 7 minutes at 95°C and illuminated with UV light for 12 seconds at a power of 200 ml/cm². The post-exposure bake process needed to take place directly after exposure. Furthermore, the development process was carried out in PM-acetate at a temperature of 25°C for 5 minutes. All conditions for photolithography are listed in Table 2.
Table 1. Processing conditions for photoresist coating and pretreatment.

| STEP | 1 | 2 | 3 | 4 | 5 |
|------|---|---|---|---|---|
| Chemical | HMDS | HMDS | SU8-2025 | SU8-2025 | SU8-2025 |
| Process | Expansion | Main spin | Dispense | Expansion | Main spin |
| Spin speed (rpm) | 500 | 2500 | 1 | 500 | 1750 |
| Time (sec) | 5 | 7 | 10 | 5 | 35 |

This study was conducted using an HG/1000 series electroforming machine (Digital Matrix Co., Ltd). This consists of a cleaning and silver spray booth, an electroforming booth, a passivation booth, and a current and temperature controller. Figure 5 shows the electroforming system used in this study. After pretreatment of the master surface with sodium dichromate (Na₂Cr₂O₇) and potassium dichromate (K₂Cr₂O₇) to ensure adhesion between the master and Ni layers, a selective electroforming process was performed on the master substrate whose fabrication was described above. In the electroforming process, the most important point is the height of the electroformed material; the height of the polymer structure (H) must be greater than the probe tip height h (H > h). Some preliminary trials were conducted and optimal electroforming conditions were determined. Figure 6 shows failed samples that were obtained owing to residual stress during demolding under unstable conditions. The electroforming was conducted over 30 minutes, which was divided into four intervals to prevent internal residual stress, as shown in Figure 7. Figure 8 presents the results under optimal electroforming conditions. The full process of selective electroforming is illustrated in Figure 9.

Figure 5. Construction of the electroforming machine.

Table 2. Processing conditions for photolithography.

| No. | Process          | Chemical   | Time | Temp. | Comments     |
|-----|------------------|------------|------|-------|--------------|
| 1   | Photoresist coating | SU8-2025   | -    | -     | -            |
| 2   | Soft bake       | -          | 7 min. | 95°C | Hot plate   |
| 3   | Exposure        | -          | 12 sec. | -     | 200 mJ/cm²  |
| 4   | Post exposure bake | -         | 5 min. | 95°C | Hot plate   |
| 4   | Development      | PM-acetate | 7 min. | 25°C | -           |
| 5   | Hard bake       | -          | 10 min. | 150°C | Hot plate   |
Figure 6. Failed samples due to internal residual stress during demolding.

Figure 7. Current settings for electroforming.

Figure 8. Electroformed probe tip under optimal conditions.

Figure 9. Entire selective electroforming process.
3. Results and discussion

In this study, the tip of a micro-probe unit was fabricated through a selective electroforming process based on UV lithography. The electroformed probe tip is shown in Figure 10. In addition, Figure 11 shows the tip-assembled probe unit. For dimensional analysis, a three-dimensional measuring machine (VIEW-300) from VIEW Micro-Metrology was used. In Figure 12, the average dimensional accuracy and standard deviation were 4.353±0.001 mm in the X-direction and 12.043±0.0009 mm in the Y-direction. In addition, the thickness distribution was 0.022±0.0008 mm. In Figure 13, a red-green-blue (RGB) lighting test is shown on a TFT-LCD panel using the electroformed tips.

Figure 10. Tip of the micro-probe unit fabricated using the selective electroforming process.

Figure 11. Micro-probe unit (the tip was assembled).

Figure 12. Dimensional accuracy deviation of micro-probe units.

Figure 13. TFT-LCD light emitting test.
4. Conclusions
In this research, a micro-probe tip was fabricated through a selective electroforming process and high dimensional accuracy was obtained. The selective electroforming process could replace conventional machining techniques such as micro-machining, laser micro-machining, and chemical etching. It will also offer advantages in terms of reducing costs and manufacturing cycle time compared to classical machining processes.

Acknowledgments
This work was supported by the Korea Institute of Industrial Technology and the Ministry of Knowledge Economy Korea (manufacturing of precision electroforming tips using micro-molds, Project No. 10S-E2-0017).

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