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Characterization of SUS Molds for Light Guide Plates by Electro-Chemical Fabrication (ECF) Method

Min-Soo Cho[1], Si-Hyeong Cho[1], Nam-Goo Cha[1], Hyun-Woo Lim[1]
Jin-Goo Park[1,*], and Jae-Seung Jo[2]

[1]Division of Materials and Chemical Engineering, Micro Biochip Center, Hanyang University,
Ansan 426-791, Korea
[2]JEIS Inc., 725 Wonsi Dong, Danwon Gu, Ansan 425-851, Korea

A new micro fabrication method termed electro chemical fabrication (ECF) is introduced to overcome conventional problems of electrochemical machining (ECM), such as low reliability and reproducibility. This ECF process defines micro patterns using a conventional photolithography, allowing it to produce micro-scale patterns with an excellent surface profile and of excellent quality. In this paper, four-inch 304 SUS and Ni molds were fabricated by using ECF and $FeCl_3$ wet etching processes, respectively. The etch rate of stainless steel was measured at nearly 0.27 μm/min at optimized ECF conditions and that of Ni was 0.77 μm/min with $FeCl_3$ dipping. To ensure a uniform depth profile of 10 μm, the process time for the SUS and the Ni mold were determined to be 36 minutes and 13 minutes, respectively. After the fabrications of SUS and Ni molds, the ECF-SUS mold showed two times better surface roughness values than the $FeCl_3$-Ni mold. To evaluate the ECF-SUS process, light guide plates (LGP) were made using an injection molding method. The LGP using the $FeCl_3$-Ni mold showed a hazy area when tilting the plate. This haze effect is believed to have formed from poor surface roughness. An LGP made with an ECF-SUS mold showed a 25% higher brightness and a 15% higher light uniformity compared to a $FeCl_3$-Ni mold.

Key words: metal molds, stainless steel mold, Ni mold, electro chemical fabrication (ECF), injection molding, light guide plate (LGP)

1. INTRODUCTION

The demand for micro-products and components has rapidly increased in the electronics, optics, medicine, biotechnology, automotive, communications and avionics industries. Specific applications are numerous, and include medical implants, diagnostic and remediation devices, micro-scale batteries and fuel cells, fluidic micro-chemical reactors with micro-scale pumps, valves and mixing devices, micro-fluidic systems, micro-holes for fiber optics, micro-nozzles for high-temperature jets, micro-molds and deep X-ray lithography masks, optical lenses, and micro components in common products such as compact disc (CD) players, air bags and inkjet printers[1]. Related miniaturized products require the production of components with features in the range of a few to several hundred micrometers. Researchers in academia and industry worldwide are striving to develop innovative manufacturing technologies to meet this demand.

Lithography-based micro electro mechanical systems (MEMS) fabrication technologies are capable of producing micro and sub-micrometer size features. However, MEMS techniques do have limitations such as the restricted choice of work-materials, the inability to produce complex geometries, and the huge capital investment and inevitable clean-room environment required[2,3].

Electrical discharge machining (EDM) is a machining method primarily used for hard metals or those that would be impossible to machine with traditional techniques. EDM can cut small or odd-shaped angles, intricate contours or cavities in extremely hard steel as well as exotic metals such as titanium, kovar, and carbide. The EDM cutting tool is guided along the desired path very close to the work without touching the piece. One critical limitation of EDM is that consecutive sparks produce a series of micro-craters on the work piece. The particles are washed away by dielectric fluid that is continuously flushed[4-6].

Electrochemical machining (ECM) is based on a controlled anodic electrochemical dissolution process of the workpiece (anode) with the tool (cathode) in an electrolytic cell under an electrolysis process. As it is a non-mechanical metal-removal process, ECM is capable of machining any

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*Corresponding author: jgpark@hanyang.ac.kr

electrically-conductive material with high stock removal rates regardless of mechanical properties such as the hardness or toughness of the material. Material is dissolved at the atomic level so that a complex surface with an excellent surface quality can be obtained. Compared with EDM, ECM generates neither electrode wear nor heat-affected zones. ECM is applied to finish an EDM surface, as ECM can produce smooth and stress-free surfaces. In spite of these advantages, ECM is rarely used in micro scale machining as the electric field is not localized and fine features are not reproduced [7-9].

To overcome the conventional problems of ECM, a new micro fabrication method known as electro chemical fabrication (ECF) has been introduced. The key point of the ECF process is that it combines ECM and photolithography. The ECF process defines micro patterns using conventional photolithography so that it can produce quality micro-scale patterns with an excellent surface profile. The ECF process can produce a metal mold at a lower price relative to conventional micro patterning methods.

A light guide plate (LGP) utilizes the phenomenon of diffraction based on the wave optics of light. An LGP with numerous micro-reflectors provides much higher and more uniform brightness over illuminated surfaces. It can assure a longer battery life for a light source through reduced power consumption[10].

In this paper, LGPs were fabricated via an injection molding technique with an ECF applied SUS mold and a conventional $FeCl_3$ wet-etched Ni mold. It was then evaluated by a range of test methods.

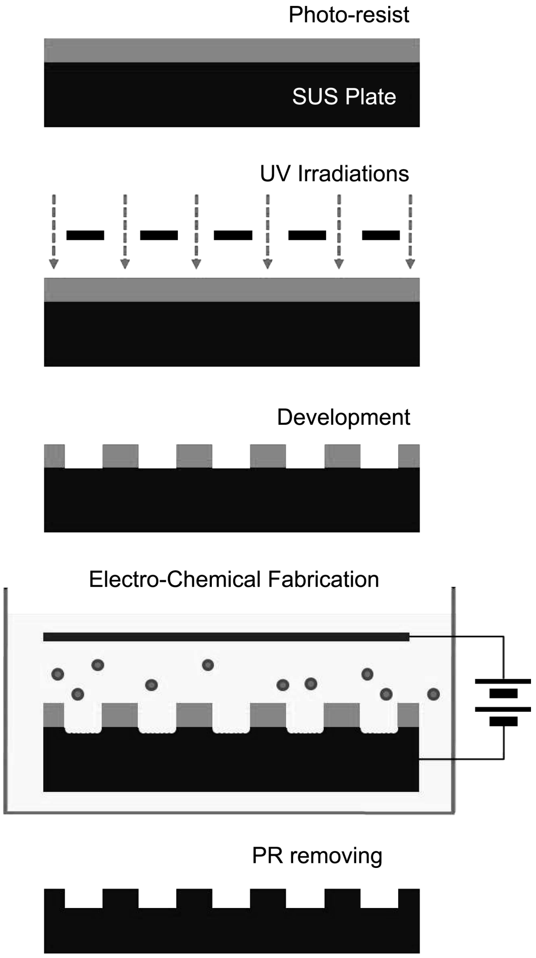


Fig. 1. Schematic illustration of the ECF (electro-chemical fabrication) process.

2. EXPERIMENTS

A four-inch 304 SUS steel wafer (0.5 mm in thickness) was prepared for the fabrication of metal molds. A photoresist (AZ1512, Clariant Co., USA) was spin-coated at 1000 rpm for 30 seconds. After soft baking at 120°C for two minutes on a hot plate, the surface was exposed by a UV contact aligner (EVG, EVG620, Austria) for 12 seconds through a photomask with various patterns. The exposed photoresist was developed for 90 seconds using a developer (MIF300, MicroChem Co., USA). After dipping and clamping the SUS wafer in a specially designed electrolytic cell, ECF process was achieved by applying a constant current under optimized conditions.

For a comparison of the properties, a four-inch electroplated Ni wafer (300 μm in thickness) was prepared for the fabrication of metal molds. The photoresist was patterned using the same photolithography process described earlier. After dipping and clamping the Ni wafer in a $FeCl_3$ (Junsei, Japan) solution, a wet etching process was achieved at room temperature.

An electrolyte bath had a volume of nearly two liters and was equipped with an automatic rectifier and stirrer. An electrolyte was joint-developed with JEIS based on H_2SO_4, H_3PO_4 and additives.

Light guide plates were fabricated via the injection molding with the fabricated SUS and Ni molds on polycarbonate at a mold temperature of 120°C and a resin temperature of approximately 350°C.

The fabricated SUS molds were observed under an optical microscope (L150A, Nikon, Japan). The surface roughness was measured using a 3D-profiler (iSurf-C, Nanofocus, Austria), and field-emission secondary electron microscopy (FE-SEM, S-4800, Hitachi, Japan) was used to confirm the submicron surface roughness. The brightness of an LGP was measured using a luminance colorimeter (BM-7, TOPCON Optical, Japan). Figure 1 shows a schematic illustration of the ECF process for the SUS mold.

3. RESULTS AND DISCUSSION

The ECF process was optimized at room temperature at a

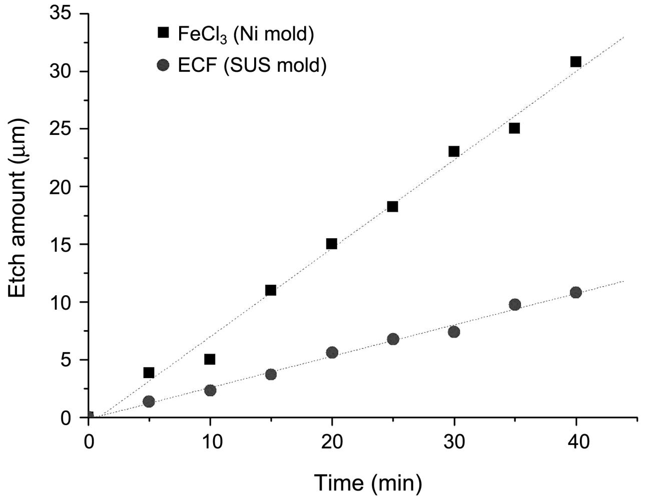


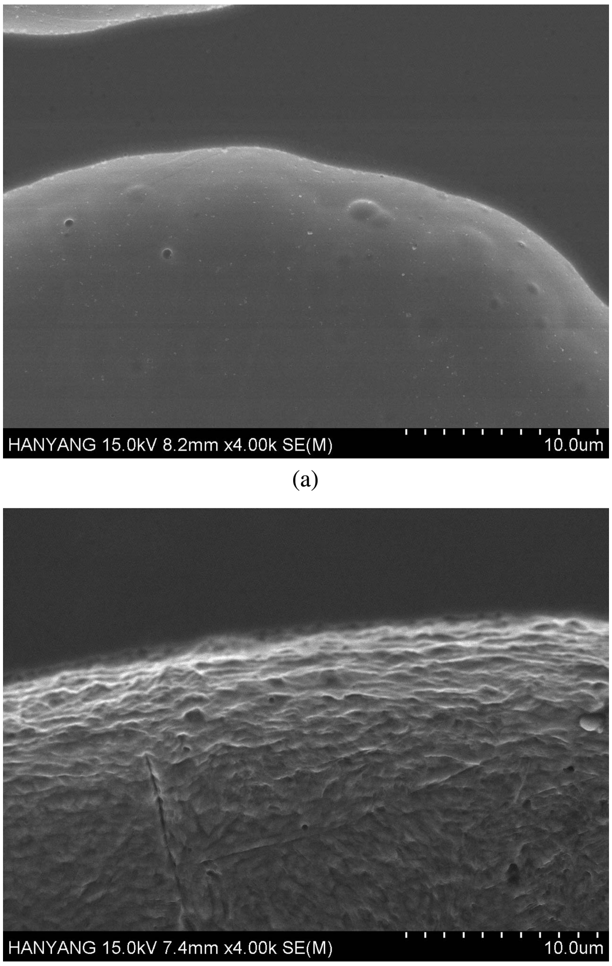
Fig. 2. Etch amount of an ECF-applied SUS mold and a $FeCl_3$ wet-etched Ni mold as a function of time at the optimized conditions.

Table 1. Comparisons of the roughness between an ECF-applied SUS mold and a $FeCl_3$ wet-etched Ni mold

Roughness (R_q : μm)	250 μm diameter (X axis)	250 μm diameter (Y axis)	150 μm diameter (X axis)	150 μm diameter (Y axis)
SUS	0.4	0.43	0.56	0.74
Ni	0.97	1.11	1.07	1.45

current of 0.5 A and a voltage of 5~7 V using a Cu electrode and a jointly developed proprietary electrolyte. The etch rate was measured as nearly 0.27 μm/min under these optimized ECF conditions. Ni molds were fabricated by dipping them in $FeCl_3$ at room temperature. The etch rate was measured as approximately 0.77 μm/min. To ensure a uniform depth profile of 10 μm, the process times for the SUS and Ni molds were determined as 36 minutes and 13 minutes, respectively. Figure 2 shows the etch amounts for SUS and Ni as a function of time.

Surface roughness causes scattering and stray light in optical systems and degrades the contrast and sharpness of optical images. Thus, the smoother the surface, the better the function of the component in general. Table 1 shows comparisons of the roughness between an ECF-applied SUS mold and a $FeCl_3$ wet-etched Ni mold. The roughness was calculated using the rms roughness (R_q), which was defined as the root mean square of the deviations of the surface profile z(x) from the mean line. Surface roughness was measured at the X- and Y- axes of 250 μm and 150 μm hole-patterns. The ECF-SUS mold showed nearly a two-fold improvement in its surface roughness values compared to the $FeCl_3$-Ni mold. Figure 3 shows FESEM images of the ECF-SUS mold in addition to the $FeCl_3$-Ni mold. The metal surface of the ECF-SUS mold was perceptibly more clear and smooth than the $FeCl_3$-Ni mold.



(a)

(b)

Fig. 3. FE-SEM images of (a) ECF-applied SUS mold and (b) $FeCl_3$ wet-etched Ni mold surfaces.

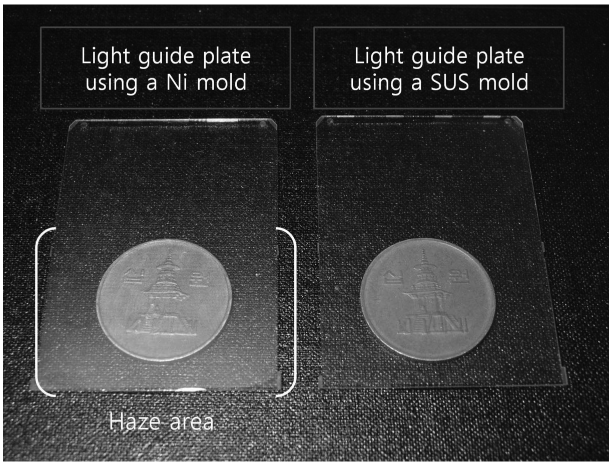


Fig. 4. Photography of injection-molded light guide plates made using the Ni and SUS molds.

Light guide plates were fabricated using an injection molding method. Figure 4 shows a photograph of the fabri-

Table 2. Brightness data of the light guide plates using a SUS mold and Ni mold

SUS mold		Ni mold	
Brightness (mm/cd^2)	Uniformity (%)	Brightness (mm/cd^2)	Uniformity (%)
4155	91	3311	79

cated light guide plates. The LGP made from the $FeCl_3$-Ni mold showed a hazy area when tilting the plate. This haze effect is believed to have resulted from the poor surface roughness. For a more accurate measurement, the brightness was measured using a luminance colorimeter. Table 2 shows the brightness and light uniformity of the light guide plates. The LGP made using the ECF-SUS mold showed a 25% higher brightness and a 15% higher light uniformity compared to an LGP made from the $FeCl_3$-Ni mold.

4. CONCLUSIONS

In this paper, LGPs were fabricated using an injection molding method with an ECF-applied SUS mold and a $FeCl_3$ wet-etched Ni mold. An optimized ECF process was achieved at room temperature with a current of 0.5 A and a voltage of 5~7 V using a Cu electrode and a proprietary electrolyte. Ni molds were fabricated by dipping them in $FeCl_3$ at room temperature. The etch rates for ECF and $FeCl_3$ wet etching were shown to be nearly 0.27 μm/min and 0.77 μm/min, respectively. Identical depth profiles of 10 ìm were fabricated by controlling the process time.

The ECF-SUS mold showed nearly a two-fold improvement in the surface roughness values compared to the $FeCl_3$-Ni mold. The metal surface of the ECF-SUS mold was noticeably more clear and smooth than the $FeCl_3$-Ni mold.

To evaluate the injection-molded LGP, a reflection test was conducted using the naked eye. The LGP made from the $FeCl_3$-Ni mold had a hazy area that could be seen when tilting the plate. For a more accurate measurement, the brightness was measured using a luminance colorimeter. The LGP made using the ECF-SUS mold showed a 25% higher brightness and a 15% higher light uniformity compared to the LGP made using the $FeCl_3$-Ni mold. The use of the ECF process led to a higher quality surface compared to when a conventional wet etching process was used.

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