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Development of rapid mask fabrication technology for micro-abrasive jet machining †

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Abstract

Micro-machining of a brittle material such as glass or silicon is important in micro fabrication. Particularly, micro-abrasive jet machining (μ-AJM) has become a useful technique for micro-machining of such materials. The μ-AJM process is mainly based on the erosion of a mask which protects brittle substrate against high velocity of micro-particles. Therefore, fabrication of an adequate mask is very important. Generally, for the fabrication of a mask in the μ-AJM process, a photomask based on the semi-conductor fabrication process was used. In this research a rapid mask fabrication technology has been developed for the μ-AJM. By scanning the focused UV laser beam, a micro-mask pattern was fabricated directly without photolithography process and photomask. Therefore, rapid and economic mask fabrication can be possible for the micro-abrasive jet machining. Two kinds of mask patterns were fabricated by using SU-8 and photopolymer (Watershed 11110). Using fabricated mask patterns, abrasive-jet machining of Si wafer was conducted successfully.

Keywords: Mask, Micro-abrasive jet machining; SU-8; Photopolymer; Micro-stereolithography

1. Introduction

Micromachining of brittle materials, such as glass or silicon, is important in MEMS and semiconductor fabrication processes, and micro-abrasive jet machining (μ-AJM) has become an effective micromachining technique [1-3]. Since the μ-AJM process is mainly based on the erosion of a mask that protects the brittle substrate from high-velocity microparticles, an adequate mask is very important. Generally in a μ-AJM process, a photomask pattern is fabricated on the substrate by photolithography. However, the photolithography process is relatively complex and requires expensive equipment. Moreover, it is difficult and time-consuming to change the mask pattern.

In this study, we developed a rapid and economic mask fabrication technique based on microstereolithography (MSTL) technology for μ-AJM [4,5]. In MSTL, a focused UV beam a few microns in diameter is used to solidify a very small area of a UV-curable photopolymer. Therefore, a micro-mask pattern for μ-AJM can be easily fabricated by scanning a focused UV beam. Furthermore, mask design flexibility can be achieved because the modification of the laser beam scanning path is very easy for mask pattern modification.

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2. Rapid mask fabrication system

The basic machining principle of μ-AJM is shown in Fig. 1. In the process, micro-abrasives (tens of μm), accelerated by highly compressed air or gases, are forced through a micro-nozzle, and collide with hard and brittle work pieces at a very high velocity and density. In order to fabricate a photomask pattern for μ-AJM process, photolithography is commonly needed [6]. Thus, additional photomask and alignment process are positively necessary in this process. However, a method of rapid mask fabrication can make the mask pattern directly on substrate without additional photomask and alignment process as shown in Fig. 2. Therefore, this technology requires less fabrication time if the production volume is low. Furthermore, mask design flexibility can be achieved because the modification of the laser beam scanning path is very easy for mask pattern modification.

Fig. 3 shows a schematic drawing and the developed mask fabrication apparatus for μ-AJM. In this system, a UV laser (375-nm wavelength) and an optical fiber were used as the light source and light mask material was fixed on the elevator. The UV delivery system, respectively. A substrate with a beam from the optical fiber was focused through the collimator so that its diameter was a few microns in size. The beam was then used to solidify a photopolymer by irradiating it on the surface. The collimator was attached to an X–Y scanning stage system. A mask with micro-patterns for μ-AJM could be fabricated directly on the substrate without photolithography process by controlling the X–Y stage system. Table 1 shows the construction of the mask-fabrication apparatus.

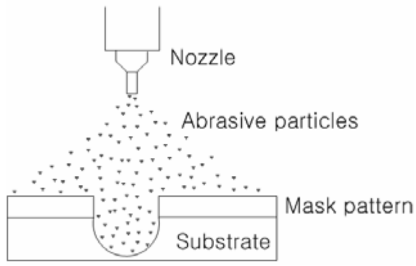


Fig. 1. The principle of micro-AJM with mask pattern.

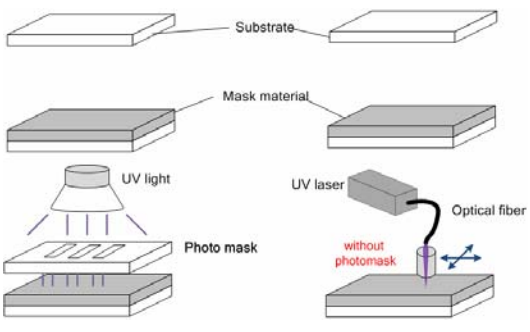


Fig. 2. Comparison of exposure process: (a) Existing mask fabrication technology and (b) New mask fabrication technology.

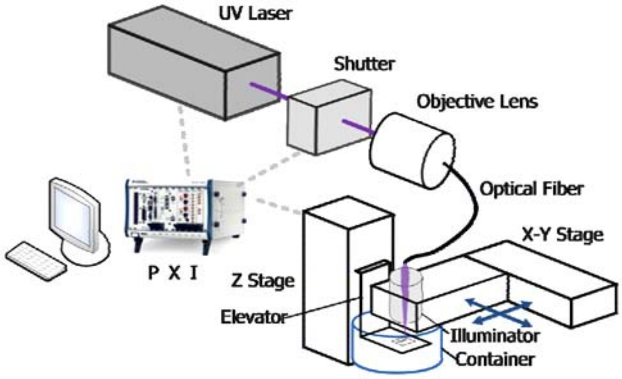
3. Solidification properties of mask materials

To investigate the cure width as a function of the laser power and scanning speed, we conducted an experiment for a single cure line. Two types of materials were used to cure the single line: SU-8 2100 photoresist (Microchem) and Watershed 11110 photopolymer (DMS). μ-AJM requires a sufficiently thick mask. For the SU-8, spin coating and baking processes were used to obtain an adequate mask thickness. For the Watershed 11110 photopolymer, which is used in rapid prototyping (RP), it was possible to fabricate a mask with adequate thickness without spin coating or baking processes because the viscosity of the photopolymer is low relatively (~92 cps at 30°C). In this case, the substrate was immersed into the photopolymer container to generate the mask. After the photopolymer covered the substrate to the desired thickness, the mask pattern was produced directly on the photopolymer by the movements of the X–Y stage.

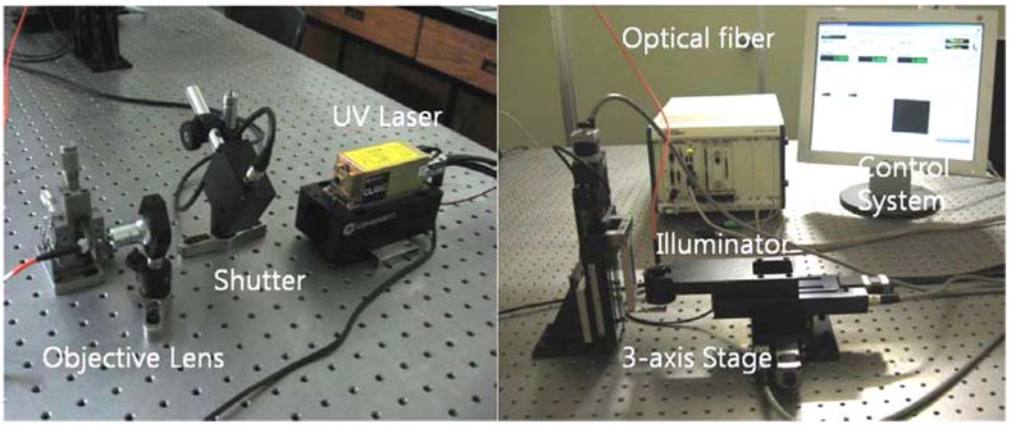
The solidification width of the mask pattern is also important in μ-AJM. Fig. 4 (a) and (b) show experimental results for different laser scanning speeds by using the two mask materials. In both cases, the solidification width deceases as the scanning speed of the UV laser increases. From these results, we determined laser beam exposure conditions for SU-8

Table 1. Construction of mask-fabrication apparatus.

UV Laser	Coherent CUBE 375-8C (375 nm)
Control system	National Instruments PXI-1024Q
Stage	SARUGA SEIKI KS262-50
Shutter	Cheongwon Mechatronics Co.
Optical fiber	Tholabs M14L02
Objective lens	Newport M-10X
Collimator	Tholabs F230SMA-A

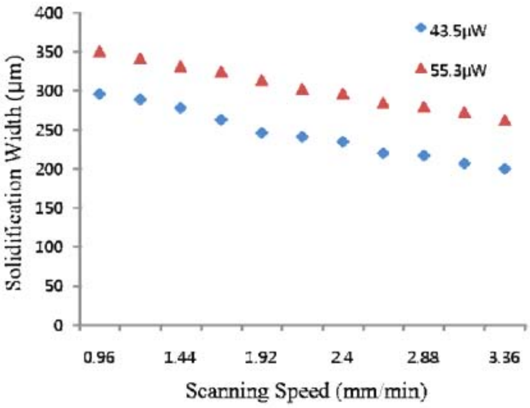


(a)

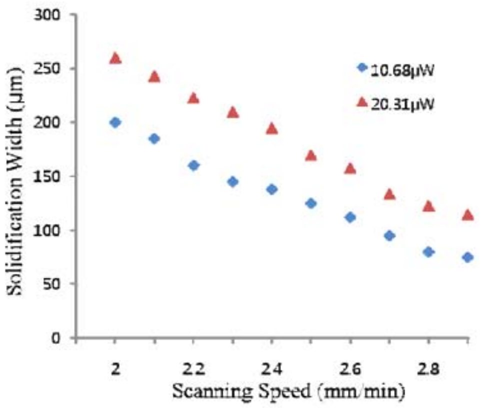


(b)

Fig. 3. (a) Schematic drawing and (b) Photograph of the mask fabrication apparatus for micro-AJM.



(a)



(b)

Fig. 4. Solidification width of two types of mask materials according to scanning speed and power of the laser beam: (a) SU-8 2100, and (b) Watershed 11110.

4. Micro-abrasive jet machining

4.1 Mask fabrication

Based on this study of the solidification properties of mask materials, a mask pattern was designed and fabricated by using a mask fabrication system. Holes of the Watershed mask were designed larger than that of SU-8 because of low solidification property and this has to be improved by successive research. Fig. 5 and Fig. 6 show the schematic drawing of the mask pattern and SEM photographs of the fabricated mask, respectively.

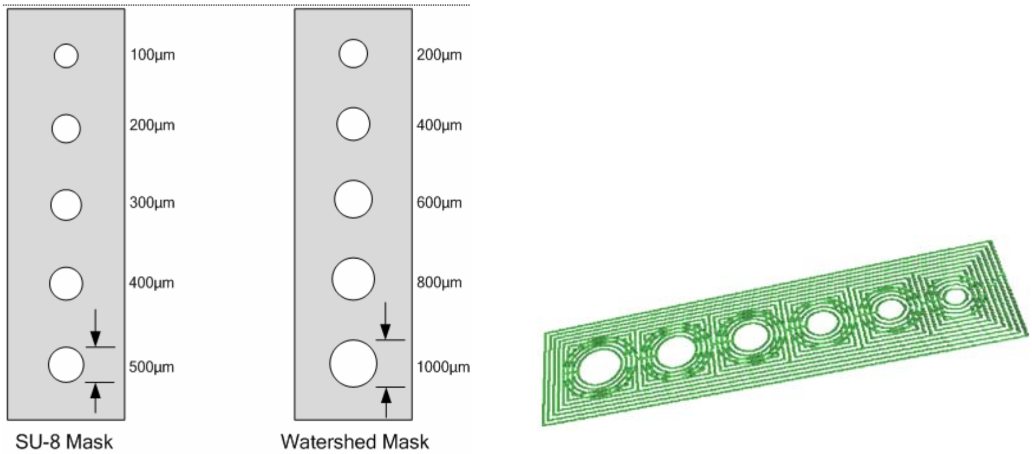
Table 2. Laser beam exposure conditions for SU-8 and Watershed 11110 patterning.

Parameters	SU-8	Watershed 11110
Beam power	43.5 μW	10.68 μW
Scanning speed	3.36 mm/min	2 mm/min
Layer thickness	200 μm	300 μm

As shown in Fig. 6, the Watershed mask compares poorly with the SU-8 mask. Table 2 shows the fabrication conditions. The fabrication time of the SU-8 and Watershed mask was 57 minutes and 96 minutes, respectively.

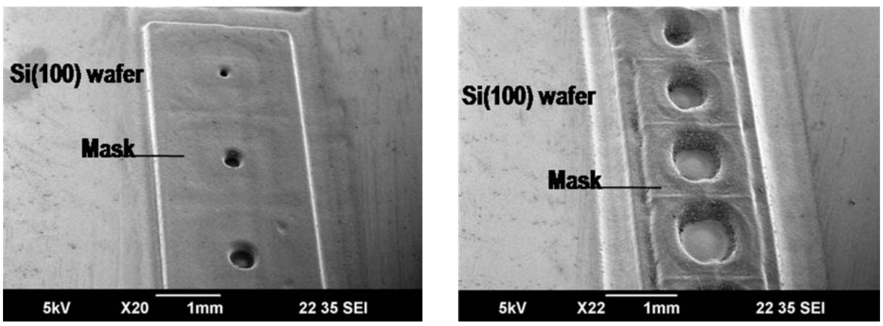
4.2 Experiments and results

Holes were fabricated in 200-μm-thick SU-8 and 300-μm-thick Watershed 11110 masks. In both cases, a Si (100) wafer was used as the substrate material.



(a) (b)

Fig. 5. Schematic drawing of mask pattern: (a) Dimension of SU-8 mask (left) and Watershed 11110 (right) (b) Screen image of code generation software.



(a) (b)

Fig. 6. SEM photographs of mask patterns for micro-abrasive jet machining: (a) Fabricated mask of SU-8 mask and (b) Fabricated mask of Watershed 11110.

The fabrication conditions are summarized in Table 3. The Si substrate was covered by a mask, and Al_2O_3 microparticles (17 μm in diameter) were blasted from a rectangular nozzle (0.18 × 3.5 mm) by a high-pressure airflow (0.2 MPa) at an incident angle of 90°. The stand-off distance was 5 mm, the particle flow rate was 2 g/min, and the scanning speed was 0.3 mm/min. Fig. 7 and Fig. 8 show the noncontact three-dimensional profiler images of the holes after μ-AJM of both mask materials.

Table 3. Experimental condition of μ-AJM.

Parameter	Value
Al_2O_2 particle diameter	17 ㎛
Nozzle size	0.18 × 3.15 mm
Distance from the sample	5 mm
Pressure	0.2 Mpa
Flow rate	2 g/min
Scanning speed	0.3 mm/min
Blasting time	2 times

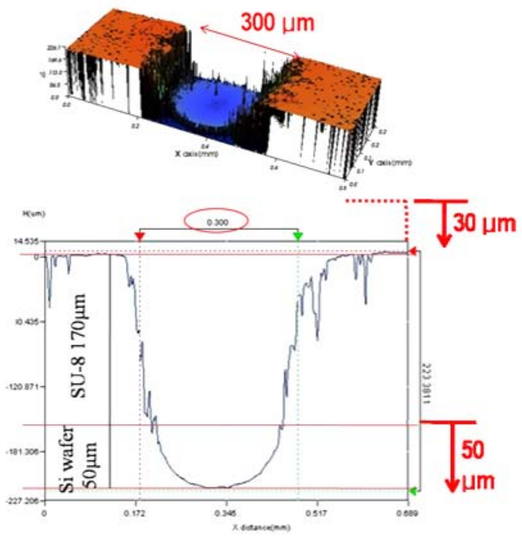


Fig. 7. Erosion profile of SU-8 mask.

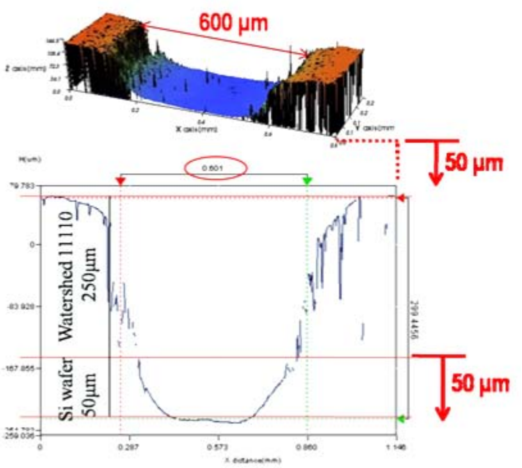
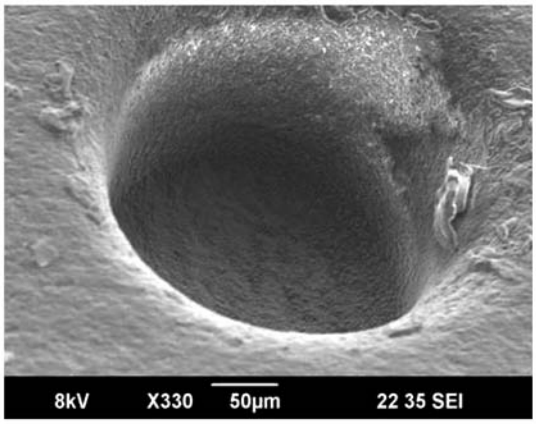
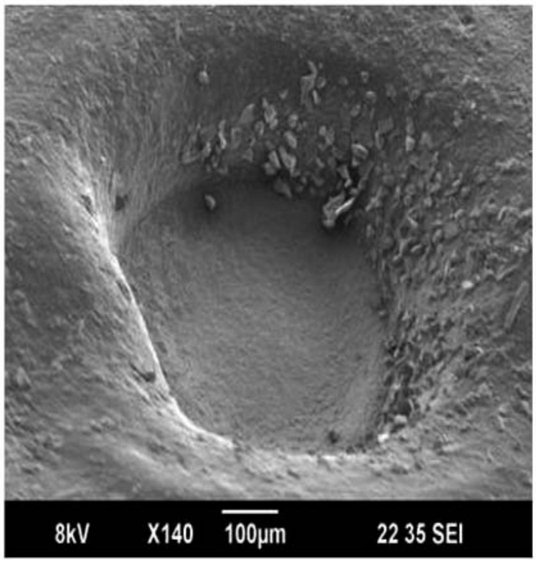


Fig. 8. Erosion profile of Watershed 11110 mask.

Fig. 9 shows an SEM photograph of the mask after abrasive jet machining. In both cases, the erosion of the Si wafer was about 50 μm. The erosion of the mask material was about 30 μm for the SU-8 and 50 μm for the Watershed 11110. After the μ-AJM process, the SU-8 mask material could be removed by



(a)



(b)

Fig. 9. SEM photograph of mask after abrasive jet machining: (a) SU-8 mask and (b) Watershed 11110 mask.

using a stripper. To remove the Watershed 11110 mask, heat was applied in a furnace for an hour at temperatures of up to 900˚C. No damage occurred to the Si substrate during the mask removal process.

As seen in Figs. 7- 9, the erosion rate of Watershed mask is larger than of the SU-8 mask. This was because the SU-8 mask was post-baked after laser beam irradiation and developed. However, the Watershed 11110 mask was rinsed right after the laser beam irradiation. Consequently, it was conjectured that the SU-8 mask was harder than the Watershed mask. Therefore, the Watershed mask has to be thicker than the SU-8 mask for the same erosion depth of substrate material.

5. Conclusions

We developed a new rapid mask fabrication technique based on microstereolithography technology successfully using SU-8 photoresist and Watershed 11110 photopolymer as mask materials. In particular, the Watershed 11110 photopolymer could be applied directly on the substrate as a mask without spin coating and post baking processes.

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