Fabrication of 3D Microstructures with Single uv Lithography Step

Man Hee Han, Woon Seob Lee, Sung-Keun Lee, and Seung S. Lee

Abstract— **This paper presents a novel microfabrication technology of 3D microstructures with inclined/rotated UV lithography using negative photoresist, SU-8. In some cases, reflected UV as well as incident UV is used to form microstructures. Various 3D microstructures are simply fabricated such as embedded channels, bridges, V-grooves, truncated cones, and so on.**

Index Terms— **3D microstructure, SU-8, inclined/rotated UV lithography, reflected UV.**

I. Introduction

Recently, 3D microstructures have been focused in various microsystems. Thus several 3D microfabrication techniques have been developed such as micro stereo lithography [1], combined process of deep RIE and bulk etching [2], moving mask LIGA process [3], inclined deep X-ray lithography [4], and inclined UV lithography [5]. Each process has its advantages and disadvantages. For example, the micro stereo lithography can make complex microstructures, however it needs special equipments and it is difficult to produce high precision structures. The inclined UV lithography with thick positive photoresist was reported using common clean room equipment in 1994 [5]. However, they did not show good results and no one has been performed a similar work using the inclined UV lithography after that.

In our work, SU-8, negative thick photoresist, is used to fabricate 3D microstructures with combinations of inclined and rotated UV lithography. In addition, reflected UV as well as incident UV is used to form 3D microstructures.

Manuscript received November 16, 2002; revised December 12, 2002.

Department of Mechanical Engineering, Pohang University of Science and Technology San 31 Hyoja-Dong Nam-Gu, Pohang, Kyongbuk 790-784, Korea.

E-mail: manhee@postech.ac.kr **Tel :** +82-54-279-8210

Fax : +82-54-279-5899

II. Fabrication Methods and the Results

1. *Equipment and fabrication process*

Figure 1 shows the basic setup of inclined UV exposure. It consists of a conventional UV source, a contact stage and a tilting stage. An UV mask and a substrate placed between the upper plate, of which center is opened for UV exposure, and the lower plate of the contact stage are fixed by pushing up the lower plate with a screw. After the contact stage is leaned against the tilting stage, the substrate is exposed to the inclined UV from the UV source.

The fabrication process starts with a single side

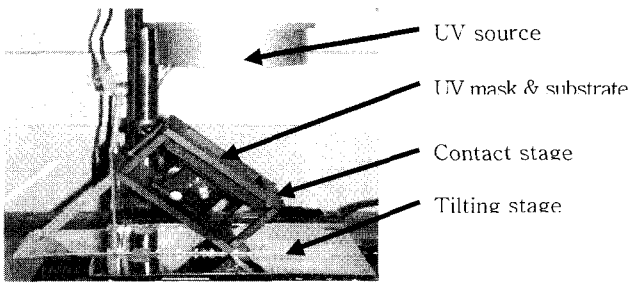


Fig. 1. basic setup of inclined UV exposure.

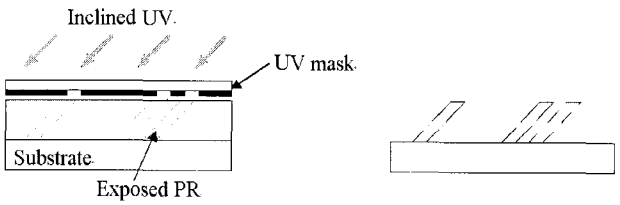


Fig. 2. Schematic diagram of 3D oblique microstructure fabrication.

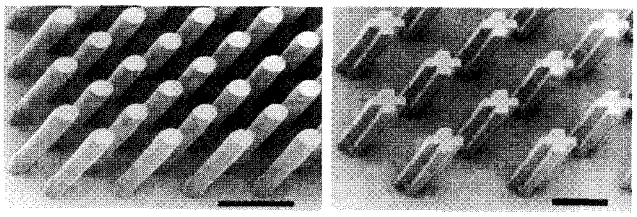


Fig. 3. Images of the 3D oblique microstructures [▬ 100 μm].

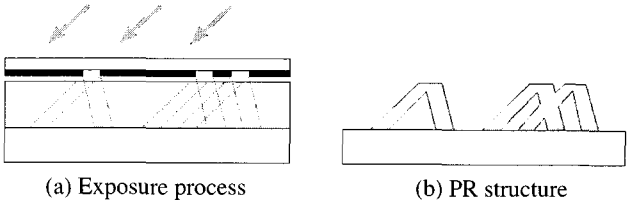


Fig. 4. Schematic diagram of 3D positive oblique microstructure fabrication.

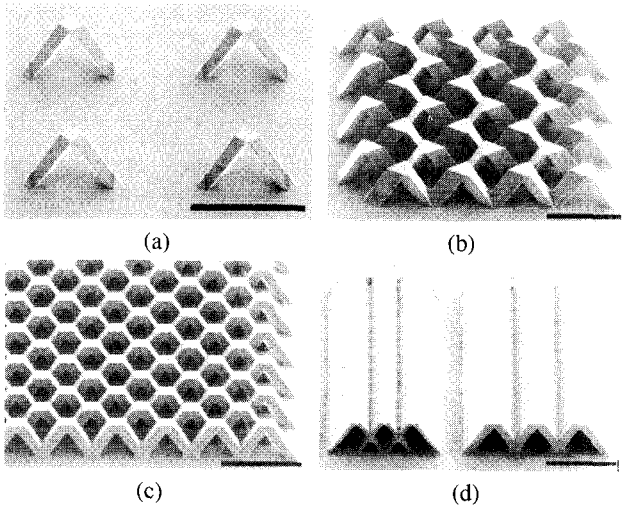


Fig. 5 Images of the 3D positive oblique microstructures [▬ 200 μm]

polished silicon wafer. SU-8, negative thick photoresist, is coated on it with 100 ~ 150 μm thick. Then the resist

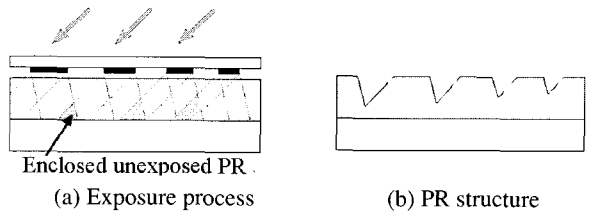


Fig. 6 Schematic diagram of 3D negative oblique microstructure fabrication.

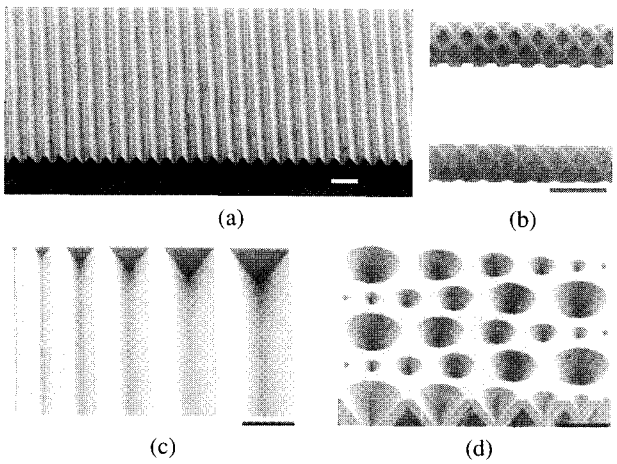


Fig. 7 Images of the 3D negative oblique microstructures [▬ 100 μm]

is soft baked on a 65°C hot plate for 10 minutes and on a 95°C hot plate for 30 minutes. It is contacted with a UV mask using the contact stage. The contact stage is leaned against the tilting stage and the resist is exposed to UV. The incident angle of the UV and the dose of 365 nm UV are about 45° and 500 mJ/cm^2, respectively. Following exposure, the resist is post exposure baked on a 65°C hot plate for 3 minutes and on a 95°C hot plate for 10 minutes. Finally, the resist is developed in SU-8 developer for 10 ~ 15 minutes at room temperature with mild agitation and rinsed with isopropyl alcohol.

2. *Inclined UV lithography*

Figures 2 and 3 show the schematic diagram and the results of the microfabrication of 3D oblique microstructures with single inclined UV exposure, respectively. When the incident angle of the UV to the soft baked SU-8 is about 45°, the angle between the structures and the substrate is about 64°, that is, the transmitted angle of the UV is about 26°. Thus the

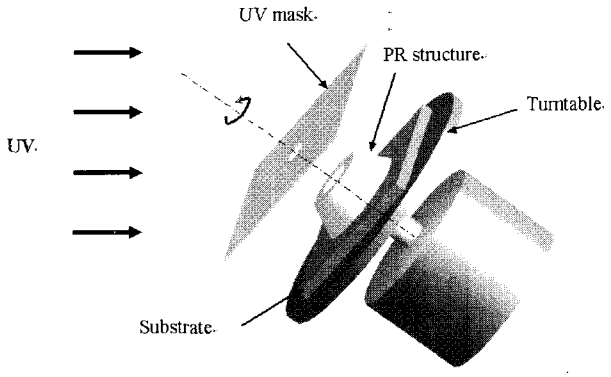


Fig. 8 Schematic diagram of inclined & rotated exposure.

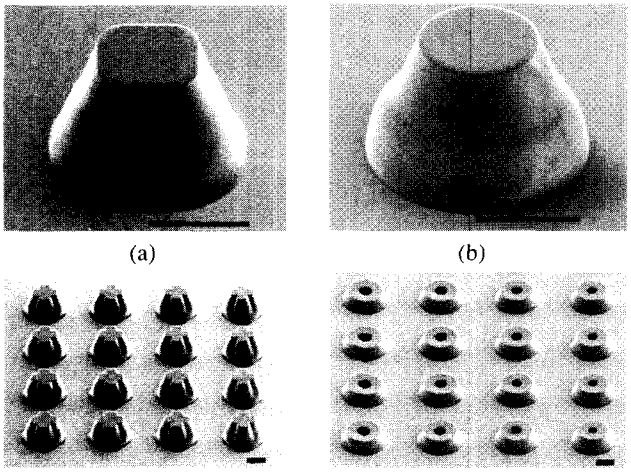


Fig. 9 Images of the 3D microstructures fabricated with inclined & rotated UV lithography [▬ 50 μm].

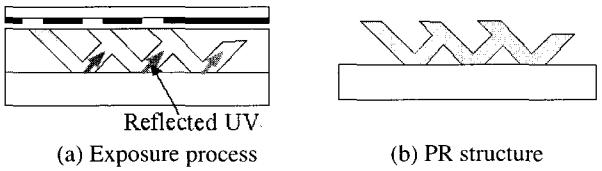


Fig. 10 Schematic diagram of 3D microfabrication using reflected UV.

refractive index of the soft baked SU-8 is about 1.6 by the following formula:

$$\text{Refractive index} = \frac{\text{Sin (incident angle)}}{\text{Sin (trasmitted angle)}} \quad (1)$$

Figures 4 and 5 show the schematic diagram and the results of the microfabrication of 3D positive oblique microstructures with two times inclined UV exposures, respectively. The experimental conditions in each

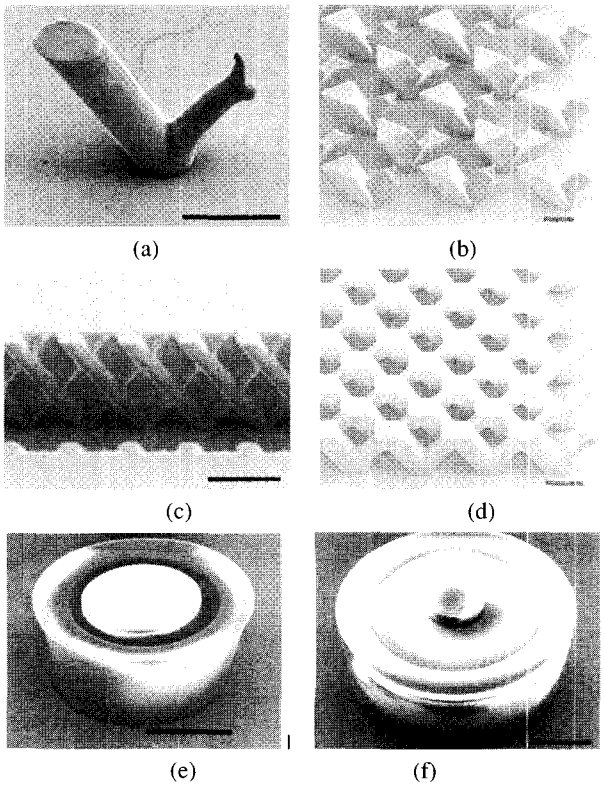


Fig. 11 Images of the 3D microstructures using reflected UV [▬ 50 μm].

inclined exposure are the same as those of the single inclined UV exposure.

Figures 6 and 7 show the schematic diagram and the results of the microfabrication of 3D negative oblique microstructures, respectively. In figure 6, the unexposed regions enclosed by the exposed regions are not developed because the regions are not revealed to developer.

3. *Inclined & rotated UV lithography*

Figure 8 shows the schematic diagram of inclined & rotated exposure. For the exposure, a turntable is added to the basic setup of the inclined UV exposure. Figure 9 shows the results of the inclined & rotated UV lithography. The incident angle of the UV is about 30° and the angle between the structures and the substrate is about 72°, that is, the transmitted angle of the UV is about 18°. The structures in Figure 9 (a), (b), and (c) are formed when the masks are contacted with the resist and the mask patterns are a square, a circle and crosses, respectively. When there is a gap between the mask and

the substrate, truncated shapes are formed such as the truncated cones in Figure 9 (d).

4. *Lithography with reflected UV*

Figures 10 and 11 show the schematic diagram and the results of the microfabrication of 3D microstructures using reflected UV as well as incident UV, respectively. The dose of the reflected UV is increased by increasing the exposure time as twice as that of a regular exposure process. With the method, the similar structures to what produced by the process illustrated in Figures 4 and 6 can be fabricated by single exposure. For example, the structures shown in figure 11 (c) are similar to what shown in figure 7 (b).

Figures 11 (e) and (f) show the structures which are fabricated with reflected UV as well as incident UV when the mask and the substrate are rotated as illustrated in Figure 8. It is thought that the convex shapes on the structures in Figure 11 (f) are formed when the upper central regions are slightly exposed due to the vibration of the mask and the substrate. Since the weekly cross-linked regions, that is, slightly exposed regions are deformed by the volume expansion of the unexposed SU-8 in the post exposure bake process.

III. Conclusion

Using negative thick photoresist SU-8, various 3D microstructures are easily and simply fabricated by inclined/rotated UV lithography with incident/reflected UV. The structures could be directly applied to various microsystems or used as the molds for electroplating. Therefore, these techniques have many applications such as microchannels, jets, nozzles, mixers, light guide panels of LCD monitor, riblets and more.

Acknowledgements

This work was supported by grant No. (R01-1999-00263) from the Basic Research Program of the Korea Science & Engineering Foundation.

References

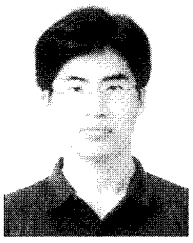
[1] K. Ikuta, S. Maruo, and S. Kojima, "New micro stereo lithography for freely movable 3D micro structure", Proc. IEEE Int. Workshop on Micro Electro Mechanical System, Heidelberg, Germany, pp. 290-295, Jan., 1998,.

[2] J.G.E. Gardeniers, J. W. Berenschot, M. J. de Boer, Y. Yeshurun, M. Hefetz, R. van't Oever, and A. van den Berg, "Silicon micromachined hollow microneedles for transdermal liquid transfer", Proc. IEEE Int. Conference on Micro Electro Mechanical System, Las vegas, USA, pp. 141-144, Jan., 2002.

[3] O. Tabata, N. Matsuzuka, T. Yamaji, S. Uemura, and K. Yamamoto, "3D Fabrication by moving mask deep x-ray lithography (M^2DXL) with multiple stages", Proc. IEEE Int. Conference on Micro Electro Mechanical System, Las vegas, USA, pp. 180-183, Jan., 2002.

[4] W. Ehrfeld and A. Schmidt, "Recent developmensts in deep x-ray lithography", J. Vac. Sci. Technol. B., Vol. 16, pp. 3526-3534, 1998.

[5] C. Beuret, G.-A. Racine, J. Gobet, R. Luthier, and N. F. de Rooij, "Microfabrication of 3D multidirectional inclined structures by UV lithography and electroplating", Proc. IEEE Int. Workshop on Micro Electro Mechanical System, Oiso, Japan, pp. 81-85, Jan., 1994.



Man-Hee Han was born in Jincheon, Chungbuk, Korea in 1979. He attended Pohang University of Science and Technology (POSTECH) where he received the Bachelor degree in mechanical engineering in 2002. He is now a candidate for the Master degree in mechanical engineering at POSTECH.

Woon-Seob Lee was born in Suwon city, Gyeonggi, Korea in 1973. He attended Soonchunhyang University where he received the Bachelor and the Master degree in material engineering in 2000 and 2002, respectively. He joined the Department of Mechanical Engineering at Pohang University of Science and Technology (POSTECH) in 2002, and he is now a researcher.

Sung-Keun Lee was born in Seoul, Korea in 1974. He attended Pohang University of Science and Technology (POSTECH) where he received the Bachelor and the Master degree in mechanical engineering in 2000 and 2002, respectively.

Seung S. Lee was born in Seoul, Korea, in 1962. He received the B.S. degree from Seoul National University, Korea, in 1984, and the M.S degree in mechanical engineering from University of California, Berkeley, CA, in 1989. After his M.S degree, he joined the Berkeley Sensor & Actuator Center (BSAC) and got his Ph.D there in 1995. After one year at Samsung research center(SAIT) in Kiheung, Korea, he joined the faculty of the Department of Mechanical Engineering in Pohang University of Science and Technology (POSTECH), Pohang, Korea, in 1997. He is an associate professor now.