Paper

Three-Dimensional Micromachining of PTFE Using Synchrotron Radiation Light

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Summary

In this paper, we propose SR etching as a new approach to fabricate 3D microstructures of PTFE. SR etching is a process of TIEGA that fabricates microstructures using polymers like PTFE by etching directly in a vacuum using SR light. The etching rate is on the order of 6-100 μm/min. SR beam direct writing was possible by SR light through a pinhole that fabricated 3D microstructures of PTFE combining a scanning stage with a high degree of freedom. 3D micromachining of PTFE by SR beam direct writing with atmospheric pressure as an exposure condition is thought to be desirable from the practical point of view. So, we approached SR etching under 2 conditions; in a vacuum and under He at 1 atm. As a result, corn shape PTFE microstructure was fabricated with a turning radius of 300 μm and a depth of 1 mm achieved.

Keywords: *3D micromachining, SR etching, TIEGA, SR beam direct writing*

1 INTRODUCTION

In order to fabricate highly functional microdevices for MEMS, three-dimensional (3D) micromachining that can form certain round or curved structures is required. Recently, micromachining has approached these requirements by surface micromachining, LIGA, etc [1-3]. These have usually been a combination of lithography with etching technology. However, these processes require several or modulated masks for LIGA and elegant feedback systems, resulting in expensive and complicated processes. Moreover these processes are difficult for more complex microstructures with round or curved surfaces fabricated with lithography and wet etching. These processes have serious problems of sticking, such as that due to the surface tension of the developer, such as occurs in wet processes.

The ideal method for 3D micromachining is direct writing to be able to form any microstructure without using masks as in the dry etching process [4, 5]. The synchrotron radiation (SR) etching in TIEGA (Teflon included etching galvanicforming) process might meet these requirements. TIEGA is a new process that fabricates microstructures using polymers like PTFE (polytetrafluoroethylene, Teflon) by etching directly in a vacuum using SR light [6, 7]. This process fabricated some polymer and metal microparts combined with electroforming and molding like LIGA. The etching rate of SR etching is on the order of 6-100 μm/min. By utilizing a high etching rate and completely dry process, SR etching might have a potential to fabricate 3D microstructures with certain round or curved surfaces by combining a scanning stage with a high degree of freedom. Fabricated microparts will be applied to highly functional microdevices including mechanical, biomedical electronic devices etc., due to the material characteristics of PTFE.

In this paper, we propose SR beam direct writing using SR etching as a new approach to fabricate 3D microstructures of PTFE and describe results of preliminary experiments by SR etching and SR beam direct writing.

2 BEAMLINE FOR SR ETCHING

SR etching has been a vacuum process. But, in order to fabricate 3D microstructures, atmospheric pressure as an exposure condition can be thought of as desirable from the practical point of view. For SR etching, we can use not only white light, but also X-rays [6]. The white light can give a higher etching rate due to its higher photon flux, but the SR etching must be conducted in a vacuum. On the other hand, the X-rays can be applied to the micromachining process in X-ray lithography (such as using an X-ray mask and processing under He at 1 atm). So, the experiments of SR etching in this paper used 2 beamlines BL-14 and BL-6 with the compact SR source "AURORA" at Ritsumeikan University. The BL-14 for SR stimulated process including TIEGA was used in a vacuum, with 10 μm-thick Be as a filter. The BL-6 was used under He of 1 atmosphere, with 200 μm-thick Be and 50 μm-thick Kapton being used as a filter [8]. The difference of BL-14 and BL-6 is shown in the table 1 and spectra of "AURORA", BL-14 and BL-6 is shown Figure 1.

3 PRELIMINARY EXPERIMENTS

The first experiment was carried out in order to fabricate PTFE microstructures with line and space (L&S) (L: 100 μm, S: 200 μm) patterns using the metal mask at the BL-14. PTFE patterns of less than 10 μm and maximum aspect ratio of 75 were successfully fabricated using this beamline [6]. The average roughness of the utilized commercial polished sheets of PTFE was 248 nm. The PTFE microstructure that was fabricated with the BL-14 is shown in Figure 2. The depth of this microstructure was 120 μm, the etching rate was 100 μm/min and the side-wall taper-ratio was 0.006. Moreover the irradiated surfaces achieved a very flat roughness of 110 nm. This is less than the roughness of PTFE without irradiation.

For the fabricated PTFE microstructures at BL-6, the etching rate was 0.8 μm/min and the side-wall taper-ratio was 0.04. The average roughness of the irradiated surfaces was 3480 nm. These results indicate that the etching rate severely influences the surface morphologies or roughness of PTFE irradiated by SR light. The saturated fluorocarbons evolved by SR may be repolymerized at the PTFE surfaces in the case of a low etching rate. Since the desorption rate of saturated fluorocarbons increased at a higher PTFE temperature during etching, the etching rate of PTFE was increased. So it is possible to make smooth surfaces of PTFE by using a higher etching rate while heating the PTFE during irradiation. Figure 3 shows the PTFE microstructure that was fabricated at 200 ℃ by using a heater attached to the rear of the PTFE. The depth of this microstructure was 180 μm, the etching rate was 6 μm/min and the side-wall taper-ratio was 0.016. Re-polymerization at the PTFE surfaces could be controlled and a smooth surface with a roughness of 450 nm was obtained.

In order to carry out 3D micromachining of PTFE by SR beam direct writing, an atmospheric pressure for processing can be adopted from a practical point of view despite the low etching rate. Under atmospheric pressure, there is no limitation of materials in the stage

Table 1 Fabrication results of various conditions by SR etching.

Beamline	BL-14	BL-6	BL-6
Wave length (nm)	0.15～2.7	0.15～0.73	0.15～0.73
Enviroment	Vacuum (10^{-5} Torr)	He 1 atm	He 1 atm
Sample temperature (℃)	200	25	200
Etching rate (μm/min)	100	0.8	6
Roughness (nm)	110	3480	450
Taper-ratio	0.6 / 100	4 / 100	1.6 / 100

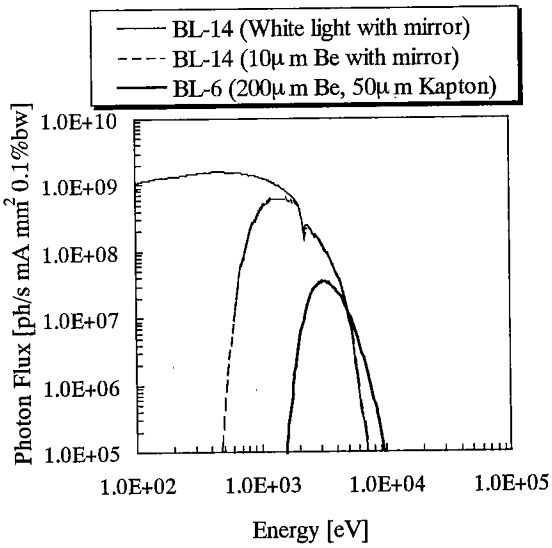

Fig. 1 Spectra of the BL-6 and the BL-14 for SR-stimulated process including TIEGA.

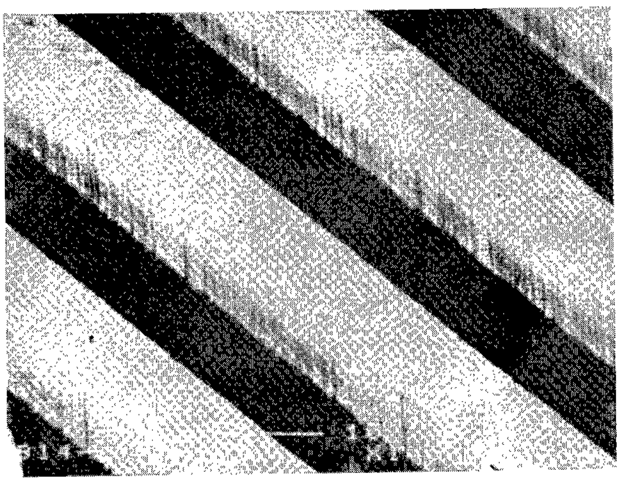

Fig. 2 SEM image of PTFE microstructure fabricated by SR etching with the BL-14.

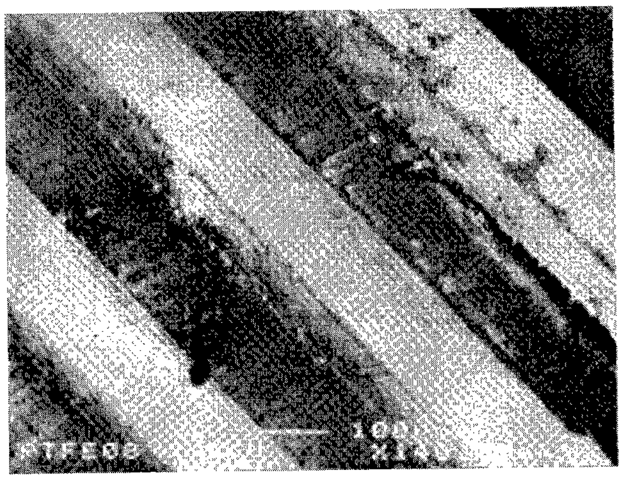

Fig. 3 SEM image of PTFE microstructure fabricated by SR etching with the BL-6.

and the mechanical systems. It is also easy to handle masks and the material for fabrication. The fabrication conditions and these experimental results are shown table 1.

4 3D MICROMACHINING

3D micromachining with the BL-14 was performed without using any masks as a result of the preliminary experiments. Figure 4 shows a schematic diagram of the experimental setup for direct writing using SR etching. This experiment was performed by direct writing using the SR beam through the pinhole with a diameter of 80 μm and heating PTFE at 200 ℃. The pinhole is attached to the end of the nozzle. Figure 5 shows a result of SR beam direct writing. PTFE was oriented perpendicular to the SR beam and irradiated controlling the X-Y stage. This result was evidence of direct writing ability for 3D micromachining. The SR beam direct writing apparatus is shown in figure 6. The stage, holding the mechanically fixed PTFE, was installed on a slant against the SR beam. It was possible to control the rotation and irradiation of the PTFE. Figure 7, 8 shows a fabricated cone shape PTFE microstructure with a turning radius of 300 μm and an achieved depth of 1 mm. These results show that any microstructures can be fabricated by SR beam direct etching combining a scanning stage with a high degree of freedom and controlling the irradiation dose.

However, deformation of a large area of the PTFE sheet occurred because a greater area than required was heated. This deformation had an influence on precision and the heater's size and wiring had an influence on the degree of freedom of the scanning stage. Local heating using a microheater-tip with a collimator for the SR beam attached to the end of the nozzle will be an alternative method for heating during processing without deformation. We will test the microheater-tip to reduce the tolerance of the processing, and experiment with the BL-6 in the future.

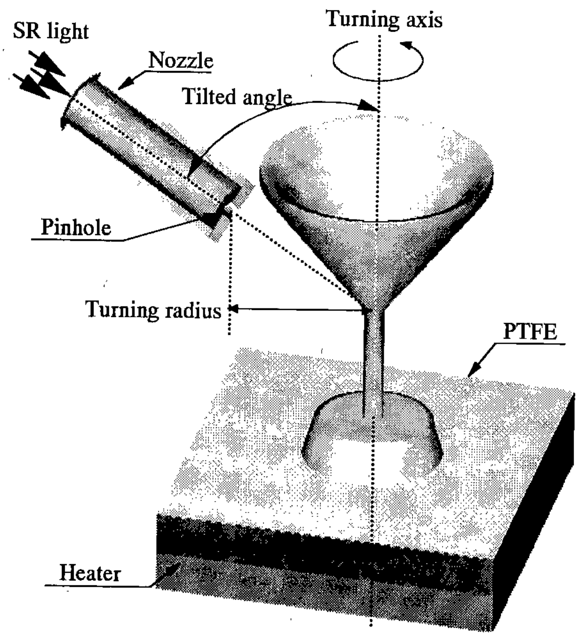

Fig. 4 Schematic diagram of experimental set up for SR beam direct writing.

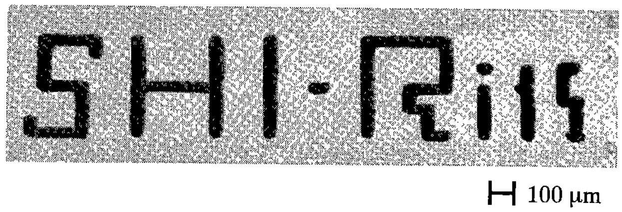

Fig. 5 SEM image of fabrication examples by SR direct writing.

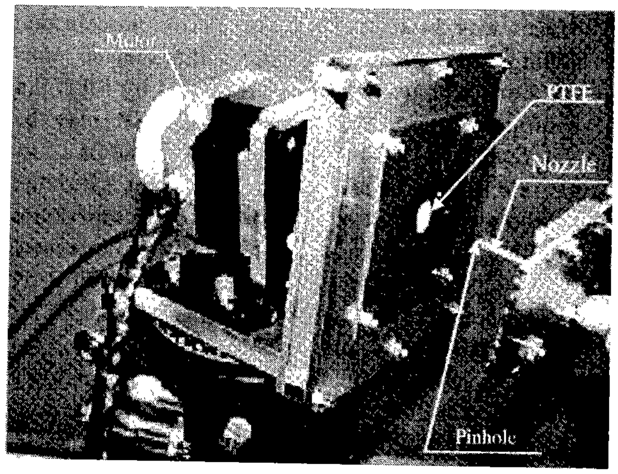

Fig. 6 The apparatus for SR beam direct writing.

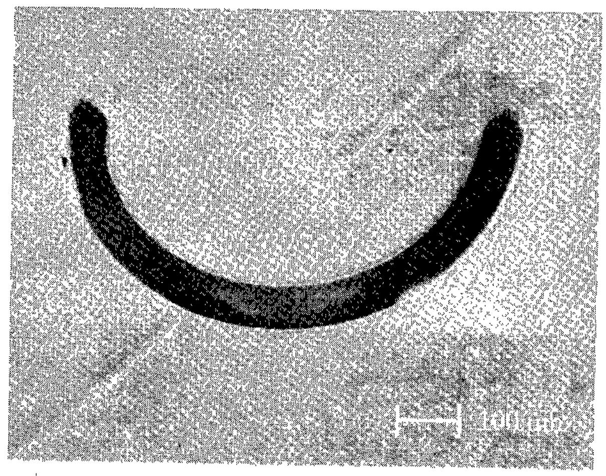

Fig. 7 SEM image of a corn shape PTFE microstructure by SR beam direct writing; surface.

5 CONCLUSIONS

In this paper, rapid 3D micromachining technology by SR beam direct writing based on SR etching without any masks was proposed. As for the experiments in a vacuum, the etching rate was on the order of 100 μm/min and the irradiated surface roughness was 110 nm. Moreover, corn shape PTFE microstructure with a turning radius of 300 μm and an achieved depth of 1 mm were fabricated. In experiments under an He atmosphere, the etching rate we achieved was 6 μm/min and the irradiated surface roughness was 450 nm. These results indicate that SR beam direct writing still has advantages for 3D micromachining under an He atmosphere. In future work, we will test various process conditions and fabricate 3D structures with well-defined curved and inclined surfaces by combining a scanning stage with a high degree of freedom.

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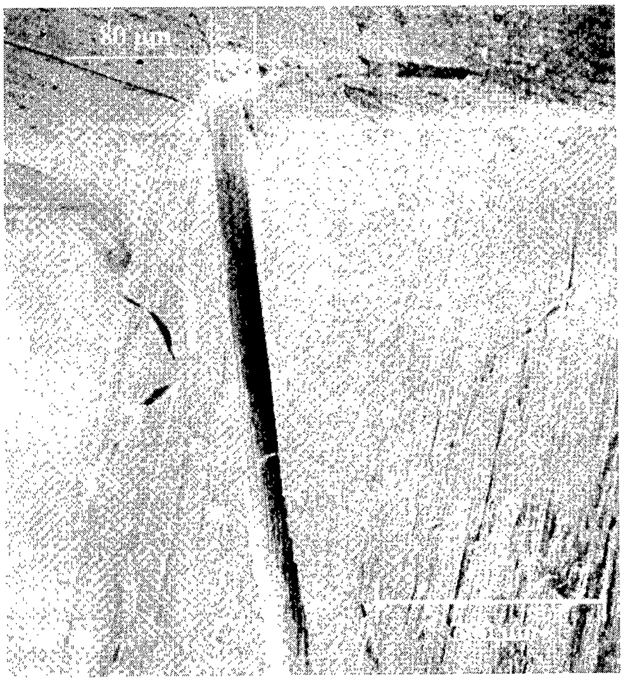

Fig. 8 SEM image of a corn shape PTFE microstructure by SR beam direct writing; cross section.

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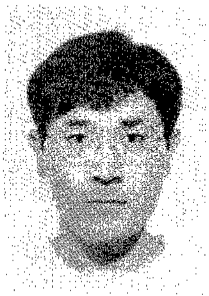

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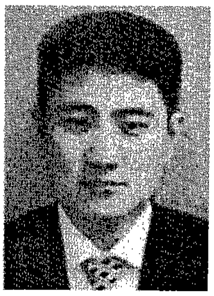

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