Study on Fabrication of 3-D PTFE Structure Utilizing Change of Etching Rate with Respect to Exposure Time

M. Horade[1, 2] and S. Sugiyama[3]

Abstract

This article describes the fabrication of three-dimensional Polytetrafluoroethylene (PTFE) microstructures utilizing direct etching with a synchrotron radiation (SR) light source. As PTFE is a remarkable material, there is a lot of expectation regarding its applications in various devices. We did research on establishing a highly accurate three-dimensional technology for microfabricating PTFE by using an SR-light source because we aimed at applying this material in future devices. However, there are also many factors which are not solved about the processing characteristic still now. In this time, it turns out that an etching rate with respect to exposure time, and the etching rate is accelerated as exposure time became long. Therefore in this time, the relation between a beam current and the processing depth is investigated under various exposure times. Moreover, different shape structures are fabricated utilizing etching rate with respect to exposure time.

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[1] *Graduate School of Science and Engineering, Ritsumeikan University, 1-1-1 Noji-Higashi, Kusatsu, Shiga 525-8577, Japan*

[2] *JSPS Fellow (Japan Society for the Promotion of Science, Research Fellowship for Young Scientists)*

[3] *Ritsumeikan-Global Innovation Research Organization, Ritsumeikan University 1-1-1 Noji-higashi, Kusatsu, Shiga, 525-8577, Japan*

1. Introduction

Polytetrafluoroethylene (PTFE) is a material of the fluoroplastics group and is remarkable for its excellent material characteristics, e.g. insulation against high voltages, resistance to chemicals and creep, and high thermal stability. Apart from its main use in nonstick frying pans and filters, PTFE is also used in a broad range of fields, such as those involving household articles,OA equipment, semiconductors and cars. Despite its long history of over 60 years, new uses for PTFE are still being developed every year with these outstanding characteristics. However, PTFE microfabrication involves the use of very difficult technology. This is because it is impossible to fabricate this material by wet etching with chemicals (acids and alkali) used in numerous microfabrication techniques such as lithography, due to its excellent resistance against chemicals. Also, if excessively high temperatures are used to fabricate PTFE, the viscosity becomes too high, and it is therefore difficult to adapt molding processes to it.

In 1996, a technique of direct etching PTFE by using an synchrotron radiation (SR) light source was reported [1]. This was entirely done with dry etching that did not use any wet etching, unlike that in X-ray lithography. It is possible to fabricate high aspect ratio microstructures that have vertical sidewalls by using this technology. However, to apply microfabrication of PTFE to microelectromechanical systems (MEMS), we need to be able to fabricate three-dimensional microstructures with complex forms such as sloped sidewalls or free-form surfaces. Some research on methods of three-dimensional microfabrication using SR has so far been done [2] [3]. However, these were used only with lithography technology, which used Polymethylmethacrylate (PMMA); they were not directly used to etch PTFE. Therefore, we tried to fabricate three-dimensional PTFE microstructures by applying the plane-pattern to cross-section transfer (PCT) technique. PCT is one method that can control the shapes of structures by using the energy distributed to the resist surface.

Fabrication of the three-dimensional PTFE microstructures by using the PCT technique has been reported [4] [5]. Moreover, fabrication of the three-dimensional PTFE microstructures using other techniques has also been reported [6] [7]. However, there are also many factors which are not solved about the processing characteristic still now. In order to establish high accuracy three-dimensional microfabricating for PTFE, investigating about a factor is important. It investigates about the factor which affects especially three-dimensional microfabrication greatly. In this time, we investigate about an etching rate with respect to exposure time. Many of three-dimensional microfabrication methods utilizing SR use the exposure energy distribution. And, energy distribution is given by reiteration of exposure and un-exposure in many cases. Therefore, a possibility that a shape error will arise according to this factor can be considered.

2. Fundamental Data about PTFE

2.1 Experimental Conditions

A number of experiments have been carried out using beam line number 14 (BL-14) at the superconductivity compact SR source 'AURORA', at the SR Center of Ritsumeikan University, Japan. A vacuum atmosphere at 10^{-5} torr can be provided and a substrate heater is installed in the BL-14 chamber. It has been noted that the etching rate generally increases when PTFE is etched in a vacuum chamber and heated during SR ablation during the PTFE fabrication process [8]. There is also a lot of flexibility in the stage system for three-dimensional fabrication in the BL-14 chamber, and fine drive control is also possible by using a PC. The BL-14 is outlined in Fig. 1.

The properties of the SR-light source AURORA used in the experiment were a wavelength of 0.15 nm to the visible light range, an applied electron energy of 575 MeV and a maximum storage current of 300 mA. The SR-light source from AURORA penetrated two 200 μm Be windows, and focused light on the 0.15 to 0.95 nm wavelength domain within the chamber.The X-ray mask consisted of a polyimide membrane with a thickness of 50 μm and an Au absorber with a thickness of 3 μm. We used a 1-mm thick product from Yodogawa Hu-tech Co., Ltd. for PTFE. The processing mechanism is outlined in Fig. 2. If PTFE is exposed to an SR-light source, it will cause a photochemical reaction and the main chain of the material will decompose. This will also change to a fluorocarbon gas and the exposed parts will be etched. The secession rate of fluorocarbon gas will increase if the PTFE temperature is excessively high during this time. To prevent the mask and Be window from becoming contaminated by fluorocarbon gas, a 25 μm thick polyimide film was placed on each.

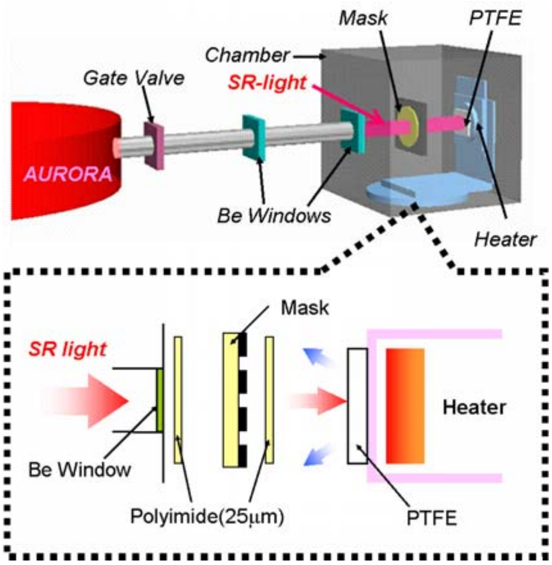


Fig.1. Schematics for the experimental system

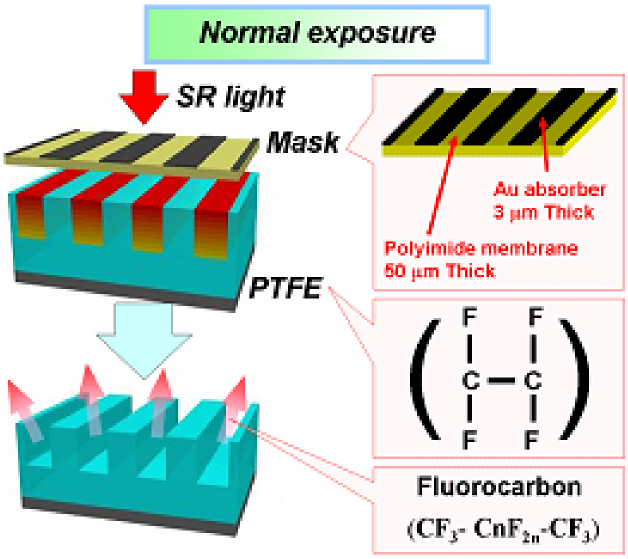


Fig. 2. PTFE etching mechanism

2.2 Processing Depth

The basic data of PTFE was investigated. PTFE was exposed by SR light using the mask. And, relation between the beam current and the processing depth are investigated. PTFE temperature with 200°C when changing exposure time, 30min, 15min, 10min, 5min, respectively. Each starting current, finishing current, and the processing depth are shown in Tables 1, 2, 3, and 4. And, the relation of each starting current and processing depth is shown in Figs. 3, 4, 5, and 6.

Table 1. Beam current and processing depth

Starting current (mA)	Finishing current (mA)	Depth (μm)
250.0	232.2	66.64
230.0	214.5	55.47
210.0	194.2	40.25
190.0	179.7	36.64
170.0	160.6	29.18

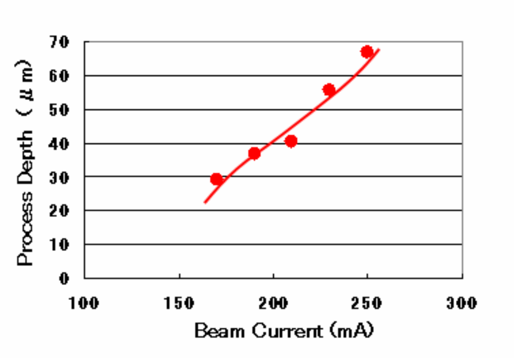


Fig. 3 Current vs. Depth (30min)

Table 2. Beam current and processing depth

Starting current (mA)	Finishing Current (mA)	Depth (μm)
270.3	257.2	27.20
250.0	240.2	23.64
200.0	192.9	24.96
170.0	164.7	21.19

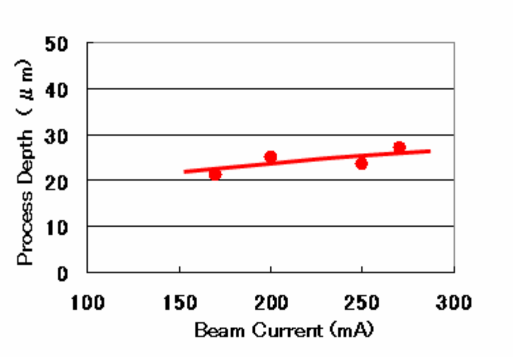


Fig. 4 Current vs. Depth (15min)

Table 3. Beam current and processing depth

Starting current (mA)	Finishing current (mA)	Depth (μm)
288.0	272.4	13.92
257.6	250.4	14.59
245.0	239.0	12.15
175.3	170.1	12.71
169.0	166.9	9.32
140.0	137.2	10.33

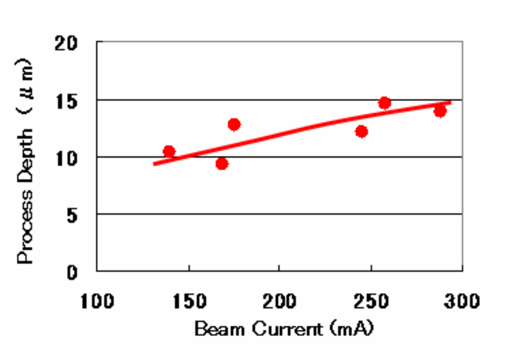


Fig. 5 Current vs. Depth (10min)

Table 4. Beam current and processing depth

Starting current (mA)	Finishing current (mA)	Depth (μm)
283.1	272.2	4.81
228.7	225.7	4.27
190.5	188.2	4.40
162.8	160.9	3.88
148.8	147.2	3.15
124.7	123.2	2.78

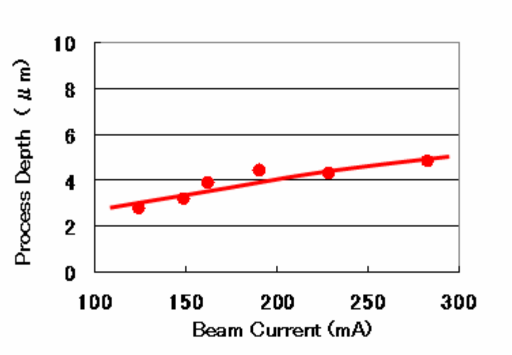


Fig. 6 Current vs. Depth (5min)

2.3 Etching Rate

Based on the relationship beam current and processing depth of Section 2.2, relationship beam current and etching rate is calculated in this section. Unlike general laser processing, the beam current gradually decreases over time in the case of SR light. In this time, it is taking into consideration about decreasing of a beam current [9]. However acceleration is not taken into consideration, the average etching rate is calculated. Fig.7 shows relationship beam current and etching rate (30min, 15min, 10min and 5min). It turns out that an etching rate with respect to exposure time, and the etching rate is accelerated as exposure time became long. Although various factors can be considered, it is thought that the rise in heat of PTFE by exposure heat is influenced as major factor. That is, PTFE surface temperature of exposure area is increasing by exposure of SR light, defection of fluorocarbon gas is increased [10].

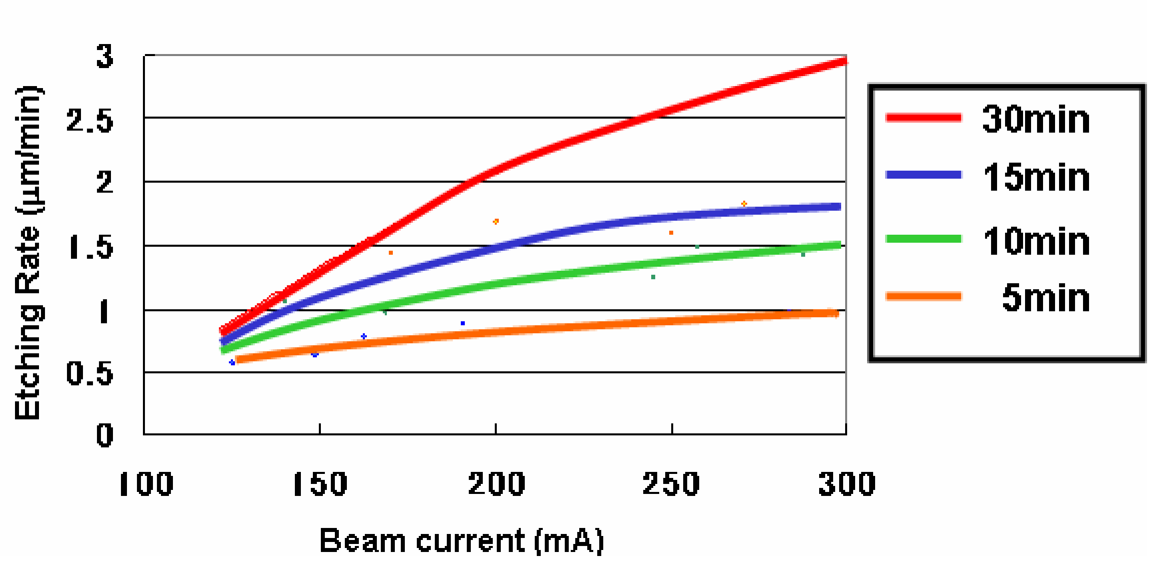


Fig. 7 Beam current vs. Etching rate (30min, 15min, 10min, 5min)

3. 3-D Fabrication Results

The PCT technique has been used as a method of controlling the exposure by adapting an exposure-energy distribution [2]. Since PCT has successfully provided an arbitrary PMMA three-dimensional structure, we have recently begun to adapt PCT to expose PTFE while the stage is in progress. Fig.8 outlines the PCT technique that involves a group of triangular masks. The resist is scanned during the process of PCT when PTFE is being exposed. During exposure, the two-dimensional configuration of the mask pattern is transferred to a three-dimensional structure whose cross-sectional shape is similar to that of the mask pattern. When scanning speed is high, exposure and un-exposure are repeated in a quick cycle and bottom of structure is etches in several steps as shown in Fig.8. Therefore, since the exposure time per 1 cycle is short, exposure is completed before etching rate is accelerated. On the other hand, when scanning speed is low, exposure and un-exposure are repeated in a slow cycle and the exposure time per 1 cycle is long.

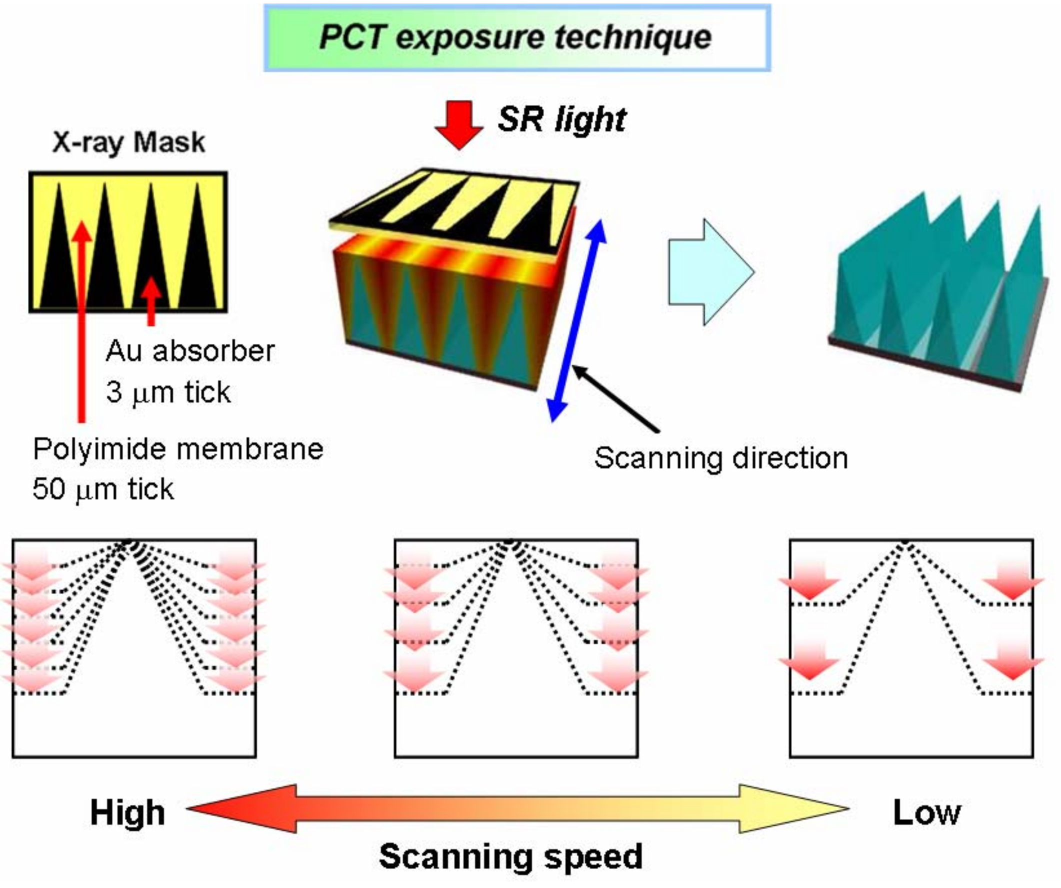


Fig. 8 PCT technique Black color is X-ray absorber, corn color is membrane. When PTFE exposed, PTFE is also scanning. As shown in figure, three-dimensional structure is fabricated. And, if scanning speed is changed, the cycle of exposure and un-exposure can be changed.

Three-dimensional structures utilizing triangle mask pattern is shown in Fig. 9. Target structure height is set to 80μm, and scanning speed made it change with 2.0mm/sec, 1.0mm/sec, and 0.005mm/sec. When scanning speed is high (2.0mm/sec), the rounded shape is fabricated. On the other hand, when scanning speed is low (0.005mm/sec), the same shape as triangle absorber was fabricated.

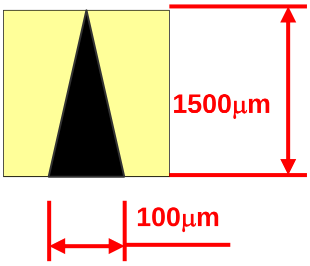
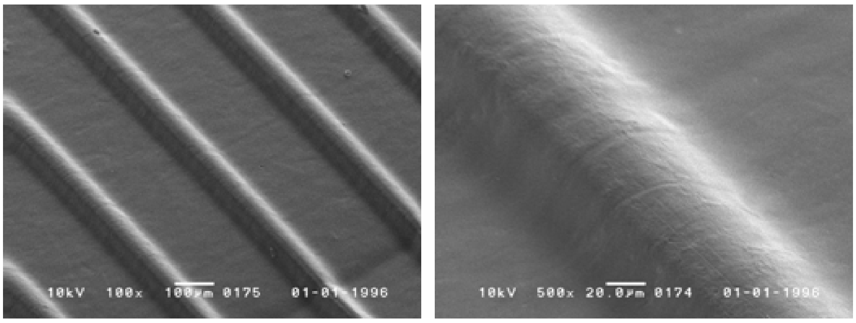
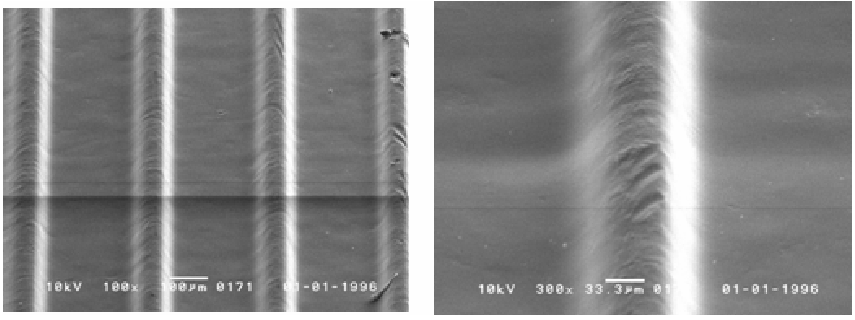
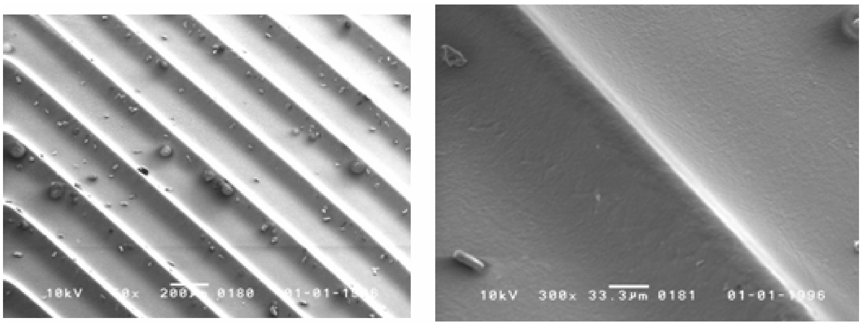
pattern	SEM Photos
 Triangle mask patter	Scanning speed 2.0mm/sec、PTFE surface temperature 200°C 
	Scanning speed 2.0mm/sec、PTFE surface temperature 200°C 
	Scanning speed 2.0mm/sec、PTFE surface temperature 200°C 

Fig. 9 Three-dimensional structures utilizing triangle mask pattern

4. Conclusion

In order to establish high accuracy three-dimensional microfabricating for PTFE, it investigates about the factor which affects especially three-dimensional microfabrication greatly. In this time, we investigate about an etching rate with respect to exposure time. Many of three-dimensional microfabrication methods utilizing SR use the exposure energy distribution. And, energy distribution is given by reiteration of exposure and un-exposure in many cases. Therefore, a possibility that a shape error will arise according to this factor can be considered. Based on the relationship beam current and processing depth of Section 2.2, relationship beam current and etching rate is calculated. And it turns out that an etching rate with respect to exposure time, and the etching rate is accelerated as exposure time became long. Although various factors can be considered, it is thought that the rise in heat of PTFE by exposure heat is influenced as major factor. That is, PTFE surface temperature of exposure area is increasing by exposure of SR light, defection of fluorocarbon gas is increased. Moreover, different shape structures are fabricated utilizing etching rate with respect to exposure time. When scanning speed is high, the rounded shape is fabricated. On the other hand, when scanning speed is low, the same shape as triangle absorber was fabricated. It will investigate about a detailed factor and acceleration from now on.

Acknowledgements

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