# Study on Height Control of 3-D Structures Fabricated Utilizing PCT Technique

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## Abstract

We report research on control of height of three-dimensional microstructures that uses Synchrotron Radiation (SR) lithography. When three-dimensional structures are fabricated by using PCT technique, in order to achieve fabrication of target structure, design of mask-pattern is important. Therefore, we set up target forms, the mask-patterns are fabricated utilizing the method of mask pattern design, and target forms are fabricated. In this time, the shapes of an isosceles triangle with 4μm width and 12.5 μm pitch were fabricated into target form. However, the tendency for the height of a structure to become low was seen. In SR lithography, processing depth is decided by exposure process and development process. The target depth can be fabricated by controlling these two processes, respectively. In this research, paying attention to these two processes, control of height of three-dimensional microstructures is tried. And structure height was able to be made high by changing developing time.

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## 1. Introduction

A variety of three-dimensional fabrication methods such as KOH anisotropic etching of silicon and laser machining [1] have been employed for fabrication of Micro Electro Mechanical Systems (MEMS). Especially, three-dimensional fabrication that uses X-ray lithography in LIGA (Lithographie, Galvanoformung, Abformung) [2] [3] [4] [5] [6] [7] [8]. LIGA draw attention from widely research area as technique that can fabricate structure that has controllable three-dimensions with respective height. Various methods have been developed for as an additional technique to enhance the three-dimensional processing. Each of these techniques has involved exposing an energy distribution onto the resist surface.

In this time, fabrication of a structure as shown in Fig.1 is aimed at. In order to fabricate this structure, we use Synchrotron Radiation (SR) lithography utilizing Plane-pattern to Cross section Transfer (PCT) technique [2]. This technique has been reported as a fabrication method for a microneedle structure with a sharp-tip and a microlens with a predictable curved surface. Fig.2 shows the PCT technique. The energy distribution is deposited in resist by scanning as shown in the same figure. 3-D structures were fabricated by developing afterwards. When PCT technique is used, the similar shape as the mask absorber pattern in the mechanism is expected to be fabricated. In addition, a more complex energy distribution can be given by exposing it by rotating the mask by 90 degrees. The needle shape can be fabricated as an example of using PCT technique.

At first, microneedle array is fabricated utilizing PCT technique, and the end of microneedle is removed. The purpose of this structure is an optical device using a side wall inclination, and the most important point is that the side wall inclines. Therefore, although this structure differs from target form a little bit, it's not a problem.

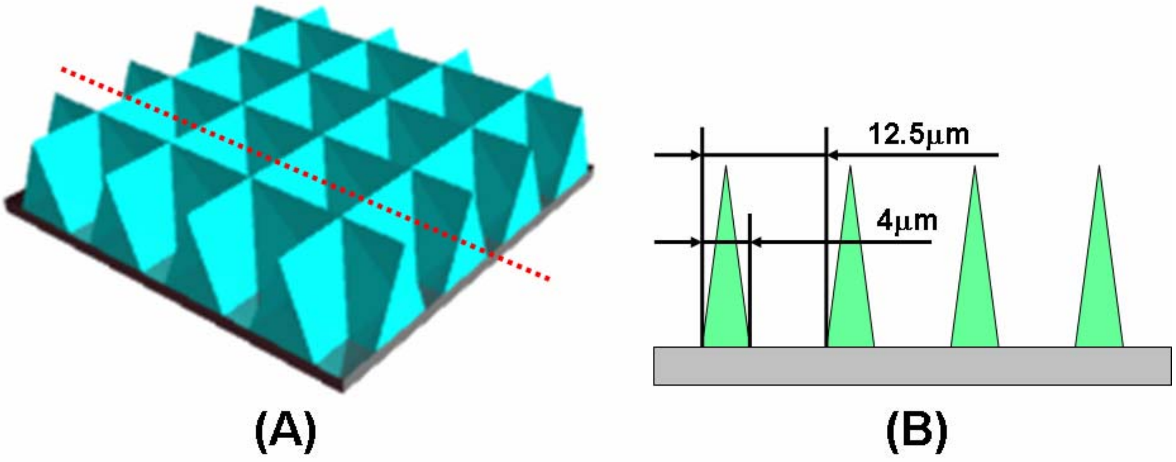


Fig.1 Target structure (A) A bird's-eye view (B) Cross-section view, the shapes of an isosceles triangle with 4μm width and 12.5μm pitch

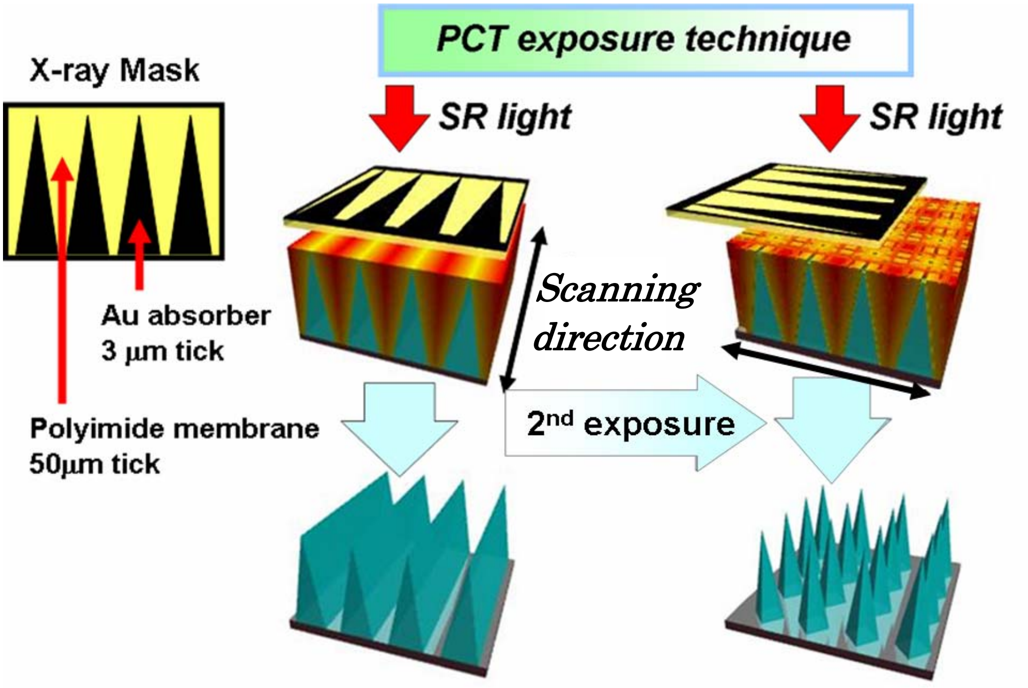


Fig.2 PCT technique, black color shows X-ray absorber and corn color shows membrane, energy amount is shown by shading

## 2. Fabrication and Experimental Conditions

### 2.1 Experiment Condition

A number of experiments were carried out using beam line number 13 (BL-13) at the superconductivity compact SR source "AURORA", located at the SR center of Ritsumeikan University, Japan. The SR conditions at AURORA for the experiment were a minimum wavelength of 0.15 nm, an applied orbital radius of 0.5m, electron energy of 575 MeV, and a maximum storage current of 300 mA.

A wavelength between 0.2 and 0.5nm is optimal for X-ray lithography also in this wavelength domain. The reasons for this are to suppress the spread of secondary electrons due to Fresnel diffraction in the long-wavelength domain and suppress secondary electrons generated within the resist in the short-wavelength domain, as well as narrow the fabrication line width and improve resolution. The light from AURORA penetrates through two 200-μm Be windows, and uses light within the chamber that has a 0.15 to 0.95-nm wavelength. The exposure environment in the chamber was covered by helium gas at 1 atm to prevent the attenuation of X-rays by $N_2$ or $O_2$ gases and to prevent damage to the mask or resist by generated heat.

A PMMA sheet provided by Nitto Jushi Kogyo Co., Ltd. was used as the resist. Since PMMA has high resolution, the reproducibility of fine structures for molding could be enhanced in a further fabrication process [9]. The exposed PMMA structures gradually appeared during development with a GG developer (60 vol% 2-(2-butoxy-ethoxy) ethanol, 20% tetra-hydro-1, 4-oxazine, 5 vol% 2-amino-ethanol-1 and 15 vol% water). After that, stopper liquid (80 vol% 2-(2-butoxy-ethoxy) ethanol, and 20 vol% water) was used for 10 min followed by rinsing the sheet in water for another 10 min. All these processes were done at the exact temperature of 37°C.

### 2.2 Mask-pattern Design

Fig.3 shows mask-pattern, energy distribution from top view using the mask-pattern and structure after development. Relationship dosage and processed depth is not linear, therefore when deciding the processing depth, this relation has to been considering. In this time the structure shown by A of Fig. 3 should become target form, mask-pattern is designed utilizing relationship dosage and processed depth [10]. However, the tendency for the height of a structure to become low was seen. As this reason, since circulation of the developing solution became good near the end of structure, it is thought that the structure height became low.

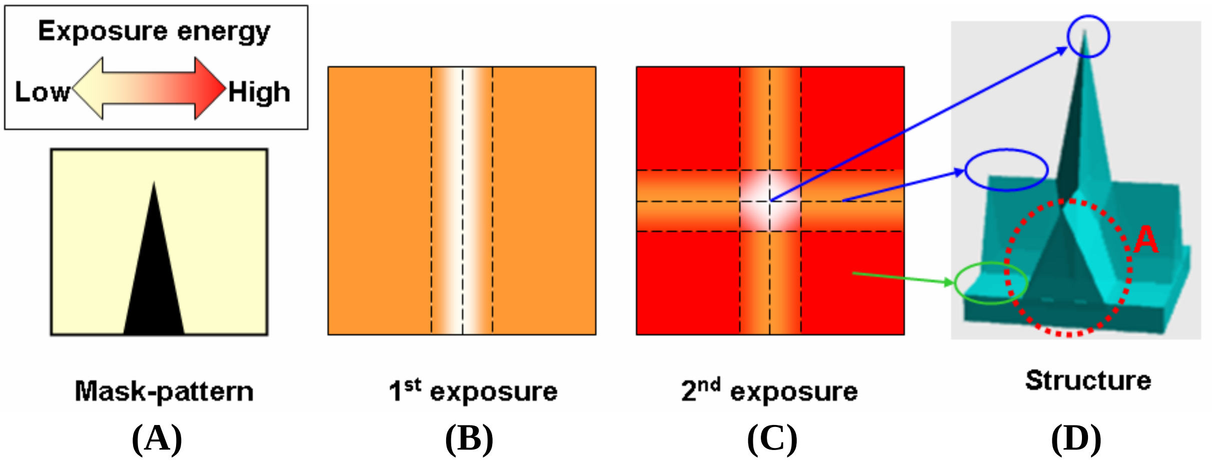


Fig.3 Exposure energy distribution (A) Mask pattern, black color shows X-ray absorber, corn color shows membrane (B) Exposure energy distribution is shown from top view after 1st exposure (C) Exposure energy distribution is shown from top view after 2nd exposure, energy amount is shown by shading (D) A (red dashed line) is target form, and the part corresponding to energy is shown.

## 3. Experiment Results

### 3.1 Prediction of Structure Height

Some improvement methods are considered. The best way is fabricated a mask again. However, since cost and time are required, the target depth is controlled by changing of the exposure condition and development condition utilizing same mask. In this time, structure height was able to be made high by changing developing time. Energy distribution and the part corresponding to energy are shown in Fig. 4. As shown in figure, structure height is decided by between part of “A” and “B”. Moreover in the nature of PCT technique, the exposure energy amount for fabricating the processing depth “a” becomes twice an exposure energy amount for fabricating the processing depth “b”. Since the relation of the exposure energy and the processing depth are nonlinear under a certain developing time, the height of a structure changes by the difference of developing time.

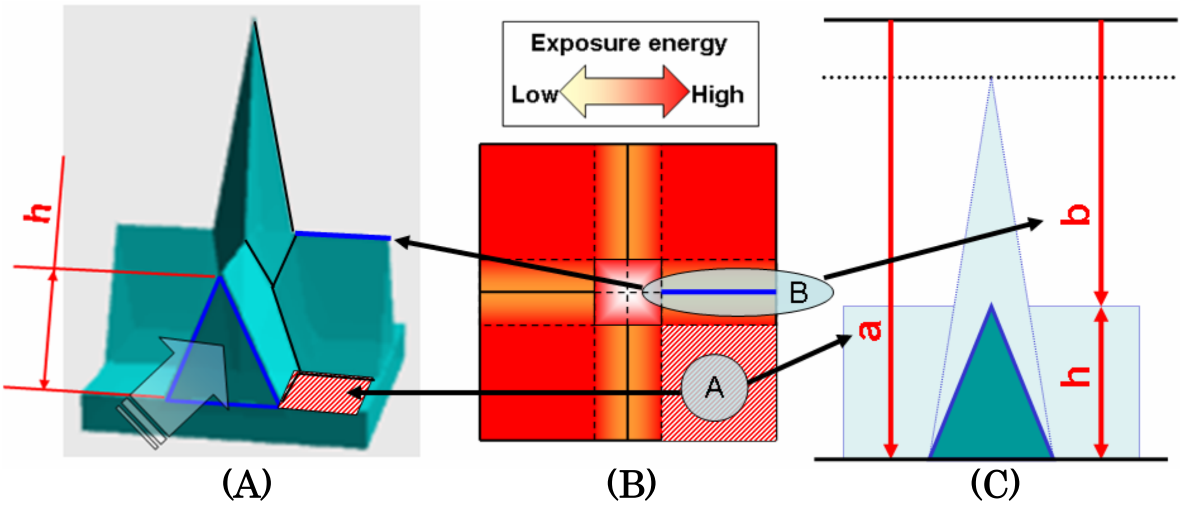
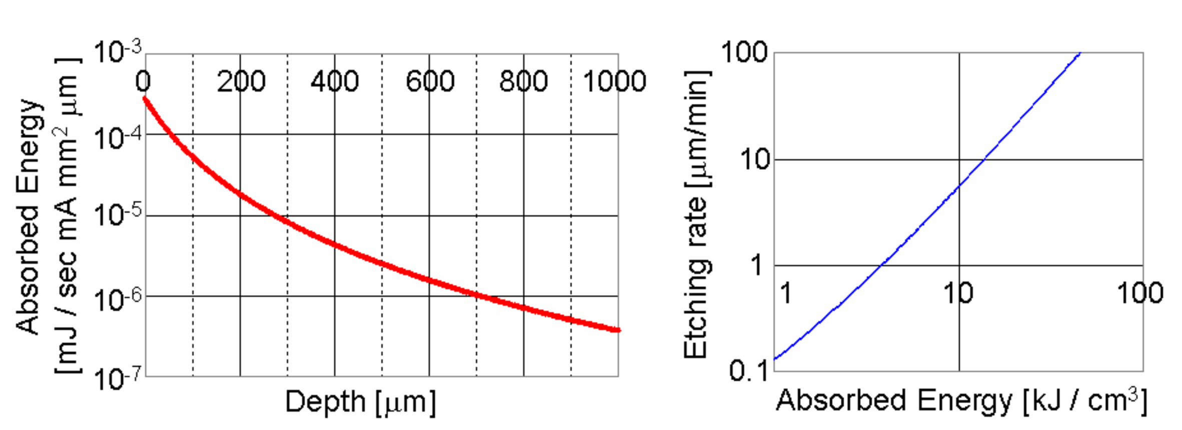


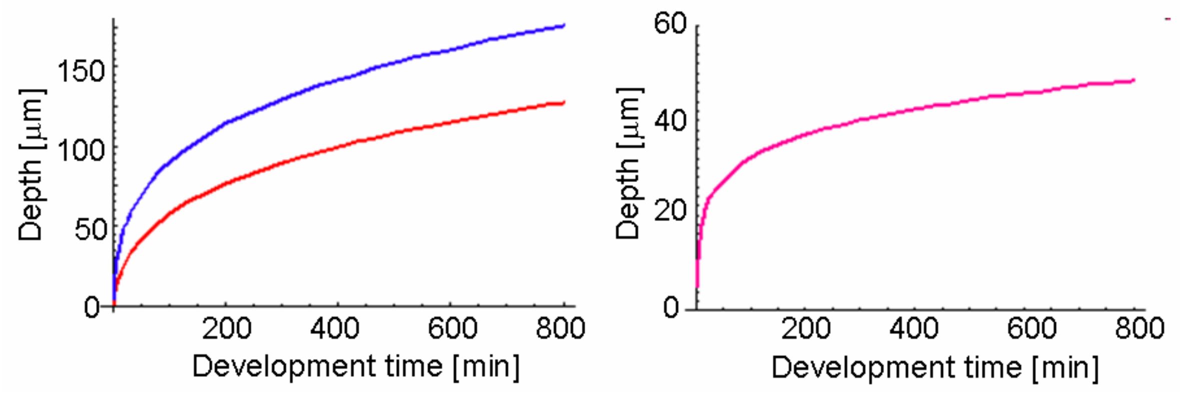
Fig.4 Energy distribution and the part corresponding to energy is shown (A) Target form, “ h” is structure height (B) Exposure energy distribution (C) Cross-section of target form, “a” is depth from surface to bottom(part of “A” ), “b” is depth from surface to structure height (part of “B” )

Fig.5 (A) shows relationship between depth and absorbed energy, and Fig.5 (B) shows relationship between absorbed energy and etching rate. The relation between the development time and the processing depth is computable under an arbitrary developing time utilizing these two relationships. Fig.6 shows relationship between the development time and the processing depth, blue line shows part of “A” (Dose: 0.0109188 A· h), red line is part of “B” (Dose: 0.0054594 A· h), and pink line shows structure height which means that difference between blue line and red line. The reason for having set the dosage amount to 0.0109188 A·h, it is because target structure height is set to 35μm utilizing relationship of dosage and processing depth when dosage amount is 0.0109188 A·h and development time is 180min. As shown in Fig. 6(B), if developing time is lengthened, it is possible to make a structure high. Moreover, if Fig. 5 is used, it is possible to predict structure height under any energy conditions.



(A) (B)

Fig.5 (A) Depth vs. absorbed energy (B) Absorbed energy vs. etching rate



(A) (B)

Fig.6 Development time vs. depth (A) Blue line is part of “A” (Dose: 0.0109188 A· h), red line is part of “B” (Dose: 0.0054594 A· h) (B) Line shows structure height

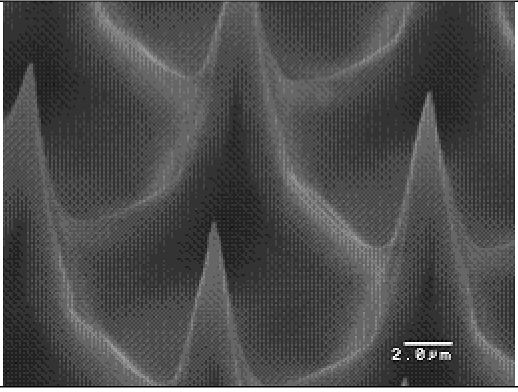
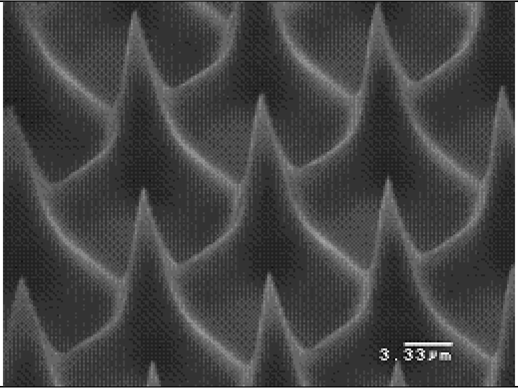
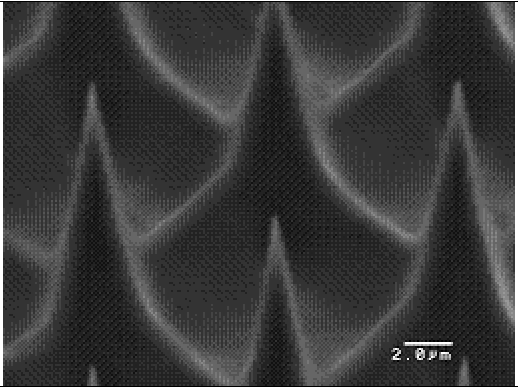
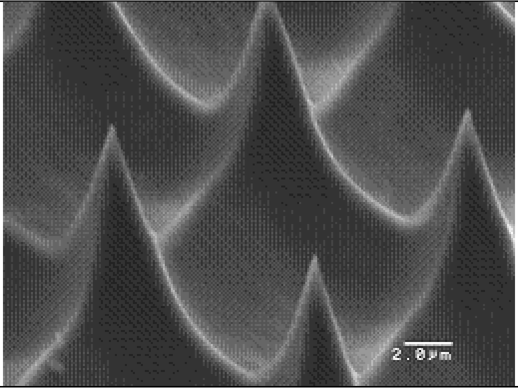
### 3.2 Fabrication Results

The structures are fabricated. Table 1 shows SEM photos of structures, actual height of structure, and prediction height of structure utilizing Fig.6 (B). Although the structure height becomes low, structure height is able to be made high by changing development time.

## 4. Conclusion

Three-dimensional structures are fabricated utilizing PCT technique. The tendency for the height of a structure to become low was seen in the previous work. Some improvement methods are considered. The best way is fabricated a mask again. However, since cost and time are required, the target depth is controlled by changing of the exposure condition and development condition utilizing same mask. In SR lithography, processing depth is decided

Table 1 Results

| **Development time** | SEM photo |
|---|---|
| **60 min** |  |
| Actual height | |
| 15.7 µm | |
| Prediction height | |
| 28.4531 µm | |
| **Development time** | SEM photo |
| **180 min** |  |
| Actual height | |
| 18.3 µm | |
| Prediction height | |
| 36.1873 µm | |
| **Development time** | SEM photo |
| **360 min** |  |
| Actual height | |
| 22.6 µm | |
| Prediction height | |
| 41.6053 µm | |
| **Development time** | SEM photo |
| **720 min** |  |
| Actual height | |
| 24.2 µm | |
| Prediction height | |
| 47.6560 µm | |

by exposure process and development process. In this time, we predict structure height utilizing theoretical value. And we set prediction results against actual structure height. Although the actual structure height becomes low, structure height is able to be made high by changing development time.

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