Study on Mask-pattern Design for Fabrication of 3-D structures Utilizing PCT Technique

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Abstract

In this study, the method of mask pattern design for fabrication of target structure is reported. When 3-D structures are fabricated by using PCT technique, in order to achieve fabrication of target structure, design of mask-pattern is important. In this time, the method of mask pattern design for fabrication of target structure is established. If using this method, the mask pattern in order to fabricate the processing depth required for fabrication of target form can be easily calculate. Target forms are actually set up and the mask-patterns are fabricated. In this time, the shapes of an isosceles triangle with 4μm width and 12.5 μm pitch were fabricated into target form. And, the fabricated form is mostly in agreement with target form is checked. 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 in near a triangular vertex, it is thought that the tip became low. Therefore, if development temperature is made low, it is thought that it is improvable.

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1. Introduction

Microfabrication of three-dimensional structures is a significant technology in producing various components for MicroElectroMechanicalSystems (MEMS). A number of process technologies, e.g. Lithographie, Galvanoformung, Abformung (LIGA) [1,2], deep reactive ion etching (DRIE) [3,4], and Excimer Laser [5], have been employed as the high-aspect-ratio microfabrication techniques. Due to the features of high sensitivity and short wavelength, deep X-ray lithography can be employed to form a high-aspect-ratio structure within the accuracy of a submicron level. Although a conventional X-ray lithography is typically used, only a vertical sidewall or an uncontrollable slope sidewall microstructure can be fabricated. A previous report on the fabrication of three-dimensional microstructures with a curved surface and a sharp-tip was given by the X-ray energy distributed to PMMA, X-ray resist using the multi-angle exposure [6], and the moving mask exposure [7]. Since a more varying shape can be produced, recently the Plane-pattern to Cross section Transfer (PCT) Technique [8] has been reported as a fabrication method for a microneedle structure with a sharp-tip and a microlens with a predictable curved surface. Fig.1 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.

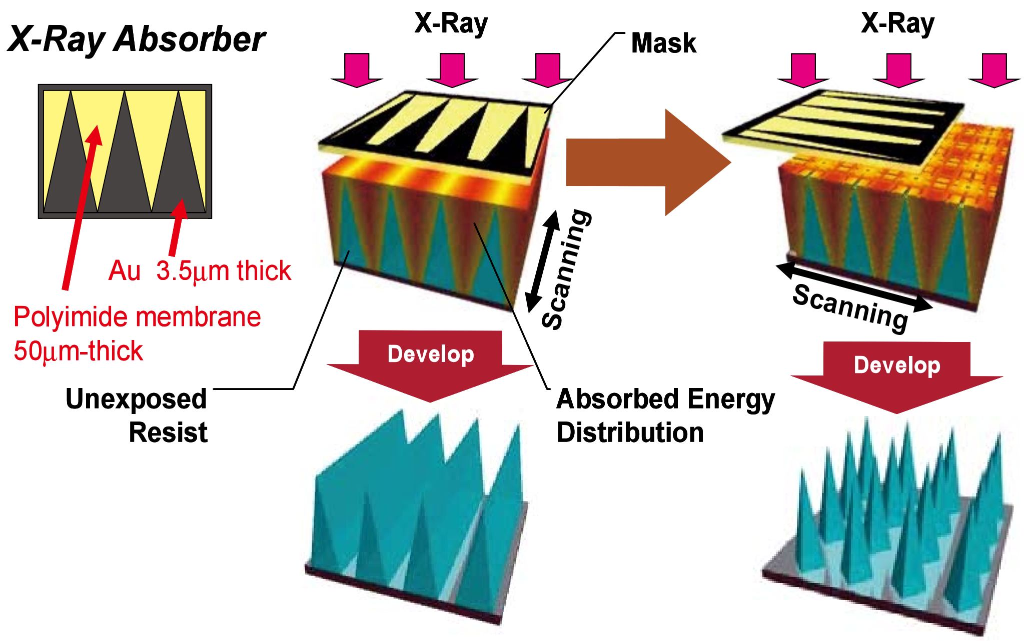


Fig.1 PCT technique

In the case of the using PCT technique, structure form is determined by the form of the absorber-pattern of a mask. Therefore, in order to achieve fabrication of target structure, design of mask-pattern is important. In this research, method of mask-pattern design for the realization of target form is reported.

2. Fabrication and Experimental Conditions

A number of experiments were carried out using beam line number 13 (BL-13) at the superconductivity compact synchrotron radiation (SR) source "AURORA", at the SR center, Ritsumeikan University, Japan. The properties of SR at AURORA are, wavelength of 0.15 nm range to visible light range, applied electron energy and the maximum storage current in the experiment were 575 MeV and 300 mA, respectively. The light from AURORA penetrates two 200µm Be windows, and uses within the chamber the light which has a 0.15 to 0.95nm wavelength domain. The exposure environment was covered with Helium gas at 1 atm in the chamber in order to prevent the attenuation of X-ray by N_2 or O_2 gases and to prevent damages of the mask or resist by heat generated. Polymethylmethacrylate (PMMA) was used as a resist.

An X-ray mask consists of a Polyimide membrane with a thickness of 50 µm and an Au absorber with a thickness of 3.5 µm. X-ray mask used the thing of Optnics Precision Co.,ltd. Exposed PMMA structures gradually appear during development using 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) is used at the 37 degree C for 180 minutes. After that, stopper liquid (80 vol% 2-(2-butoxy-ethoxy) ethanol, and 20 vol% water) is used at the same temperature for 10 minutes, followed by DI-water rinsing for another 10 minutes. Fig.2 shows relationship dosage and processed depth.

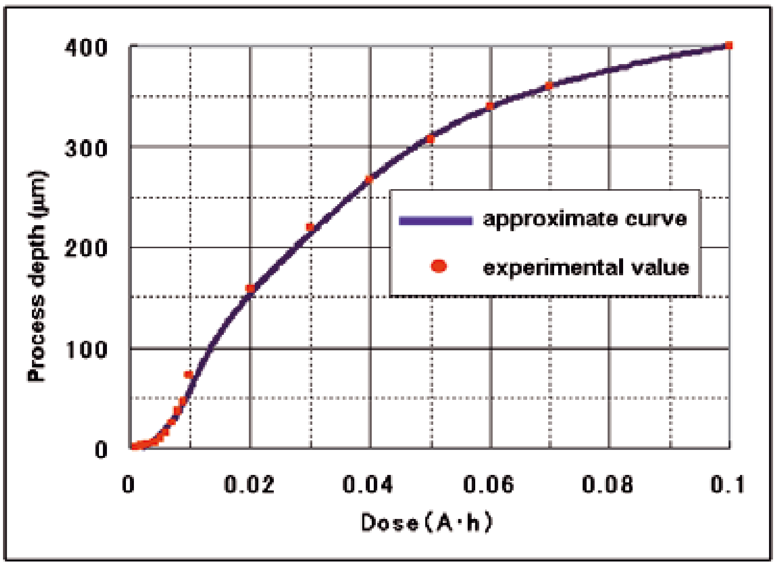


Fig.2 Relationship dosage and processed depth

3. 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.

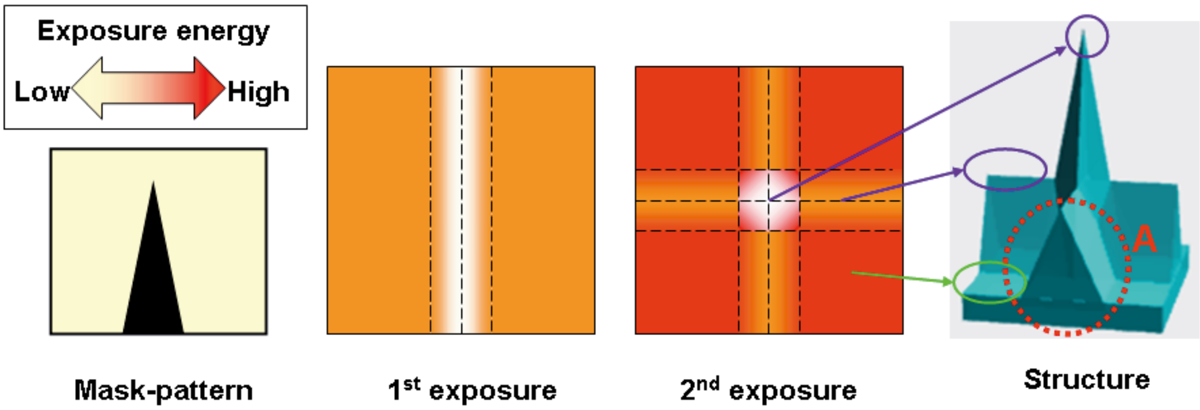


Fig.3 Exposure energy distribution

In this time, fabrication of a structure shown in A of Fig.3 is tried. The isosceles triangle of height h as shown in Fig. 4 is explained in an example. As shown in Fig.4, the required processing depth in the part of A is given by the following formula.

$$a + m \tag{3-1}$$

And, n is for revision of the processing depth and fills $n \geq 0$. As shown in a figure, the height of the structure is not changed even if the value of A is which value.

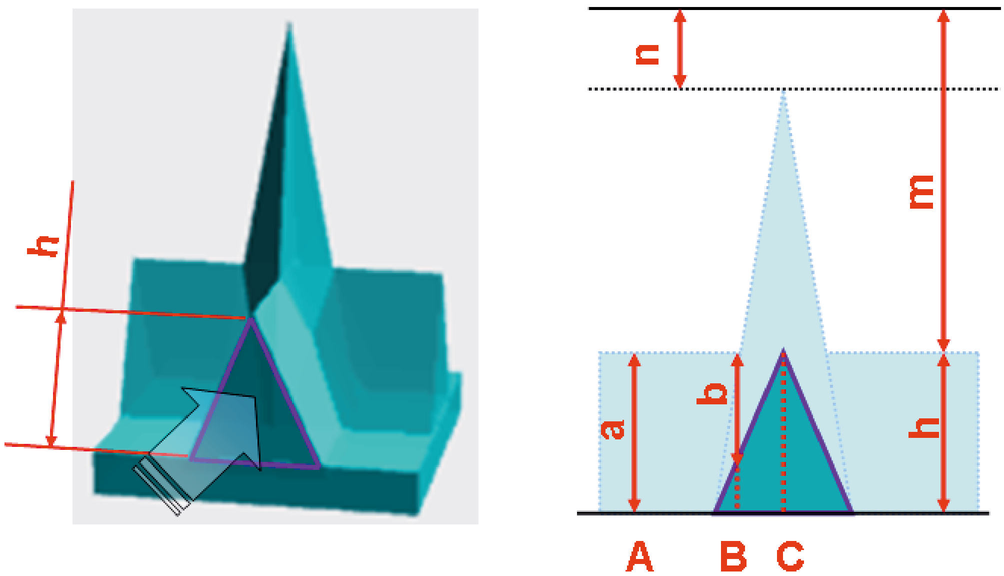


Fig.4 View showing a frame format of structure utilizing PCT technique

Similarly, the required processing depth in the part of B and C is given by the following formula.

$$b+m \tag{3-2}$$

$$m \tag{3-3}$$

And based on approximate curve in Fig.2, the relation with the dose $D(x)$ [A· h] required in order to become processing depth x [μm] is given by the following formula.

$$D(x) = -8.317\times10^{-17}\times x^6 + 1.695\times10^{-13}\times x^5 - 1.056\times10^{-10}\times x^4 + 2.892\times10^{-8}\times x^3 \\ -3.428\times10^{-6}\times x^2 + 2.568\times10^{-4}\times x + 2.080\times10^{-3} \tag{3-4}$$

Therefore, required dosage in each part (A, B, C) is given by the following formula.

$$D(a+m) \tag{3-5}$$

$$D(b+m) \tag{3-6}$$

$$D(m) \tag{3-7}$$

When 2nd exposure finished, PMMA is given these energy in each part (A, B, C) as shown in Fig.5. Therefore when 1st exposure finished, required dosage in each part (A, B, C) is given by the following formula.

$$D(a+m) - \tfrac{1}{2}D(a+m) \tag{3-8}$$

$$D(b+m) - \tfrac{1}{2}D(a+m) \tag{3-9}$$

$$D(m) - \tfrac{1}{2}D(a+m) \tag{3-10}$$

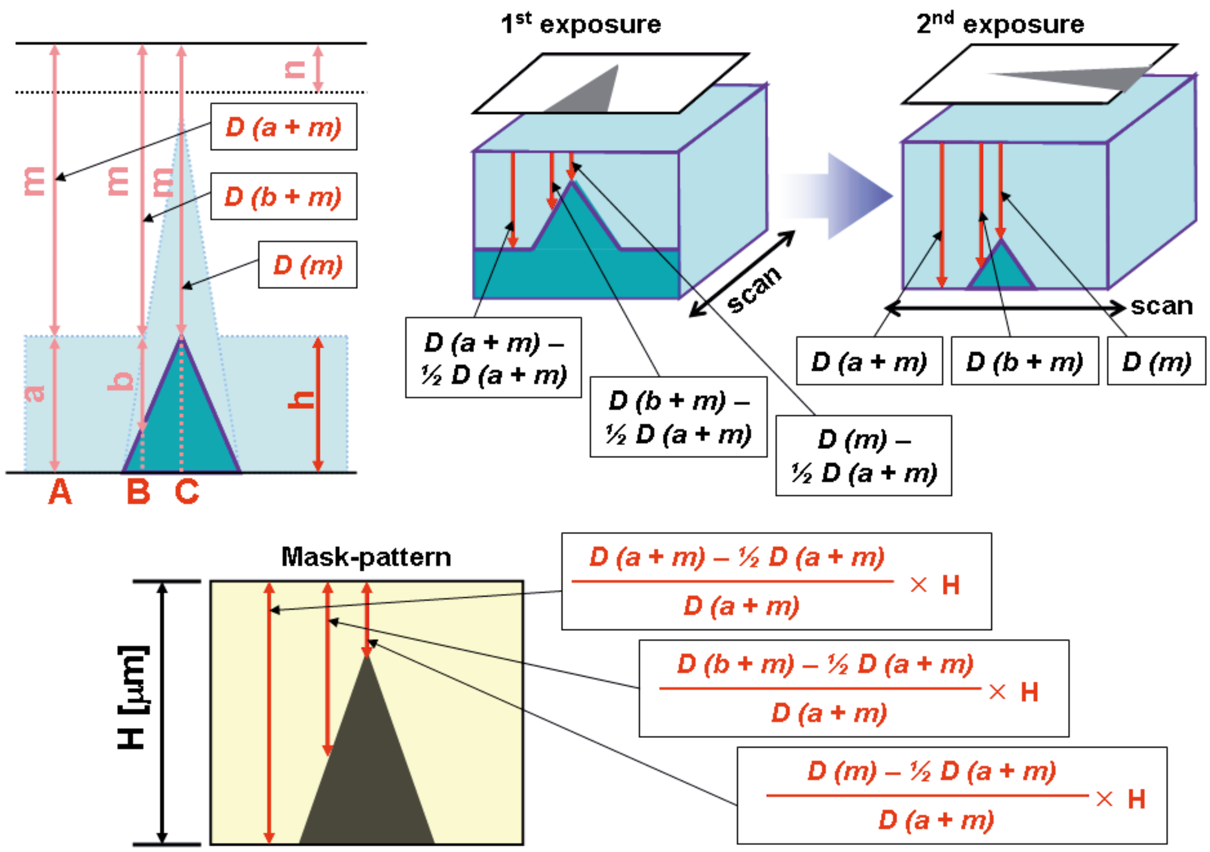


Fig.5 Mask design for PCT technique

Moreover, the value of m should just decide to fill the following formula. If this is not filled, it will become $n < 0$ and structure is impossible to fabricate.

$$D(c+m) - \frac{1}{2} D(a+m) \geq 0 \quad (3\text{-}11)$$

As shown in Fig.5, if the height of a mask pattern is set to H [µm], the length of the membrane on the mask pattern for fabricate target depth in each part (A, B, C) are given by the following formula.

$$\frac{D(a+m) - \frac{1}{2} D(a+m)}{D(a+m)} \times H \quad (3\text{-}12)$$

$$\frac{D(b+m) - \frac{1}{2} D(a+m)}{D(a+m)} \times H \quad (3\text{-}13)$$

$$\frac{D(m)-\frac{1}{2}D(a+m)}{D(a+m)}\times H \tag{3-14}$$

These formulas are generalized. As shown in Fig.6, the height of the structure in X point is set to x [µm], and the length of the membrane for fabricate target depth in X is set to $menbrane$ [µm]. $menbrane$ [µm] is given by the following formula.

$$\frac{D(h-x+m)-\frac{1}{2}D(h+m)}{D(h+m)}\times H \tag{3-15}$$

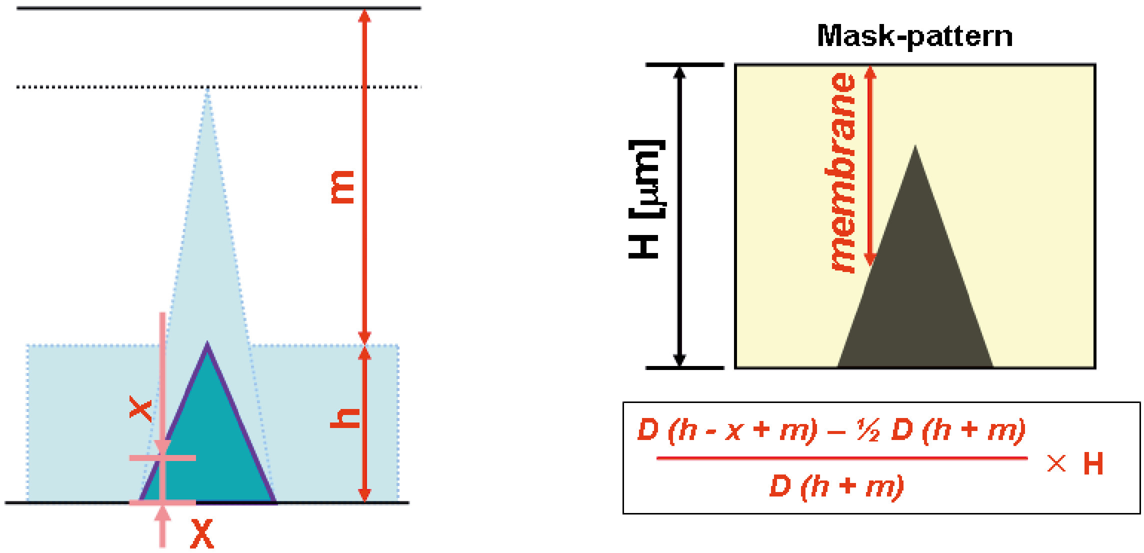


Fig.6 Mask design based on target form

4. Experimental Results

In this time, the shapes of an isosceles triangle with 4µm width and 12.5 µm pitch were fabricated into target form. And, the height of a mask pattern is set to 400[µm]. The design of the mask pattern and the fabricated structures are shown in tables. Target height was set to 25µm, 30 µm, and 50 µm. Each result is shown in Table 4-1, 4-2, and 4-3.

The tendency for the height of a structure to become low was seen. As this reason, since circulation of the developing solution became good in near a triangular vertex, it is thought that the tip became low. Therefore, if development temperature is made low, it is thought that it is improvable.

Table 4-1

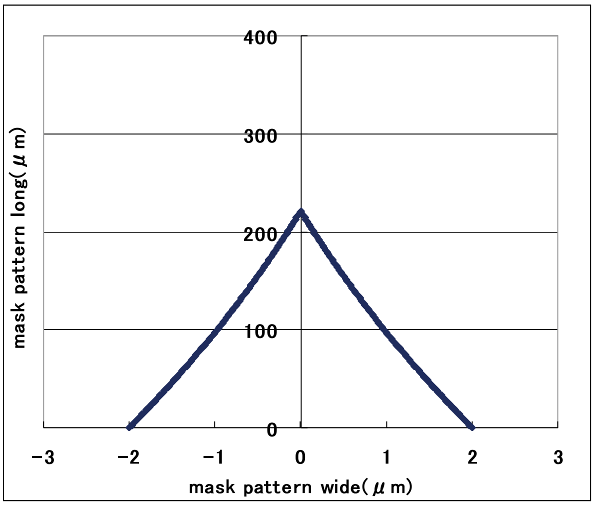
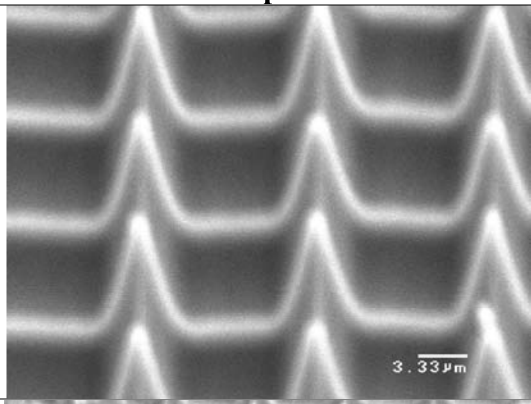
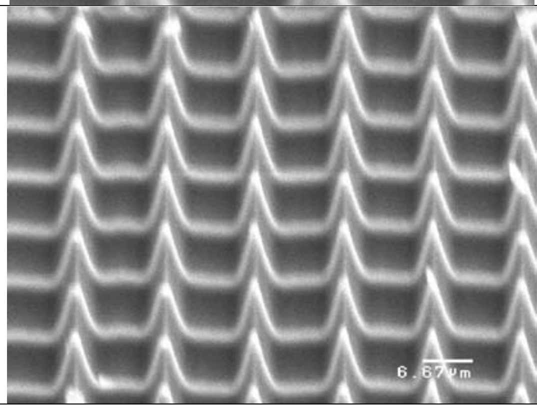
Mask pattern	SEM photos
	 

Table 4-2

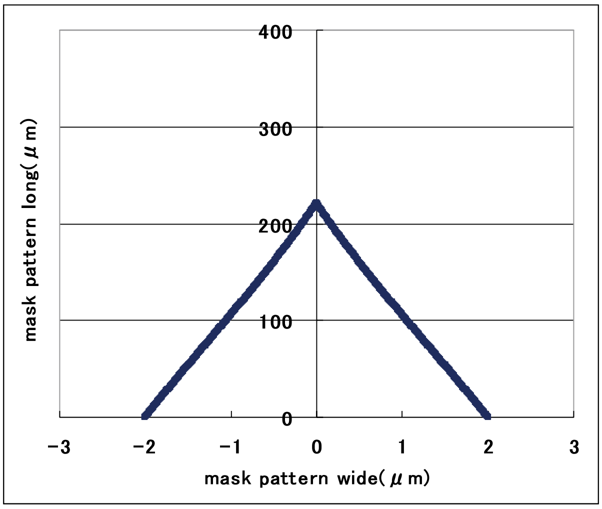
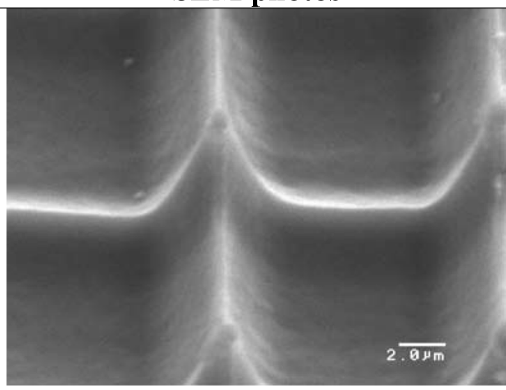
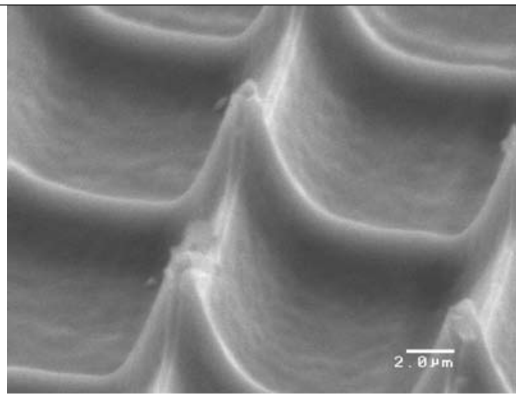
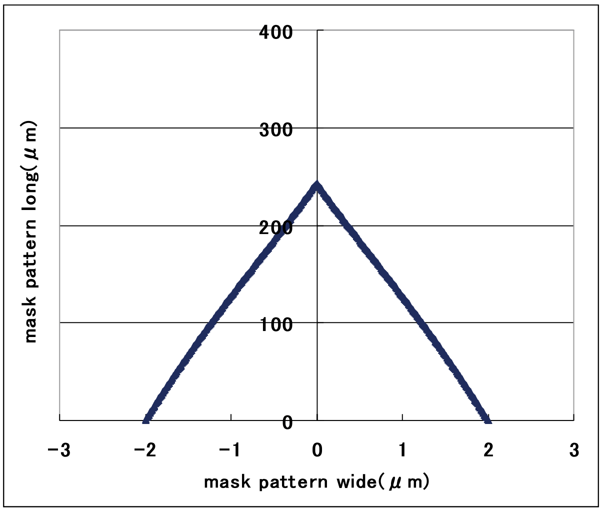
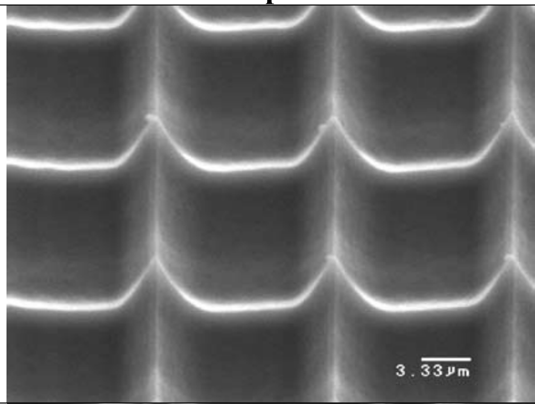
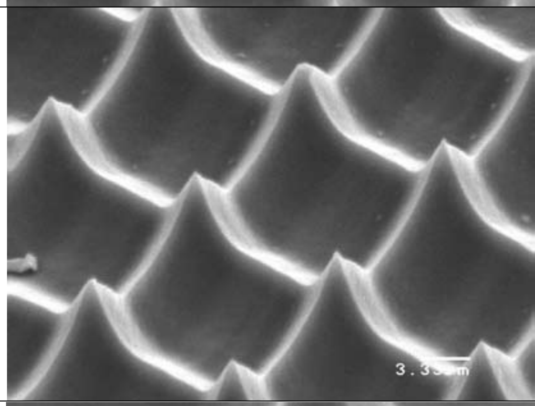
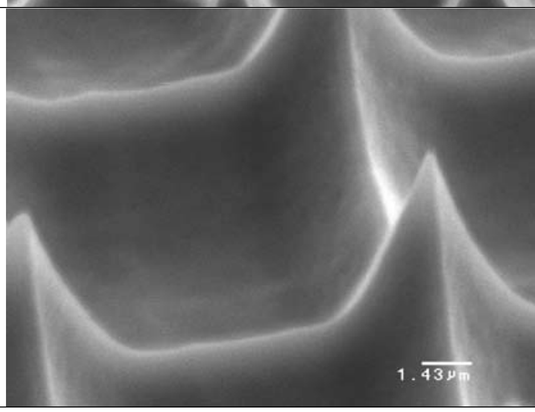
Mask pattern	SEM photos
	 

Table 4-3

Mask pattern	SEM photos
	  

5. Conclusion

When 3-D structures are fabricated by using PCT technique, in order to achieve fabrication of target structure, design of mask-pattern is important. In this time, the method of mask pattern design for fabrication of target structure is established. If using this method, the mask pattern in order to fabricate the processing depth required for fabrication of target form can be easily calculate. Target forms are actually set up and the mask-patterns are fabricated. And, the fabricated form is mostly in agreement with target form is checked. 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 in near a triangular vertex, it is thought that the tip became low. Therefore, if development temperature is made low, it is thought that it is improvable.

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