Study on SR lithography using Mask-less Exposure Method

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Abstract

Research on establishment of a fabrication method of three-dimensional microstructure which used SR (Synchrotron Radiation) light is reported. As the advantage of this method, since there is no necessity of fabrication masks and it is suitable for rapid prototyping, reduction of fabrication time and cost is mentioned. It succeeded in fabrication of the free-form surface by exposure between pixels overlap this time, using a single shaped-beam as a basic experiment. Next, we aimed fabrication of arbitrary three-dimensional microstructures. Firstly, the method of leading an experimental condition from target form was established. And, fabrication of the target form using experimental condition which is leaded by this method was succeeded. It is examining using this technique for fabrication of μ-TAS or a reactor. The channel which has the inclination and free-form surface are fabricated by this method, improvement in functionality is promising.

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1. Introduction

Three-dimensional structure microfabrication is a significant technology in producing various components for micro electro mechanical systems (MEMS). KOH anisotropic etching of silicon and laser machining[1] have been employed for fabrication of MEMS. Three-dimensional microfabrication technology using Synchrotron Radiation (SR) lithography is possible to be nanoscale and high aspect ratio fabrication which harnessed the characteristic of SR, and fabricate structures which has free-form and sidewall inclination surface. Before now, some research of three-dimension processing methods using SR light is already reported [2] [3] [4]. Each of these is techniques of giving exposure energy distribution to a resist surface. In order to fabricate arbitrary 3-D structures, complex energy distribution need to give to resist surface.

In order to give a complicated energy distribution, there are the techniques of using two or more masks, the gray mask method for having changed the thickness of X-ray absorber, etc. However, these techniques are the complexity of a process and the difficulty of material processing being high, and have the subject of the structure which can be fabricated being limited.

In this time, we carry out basic research about fabrication method which is possible to fabricate arbitrary three-dimensional microstructures by the mask-less exposure using the shaped SR beam. The outline of mask-less 3D fabrication method is shown in Fig. 1. SR light is shaped by an aperture, and volume of exposure energy is controlled by closing motion using actuator. It is the technique of giving the energy distribution of the shape of a mosaic-like as shown in a figure. As the advantage of this method, since there is no necessity of fabrication masks and it is suitable for rapid prototyping, reduction of fabrication time and cost is mentioned. It aims at the application to three-dimensional fabrication by this method, the aperture of 75µm x 80µm for shaped SR is fabricated, and the free-form surface was fabricated only by the single shaped beam from a basic experiment.

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. Since a resolution of PMMA is high, a reproducibility of fine structures for molding can be enhanced as the further fabrication process [5].

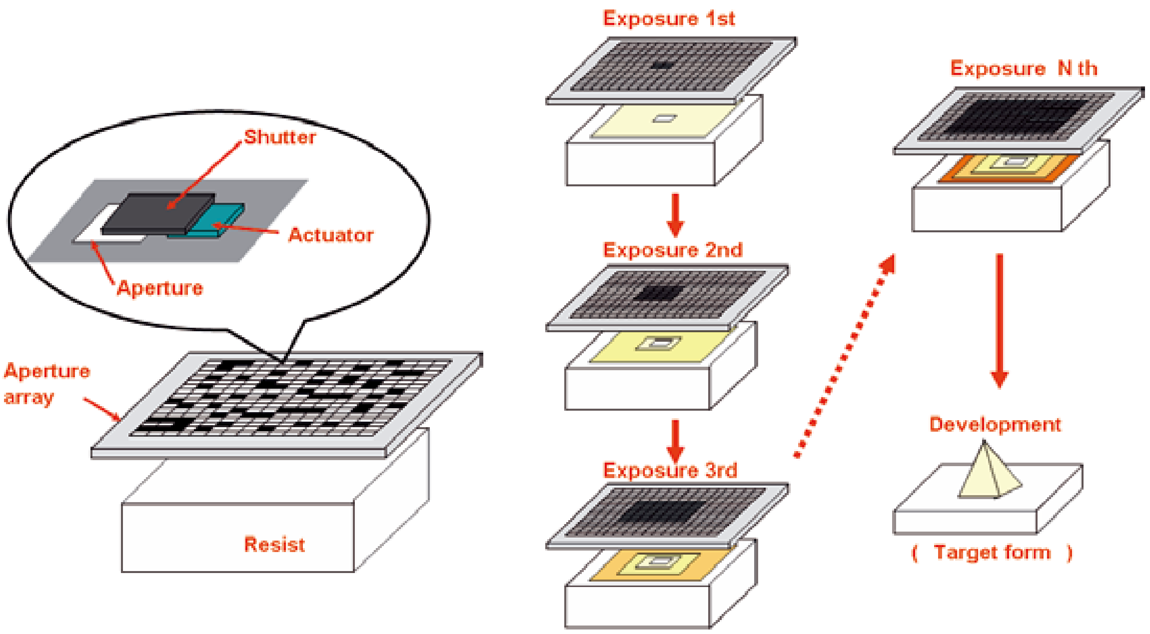


Fig.1 Fabrication outline

The exposed PMMA structures gradually appeared during developing by 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) for 3 hours. After that, stopper liquid (80 vol% 2-(2-butoxy-ethoxy) ethanol, and 20 vol% water) was used for 10 minutes then rinsing by water at for another 10 minutes. All the processes listed were done at the exact temperature of 37℃.

In order to experiment for giving mosaic-like exposure energy distribution to the resist surface, stage program was made to improve with C++ programming language. An improvement of this new stage program contains not only driving method of stage for exposure, but also loading current value and dose amount of AURORA. If we use this new stage program and input necessary dose amount to corresponding grid, the stage will be possible to automatically moved and expose next grid after the grid leach to necessary dose amount.

This method is needless to fabricate a mask for every target form. However, the aperture for beam forming is need. We fabricated this aperture by Ni using LIGA process and the aperture for beam forming which is fabricated is shown in Fig.2. The form of the aperture area is 75μm ×80μm.

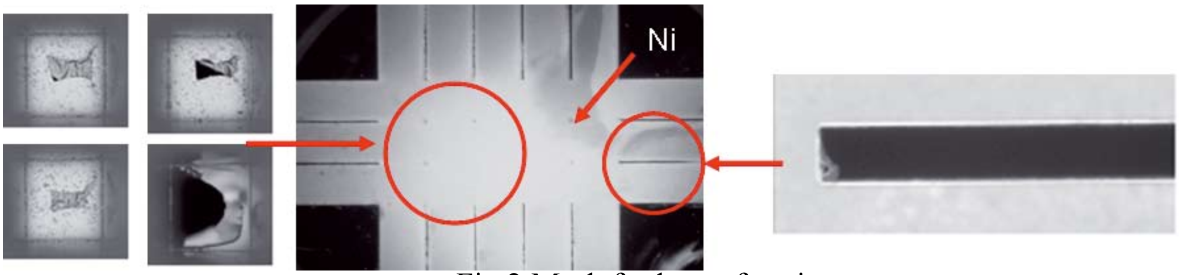


Fig.2 Mask for beam forming

3. Experimental Results

3.1 Basic Experiment for Mosaic-like Exposing

As a basic experiment, PMMA resist is given mosaic-like exposure energy distribution by the same pitch as aperture size. As shown in Fig.3, when adjoining pixels overlap or a gap arises between pixels, a smooth free-form surface cannot be fabricated. Although the error between the adjoining pixels was exposed so that it might be set to less than ±100nm, as shown in a figure, when it overlapped, the channel is appeared in the boundary surface. And, when a gap arose, pillar form is appeared. As this factor, in order that the resolution of PMMA resist used with SR lithography might show a value as high as 50Å, it turned out that a three-dimensional structure cannot be fabricated by the method of mosaic-like exposing by the same pitch as aperture size.

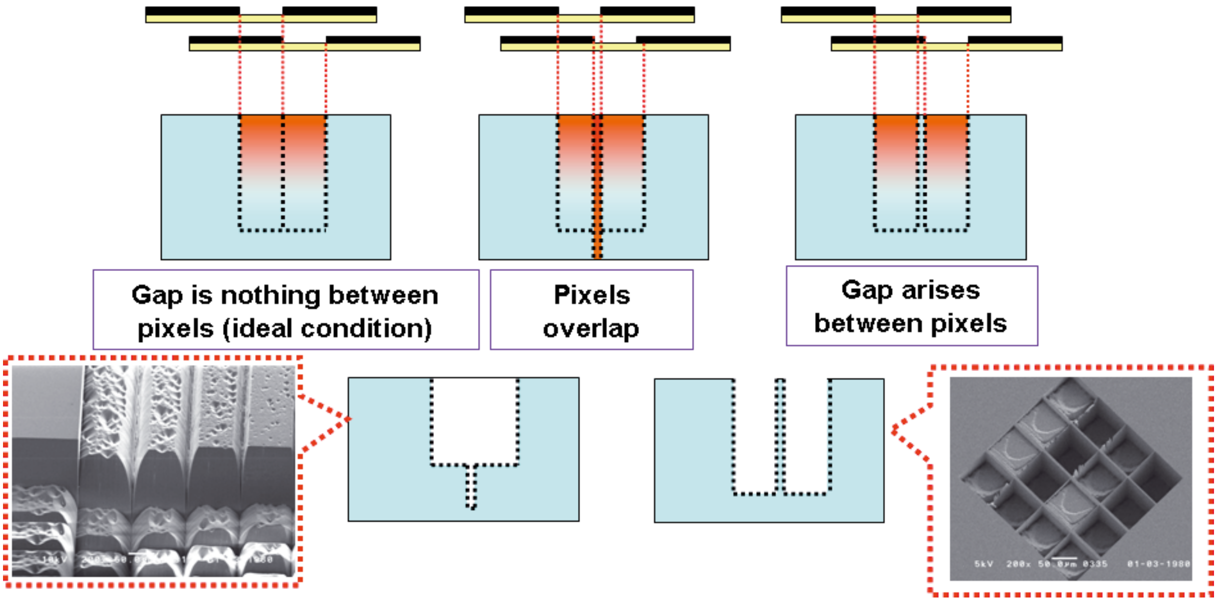


Fig. 3 The exposure state between pixels

Therefore, as shown in Fig.4, fabrication of the free-form surface was tried by overlapping between pixels beforehand. Fig.4 (1) is by a pitch of the half of aperture size (37.5μm x 40μm), and Fig.4 (2) is by a 10 μm pitch performed mosaic-like exposure respectively. And as shown in a figure, it succeeded in fabrication of the free-form surface. Moreover, it turns out by narrowing pitch width that the processing surface became smoother.

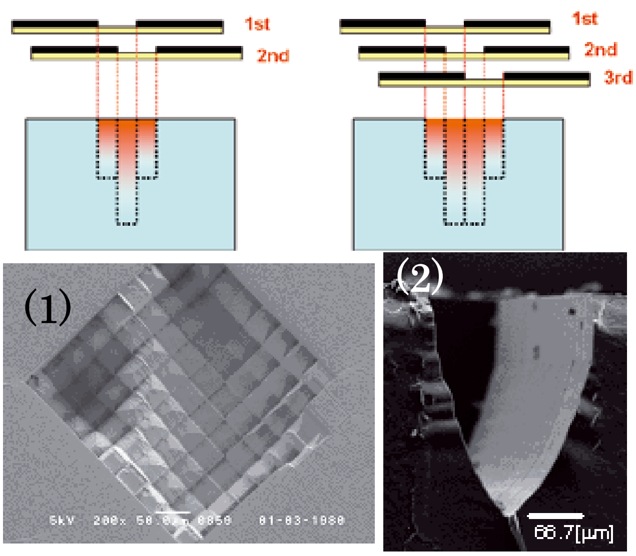


Fig.4 3-D structures by mosaic-like exposure

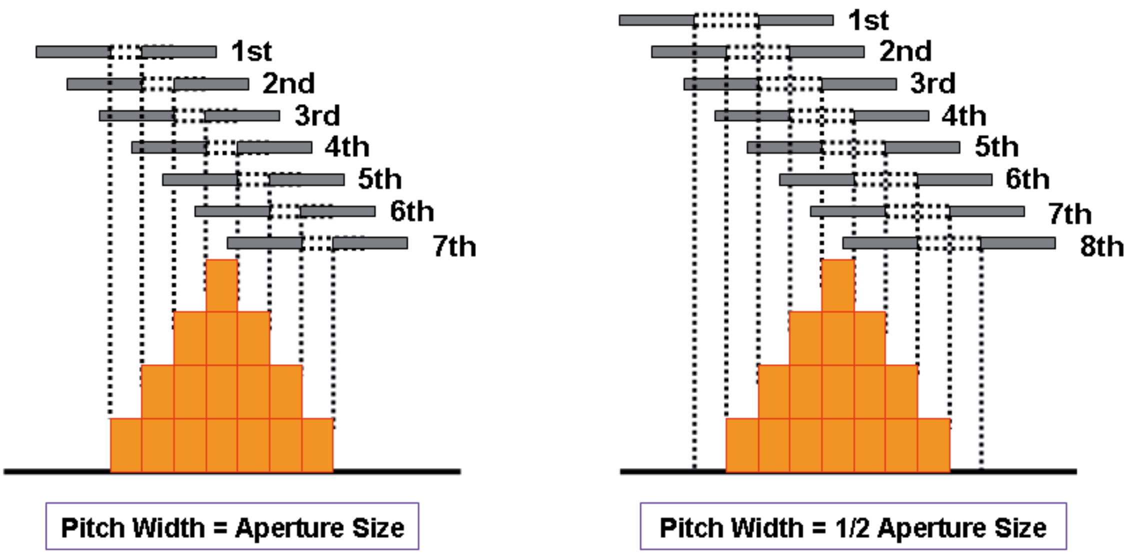


Fig.5 Difference of pitch width and discretized energy

3.2 Optimization of Experimental Condition

This section is reported about the approach for leading experimental conditions required for fabrication of target form. First of all, the required dosage is calculated from target form based on relationship between dosage and processed depth. In order to give the exposure energy distribution of a digital type in mosaic-like exposure, the calculated exposure energy of continuous quantity is changed into the discretized exposure energy which is divided the arbitrary numbers of pixels in manner of A/D conversion. When pitch width and aperture size are in agreement, actual energy amount make to conform to discretized exposure energy it as shown in the left of Fig.5. However, be shown in the right of Fig.5, when pitch width and aperture size are not in agreement, energy amount must be decided in consideration of overlap. The 3.1st clause described, if overlap exposure is not performed, fabrication of 3-D structures with the free-form surface is unrealizable. Therefore, there is the necessity of calculating exposure amount in consideration of overlap.

When taking the overlap of only one direction into consideration, the calculation method of the energy amount is described. Firstly, pitch width is decided so that pitch width may be $1/l$ times the aperture size. However, l is taken as one or more integers at this time. Next, the number n of pixels is decided from the relationship between pitch width and processing range required for target form fabrication. In this time, n must fill $l \le n$. When the required processing depth in a certain arbitrary positions x is $Depth(x)$ [μm], the required energy amount $Dose(x)$ [A· h] in x is calculated. Calculated $Dose(x)$ [A· h] is divided with the number of pixels, and the average value of energy amount within a pixel is calculated. Be shown in Fig.6, the average value of energy amount in the k th pixel is set to $D(k)$ [A·h], the actually performed energy amount $E(k)$ is calculated. Fig. 6 is a pattern diagrams at the $l = 2$. $D(k)$ is expressed in the following equation. However, k must be $2 \le k \le n-1$.

$$D(\mathrm{k}) = E(k-1) + E(k) \tag{3-1}$$

And, $D(1)$ and $D(n)$ are expressed in the following equation.

$$D(1) = E(1) \tag{3-2}$$

$$D(n) = E(n-1) \tag{3-3}$$

Unknowns $E(k)$ are calculated from these simultaneous equations.

A series of formulas (3-1) (3-2) (3-3) is realized when filling $l = 2$. When these formulas make generalization, $D(k)$ is expressed in the following equation. However, k must be $l \le k \le n+1-l$.

$$D(\mathrm{k}) = E(k+1-l) + \Lambda + E(k-2) + E(k-1) + E(k) \tag{3-4}$$

When k fills $k < l$, $D(k)$ is expressed in the following equation.

$$D(k) = E(1) + E(2) + \Lambda\ + E(l-1) \tag{3-5}$$

When k fills $n+1-l<k$, $D(k)$ is expressed in the following equation.

$$D(k) = E(n-1) + E(n-2) + \Lambda\ + E(n+1-l) \tag{3-6}$$

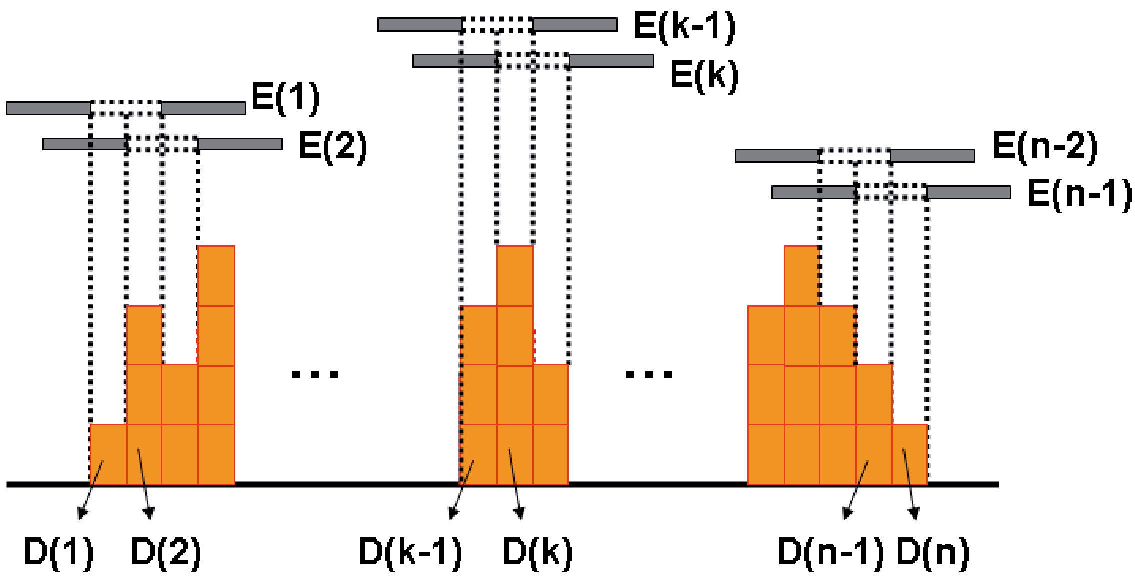


Fig.6 Pattern diagrams of $D(n)$ and $E(n)$

Unknowns $E(k)$ are calculated from these simultaneous equations. In this time, the case of only one direction was described. Calculating is possible if simultaneous equations are set up similarly in the case of two directions.

3.3 Results

Arbitrary target form is defined, and 3-D microstructures are fabricated based on the 3.1st clause. A 3-D microstructure which is expressed in the following equation in an X-Y coordinate is fabricated.

$$Depth(x,y) = -50\left[1-\sin\left(x^2+y^2\right)\right]-20 \tag{3-7}$$

The target form with which a formula (3-7) is filled is shown in Fig.7. In order to fabricate this target form, the dosage required is shown in Fig.8. The dosage is calculated from relationship between dosage and depth at the time of developing time 180 minutes. Next, the dosage is discretized. Fig.9 shows discretized dosage distribution by 1/2 aperture size and 1/4 it.

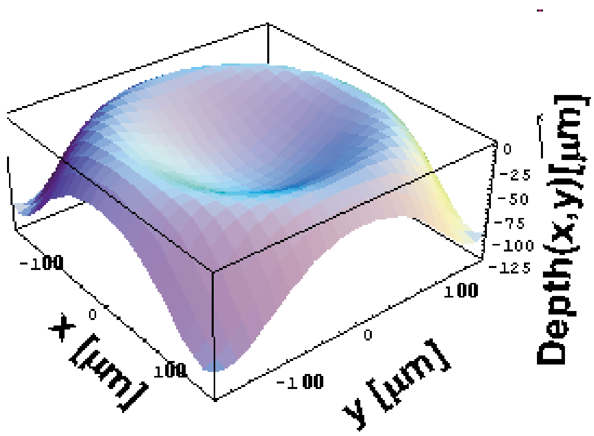


Fig.7 Target form with which a formula (3-7) is filled

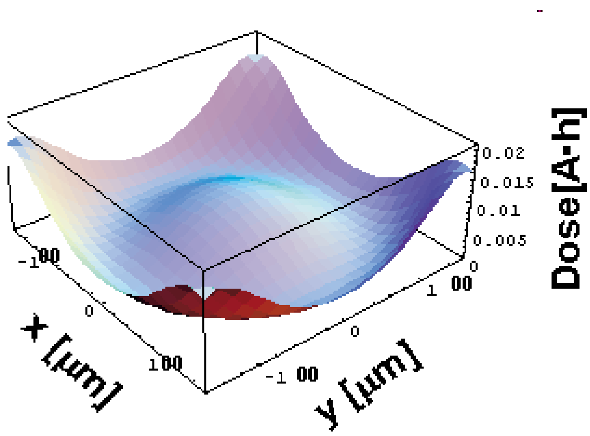


Fig.8 The dosage in order to target form with which a formula (3-7) is filled

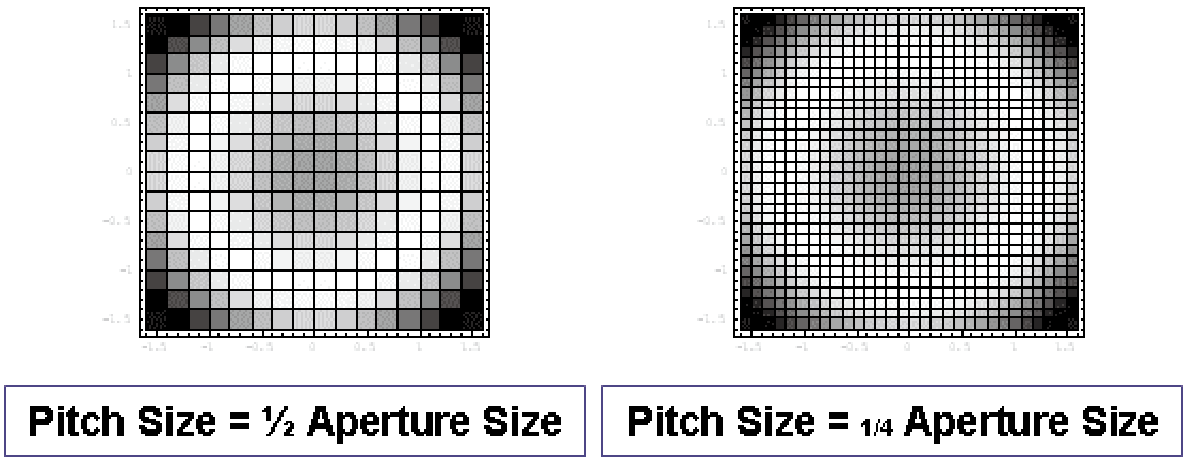
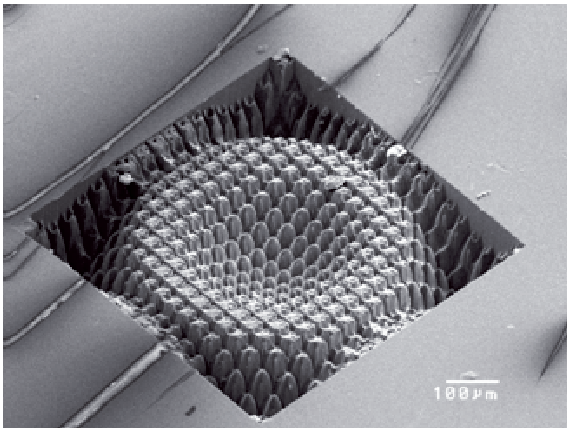
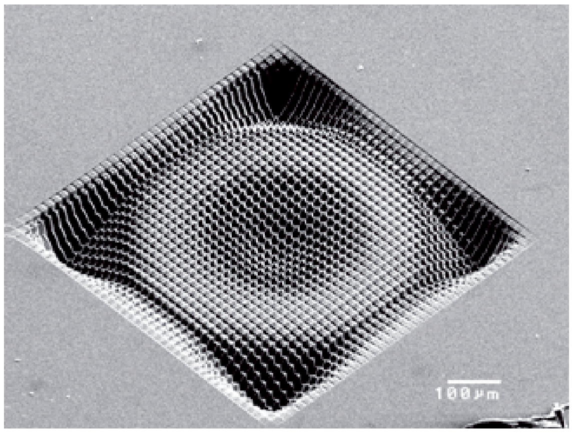


Fig.9 Discretized dosage

This target form is fabricated based on this discretized dosage and 3.1st clause. Fig.10 shows the actually fabricated structures.



Pitch Size = ½ Aperture Size



Pitch Size = 1/4 Aperture Size

Fig.10 3-D structures

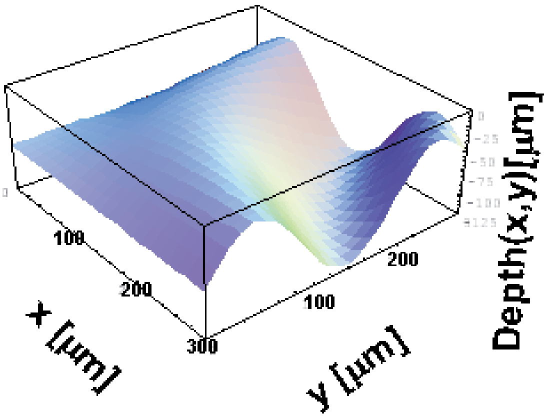
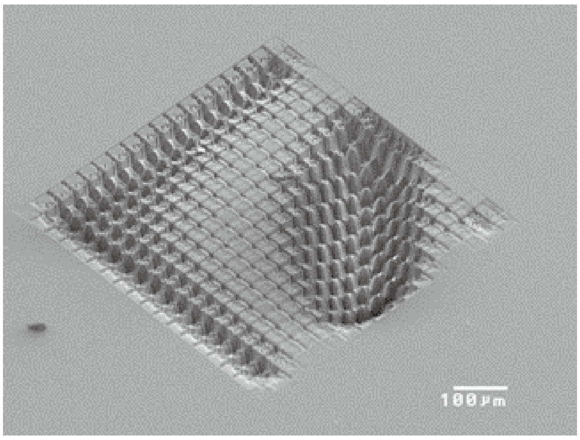
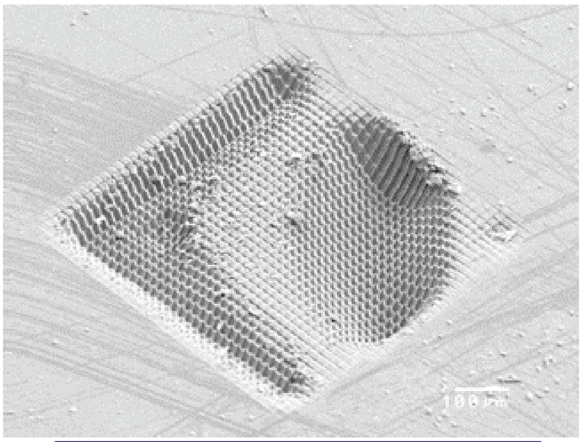


Fig.11 Target form with which a formula (3-8) is filled



Pitch Size = ½ Aperture Size



Pitch Size = 1/4 Aperture Size

Fig.12 3-D structures

At the same time, other structures are fabricated using another formula (3-8). The target form with which a formula (3-8) is filled is shown in Fig.11. In order to fabricate this target form, the dosage is calculated from relationship between dosage and depth at the time of developing time 180 minutes. Next, the dosage is discretized by 1/2 aperture size and 1/4 it. This target form is fabricated based on this discretized dosage and 3.1st clause. Fig.12 shows the actually fabricated structures.

$$Depth(x, y) = -50[1 - \sin(x \times y)] - 20 \qquad (3\text{-}8)$$

4. Conclusion

The concept of the new mask-less exposing method by SR of having been suitable for rapid prototyping was proposed. In this time, it succeeded in fabrication of the free-form surface by making between pixels overlap, using a single shaped beam as a basic experiment. By making aperture size and pitch width small (submicron) from now on, the flexibility of fabrication form is raised more. It is examining using this method for fabrication of μ- TAS (Micro Total Analysis System) or a reactor. By fabrication the channel which has an inclination and a curved surface, improvement in functionality is promising.

Acknowledgements

Authors would like to thank Mr. Shunsuke Kajita for a number of useful data, and Mr. Hiroyuki Ikeda, a technician in the SR center, Ritsumeikan University, for his technical assistance. This research was partially supported by the Ministry of Education, Culture, Sports, Science and Technology, Grant-in-Aid for JSPS Fellows.

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