Shape-Prediction of Microstructures Fabricated by PCT Technique

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Abstract

We have investigated and report in this paper simulations for deformed shape-predictions of the 3-dimensional microstructures fabricated by Plane-pattern to Cross-section Transfer (PCT) Technique and Synchrotron Radiation (SR) lithography. The investigation of the shape-prediction system enhances a possibility for higher accuracy of the prediction. In addition, the desired shapes can be confirmed by the simulations before the mask design and running experiments. It is necessary to investigate a variety of errors factors to shape-prediction. We attempted various investigations. One of the possible causes could be the etching direction dependent on the developing time. Therefore, we currently emphasize on the factor causing this error. In order to comprehend the mechanism of the factor, we have developed the mathematical system of X-ray energy distribution on to PMMA (poly-methylmethacrylate) resist. And, the shape-prediction is consequent of the simulations based on calculations from the mathematics software. The mathematical system for energy distribution dependents on the SR light source, X-ray mask specification, and resist specification. As a result, the predicted structures relevant to the absorbed energy-depth-position parameter set and absorbed energy-etching rate parameter set were obtained from this system. The simulations for shape-prediction were completed by the above parameter sets with the C language.

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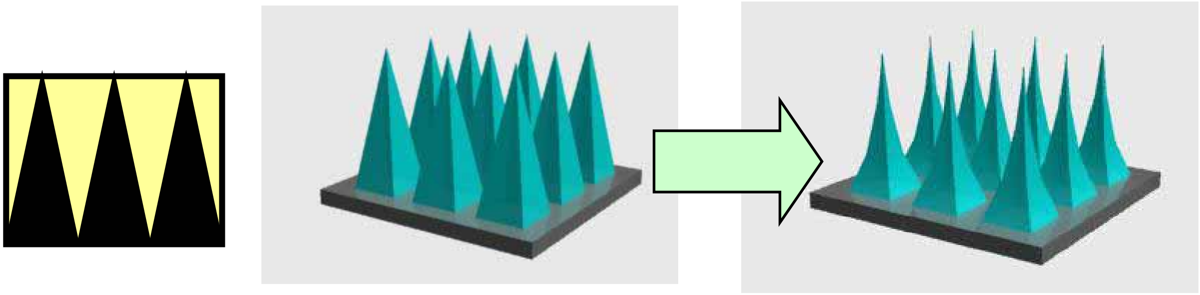
1. Introduction

A variety of three-dimension processing technologies such as KOH anisotropic etching of silicon and laser machining[1] have been employed for fabrication of Micro Electro Mechanical Systems(MEMS). Especially, 3-dimension fabrication that uses X-ray lithography in LIGA (Lithographie, Galvanoformung, Abformung) [2,3,4,5,6]. LIGA draw attention from widely research area as technique that can fabricate structure that has controllable 3-dimensions with respective height. Various methods have been developed for as an additional technique to enhance the three dimensional processing. However, the method for shape-prediction was not commonly available for these techniques. The comprehension of the deformed shape available in the literature so far, was not actually conformed to the experiment. Moreover, the development of the shape-predication system made possible to suppress the production cost, especially in LIGA such as SR (synchrotron radiation) facility consumptions and the cost of reproduction of X-ray mask.

When PCT technique is used, the similar shape as the mask absorber pattern in the mechanism is expected to be fabricated. Therefore, if the exposure distribution onto the resist is expected to form curved shape or sloped side-wall structure whose cross-section is similar to the mask absorber pattern as the target shape. However, when the mask e.g. as shown in Fig.1(a) is used, actual shape becomes error as the resulting sidewall in Fig. 1(b). Many of 3-dimension fabrication by X-ray lithography are processed by giving a complex energy distribution in resist. Since the energy distribution is complex, the development of the technique for shape-prediction is also complicated. In this research, we have tried to consider the factors influencing the shape-deformation and developed a simulation system for the shape-prediction.



(a) (b)

Fig.1 mask pattern (a) and actual shape (b).

The processing depth in the X-ray lithography depends on the X-ray irradiation on surface of the resist. Therefore, we focus on the nonlinear relation between an X-ray irradiation and a processing depth. PCT is a method of controlling the amount of the irradiation by exposing while resist is moving. The amount of the irradiation can be easily controlled by carefully designing the absorber pattern of X-ray mask and the structure depth was consequently controlled by considering absorber pattern of X-ray mask according to this nonlinear relation. However, there was the measurement of errors occurred between the cross-sectional shape of fabricated structure and original 2D-shape of mask patterns [7]. A complex etching mechanism was considered as a reason that was not possible to correct it though the amount of the irradiation was controlled.

The etching rate is proportional to the amount of the absorbed energy. When the energy distribution shown in Fig.2 (a) is accumulated in the resist, the etching rate is in the direction as shown by vectors in the figure. The more concentration of the color, the higher energy is absorbed. Therefore, it is predictable that the structure which has the sloped side-wall as shown after the arrow can be expected. However, the etching direction changes by the inclination of resist surface which is also changes by the adjustment of developing time (Fig.2 (b)). As a result, the deformation was occurred. Therefore, we have tried to develop the algorithm for comprehension of this etching mechanism, and for a shape-prediction.

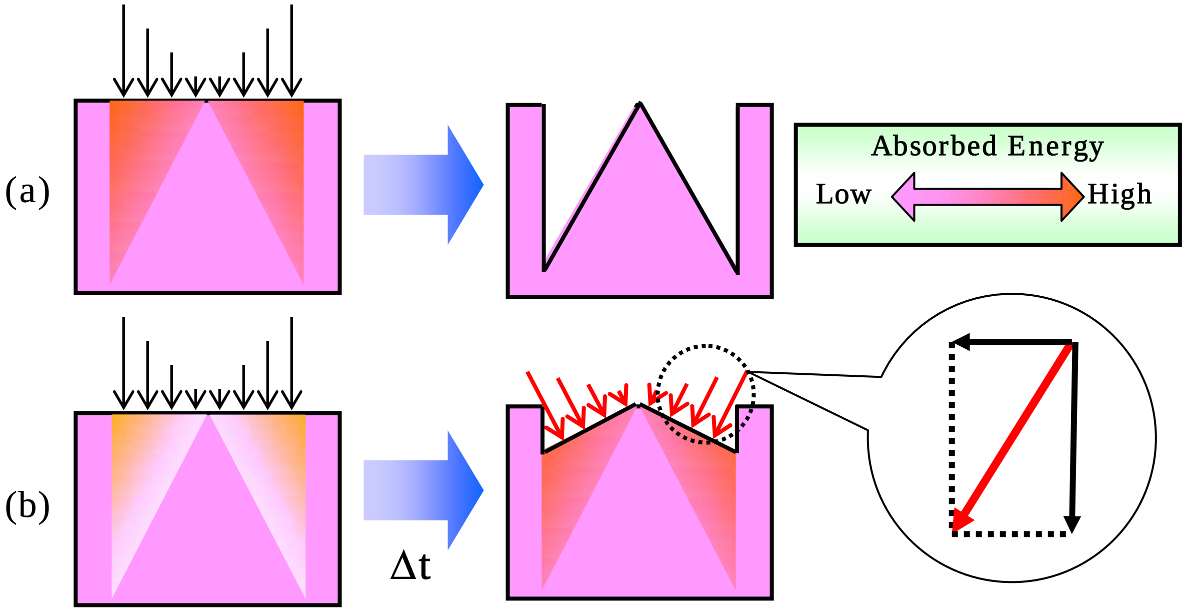


Fig.2 Etching mechanism

Our simulation system reported in this paper was developed for PCT process. While PCT technique is used, absorbed energy distribution in the resist is shaped by mask absorber pattern. Thus, our simulation system arranged the mask absorber pattern as an input parameter. The absorbed energy distribution could be calculated from the parameter and the etching mechanism afterward. The result of simulations compared to fabricated structure illustrated by SEM (Scanning Electron Microscope) images is reported and discussed in this work.

2. Fabrication and Experimental Conditions

An exposure was performed using the equipment schematically shown in Fig.3, The superconductivity compact synchrotron radiation (SR) source "AURORA" currently installed at SR center, Ritsumeikan University, Japan, has been operated as the X-ray light source. The SR light has wide wavelength from X-ray to visible light. The exposure environment was covered with Helium gas at 1 atm in the chamber in order to prevent the attenuation of the X-ray by N_2 or O_2 gases and to prevent the damage of the mask or resist by heat generated. The mask consisting of Polyimide supporting membrane with a thickness of 50 μm and Au absorber film with a thickness of 3 μm was used. Fig. 4 shows the relation between wavelength and the spectrum, after the X-ray passed through Be1 (200 μm), Be2 (200 μm), He, Polyimide (50 μm) and Au (3 μm). PMMA was used as a resist. Since the resolution of PMMA is high, a reproducibility of fine structures for molding can be enhanced as the further fabrication process [8].

Fig.5 shows the PCT technique. The energy distribution is deposited in resist by scanning as shown in the same figure. 3-dimensional structures were fabricated by developing afterwards. 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 method.

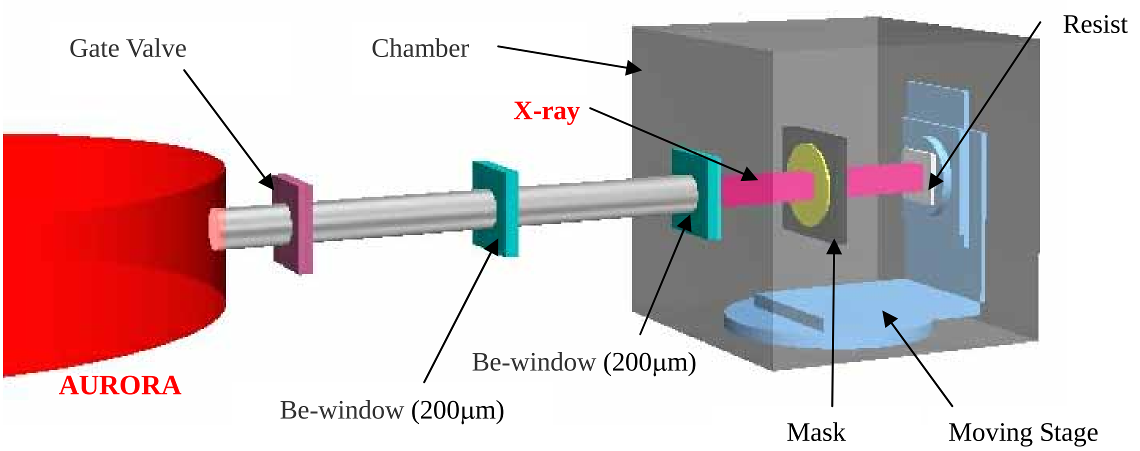


Fig.3 The schematic of AURORA and the exposure chamber of BL-13.

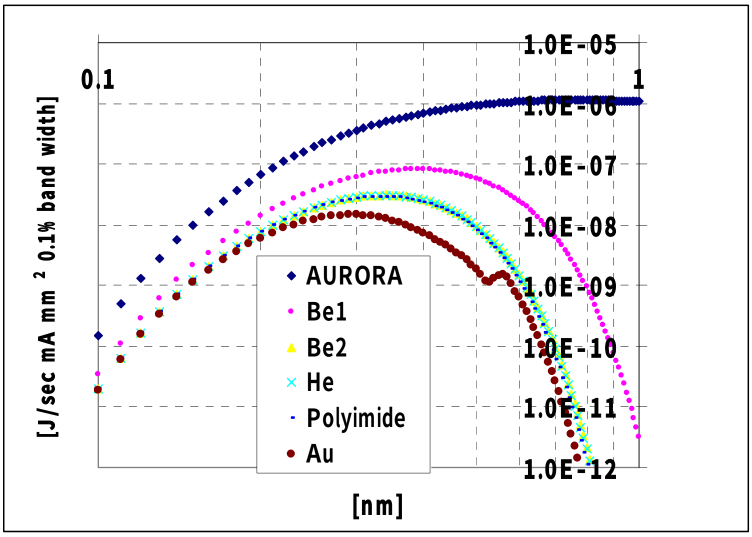


Fig.4 Wavelength VS Photon Density of X-ray from AURORA to the resist

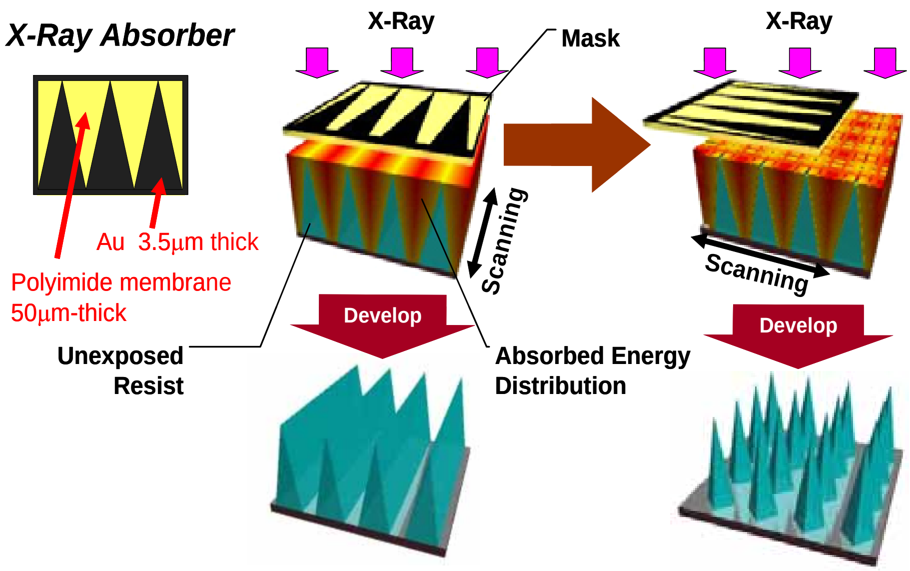


Fig.5 PCT steps for shaping microneedle array

3. Simulation System

In order to develop a method for accurately fabrication, establishing a method for shape-prediction which can illustrate complex etching mechanism is necessary. Due to a number of complex factors e.g. the X-ray absorbed energy distribution and the developing condition in the resist are corresponded to the three-dimension processing by PCT. Therefore, the system that explains the 3-D fabrication by modeling these factors is needed. Especially, to consider the etching mechanism as shown in Fig. 2, a simulation system which can simulate the absorbed energy distribution, etching direction dependent, and etching rate is reported in this work.

The energy distribution is shaped by mask absorber pattern for PCT process. For example, when we used a triangular mask as illustrated in Fig. 6, and resist stage was scanned, a variety of irradiated patterns was controlled by the part where only exposure with membrane (area A in Fig.6) and exposure with membrane and absorber (area B in Fig.6). For example the area C in Fig.6, the irradiation was partly into the membrane by 50% and membrane + absorber by 50%. Therefore, the amount of the absorbed energy on PMMA after the SR transmitted through the membrane (50 μm-thick polyimide) and absorber (3 μm-thick Au) was calculated. And on the basis of the amount of the absorbed energy, the relation among the % of absorber, depth, and the amount of absorbed energy is calculated (Fig.7).Consequently, the system that calculates the energy distribution on PMMA resist corresponding to the X-ray mask pattern was constructed.

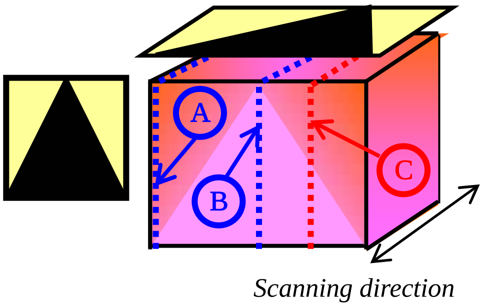


Fig.6 Exposed area corresponded to the mask pattern

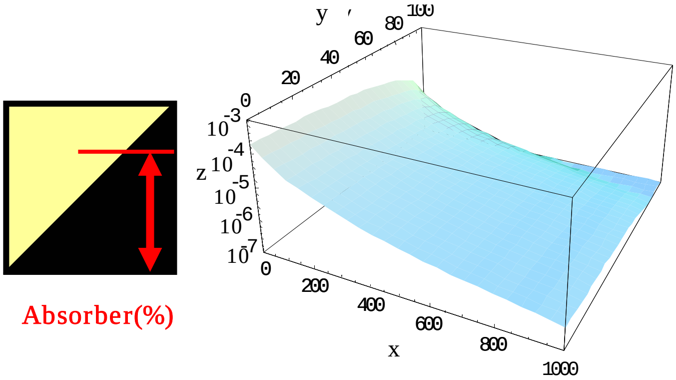


Fig.7 x:Depth(μm)vs y:Absorber(%)vs z:Enegy(J/sec mA mm^3)

The etching rate depends on the amount of the absorbed energy is made to adjust to the energy distribution, and the shape-prediction at arbitrary time is calculated.

4. Results

The algorithm that fills this simulation system derived in this work was programmed by C language. The various mask patterns were used in order to compare the results with the simulations. The result of the simulation used and displayed graphically by MATHEMATICA®.

Triangular Mask

Fig.8 shows the result when the triangular mask was used. The X-ray dosage at 0.0474 A·h was exposed, and developing time was 180min. With the dosage and developing time, the structure height was controlled to be 300 μm.

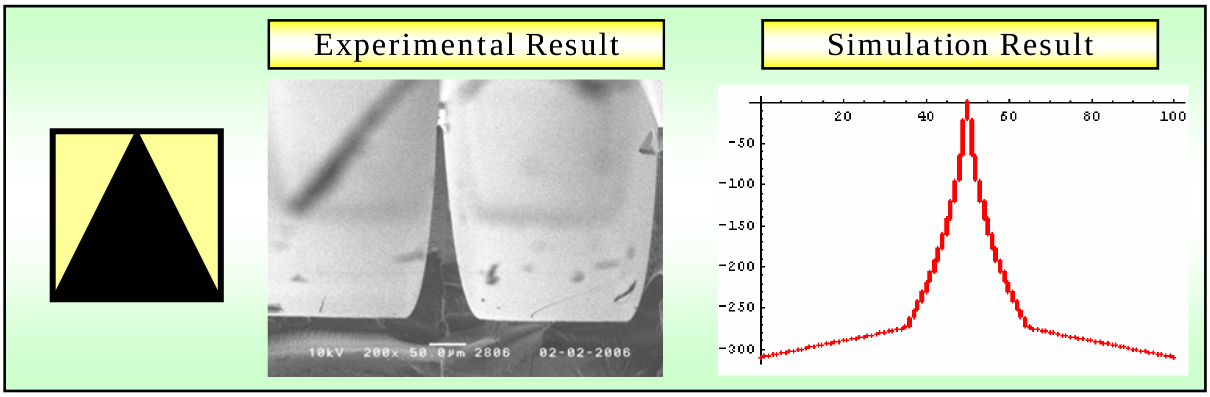


Fig.8 The experimental result compared to simulation result from a triangular mask

Circular mask

Fig.9 shows the result when the circular mask was used. (Dosage: 0.0474 A·h, developing time: 180min)

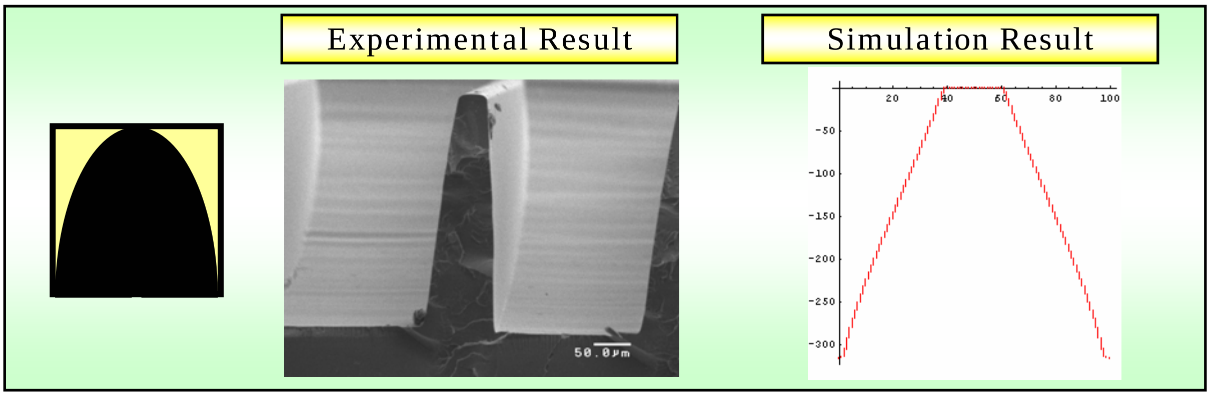


Fig.9 The experimental result compared to simulation result from a circular mask (300μm)

In addition, Fig.10 shows the result when the dosage of 0.0098 A·h was used, and developing time was 180min. With the dosage and developing time, the structure height is controlled to be at 50μm.

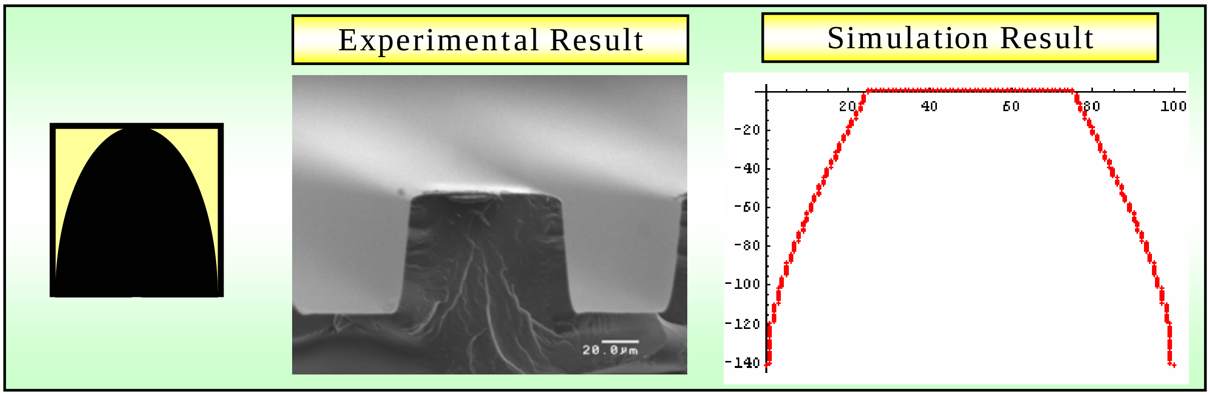


Fig.10 The experimental result compared to simulation result from a circular mask (50μm)

Lens mask

Fig.11 shows the result when the sine-curve mask was used. The X-ray dosage of 0.0044 A·h was exposed, and development time was 180min. The expected form of a microlens was, 100μm-base, 14μm-height, and the radius of curvature at 100μm.

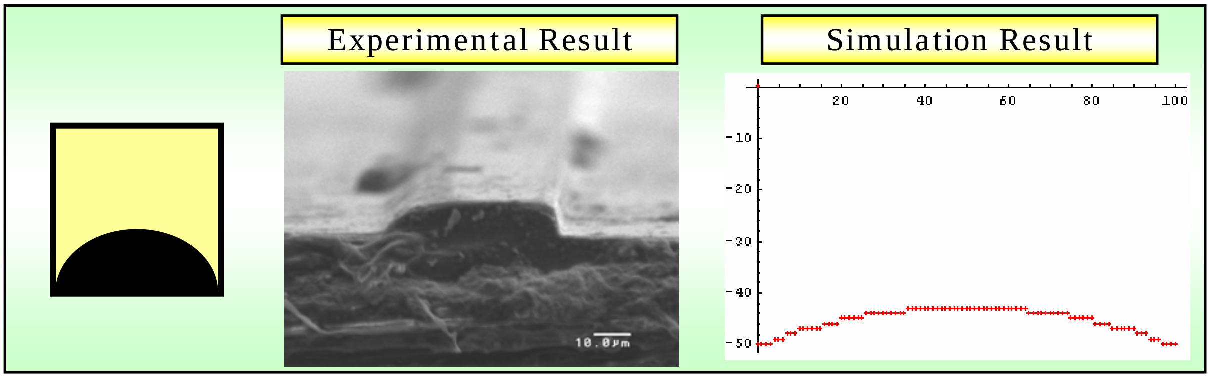


Fig.11 The experimental result compared to simulation result from a lens mask.

Sine-curve mask

Fig.12 shows the result when the sine-curve mask was used. (Dosage: 0.0098 A·h, development time: 180min)

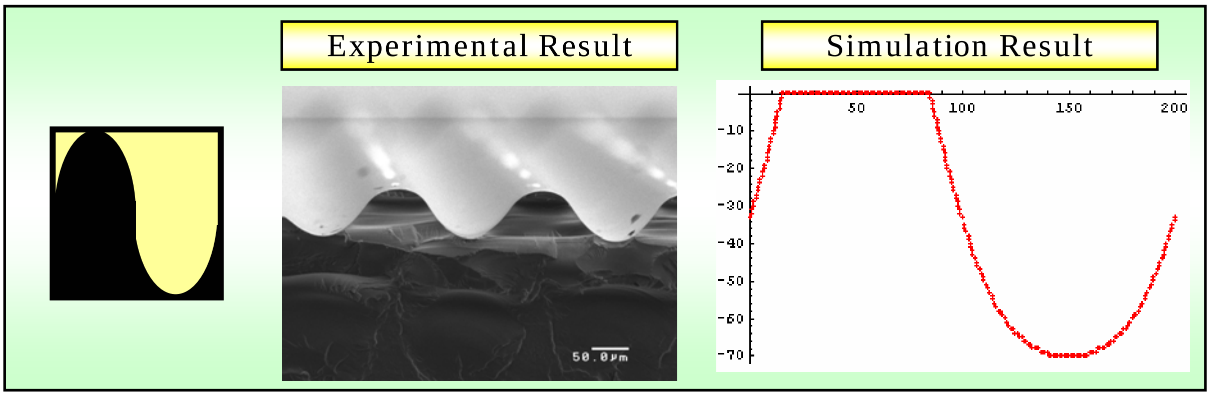


Fig.12 The experimental result compared to simulation result from a sine-curve mask.

Double-triangular Mask

Fig.13 shows the result when the triangular mask was used. (Dosage: 0.0474 A·h, development time: 180min)

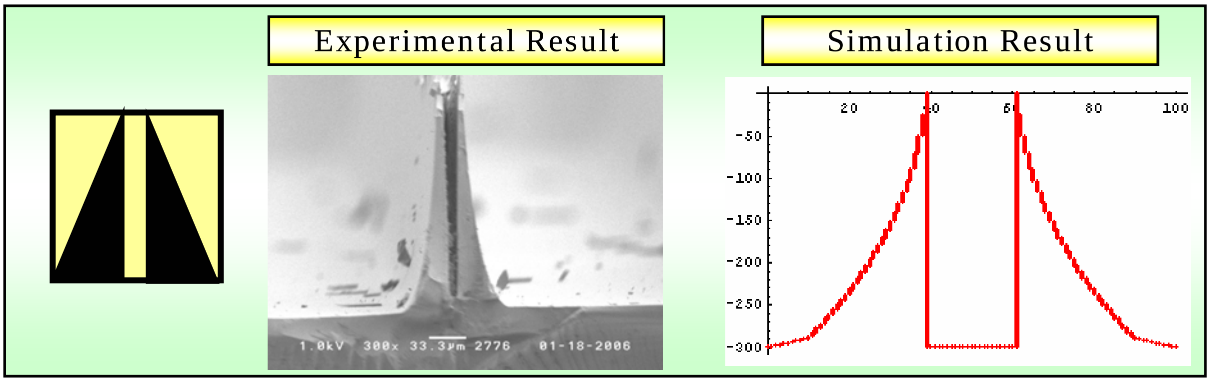


Fig.13 The experimental result compared to simulation result from double-triangular mask.

5. Discussion

The experiment result and the simulation result were compared. In the previous work, it was difficult to predict the curve of the fabricated structure sidewall so far when a triangular mask was used. In this work, the curve of the sidewall was able to be predicted by the developed simulation. Similar shapes of fabricated structures have been able to be calculated, when other mask patterns were used. Therefore, we conclude that this proposed algorithm can considerably reproduce the etching mechanism. However, there was some mask patterns that the shape prediction was not completely conformed. The error was caused in the vicinity of the top though the vicinity of the bottom was able to be reproduced when the sine-curve mask was used. As for this factor, the algorithm did not cause the problem where the relational expression of energy and the etching rate did. In addition, the error was occurred in the depth of the simulation results. It is considered that this factor causes a problem of the relational expression of absorbed energy and the etching rate as well. Therefore, it is necessary to calculate the relational expression of energy and the etching rate with more accuracy in the future. In addition, the inner curve of double-triangular mask cannot be simulated while the curve of the outside can be predicted. The diffraction during the exposure and the secondary electron are considered as the influencing factors [9]. These factors cannot be considered by the present simulation system.

6. Conclusion

The shape prediction of 3-D structure fabricated by X-ray lithography using PCT is presented in this work. It is necessary to correct a number of errors in order to be more accurately 3-D shape-predictable. Therefore, the complex etching mechanism was considered as the main factor causing the error. We have proposed a simulation system to study on this factor. The simulation system has been used in practice. The experiment result and the simulation result were compared. The prediction in some mask patterns still included some errors. However, the improvement of accuracy shape prediction was successful compared to the previous work. The prediction system will be continuously improved by other influencing factors in the future.

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