Fabrication of 3-D Microstructures with Sidewall Inclination Controlled by Development Temperature

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Abstract

This paper describes about the fabrication of PMMA microstructures with sloped sidewall. In this research, three-dimensional microstructures with sloped sidewall are fabricated by normal synchrotron radiation lithography process. Inclination angle of sidewall of PMMA microstructures are decided by development temperature. The more development temperature is high, the more inclination angle is large. In this time, it succeeded in fabrication of the PMMA microstructure which inclination angle differs by changing development temperature. Fabrication technologies of microstructures with sloped sidewall are very important, and this inclination angle of sidewall will become draft angle for molding process.

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). Before now, some research of three-dimension processing methods X-ray lithography using SR is already reported [2] [3] [4] [5] [6]. Each of these is methods of giving exposure energy distribution to a resist surface. In order to fabricate arbitrary three-dimensional structures, complex energy distribution needs to give to resist surface. Various methods have been developed for as an additional method to enhance the three-dimensional fabrication. However, most of these three-dimensional fabrication methods need two or more masks, expensive stage system and the gray-mask to change the thickness of X-ray absorbers that have been used to apply complicated energy distributions. Therefore in this time, the fabrication method which is possible to fabricate three-dimensional microstructures by simple process flow was considered. This method is three-dimensional microstructures are fabricated by normal synchrotron radiation lithography.

As shown in figure 1, since absorber of X-ray mask is not completely absorbed X-ray, PMMA resist surface under absorber part of X-ray mask is exposed. Therefore in order not to developed Polymethylmethacrylate (PMMA) under absorber part of X-ray mask, it is necessary to raise contrast of X-ray mask. On the other hand, in order to develop PMMA under absorber of X-ray mask, it is necessary to make exposure energy value of PMMA under absorber of X-ray mask high such as utilizing gray-mask. Because the lager the amount of the absorbed energy, the faster the etching rate. However, it's important to note that if PMMA under absorber part of X-ray mask is developed, not only aspect ratio is low but also inclination angle of sidewall of PMMA become large. In this time, three-dimensional microstructures with sidewall inclination are fabricated by the daringly development of PMMA under absorber part of X-ray mask.

Next, we describe about development temperature.when development temperature is high, even if not high in energy under absorber of X-ray mask, it is also possible to develop PMMA. Because the more development temperature is high, not only the etching rate becomes faster but also value of "development limit energy amount" becomes lowly [7]. Therefore in this time, the relation between development temperature and "development limit energy amount" is used, inclination angle of sidewall of PMMA microstructures are controlled by only development temperature. If based on etching mechanism, it is thought that the more development temperature is high, the more inclination angle is large. Figure 2 shows the image of the microstructures with sloped sidewall is fabricated by changing development temperature. Because when temperature is high, even if there is few absorbed energy, PMMA is dissolved to developer. Therefore bump forms are fabricated as shown in figure 2. Moreover since side of the bump is also exposed, side of the bump is also dissolved to developer. And as shown in gradation of the figure, near the surface is higher in absorbed energy. Since etching rate is proportional to the amount of the absorbed energy, structures with sloped side wall are fabricated.

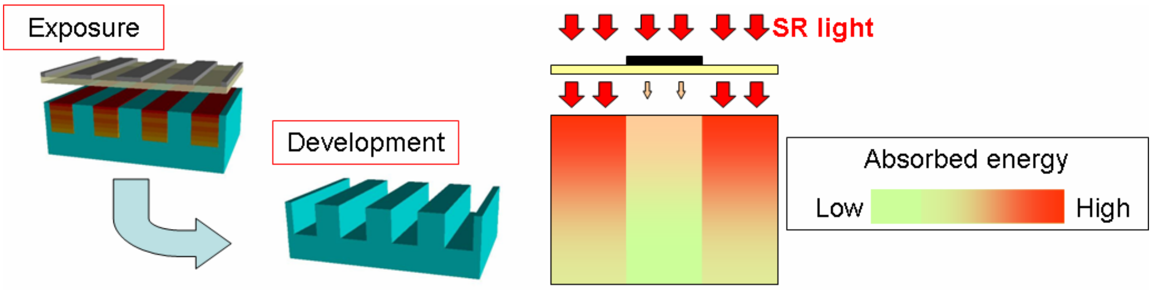

Fig.1 Outline of normal SR lithography and absorbed energy distribution

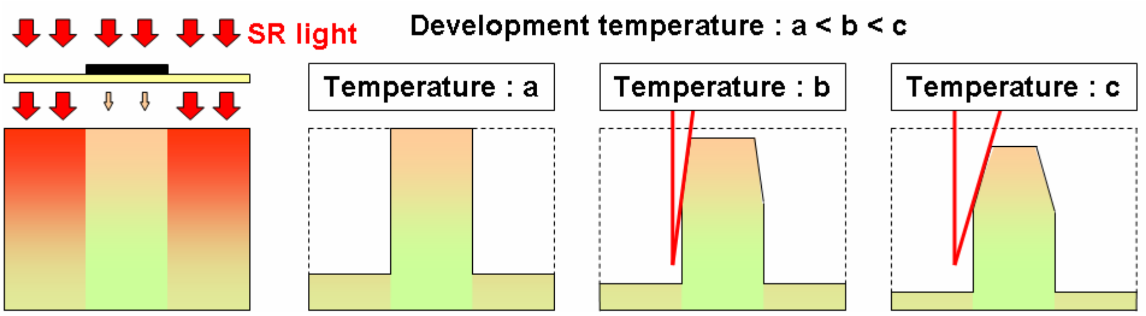

Fig.2 Microstructures with sloped sidewall are fabricated by changing development temperature

2. Fabrication and Conditions

A number of experiments were carried out using beam line number 6 (BL-6) at the superconductivity compact 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 domain, applied orbital radius, electron energy and the maximum storage current in the experiment were 0.5m, 575 MeV and 300 mA, respectively. The wavelength of between 0.2nm and 0.5nm is said to be the best for X-ray lithography also in this wavelength domain. This reason is for suppressing a spread by the secondary electron by the Fresnel diffraction in a long wavelength domain and the secondary electron generated within resist in a short wavelength domain, and making the fabrication line width narrow and raising resolution. The light from AURORA penetrates two 200 μm 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.

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. The X-ray mask consisted of a SiN membrane with a thickness of 2.5 μm and a Ta absorber with a thickness of 2 μm, mask-pattern is 20 μm Line and 50 μm Space. The contrast of this mask is about 22. In addition, the distance from a light source to a sample is 3.388m. 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.

3. Fundamental Data

The amount of the absorbed energy on the PMMA after the SR transmitted through the mask was calculated (Figure 3). We approximated by the polynomial of the amount of the absorbed energy [J/sec mA mm^3] to a depth [μm] when SR penetrates the membrane (2 μm thick SiN) as $F_{SiN}(x)$, and the amount of absorbed energy after SR penetrates the membrane (SiN) and absorber (3 μm thick Ta) as $F_{Sin+Ta}(x)$. As shown in figure 4, the relation of the development time and processing depth through the only "membrane part" and through the "membrane and absorber part" is checked. The relation of the development time and processing depth where the development temperature is 25 °C shows figure 5, and where the development temperature is 40 °C shows figure 6.

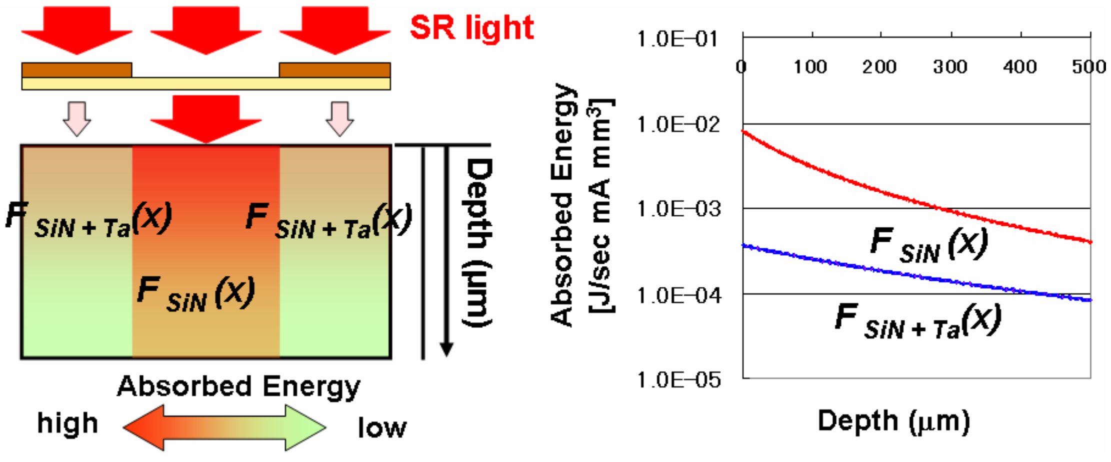

Fig.3 Relation of etching depth and X-ray absorbed Energy on exposed the PMMA

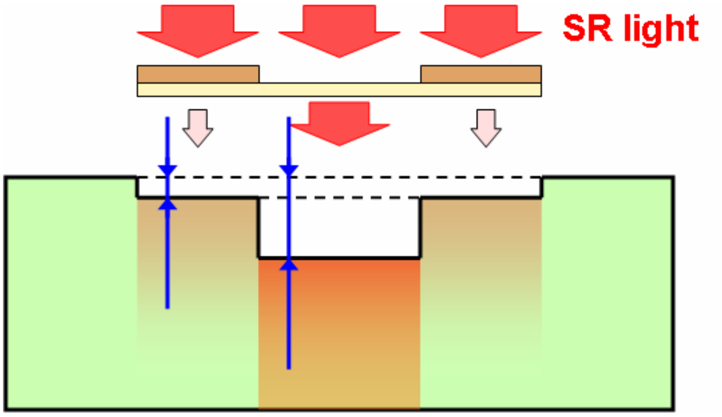

Fig.4 Processing depth of "membrane part" and "membrane and absorber part"

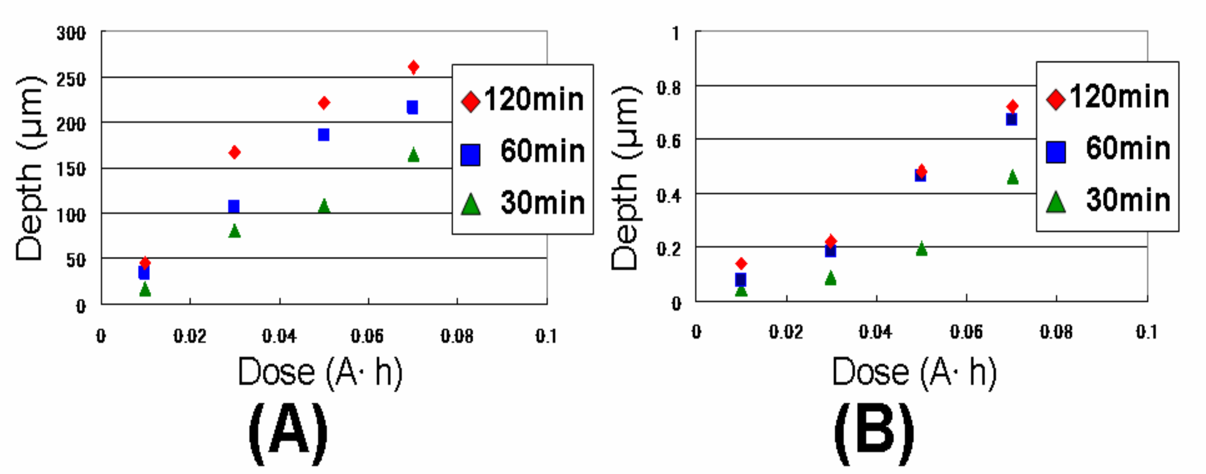

Fig.5 The relation of the development time and processing depth where the development temperature is 25 °C; (A) is through the "membrane part" ; and (B) is through the "membrane and absorber part"

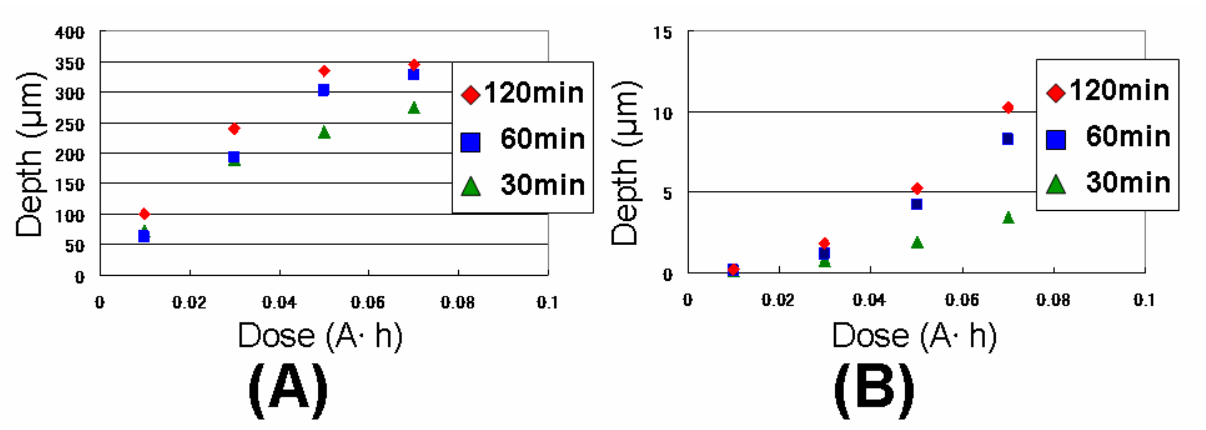

Fig.6 The relation of the development time and processing depth where the development temperature is 40 °C; (A) is through the "membrane part" ; and (B) is through the "membrane and absorber part"

And the relation of the development temperature and development limit energy shows figure 7. This data are based on both experimental values and theoretical values. If absorbed energy amount of PMMA is lower than development limit energy, PMMA dissolve to developer.

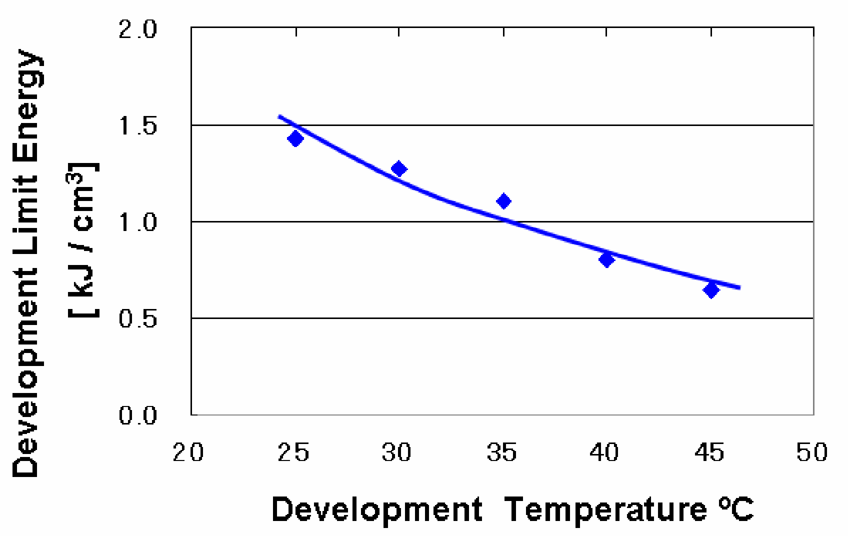

Fig.7 The relation of the development temperature and development limit energy

4. Fabrication of 3-D Structures

Three-dimensional PMMA microstructures are fabricated utilizing this method. Figure 8 are results when development temperature is 25°C, (A) is dasage:0.03A· h, development time:1h, (B) is dasage:0.05A · h, development time:1h. Figure 9 are results when development temperature is 40°C, (A) is dasage:0.05A· h, development time:1h, (B) is dasage:0.07A· h, development time:2h.

As shown in figure, when development temperature is low, inclination angle is nearly 0 degree regardless of dosage. On the other hand, when development temperature is high, microstructures with sloped sidewall are fabricated. And when dosage is high and development time is long, inclination angle is large. These results show inclination angle and structure height are controlled by dosage, development time, and development temperature. The deeper dissolution of PMMA under absorber part of X-ray mask, the lager inclination angle.

Although complex microstructures are not possible to fabricate utilizing this method, microstructures with draft angle for molding process are fabricated easily. Moreover high aspect ratio structures are fabricated at low development temperature even if low contrast mask is used.

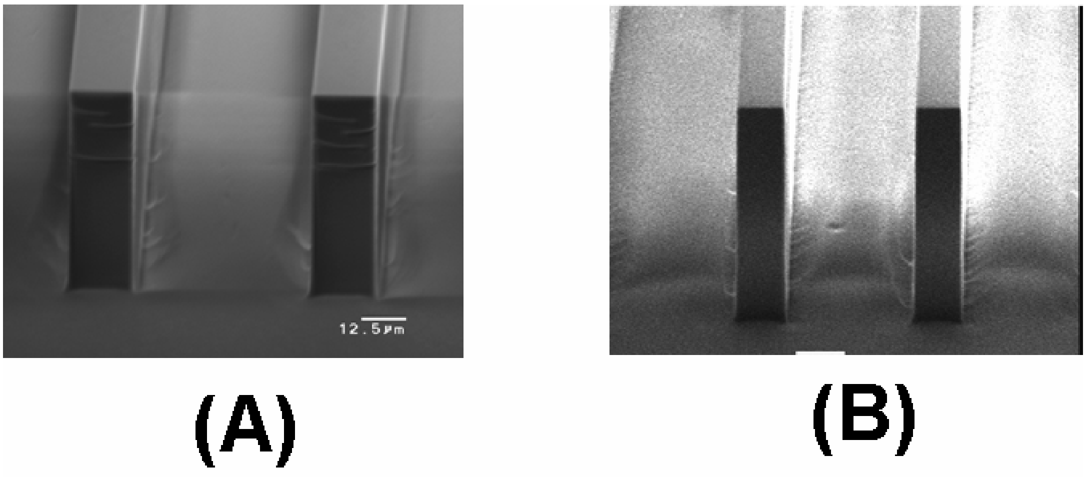

Fig.8 The SEM photos when development temperature is 25ºC, (A) is dasage:0.03A·h, development time:1h, (B) is dasage:0.05A·h, development time:1h.

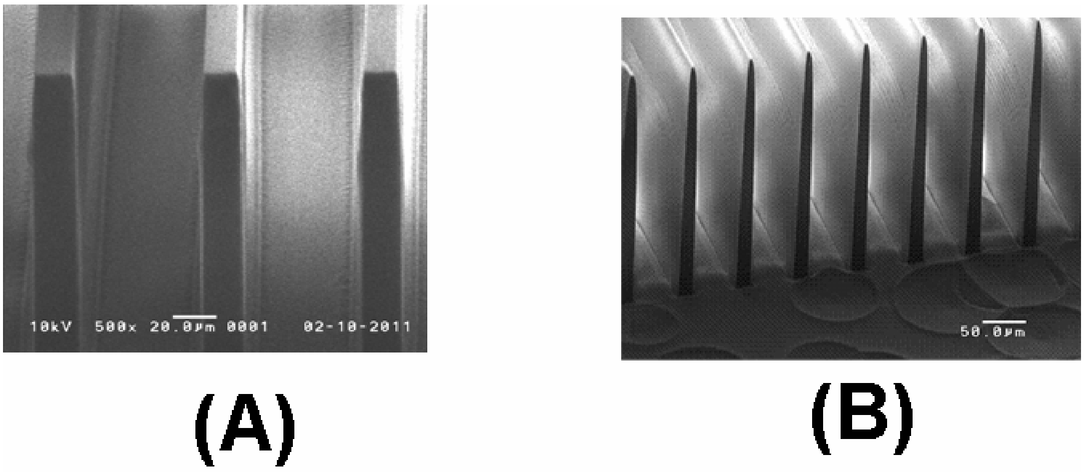

Fig.9 The SEM photos when development temperature is 40ºC, (A) is dasage:0.05A·h, development time:1h, (B) is dasage:0.07A·h, development time:2h.

5. Conclusions

We devised a new method of three-dimensional microfabrication utilizing SR lithography. This method is used the relation of the development temperature and development limit energy, three-dimensional microstructures with sidewall inclination are fabricated by the development of PMMA under absorber part of X-ray mask. Although complex microstructures are not possible to fabricate utilizing this method, microstructures with draft angle for molding process are fabricated easily. In this time, we describes not only fabrication results of three-dimensional PMMA microstructures, but also the relation of the development time and processing depth where the development temperature is changed, and the data of relation of the development temperature and development limit energy amount. As the results, we succeed fabrication of three-dimensional PMMA microstructures. When development temperature is low, inclination angle is nearly 0 degree regardless of dosage. On the other hand when development temperature is high, since PMMA under absorber part of X-ray mask is developed, inclination angle become large. Since this method is easy process and possible to fabricate microstructures with sloped sidewall, this research was aimed at the fabrication of draft angle for molding process.

References

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