

# **A sub-micron Line and Space fabrication by the X-ray lithograph technique**

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## **Abstract**

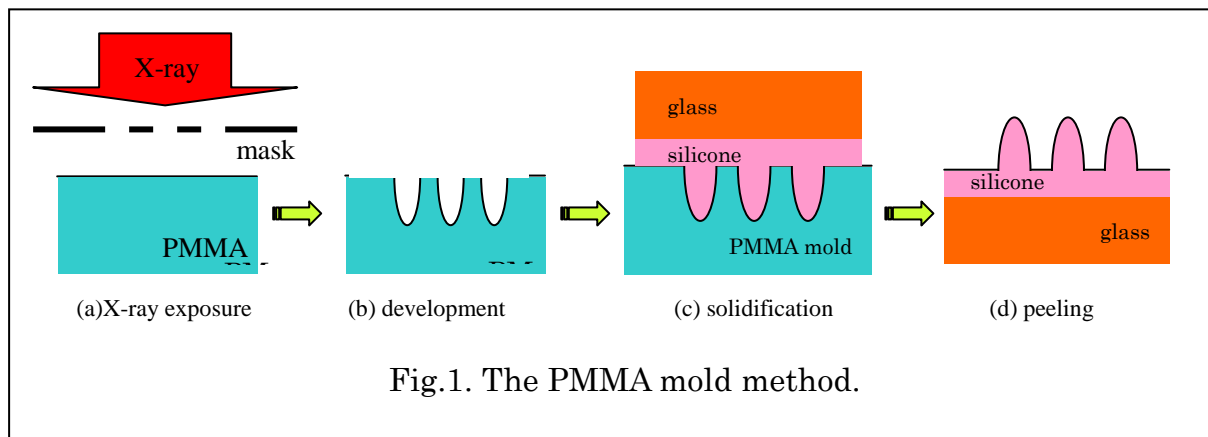
To establish a basic process for visible optical device, the sub-micron line and space (L&S) structures were produced experimentally by the X-ray lithograph technique. It was confirmed that a  $0.25 \mu\text{m}$  L&S can be made on a commercial PMMA seat, not a PMMA resist [1]. This PMMA could be used as a mold and many silicone replicas could be fabricated. Any damage of the PMMA was hardly observed because silicone is soft. The silicone was peeled off easily. The aspect ratio limit was approximately ten.

## 1. Introduction

It is very attractive to fabricate visible light system elements with a low cost. It is necessary to make a sub-micron structure device and to establish a replica making process.

Usually a lot of replicas are fabricated from the metal dies by the plating method [2].

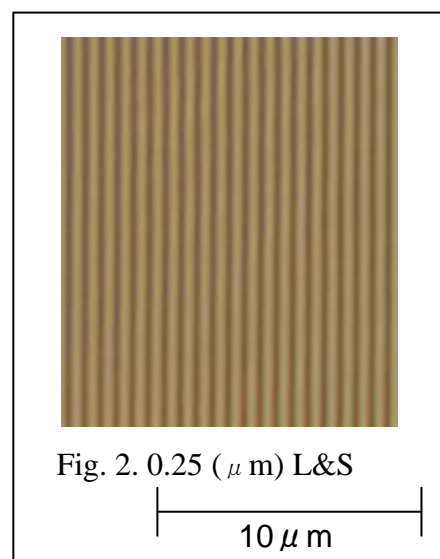
In contrast with it, in this paper, I propose a method to use an exposed PMMA as die [3]. Figure 1 shows the outline. First a PMMA mold is made by the X-ray lithography technology and is developed. Next silicone is dripped on the PMMA and is solidified by heating. The silicone can separate from the PMMA easily because there is no adhesion. This method could produce a lot of replicas. Silicone is transparent and soft. To be transparent is desirable, but to be soft is not for an actual device.



## 2. Results and Discussion

In the present experiment, a mask with 1.0, 0.5, and 0.25  $\mu\text{m}$  line and space pattern was used.

The photograph of the mask with 0.25  $\mu\text{m}$  lines is shown in Fig. 2, in which white lines are Ta metal for X-ray absorber, and black lines are SiN membrane. These masks were made by NTT-AT co., by using the electron beam lithography. The 0.25  $\mu\text{m}$  line width can be seen clearly. And the line interval was 0.50  $\mu\text{m}$ .



## 2.1 X-ray mask

Figure 3a shows a typical X-ray mask which is composed of Au deposited on polyimide. However, it is impossible to make a several micron structure, since polyimide membrane expands thermally by X-ray exposure (about  $50^{\circ}\text{C}$ ). Accordingly, in the experiment, I adopted  $2\ \mu\text{m}$  thick SiN film as the membrane, as shown in Fig. 3b. SiN has a smaller thermal expansion than polyimide. But this mask was very fragile and expensive, and its handling should be very careful so as not to break. So the safeguard is added.

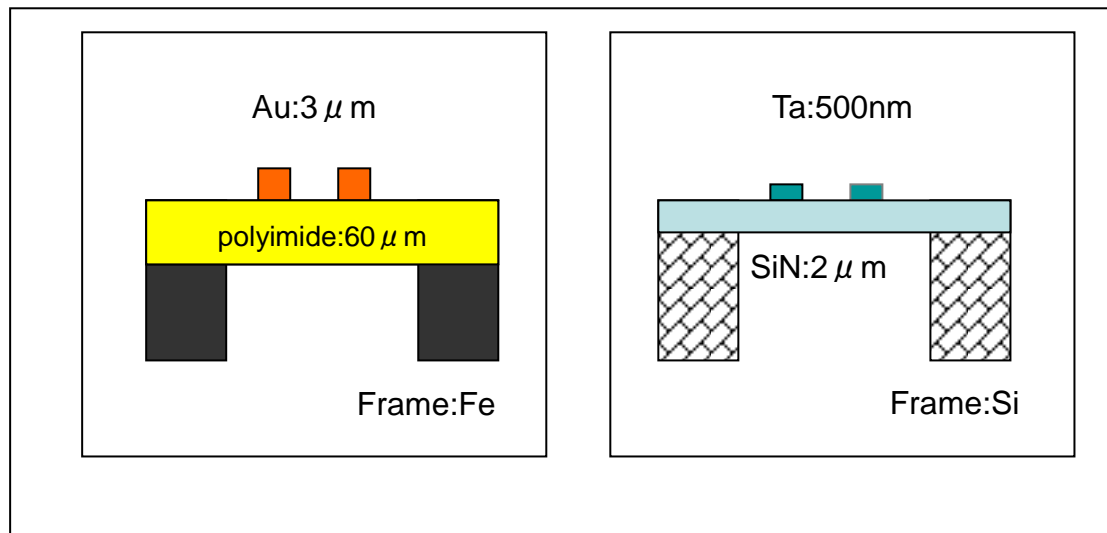


Fig. 3a. Typical X-ray mask

3b The X-ray mask used in the paper

## 2.2 Narrowing of the pattern width

Under the sub-micron patterning, a narrowing of the line's width was observed. It was found that the line's width has a close relation with the gap between the mask and PMMA (see Fig. 4). The results are shown in Fig. 5. The width becomes narrower as the gap is longer. As shown in Fig. 6, the PMMA was cut in the dashed line direction and its cross section was examined. The shape was not rectangle, but triangle. Two possible causes can be considered; one is due to X-ray diffraction, and another is due to non-parallel beam effect. Although it is not decisive which is correct, the above experiment suggests that

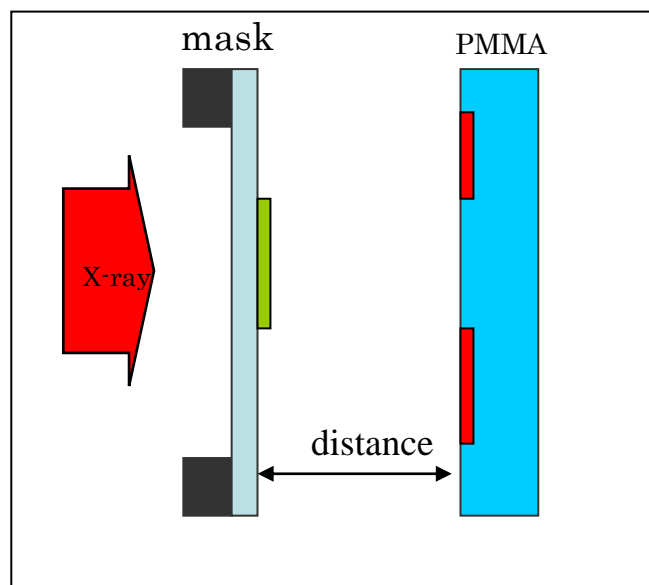
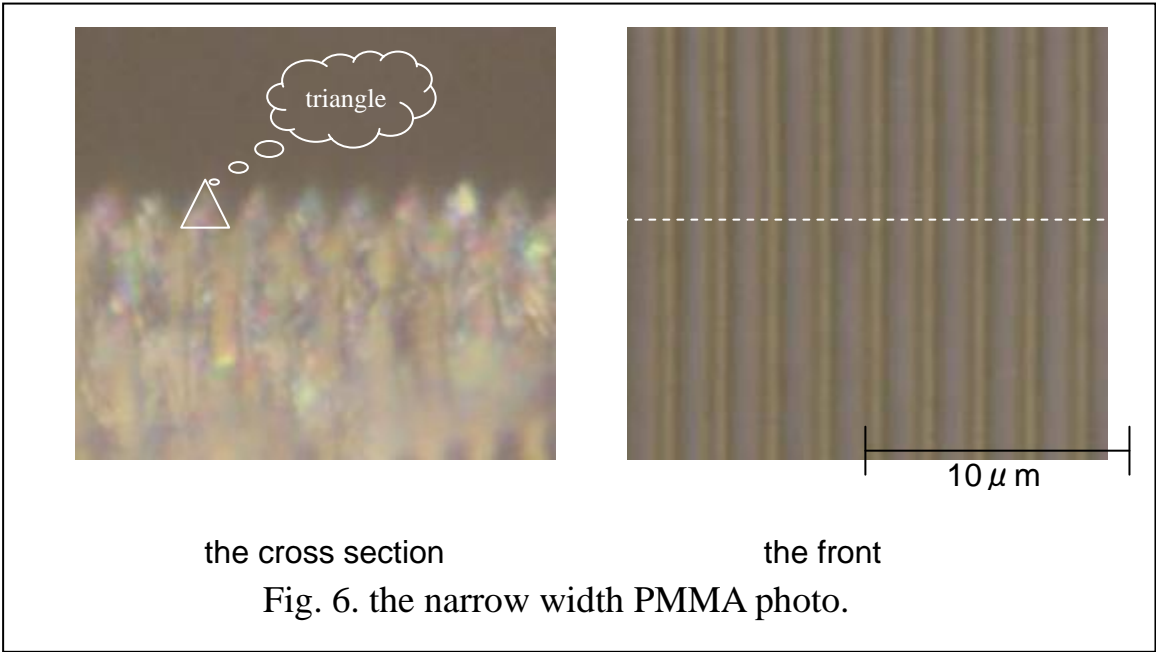
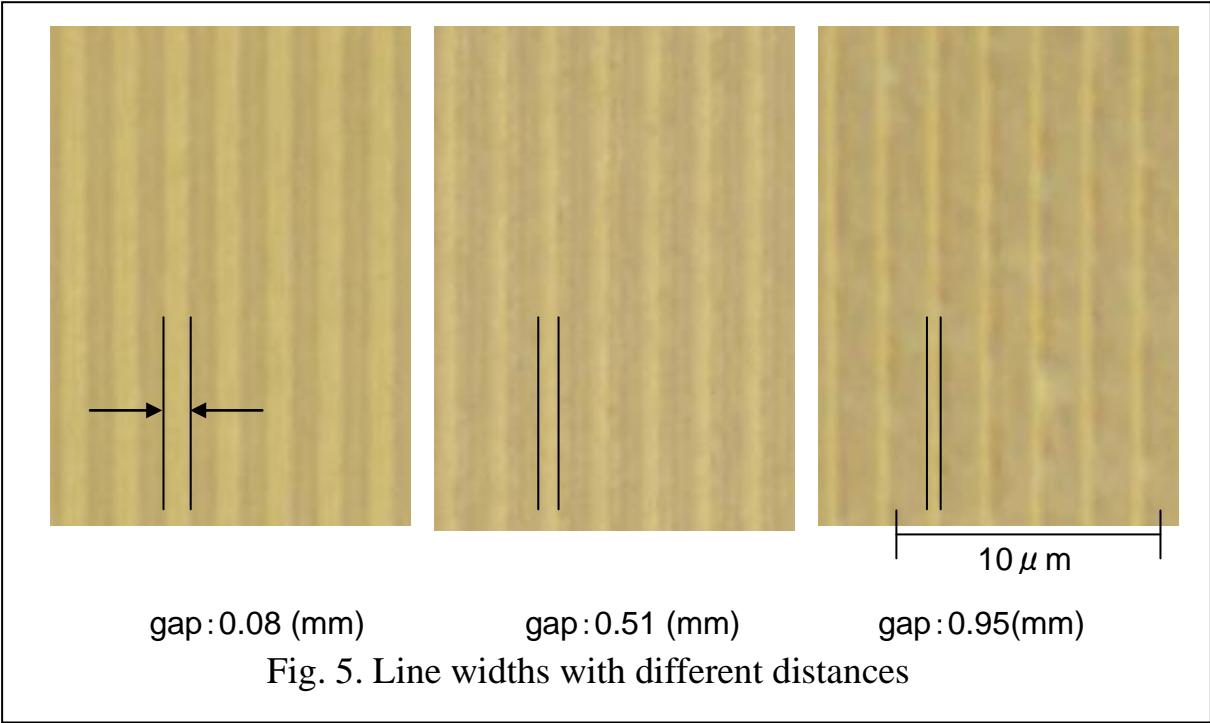


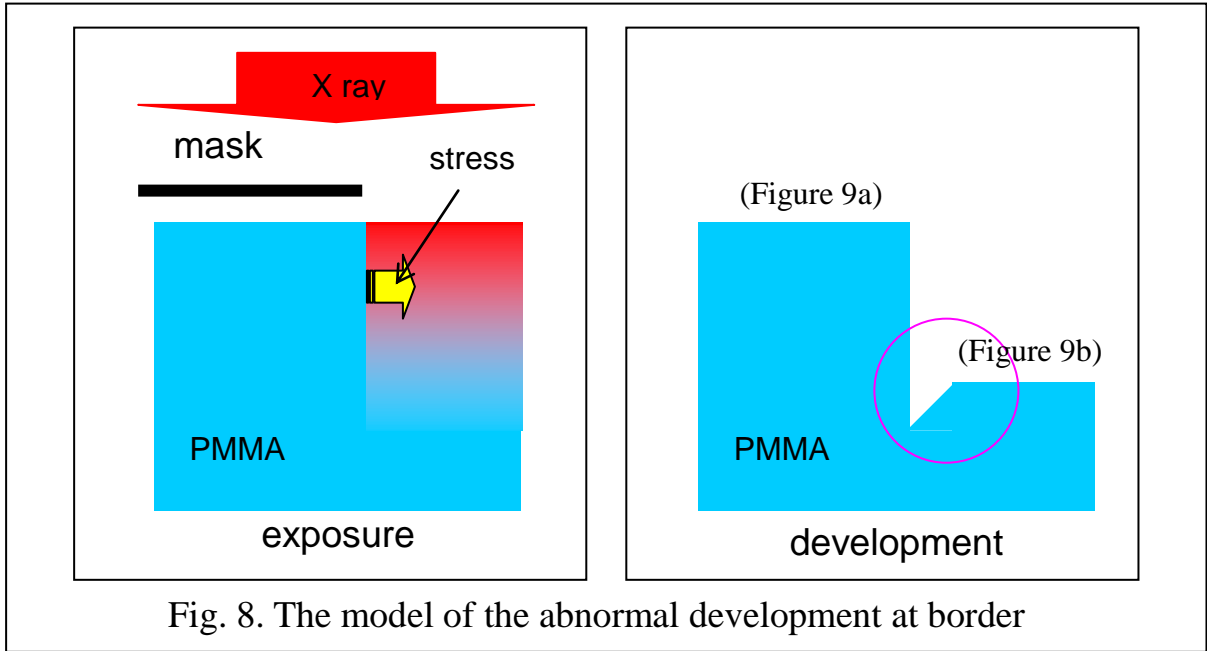
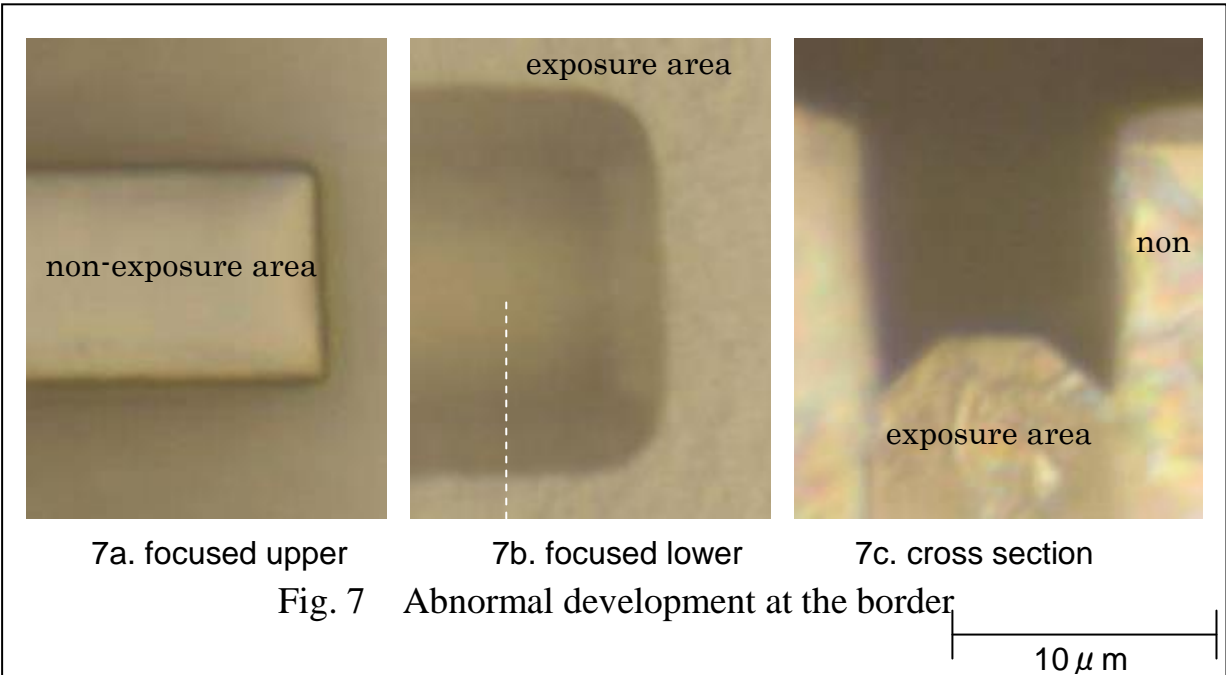
Fig. 4. Exposure condition

the short distance is necessary to keep the line width. This distance must be less than 0.1 (mm). Therefore remodeling was necessary to set the mask safely on the exposure device.



**2.3 Abnormal etching at the exposing border**

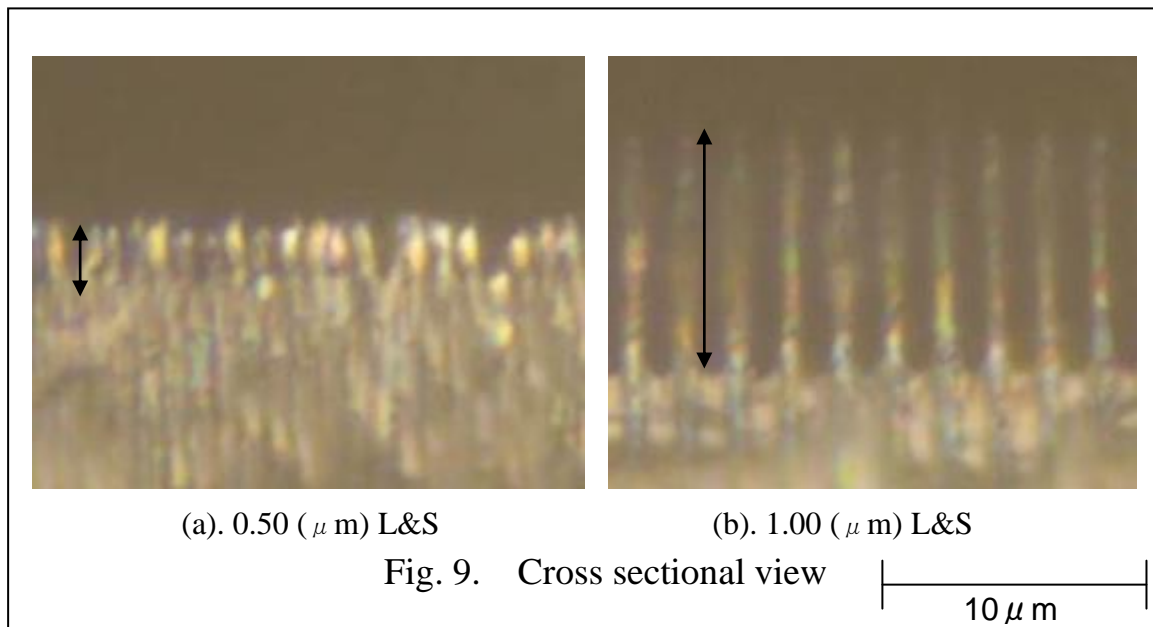
The abnormal development was seen at the border of the exposure and non-exposure, as shown in Fig. 7. The Fig. 7a was focused at an upper part and 7b was at a lower part. Fig. 7c was the cross section of the PMMA cut in the dashed line. Schematic model is shown in Fig. 8. This abnormal etching was observed at an early stage of development, and became bigger as the development proceeded. This might be associated with the stress at the border by the fact that the broken PMMA by X-ray shrinks. The etching rate is higher under the stress than that of other area. Etching rate at the border has something to do with mechanical matter. And annealing test was tried, but any distinct effect was not observed yet.



## 2.4 The development depth

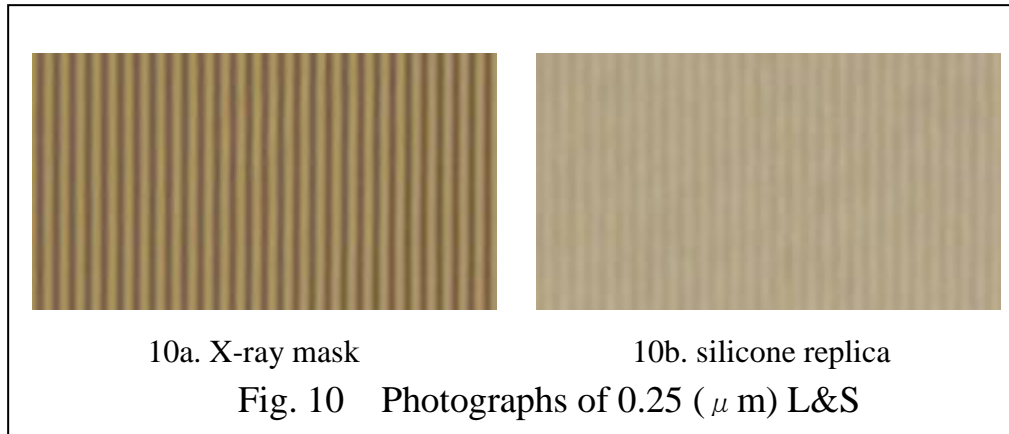
Under the sub-micron patterning, the etching depth was different, depending on the pattern width. The cross section photos are shown in Figure 9. The 9a is  $0.5 \mu\text{m}$  L&S, and 9b is  $1.0 \mu\text{m}$ . These were done under the same dose and development conditions. The  $1.0 \mu\text{m}$  L&S is deeper than approximately 4 times than  $0.5 \mu\text{m}$ . It is clear that this difference happened during the development. It is thought first that the etching rate is limited by the etchant supply.

When the exposed PMMA samples were observed in detail during the development, the material with the adhesiveness was observed in the development early time. And this material was not seen after 20 min yet. The polymer etching is said that it is swell and spread in a solvent unlike the metal. The exhaust process of this material might be limited in case of the narrow patterning development. This is suggested that the pattern width as well as the exposure and the etching conditions is the important factor for the etching depth.



## 2.5 Sub-micron L&S

The sub-micron L&S were produced experimentally to base on an upper laboratory finding. The silicone replica was made as shown in Fig. 10 in which (a) is the mask's photo, and (b) is the silicone replica. The transfer can be performed satisfactorily. Any damage was not observed in the PMMA mold by the cyclic test. When we make a deeper L&S structure, it sometimes occurs that neighboring lines adhere to each other after silicone replica process. In case of  $1.00 \mu\text{m}$  L&S structure, the depth was limited to about  $10 \mu\text{m}$ .



## 2. Summary

I have made sub-micron L&S silicone replicas successfully. It is also important how many pieces can be fabricated, since this is related to the production cost. I confirmed that the same PMMA could be used without any serious damage over 20 times.

## References

- [1] S.Fujinawa, F.Kato and S.Sugiyama : *Memoirs of the SR Center, Ritsumeikan University*, 2006, No.8, pp.27-33
- [2] H.Ueno, N.Nishi and S.Sugiyama : *Memoirs of the SR Center, Ritsumeikan University*, 2000, No.2, pp.39-49
- [3] H.Ikeda : *Memoirs of the SR Center, Ritsumeikan University*, 20110, No.13, pp.39-47