Manufacturing a micro lens array with X-ray lithography using a new exposure method

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Abstract

A new method to fabricate a 3D structure by using X-ray lithography was proposed and applied to manufacture a micro lens array system. The key idea of the method is to make a wide gap between a mask and PMMA resist. By making a wide gap, the exposed area on the PMMA resist is expanded and the square pattern corner is rounded. The cross section at the boundary changed to an S-type shape. This new method must be appropriate to make a taper or round structure. A micro lens array was manufactured with this newly developed process using PMMA mold and silicone rubber.

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1. Introduction

X-ray lithography is a very unique technology, but its applications have been rather limited, compared with other lithography techniques. Making a 3D structure is a challenging task. Although several methods for 3D manufacturing have been reported, they are all complicated. A simple and cheap method to fabricate a 3D structure is more promising. Here, I propose a new method, which is simple and straightforward. Figure 1 shows several methods to make 3D structures schematically.

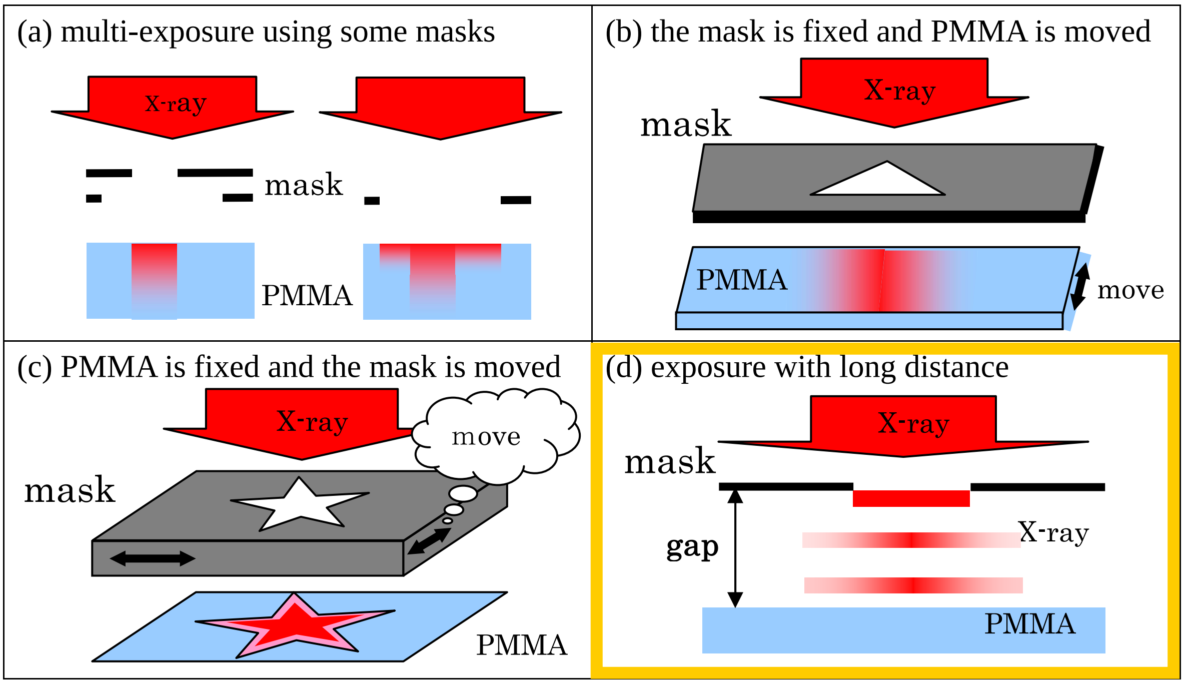

Fig.1 Several methods to fabricate a 3D structure

They are multi-exposure methods using several masks[1], fixed mask and moving PMMA[2,3,4], and fixed PMMA and moving mask[5,6]. All of these methods are based on the common idea to change the spatial dose on the PMMA resist.

Another method might be to expose X-rays, making a wide gap between the mask and resist. The conceptual diagram of this method is shown in Fig.1(d). Even though the synchrotron radiation is highly directional, an exposed pattern is not clear at a long distance. In fact, X-ray intensity changes gradually at the boundary of exposed and non-exposed areas. It is not only due to diffraction, but also scattering by Be windows and a mask.

2. Experiments and Results

A. The exposure apparatus

The apparatus for these experiments is very simple as shown in Fig.2. The distance between the mask and PMMA were fixed by inserting several spacers of a thickness of 5.0±0.1mm.

The X-ray mask was fixed on the stage with screws to prevent from staggering. An automatic supply can be set easily as an attached part.

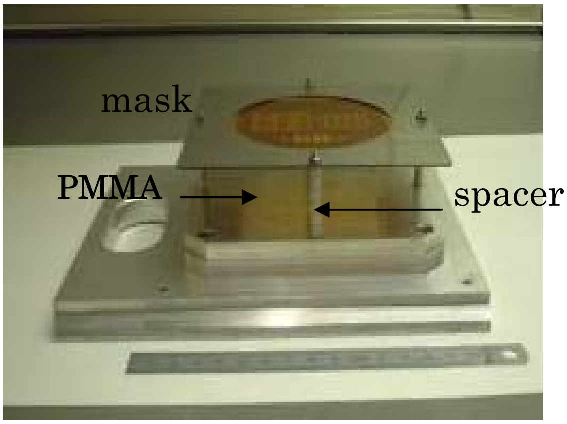

Fig.2 Photo of the apparatus

B. Effect of the gap change

The synchrotron light comes from the storage ring, AURORA through two 200 μm thick Be windows and a mask of Ni mesh for TEM to the PMMA resist. I examined the relation between the X-ray exposed area size and the gap between the mask and PMMA resist. The PMMA sheets were exposed with same dose and developed for the same time. The results of the gap 10, 20 and 30 mm are shown in Fig.3. The 400 mesh/inch mask (above step) and 150 mesh/inch masks (below) are used. The shape at no gap was just same of the mask's hole, but with a wider gap, following features were observed.

a. The pattern area was larger.
b. The corners of the square were rounded.
c. A little difference was observed along horizontal and virtual directions.

First, the relation between gap and expanding form was investigated. In Fig.4, the increased width is plotted as a function of the gap, where the width is defined as the length of an arrow shown in Fig.3. A good linearity was observed, and both 400 mesh/inch mask and 150 mesh/inch were on the same line. It shows that the expanded quantity depends only on the gap width.

Second, roundness arrives at the corner by nature. This method is not so good for fabricating a square pattern, but it may be no problem because this is so small circle pattern.

Third, the differences along horizontal and vertical directions might come from the character of the SR light. The adjustment is possible at making the mask. But actually this will be no problem because the difference is rather negligible.

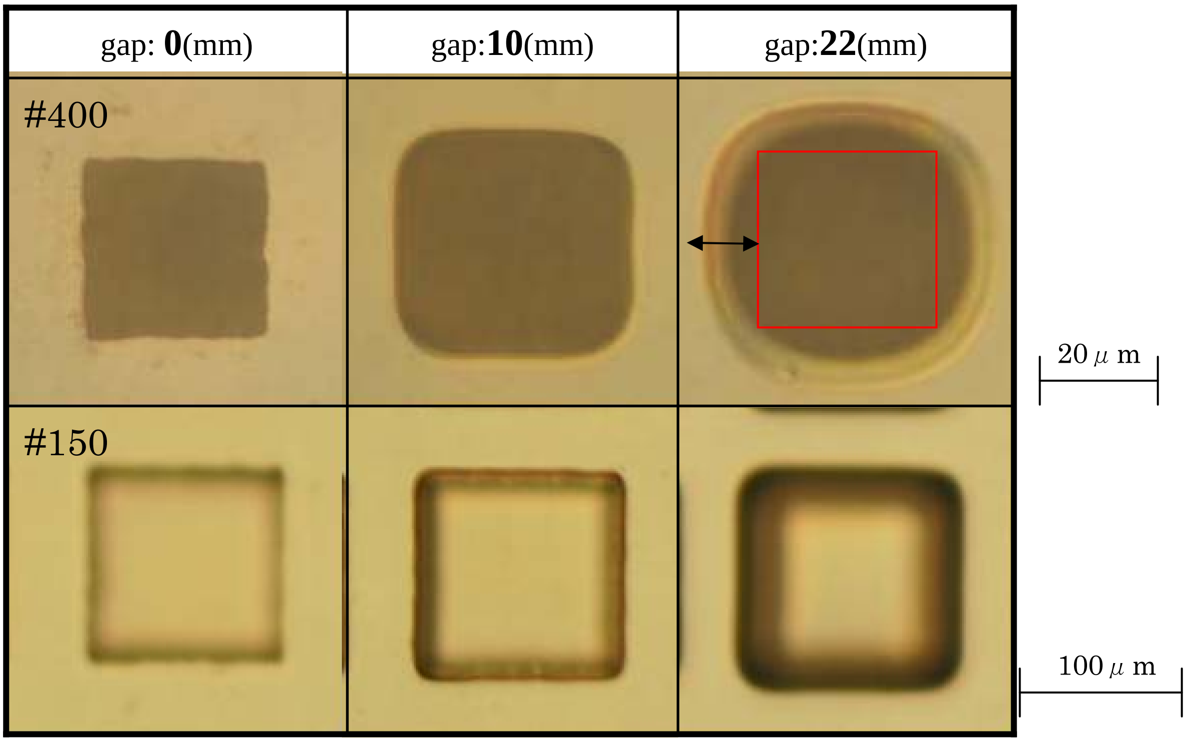

Fig.3 the PMMA shape images with several gaps

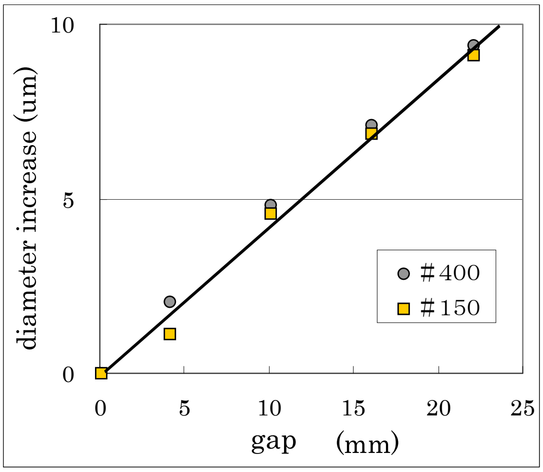

Fig.4 the relation of exposed area and gap

C. Cross section of the PMMA hole

The PMMA resist can be patterned vertically with X-ray lithography. This is not only due to the high directionality of the SR light, but also due to the development mechanism. However, making a wide gap collapses the vertical and straight patterning character.

The cross sections of the PMMA resist exposed with several gaps were examined. The results are shown in Fig.5. In the precise observation, the cross section is not linear, but tapered with the letter, ‘S’. These shapes are decided by the dose change in the plane and depth directions, and the PMMA etching rate. The X-ray dose change on the plane is mainly caused by the gap between the mask and the resist. On the other hand, the dose change along the depth direction depends on the absorption coefficient of PMMA, and the energy distribution of SR light is also an important factor.

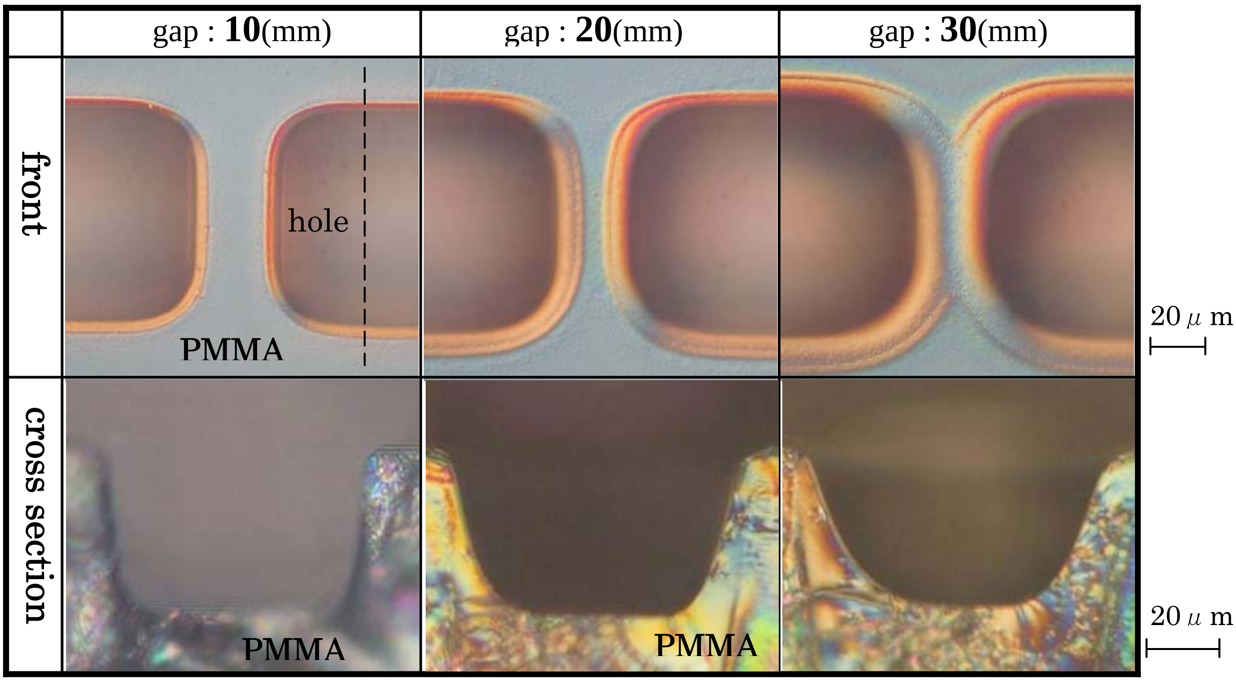

Fig.5 The front and cross section with each gap

D. Process of making a micro lens by the exposure method with a long gap

Next a micro lens array manufacture process is examined using the new exposed method. Three processes were considered to make the convex lens as shown in fig.6.

(a) X-ray mask for the convex lens structure is prepared. This mask's figure is shown in fig.7 (1), which consists of Au circle dots on the polyimide membrane.

(b) The PMMA mold is exposed by SR light through the mask (shown in fig.7 (2)) and is developed, Array of holes is made on the mold. This mask consists of the circle holes in the Ni thin sheet. Next transparent and high permittivity material is put in the hole on the mold.

(c) The circle hole is made on the mold by the process (b). Next a silicone rubber is put on the PMMA mold, and solidified. Then this is stripped from the mold.

In these three processes, the cost performance of the process (c) is the best, because a lot of products can be manufactured by one PMMA mold.

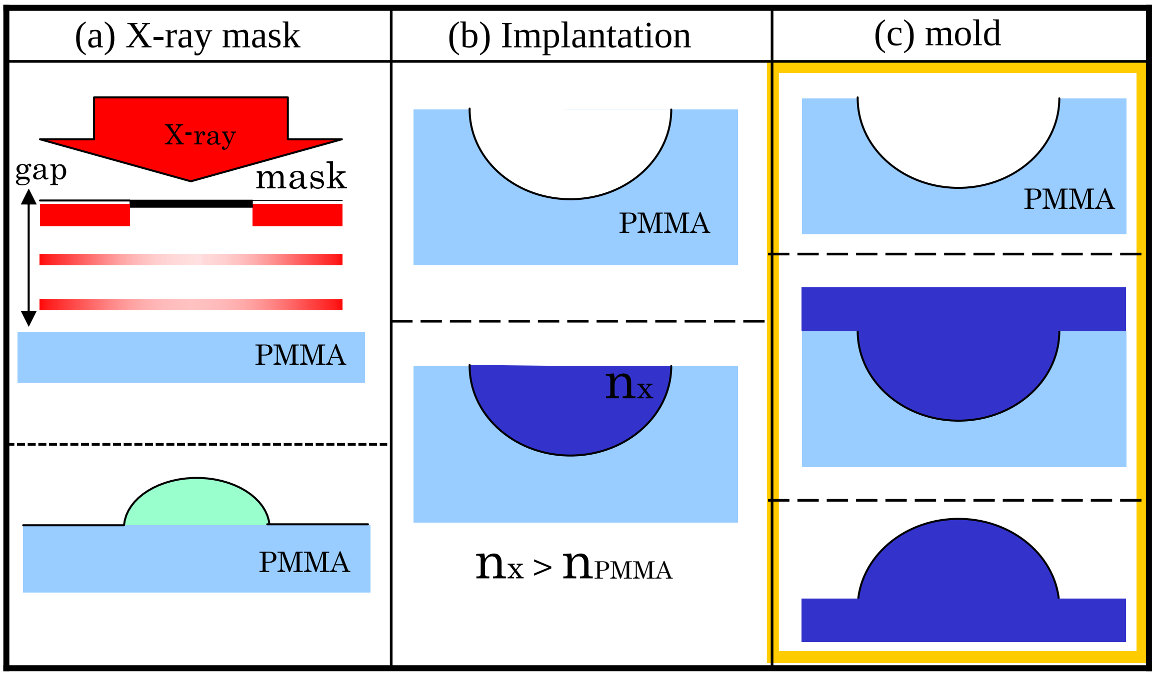

Fig.6 The examined methods to make the micro lens

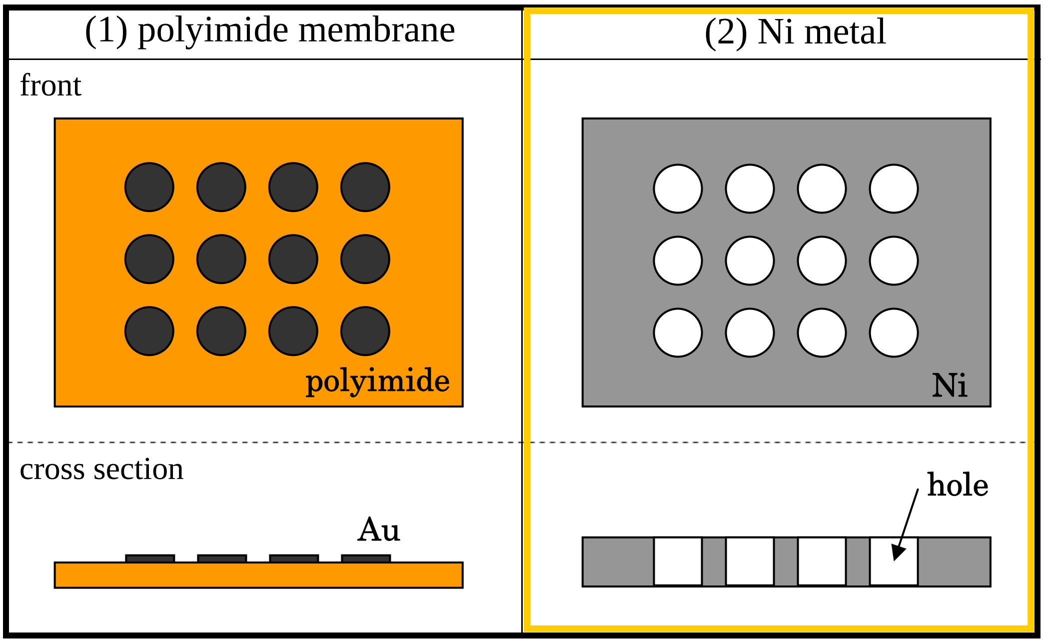

Fig.7 The X-ray mask

E. Detailed description of the process (c)

To establish the process (c), selection of the material putting on the PMMA is the most important. This material should be transparent and non-coherent with PMMA. Furthermore, it is better to complete in a short time. Examining several materials, silicone rubber was chosen.

But it has a problem that it takes about 30 min to solidify, and is so soft that it needs a glass to support. The process is summarized as follows; (a) exposure and development, (b) a silicone rubber is put on PMMA and de-bubbled, (c) a sheet of glass put on the rubber and solid silicone rubber in oven, and (d) strip silicone rubber out from the PMMA. The process summary using silicone rubber is shown in fig.8.

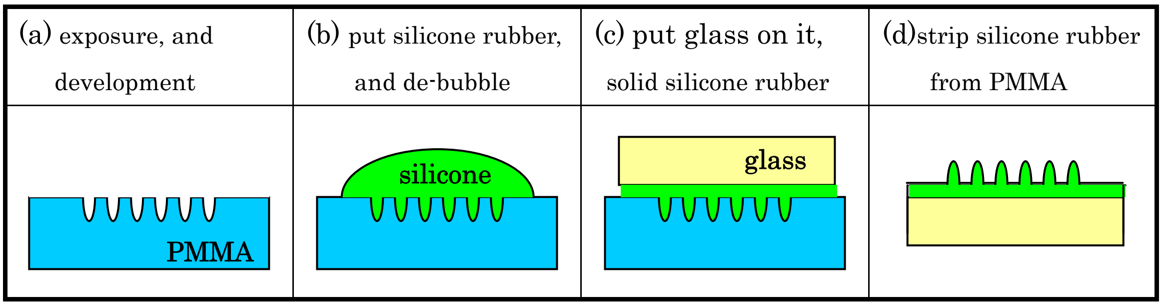

Fig.8 The PMMA mold process using silicone rubber

F. Manufacture of a micro lens

A Ni foil was used as an X-ray mask, whose thickness is 20 μm with holes of ϕ40 μm (in Fig. 9). This was a commercial product for printing use, and the precision of the holes was not so good. If the mask's demanded size is over 30 μm level, the metal mask for printing is enough. In case of this micro lens, it was no problem due to gradual X-ray change fortunately.

The PMMA was exposed for 10 min with 30 mm gap between the mask and PMMA. Then, it was developed for 4 hr at 35 ℃ by GG etchant. As shown in fig.9, the circle size on the PMMA is larger for the planned one of the mask.

The silicone rubber was stripped out from the PMMA mold by the process of Fig.8. It was well replicated without using any remover as the SEM photograph shown in Fig.9. Replicated surface was smooth and not damaged apparently. However, if we aim to make a deep structure without any taper, a strong force might be necessary to strip the silicone rubber from the PMMA. Whether a remover is necessary or not should be decided, dependent on the structure with a limited height, size, taper, and exposure area.

Finally, the copying time was examined. The PMMA mold was made from 200 μm thick sheet. The etching depth was 40 μm, and the exposed area was about 100 mm^2. The mask and copying process were described above. The 20 times copying by one PMMA mold was tried in succession. There was no problem as shown in Fig.10, except residual wastes of silicone rubber. I did not check how many repeating process is allowed for the PMMA mold. The waste happened to generate not at the exposed area, but at the protruded position from the glass cover. For the mass production, cleaning of the PMMA mold may be necessary.

X-ray mask	PMMA mold	Replica: silicone rubber
Ni metal	gap : 20(mm),	transparent silicone
100,000 yen	exposure:10(min)	copy : 20 (times)

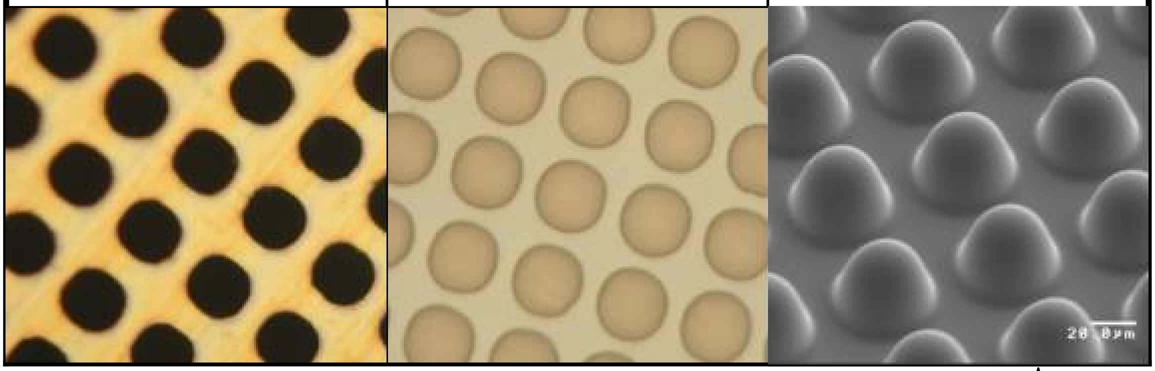

Fig.9 The micro lens making by PMMA mold

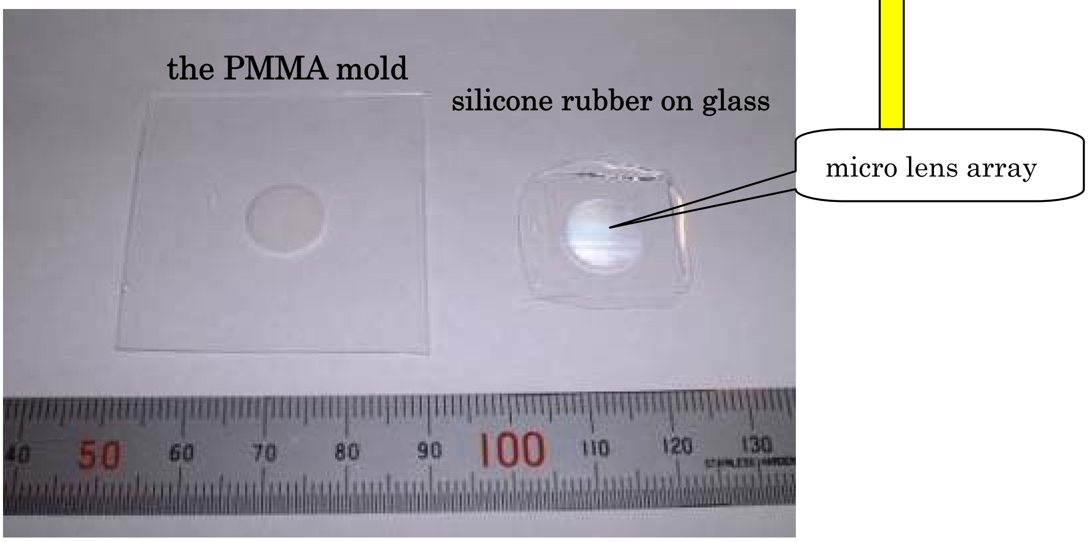

Fig. 10 The PMMA mold and silicone rubber on a glass

3. **Summary**

A new method to make a 3D structure by X-ray lithography was proposed. This method is based on making a wide gap between the mask and PMMA resist. With a wide gap, X-ray intensity changes gradually at the boundary of exposed and non-exposed areas. As the gap is wider, an etched pattern is larger and a square corner is more rounded. The shape increase is in proportion to this distance. In the vertical direction, the cross section is not linear, but is curved as a letter ‘S’. From these results, this new method is good to make a taper and round shape structure, for example, a lens.

The basic fabricating process of a micro lens array was established, named "PMMA mold method". This method uses PMMA as a mold, instead of metal. Silicone rubber was chosen as a replicating material because of its transparency and non-coherency with PMMA. The silicone rubber takes about 30 min to solidify. This basic process can be applied to any kind of structures theoretically, but in case of a complicated structure, stripping process from the PMMA mold would be a key factor. Use of a remover might be important. From the view of mass production, it is important how many times the PMMA mold can be used for replication. After 20 times of repeated process in succession, no damage in the PMMA mold and no deterioration in silicone rubber were observed. In this work all the processes were performed manually. An automatic stripping machine might be necessary for mass production.

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