# Study on Deep X-ray lithography for Fabrication of Microactuator

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**Abstract**

This paper is reported about a research of deep X-ray lithography for the realization of an electro-magnetic linear actuator. X-ray lithography is most important process in the LIGA (Lithographie, Galvanoformung, Abformung) process. If accuracy of a matrix structure fabricated by X-ray lithography is bad, next processes will also be affected. In order to enable deep etching, increasing, there is approach of an increase in a dose amount, an increase in development temperature, etc. However, these have a relation of a trade-off to processing accuracy. In this research, we tried penetration exposure of thickness PMMA on a Si chip and investigated about a optimal condition of exposure and a development process. Moreover, it considered about etching in narrow space.

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## 1. Introduction

LIGA (German acronym for Lithographie, Galvanoformung, Abformung) process using Synchrotron Radiation (SR) light is one of a most promising technique to fabricate high aspect ratio microparts for Micro Electro Mechanical Systems (MEMS) [1]. In the LIGA process, X-ray lithography is possible to make higher aspect ratio structures than photo lithography using ultra violet (UV) rays.

Microactuator is one of the components of MEMS, and some actuators various type are studied. Electrostatic microactuator is one of them, and the output is determined by the touch area, gap distance, etc. So far, there are many reports about microactuators fabricated by surfacemicromachining. The height of microactuators is limited to about 1 to 10 micrometer in surfacemicromachining. However, the LIGA process can fabricate high aspect ratio microactuators with height of more than 100 μm. Therefore, the drive in high output is possible. In this research, we study on fabricate of microactuator with height of more than 400 μm.

## 2. Fabrication and Experimental Conditions

Process flow is shown in Fig.1. Since Ni has to be electroforming from Si surface (TiOx layer), we have to be penetration exposure of thickness PMMA on the Si chip.

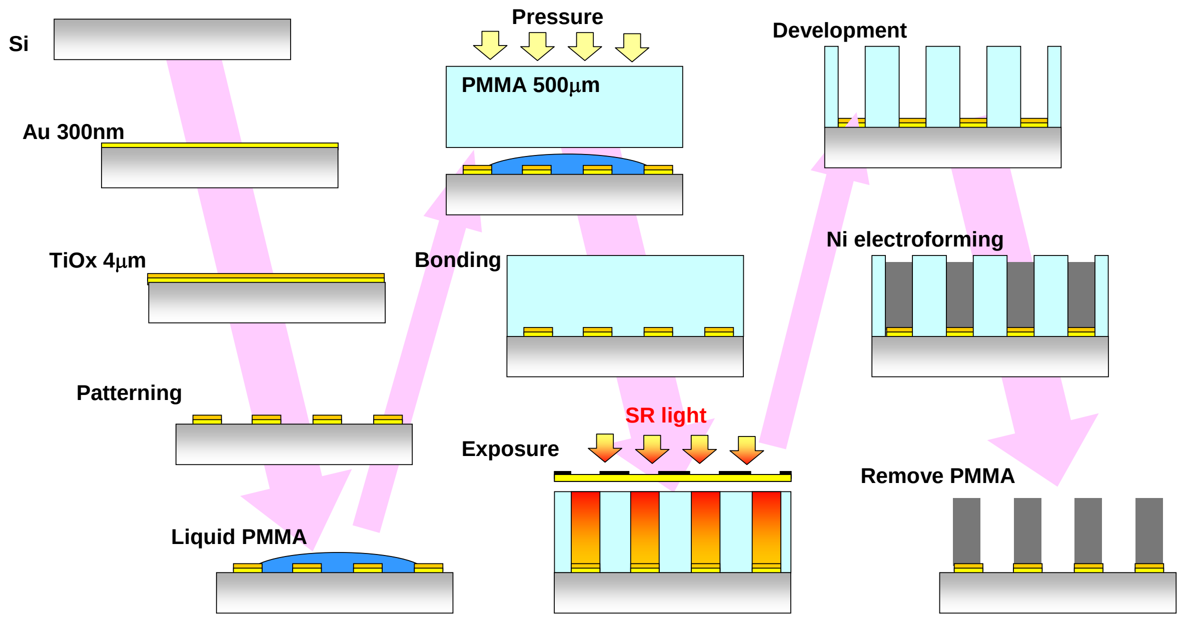


Fig.1 Process flow

A number of experiments were carried out using beam line number 6 (BL-6) at the superconductivity compact synchrotron radiation (SR) source "AURORA", at the SR center, Ritsumeikan University, Japan. 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 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 the X-ray by $N_2$ or $O_2$ gases and to prevent the damage of a 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 [2].

An X-ray mask consists of a Polyimide membrane with a thickness of 50 μm and an Au absorber with a thickness of 3 μm. X-ray mask used the thing of Optnics Precision Co.,ltd. Exposed PMMA structures gradually appear during development using a 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). After that, stopper liquid (80 vol% 2-(2-butoxy-ethoxy) ethanol, and 20 vol% water) is used at the same temperature for 10 minutes, followed by DI-water rinsing for another 10 minutes.

## 3. Optimal Condition of Exposure and Development Process

In order to enable deep etching, increasing, there is approach of the increase in a dose amount, the increase in development temperature, etc. However, these have a relation of a trade-off to processing accuracy.

### 3.1 Optimal Condition of Exposure Process

Since it must be deep etching, much exposure energy is needed. If exposure energy is lowly, absorbed energy is not reached to energy which is the minimum amount of it required for development at a position deep from the surface. On the other hand, if exposure energy is highly, PMMA become severely damaged and it is become a cause of degradation of the processing accuracy. If dosage is high, babble is appeared. When dosage is 2.3 A·h (exposure area is half of the total area), babble is appeared near the PMMA surface (Fig.2). However when dosage is 1.7 A·h, babble is not appeared. Fig.3 shows relation of distance from surface and absorbed energy, red is 2.3 A·h and blue is 1.7A·h. Therefore we think that if absorber energy is leached 80~90 kJ/cm$^3$, babble is appeared. If dosage is 1.9 A·h (exposure area is half of the total area), absorber energy of surface is 78 kJ/cm$^3$. Therefore, we think that best dosage parameter is about 1.9 A·h. Actually, dose is about 1.9 A·h, most bubbles is not seen.

Fig.2 Photos of babble (2.3 A·h)

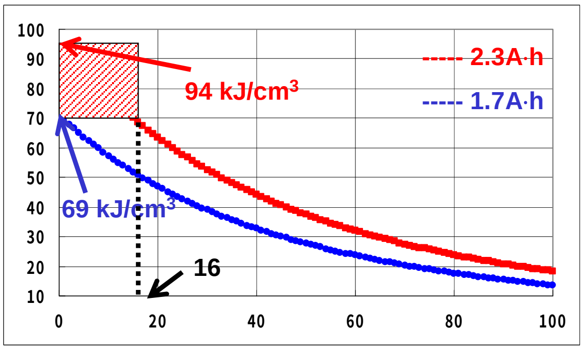


Fig.3. Absorbed energy (2.3 A·h and 1.7 A·h)

### 3.2 Optimal Condition of Development Process

If development temperature is highly, energy required for development is only little [3]. Therefore, the usual development temperature is 37 ℃, this time development temperature change to 50 ℃. Results show in Fig.4. Color changed to white and PMMA came unstuck from substrate. Therefore, development temperature is kept 37 ℃.

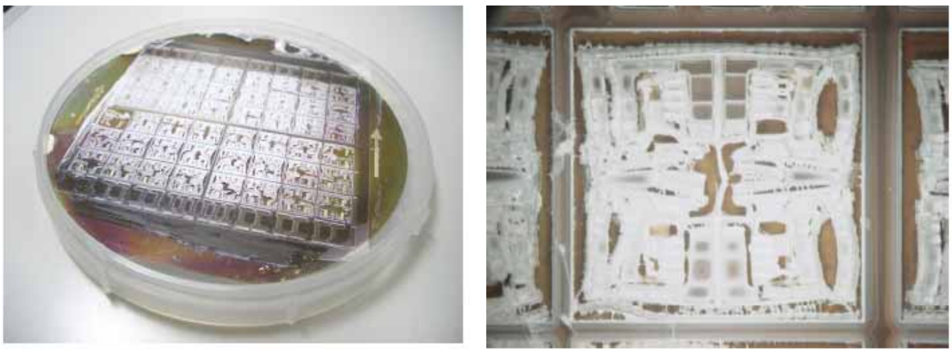

Fig.4. Experiment results (development temperature:50℃)

## 4. Results

Based on results of section3, dosage is decided on 2.3 A·h (exposure area is half of the total area) and development temperature is decided on 37℃. Using 500 or 600 μm thickness PMMA on the Si, it experimented several times. However, penetration exposure of thickness PMMA was not successful. Processing depth was more over than 450 mm. In addition, we also checked etching rate is very slowly in narrow spaces.

We thought liquid PMMA is bad (Develop is not possible). So I exposed to only liquid PMMA by using casting method (Fig.5). Dose is 0.7A·h (quarter of the total area) and develop time is 3 hour. Result is that processing depth of liquid PMMA is same to PMMA sheet (Processing Depth: 120 ~ 130 μm). Therefore liquid PMMA might not be a big problem. However, liquid PMMA by using bonding method is compressed, therefore PMMA molecular weight is increasing and it is slightly soluble in developer.

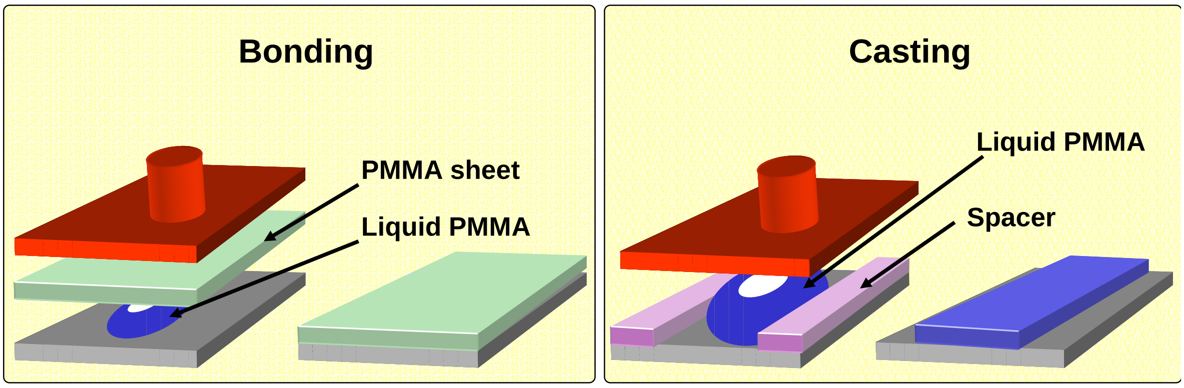


Fig.5. Bonding method and casting method

Next, in order to be penetration exposure of PMMA, PMMA thickness is changed to 300 or 400 μm and development time changed to longer. Penetration exposure of PMMA in large areas are succeed, however narrow areas are not succeed (Fig.6).

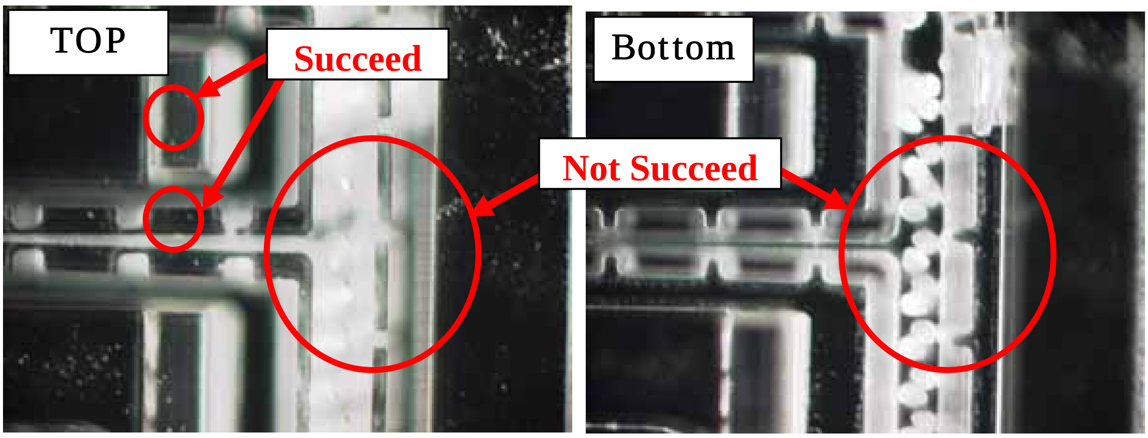


Fig.6 300 μm PMMA sheet (top view and bottom view)

## 5. Conclusion and Discussion

We investigated about the optimal condition of exposure and a development process. And, we tried penetration exposure of thickness PMMA on the Si chip. However it was possible to pass through only limited area. Development of narrow area is not complete. We tried dosage or developing time is increasing, or development temperature is up. However it was not improve so much. Fig.7 shows narrow area of 600 μm PMMA after development. Areas encircled by heavy black line of (A) and (B) are not etched so much.

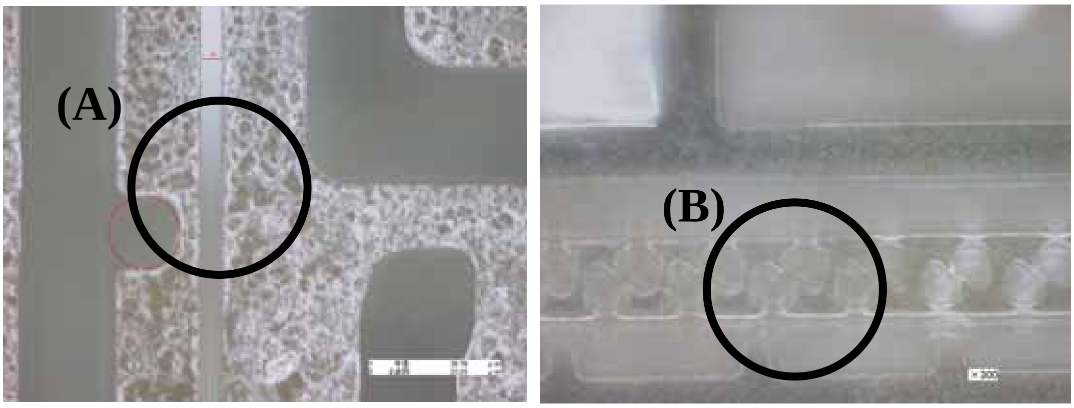


Fig.7 600 μm PMMA sheet (top view and bottom view)

In concession when process depth is about 300μm, width which is possible to pass through is ≥ 15 μm and when process depth is about 500μm, width which is possible to pass through is ≥ 30 μm. Now I think that circulation of developer is bad in narrow area (Fig.8). Therefore, if dosage is increasing, it is not improve so much. There is some improvement plan. For example, it is using ultrasonic wave, changing developer…etc.

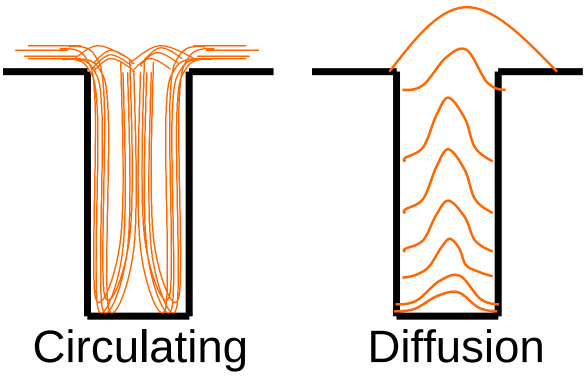


Fig.8 Diffusion effect (micro-loading effect)

**Acknowledgements**

Authors would like to thank Mr. Hiroyuki Ikeda, a technician in the SR center, Ritsumeikan University, for his technical assistance.

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