Paper

Fine Pattern Fabrication on a Polymer Plate by Direct Imprint Lithography

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Fine pattern fabrication on a polymer surface is expected to realize low cost micro/miniaturized total analysis system (μ-TAS), or diffractive optical elements (DOE). Line and space patterns are fabricated on an acrylic plate and a poly L-Lactic acid plate by imprint lithography using Si/SiO_2 mold. The mold is pressed to the polymer plate beyond its glass transition temperature and released after cooling down. Fine pattern fabrication on the polymer surface is successfully demonstrated without expensive advanced lithographic tool and dry etching system. The minimum feature size of the imprinted pattern is 300nm and field size is 1 inch square. This fabrication method is expected to apply for micro/nano structures such as micro/nano channels of micro/miniaturized total analysis system or diffractive optical elements.

Keywords: imprint lithography, mold, polymer plate, acrylic, poly L-Lactic acid

1. Introduction

Fine pattern fabrication is indispensable for research and development of micro/nano mechanical system. Recently, micro/miniaturized total analysis system (μ-TAS), diffraction optical element (DOE), or photonic crystals are reported in elsewhere. These devices have sub-micron fine structures, which are usually fabricated on Si or glass (SiO_2) substrate by photolithography or direct electron beam lithography. Further more, nano fabrication is indispensable technology for advanced integrated bio-chemical analysis system(1). For example, nano pillar array works as artificial gels for deoxyribonucleic acids (DNA) separation chip(2). There have been reported bio-chemical devices by Si or SiO_2 materials using VLSI fabrication process.

One of the difficulties for industrial application of these micro/nano-structures is a fabrication cost because these advanced lithography systems are too much expensive. Also, Si materials are expensive compared with plastics.

Nano-imprint lithography(3) is one of the promising technologies for fabricating an integrated nano structure without advanced equipments or advanced resist materials. There have been reported some applications of this new lithographic technology, which are mainly focused on nano-meter resist pattern fabrication for Si very large integrated circuit system (VLSI).

Polymer materials such as an acrylic plate are suitable for bio-chemical devices or optical elements because they have good dielectric characteristics and high optical transmittance. Also, they are cheaper than Si materials. Micro channels for capillary electrophoresis systems using polymer materials have been reported(4) and delivered in commercially(6),(7). However, the minimum feature size is several tenth micro meter, which is not enough small for DNA analysis or an optical diffractive optical elements.

In this paper, we use an acrylic plate as a substrate material, which is cheaper than Si materials and suitable for hot press processing. Also, we demonstrate fine pattern fabrication on poly L-Lactic acid, which is a biodegradable plastics and disposal material.

2. Direct imprint lithography for polymer plates

Figure 1 shows the process flow of direct imprint lithography for polymer surface. First, a mold and a polymer plate are pre heated over glass transition temperature of the polymer. Then, the mold is pressed into the polymer plate and hold for minutes. Finally, the mold and polymer plate are cooled down below the glass transition temperature and the mold is released from the plate.

Using this method, integrated fine patterns are transferred by a single step without any pre or post processes such as resist coating or etching processes. This method realizes low cost micro/nano fabrication for polymer surfaces.

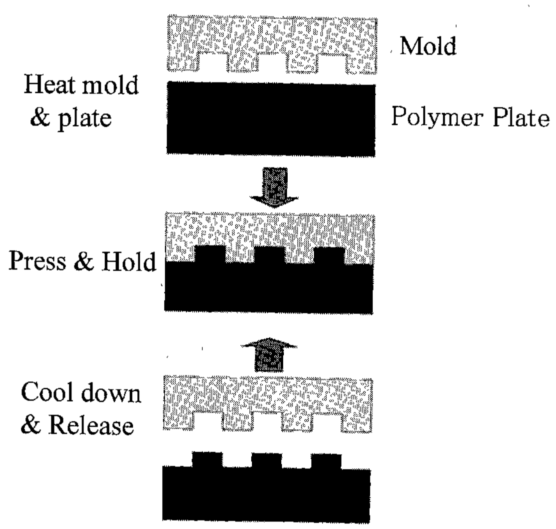


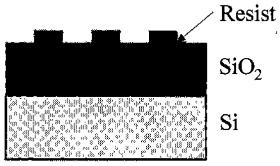
Fig.1 Schematic view of direct imprint lithography process for the polymer plate.

3. Mold fabrication

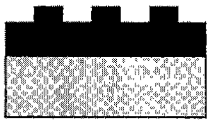
In imprint lithography, resolution is restricted by the mold pattern. To fabricate a fine mold, Si materials and Si process are used. On the other hand, anti-sticking is very important problem. Fluoropolymer is coated on the mold surface to decrease surface energy.

The mold fabrication process is shown in Fig.2. First, a resist is coated on a SiO_2/Si substrate. In this study, line & space patterns are formed by photolithography.

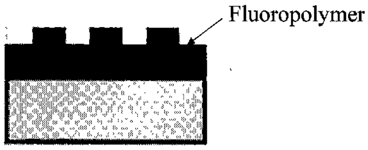
Next, the substrate is etched by anisotropic dry etching system. Finally, a fluoropolymer monolayer is coated on the mold by a silane-coupling agents to eliminate the sticking problem with the polymers. We use perfluoropolyether-silane (PFPE-S), which has methoxy hydrolysable group with perfluoropolyether. The PFPE-S is easy to handle even in an air ambient[8].



a) Resist pattern fabrication on the SiO_2/Si substrate



b) Anisotropic dry etching



c) Fluoropolymer monolayer coating

Fig.2 Process flow of the mold fabrication.

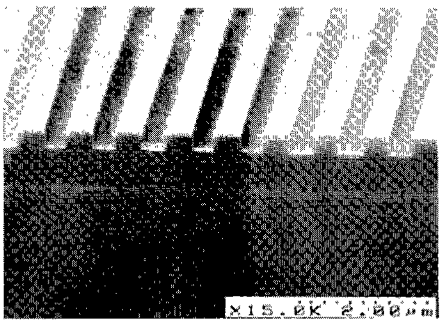
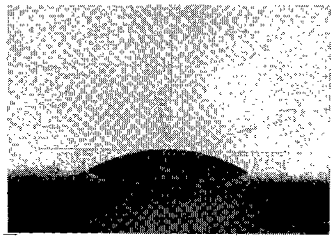


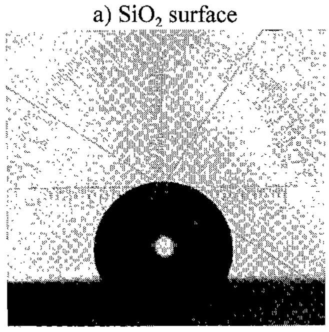
Fig.3. The cross sectional image of the SiO_2/Si mold. The pattern size is 400nm lines and 300nm spaces. The mold size is 1.0 inch square.

Figure 3 shows the cross section of the fabricated mold. Fine pattern is successfully fabricated. The depth of the groove is about 270nm and the width of the lines are varied from 300nm to 1.0 μ m. The field size of the mold is 1 inch square.

Figure 4 shows measured contact angles for water droplet on the SiO_2 mold surface before and after PFEE-S treatment. It shows that the surface energy is drastically reduced by PFEE-S treatment, which would help smooth releasing of the mold from polymer plate.



a) SiO_2 surface



b) after PFPE-S treatment

Fig. 4 Contact angle for water droplet before and after PFPE-S treatment.

4.Experiments

Using the fine mold, imprint lithography for an acrylic plate and a poly L-Lactic acid plate are carried out. We use modified air press machine for imprinting. Figure 5 shows the photo of the machine. The mold and the substrate are set between the stages, which surfaces are finished by mirror polished. The temperature of the stages is controlled. The imprinting experiments are done under air ambient.

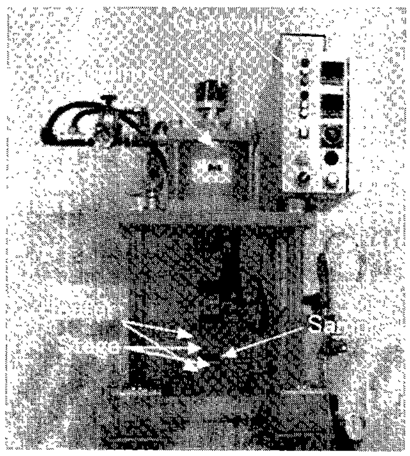


Fig.5 Schematic view of the imprinting machine.

Figure 6 shows the measured shear modulus of the acrylic plate for various temperatures using soliquid meter. The thickness of the acrylic plate is 2.0mm and the molecular weight is 500,000. Over around 100℃, the shear modulus begins to decrease and it is saturated at about 170℃. The proper condition for imprinting is predicted to be around 140℃ because the modulus of the polymer is enough decreased.

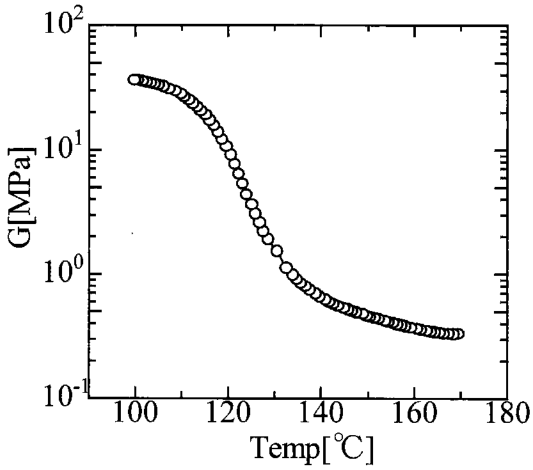
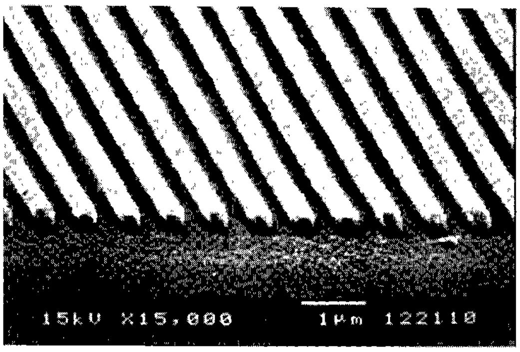
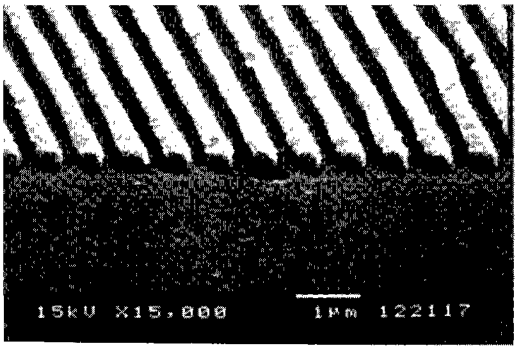


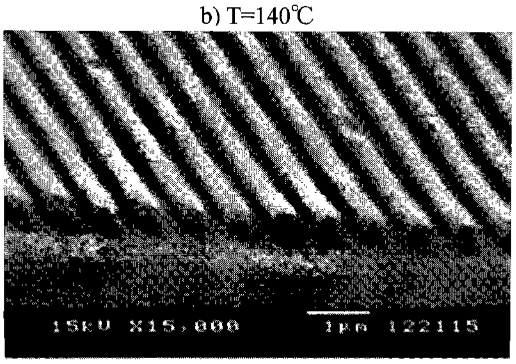
Fig.6 Measured shear modulus of a acrylic plate in various temperature.



a) T=110℃



b) T=140℃



c) T=170℃

Fig.7 SEM images of the imprinted line & space pattern on an acrylic plate for various temperatures. The feature size of the lines is 300nm.

Figure 7 shows a scanning electron microscopy (SEM) images of the imprinted patterns at 110℃, 140℃ and 170℃. The imprint pressure is set to be 5.0 MPa. The mold is hold for 5 minutes at imprinting temperature and cooled down to be 60℃ by water cooling. The imprinted pattern becomes poor at 170℃. The proper temperature condition for hole array thought to be 110℃ to 140℃ with 5.0MPa.

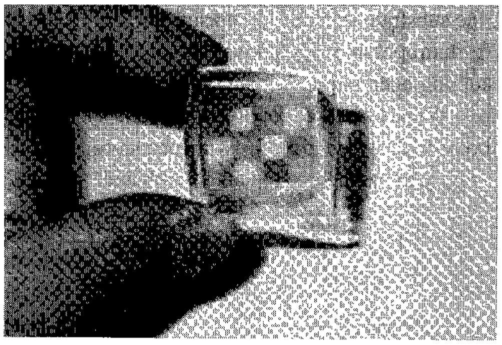
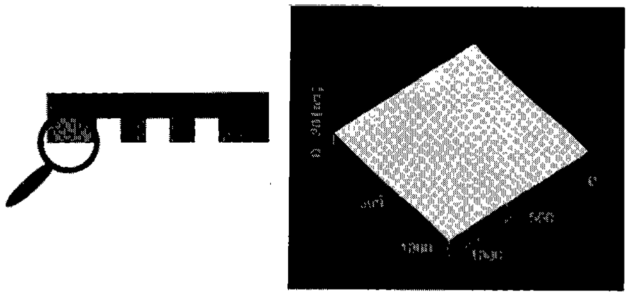
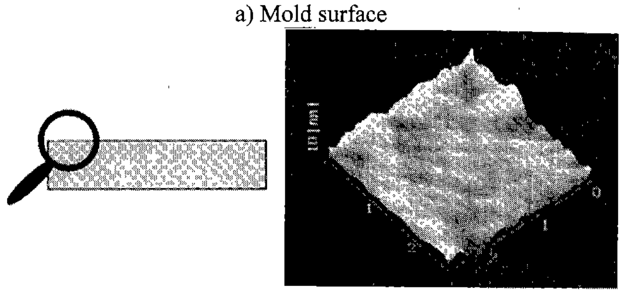


Fig.8 Photo of the acrylic plate after imprint. The field size is 1.0 inch square. The plate thickness is 2.0 mm

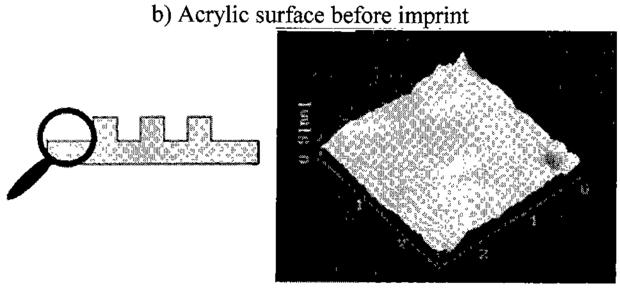
Figure 8 shows the photograph of the imprinted acrylic plate at 140℃ by 5.0MPa. Line & space patterns are successfully fabricated over 1.0 inch square.



a) Mold surface



b) Acrylic surface before imprint



c) Acrylic surface after imprint

Fig.9 AFM image of the mold surface and the acrylic surfaces before and after imprint.

The surface roughness at each process step are evaluated at the flat area. Figure 9 and table 1 show the results measured by an atomic force microscopy (AFM). The surface roughness of the acrylic plate after imprint is less than 1nm. It is decreased from the initial roughness of the acrylic plate. The surface roughness after imprinting is sufficiently smooth for DOE or μ -TAS applications.

Table 1 Surface roughness of the mold and the acrylic plates

	RMS [nm]	Ra [nm]
Mold surface	0.51	0.41
Acrylic surface before imprint	1.17	0.95
Acrylic surface after imprint	0.75	0.57

Next, we firstly try to fabricate fine patterns on a poly L-Lactic acid plate. The glass transition temperature of the poly L-Lactic acid is about 60℃. The imprint temperature is 75℃ and the pressure is 5.0 MPa. The mold is released at 40℃.

Figure 10 shows the SEM image of the experimental result. Line & space pattern with 300nm-feature size and 270nm in height is successfully fabricated. However, the polymer turns hard and can not imprinted at 110℃.

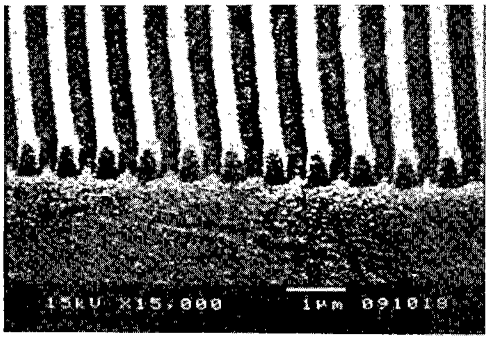
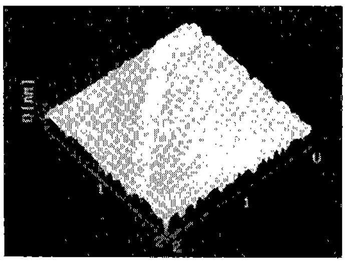
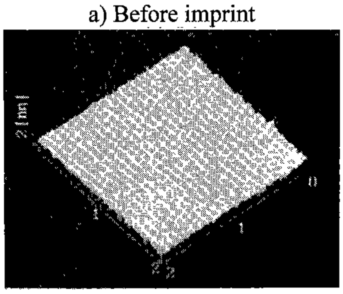


Fig.10 SEM images of the imprinted line & space pattern on a poly L-Lactic acid plate. The feature size of the lines is 300nm.



a) Before imprint



b) After imprint

Fig. 11 AFM image of the poly L-Lactic acid surface before and after imprint.

The surface roughness of the poly L-Lactic acid plate is also evaluated. The measurement results by AFM are shown in Fig. 11 and table 2. The surface roughness is excellent for practical usages.

Table 2 Surface roughness of the poly L-Lactic acid plate

	RMS [nm]	Ra [nm]
Before imprint	0.75	0.56
After imprint	0.30	0.24

As discussed above, fine pattern fabrication on bio-plastics is firstly demonstrated. This method is one of the promising candidates for fabrication of drag delivery systems or disposal usage for biochemical inspections.

5. Conclusion

We have firstly demonstrated sub-half-micron fine pattern fabrication on acrylic and ploy L-Lactic acid plates by imprint lithography.

Line & space patterns with 300nm feature size are successfully fabricated without any advanced lithographic tools and dry etching system. The surface roughness of the imprinted plane are fairly good. These fine patterns are expected to apply for bio-chemical analysis chips or diffractive optical elements.

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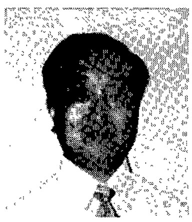

He received the B.S., M.S. and Dr. E.. degrees in electronics engineering from the Osaka Prefecture University in 1979, 1981, and 1994, respectively.

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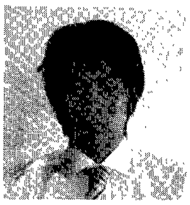

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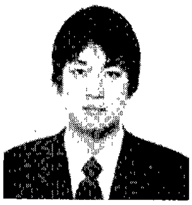

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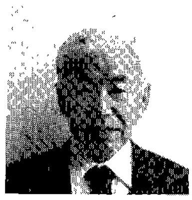

He received Dr. E. in precision machinery from Osaka University in 1967. He jointed Osaka Prefecture University in 1967. From 1989, he has been a professor at Osaka Prefecture University in mechanical system engineering. His research interests are precision machining and micro machine.