Application of Nano-imprint Lithography

Yoshihiko Hirai and Yoshio Tanaka

Mechanical System Engineering, Graduate School of Engineering, Osaka Prefecture University
1-1 Gakuen-cho, Sakai, 599-8531, Osaka, Japan

Nano-imprint lithography is one of the promising technologies for low cost mass production of Giga-bit-scale integration systems. This paper demonstrates various possibility of the nano-imprint lithograph for fine pattern fabrication. Fabrication of optical elements or bio-chemical analysis systems is one of the suitable field of nano-imprint lithography, because the resist structure it’s self works as an functional element such as a diffractive grating, an anti-reflection structure or a fluid channel. Also, application of nano-imprint lithography to various materials are discussed such as acrylic plate, glass plate and biodegradable polymer.

Keywords: imprint lithography, mold, surface treatment, optical element, dots, curved surface.

1. Introduction

Nano-imprint lithography is one of the promising technologies for fabricating Giga-bit scale integration system under low production cost. There have been reported many studies about nano scale pattern fabrications by this method[1][2].

Typical method is a thermal process as shown in Fig.1[1]. Thermoplastic polymer, which becomes hard over it’s glass transition temperature (Tg) and becomes soft below the grass transition temperature, is used for pattern fabrication. The mold with fine pattern is pressed to the polymer over glass transition temperature and released after cooling down. The fine pattern on the mold is transferred to the polymer. Chou et al. reported sub-10nm pattern fabrication using PMMA thin film on Si substrate[3]. Using this method, large scale integrated pattern is reputedly fabricated on substrate once the mold is fabricated by advanced lithographic tools.

The advantages of this lithography are thought to be as follows;
1) The equipment cost is significantly low.
2) Expensive high-resolution resist is not necessary.
3) Resist sticking or falling down never occurs because wet development process is unnecessary.
4) Many kinds of thermoplastics can be used for fine pattern fabrication.
5) Cross-sectional profile can be designed by the mold structure.

![Diagram](image)

Fig.1. Schematic diagram of the nano-imprint lithography by thermal curing process.

On the other hand, the problems are thought to be as follows:[4]-[7]
1) Resolution is restricted by the mold.
2) Residual polymer is remained under the pattern.
3) Difficult for stepped substrate.
4) Adhered polymer on the mold caused defects.
5) Layer by layer alignment system is not established.
6) Thermal compensation correction would be required for mold pattern.

At present, a Giga-bit scale pattern fabrication has not been perfectly demonstrated for VLSI fabrication, because the problems about fine alignment and residual resists have not been solved. Also, the resolution limit has not been discussed in detail.

On the other hand, the nano-imprint lithography is applicable for fabrication of nano scale polymer structure without layer by layer process or additional etching processes. In this point of view, advanced optical elements which have sub-wave length or 1/4-wave length feature size, such as diffractive optical elements (DOE) or non linear optical devices, are thought to be suitable application fields of the nano-imprint lithography.

In this paper, we present resent results about fine pattern fabrication for optical and bio-chemical devices using various materials and novel mold by nano-imprint lithography.

2. Equipment and material

We briefly discuss about basic technologies about the nano-imprint lithography.

Figure 2 shows the in-house hot press machine for imprint lithography based on a commercial available machine (Maruni Co. Ltd., MSP series).

Fig. 2. Hot press machine for imprint lithography. The maximum load is 1,500Kgf by air press. The stage temperature is controlled up to 200°C.

The sample is held on the mirror-finished stage and pressed by air cylinder. The stages are thermally controlled up to 200°C. The stage size is 3 inch in diameter. The maximum load is 1,500Kgf. The output load is continuously controlled by a regulator, which is convenient for dynamic control of the applied load in process. The stages are also cooled down by air or water-cooling. It takes about 5 minutes to cool down from 170°C to 60°C by water cooling. The total processing time for one chip is about 15 minutes. Vacuum ambient is available for imprint process. The size of the system is around 500 × 500 × 1000mm.

Next, we briefly discuss about mechanical property of the thermoplastics. Figure 3 shows measured properties of a thin acrylic (poly methyl methacrylate) plate by soliquid meter (Rheology Co., MR-500). The molecular weight of the polymer is 500,000. The shear modulus G decreases over glass transition temperature Tg (around 110°C) and it becomes to be around 0.5 MPa over 140 °C. On the other hand, the retardation time τ is around 1 s over 140°C.

According to these results, imprint pressure should be over 0.5 MPa, the temperature over 140°C and imprinting time over several seconds, respectively.

![Graph showing mechanical properties](image)

Fig. 3. Measured mechanical properties of the PMMA plate (Mw=500k). G: shear modulus, τ : retardation time.

3. Application to optical elements

Usually, an etching process followed by a lithography process is indispensable for VLSI fabrication because semiconductor substrate or underneath thin films are the final processing targets. The resist pattern is used as a mask layer for etching process. On the other hand, residual resist is remained after imprint lithography. This is a concerning problem of the imprint lithography.

However, fine polymer structure is useful for
advanced optical devices [8] or fluid devices, because acrylic polymer such as a PMMA resist is suitable material for optical element. However, fabrication of sub-wavelength or 1/4-wavelength scaled feature size is very expensive by the conventional semiconductor lithography. In this section, applications of the nano-imprint lithography for optical element are demonstrated.

3.1 High aspect ratio pattern for optical switch

High aspect ratio pattern, whose feature size is sub-wave length, works as an optical switch. In conventional lithography, resist sticking or falling down is a significant problem at a wet development process.

On the other hand, there is no afraid of the resist sticking problems by the imprint lithography, because the wet process is unnecessary.

We fabricate a novel mold by Si substrate having steep groove with 200nm in width and 1200nm in depth. Using low molecular weight PMMA (Mw=15000), a high aspect ratio pattern is fabricated by imprint lithography.

Figure 4 shows the experimental result of the imprinted PMMA pattern on Si substrate suing the mold. High aspect ratio pattern up to 6.0 is successfully fabricated without resist sticking or falling down by wet process.

![Fig.4. SEM image of the PMMA pattern on Si substrate. The imprinting is performed at 10MPa, 170°C. 0.6 μm PMMA on Si substrate.](image)

3.2 Saw tooth like pattern for diffractive grating elements

A saw tooth like pattern is useful for diffractive optical element to enhance the 1-st order diffraction efficiency. These devices are difficult to fabricate using conventional photolithography because the cross-section profile is not simple. However, once the mold is fabricated, the complicated profile would be transferred to a resist by imprint lithography.

Figure 5 shows mold fabrication process by modulated dose exposure by electron beam lithography. To fabricate a mold, we have developed automatic dose optimization system for electron beam lithography to obtain desired cross-sectional resist profiles [9]. Using the system, saw tooth like PMMA pattern is successfully fabricated on a Si substrate by electron beam lithography. Then, the Si substrate is dry etched and saw tooth like pattern is obtained on the Si surface.

Figure 6 shows the imprint result using the mold. Fine lines with triangular shaped cross-sectional profiles are successfully fabricated on Si substrate.

Using imprint lithography, novel cross-sectional pattern is successfully transferred to the polymer once the mold is fabricated.

![Fig.5 Schematic view of a mold fabrication for saw tooth like pattern.](image)

![Fig.6 SEM image of the resist pattern using saw tooth like shaped mold.](image)

3.3 Anti-reflection pattern to optical element

Anti-reflection is one of the most important matters for practical usages of optical devices...
because the optical transfer efficient is deteriorated by optical reflection. Fine corn like structure, whose feature size is smaller than the wavelength, is one of the effective anti-reflection structures.

Figure 7 shows the process flow to fabricate acrylic grating with anti-reflection structure. First, a quartz mold, which has a grating pattern with fine corn like structure on the surface, is fabricated by electron beam lithography and dry etching [10]. The mold is directory imprinted to an acrylic plate to transfer the mold pattern to the acrylic plate.

![Mold](image1)

![Acrylic Plate](image2)

(a) Pre-heating (140°C)

(b) Press (5MPa, 5min)

(c) Release (60°C)

Fig. 7 Process flow of the grating pattern with anti-reflection structure.

![SEM image of the grating with anti-reflection structure. The step height of the grating is 2.0 μm and the pitch is 12 μm. The anti-reflection structure is corn shaped holes.](image3)

Fig. 8 SEM image of the grating with anti-reflection structure. The step height of the grating is 2.0 μm and the pitch is 12 μm. The anti-reflection structure is corn shaped holes.

Figure 8 shows the imprint result of the grating with anti-reflection structure. The acrylic plate is 2.0mm in thick and 500,000 in molecular weight. Fine holes are fabricated on the grating structure. The grating is 12 μm in pitch with 1.0 μm steps. The hole is 130nm in diameter with 250nm pitch.

To confirm the cross sectional profile of the holes, the acrylic plate is partially sputtered by focused ion beam (FIB). Figure 9 shows the cross section of the holes. Corn like shaped holes with 130nm in diameter and 300nm in depth are fabricated on the surface.

![Cross-sectional images of the acrylic plate by FIB treatment. Tilt angle=45°.](image4)

3.4 Imprint to silica film

For optical application, optical glass is the most suitable material. However, the glass transition temperature is over several hundred degrees. There are few reports about fine pattern fabrication of a glass material by imprint lithography.

![Imprint process flow for silica glass formation by SOG film.](image5)

A ‘spin on glass’ (SOG) film is one of the attractive materials for imprint lithography [11],
because it is easy to handle like a resist. Using a silica film (Tokyo Oka Co., OCD series), SiO₂ pattern is fabricated by imprint lithography on Si substrate at low temperature.

Figure 10 shows a process flow of the imprint process for silica film. First, a SOG is dropped on a Si substrate. Then the mold is pressed and heated to 60°C. After cooling down, the mold is released.

Figure 11 shows the experimental result. Fine grating pattern is successfully fabricated on Si substrate.

3.5 Imprint to low Tg glass plate

Next, we demonstrate fine pattern fabrication by imprint lithography using low Tg (343°C) optical glass (Sumita Optical Glass Inc., K-PG375). We use spark plasma sintering system (Sumitomo Coal Mining Co. Ltd., SP-1020) as a hot press imprint machine.

The glass plate is heated to 370°C and the mold is pressed by 15MPa in vacuum ambient. Figure 12 shows the experimental result of the glass pattern by imprint lithography. Fine lines with 470nm in width are successfully fabricated on the glass surface. At present, the mold pattern is partially transferred to the glass. There remains adhesion problem between the mold and the glass.

As discussed above, nano-imprint lithography is a promising technology to transfer micro-nano scale novel patterns to optical materials without wet development and etching processes.

4. Application to biodegradable plastic

Bio-devices such as a DNA or a protein analysis chip are promising systems for human medical examinations [12]. These devices are consists of micro-nano fluid channels, pillars, or holes. Several products have been delivered using glass material or plastics such as acrylic plate or polyethylene terephthalate (PET), which are fabricated by conventional semiconductor process technology using lithography and etching. However, they are required to be fabricated by low cost process and the materials should be disposal usage to avoid infection or pollution by handling infected human blood or body liquid.

To clear these requirements, nano-imprint lithography using biodegradable plastics is one of the most attractive approaches. We try to fabricate nano channels and hole array on a poly-(L-lactic acid), using commercial available biodegradable plastics (Shimadzu Co., LACTY). The glass transition temperature of the poly-(L-lactic acid) is around 60°C and the Young’s modulus is 3GPa at room temperature.
Figure 13 shows the SEM images of the imprinting results for the poly-(L-lactic acid) plate at 75 °C. Figure 13 (a) shows line and space pattern. The line width is around 350nm and the height is 270nm. Figure 13 (b) shows hole array pattern. The diameter of the holes is around 130nm in average.

Fine patterns are successfully obtained on the biodegradable plastic surface, which is expected to fabricate bio-chemical chips by imprint lithography.

6. Conclusion

Fabrication of fine and novel shaped patterns for optical elements and bio-chemical chips is demonstrated by nano-imprint lithography using various materials. We believe that nano-imprint lithography is a promising way to fabricate integrated systems for advanced optical elements or bio-chemical components without resist development and etching processes.

Acknowledgements

The authors deeply thank to Prof. K.Iwata, Prof. K.Murata and Dr. H. Kikuta at Osaka Prefecture University for their valuable discussions and great supports.

This work is partially supported by a Development of Basic Optical Information Technology, Joint-Research Project for Regional Intensive in Osaka Prefecture.

The authors also thank to Dr. M.Sasago and Dr. M.Endo at Matsushita Electric Co. Ltd., Mr. K. Yao and Mr. M.Okada at Nalux Co. Ltd., Mr. T.Matsuura at Sumitomo Electric Industries Ltd., and Dr. H.Toyota and Mr. M.Okano at Osaka Science and Technology Center for their helpful discussions and supports.

References