Spherical Micro-lens Array of PMMA Produced by Micro-molding

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Micro-lens (ML) and Micro-lens array (MLA) are important optical components widely used in many fields; Soft-lithography, a vital little process technology, has its unique performance to produce ML and MLA; The cylinder and spherical MLA of polymethyl methacrylate (PMMA) were successfully obtained by micro-molding in Soft-lithography. Some suitable experimental parameters in the process were discussed, and the imaging property of the MLA was also studied simply.

Key words: Micro-molding, Polymethyl methacrylate (PMMA), Micro-lens array

I. INTRODUCTION

As one of important optical components, the micro-lens and micro-lens array (MLA) are used in many fields, such as optical systems [1,2], optical communications [3] and photolithography [4,5] etc.. With thermal technique, macroscopic pattern or structure can be reduced into millimeter even micron level precisely and easily through the imaging technique. In addition, every micro-lens in the MLA can image individually, thus the periodical and complicated patterns or structure in a large area can be conveniently and economically manufactured by one template with single pattern only. Many techniques, such as focused ion beam [6,7] (FIB), Ink-jet [8], a monolayer of micro-sphere [9] and RIE [10] etc. have been introduced in MLA, but they are not so popularized and not easy to apply in mass production because of expensive equipments used in the course of fabricating. Soft lithography (SL) [11,12] is a new technology in the micro fabrication field and developing rapidly in recent decade. Instead of using properties of traditional light and electrons in FIB, RIE etc., SL use the mechanical behavior of matter in MLA which is familiar as that meet in everyday life: printing, stamping, molding and embossing.

The key procedure in SL is to transfer the micro patterns by polydimethylsiloxane (PDMS) elastomeric stamp, both from template to the stamp and from the stamp to the substrate. Although the cost of producing an original template with finely detailed micro patterns is expensive because it requires electron-beam lithography or other advanced techniques, transferring the pattern by PDMS stamps is very convenient, easy and cheap indeed. Once a stamp with micro patterns on it is in hand, the stamp can be used to produce micro patterns even nano-structure with low cost. It is the micro-molding of soft lithography that we used to manufacture spherical micro-lens array of polymethyl methacrylate (PMMA) in present manuscript.

II. PRINCIPLE

Any materials in liquid state tend to exist in their lowest surface free energy, resulting in the least surface area, and spherical shape. The polymer particle on the smooth surface of substrate will shrink into hemispherical lens due to the surface tension when heated up above their soften temperature. The key problem here is to make sure of regular arrangement of lens in a two dimensional plane. It is the micro-molding in SL that can do it very well (Fig.1).

III. EXPERIMENTS

A. Materials

The elastomeric stamp was made of PDMS (Sylgard 184, Dow Chemistry Company). Silicon templates with raised micro-cylinder array on the surface were electronically lithographed by No.13 Science and Technology Institute, China. The optical imaging of micro-patterns were taken by optical microscope GALEM/CTV, the Nanjin Chiang-Nan Light Electricity Share Group, metallographic microscope (NJF-1, Ningbo Yongxin Optical Incorporated Company) with CCD on them and KYKY-101OB scan electron microscope.

The substrate was glass optical microscopic slide cover. It was immersed in the saturated ethanol solution of NaOH for 12 h, then rinsed in the ethanol solution by ultrasonic vibration twice, finally washed with distilled water, dried by nitrogen before spin-coating.

B. The fabricating of elastomeric stamp

According to the prescription for Sylgard 184, the prepolymer A was homogeneously mixed with crosslinking...
FIG. 1 The sketch of micro lens produced by thermo melting.

ing agent B at the ratio of 10:1 by weight, then the mixture was cast on templates patterned with micro-patterns on it, and cured at 70 °C for 4 h. Finally the elastomeric stamp of PDMS with accurate replication of micro-dots was taken off from the template gently [13]. In order to make this procedure easier, it is necessary to coat a layer of octadecyltrichlorosilane (OTS) on the template before coating.

C. The preparation of PMMA cylindrical micro patterns by hot-embossing

The PMMA solutions with the concentration of 9.1% were prepared in the solvents of benzene and MMA separately. The solution was spin-coated on the glass substrate at the speed of 1000 r/min for 30 s, and then heated up to the temperature of 100 °C gradually, let the solvent escape. The patterned surface of PDMS stamp was contacted with the film of PMMA with accurate replication of micro-dots was taken off from the template gently [13]. In order to make this procedure easier, it is necessary to coat a layer of octadecyltrichlorosilane (OTS) on the template before coating.

D. The fabrication of spherical micro-lens

The cylindrical micro-lens array of PMMA film on the glass substrate was kept at the temperature beyond its soften temperature for suitable time period till every micro cylinder was shrunk into hemispherical lens completely (Fig.2).

FIG. 2 Microscopic image of PMMA microlens array.

IV. RESULTS

A. Micro cylinder array produced by micro-molding

By comparing the results of using different solvent system of PMMA/benzene and PMMA/MMA, and different thickness (one layer or more) of the PMMA film spin-coated on the glass substrate, it was found that better results of micro cylinder array would be obtained if using the PMMA/benzene solution and two spin-coated layers. Figure 3 showed the SEM image of PMMA micro cylinder array produced by the conditions mentioned above.

FIG. 3 SEM image of PMMA micro cylinder arrays.

B. The shrinkage of micro cylinder array into MLA of PMMA

The temperature and the time period of heating were two important factors in fabrication of spherical micro-lens from micro cylinder array. It was found that at
a temperature of 150 °C and keeping for 20 min for 20 min every micro cylinder shrunk into hemispherical lens completely. Figure 4 and Figure 5 were the SEM image of PMMA micro hemispherical lens. It could be seen that the obtained micro hemispherical lens were regular and orderly.

![FIG. 4 SEM image of PMMA micro lens arrays.](image1)

![FIG. 5 (A) Images that were recorded with a transmission optical microscope by projecting an mask of “∧” through a 2D MLA. (B) The image of a dot object formed through a 2D MLA.](image2)

C. Reduction lithography using MLA of PMMA

Macroscopic patterns can be reduced into µm or mm size through the imaging technique of MLA. Figure 4 showed the images that were recorded with a transmission optical microscope. Of course, three dimensions structure can also be fabricated using Gray Scale photomask through the imaging of MLA. The further experiment is under the way.

V. DISCUSSION

A. PDMS stamp

The quality of the PDMS stamp is an important factor in the course of fabricating the excellent MLA for its basic function. Many details should be taken care: the PDMS prepolymer and the curing agents must be mixed uniformly, and the air bubble must be removed off completely. Before the micro-molding, a thin layer of OTS should be spin-coated on the template so that the stamp could be removed off from the glass substrate easily. After curing, the PDMS stamp should be removed off from the template carefully and gently to avoid any damage to the stamp.

Any dirt on the stamp has great effect on the MLA, so the PDMS stamp must be cleaned carefully before use.

B. PMMA film

The roughness of the film has much effect on the optical performance of the MLA. It will be not able to obtain the MLA if the roughness is high enough. Comparing the PMMA films spin-coated from PMMA/benzene with those from PMMA/MMA solution, it was found that the films spin-coated from PMMA/benzene solution fabricated MLA with better quality. Because the volatility of MMA is stronger than that of benzene, the MMA could be escaped out during the spin-coated process in the room temperature, resulting in more rough PMMA film. On the other hand, the PMMA film spin-coated from PMMA/benzene has smooth surface due to less volatility in room temperature.

The thickness of PMMA film has much influence on the MLA as well. Obviously the spin-coated PMMA film should be thick enough. It found that the PMMA film obtained by twice spin-coating at 1000 r/min for 30 s would be suitable for the micro-molding.

C. Some factors in the micro-molding

There were some other factors influencing the quality of MLA in the micro-molding, such as pressure, the time period of heating, the process of removing off etc..
Obviously, the pressure should be uniform and proper. The stamp distorted seriously if pressure was higher, and the effect of pattern replicating was bad if pressure was lower. Concerning the time period of heating, it was hardly to obtain the cylinder array in large area if the heating time was shorter. Besides, the PDMS stamp should be removed off carefully and gently in order to avoid the rupture of the cylinder.

D. The factors in the hot melting

To obtain the hemispherical micro lens array, the temperature and the keeping time should be controlled accurately. If the temperature is higher than the soften temperature too much, the PMMA cylinder will totally melt and become a film; but in lower temperature, the PMMA cylinder will not be liquefied enough to shrink into hemispherical micro lens array. The suitable keeping time for total shrinkage was 20 min.

VI. CONCLUSION

Cylinder and spherical MLA of polymethyl methacrylate (PMMA) were successfully obtained by micro-molding of Soft-lithography, and the imaging property of the MLA was also studied simply in our experiment. Some suitable experimental parameters was searched through the producing process.

VII. ACKNOWLEDGMENTS

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