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Polymer microlens replication by Nanoimprint Lithography using proton beam fabricated Ni stamp

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Abstract

It is essential to have a simplified and a rapid method for fabricating micro/nano structures in different kinds of polymeric materials. Though it is possible to fabricate arrays of microlens directly by P beam writing (PBW), it is restricted to a few types of resist materials. Therefore we have fabricated a Ni electroplated metallic stamp comprising of arrays of inverse/negative features of microlenses. The metallic stamp of about 500 μm thick is made on a silicon wafer coated with 10 μm thick polymethylglutarimide (PMGI) resist and the desired structures are written by PBW followed by thermal reflow and Ni electroplating. An array of microlenses is imprinted on a polycarbonate (PC) substrate by the Nanoimprint Lithography (NIL) technique and the replicated microlenses featuring various numerical apertures, diameters and pitches are characterized.

Keywords: Proton beam writing; PMGI resist; Electroplating; Nanoimprinting Lithography; Microlens array

1. Introduction

Microlenses and microlens array are finding applications mainly in the domain of optical microsystems, e.g. optical trapping [1], optical interconnects [2], biomedical instruments [3], optical data storage and optical communications [4]. Such a wide range of potential applications of these microphotonic devices have attracted a lot of different types of fabrication techniques. The fabrication of 3D lenses and array of microlenses are attempted using different types of micromachining techniques, for example: reflow of photoresist [5], LIGA [6], e-beam writing [7], polymer surface controlled microlens [8], eximer laser [9], focused ion beam – milling and deposition of SiO_2 [10], MeV proton deep lithography [11]. Each of these fabrication techniques has its own advantages and disadvantages, mainly with respect to physical type, quality of the microlenses and fabrication time.

In this regard, proton beam writing (PBW) technique, which is a direct write method, has been shown to be an effective one in constructing such microlens array [12]. Inspite of several positive features about fabrication by of PBW [13], it is comparatively a slow process. In order to have a large scale production of such microstructures, the following criteria needs to be fulfilled – (a) high through-put, (b) cost effective and (c) ability to fabricate a high quality metallic stamp for fast replication/prototyping.

In this paper, we report a method for fast prototyping of microlens array with a combination of PBW and Nanoimprint Lithography (NIL) technique. For this purpose a metallic stamp is fabricated by electroplating on a resist after creating suitable microlens features by PBW. The focal lengths of the prototyped microlenses are optically characterized.

2. Materials and methods

The process for metallic stamp fabrication using PBW has been extensively discussed earlier [14]. Briefly, a

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conductive seed layers of Cr (20 nm) and Au (100 nm) were coated on a clean Si wafer followed by spin coating of 10 μm of PMGI positive resist. A suitable microlens array of various diameters and pitches (e.g. 80 μm, 100 μm, 120 μm and 150 μm) were patterned using P-beam writing facility at National University of Singapore [15].

A schematic flow chart of the above procedure is shown in Fig. 1. A 2 MeV proton beam focused to a spot size of 1 μm × 1 μm, was scanned magnetically over an area of 400 μm × 400 μm. The scanning was done in such a manner that array of desired circular features were unexposed. Such a patterned resist was developed in a mixture of 1-methoxy-2-propanol-acetate : ethanolamine : de-ionised water at a volume ratio of 60:20:5:15. This gave rise to pillar like cylindrical resist, which was heated above glass transition temperature, at 290 °C for 30 min. The resist melted and due to surface tension these array of cylindrical resist took a shape of spherical microlens array. A thin layer of second metallization, i.e. Ti, was coated on top surface which acted as a cathode base for metallic electroplating. The metallic stamp was delaminated from polymer layer by immersing in toluene. This metallic stamp with a base of 500 μm thickness was used for Nanoimprint Lithography (NIL). The surface of the stamp featuring structures for replicating microlens array required cleaning by diluted hydrochloric acid and rinsed with isopropyl alcohol.

For NIL prototyping, the metallic stamp was hot embossed against 500 μm polycarbonate (PC) sheet (refractive index of 1.587) for 30 s at 150 °C and 30 bar pressure in a Nanoimprinter. In this method, array of spherical microlenses and different dimensions of cylindrical lenses were replicated on PC sheet.

3. Results

A representative replica of an array of microlens of 150 μm diameter is shown in Fig. 2(a). The detailed feature of a microlens from an array of 150 μm microlens is a representation of the quality of the fabricated microlenses (shown in Fig. 2(b)). Further, 1D line profiling of these microlenses shows their nature of curvature and surface smoothness. The profilometer measurements were the experimental evidences of the diameter and height of the fabricated microlenses (Fig. 3). The heights of replicated microlenses were also measured from optical microscopy and were found to be in good agreement with the coated resist thickness (±1 μm) and to that of the profilometer measurements. A visual inspection in a microscope with white light illumination showed: (a) focal plane of a

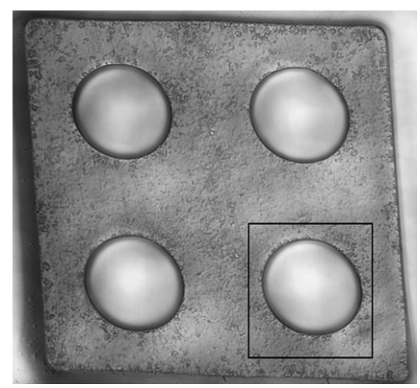

Fig. 2(a). Array of microlens of diameter 150 μm replicated by Nanoimprint Lithography on polycarbonate.

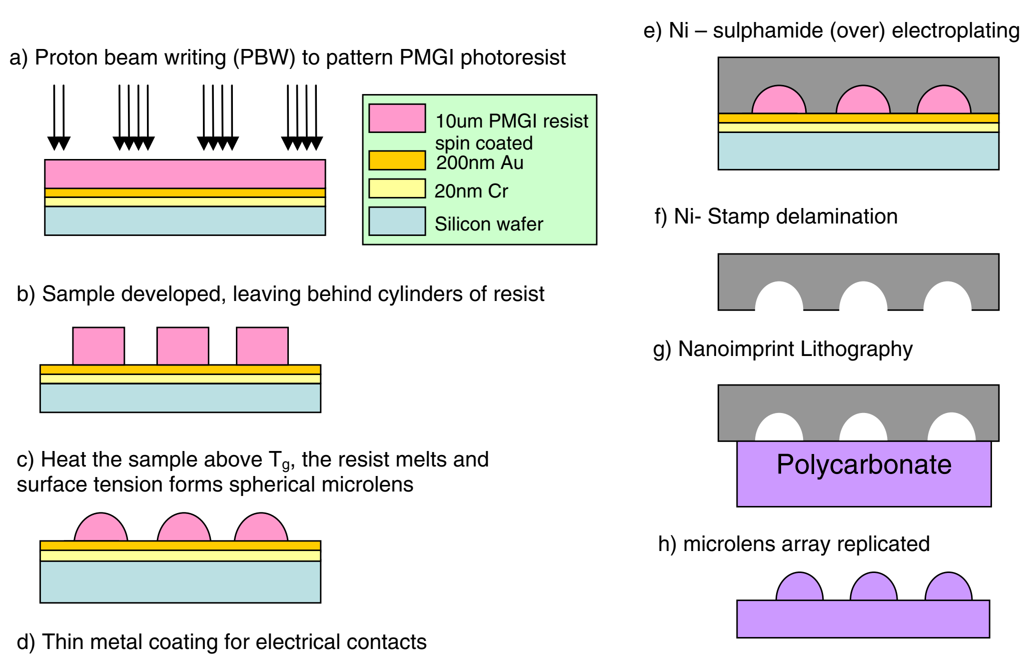

Fig. 1. A schematic flow chart for replicating microlens array in polycarbonate (PC). This includes patterning of resist by P beam writing, developing the patterned resist, reflow by heating, electroplating of Ni to make Ni stamp and finally Nanoimprinting Lithography on PC.

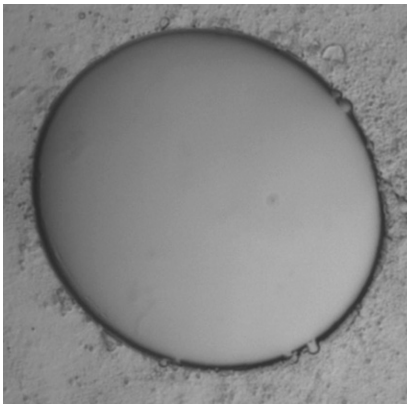

Fig. 2(b). Zoomed image of a replicated microlens (as marked by a box in Fig. 2(a)) showing details of the structure.

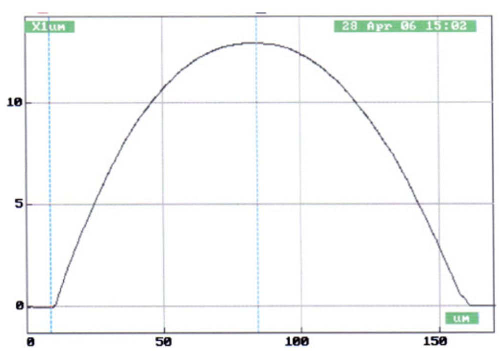

Fig. 3. Line profilometer measurement of one of the replicated microlenses out of an array of microlens of 150 μm diameter. The horizontal direction represents diameter of a microlens, and the vertical direction represents the height of the lens.

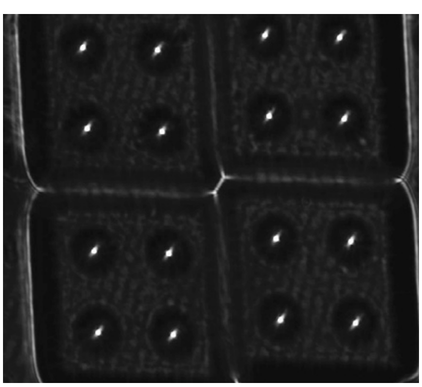

Fig. 4(a). View of the focal plane of the microlens array of diameter 150 μm, showing uniform arrays of focal points. It is a measure of the quality of replicated microlens array.

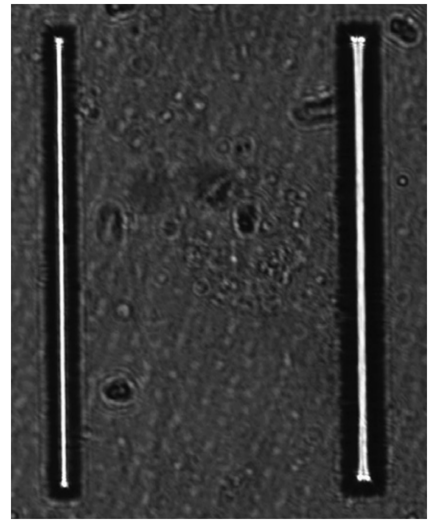

Fig. 4(b). View of the focal plane of cylindrical microlens of 70 μm width (the left of the fig). Note that the cylindrical lens on the right is out of focus as its width is 100 μm.

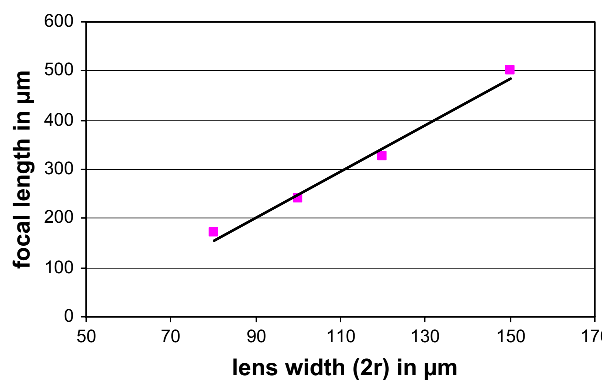

Fig. 5. A plot showing linear relationship between width of microlens (aperture) in x-axis vs. measured focal length in y-axis. The linearly drawn line represents the expected focal length against its corresponding aperture of the lens. The dots are experimentally measured values of focal length with respect to its corresponding aperture of microlens.

microlens array in Fig. 4(a) (100 μm diameter) and (b) focal plane of cylindrical microlens in Fig. 4(b) (width of 80 μm). The height of replicated microlens array was optically measured using focus/defocus method by subtracting from the top of the hemispherical lens to the base of it, with an estimated error of ±3 μm. Similarly, the focal length of microlens array was derived by subtracting the focal point of a microlens from its base. These optical measurements were done in transmission mode. The optically measured focal lengths (f) were found to be in good agreement (Fig. 5) with those calculated using the following equation: $f = R/(n-1)$, where R (the radius of curvature) = $(r^2 + h^2)/2h$; where r = half the aperture, i.e. width of the lens and h is the height of the fabricated lens and n = refractive index of the material.

4. Conclusion

Proton beam writing technique was used to fabricate a high quality mold on which Ni electroplating was done and a high quality metallic stamp was made. This stamp was successfully used to replicate good quality microlens array and will be used for prototyping microlens array in other types of polymer by Nanoimprinting Lithography in future.

References

[1] C.H. Sow, A.A. Bettiol, Y.Y.G. Lee, F.C. Cheong, C.T. Lim, F. Watt, Appl. Phys. B 78 (2004) 705.

[2] H. Thienpont, C. Debaes, V. Baukens, H. Ottevaera, P. Vynck, P. Tuteleers, G. Verschaffelt, B. Volkaerts, A. Hermanne, M. Hanney, Proc. IEEE 88 (2000) 769.

[3] P.J. Smith, C.M. Taylor, E.M. Mccabe, D.R. Selviah, S.E. Day, L.G. Commander, Rev. Sci. Instr. 72 (2001) 3132.

[4] S.D. Moon, S. Kang, J.U. Bu, Opt. Eng. 41 (2002) 2267.

[5] C. King, L. Lin, M. Wu, IEEE Photon. Technol. Lett. 8 (1996) 1349.

[6] P. Ruther, B. Gerlach, J. Gottert, M. Ilie, J. Mohr, A. Muller, C. Obmann, Pure Appl. Opt. 6 (1997) 643.

[7] X.Q. Fan, H.H. Zhang, S. Liu, X.F. Hu, K. Jia, Microelectron. J. 37 (2006) 121.

[8] C.-M. Cheng, J.D. Kubicek, P.R. LeDuc, Appl. Phys. Lett. 88 (2006) 053902.

[9] M.F. Jensen, U. Kruhne, L.H. Christensen, O. Geschke, J. Micromech. Microeng. 15 (2005) 91.

[10] Y. Fu, B.K.A. Ngoi, Opt. Eng. 40 (2001) 511.

[11] H. Ottevaere, B. Volckaerts, J. Lamprecht, J. Schwider, A. Hermanne, I. Veretennicoff, H. Thienpont, J. Opt. A 4 (2002) S2228.

[12] A.A. Bettiol, T.C. Sum, F.C. Cheong, C.H. Sow, S. Venugopal Rao, J.A. van Kan, E.J. Teo, K. Ansari, F. Watt, Nucl. Instr. and Meth. B 231 (2005) 364.

[13] F. Watt, A.A. Bettiol, J.A. van Kan, E.J. Teo, M.B.H. Breese, Int. J. Nanosci. 4 (2005) 269.

[14] K. Ansari, J.A. van Kan, A.A. Bettiol, F. Watt, Appl. Phys. Lett. 85 (2004) 476.

[15] J.A. van Kan, A.A. Bettiol, F. Watt, Appl. Phys. Lett. 83 (2003) 1629.