Low cost fabrication of polymer based optical devices

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We present a low-cost fabrication method for polymer based micro-optical devices such as binary gratings, surface relief gratings and optical waveguide structures. A maskless lithography system is employed for fabrication and a hot embossing system for replication. The waveguide structures are filled with UV curable core material by doctor balding. The fabricated optical devices will be used for applications in illumination technology, sensing and optical interconnects.

1 Introduction

Optical elements such as grating structures have number of applications in illumination and sensing. The fabrication of these optical elements on materials such as silicon or glass leads to high production cost [1]. On the other hand, polymer materials provide several low-cost production processes. In this work, we will present our recent results in fabrication of basic optical components for integrated photonic structures. We describe a low-cost fabrication process for grating as well as waveguide structures on PMMA (polymethyl methacrylate).

2 Fabrication of optical components

In order to fabricate microstructures on polymers such as PMMA, we have employed a photolithographic optical system. It consists of a UV LED as a light source and a liquid crystal spatial light modulator (LCD-SLM). The SLM consists of liquid crystals with a resolution of 1920x1080 pixels. The desired pattern displayed on the SLM is projected onto the sample through an objective lens with numerical aperture (NA) of 0.3 and magnification of 10.

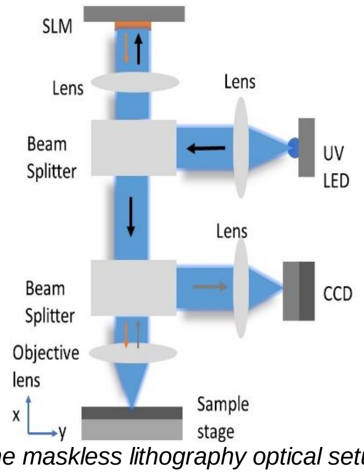

Fig. 1 *The maskless lithography optical setup.*

The sample is a photoresist spin coated on a silicon wafer with a thickness of 250 µm. We have used an electronic photoresist (Shipley S1813) and a grayscale photoresist (Ormocomp) for two and multilevel structures respectively. The sample is placed on a piezo stage (M-682.174, Physik Instrumente GmbH) which is included in the setup to stitch single patterns of area 1.32 mm^2 to a processable total area of 13.2 mm^2 by moving the sample in *x* and *y* directions, depending on the desired intensity distribution.A CCD camera is also installed in the setup to monitor the displayed pattern, see Fig.1. The photoresist is coated on the silicon wafer at a spin speed of 4000 rpm to yield a layer thickness of 600 nm. The sample is then soft baked at 105 ^{0}C for removing residual water. Then the sample is exposed to the modulated UV light and afterwards developed with the MF-321 developer. Similarly, the grayscale photoresist is prebaked at 80 ^{0}C, exposed to modulated UV light and then post baked at 115 ^{0}C and developed with OrmoDev developer. The fabricated binary and multilevel structures are characterized using confocal microscopy see Fig. 2-(c).

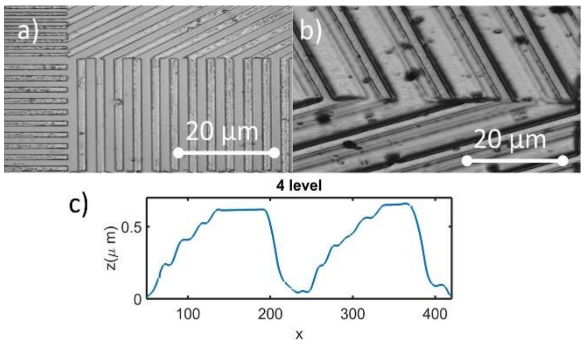

Fig. 2 *Fabricated microstructures (a) binary grating, (b) surface relief grating, and (c) measured profile of 4-level grating.*

Similarly, waveguide structures were also fabricated with the employed optical system by stitching multiple single exposure patterns and creating a long structure. A single exposure pattern on the silicon wafer is fabricated and its profile is imaged using, again, confocal microscopy, see Fig.3.

DGaO-Proceedings 2019 – *http://www.dgao-proceedings.de* – ISSN: 1614-8436 – urn:nbn:de:0287-2019-A034-5

submitted: 29.Jul.2019 published: 04.Sep.2019

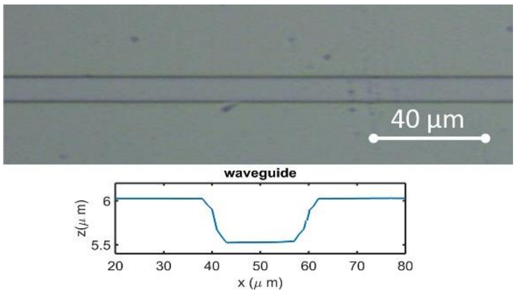

Fig. 3 *Single exposure fabricated pattern for waveguide structure and its profile measured using confocal microscope.*

In order to replicate the microstructures on PMMA, a hot embossing system is employed. An intermediate stamp is required as the silicon stamp is not stable at high thermal loads. We have converted the fabricated structures onto polydimethylsiloxane (PDMS) using PDMS casting. In the hot embossing system, the PDMS stamp and the polymer foil with a thickness of 500 µm are placed between two heating plates with a configuration described in [2], and then the stamps are heated above the glass transition temperature of the PMMA to 135 ^{0}C. An embossing force of 6kN is applied for 2 mins, see Fig. 5(a). The PDMS stamp and PMMA replica are then demolded at a temperature of 50 ^{0}C. The replicated structures on PMMA using hot embossing can be seen in Fig 4.

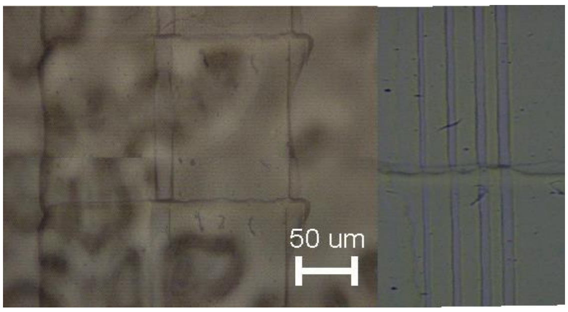

Fig. 4 *The replication of fabricated waveguide structures using hot embossing.*

For waveguides, the structures are filled with a core material. We used UV curable NOA68 with refractive index of 1.54 from NORDLAND Inc. The structures are filled with the core material and doctor blading is applied to remove excess material, see Fig. 5(b). The core material is then cured for 15 mins, see Fig. 5(c). Using the same methodology waveguide structure of arbitrary planar geometry can be fabricated. Thus, all the basic optical elements for integrated photonic structures can be fabricated. The next step is to combine all the components and add functionalities for sensors and optical interconnects as in [3,4].

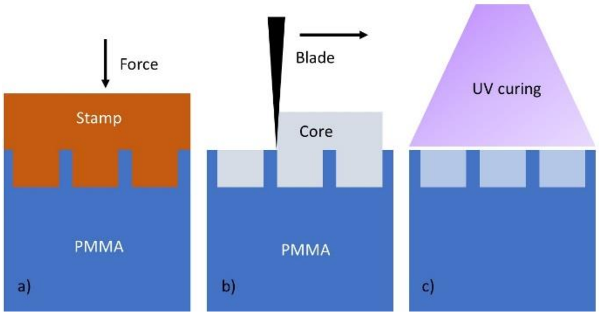

Fig. 5 *(a) Hot embossing system, (b) doctor blading to remove excess material and (c) UV curing of the core material.*

3 Conclusion

We presented a low-cost fabrication method for polymer based optical devices. We have employed an SLM based maskless lithographic optical setup for fabrication of microstructures such as gratings and waveguides by stitching multiple single exposure patterns on photoresist. A hot embossing system is employed to replicate the fabricated structures on PMMA. The waveguide structures are filled with UV core material, i.e. NOA68, and doctor blading is applied. With the described process, fabrication of basic optical elements for integrated photonic structures in combination with sensor functionalities can be realized.

4 Acknowledgement

We acknowledge the financial support provided by the Lower Ministry of Science and Culture (MWK) under the PhD program Tailored Light.

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