Reduced Surface Roughness with Improved Imprinting Technique for Polymer Optical Components *

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***Abstract* – We demonstrate a molding process to imprint optical components on polymer. The hard mold is fabricated by either evaporation or electroplating. The roughness of molded polymer surface is reduced by 5nm compared to those fabricated by ion-etching.**

Index Terms – polymer waveguide, molding, electroplating, electron-beam evaporation, surface roughness.

I. INTRODUCTION

Polymer photonic devices have demonstrated several advantages over other optoelectronic materials, such as lithium niobate and gallium arsenide, in terms of high electro-optic efficiency [1], ultra-wide bandwidth [2], and small footprint [3]. However, the fabrication of current polymer photonic devices relies heavily on conventional photolithography (or e-beam photolithography) and ion-etching, which causes surface roughness on both bottom surface and sidewalls, thus cause a significant amount of scattering loss during light propagation. In order to overcome this problem, recent studies have shown the progress of various low-cost lithography-free fabrication methods for micro and nano-scale structures with high precision on a wide variety of materials, such as nano-imprint lithography (NIL) [4]. However, these lithography-free fabrication processes face great challenges for micrometer scale patterning like polymer photonic structures with deeper trenches. Soft molds using PDMS have been used to create polymer devices with typical feature sizes of several micro-meters. Yet, the mold durability becomes another issue. It is highly desirable to develop a low cost, flexible, lithography-free fabrication technology for high throughput reproduction of polymer photonic devices that can further advance manufacturing of polymer integrated photonics with feature sizes from hundreds of nanometers to several micrometers, and with improved surface quality to reduce light propagating loss.

In this work, a waveguide fabrication method is proposed to directly replicate the structures of the mold into the substrate without lithography and ion-etch. Similar to other molding methods, the fabrication of a durable mold is the key point because any defect and roughness will be transferred into the final device. In the proposed method, hard mold (Ni or SiO_2) are deposited directly in-between the patterned photo resist through electroplating process (for thicker deposition with low cost) or evaporation processes (for improved uniformity over large area). Such hard mold is more rigid and durable compared to conventional PDMS soft mold. Besides, the surface roughness of the fabricated devices is found to be 5nm better that those fabricated by lithography/ion-etch because the mold material is deposited in such way that its top surface is naturally formed and its sidewalls are conformal to the photo resist sidewalls.

II. FABRICATION METHOD

The polymer waveguide bottom cladding imprinting using hard molding method includes two main steps as indicated in Fig. 1 and Fig. 2. The first step is the mold fabrication. Two mold fabrication methods, using electroforming and evaporation methods are described here. In the electroforming method shown in Fig. 1(a), 1mm thick glass slices are used as substrate and coated with Cr/Au (10nm/50nm) as the seed layer for the electroplating process. Then, 5µm wide waveguide trenches are patterned using 1.45µm thick photo resist. Next, the samples are exposed to two minutes oxygen cleaning using an Oxford Reactive Ion Etch (RIE) system so that the developed regions are left residue free. The samples are then transferred into the electroplating bath and connected to the cathode. Nickel is electroplated inside the photo resist pattern with sidewall conformal to the resist pattern. The resist is removed after the electroplating process. In the evaporation method shown in Fig. 1(b), it is not necessary to evaporate seed layer and the photo resist is directly patterned on glass slides. After resist residue removal, lift-off process is performed by evaporating 550nm of silicon dioxide and removal of the bottom resist.

The second step is the molding process, which is demonstrated in Fig. 2. Before molding, the mold is rendered hydrophobic by treating with 1H,1H,2H,2H-Perfluorodecyltrichlorosilane 96% ($CF_3(CF_2)_7(CH_2)_2SiCl_3$) monolayer precursor solution. Waveguides are fabricated on the glass substrate that is pre-treated with the TranSpin adhesive promoter. The UV-15LV polymer (n=1.5) is then coated as the bottom cladding layer in the waveguide system. The molding process is performed by bringing together the mold and the sample with proper pressure maintained for 20min allowing the polymer to fully fill into the mold structure. Another 20min of UV exposure is performed to

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completely cure the surface. After curing, the mold and device substrate can be detached easily due to the low surface energy of hydrophobic treated mold surface. Finally, after acetone rinse, the mold can be re-used to imprint the next device substrate. The third fabrication step includes filling the molded bottom layer with the waveguide core material (n=1.63) and covering the core layer with the top cladding (n=1.4956) by spin coating and thermal curing.

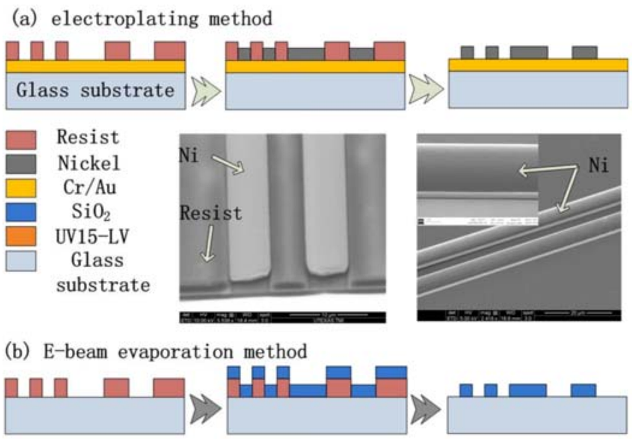

Fig. 1 mold fabrication using (a) electroplating method and (b) electron-beam evaporation method

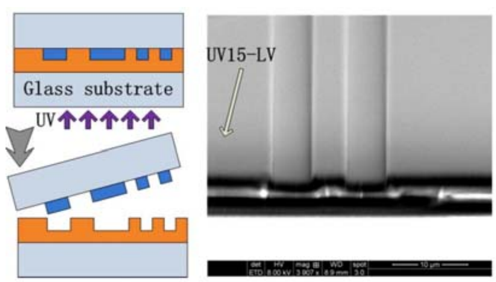

Fig. 2 imprinting/molding with hard mold on UV15-LV polymer

III. Mold and Device Evaluation

Due to the fact that the electroplated or evaporated materials are conformal to the sidewall of the photo resist, smoother sidewall surface can be achieved as well as the bottom surface of the trench. Fig. 3 compares the waveguide surfaces roughness resulting from our molding method to that using ion-etching for patterning. From the atomic force microscopy (AFM) scan, the bottom surface is much smoother in the molding method (Ra=4.92nm) than in the RIE etched method (Ra=9.71nm), due to the high quality of the mold. The Scanning electron microscope (SEM) pictures further confirm this. The electroplating and evaporation method are “bottom-up” methods, in which structure material accumulates to form the smooth surface of the mold that finally gives low surface roughness of the molded trench. In the RIE method, high energy ions bombard the surface not covered by the photo resist, thus relatively rougher surfaces are achieved. Similarly, in the molding method, the mold is fabricated in a way that the deposited material is conformal to the smooth sidewall profile of the photo resist, which is finally transferred onto the polymer. In RIE method, the sidewall is “cut” out from the polymer material thus rendering high roughness.

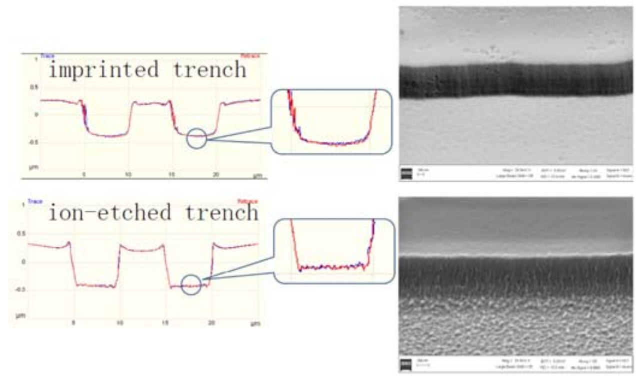

Fig. 3 surface roughness evaluation with AFM scanning and SEM inspection, for imprinted sample and ion-etched sample

The same process can be scaled down to make patterns in nanometer-scale thus having a potential application in fabricating photonic crystal structures by patterning the photo resist without e-beam lithography process. As shown in Fig. 4, photonic crystal structures with holes of 250nm in diameter are imprinted using electroplated Ni hard mold.

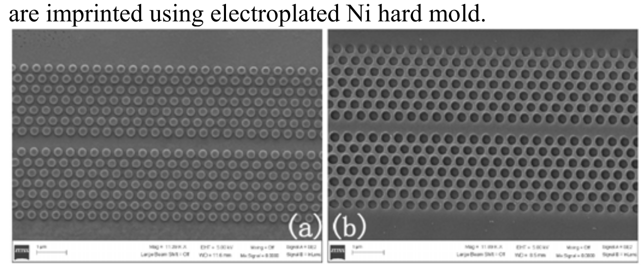

Fig. 4 Nickel mold and imprinted polymer for photonic crystal structure. Pillars and holes are 250nm in diameter

IV. Conclusion

We presented a hard mold fabrication and imprinting method for fabricating optical components in polymer materials. The process does not involve RIE process to waveguide layers thus better surface quality is achieved. The measured surface roughness results show 5nm improvement on the bottom surface of imprinted polymer, compared to ion-etched surface.

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