SOFT-LITHOGRAPHY OF INORGANIC-ORGANIC HYBRID GLASSES FOR THE FABRICATION OF MICRO-STRUCTURE DEVICES

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Soft-lithography has been actively studied and developed to overcome the diffraction limits of photo-lithography, and provided access to micro-structures with polymeric materials. The inorganic-organic hybrid materials prepared by sol-gel process of organo-alkoxy silanes(or HYBRIMERs), can be used as replicable candidates instead of polymers. With the polymerizable methacrylic group in HYBRIMER glasses, key strategies of soft-lithography which we challenge are UV embossing, UV stamping, and thermal embossing. In this paper, the authors will show the availability of soft-lithographic patterning of HYBRIMER glasses for fabrication of micro-structure devices.

(Key words: HYBRIMER glasses, sol-gel process, soft-lithography, micro-structure devices)

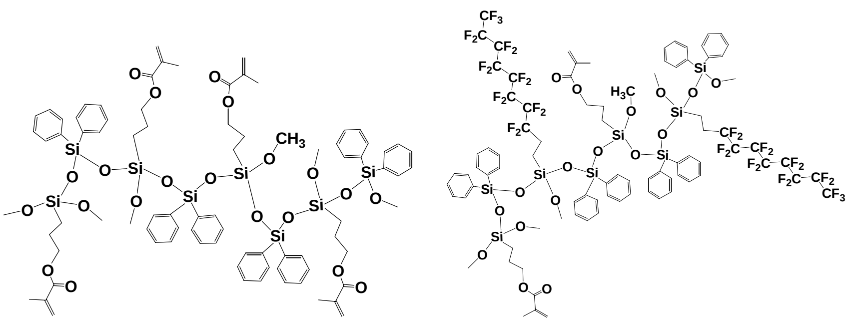
1. Introduction

Soft lithographic method is a promising strategy for the fabrication and manufacture of micro-and nanostructures, which require little in capital investment and most can be carried out in ambient laboratory conditions at low cost. [1-2]. Unlike conventional lithography, these techniques are able to generate features on various substrates, e.g. curved or large areas. A variety of materials have been patterned using the above techniques, including metals, polymers and ceramics [3-5]. The organic-inorganic hybrid glasses made by sol-gel processes (HYBRIMERs) can be applied to these soft lithographic methods with curing by UV irradiation and heat. These have attracted great interest due to their physical and chemical properties, which arise from their hybrid nature. HYBRIMERs are synthesized by sol-gel processing, and offer the flexibility for one to tailor their properties to a particular application [6].

In this report, the fabrication of representative HYBRIMERs containing both an organically methacrylic functionality and a silica inorganic network are described. Specially, because non-hydrolytic sol-gel HYBRIMERs are synthesized without solvent, the HYBRIMERs synthesized by non-hydrolytic process are suitable for soft lithographic applications, regardless of pattern volume contraction [7]. Usually, the stamp of UV stamping method is fabricated by transparent quartz, metal or poly dimethyl siloxane (PDMS) rubber. PDMS rubber can cover large areas and has very low reactivity and interfacial energy toward the organic materials. In addition, it is so elastic that we may remove it from patterned organic materials without any deformation of replicated patterns [8]. Because the HYBRIMER material is compatible with silicon wafer substrate and PDMS replica mold, it is very simple to remove PDMS mold from the final patterned structure without any other processes.

2. Experimental

The Non-hydrolytic sol-gel HYBRIMER is synthesized by alkoxylation of diphenylsilanediol and 3-methacryloxy-propyltrimethoxysilane for the core layer of optical waveguide[9]. The HYBRIMER for the cladding layer is synthesized by alkoxylation of diphenylsilanediol, 3-methacryloxypropyl trimethoxysilane and perfluorodecyl-trimethoxysilane[10]. The refractive index of the core HYBRIMER is 1.532 at 1550 nm and that of the cladding HYBRIMER is 1.50 at 1550 nm. Figure 1 shows the structure of two non-hydrolytic sol-gel HYBRIMERs (MD & MFD system)which are the core candidate and the cladding candidate materials. The methacrylic HYBRIMER, used for the core layer (MD), shows low optical absorption because it contains low Si-OH content. The fluorinated methacrylic HYBRIMER is used for the cladding layer (MFD). In this HYBRIMER C-H is partially substituted by C-F, which results in a decrease of absorption over the whole detected spectral range. The optical absorption losses of fluorinated methacrylic HYBRIMER are 0.4dB/cm at 850 nm, 0.4dB/cm at 1310 nm and 0.5dB/cm at 1550 nm, respectively. The used photoinitiator, which may help to be cured by UV light dose during UV embossing step, is Irgacure369 (Ciba Geigy) and the used UV light is mainly 365 nm wavelength source.



(a) (b)

Fig.1 Structure of Non-Hydrolytic Sol-Gel Methacrylic HYBRIMERs: (a) MD, (b) MFD

The transparent and low cost PDMS polymer mold is fabricated by the photo-lithography using the AZ9260 photoresist on silicon wafer [11]. In order to transfer the patterns of PDMS mold, we use UV embossing or stamping. In the UV embossing method, the HYBRIMER is spin-coated on the substrate. Then, PDMS mold is pressed on the HYBRIMER film. When the mold has a contact on the coated substrate, the air bubbles can be trapped between the substrate and the mold. Deforming the PDMS mold in a convex shape is necessary when placing the mold upon the substrate. Similarly in the UV stamping method, the bare substrate is covered by PDMS mold containing the HYBRIMER and then pressed by the mold (Fig.2).

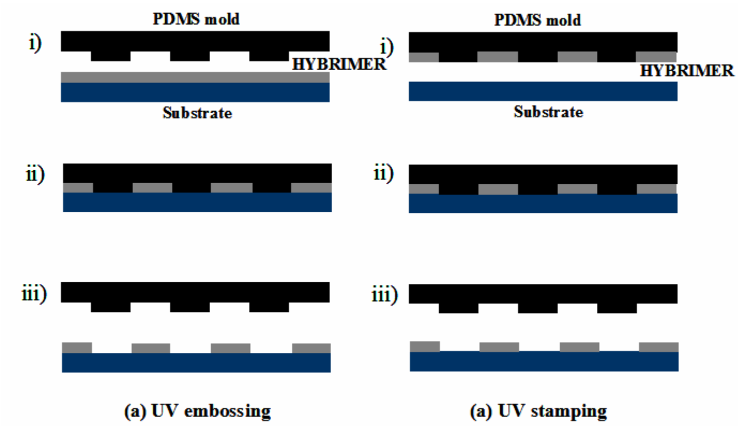
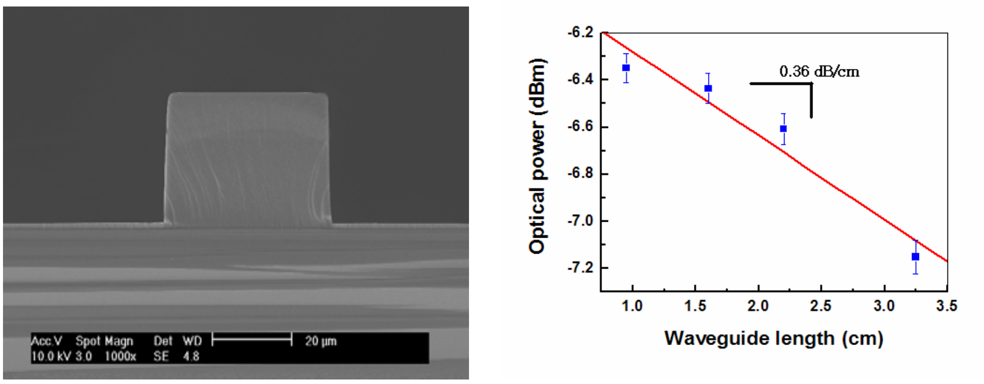


Fig.2 Soft-Lithography Methods: (a) UV embossing, (b) UV stamping

Because we obtain the same result from the two methods, we will explain representatively about UV-embossing method. First of all, we prepare the under-cladding layer of about 10μm by spin coating of fluorinated HYBRIMER and curing by UV light. Then, the core HYBRIMER is spin-coated on the cladding HYBRIMER layer. And PDMS mold is covered and pressed on the coated sample. The waveguides are formed by filling the trenches of the mold by pressure and the core material is polymerized by UV light to maintain original replicated grooves. After detaching the PDMS mold, the replicated HYBRIMER waveguide pattern is obtained. Finally, the fabricated ridge waveguide is thermally cured. The curing process of the HYBRIMER is obtained in two steps, soft baking at 80 °C and hard curing at 150 °C to remove remained solvents in the HYBRIMER.

3. Results and Discussion

Fig.3 (a) shows the end face of ridge waveguides fabricated by UV embossing. The waveguide width is about 45 μm and its height is about 35 μm and the residual layer thickness is about 1 μm. Because the thickness of HYBRIMER is variable from 5 to 150 μm by changing the speed of spincoater, we can make different size of optical waveguide core easily. Thus HYBRIMER is suitable for the fabrication of multi-mode optical waveguide as well as single mode waveguide.

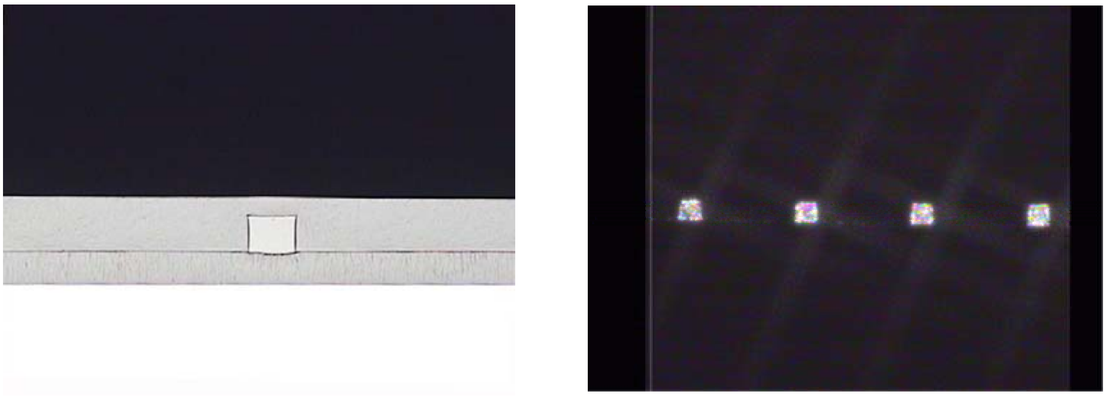


(a) (b)

Fig.3 SEM Image of Fabricated Multi-Mode Ridge Waveguide (a), and The Cut-Back Optical Loss Result of Fabricated Ridge Waveguide at 850 nm

As shown in Fig.3 (a), we have a residual layer of about 1 μm between the core and the cladding layer, which raise little problem for our multimode waveguide. The average propagation loss of the fabricate optical waveguides is 0.36 dB/cm at 850nm wavelength, which is measured by cutback method (Fig.3 (b)).

After confirming the condition of ridge waveguide, we make optical channel waveguide (Fig.4 (a)). The over cladding material is spincoated after core is formed by UV stamping process. The residual layer cannot be formed during molding process because the lest resin is spread out from the trenches by rolling.



(a) (b)

Fig.4 Optical Microscope Image of Fabricated Multi-Mode Channel Waveguide (a), and Light Propagated Mode Profile of Fabricated Multi-Mode 1×4 Splitter

Fig.4 (b) shows that the light propagation of 850 nm wavelength through 1×4 optical splitter, which is fabricated by UV stamping methods,too. The core and the cladding materials' condition is consistent with fabricated optical channel waveguide (Fig.4 (a)).

A new UV-based soft-lithographic technique for obtaining submicron patterns via thermo-wetting of organic-inorganic hybrid materials (HYBRIMERs) is proposed (Fig.5)[12].

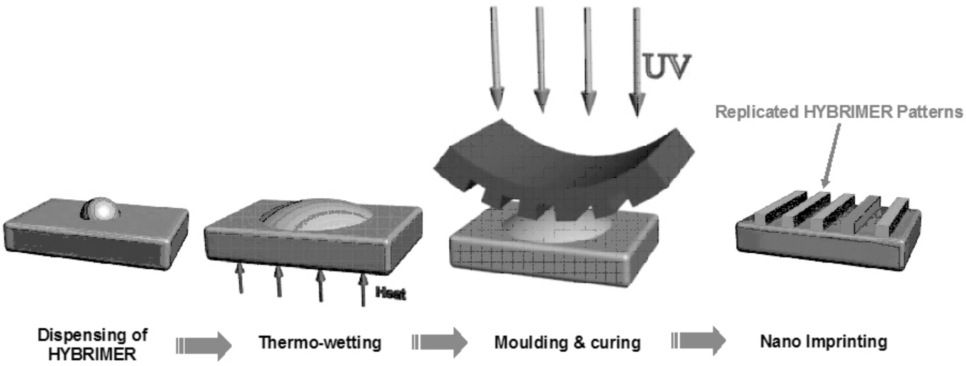


Fig.5 Processes of thermo-wetting embossing nano imprinting (or TENI)

Specifically, 300 nm scale patterns are replicated utilising this coating-free fabrication method (Fig.6). With this thermo-wetting embossing nano imprinting (or TENI) technique, a poly dimethyl siloxane mold with a submicron-scale relief is placed on a thermally wetted organic-inorganic hybrid material, which is then polymerized with UV light. The TENI process can be applied universally to patternable HYBRIMERs, such as methacrylic and vinylic HYBRIMERs. the TENI process is a modified, UV-based soft lithography, promising a synergistic approach to the patterning of sol-gel HYBRIMERs with low temperature heating for submicron applications. Although 300 nm patterns are replicated in these experiments using a methacrylic HYBRIMER, thermo-wetting of solution-type organic-based materials can be universally applied to nanometer scale patterns by a coating-free TENI process. A lower resolution of patterns can be achieved depending on the original master. This process is simple, cheap, and reproducible, and avoids the difficulties associated with spin-coating. A more detailed and systematic investigation of the various parameters is necessary to further optimize the TENI process.

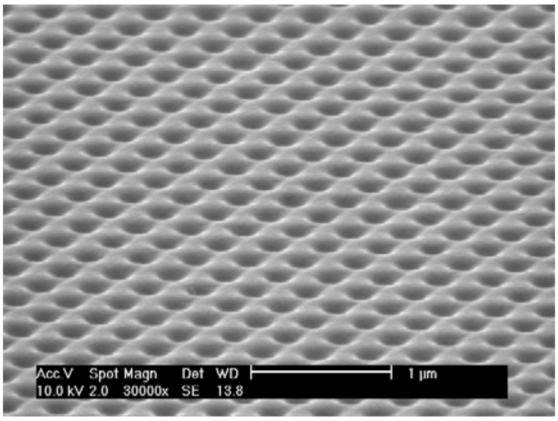


Fig.6 SEM Image of Fabricated Nano-Scale Embossed Structure

4. Conclusions

We demonstrated a multimode optical ridge waveguide, channel waveguide and 1×4 splitter of organic-inorganic hybrid materials fabricated by simple UV embossing and stamping methods. At a condition of low temperature and pressure, we can get thermally stable (over 300°C) waveguide patterns with well-defined edges. We also proposed a new soft-lithographic methods(TENI) process. It will open a way through a simple and easy pattering process with HYBRIEMRs as a soft lithograpy.

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