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Fabrication technology for PDMS ridge waveguide using DLW

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ABSTRACT

In this paper, we demonstrate polydimethylsiloxane (PDMS) ridge waveguide prepared by new technology. Maskless direct laser writing (DLW) process for photoresist master patterning was used in combination with PDMS imprinting technique. PDMS ridge waveguide was prepared using combination of two different PDMS – Sylgard 184 and LS-6941. Morphological properties of prepared waveguide were investigated by confocal laser scanning microscope (CLSM) and atomic force microscopy (AFM). Guiding properties were studied by beam propagation method (BPM) simulations and by near-field scanning optical microscope (NSOM) where multimode propagation in the visible spectrum of light was revealed.

1. Introduction

Integration of different functional devices on a single chip – Lab on a chip (LOC) technology is a new trend in sensing systems and generally means a reduction in detection volumes and leads to smart sensing systems. The LOC devices and waveguides require material with good transparency, and more importantly, compatibility with the materials and the current fabrication techniques. Polydimethylsiloxane (PDMS) material is excellent candidate for LOC technologies. PDMS has become very useful for different photonic applications such as nanostructure fabrication [1], microfluidics [2,3] soft lithography [2] and sensing area [4]. In photonics, various PDMS optical devices were presented, for example, PDMS optical fibers [5], optical waveguides for biosensing applications [6], stretchable optical waveguides [7].

Its unique mechanical, chemical and optical properties are interesting for development of new devices in visible and near-infrared applications, especially different waveguide structures and tunable devices. One of the best advantages on PDMS materials is flexibility. It means that structure shows unique elastic properties often allowing elongation of more than 100% [8], what is attractive for tunable devices with unique optical properties. A typical planar optical waveguide is formed by a strip of the higher refractive index material as a core surrounded by the lower refractive index material as a cladding. Polymer LOC devices use combination of different solid polymers and liquids for planar waveguide formation. In the case of solid core-cladding waveguides, most of groups uses SU8 [9] and PDMS for core and cladding formation. Some perspective PDMS techniques use UV curable resist [10] and proton beam writing [11] to achieve appropriate refractive index contrast. Another principle is soft lithography, where channel patterning in photoresist material is followed by filling with higher refractive index material [12,13].

All these treatments use lithographic mask. Also channel filling in photoresist layer with liquid PDMS produces residuals using razor scraping technique [12]. To overcome these drawbacks we developed maskless technique where photoresist channel is patterned by direct laser writing (DLW) and channel is filled by spontaneous capillary process.

In this paper, we describe the fabrication technology for preparation of the ridge waveguide structures for different waveguide applications based on PDMS material. For waveguide patterning we developed a technique of DLW lithography using photoresist patterning as a master in combination with imprinting technique of liquid PDMS. Using this technology, we prepared PDMS based ridge waveguide. Its morphology was analyzed using confocal laser scanning microscope (CLSM). Guiding properties of the prepared waveguide were studied by characterization of optical field output by beam propagation method (BPM) simulation and by measurement of optical near field using near-field scanning optical microscope (NSOM).

2. Experimental

For the waveguide structure fabrication, DLW lithography system that we constructed in arrangement with high resolution

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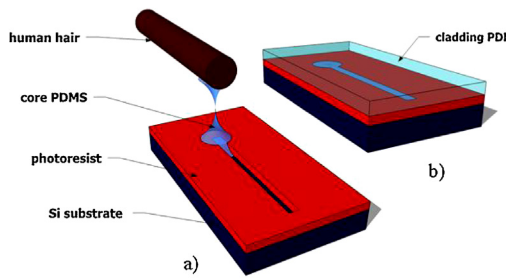

Fig. 1. Illustration of PDMS waveguide preparation of (a) the core and (b) the cladding part.

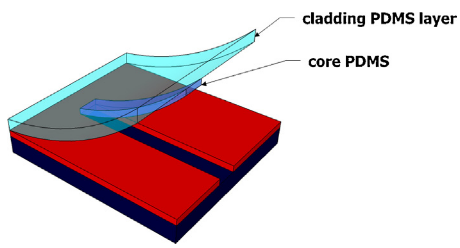

Fig. 2. Illustration of mechanical separation of cured PDMS ridge waveguide.

dual-axis galvanometer scanning mirror system CT 6215 was used in our experiments [14]. Patterning of thin photoresist layer was carried out by 2D scanning of the focused laser beam over the sample surface. This DLW process is cost-effective and maskless. Diode Pumped Solid State laser–DPSS with 473 nm wavelength was used for the exposition and CCD camera was used for writing process monitoring and for precise adjustment of the sample position. DLW system enables real resolution from tens of micrometers up to submicrometer scale depending on the used objectives [14].

Basic principle of the waveguide structures prepared in PDMS consists of several steps. First, as a master for the next PDMS imprint, positive photoresist Microposit S1828 G2 was used. Thin photoresist layer (app. 3 μm) was spin coated on Si substrate using SPIN 150 spin coater at 4000 rpm and cured at temperature of 115 °C for 60 s. In the next step, DLW in configuration with 20× objective was used for photoresist exposure. The exposure time was determined 500 ms for intensity 1.3 mW/cm^2. In the next step, the sample was developed in AZ 400 K developer for 10 s and rinsed in deionized water.

To achieve appropriate core-cladding refractive index contrast some groups used different mix ratio of Sylgard 184 [13]. In our experiment we used combination of different siloxanes – Sylgard 184 and LS-6941 for core and cladding. First, liquid PDMS for core of the waveguide was prepared from combination of liquid Sylgard 184 elastomer and curing agent at ratio 10:1 with refractive index of 1.413 at wavelength of 600 nm at room temperature [8]. Small amount of this PDMS was very precisely dropped directly on the photoresist surface near the edge of patterning waveguide (Fig. 1a). Immediately, after the spontaneous filling of the patterned area with liquid PDMS (app. 2 min for 500 μm length) the sample was cured for 45 min at 75 °C. In the next step, the cladding PDMS layer was spin coated at 2000 rpm on the sample surface and cured (Fig. 1b). The thickness of this layer was 200 μm. The cladding PDMS was prepared from polymer LS-6941 with 1.4086 refractive index [15].

Using imprint technique, the cladding layer with imprinted core PDMS waveguide was mechanically separated from the photoresist layer (Fig. 2). In the final step, precise razor blade cut perpendicularly to the waveguide was used to create end-faces of the waveguide.

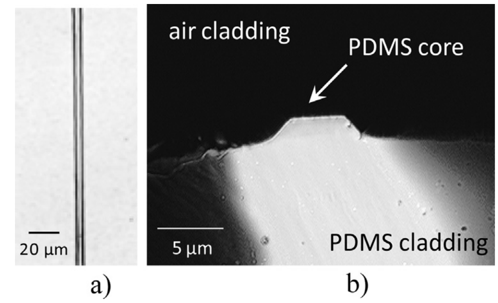

Fig. 3. (a) Top view of the PDMS ridge waveguide and (b) cross-sectional view using CLSM.

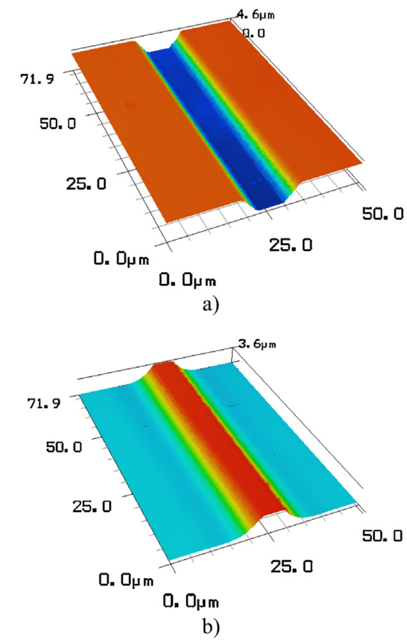

Fig. 4. CLSM 3D image of (a) photoresist channel and (b) imprinted PDMS ridge waveguide.

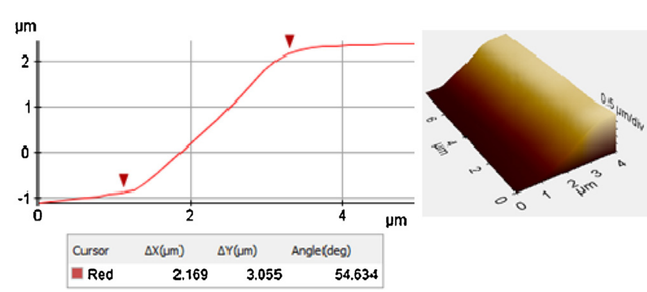

Fig. 5. Detailed line profile of prepared PDMS ridge waveguide using AFM microscope.

In the next experimental investigations we characterized the morphological structure of the prepared waveguide using CLSM and AFM and its optical properties using NSOM.

3. Results and discussion

This technology using developed system allows fabrication of the ridge waveguides with lengths up to 10 mm and different thickness and width. CLSM image in Fig. 3 shows top and cross-sectional view of the prepared PDMS ridge waveguide after the razor blade cut. The imprinted PDMS sample very well reflects the