Heat-resistant optical waveguides using new silicone-based polymers

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Abstract: Single-mode optical waveguides have been fabricated from the silicone-based polymer with good transparency. The waveguides with novel structure can be easily processing by the common spin coating technique. In addition, they have high thermal stability because of high temperature curing (above 300°C).

Keywords: Optical waveguide, thermoresistivity, optical losses, refractive control, deuterated silicone

I. INTRODUCTION

The use of polymer in economical optical devices for future optical communication systems has attracted much attention because polymer devices have two significant advantages. First, large devices can be obtained more easily since polymer optical waveguides are easier to be fabricated than those of silica-based. Second, the thermooptic (TO) effect of polymers is ten times larger than that of silica. Therefore polymers have significant advantages in the implement of TO switches than silica [1].

Hard effort has been focused on applying polymer optical waveguides [2]-[3] to economical and practical optical devices, and to interconnections in optical communication systems [4]. This is because polymer optical waveguides can be fabricated by spin casting more easily than inorganic material waveguides can be fabricated. Several polymers, such as poly(methylmethacrylate) (PMMA) [5]-[7], epoxy resin [8], polystyrene [9], deuterated fluoromethacrylate polymer (d-PFMA) [1], crosslinked benzocyclobutene (BCB) [10], crosslinked acrylate polymer [l1], and fluorinated polyimide [12] have been investigated by researchers in different country.

We have synthesized new deuterated silicone-based polymer for use as optical waveguide materials. This deuterated silicone-based polymer exhibit excellent optical transparency in the near infrared region (0.2 dB/cm at 1.5 μm). A nova polymer waveguide process has also been presented in the later of this paper.

II. MATERIAL PROPERTIES OF DEUTERATED SILICONE-BASED POLYMER

The most impotent characteristics of polymer optical waveguides used in optoelectronic devices should be high thermal stability that will make them used in communication system, precise control of the refractive index that is essential for fabricating single-mode channel optical waveguides, and low optical loss at the near-infrared wavelengths of l.3 and l.55 μm that is lowest wavelength window in optical telecommunication.

We have developed two kind deuterated silicone-based polymers (DSBP1 and DSBP2), which have high thermal stability over 300 °C are therefore attractive materials for fabricating optical waveguides. Due to deuteration, the DSBP1 and DSBP2 exhibit low water absorption (0.3%) and excellent optical transparency at communication wavelength. Fig.1 shows the light absorption spectrum of DSBP1. A 20wt% toluene solution was used in measuring light absorption; toluene was used as the reference. Two peaks are observed in the near infrared region: the third harmonics of the stretching vibration of the C-H bond ($3\nu_{CH}$, 1.l μm), and the second harmonics of the stretching vibration of the C-H bond ($2\nu_{CH}$, l.65 μm). There are no clear peaks, however, at the telecommunication wavelengths from l.3 to l.55 μm. the optical loss of DSBP1 is estimated to be less than 0.05 dB/cm at 1.55 μm as measured with spectrophotometer.

The refractive indices (*n*) were measure with a Metricon 2010 prism coupler with light from a 1.55 μm laser diode. An error associated with these measured values of *n* is less than 0.001. The samples were deuterated silicone-based polymer films coated on the silica substrate. The refractive indices, *n*, at a

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wavelength of l.55 μm can be widely and precisely controlled by changing the DSBP1/DSBP2 content, as shown in Fig. 2. We fabricated optical waveguides with refractive index differences between the core and up-cladding Δn varied from 0.32 to l.2%.

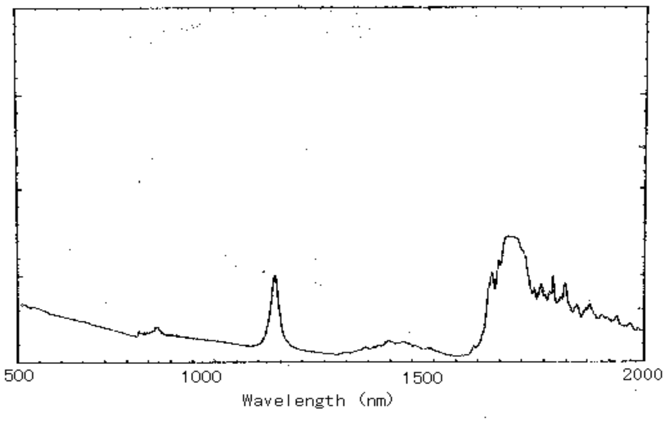


Fig.1 Light absorption spectrum of DSBP1

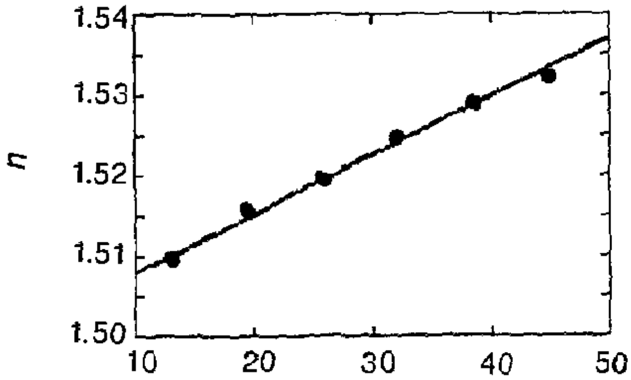


Fig. 2 Refractive indices n dependence on DSBP1/DSBP2 content at wavelength 1.55 μm

III. WAVEGUIDE FABRICATION

In our design, the waveguides are different from other polymer waveguide structure. As shown in Fig. 3, an inverted rib-waveguide structure is formed on silica substrate, and the silica substrate serve as the waveguide sub-cladding layer. Main definitions of this waveguide is waveguide width w, rib height h and core-layer thickness d. Inverted rib-waveguides were fabricated using the SiO2 and DSBP1/DSBP2 by conventional photolithographic patterning, reactive ion etching (RIE) and spin casting.

Fig. 4 is a schematic diagram of the fabrication process of the polymer waveguide. The sub-cladding was fabricated on SiO2 substrates by photolithographic patterning and reactive ion etching. Then, the core layer and over-cladding layer of the inverted rib-waveguide were formed by spin casting and curing. Two types of ridge waveguides, guide I and guide II, were prepared. Guide I consists of core (n = l.520, w = 6 μm, h = 4 μm, d= 2 μm) and under cladding layer with 5 μm thick (n = 1.507, cured at 300 °C). Guide II consists of a high refractive index core (n = 1.520, w = 6 μm, s = 3 μm, d = 3 μm) and under cladding layer with 5 μm thick (n = 1.507, cured at 300 °C). The detail fabrication process is as follows. Grooves on fused silica substrate were patterned and formed by conventional photolithography and consequently RIE process. Next, the 26wt% DSBP1/DSBP2 precursor in a solution of toluene was spin-cast on the etched substrate. After 10 minutes 80 °C soft baking, the over cladding layer (10wt% DSBP1/DSBP2) was spin-cast, and then heated for curing. High thermal stability in these waveguides is achieved by high temperature curing (above 300 °C)

IV. OPTICAL PROPERTIES

Loss measurements were performed using a laser diode as a l.55 µm light source and HP-E5970A optical power meter. The light was introduced into the waveguide using single mode fibers with a mode-field diameter of 8 µm. The input fibbers as then precisely butted against the waveguide. The propagation losses and connection losses were measured using the cut-back method and were calculated from the relationship between the insertion loss and the waveguide length. Fig. 5 shows the transmission losses against waveguide length. Guides I and II have losses at of 0.42 dB/cm and 0.46 dB/cm, respectively.

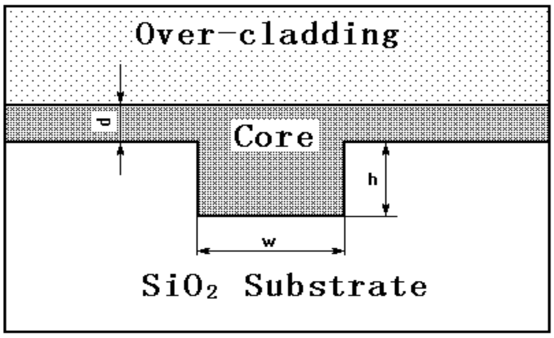
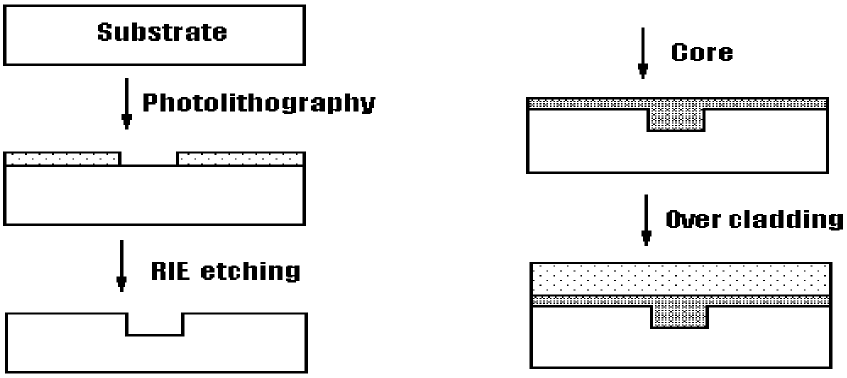


Fig. 3 the schematic diagram of inverted rib-waveguide



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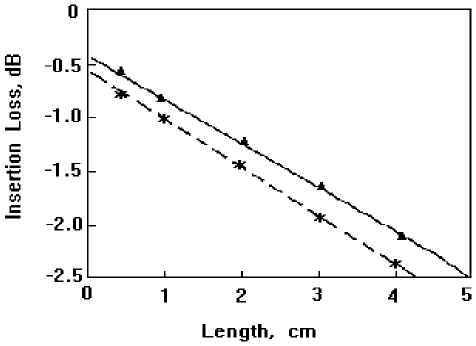

Fig. 5 Insert losses of inverted rib waveguides at 1.55 µm

BPM and mode solver simulations were carried out to estimate the mode-field diameter and coupling losses. These simulations resulted in the waveguide design with a waveguide width of 6 µm, rib height of 4 µm, core film thickness of 2 µm, which the field mismatch coupling loss decrease to 0.4 dB. Fig 6 shows the calculated mode field of polymer waveguide I.

V. CONCLUSION

We have synthesized deuterated silicone-based polymer, which exhibits excellent transparency, refractive index controllability and thermo-resistibility. Inverted rib waveguides based on the deuterated silicone-based polymer were fabricated on the fused silica glasses. At wavelength 1.55 µm, these waveguides operated in single mode and had optical losses less than 0.5 dB/cm.

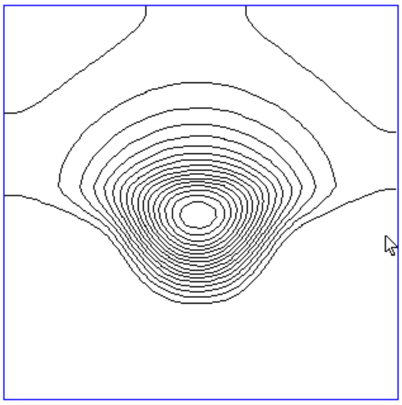

Fig. 6 The calculated mode field distribution of waveguide I

Acknowledgement: We thank Prof. Weiyou Chen for his simulation programs, and Prof. Fengguang Luo for his help with the optical measurement.

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