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Notes

Direct Pattering of Polymer Optical Waveguide Using Liquid State UV-Curable Polymer

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Introduction

Polymer optical waveguides have attracted considerable attention for their possible application as optical components in optical communication systems because of easier fabrication process than inorganic materials.[1-14] Conventional processing steps for fabricating polymer waveguides include spin-coating of a polymer thin film, photolithographic patterning of a photoresist etch mask to define the waveguide structure, and plasma etching to form a channel waveguide structure in the polymer film. There are a number of other simple methods to fabricate polymer waveguides, which include photo-exposure/wet etching,[3,4] molding/embossing,[5,6] and photocrosslinking.[7-9]

Direct patterning of waveguides using a photo-crosslinkable polymers allows the elimination of the photolithography and plasma etching process. In the process, a photo-crosslinkable polymer is spin coated and baked to form a solid film. The film is exposed by UV through a photomask, which is in contact with the polymer film, followed by wet etching of the unexposed region to form waveguides. In order to apply the process, the polymer should not be crosslinked during the thermal baking process after spin coating. Unfortunately, however, many photo-crosslinkable polymers are crosslinked not only by UV but also by heat so that the polymers are crosslinked during the baking process, significantly reducing the availability of photo-crosslinkable polymers for waveguide application.

This paper reports on the direct pattering of polymer optical waveguides using a *liquid*-state UV-curable film to overcome the limit of the contact lithography process. In the method, a UV- and thermally curable *liquid* film is exposed by UV light through a photomask which is in proximity-contact with the liquid layer followed by wet-etching of the unexposed region by organic solvent to form waveguide patterns. The method allows the use of UV- and thermally curable polymers for waveguide fabrication because there is no baking process, thus significantly expanding the available photo-crosslinkable polymers for waveguides. The direct patterning method was successfully applied to the fabrication of polymeric optical waveguides with 4~8 μm-width having a low propagation loss at the telecommunication wavelengths.

The method is also important for the fabrication of polymer waveguides on polymer substrates; "flexible waveguides", which is important to achieve temperature insensitive waveguide devices. One difficulty of the fabrication of polymer waveguides on polymer substrates is the thermal instability of the substrates. Polymer waveguides are formed by spin coating of polymer solution followed by baking at elevated temperature to dry out the solvent. The baking process induces bending and shrinking of the substrates to make the process almost impossible. By using the liquid films followed by directly patterning can overcome the difficulty easily.

Experimental

To fabricate channel waveguide using the direct patterning of liquid films using a proximate contact lithography, UV-curable epoxy based resin of Norland Optical Adhesive 61 (NOA61, n=1.547 at 1.55 μm) and 71 (NOA71, n=1.540 at 1.55 μm) were used as the core and cladding layer, respectively. The expoxies are crosslinked by heat as well as by UV so that conventional proximate contact lithography using solid films are not applicable to this system because of the baking process to dry out the solvent. Figure 1 shows the schematic diagram to fabricate channel waveguides by the direct pattering using liquid-state UV-curable polymer. 15 μm-thick NOA71 was spin-coated on a Si substrate as the lower cladding layer and then cured for 15 min by UV light with the intensity of 100 mW/cm^2 at a wavelength of 300-400 nm. To further improve the adhesion between the cladding and substrate, the film was baked at 50 °C for 12 hr on a hot-plate. 5 μm-thick NOA61 was spin-coated as the core layer and UV was irradiated for 10 min through the photomask with 25 μm-height space between the core layer and photomask. 25 μm-thick polyimide spacers located at the both edges of the sample were used to prevent the core layer and photomask from contact. After UV exposure, the pho-

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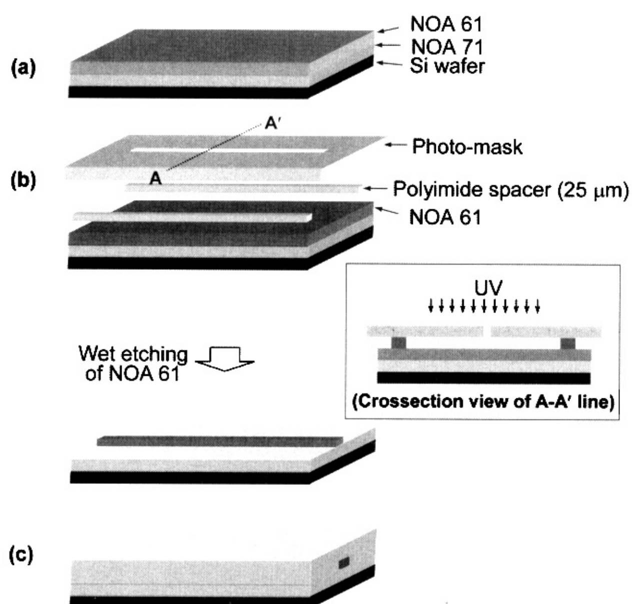

Figure 1. Schematic diagram for fabrication of polymer waveguide using the proximate-contact lithography. (a) The spin-coating of lower cladding and core layers, (b) the fabrication of channel waveguide using the proximate-contact lithography, and (c) the spin-coating of upper cladding layer.

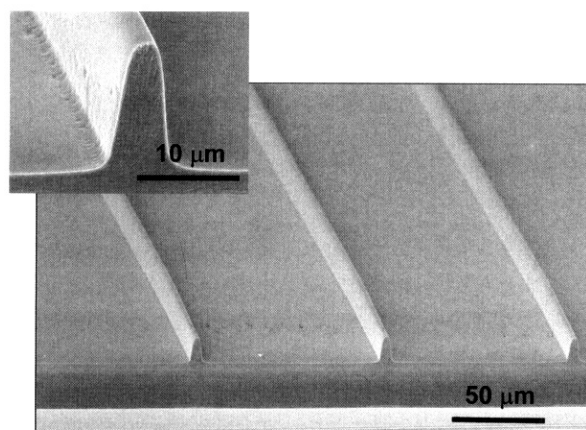

Figure 2. SEM photographs of the fabricated channel waveguides.

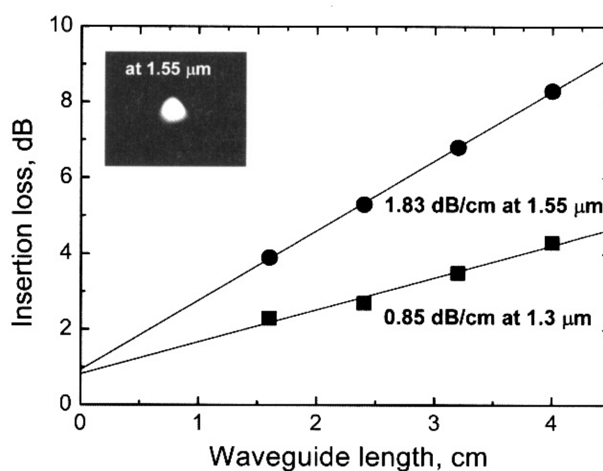

Figure 3. Propagation loss of polymer waveguide measured by the cutback method, which shows propagation loss of 0.85 and 1.83 dB/cm at the wavelength of 1.3 and 1.55 μm, respectively. The inset of figure: optical near field pattern at 1.55 μm wavelength.

tomask was removed from the sample and unexposed area was wet-etched using acetone and methanol. In the wet etching process, there are no chemical attacks in the exposed area, which was transferred to the channel waveguides. Finally, 15 μm-thick NOA71 was spin-coated as the upper cladding layer followed by UV curing for 15 min and baked at 50 °C for 12 hr.

Results and Discussion

Figure 2 shows the scanning electron micrograph (SEM) of the fabricated core of the channel waveguides with a dimension of ~6×12 μm^2 (width×height). The patterned waveguides exhibit smooth side walls to give low optical scattering loss. The optical near-field patterns of the guided modes with the waveguide dimension of 6×5 μm^2 are shown in the inset of Figure 3 for a straight waveguide at 1.55 μm wavelengths, indicating that the fabricated waveguides support a single-mode. Figure 3 shows the propagation loss of polymer waveguide measured by the cutback method.[8,14] The propagation losses were 0.85 and 1.83 dB/cm at the wavelength of 1.3 and 1.55 μm, respectively.

The high-index liquid immersion technique[14,15] was employed to measure the absorption loss of NOA 61 using a Sairon SPA-3000. In the technique, light is coupled to a slab waveguide by prism coupling. After propagating a certain distance, the light is out-coupled from the waveguide by immersing it in a high-index liquid and the out-coupled optical power is measured as a function of the propagation distance. The measured absorption loss was 1.5 dB/cm at 1.55 μm, indicating that the excess optical loss due to fabrication imperfections of the channel waveguide was about 0.33 dB/cm at 1.55 μm. This loss coming from the fabrication imperfection of the direct patterning of liquid-state UV-curable polymer is comparable to conventional reactive ion etching (RIE).[14] Moreover, this technique can be applicable to polymeric WDM components, which are now under progress.

Conclusions

We demonstrated the fabrication of single-mode optical

waveguides using the direct patterning of a *liquid*-state UV- and thermally curable polymer. The propagation loss of channel waveguide was 0.85 and 1.83 dB/cm at the wavelength of 1.3 and 1.55 μm, respectively, and excess loss from device imperfection was 0.33 dB/cm. These results indicate that the direct patterning of waveguide using liquid-state polymer can be a promising alternative to conventional RIE. This method allows to use UV and thermally curable optical expoxies for the fabrication of waveguides and it is a simple process without RIE.

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