

Fabrication and Characterization of Polymer Waveguides from Alicyclic Methacrylate Copolymer

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Abstract: We investigate the deep-UV induced refractive index modification of alicyclic methacrylate copolymer for realizing integrated optical circuits for the development of cheap, disposable integrated optical sensors for chemical and biological monitoring.

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1. Introduction

Polymer waveguides are not suitable for long range communication, because of their large propagation loss, but they have other merits such as low fabrication cost and flexibility.¹⁾ From the material science point of view, polymers can easily be combined with other materials. The combination with fluidics and biological substances offers the possibility to build a biosensor with various optical components.

We have already reported a waveguide fabrication technology from poly(methyl methacrylate) (PMMA) by deep-UV exposure.²⁻⁵⁾ But PMMA has a lower refractive index (1.49) and its thermal stability is insufficient [glass transition temperature (T_g), 105 °C]. Polymers which possess a higher refractive index and glass transition temperature are required for practical applications.⁶⁾

In order to overcome the drawback of PMMA, an alicyclic ring structure was introduced to the methacrylate polymer to obtain a higher T_g , a higher refractive index and a lower water absorption.⁷⁾ We have investigated alicyclic methacrylate copolymers as a new material for the waveguide fabrication by deep-UV refractive index change.⁸⁾

By using lithographic techniques such as standard photomasks (Cr on glass) a local and controllable increase of the refractive index in the exposed areas of the polymer surface has been achieved, generating the integrated-optical waveguiding structures. Since only a thin surface layer of a few micrometers is modified by the deep-UV light, a single homogeneous polymer plate is required, which serves as the substrate and waveguide as well and no further etching or development steps are required.

Previously fabricated waveguides made from alicyclic methacrylate copolymer had a propagation loss of 1.5 dB/cm at 1550 nm.⁹⁻¹⁰⁾

In this paper, we report on the recent progress for realizing integrated optical circuits from alicyclic methacrylate copolymer and demonstrate a propagation loss of only 0.8 dB/cm by improving the fabrication technology.

2. Experimental

Alicyclic methacrylate copolymer was obtained from Hitachi Chemical Co., Ltd. as OPTOREZ-Series (OZ-1100). This compound contains tricyclodecyl groups. OZ-1100 has a better thermal stability (T_g : 130 °C)

than PMMA and in our previous study the waveguide from OZ-1100 worked well as a waveguide. The details of this material are already described elsewhere.⁸⁾

At first, we fabricated the plane polymer sheet of OZ-1100 by hot embossing. Because OZ-1100 is offered as beads, it was necessary to form sheets for the waveguide fabrication and refractive index measurements. The hot embossing was performed using a HEX 03 (Jenoptik).

For the deep-UV modification of the refractive index, we used a commercial mask aligner (EVG 620, EV Group) with a deep-UV configuration. Exposed light intensity was measured by an UV intensity meter (Model 1000, Karl Suss) at 240 nm. The exposure was performed under vacuum condition in order to avoid an oxidation reaction during UV exposure.

Refractive index measurement was carried out by m-line spectroscopy using a self-made prism coupler arrangement.

The structuring of the waveguides was carried out by contact UV exposure using a quartz / chromium mask as sketched in Fig. 1.

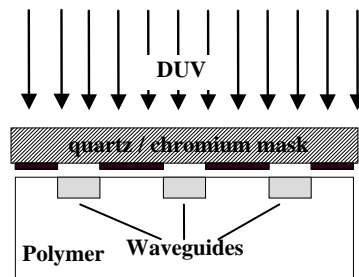


Fig.1. Scheme of waveguide fabrication

The width of the waveguides is 7.5 μm . The UV exposed area of the polymer surface becomes the core of the waveguide and no further processing like development steps are necessary. This method is therefore very simple and cost effective.

All transmission experiments were carried out using randomly polarized light.

3. Results and Discussion

3.1 UV Exposure Conditions for Waveguide Fabrication

In order to optimize the UV exposure conditions for single-mode waveguide fabrication with low

propagation loss, we investigated the influence of the exposure doses. In our previous study, we could achieve a single-mode waveguide from OZ-1100 by deep-UV exposure using the EVG 620, but the propagation loss was 1.5 dB/cm at 1550 nm.⁹⁻¹⁰⁾ It was much larger than that of PMMA (< 1 dB/cm).⁵⁾

In order to improve the propagation loss of the waveguide, we changed the exposure doses. Fig. 2 shows the effective refractive index of OZ-1100 with different exposure doses.

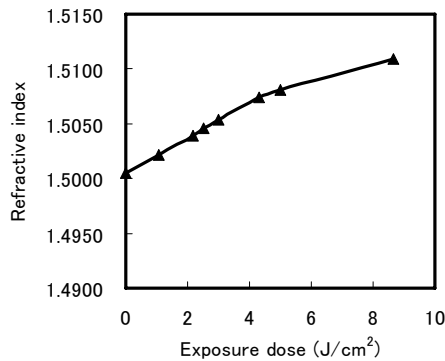


Fig.2. Effective refractive index of OZ-1100 as function of exposure dose

So far we exposed with a dose of 5 J/cm², which results in a refractive index difference between exposed and unexposed areas of 0.008. In a next step we used an exposure dose of 3 J/cm² for the waveguide fabrication. In this case, the difference of the refractive index between exposed and unexposed area is 0.005.

3.2 Waveguide Characterization

The OZ-1100 waveguide was analyzed by near-field measurements. Fig. 3 shows the near-field pattern of a 7.5 μm wide straight waveguide exposed with EVG 620, using an exposure dose of 3 J/cm².

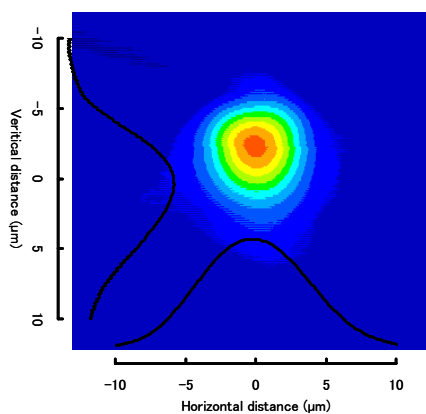


Fig.3. Near-field photograph of the straight waveguide

This photograph shows an asymmetrical single-mode profile.

For the waveguide exposed with 3 J/cm², the propagation loss of the waveguides is found to be 0.8

dB/cm at 1550 nm. The waveguide shows a polarization dependent loss less than 0.15 dB. By changing the exposure dose to 3 J/cm², we could improve the propagation loss of the waveguide made from OZ-1100 considerably by a factor of nearly 2. One of the reasons of this improvement may be the different surface profile of UV exposed area that works as waveguides. The waveguide exposed with 3 J/cm² has better surface profile than the waveguide exposed with 5 J/cm².

4. Conclusion

We investigated the waveguide fabrication from alicyclic methacrylate copolymer by deep-UV modification of the refractive index. The resulting mode spectra and optical properties of the waveguide were studied in dependence of the exposure dose. Depending on the exposure dose single-mode propagation with low propagation loss could be achieved at 1550 nm. The waveguide loss was 0.8 dB/cm at 1550 nm. This loss is comparable to the loss of PMMA waveguides. This new copolymer is shown to be a promising material for polymer waveguide. Besides short distance applications in telecommunication, the fabrication process opens up new applications in the field of sensor technology due to the use of a flexible, low cost polymer substrate.

5. Acknowledgements

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