

# FABRICATION OF NOVEL POLYMER WAVEGUIDES CONSISTING OF ALICYCLIC METHACRYLATE COPOLYMERS BY DEEP UV EXPOSURE

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**Abstract:** We have developed novel polymer waveguides consisting of alicyclic methacrylate copolymers by deep UV exposure. It was shown that these copolymers have better thermal stability and a higher refractive index than PMMA. These properties show that alicyclic methacrylate copolymers are promising materials for polymer waveguides.

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## 1. Introduction

Recently, the demand for high speed communication networks has increased. Normally, glass optical fibers are used for the back bone of the network, because of their low propagation loss. On the other hand, 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, flexibility and are suitable for local area networks.

Since Tomlinson et al. have found that poly(methyl methacrylate) (PMMA) exhibits a significant increase of the refractive index with deep UV exposure in 1970 [1], PMMA has been investigated for the fabrication of polymer waveguides. PMMA is a very common polymer, but the refractive index is low (1.49) and the thermal stability is insufficient (glass transition temperature,  $T_g$ , 105 °C) [2]. Polymers which possess a higher refractive index and  $T_g$  are required for practical applications.

In this paper, we report on the chemical and physical properties of alicyclic methacrylate copolymers and the fabrication of polymer waveguides.

## 2. Experiments

### 2.1 Materials and analysis

Alicyclic methacrylate copolymers were obtained from Hitachi Chemical Co., Ltd. as OPTOREZ-Series (OZ-1000, 1100, 1310 and 1330) [3-5].

For refractive index measurements and waveguide fabrication 500  $\mu\text{m}$  thick polymer plates were fabricated by hot embossing. Spincoating was used to make thin films, for ultraviolet (UV) spectra measurements and differential scanning calorimetry (DSC) measurements. Therefore OPTOREZ was dissolved in anisole.

For deep UV-modification, a commercial UV-exposure equipment (UVAPRINT CM, Dr. Hönle GmbH) was used. A 100 W/cm mercury xenon arc lamp combined with a cold mirror with reflectance in the range of 220 nm - 420 nm was used in the exposure system. The resulting output was 0.6 mW/cm<sup>2</sup> at 240 nm. The exposure was performed under vacuum condition. UV spectra of polymer films spincoated on quartz glass were measured with a Perkin-Elmer Lambda 2 UV/VIS-spectrometer. Refractive index measurements were carried out by m-line spectroscopy using a self-made prism coupler arrangement.  $T_g$  was determined

with differential scanning calorimetry (DSC-204 Phoenix, Netsch Gerätebau GmbH).

### 2.2 Waveguide fabrication

The structuring of the waveguides was carried out by conventional photolithographic techniques, using a quartz / chromium mask. The UV-irradiation results in a local and controllable increase of refractive index in the illuminated areas of the polymer surface generating the integrated-optical waveguiding structures in a planar polymer plate. The width of the waveguides was 7.5  $\mu\text{m}$ . The exposure dose was 8.64 J/cm<sup>2</sup>. All transmission experiments were carried out using randomly polarized light.

## 3. Results and discussion

### 3.1 UV spectroscopy

Fig. 1 shows the UV Spectra of OZ-1000 with different exposure doses.

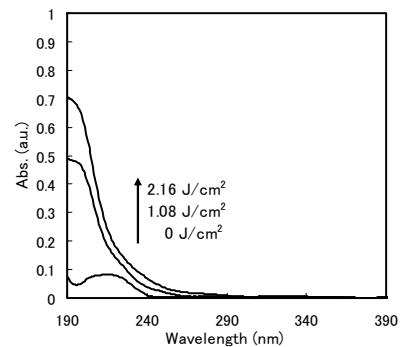


Fig. 1. UV absorption spectra of 0.5  $\mu\text{m}$  thick OZ-1000 with different exposure doses.

Henzi et al. have already reported that the absorption of PMMA at 190 nm – 290 nm increases with the increase of the exposure dose under vacuum condition [6]. Like PMMA, the absorption of the shoulder peak of OZ-1000 becomes larger with an increase of the exposure dose. The increasing absorption peak below 200 nm represents the generation and reaction of unsaturated bonds. This peak is due to a  $\pi-\pi^*$  transition of C=C bonds. The increasing branch of the absorption peak to longer wavelengths is essential for single mode waveguide fabrication, since the penetration depth of the UV-light must fall under a certain value to guarantee single mode propagation.

### 3.2 DSC

In the case of PMMA, the cleavage of pendant methylester groups and a decrease in molecular weight cause a reduction of  $T_g$  [6]. Table 1 shows the change of  $T_g$  of OZ-Series before and after exposure. The exposure dose was  $4.32 \text{ J/cm}^2$  and the samples thickness was  $20 \mu\text{m}$ . Except for OZ-1310,  $T_g$  decreases after exposure, but the decrease of  $T_g$  is relatively small when compared to PMMA. The  $T_g$  of PMMA is  $105 \text{ }^\circ\text{C}$  and after exposure with  $4 \text{ J/cm}^2$  it is approximately  $80 \text{ }^\circ\text{C}$ .

Table 1.  $T_g$  of OZ-Series before and after exposure.

Sample name	$T_g$ before exposure ( $^\circ\text{C}$ )	$T_g$ after exposure ( $^\circ\text{C}$ )
OZ-1000	125.3	110.2
OZ-1100	130.5	123.7
OZ-1310	129.9	130.8
OZ-1330	120.1	107.0

### 3.3 Refractive index

Fig. 2 shows the effective refractive index of the lowest order mode at  $633 \text{ nm}$  as a function of exposure dose for the OZ-Series. By increasing the exposure dose, the effective refractive indexes become larger in all samples.

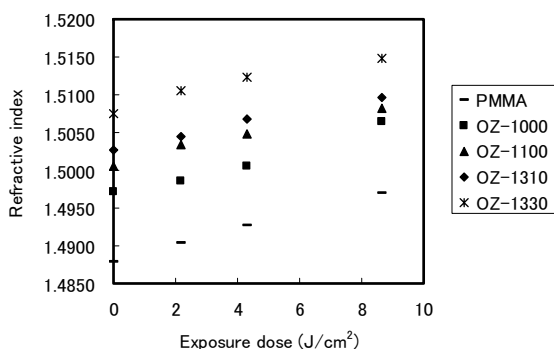


Fig. 2. Effective refractive index of OZ-Series as a function of exposure dose.

### 3.4 Waveguide performance

The waveguide has a graded index profile with an exponential decay [7]. We have measured the performance of a straight waveguide consisting of OZ-1100. Fig. 3 shows the near field pattern of the straight waveguide.

The waveguide loss at  $1550 \text{ nm}$  was  $2 \text{ dB/cm}$ . The polarization dependent loss is less than  $0.15 \text{ dB}$ . In the case of a PMMA waveguide, the waveguide loss is  $1 \text{ dB/cm}$  at  $1550 \text{ nm}$ . This difference might come from the larger roughness of our polymer substrate. The OZ-1100 substrate, that we have prepared for this measurement, has approximately  $50 \text{ nm}$  roughness. We believe that the waveguide loss can be reduced by decreasing the roughness of the polymer substrate.



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

## 4. Conclusion

We have developed novel polymer waveguides consisting of a variety of alicyclic methacrylate copolymers by deep UV exposure. We investigated the physical and chemical properties of the polymers and compared them with PMMA. It was shown that these alicyclic methacrylate copolymers have better thermal stability and a higher refractive index than PMMA. The waveguide loss of OZ-1100 was  $2 \text{ dB/cm}$ . These properties show that alicyclic methacrylate copolymers are promising materials for polymer waveguides.

Future work will concentrate on improving the hot embossing process in order to reduce the surface roughness of the polymer films.

## 5. Acknowledgement

The authors would like to thank C. Mehne and H. Biedermann for the hot embossing process and G. Papagno for cutting the samples.

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