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Amorphous Polyethylene Terephthalate Optical Channel Waveguide

Koichi Iiyama[1], Yusuke Ono[1], Takeo Maruyama[1], Tadaaki Yamagishi[2]

[1]Kanazawa University, School of Electrical and Computer Engineering
[2]Kanazawa University, School of Chemistry
Kakuma-machi, Kanazawa, Ishikawa 920-1192, Japan
Phone: +81-76-234-4887 E-mail: iiyama@t.kanazawa-u.ac.jp

1. Introduction

Transparent polymer thin films are very attractive for optical waveguides because of their flexibility, easy manufacturability and low-cost nature [1], and a number of polymers such as poly-methylmethacrylate (PMMA) [2-5] and polyimide [6,7] have been investigated. Some polymer optical waveguides exhibit low propagation loss below 0.5 dB/cm, and then polymer optical waveguides can be applicable to optical interconnection systems and long haul optical communication systems. For long haul optical communication systems, some polymers are fluorinated to decrease strong optical absorption in the wavelength range of 1.1~1.6 μm due to C-H bond vibrational absorption. On the other hand, in short-range optical transmission such as optical interconnection between integrated circuits or between printed circuit boards, a short wavelength light such as 650 nm or 830 nm will be used because the optical interconnection is a cost-effective system. Most of polymers are transparent in the short wavelength range and can be used as optical waveguide materials in the optical interconnection systems.

Polyethylene terephthalate (PET) is a popular polymer material because it is widely used as bottles of drinks. PET has some excellent performance such as very low-cost, chemically stable, good gas barrier performance, mechanically strong, and transparent in, at least, visible wavelength range. However, PET has not been examined as a material of optical waveguides. The reasons are may be low glass transition temperature (about 70°C) and the crystalline nature. When a PET film is fabricated by, for example, a spin coating method, the PET film tends to be partially crystallized during cooling after baking process, which may causes light scattering inside the PET film. PET-G, which was developed by Eastron Kodak, is a kind of PET co-polymerized with 1,4-cyclohexanedimethanol (CHDM), and is widely used as a coating film on IC cards. PET-G is perfectly amorphous, and then PET-G is a desirable material for optical waveguides.

Here we report PET-G optical channel waveguide for the first time. The propagation loss of a multimode waveguide was 0.84 dB/cm at 660 nm wavelength.

2. Fabrication

In our experiments, PET-G films were fabricated by a spin coating method. A PET-G solution is prepared by dissolving a small amount of PET-G in ortho-chlorophenol. Ortho-chlorophenol is one of phenols and the boiling point is 175°C in atmosphere. The maximum concentration of the PET-G solution was 17wt%. The PET-G films are formed on substrates by spin coating, and then baked in an electric vacuum furnace at 200°C for 1 hour. The substrate used was a polyimide substrate, on which a 15 μm-thick perfluorinated polyimide (PFPI) was coated as a transparent under clad, which was prepared by NTT-AT. An organic SiO_2 film was coated on the PET-G film by spin coating followed by baking at 150°C as an etching mask of the PET-G film. The waveguide pattern was delineated by photolithography, and the channel waveguide was fabricated by SiO_2 reactive ion etching with CF_4 gas and the following PET-G reactive ion etching with O_2 gas. Finally, the waveguide was cut by a dicing saw for achieving smooth facet.

3. Characterization

Figure 1 shows the thickness of the PET-G film against the rotation speed of the spin coating. The thickness increases according to the PET-G solution concentration, and the maximum thickness was 9 μm.

The refractive index of the PET-G film is shown in Fig. 2, which was estimated by using a spectroscopic ellipsometer (J. A. Woollam Co. Inc., M-2000) and a prism coupler (Metricon Model 2010). In this measurement, the PET-G films were formed on Si or glass substrates. In the spectroscopic ellipsometry, the refractive index is modeled by the Cauchy model; that is; the refractive index dependence on the wavelength, $n(\lambda)$, is assumed to be the following relation;

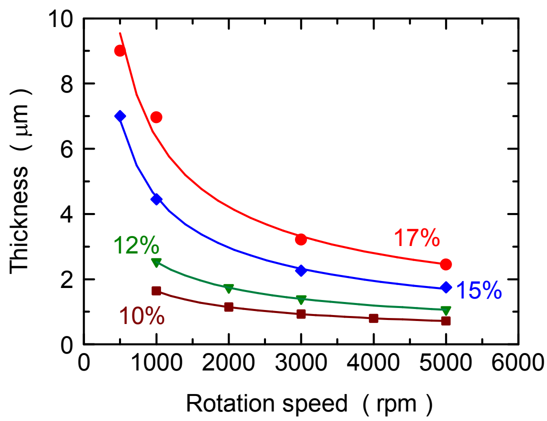

Fig. 1: Measured thickness of the PET-G film for various PET-G solution concentrations.

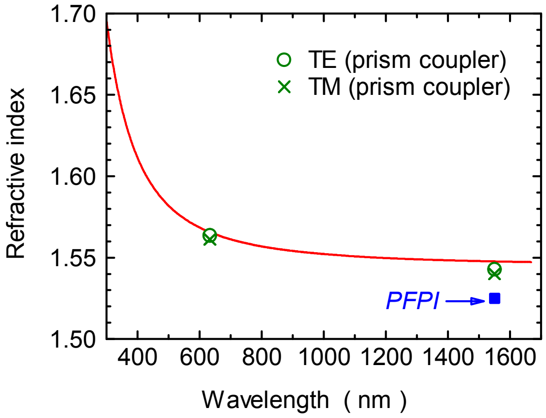

Fig. 2: Refractive index of the PET-G film measured by a spectroscopic ellipsometer and a prism coupler.

$$n(\lambda) = A + \frac{B}{\lambda} + \frac{C}{\lambda^2}$$

where A, B and C are obtained in the ellipsometry analysis. In Fig. 2, the solid line is the result by the spectroscopic ellipsometry, and the open circles and the crosses are the results by the prism coupler for the TE and the TM modes, respectively. The difference between the spectroscopic ellipsometry analysis and the prism coupler analysis is that the refractive index is slightly different from the Cauchy model. The closed square is the refractive index of the PFPI. The PET-G film is slightly birefringent, and the refractive index is higher than that of the PFPI. The result shows that the PET-G film works as a core on the PFPI film.

Figure 3 shows the photograph of the facet of the PET-G. No overclad is coated onto the waveguide. We can see cutting burr on the facet because the PET-G film is soft. No cutting burr is observed when cutting a polyimide, a normal PET and a PMMA films. However, such a cutting burr can be avoided by coating an overclad onto the PET-G film.

Finally we measured the transmission loss of the PET-G channel waveguide and the propagation loss is evaluated by the cut-back method. The core thickness was 6 μm and the core width was 20 μm. The result is shown in Fig. 4 for 660 nm wavelength. The propagation loss is evaluated to be 0.84 dB/cm. The propagation loss is due to roughness of the core wall caused by the etching process.

4. Conclusions

In conclusion, a polymer optical waveguide made of amorphous PET (PET-G) was fabricated and was characterized. A 6 μm-thick PET-G film was formed on a PFPI/polyimide substrate by spin coating, and a straight optical waveguide with 20 μm width was fabricated by O_2 reactive ion etching. The propagation loss was evaluated to be 0.84 dB/cm at 660 nm wavelength.

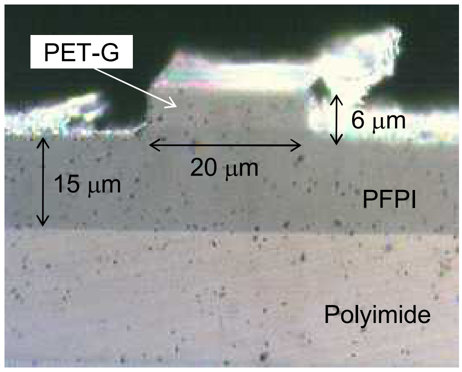

Fig. 3: Photograph of the facet of the PET-G channel waveguide.

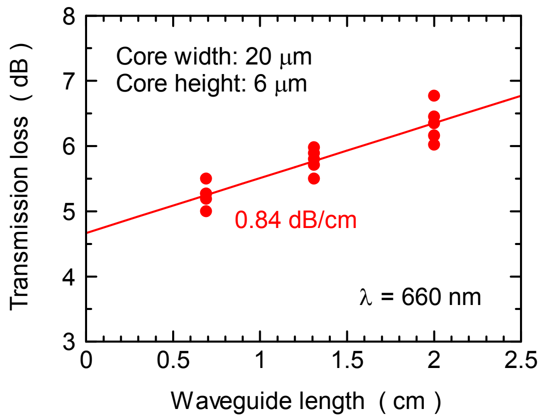

Fig. 4: Measured transmission loss of the PET-G channel waveguide.

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