Poly (carbonate) thin film optical waveguides

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The effect of annealing on the guided modes of polycarbonate thin film optical waveguides is investigated. The effect of variation in guide formation temperature is also studied. It is found that on increasing the annealing temperature, the number of propagation modes decreases. The optical losses are found to be < 1 dB/cm.

Polymers have emerged as promising for preparation of devices for integrated optics and optical interconnects. The potential applicability of organic and polymeric materials to integrated optics is due to their microscopic and bulk properties. Polymers offer the advantage of their flexibility in the fabrication and their low cost involved in preparation of optoelectronic device. Their good processability makes it possible to form a polymeric multilayer structure easily. Integrated optical devices like couplers, switches, polarizers, modulators²,³, etc. have been developed using various polymeric materials. For integrated optical devices a material should have good transmission in the wavelength range and excellent physical and chemical stability. These properties are dependent upon the temperature of the waveguide formation and the post preparation treatment. Since the waveguide performance depend upon the formation conditions, the temperature of formation and after preparation annealing of the thin film waveguides, a detailed study helps optimize the guide formation conditions. We hereby report the effect of variation in guide formation temperature and the effect of annealing on waveguide performance and guided modes.

Experimental Procedure

The planar waveguides were fabricated from a clear viscous solution of polycarbonate in dioxane (10% w/v). The dip coating technique was used to prepare a uniform thin film of the polymer solution on the cleaned soda lime glass slides (refractive index 1.51 at 0.6328 µm). The thickness of the guide was controlled by varying the drawing speed of the glass slide. The thin film waveguide were stored in vacuum for 24 h at 70°C. In certain cases annealing of the waveguides was carried out at temperatures from 90 to 120°C for 20 h.

The waveguide parameters (number of modes, refractive index, thickness and losses) were determined by using prism coupling technique (Fig.1). Two prisms for input and output coupling, were clamped to the waveguide surface to observe m-lines, indicating the number of modes the guide can support. A He-Ne laser beam (λ= 0.6328 µm) was coupled into the guide using SF-15 glass prism of refractive index 1.717. The effective refractive index is calculated using relation¹:

\[ n_{\text{eff}} = n_p \sin(\alpha + \sin^{-1}(\sin\theta/n_p)) \]  

where \( n_p \) is the refractive index of the prism material, \( \alpha \) is the angle of the prism (60°) and \( \theta \) is the incident angle. The incident angle could be measured up to an accuracy of 0.01 so the value of \( n_{\text{eff}} \) could be estimated to an accuracy of 1x10⁻⁴ for measurement of \( n_{\text{eff}} \). Fig.1 shows the optical set-up for determination of waveguide parameters.

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Results and Discussion

The large number of waveguides were fabricated and studied which supported 3 to 6 modes. The refractive index was determined to be 1.587. The refractive index and depth of these guides were calculated by using a method suggested by Jussaud and Chartier. According to this method, the effective mode index \( n_{\text{eff}} \) can also be expressed as a function of the mode order

\[
n_{\text{eff}}^2 = n_{\text{sw}}^2 - \lambda^2 x p^2 / 4 t^2 \quad \ldots (2)
\]

where \( n_{\text{sw}} \) is the refractive index of the surface (polycarbonate), \( \lambda \) is the wavelength used, \( p \) is the mode order and \( t \) is the thickness of the waveguide. A plot of \( n_{\text{eff}}^2 \) versus \( p^2 \) is found to be linear and gives the value of \( n_{\text{sw}} \) from the intercept. The plots are shown in Fig. 2. To compare the experimental results with theoretical values, dispersion curves (Fig. 3) are generated using the computer programme based on the eigen value equation

\[
V (1-b)^{1/2} = m \pi + a \tan[b(1-b)]^{1/2} + a \tan[(b+a)(1-b)]^{1/2} \quad \ldots (3)
\]

where

\[
a = (n_t^2 - n_g^2)(n_t^2 - n_c^2) \quad \ldots (4)
\]

is the asymmetry measure,

\[
b = (n_{\text{sw}}^2 - n_t^2)(n_{\text{sw}}^2 - n_c^2) \quad \ldots (5)
\]

is the normalized film index and

\[
V = [2\pi \lambda] \times d \times (n_t^2 - n_g^2)^{1/2} \quad \ldots (6)
\]

is the normalized film thickness. \( n_t, n_c, n_g \) are respectively the refractive indices of the substrate, film and cover (air in this case). The experimental values are shown by dots. It can be observed that the measured mode indices coincide with the theoretical values.

The effect of the temperature at which guides are fabricated on the guided mode was also studied. We observed that, at the same drawing speed, the guide thickness decreases as the temperature of the guide formation increases, which is consistent with the results reported earlier. The guides fabricated at 24, 35 and 45°C supported five, three and two modes, respectively. The thickness of the guides fabricated at 24, 35 and 45°C are 3.11, 2.06 and 1.3 μm, respectively. The losses are 6, 1.4 and 3 dB/cm for the TE₀ mode. The results summarized in Table 1 indicate that the thickness and number of modes supported by the waveguide decrease with increase in the temperature of guide formation. However, the losses decrease with temperature of guide formation up to 35°C and then there is a further increase of losses in the guides can be obtained by preparing waveguide films 35°C. This indicates that optimum performance of waveguide can be obtained by preparing waveguide films at 35°C. To study the effect of annealing on the waveguide performance, the guides were annealed at 90, 100, 120°C for 20 h. The effect of annealing on the various parameters of the waveguide is presented in Table 2. The value of losses is 0.95 dB/cm for films at 90°C, 0.85 dB/cm for films annealed at 100°C and 0.89 dB/cm for films at 120°C, and supported modes 6, 5 and 5 respectively. The decrease in number of modes and

![Fig. 2—The \( n_{\text{eff}}^2 \) versus \( p^2 \)](image)

![Fig. 3—Theoretical dispersion curves for the TE modes](image)

(Experimental values are also shown by dots)
losses on annealing temperature is due to decrease in the surface stresses or relaxation of the polymer. The increase in losses around 120°C may be because of structural changes as this temperature is very close to the melting point 140°C of polycarbonate. Since, there is no change in the thickness of the film after annealing, the effect can only be attributed to surface or internal relaxation of the polymer and not the change in thickness.

**Conclusion**

The annealing of polycarbonate thin film waveguides at temperatures 90 to 120°C, for 20 h, has a marked effect on the optical waveguiding in polycarbonate thin film waveguides. The optical losses with the increasing annealing temperature were found to be in the range 0.85 to 2 dB/cm.

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