Fabrication and characterization of thin film polyacrylate waveguides

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The fabrication and characterization of polyacrylate thin film optical waveguides prepared by dip coating method is reported. The waveguiding parameters: refractive index, propagation loss and depth have been measured. The planar optical waveguides exhibit low propagation loss (<1.5 dB/cm) and a refractive index 1.567. Polyacrylate exhibit excellent transmission spectra (70-80%) in the visible regions, which shows that the materials is promising for integrated optics.

Polymers are important materials for the preparation of active elements for electronic and optoelectronic applications for integrated optical circuits. The potential applicability of organic and polymeric materials to integrated optics circuitry is due to their microscopic and bulk properties. The advantages of using such materials for the preparation of optical devices are the flexibility of their optical properties through material engineering and easy processibility, which make it possible to prepare polymeric multilayer structures and optical circuits for integrated optic applications. One of the much desired application of such materials in integrated optics is the fabrication of optical waveguides, and the performance of the optical circuits depends upon the efficiency of the waveguide, for proper delivery of the optical energy. The fabrication of an efficient optical waveguide thus becomes very important for the optimum performance for optical integrated circuit. Although the optical waveguides can be fabricated by many methods, the dip coating technique is usually preferred to prepare uniform and optical quality thin films. We report herein the preparation and characterization of polyacrylate thin film optical waveguides prepared by dip coating technique and study of the waveguiding parameters namely, refractive index, propagation loss and depth.

Experimental Section

The polyacrylates contain an easily removable tertiary hydrogen atom, they undergo some chain transfer to polymer when polymerized to high conversion. This leads to highly branched, less soluble materials. Copolymers of ethyl acrylate with a few percent of a chlorine containing monomer such as 2-chloroethyl vinyl ether have elastomeric properties. Vulcanization agents and α-hydrogens on the chain, numerous rubber vulcanization agents and accelerators vulcanize these resistance to oxidations allowing their use to over 180°C. However, for our purpose the material was commercially available. The optical waveguides were prepared by dip coating on optically cleaned glass sheets in viscous solution (10% w/v) of polyacrylate and analar grade (AR) dioxane. The cleaned glass slides were dipped in the solution and drawn at various speeds, which resulted in wave guides of varying thickness. The films were dried at room temperature for 1-2 hr to allow excess solvent to escape. Subsequently, the dried films were placed in vacuum at about 70°C for 10 hr.

Prism coupling technique was employed to determine the thin film optical waveguide parameters. TE polarized He-Ne laser (output wavelength 0.6328 μm) was coupled into these guides using SF-15 glass prism (refractive index 1.717) to observe the guided modes. The angle at which mode excitation occurs is related to the mode index as shown in Eqn (1).

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

where \( n_p \) is the refractive index of prism material, \( \alpha \) is the prism angle and \( \theta \) is the prism and incident angle with respect to the prism normal.

The incident angle is measured within an accuracy of 0.01 so that value of \( n_{\text{eff}} \) could be estimated to an accuracy of \( 1 \times 10^{-4} \). The propagation losses were estimated by varying the propagation length between the input and output prisms using precalibrated mounts. The output intensity was measured by a large area photodetector as a function of distance. Propagation losses were measured from a lock-in-amplifier (EG & G 5301 Princeton, Applied
Research). Polyacrylate has excellent transmission (70-80%) in the wavelength range 500-700 nm. The typical losses are found to be in the range of 1.33 - 2.95 dB/cm for waveguides of different thickness.

Results and Discussion

The films permitted the observations of 3 modes. When used as a waveguide medium, a 2.35 μm thick film of polyacrylate showed three modes corresponding to three incident angles. The refractive index was determined to be 1.567. The refractive index and depth of these guides were estimated using a Jussaud and Chartier's method which is valid in the present investigation because the index profile of these guides is step like as shown in Figure 1. From the set of mode indices, index profile n(x) can easily be estimated using the WKB approximation. For a step index profile, the effective mode indices can also be expressed as a function of the mode order according to the following relation (see Eqn 2).

$$ n_{eff}^2 = n_{sur}^2 - \lambda^2 \frac{m^2}{4t^2} $$

where $n_{sur}$ is the refractive index at the surface, $\lambda$ is the wavelength used, $m$ is the mode order and $t$ is thickness of the waveguide.

This equation is used to determine the refractive index and depth of the guide. A plot of $n_{eff}^2$ vs $t^2$ gives the value of $n_{sur}$ from the intercept and $t$ from the slope. A typical curve is shown in Figure 2. It can be seen that the plot is linear and the estimated value of $n_{eff}$ and $t$ is 1.567 and 1.34 μm, respectively.

The experimental values were then compared with theoretical values by generating dispersion curves (see Figure 3) using a computer simulation program, which is based on the eigen value equation (Eqn 3).
Table 1—The experimentally obtained values for polyacrylate

<table>
<thead>
<tr>
<th>Mode</th>
<th>Incident angle</th>
<th>Loss</th>
<th>$n_{\text{eff}}$</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.13</td>
<td>2.95</td>
<td>1.567</td>
<td>2.139</td>
</tr>
<tr>
<td>2</td>
<td>9.81</td>
<td>2.91</td>
<td>1.565</td>
<td>5.062</td>
</tr>
<tr>
<td>3</td>
<td>9.30</td>
<td>2.87</td>
<td>1.561</td>
<td>6.991</td>
</tr>
</tbody>
</table>

Film thickness = 2.35 $\mu$m, Substract index = 1.52.

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

... (3)

where, $a = n_c^2 - n_e^2 / n_f^2 - n_e^2$ is the asymmetry measurer, $b = n_{\text{eff}}^2 - n_e^2 / n_f^2 - n_e^2$ is the normalized guide index and $V=[2\pi/\lambda]t \cdot (n_f^2 - n_e^2)^{1/2}$ is the normalized film thickness, $n_c$, $n_e$, and $n_f$ are respectively, the refractive indices of the cladding, substrate and film layer.

It can be observed that the measured mode indices coincide with the theoretical curves. The modes are shown in theoretical curves in (Figure 3). The propagation losses were found to be in the range of 2.80-3.0 dB cm$^{-1}$ (Figure 4). Polyacrylate shows excellent transmission (70-80%) in the wavelength range of 500-700 nm. The losses for the TE modes are summarized in Table 1.

Conclusion

We have optimized various waveguide parameters, viz refractive index, propagation loss and depth on polyacrylate thin films. It is observed that the material exhibits properties such as high transparency, toughness, adhesion, high thermal stability and flexibility in fabrication when compared to other polymers. The influence of annealing temperature on the polymer films reduces the propagation losses. Thus the material is promising for use in optical waveguide and integrated optical devices.

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