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Optical Waveguide Characterization of Some Pyroelectric Polymer Thin Films

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1. Introduction

Organic films have played an important role in understanding the guided wave phenomena with a special reference to development of integrated optics [1]. Recently thin films especially polymers have attracted much attention for their applications in non linear integrated optical devices to garnet practical utilities [2-6]. However, the optical application and fabrication of a number of polymer thin films are yet to be ascertained.

Present work reports the successful preparation and characterization of pyroelectric PVF_2, PVF (polyvinyl fluoride) and their mixed polymer thin film optical waveguides.

2. Waveguidance through the thin film waveguide

A simple planar waveguide consists of thin transparent film (refractive index n_f) on a transparent and optically flat substrate (refraction index n_s) covered itself with a medium (usually air, refractive index n_a) such that $n_f > n_s > n_a$. When the light traveling in a denser dielectric medium is incident on an interface with a rare dielectric medium with an angle greater than the critical angle θ_c, the light undergoes total internal reflection. After getting total internal reflection inside the film on either boundary the light travel through different discrete angles are called mode angles. The propagation of light at one of these mode angles constitutes a guided wave.

3. Experimental Methods

Fabrication of thin films

In this study, planar optical waveguides of PVF, PVF_2 and mixed polymer films were fabricated by using solution casting spinning disc technique.

The Kynar product PVF_2 powder and PVF polymer sheets were used for making their supersaturated solutions in the dimethyl formanide (DMF) solvent.

The solutions of these materials were slowly evaporated and their supersaturated solution were used to deposite the films on quartz (for PVF_2 film) and blue star glass slides (for PVF and mixed polymer films). The deposited films have been examined by Scanning Electron Micrograph study (Fig. 1, 2 and 3).

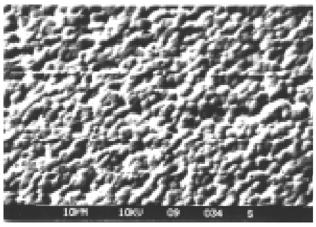

Fig. 1 SEM photograph of PVF_2 film

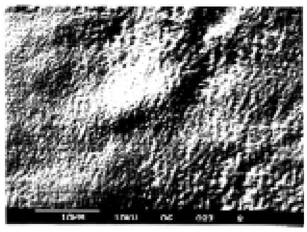

Fig. 2 SEM photograph of PVF film

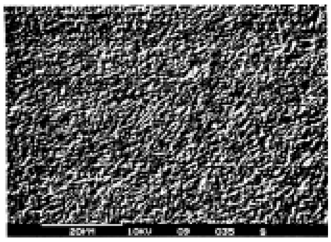

Fig. 3 SEM photograph of mixed polymer film

Mixed polymer films

A study was undertaken to make waveguides of having specific refractive index between that of PVF_2 and PVF film by mixing them in common solvent in appropriate proportion. The resultant refractive index n_{res} was obtained by mixing these polymers and to vary according to the weight and refractive index of the combination proportion of the respective polymers as per the following equation,

$$n_{res} = (w_1 n_1 + w_2 n_2) / (w_1 + w_2) \qquad (1)$$

The mixed films were casted by varying w_1 and w_2. The n_{res} for these films were measured by m-lines experiment. The value of n_{res} of the mixed films was evaluated by using the above equation and it was found to be consistent in terms of accuracy of the measured values.

Optical Waveguide Characterization

The optical waveguide parameters and the coupling angles were measured by using a symmetrical prism coupler for coupling the He-Ne laser beam (λ~6328 A^0). Mode angles were measured by using the successful waveguiding condition i.e. $n_f > n_s > n_a$ (Fig. 4 and 5). From the measured coupling angles the effective index, refractive index of the film samples, refractive index of the substrate were calculated by using the known relation between them [7].

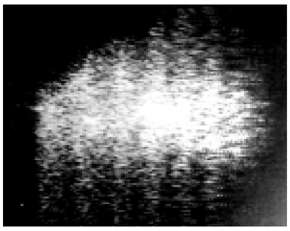

Fig. 4 m-lines for PVF_2 film

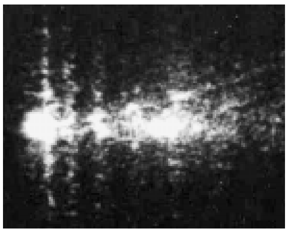

Fig. 5 m-lines for PVF film

The propagation loss for different films samples were measured by using the right angled prism coupler. All the light that coupled out was focused onto a photodetector. The distance between two prisms and the detector output were noted by changing the distance between these two prisms. Propagation loss was evaluated by taking a logarithmic ratio of output intensities between two positions.

4. Results and Discussion

The computed optical waveguide characterizing parameters of PVF2, PVF and1 mixed polymer films are shown in Table I, II and III.

TABLE I. Optical waveguide parameters of PVF_2 film

S.No.	Parameters	Film No. 1	Film No. 2	Film No. 3
1.	Angle of incidence TE mode	30.92^0	31.04^0	31.35^0
2.	Angle of incidence TM mode	30.30^0	30.83^0	30.98^0
3.	Angle of prism	60^0	60^0	60^0
4.	Refractive index of the substrate	1.427	1.427	1.427
5.	Refractive index of the film	1.4463	1.4447	1.4452
6.	Film thickness in µm	4.234	3.863	3.239
7.	Average propagation loss in dB/cm	1.31	1.32	1.32
8.	No. of modes	6	5	5

TABLE II. Optical waveguide parameters of PVF film

S.No.	Parameters	Film No. 1	Film No. 2	Film No. 3
1.	Angle of incidence TE mode	32.52^0	31.89^0	31.14^0
2.	Angle of incidence TM mode	31.57^0	30.99^0	30.74^0
3.	Angle of prism	60^0	60^0	60^0
4.	Refractive index of the substrate	1.509	1.509	1.509
5.	Refractive index of the film	1.5229	1.5264	1.5289
6.	Film thickness in µm	2.652	2.432	3.968
7.	Average propagation loss in dB/cm	1.27	1.27	1.26
8.	No. of modes	3	3	5

TABLE III. Optical waveguide parameters of mixed polymer films

S.No.	w_1 in mg (PVF_2)	w_2 in mg (PVF)	n_{res} estd.	n_{res} meas.	No. of modes	Thickness in µm
1.	01	10	1.5219	1.5216	4	3.108
2.	02	10	1.5150	1.5171	4	3.683
3.	05	20	1.5124	1.5129	5	4.269

The solution casting spinning disc technique used in the present study produces uniform and transparent films of PVF, PVF_2 and mixed polymers. For both PVF and PVF_2, a variation in refractive index of the order of 10^{-3} observed. Such types of variation with thickness of the film are reported in the literature [9]. For PVF_2 film the maximum number of modes were 6 while for PVF film the maximum modes were 5. The average propagation loss for PVF_2 was 1.31 dB/cm and for PVF films it was 1.27 dB/cm. The birefringence is one of the most useful properties for the optical devices that require a degenerate mode of operation. Only PVF_2 film exhibited this property significantly. The birefringence could be attributed to the crystalline structure and stress caused during the evaporation of the solvent.

However it was reported that PVF_2 is an induced ferroelectric and it behaves like a ferroelectric ceramic [7]. In semicrystalline state the microcrystal are dispersed in the polymer matrix. Due to microcrystalline present in PVF_2 it produces birefringence. In the present study we observed the birefringence of unpoled and unstretched PVF_2 film which was of the order of 4.9×10^{-3} to 6.1×10^{-3}. During the coupling process birefringence might be increased by increasing the applied pressure from the knife edge resulting a slight stretching pressure in few mm. area.

5. Conclusion

Thin optical waveguides that show birefringence provide an ideal condition for second harmonic generation [9] i.e. intense field within the medium ensures sufficiently large second harmonic generation and phase matching to assure efficient coupling of electromagnetic field due to polarization.

In a present study both PVF and PVF_2 have shown very low propagation loss supported by 5 and 6 modes, respectively. Further being pyroelectric (PVF_2 is ferroelectric also) and piezoelectric, these films may be very useful in switching and modulation of light [8], second harmonic generation and in pyroelectric detection. This substantiates that both PVF and PVF_2 may be very useful in IO device applications.

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