정보처리를 위한 전기 광학 고분자 광도파 소자

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Electro-Optic Poled Polymer Waveguide Devices for Information Processing

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Introduction

Electro-optic (EO) poled polymer has attracted large attention during the last decade because of its application potential for information processing[1-3]. Organic EO materials offer significant advantages over conventional inorganic materials such as LiNbO3 or semiconductors in several key areas for EO devices. These include large EO coefficients, low dielectric constant, fabrication flexibility and simple processibility which lead to high bandwidth modulators and switches, and high integration densities of many functional devices either in monolithic or hybrid forms on a single wafer.

Much research effort has been poured into molecular engineering to improve the material properties such as linear and nonlinear optical properties and thermal stability with great success during the last several years. Potential of nonlinear optical polymer devices have been demonstrated with test devices such as electro-optic modulators with tens of GHz modulation bandwidth, multilevel modulators and switches, and hybrid integration of polymer external modulator with semiconductor laser diode. There are, however, still many areas to refine from the device design to process in order to realize EO polymer waveguide devices for the application to information processing.

In this presentation, research progress on EO polymer waveguide devices made at ETRI during the last couple of years will be introduced. This includes the delineation of refractive index profiles formed by photobleaching, design and fabrication of waveguide structure, demonstration of various devices, and so on..

Materials

A poly(methyl methacrylate) (PMMA) based copolymer with 4-dimethylamino-4'-nitro-stilbene as a side chain (P2ANS, x=0.5) has been used as the guiding layer (Fig. 1) which was supplied from Hoechst Celanese Co.. The electro-optic coefficient and the refractive index (n) of the material was characterized to be 9 pm/V/(100 V/μm poling field) and 1.634[4], respectively. P2ANS with slightly lower chromophore composition (x=0.35, n=1.619) than the guiding layer and NOA61 (n=1.535) were used as lower and upper cladding layers, respectively.

Delineation of refractive index profiles formed by photobleaching in nonlinear optical polymer thin films[5-7].

Various technique such as photobleaching, poling, reactive ion etching have

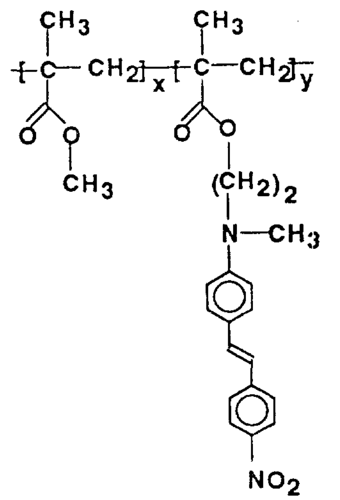

Fig. 1. Electro-optic polymer (P2ANS) used for the waveguide formation.

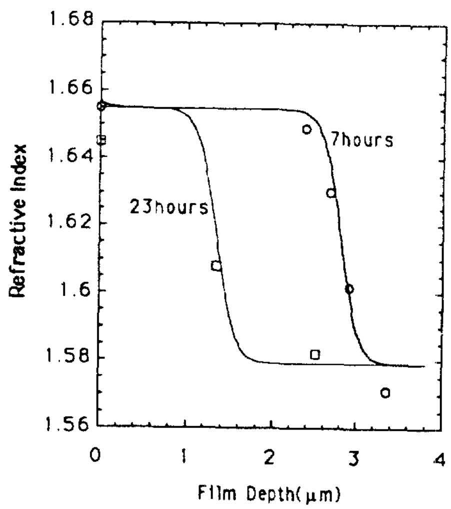

Fig.2. Refractive index profiles bleached with 458 nm for two different bleaching times. Theoretical results (solid lines) are compared with experimental ones (o,□).

been employed to form channel waveguides with nonlinear optical polymers. Among others photobleaching technique has been widely used because of its simplicity and controllability. Since the performance of the devices can be improved by the precise control of refractive index profiles, detailed information on the refractive index profiles is important for modeling the propagation of light through polymeric thin film waveguide and for the design of the waveguide devices. However, less attention has been paid for the refractive index profile in the film formed by the technique.

A simple but realistic kinetic model has been developed to describe the refractive index profiles formed by photochemical reaction in the dye attached polymers shown in Fig. 1. The effects of the absorption of bleaching light due to the unconvertible reactant and the photoproduct are included in the model. Graded refractive index profiles formed by the technique is shown to be delineated by a simple mathematical equations very well as shown in Fig. 2. The parameters required in the model are obtained from a simple transmission experiment The rate of the bleached depth change with time becomes slower as the bleaching proceeds, while the shape of the index profile was kept nearly the same. Small absorption of bleaching light due to the photoproduct has a significant effect on the resulting refractive index profiles. Details of the modeling and the experiment will be presented.

Design and fabrication of EO polymer waveguide devices[8)]

With large success of material research and demonstration of nonlinear optical polymer waveguide devices it is appropriate time to consider the detailed design of EO polymer waveguide to fully utilize material properties for the devices.

To find the optimum device structure, issues related to the design of poled electro-optic polymer waveguide such as the selection of the buffer layer materials and the thicknesses of the guiding and cladding layers have been analyzed in terms of modulation voltage, optical loss due to metal electrode and mode size. The analysis suggests a couple of general guidelines for the device fabrication. Firstly, asymmetric structure gives better performance than symmetric structure in terms of modulation voltage and mode size, where the refractive index of one of the buffer layers is close to that of the guiding layer and that of the other layer is much smaller than the guiding layer, by more than 0.1. Secondly, the guiding layer needs to be fabricated as thick as possible within the range of the single mode operation for a given material system to obtain lowest possible modulation voltage under a given limit of the electrode associated loss.

Electro-optic polymer waveguide devices such as electro-optic modulators and 2x2 directional coupler type switch have been fabricated following the guidelines from the above analysis. Materials described before have been used for the fabrication of the devices. Electro-optic modulators fabricated using the photobleaching technique confirmed the analysis. Lower modulation voltage and lower metal electrode associated optical loss with better mode size matching to optical fiber have been obtained with asymmetric waveguide structure than the symmetric structure. Electro-optic modulators with the modulation voltage of 6.7 V and the extinction ratio of over 20 dB have been successfully fabricated (Fig. 3). Modulation speed of 300 MHz with a lumped type electrode was obtained which was considered to be limited by the measurement.

Post photobleaching technique to control the beam propagation direction in a directional coupler[9].

A new method (we named it as the post-photobleaching technique) has been developed to tune the initial state of the directional couplers to the cross state after the completion of the device fabrication. The method utilizes the change of the refractive index of the electro-optic polymer if it is exposed to ultra-violet or visible light. If the coupling region of the directional coupler is selectively exposed after the device fabrication, the coupling coefficient in the region will be changed due to the refractive index change. Coupling order can also be changed by the method resulting in the lowering of the switching voltage. The idea was successfully applied to the polymer 2x2 directional coupler type switch to get the initial cross state and to lower the switching voltage. Extinction ratios of more than 20 dB in cross state and about 15 dB in bar state have been obtained from the devices (Figure 4).

Waveguide devices for polarization control [10,11]

Many electro-optic waveguide devices are sensitive to the polarization of light and it should be strictly controlled to utilize the device function properly. Waveguide devices which can control the polarization of the light propagating through them are very valuable to integrated optics, for instance to form a polarization independent modulator. We have designed and fabricated many polarization control devices such a TE-TM mode converter, a general polarization transformer, a polarization filter, a polarization rotator and on. The devices utilize the controllability of electro-optic axis of poled EO polymers to arbitrary directions by arranging the poling electrode as desired. The structures and the characteristics of the devices will be given in the presentation.

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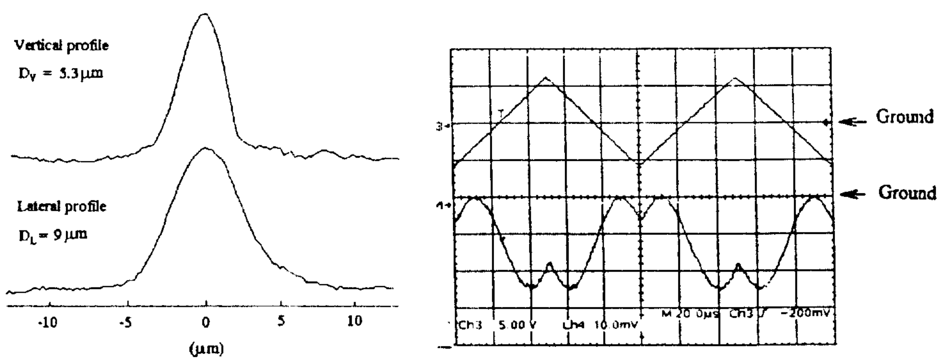

Figure 3. Modulation characteristics and mode profiles of an electro-optic modulator formed by polymer. Modulation voltage of the device was 6.7 V with the extinction ratio of over 20 dB.

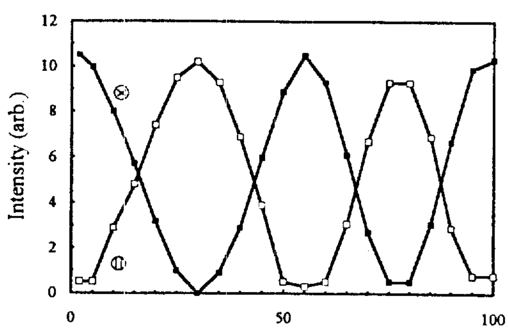

Figure 4. Switching behavior of a 2x2 directional coupler. Extinction ratios were about 20 dB for the cross state and 15 dB for the bar state, respeetively.