Polymer-Based Electrooptical Circular-Polarization Modulator

Jianyi Yang, Qingjun Zhou, Xiaoqing Jiang, Minghua Wang, and Ray T. Chen

***Abstract*—An integrated circular-polarization modulator (CPM) is designed and fabricated with electrooptic (EO) polymeric materials employing contact poling. Tilted-poling is employed to activate the conversion between TE and TM modes, while the tensor nature of the poled polymeric materials is used to generate the phase-difference modulation. With appropriate voltage control, the outputs at the 45°-tilted linear, left-hand-circular (LHC), −45°-tilted linear, and right-hand-circular (RHC) polarization states are achieved. The extinction ratios at the linearly polarized states are larger than 25 dB.**

***Index Terms*—Electrooptic modulation, integrated optics, optical planar waveguide, optical polarization, optical polymers.**

I. Introduction

The OPTICAL circular-polarization modulator (CPM) can be employed as a source of both left- and right-hand-circular (LHC and RHC) lights, which are needed for detecting and measuring chirality [1]. It can also find uses in optical communications [2]. Commonly the CPM is made by employing the bulk-optic technology with electrooptic crystals [3]. Using electrooptical (EO) polymeric materials and contact-poling technique, we present a monolithically integrated CPM for the first time.

II. Principle of Operation

This CPM consists of two main sections, the TE–TM polarization balancer and the TE–TM phase-difference modulator, as shown in Fig. 1. When a linearly polarized light in the vertical or horizontal direction enters into the CPM, TE–TM polarization conversion takes place in the polarization balancer. By applying and adjusting the biasing voltage, the conversion can be controlled and the powers of the TE and TM modes will be delivered equally to the output of the CPM. Then, in the phase-difference modulator, the variable phase difference between the TE and TM modes is generated and the polarization state of the output light is modulated. The phase-difference modulator is the portion that actually causes the modulation while the polarization balancer is a static portion of the overall CPM, which is needed to ensure that the output alternates between the LHC and RHC states.

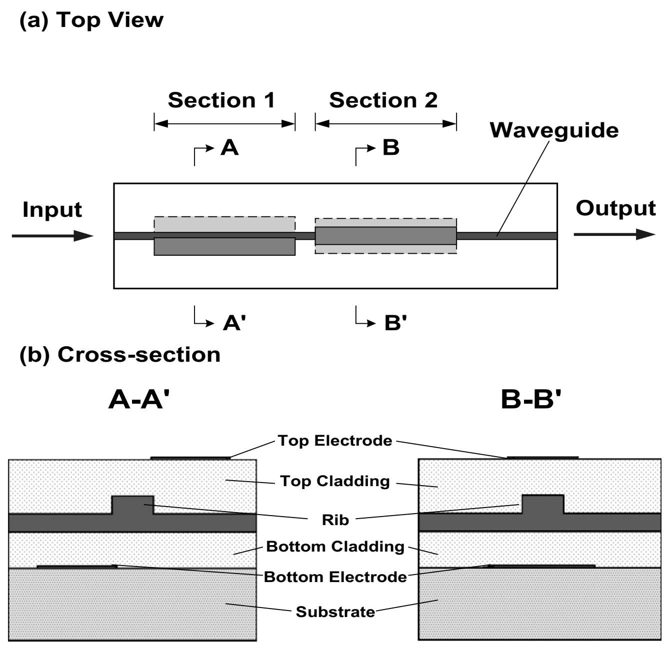

Fig. 1. Schematic diagram of the EO-polymer-based optical circular-polarization modulator.

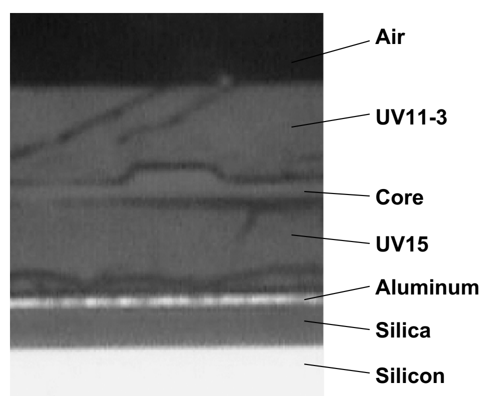

Fig. 2. Cross section of the polymeric waveguide.

The TE–TM polarization balancer follows the principle of the EO-polymer-based TE–TM polarization converter [4], [5]. Since the optical principal axis of the poled EO polymer depends on the direction of the electrical field in the poling procedure, polarization conversion can be realized in the tilt-poled polymeric waveguides and the conversion length can be controlled by applying a biasing voltage. To obtain the largest conversion range, a poling field tilted at 45° with respect to hori-

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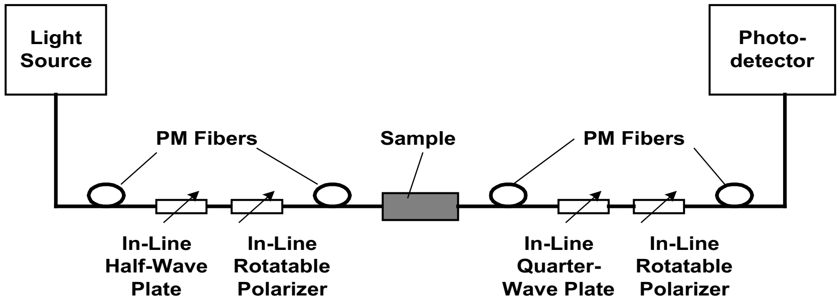

Fig. 3. Schematic diagram of the optical measuring setup.

zontal direction is required [5]. Employing the configuration of poling electrodes as shown by the cross section A-A′ in Fig. 1(b) and setting an appropriate horizontal displacement between the upper and lower electrodes, the 45°-tilted electrical field, which is approximately uniform in the waveguide core, can always be obtained [4].

The TE–TM phase-difference modulator is realized via the tensor nature of the poled EO polymer and its EO effect. Using the configuration of the poling electrodes as shown by the cross section B-B′ in Fig. 1(b) and applying contact poling, the EO coefficients of the TM and TE modes, r_{33} and r_{31}, have the approximate relationship of $r_{31} \approx (1/3)r_{33}$ [6] and, with the applied modulating voltage V, the change of the phase difference between the TM and TE modes can be described as

$$\Delta\varphi_{\mathrm{TM-TE}} \approx -\frac{2\pi}{3\lambda} n_e^3 r_{33} \frac{V}{d} \Gamma L \tag{1}$$

where d is the total thickness of the polymeric film, L is the length of electrodes, n_e is approximately the refractive index of the core, and Γ is the overlap integration of the modulating electrical field and the optical mode.

III. Experiment and Results

In our experiment, the upper and lower cladding layers of the waveguide are the UV11-3 and UV15 films with the thickness of 6.5 and 5.5 μm, respectively. Both UV11-3 and UV15 are UV epoxies, the products of Master Bond Inc. The rib core, which is 5-μm wide, 2-μm thick and 1-μm high, was realized by spin-coating DR1/PMMA [7] and then RIE. Fig. 2 shows the cross section of the fabricated polymer rib waveguide. The length of the electrodes in the polarization balancer is 1.2 cm and the width is 50 μm. The horizontal displacement is 2.8 μm, which is designed to realize the 45°-tilted poling field. The length of the electrodes in the phase-difference modulator is 1 cm. Contact poling was performed at 125°C by applying 1200 and 1100 V to the polarization balancer and the phase-difference modulator, respectively. The processing details of fabrication and poling has been described in [8].

The measuring system is shown in Fig. 3 with a light source at the wavelength of 1550 nm. The Newport AutoAlign System is employed to realize the light coupling between the polarization-maintaining fibers and the sample. The light source is the Multi-Channel Stabilized Laser Source MSLS-1000 from E-Tek Inc. The detecting system is the Model 2832-C Optical Power Meter with a Model 818 photodetector, both from Newport Inc. The TE–TM polarization balancer was characterized as a polarization converter [5]. By controlling the polarization direction of the input light, it was measured that the conversion efficiency between the TE and TM modes was about 90%, which was large enough to support the polarization power balance. The corresponding voltage for a conversion cycle is about 230 V. Then, with the balanced TE and TM modes, the polarization characteristics of the output were measured when the modulating voltage was applied to the TE–TM phase-difference modulator and the in-line quarter-wave plate was rotated at different angles. With the measured data, as shown in Fig. 4, we can find that the polarization state of the output light at States A, B, C, and D are the 45°-tilted linear, LHC, −45°-tilted linear, and RHC polarization, respectively. This means that the circular-polarization state of the output light has been modulated by varying the applied voltage. The extinction ratios at the linearly polarized states are larger than 25 dB, which indicates the quality of the circular-polarized light. The half-wave voltage of the modulating curve shown in Fig. 4 is about 96 V, corresponding to an EO coefficient r_{33} of about 11 pm/V.

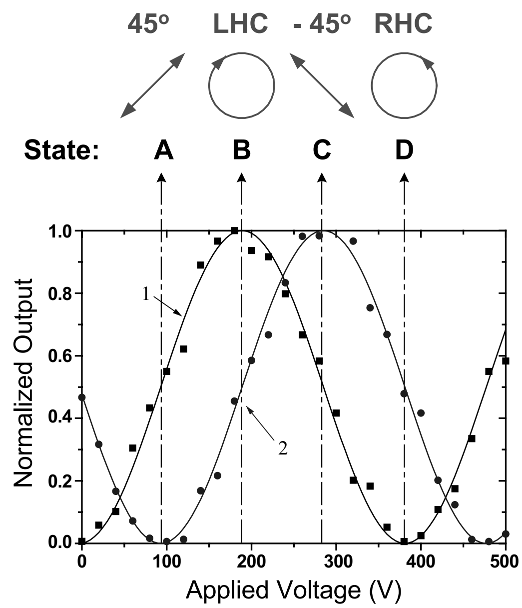

Fig. 4. Measured output of the 45°-tilted-polarization component versus the modulating voltage. ● the principal axis of the quarter-wave plate is 45° tilted; ■ the principal axis of the quarter-wave plate is vertical; ——— the curve of the Sine function.

IV. Conclusion

In this letter, an EO-polymer-based CPM is designed and fabricated. Tilted poling is employed to activate the conversion between TE and TM modes and the tensor nature of the poled polymeric materials is used to generate phase differences. With appropriate voltage control, it is achieved that the polarization state of the output from the CPM can alternate between the LHC and RHC states. The extinction ratios at the linearly polarized states are larger than 25 dB. The biasing voltage for the first section and the half-wave voltage of the second section are rather high. However, these working voltages can be lowered if chromophores with larger EO coefficients are used, such as CLD1 [9].

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