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Wavelength insensitive passive polarization converter fabricated by poled polymer waveguides

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A passive TE to TM polarization mode converter is fabricated by using poled polymer waveguides. The optic axis of the poling induced waveguide is slowly rotated 90° by using a slowly varying structure of poling electrodes. Thus the polarization conversion is achieved as the guided mode propagates through the waveguide. TE to TM mode conversion is observed with a polarization extinction ratio higher than 30 dB, and the excess loss is less than 1 dB. The polarization conversion is relatively insensitive to wavelength since the device contains no periodic structures. These devices are easier to fabricate than others containing periodic structures. © *1995 American Institute of Physics.*

The TE/TM polarization mode converter is a useful device in integrated optics. Electro-optic polarization converters have been fabricated by $LiNbO_3$ and InP waveguides.[1,2] However, passive operation is preferable for some system applications. Recently passive polarization converters have been fabricated by using a periodically tilted rib waveguide[3] and an asymmetric periodic load.[4] In this work, we report a TE/TM polarization mode converter fabricated by using poling-induced waveguides in electro-optic (EO) polymer. The electric field-assisted poling increases the refractive index of the EO polymer for the light polarized along the poling direction, while decreasing it for the light polarized perpendicular to the poling direction.[5] Thus it is utilized to fabricate channel waveguides that confine only one polarization component.[6] To convert the polarization of the channel waveguide mode, the azimuth angle of its optic axis is adiabatically changed along the propagation direction by using a slowly varying structure of poling electrodes.[7,8]

The polarization converter in this work is composed of three sections: a polarizer, a rotator, and an analyzer, as shown in Fig. 1. The device was built using three polymer layers: a lower cladding, a core layer of slightly higher index, and a top cladding. All four electrodes are poled at the same time. This results in a horizontal field in the polarizer section, a slowly rotating field in the rotator section, and a vertical field in the analyzer section, as shown in the cross sections of Fig. 1. Because of the birefringence induced by poling, a channel waveguide is formed with higher index for TE polarization in the polarizer section, due to the horizontal electric field at this location. Hence, the polarizer section operates as a TE-pass filter. The polarization rotator section has a slowly varying electrode structure which makes the optic axis rotate from horizontal to vertical direction. It is unnecessary to control the optic axis precisely in the rotator section as long as the optic axis is varying slowly enough to suppress the excess scattering loss. The final section is an analyzer which is poled by two electrodes vertically aligned. In contrast to the polarizer section, the analyzer section has an enhanced index profile only for TM polarization, and it works as a TM-pass filter. When the light is coupled into the input end of the device, a TE polarized guided-mode is evolved in the polarizer section. As the light propagates along the rotator section, the polarization of guided mode rotates gradually from TE to TM mode following the optic axis direction. This resembles the polarization rotation in the twisted nematic liquid crystal. Finally, a TM polarized guided mode is extracted from the analyzer section. Since the device contains no periodic structures, it is much less sensitive to wavelength, channel dimensions and polarizing structures compared with devices containing such structures. It may be noted that this device can operate under multimode conditions since the poled polymer waveguide supports only one polarization component.

By using a vector beam propagation method for anisotropic media we made a numerical simulation for the polarization converter.[8] It was shown that efficient polarization

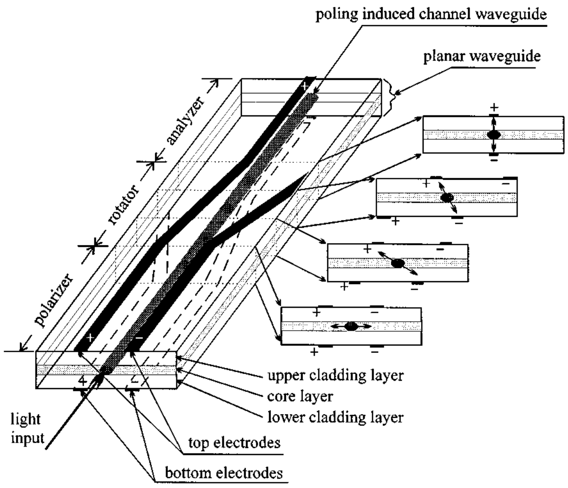

FIG. 1. Schematic diagram of the proposed polarization rotator; cut views show the major direction of the poling field or the optic axis of the poling induced waveguide for given electrode structure.

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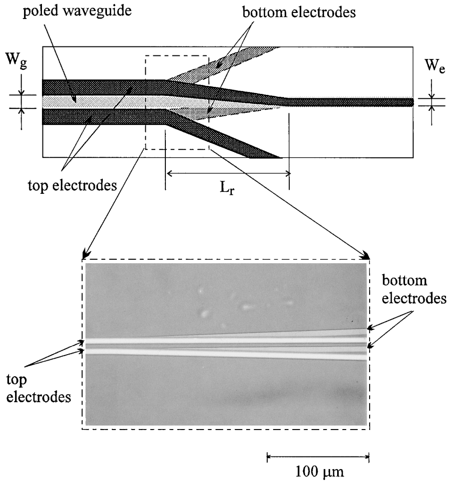


FIG. 2. A top view of the polarization rotator and a microphotograph of the fabricated device at the interface between the polarizer and the rotator section.

conversion is possible and the design of the device is not stringent. In Fig. 2, a top view of the polarization converter is illustrated and its dimensions are specified. L_r is the length of the rotator section, W_g the width of the gap between the electrodes in the polarizer section, and W_e the width of the electrode in the analyzer section. W_g and W_e may be chosen to meet the single mode condition of the channel waveguide.

The fabrication procedures of the poled polymer waveguides are as follows. On a thermally oxidized Si wafer, bottom electrodes are constructed by vacuum evaporation of Au-Ti and by lift-off process. The EO polymer used in this work is the PMMA based copolymer with a stilbene derivative as a side chain [poly ((4-dimethylamino-4'-nitro-stilbene methylmethacrylate)$_x$-co-(methylmethacrylate)$_{1-x}$); P2ANS] which is supplied by Hoechst-Celanese Co. For the lower cladding and core layers, P2ANS(x=0.35) and P2ANS(x=0.5) are spin-coated to be 3.5 μm and 4 μm thick, respectively. For the upper cladding layer, an UV-curable epoxy, NOA61 (Norland optical adhesive 61) is spin-coated to be 2 μm thick, and cured by exposing under UV light. After each spin-coating the polymer is baked sufficiently. The top electrodes are formed by thermal evaporation of Au and by wet etching process. Over the top electrodes, a photoresist is spin-coated and baked completely. It serves as an electrical insulating layer to prevent the air-breakdown between adjacent top electrodes during the poling. A microphotograph of the fabricated device is partially shown at the bottom of Fig. 2. Finally, the device is poled on a hot plate at 135 °C by applying 400 V across the electrodes. It may be emphasized that the poling voltage is applied to the four electrodes simultaneously. After poling, the sample is cleaved for the coupling of light. In Fig. 3, a microphotograph of the cleaved facet is shown.

To determine how device parameters affect the results, a sample of 10 devices was fabricated with different parameters as denoted in the table of Fig. 4. To test the fabricated device, TE polarized light from a 1.3 μm diode laser was launched to its input end. The light from its output end, passing through a Glan-Thompson polarizer, was detected with a photodiode. The power in each polarization component was measured by rotating the Glan-Thompson polarizer to the appropriate angle. For TE to TM mode conversion, the measured polarization extinction ratio was higher than 30 dB for the best device. To measure the excess loss of the device, we also fabricated vertically poled waveguides on the same substrate using the same poling condition, and the output power was measured and compared with that of the polarization converter. The excess loss was less than 1 dB for all the devices. The TM to TE mode conversion efficiency was also measured by reversing the light propagation direction and changing the input polarization. The measured results are also shown in Fig. 4. The polarization extinction ratio higher than 20 dB was obtained. However, the results are worse than the case of TE to TM mode conversion. The vertical poling electrode structure is almost ideal for TM polarization so that the quasi-TM mode of the waveguide has negligible TE component. On the other hand, the horizontal poling which is less ideal than the vertical poling supports the quasi-TE mode that retains a little TM component. This fact causes the degradation of the output polarization extinction ratio for TM to TE mode conversion.

In conclusion we have proposed and fabricated a polar-

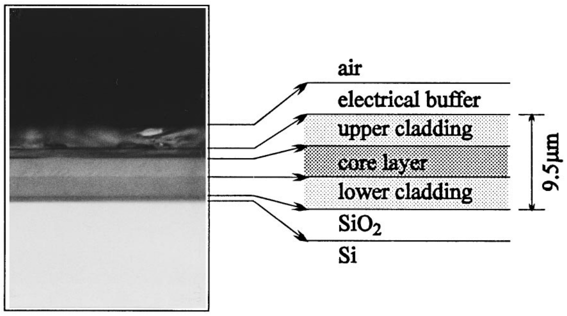
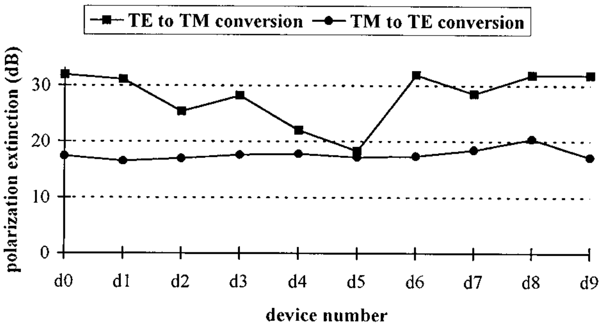


FIG. 3. Microphotograph of the cleaved facet of the fabricated device to show the multilayer structure.



device number	d0	d1	d2	d3	d4	d5	d6	d7	d8	d9
L_r (mm)	3	3	3	3	3	4	4	4	4	4
W_g (μm)	10	8	8	6	6	6	6	8	8	10
W_e (μm)	8	8	6	6	4	4	6	6	8	8

FIG. 4. Measured polarization extinction ratio of the output light of the 10 polarization converters fabricated with different parameters. Output polarization extinction ratio was measured for both TE to TM and TM to TE mode conversion.

ization converter by using poling-induced waveguides in EO polymer. TE/TM polarization mode conversion was successfully demonstrated. The output polarization extinction ratio was higher than 30 dB for TE to TM mode conversion. The fabricated polarization converter is insensitive to wavelength in principle. It is also easier to fabricate than the devices containing periodic structures. The polarization rotator possessing an arbitrary output polarization angle may be fabricated by appropriately designing the structure of poling electrodes.

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