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TE-TM Mode Converter with Rapid Response Using Photoelastic Effect of Surface Acoustic Wave
弾性表面波による光弾性効果を用いた高速応答 TE-TM モード変換素子

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1. Introduction

The acoustooptic (AO) devices using the AO effect between an optical guided wave in the optical waveguide and a surface acoustic wave (SAW) have been investigated for a long time.

The authors have realized a waveguide-type AOM driven by SAW using coplanar AO coupling, that is Bragg diffraction, in which laser light of the three primary colors, red, green, and blue (RGB), can be modulated by the same modulator at the same driving frequency.[1,2] For the application in the field of laser display, by combining the AOM module, laser sources, wavelength division multiplexing couplers, and fiber delay lines, a simple simultaneous modulation of RGB laser lights have been proposed and constructed.[2] However, it is difficult to realize an extinction ratio higher than 24 dB, which is required for practical use, because part of the incident guided optical wave inherently leaks to the diffracted port in the configuration of coplanar AO coupling.

In this study, to obtain a high extinction ratio, a rapid response, and a wide band pass, a TE-TM mode converter with a new configuration using the photoelastic effect of an SAW was proposed and demonstrated.

2. Configuration and Fabrication of TE-TM Mode Converter

Conventional TE-TM conversion using the collinear AO interaction can be achieved by not only perturbing off-diagonal elements of the dielectric tensor by using the photoelastic effect of the collinear propagating SAW but also satisfying the phase-matching condition among the TE and TM modes of the optical guided wave and SAW. In a conventional TE-TM converter, it is difficult to obtain a rapid response and a wide band pass because the length of the AO interaction region is of 10 mm order.

Thus, to obtain a rapid response and a wide band pass, a new configuration in which the perturbation of off-diagonal elements of the dielectric tensor can be provided by propagating an SAW perpendicular to a straight-channel optical waveguide was proposed, as shown in **Fig. 1**.

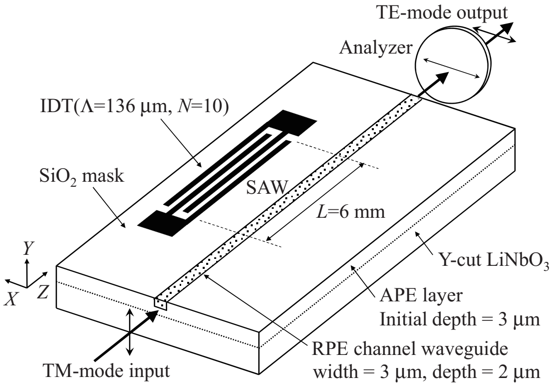

Fig. 1　Configuration of TE-TM mode converter.

When the optical guided wave propagates parallel to the optical axis (Z-axis) of LiNbO$_3$, TE-TM mode conversion can be achieved without adding the SAW wavenumber to the propagation constant of the incident optical guided mode because the propagation constants of both modes are close to each other. Only the light of the converted optical mode is filtered from the output light by an analyzer and the extinction ratio is determined from the performance of the analyzer. Therefore, a higher extinction ratio can be expected.

To fabricate the optical waveguide, we adopted the reverse-proton-exchange (RPE) process, which increases only the ordinary refractive index and maintains both the TE and TM modes. Furthermore, we utilized a leaky SAW (LSAW) with a high electromechanical coupling factor on Y-X LiNbO$_3$ as the SAW propagating mode.

The fabrication process of the mode converter is as follows. First, an annealed PE (APE) planar waveguide with a depth of 3.0 μm was formed on the whole surface of the Y-cut LiNbO$_3$ by immersing the substrate in a solution of benzoic acid (Li 1.0 mole %) at 240°C for 7 h 45 min and annealing for 40 min at 400°C. For the fabrication of RPE channel waveguides, RF-sputtered SiO$_2$ masks with a thickness of 0.25 μm and a mask width of 3 μm were formed by a lift-off technique. Next, an RPE channel waveguide with a depth of

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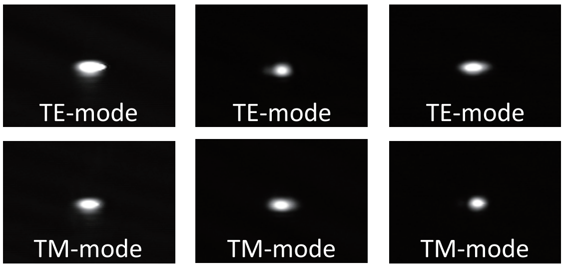

(a) Red (b) Green (c) Blue

Fig. 2 Near field patterns of RPE waveguide.

2.0 μm was formed by immersing the APE sample in an equimolar mixture of $LiNO_3$-$NaNO_3$-KNO_3 at 350°C for 8 h. The ordinary refractive index change in the RPE waveguide was measured to be 0.02. These parameters were chosen so that the RPE channel waveguide maintains a single-mode guided wave in the depth direction for RGB laser lights. Finally, after polishing the end face, interdigital transducers (IDTs) with a period of 136 μm, 10 finger pairs and an overlap length L_g of 6 mm were fabricated for X-propagating direction using an aluminum film.

3. Evaluation of TE-TM Mode Converter

A red (633 nm), green (532 nm), or blue (473 nm) laser beam was guided into the end face of the PE waveguide through an objective lens with a magnification of x40. **Figure 2** shows the observed near-field patterns of the optical guided wave in the output ports for each laser beam using an infrared (IR) camera when the driving voltage was not supplied. For each optical wavelength and each mode, a good confinement of the field distribution of the optical guided wave was confirmed.

The insertion loss between the input and output ports, including Fresnel-reflection loss for the optical wavelength of 633 nm, was measured to be 12 dB for TE mode and 9.8 dB for TM mode.

A pulse-modulated RF voltage was supplied to the input IDT. When the incident light was TM mode, the light power of the TE mode filtered through the analyzer was measured using a photodetector as a function of the input voltage of an RF burst signal. The driving frequency was fixed at 31.8 MHz for all wavelengths.

The mode conversion efficiency was determined from the modulated beam power of the TE mode divided by the output beam power of the TM mode without the driving voltage. **Figure 3** shows the measured mode conversion efficiency. The maximum conversion efficiencies for optical wavelengths of 633, 532, and 473 nm were 65, 44, and 39%, respectively. These maximum efficiencies were smaller than the diffraction efficiency of the Bragg diffraction type AOM because there is a slight phase mismatch between the propagation constants of the TM and TE modes. However, these maximum efficiencies were obtained at a relatively low incident electrical power of 0.25-0.41 W. It can be considered that the bulk wave radiation loss of the LSAW was suppressed by forming the APE layer.

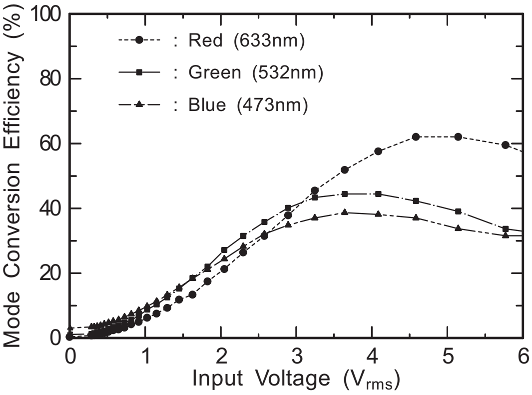

Fig. 3 Measured conversion efficiency.

Furthermore, we determined the extinction ratio from the output beam power of the TE mode without the driving voltage divided by the maximum beam power of the TE mode. The extinction ratio was measured to be 22.5-11.0 dB and was lower at a shorter optical wavelength owing to the performance of the analyzer.

The response time for mode conversion was measured to be approximately 200 ns. The response time of this converter is considered to be almost equivalent to the time required for the propagation of the SAW through the IDT width of 1.36 mm (360 ns) because the time required for the propagation of the SAW through the optical waveguide width (0.8 ns) is sufficiently small. A rapid response of about 10 ns can be obtained by decreasing the SAW wavelength and the number of IDT pairs.

4. Conclusions

A TE-TM mode converter with a new configuration in which the perturbation of off-diagonal elements of the dielectric tensor can be provided by propagating an SAW perpendicular to a straight-channel optical waveguide was proposed and demonstrated. A device with a rapid response can be fabricated by decreasing the SAW wavelength and the number of IDT pairs.

Acknowledgment

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