Digest of Papers The 8th Conf. (1976 International) on Solid State Devices, Tokyo

B-4-7

Phase Tuning in Optical Directional Coupler

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Optical directional couplers have a potentiality in integrated optical devices. Especially, active directional couplers fabricated in electro-optic materials such as $LiNbO_3$ and $LiTaO_3$ are extremely attractive as amplitude modulators and switches in the future optical communication systems. In fabrication of the directional couplers, two parallel waveguides should be made to have the same propagation constant, otherwise it will lead to considerable reduction in the coupling power and the modulation efficiency. Therefore, the same dimensions and refractive indices are required for both waveguides which are closely placed within a few microns. However, it seems to be quite difficult to satisfy these conditions due to the limitation of fabrication technique in making the waveguides. In this report, a new phase tuning method is proposed and examined experimentally. The method consists of applying a bias voltage to an additional electrode.

The configuration of the directional coupler is shown in Fig. 1. This structure provides an efficient modulation by concentrating the electric field perpendicular to the surface in the waveguide regions. The additional electrodes fabricated outside the electrodes for modulation play an important role in phase tuning the waveguides. When a bias voltage is applied between the additional electrode and adjacent one on one of the waveguides, the refractive index change is induced mainly in this guide. Therefore, the phase mismatching between the two waveguides can be compensated by tuning the bias voltage. Fig. 2 shows an example of the calculated electric field when 1 V is applied to one of the electrodes for tuning. Two dotted regions under the electrodes indicate the waveguides. When the propagation constants of waveguides 1 and 2 are β_1 and β_2, respectively, the bias voltage V_B needed to compensate the phase mismatching ($\beta_1 - \beta_2$) is approximately given as follows;

$$V_B = \frac{\beta_1 - \beta_2}{\beta_1} \frac{2g}{n_e^2 r_{33} \Gamma} ,$$

where n_e is the refractive index of waveguide, r_{33} is the electro-optic constant, g is the spacing between the additional electrode and the adjacent one, and Γ is correction factor for the electric field.

The optical directional coupler was fabricated as follows. A TiO_2 film of about 400 Å was deposited on the surface of a c-plate $LiNbO_3$ by sputtering. Patterning of TiO_2 film was done by sputter-etching using an Al mask. Diffusion of TiO_2 was performed at 1000°C for 10 hrs in O_2 atmosphere. In this sample, the waveguides had the width of about 8.3 μm and were separated each other by approximately 7.9 μm. The length of coupling region was 16.0 mm. After TiO_2 diffusion, the Al electrodes were formed photolithographically.

The He-Ne laser beam (6328 Å) was fed into the end face of the waveguide 1 by an objective lens (× 10). The observed near field pattern of TE mode is shown in Fig. 3. The optical coupling was about -10 dB in this sample. The output light intensity from the waveguide 2 was measured as a function of applied voltage to the electrodes for modulation, where the bias voltage was taken as a parameter. The result of phase tuning is shown in Fig. 4. When the bias voltage was 0 V, the maximum coupling occured at the modulation voltage of +2 V due to the phase mismatching between both waveguides. Whereas, when the bias voltage was +5 V, the maximum coupling was obtained at the modulation voltage of 0 V. This result means that the propagation constants of the two waveguides could be made equal by a bias voltage. The modulation voltage of 8 V required from maximum to minimum coupling was not affected by the bias voltage.

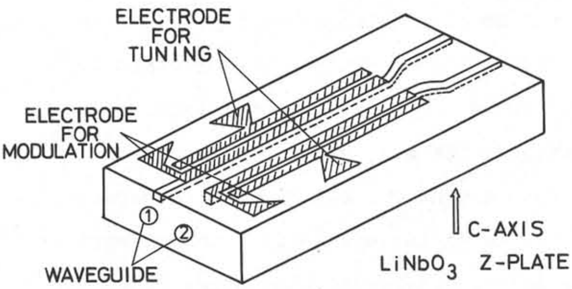

Fig. 1 New configuration of optical directional coupler with phase tuning electrodes.

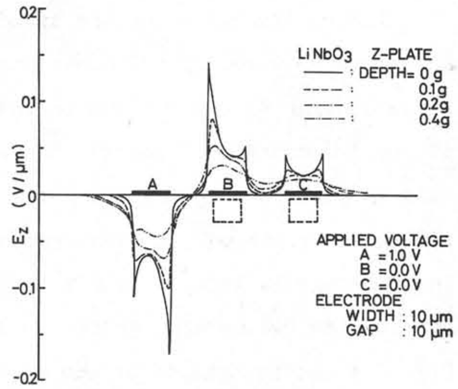

Fig. 2. Distribution of the electric field.

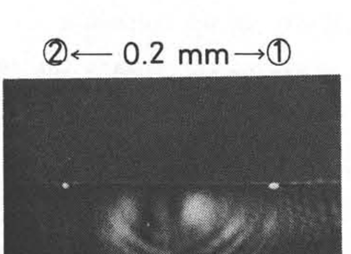

Fig. 3. Observed near field pattern.

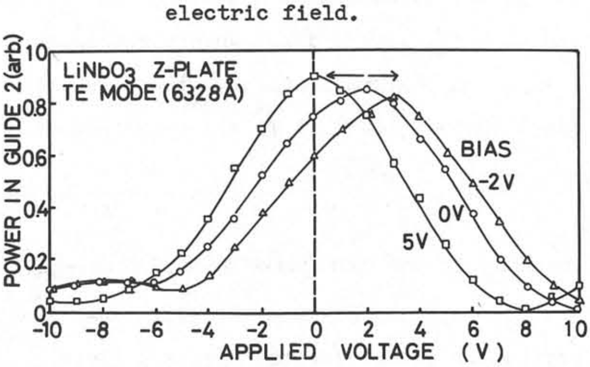

Fig. 4. Experimental result of phase tuning.