Digest of Tech. Papers The 9th Conf. on Solid State Devices, Tokyo

B—2—1

Mirror Type Optical Switch

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Considerable efforts have been made in the last several years for the development of electrooptic switches constructed by waveguides of ferroelectric single crystals. In this work, we fabricate the optical switch based on a unique mirror effect by varying the amount of diffused Ti in a waveguide of $LiNbO_3$. The switches in two and three dimensional waveguide type are shown in Fig. 1 (a) and (b). n_1 and n_2 are the effective indices of guide 1, 2 and 3, respectively. When n_1 is not equal to n_2, the light propagating to X direction is partially reflected and partially transmitted at the mirror line. The reflectivity R can be varied, when n_2 is varied by electrooptic effect. This effect constitutes the electrooptic switch. In Yplate of $LiNbO_3$, the electric field is mostly Z component contributing to largest r_{33} component of electrooptic coefficients of $LiNbO_3$ for the parallel electrode shown in Fig. 1, when Θ is close to 0. The electric field $E_z(y,z)$ between electrode in Fig. 1 is written by

$$E_z(y,z) = (Vo/\pi)\left\{(d^2/4 - z^2 + y^2) + 4z^2y^2\right\}^{-1/4}\cos\left\{\frac{1}{2}\tan^{-1}\left\{2zy/(d^2/4 - z^2 + y^2)\right\}\right\} \quad (1)$$

where Vo and d are the applied voltage and electrode gap (50 μm), respectively. y and z are depth from the surface of waveguide and the distance from the center of electrode. The field profile of propagating light under the surface of waveguide is represented by E(y).[1] From eq.(1), the variation of reflectivity with E_z due to decrease of n_2 by electrooptic effect is written by

$$R = \frac{\int_0^{y_o} E(y)^2 \left(\frac{\{n_2 - 1/2\, n_2^3\, r_{33}^{eff} E_z(y)\}\cos\alpha_1 - n_1\cos\alpha_2}{\{n_2 - 1/2\, n_2^3\, r_{33}^{eff} E_z(y)\}\cos\alpha_1 + n_1\cos\alpha_2}\right)^2 dy}{\int_0^{y_o} E(y)^2 dy} \quad (2)$$

where r_{33}^{eff} is observed effective electrooptic coefficient (20×10^{-12} m/V). Here $E_z(y)$ is equal to $E_z(y,d/2)$ on the edge line of electrode which is along mirror line. α_1 and α_2 are incident and refracted angle, respectively. y_o is defined as $E(y_o) \simeq 0$. When n_1 is equal to n_2, R versus E_z calculated from eq. (2) is shown in solid line of Fig. 2. As shown in Fig. 2, impractically high electric field is needed for total reflection. When n_1 is set higher than n_2, i.e., $n_1 = 2.2050$, $n_2 = 2.2036$, R versus E_z calculated from eq.(2) is shown in dashed line of Fig. 2. But in this case, about 10% of incident light energy is reflected when no voltage is applied. The switches made of two and three dimensional waveguide, where n_1, n_2 and Θ were set to 2.2050, 2.2036 and 2.5°, respectively were tested by monitoring the output power of reflected and transmitted light at 0.6328 μm as increasing dc voltage. Fig. 3 and 4 are plots of output signals of reflected and transmitted light in two and three dimensional waveguide, respectively. The light was propagating to X direction so that r_{33} component was utilized with a TE_o polarized light. The electrode of 50 μm gap was Al metal and photolithographic registration was achieved with conventional alignment mask. The solid lines of Fig. 3 and 4 represent the theoretical curves calculated from eq. (2). Excellent agreement of observed points with theoretical curve in Fig. 3 indicates that variation of reflectivity R with electric field in two dimensional waveguide can be explained by eq. (2).

Poor agreement of observed points with theoretical curve in Fig. 4 may be due to the modes of z direction for three dimensional waveguide, because the modes of z direction were not considered in eq. (2). It is found from Fig. 3 and 4 that switching ratio (ratio of intensity of reflected light to that of transmitted light) is varied from 0.1 to 12.4 in two and three dimensional waveguide when 300 and 400 V are applied to the electrode of 50 μm gap, respectively.

The main features of this switch are that 1) simple and small electrode form and 2) large separating angle ($2\Theta = 5^{\circ}$) enough to accommodate a large number of switches in a single substrate.

Reference

1) E. Conwell, Appl. Phys. Lett. 25, 40 (1974)

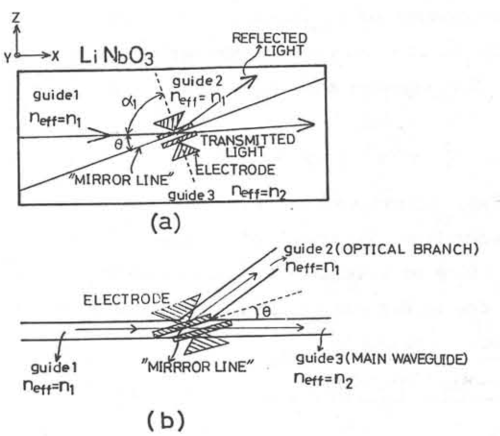

Fig. 1 Basic structure of mirror type optical switch. X, Y and Z represent each crystal axis of $LiNbO_3$

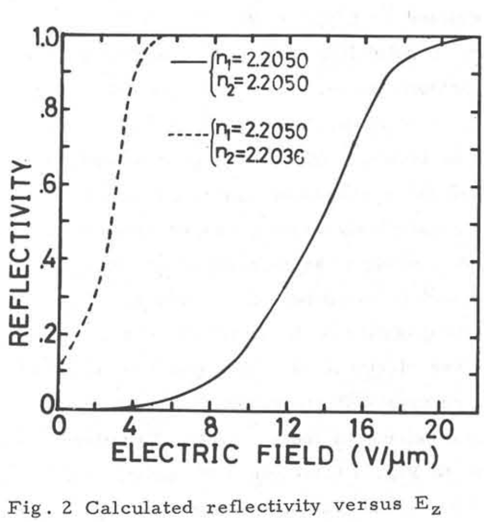

Fig. 2 Calculated reflectivity versus E_z

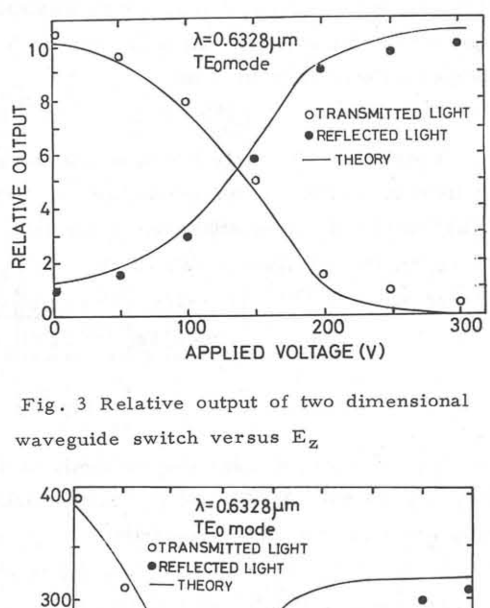

Fig. 3 Relative output of two dimensional waveguide switch versus E_z

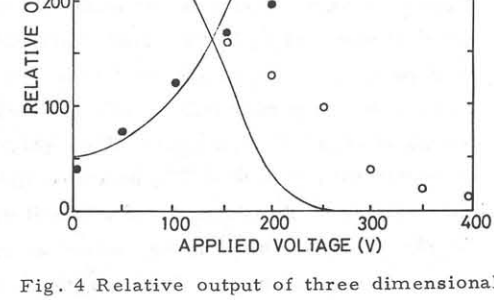

Fig. 4 Relative output of three dimensional waveguide switch versus E_z