EXPERIMENT ON LIGHT INTENSITY MODULATION BASED ON GUIDED-TO-RADIATION MODE COUPLING IN HETERO-STRUCTURE THIN FILM WAVEGUIDE

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ABSTRACT

Coupling of TE_0 guided mode to TM radiation mode is controled by a modulation signal applied to coplanar electrodes. Almost 30dB/cm of modulation efficiency at 0.6328μm wavelength has been obtained using a Nb_2O_5-$LiTaO_3$ planar waveguide with modulation voltage 350V and electrodes gap 55μm.

Introduction

The recent development of optical guided-wave-modulators has stimulated interests in integrated optical systems. The linear electrooptic (Pockels) effect in crystals is generally most useful in terms of high frequency modulation.

Marcuse suggested to use guided-to-radiation mode coupling in electrooptic crystals for obtaining a light intensity modulator[1]. It has the advantage of simple structure together with relaxed tolerance of fabrication. However, the calculated and experimented modulation efficiencies were very low[2, 3].

Previously, we have shown theoretically, that the efficiency can be very much improved by selecting a proper combination of refractive indices of the film and substrate so as to increase the overlap integral between the guided and radiation modes[4]. The present paper describes the experimental verification of the theory.

Choice of material

The structure and the coordinate system are shown in Fig.1. According to our theory, the birefringence of substrate is the less, the greater is the efficiency[4].

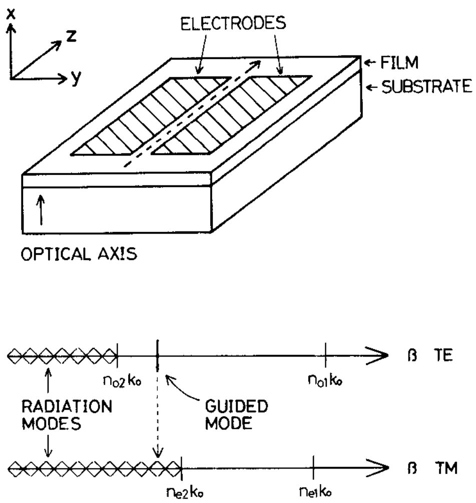

Fig.1 The structure of a light intensity modulator and the ranges of TE and TM modes. A TE guided mode degenerates to a TM radiation mode.

If we take $LiTaO_3$ (n_o=2.176, n_e=2.181) as the substrate crystal, TE guided mode can couple to degenerating TM radiation mode through electrooptic coefficient r_{42}, when a modulation field is applied in the y direction. The modulation efficiency strongly depends on the refractive index and the anisotropy of the film grown on the substrate. Though the theory predicts that the anisotropic film with electrooptic effect e.g. $Li(Nb_x Ta_{1-x})O_3$ gives beteer result than isotropic one[4], here we choose the latter because of easier growing technique. Figure 2 shows the efficiency versus film thickness for several isotropic films with different refractive indices where the guided mode is TE_0 and the modulation field is 3V/μm.

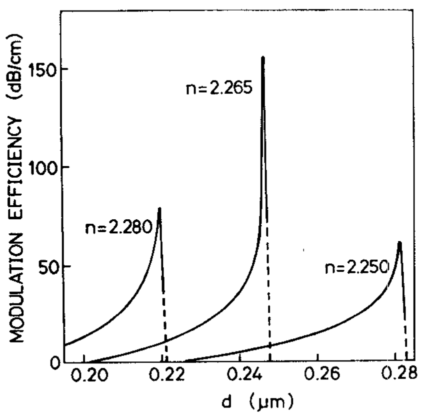

Fig.2 Modulation efficiency versus film thickness d. Parameter is the refractive index of the isotropic film. $LiTaO_3$ is assumed as the substrate.

Compared with the result by Marcuse[1], one notices that at least 100 times improvement may be expected in the efficiency (dB/cm) without deteriorating the tolerance of fabricaion.

Fabrication

We deposited amorphous Nb_2O_5 film[5] on z-cut $LiTaO_3$ by reactive RF sputtering for 48 minutes. A metal Nb target was used in a planar magnetron diode sputtering system, with the growth conditions of gas content of Ar(80%) + O_2(20%), gas pressure of 2.2 x 10^{-2} Torr and RF power input of 100W. The substrate was cooled by water.

Figure 3 illustrates the refractive index of the film deposited on Corning 7059 glass versus gas pressure in the chamber. The value of gas pressure above mentioned has been taken in order to have 2.265 of refractive index, which would give the best modulation efficiency referring to Fig.2.

Although we have not measured the film thickness and refractive index yet, the propagation constant (effective refractive index) of TE_0 mode was estimated to be 2.178 by the m-line method. It is in between n_o and n_e of the substrate, so that TE_0 guided mode can

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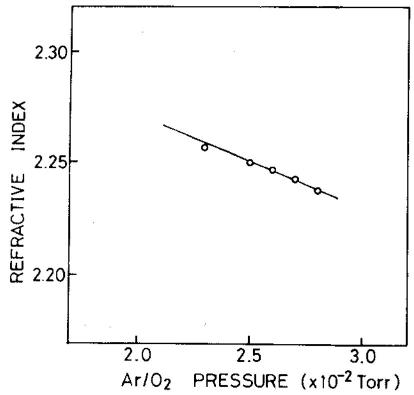

Fig.3 Refractive index of the Nb_2O_5 film on Corning 7059 glass versus the atmosphere gas pressure. The gas content is Ar(80%) + O_2(20%).

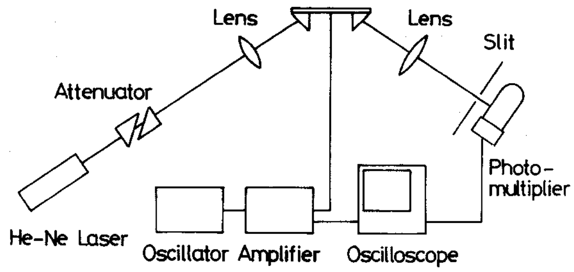

Fig.5 Experimental set-up. TiO_2 prisms are used as input and output couplers.

degenerate with TM radiation mode.

Thus, we have made a pair of Al electrodes of 4.9mm long, 45μm wide and 55μm separated using lift-off technique. The picture of the electrodes is shown in Fig.4.

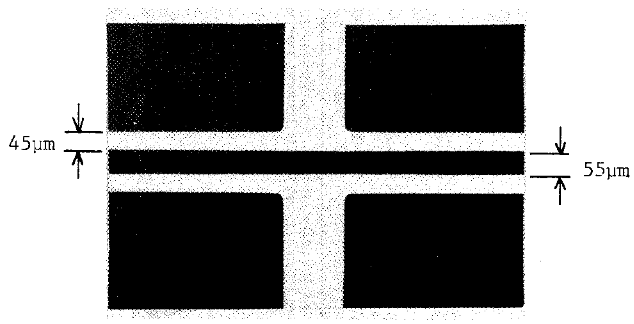

Fig.4 Photograph of the modulation electrodes. Only the central part is shown.

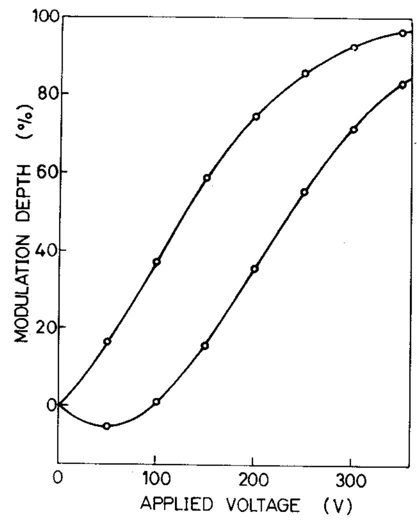

Fig.6 Modulation depth versus modulation voltage. The deviation of C-axis from the x-direction induces the different light output for the polarity change of the modulation field.

Experiment

We have measured the output light intensity by a photomultiplier applying 500Hz sinusoidal signal to the electrodes. (Fig.5) The output light power is plotted versus the modulation voltage in Fig.6. "The modulation depth" in the ordinate is defined as

$$\frac{\text{Output}|_{V_m=0} - \text{Output}|_{V_m}}{\text{Output}|_{V_m=0}} \times 100\%$$

Depending on the polarity of the applied signal, the modulation depth exhibits different values. This is well accounted for by assuming the deviation of the C-axis of $LiTaO_3$ from the x-direction in Fig.1. If the deviation angle is 0.7° in the x-y plane and the film thickness and refractive index are 0.28μm and 2.243 respectively, the theoretical curves fit those in Fig.6 very well.

The modulation depth at 350V is 96% and 83% for each polarity, which stands for the modulation efficiency of 29dB/cm and 16dB/cm respectively. These values are greater than those of Lee and Wang[2] by more than one digit. Figure 7 shows an example of the observed light intensity and the modulation signal.

At the present stage, the experiment is preliminary, and hence we have obtained only qualitative agreement with our theory. The theoretical prediction has been, however, confirmed that the efficiency should be increased drastically by arranging the refractive indices of the film and substrate in favorable condition.

Acknowledgement

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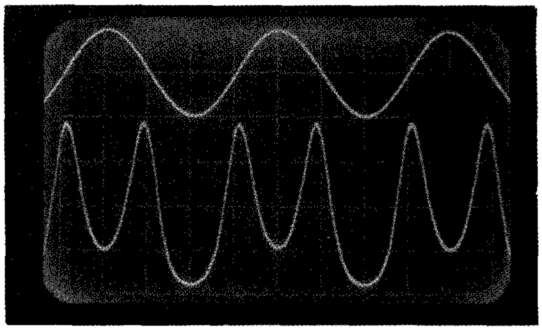

Fig.7 Typical oscilloscope trace of 500Hz modulation.

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