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OPTICAL CROSSTALK DUE TO ELECTRICAL COUPLING IN HIGH-SPEED LITHIUM NIOBATE DEVICES

P. Perlmutter, J. E. Baran and Y. Silberberg

Bell Communications Research, Red Bank, NJ 07701

Abstract

Two high-speed phase modulators with traveling wave electrodes fabricated on the same lithium niobate crystal were used to measure the optical crosstalk caused by electrical coupling between the electrodes as a function of frequency up to 7 GHz.

Introduction

The bandwidth available at optical frequencies has generated a great deal of interest in high-speed integrated optical devices. Consequently various high-speed modulators and switches have been demonstrated using lithium niobate technology. In most cases only one high-speed device with a single pair of electrodes was fabricated on each crystal. Future applications of integrated optics will eventually require more complicated structures with integration of several high-speed components on the same crystal. As a first step in that direction, we have recently demonstrated a high-speed phase modulator using a symmetric coplanar transmission line, geometrically suitable for incorporating many devices on the same crystal [1]. Packing more components on the same crystal means a smaller distance between the electrodes, which may cause excessive optical crosstalk because of electrical coupling between the electrodes. In this work we report on the measurements of this effect as a function of frequency up to 7 GHz.

Device Fabrication

We have used a Z-cut lithium niobate crystal on which some twenty optical channel waveguides were formed by titanium indiffusion [2]. On two optical waveguides we fabricated traveling wave electrodes thus making high-speed phase modulators. We used symmetric coplanar electrodes with a gap of 6 um. For one modulator the electrode was 15 um wide and 1.5 cm long. For the other modulator the electrode width was 9 um and the length 1.0 cm. A section of the device is shown in Fig. 1. Note that between the phase modulators, i.e. optical waveguides with traveling wave electrodes, there is a passive optical waveguide with no electrodes.

Measurement Setup

The setup used is shown in Fig. 2. The light source is a HeNe laser operating at a wavelength of 1.52 um. The light from the laser is focused by a lens on the endface of the lithium niobate crystal and coupled into the optical waveguide. The light emerging from the waveguide is collimated and passed through a scanning Fabry-Perot resonator which functions as an optical spectrum analyzer. The light transmitted by the analyzer is detected with a germanium detector and displayed on the oscilloscope.

The phase modulator is electrically driven by a sinusoidal signal from a microwave sweeper. The signal is amplified with a power amplifier to the 20-30 dBm range, which is needed to induce 180 degrees optical phase shift. A variable attenuator is used to control the power level coupled into the modulator's electrodes, and a directional coupler is used to tap some of the power for monitoring purposes.

We have used the optical spectrum analyzer because it allowed us to employ a sensitive low-bandwidth (slow) detector to measure high speed modulation [3]. The Fabry-Perot is a tunable narrow band filter and enables us to measure the optical power in the modulation induced sidebands directly, without having to convert them first to electrical signals at the modulation frequency.

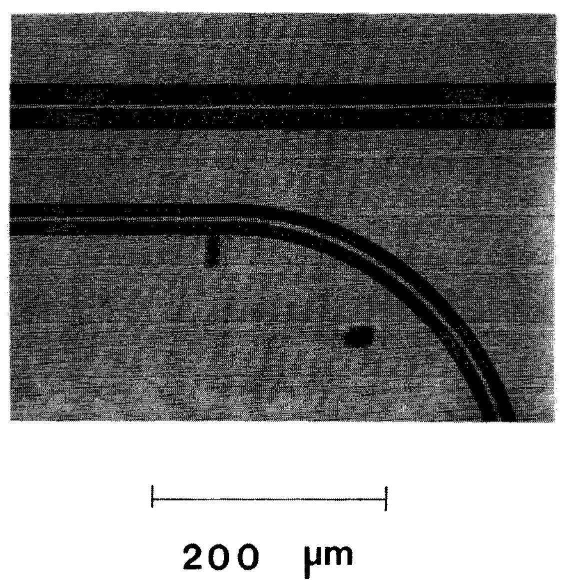

Figure 1. *Photograph of a section of the crystal, showing the two coplanar symmetric electrodes. The two phase modulators are separated by 100 um. A passive channel waveguide can be seen between the two phase modulators.*

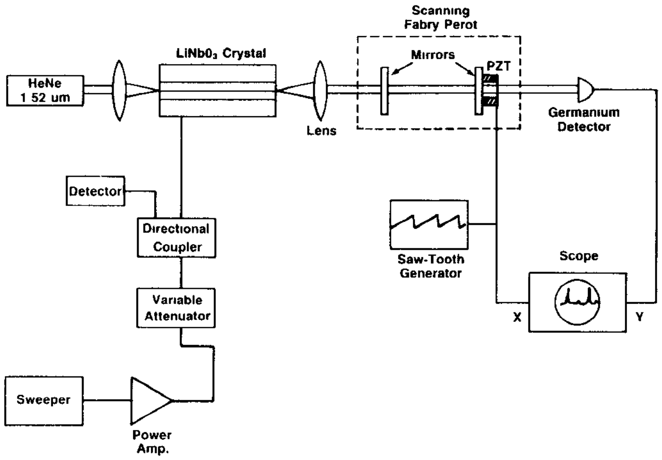

Figure 2. *A schematic illustration of the measurement setup.*

Phase Modulation Detection

The voltage in the electrodes induces an index change in the optical waveguide such that the light passing through the waveguide accumulates a phase shift which is proportional to the voltage. This means that the light coming out of the modulator has a time dependent phase:

$$S(t) = A \cos\left(\omega_o t + \Delta\phi(t)\right)$$

where

$$\Delta\phi(t) = \frac{\pi}{2}\frac{V_{PP}}{V_\pi}\cos\left(\omega_m t\right) = m\cos\left(\omega_m t\right)$$

V_π is the voltage which introduces a 180 degree phase shift, and V_{PP} is the peak-to-peak voltage of the microwave signal. The optical and microwave frequencies are denoted with the subscript o and m, respectively. The spectrum of the phase modulated light can be found immediately from the well known expression:

$$S(t) = A\cos\left[\omega_o t + m\cos\left(\omega_m t\right)\right]$$

$$= A\sum_{n=-\infty}^{\infty} J_n(m)\cos\left[\omega_o t + n\,\omega_m t + \frac{n\pi}{2}\right]$$

where $J_n(x)$ is a Bessel function of order n.

With sinusoidal microwave modulation the scanning Fabry-Perot yields an optical spectrum which consists of a set of discrete sidebands at frequencies that are removed from the optical carrier by multiples of the modulating microwave frequency, as seen in Fig. 3. The amplitude of the n-th sideband is determined by $J_n(m)$ where m is the modulation index. Since the output of the Fabry-Perot is detected with a square-law detector, the oscilloscope shows the intensity of the various frequency components.

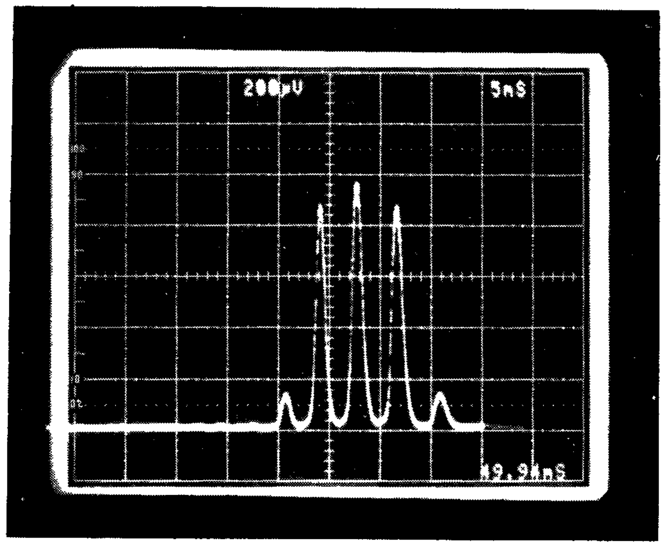

Figure 3. *Spectrum of sinusoidal phase modulated light at 2.7 GHz. Only the first two sidebands can be observed. Note that the vertical scale is linear.*

Crosstalk Measurement.

The crosstalk measurement was performed with the microwave source connected to the 1.5 cm long electrodes. The electrodes were terminated by an external 50 ohms. The other high speed electrodes were terminated with external 50 ohms at both ports.

The light from the laser was alternately coupled into each of the three optical waveguides. First, the light was coupled into the optical waveguide with the 1.5 cm long electrodes. The microwave power was then adjusted so as to generate a phase shift of 180 degrees. This is the level of excitation to be expected in real optical communications applications. Keeping the microwave power at the same level, the light was coupled into the two other optical waveguides: the one with no electrodes, and the one with the terminated 1.0 cm long electrodes. The strength of the modulation in the other guides was measured by studying the ratio of the first sideband to carrier in the optical spectrum.

Figure 4 shows the optical response for the three waveguides when microwave excitation is applied to the 1.5 cm long electrodes. The upper photo corresponds to the active phase modulator. The first sideband is a large fraction of the carrier indicating a considerable phase shift. The center photo corresponds to the passive waveguide, which has no electrode. The modulation is too small to be observed on this scale. The lower photo shows the modulation induced in the inactive phase modulator. A sizable amount of crosstalk is apparent.

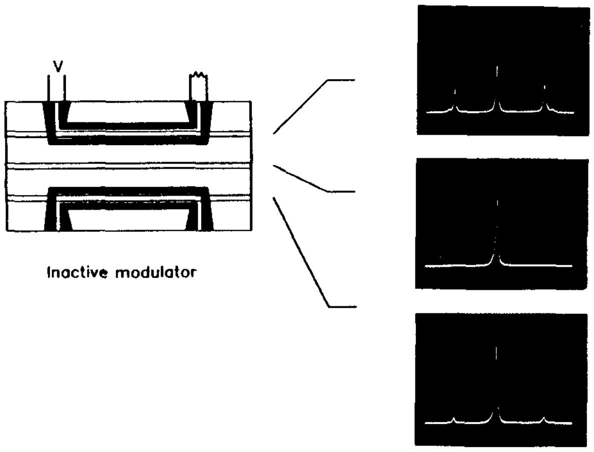

Figure 4. *A typical result showing the carrier and sidebands for the two phase modulators and the passive guide between them.*

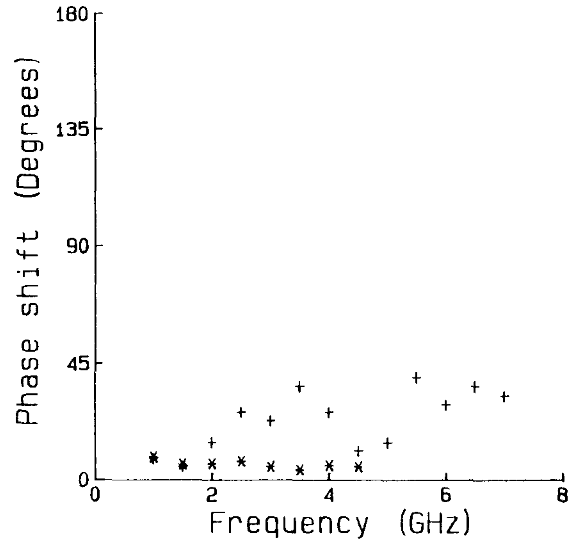

Figure 5. *The measured phase shift for light traveling in the passive guide (*) and in the inactive phase modulator (+) as the active phase modulator is driven by a 180 degree signal.*

Figure 5 shows the optical phase shift measured for the passive guide and the inactive phase modulator as a function of the modulation frequency. The measurements indicate that the light in the passive guide is phase modulated with an amplitude of 5-10 degrees and shows minimal frequency dependence. On the other hand, we have found that the light in the inactive (but terminated) phase modulator shows a much stronger degree of crosstalk at frequencies above 2 GHz. Optical phase shifts of up to 45 degrees have been measured. This crosstalk is apparently due to the electrical coupling between the electrodes. Note that the inactive phase modulator is twice as far from the active modulator compared with the passive guide.

Summary and Conclusions.

We have found substantial optical crosstalk between two high speed phase modulators fabricated on the same crystal. The optical crosstalk is due to electrical coupling between the electrodes of the two devices. It seems that such crosstalk will limit the complexity of future high speed integrated optics circuitry with traveling wave electrodes.

References

1. P. Perlmutter, J. E. Baran, P. L. Liu and Y. Silberberg, "Symmetric Coplanar Electrodes for High Speed Ti:LiNbo3 Devices", SPIE vol. **716** , High Frequency Optical Communications (1986), 42-47.

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