H-3

CAPACITIVELY LOADED TRANSMISSION LINE FOR SUBNANOSECOND STEPPED Δβ OPERATION OF AN INTEGRATED OPTICAL DIRECTIONAL COUPLER SWITCH

U. Langmann and D. Hoffmann
Institut für Elektronik, Ruhr-Universität Bochum
D-4630 Bochum 1, W.-Germany

A coplanar transmission line loaded with lumped electrode capacitances, which are distributed along the line, is used for a broadband traveling wave type Δβ operation of an integrated optical directional coupler switch on a $LiNbO_3$ substrate.

Introduction

Fast external modulators and switches are important devices in prospective integrated optical (i.o.) systems. The i.o. directional coupler on $LiNbO_3$ substrates is, at present, one of the intensively studied devices for modulating and switching operation: The optical waveguides are usually implemented by Ti-indiffusion into $LiNbO_3$, and the electrodes, for example, on top of the optical waveguides induce the electric fields for the desired electrooptical interaction between the microwave signal and the optical wave.

There are two different electrode configurations suited for driving a directional coupler switch: Electrodes as (1.) lumped elements or (2.) a traveling wave type impedance matched transmission line. Recently, Alferness[1] compared advantages and disadvantages of both electrode configurations: The lumped electrode can be used easily for a stepped Δβ operation[2] of the directional coupler, whereas the traveling wave concept offers a large potential modulation bandwidth. The Δβ configuration, however, appears to be less suited for a broadband operation, whereas the traveling wave approach is impaired by both (a) a velocity mismatch between the microwave signal and the optical wave and (b) a high series resistance of the line; the small gap between the electrodes requires very small cross-sectional dimensions for a 50 Ω characteristic line impedance, which leads to the large series resistance (e.g. about 80 Ω for a 50 Ω asymmetric coplanar transmission line on $LiNbO_3$: strip electrode width 3 μm, gap 5 μm, and Al layer thickness 1 μm).

An optical pulse response of about 400 psec obtained by traveling wave type modulation of an i.o. directional coupler was reported recently by Kubota et al[3]. The optical signal was measured by direct photodiode detection.

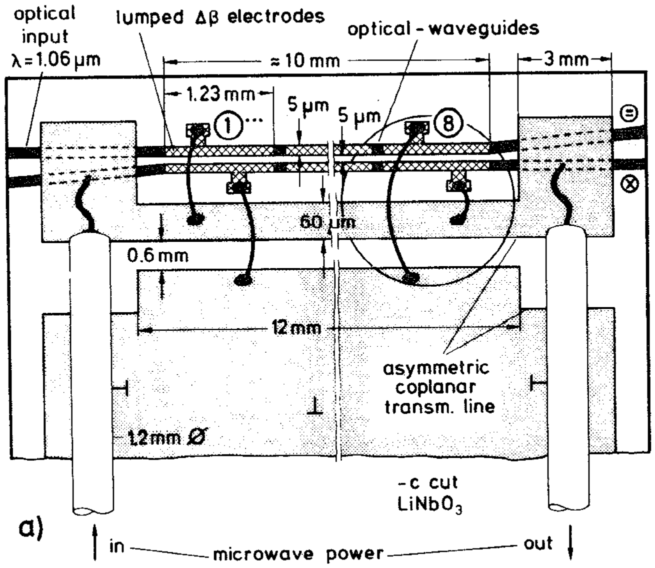
The aim of this contribution is to show that the advantages of both concepts, Δβ and broadband operation, can be combined by the capacitively loaded coplanar transmission line approach. This novel approach, in addition, avoids the high series resistance of the microwave line and appears to be favourable for an improved velocity matching design.

The loaded transmission line

Fig. 1a shows the main details of the proposed and implemented loaded transmission line: An asymmetric coplanar line (length 12 mm), close to the optical waveguides, is loaded, for example, with 8 lumped electrode capacitances (electrode width and separation 5 μm, section length 1.23 mm), which cover the optical waveguides. The capacitances are distributed along the line. The distance between the lumped electrode sections has to be short in comparison with the microwave wavelength. The coupling is made by bonding. The bonding is performed according to an alternating Δβ sequence (4 +Δβ-sections and 4 -Δβ-sections, cf. Fig. 1a). The loaded line is fed and terminated, according to Fig. 1a, by micro-semirigid 50 Ω coaxial lines. The characteristic impedance Z_o' of the loaded line has to be matched to the coaxial line impedance : The coplanar line has a characteristic impedance Z_o of about 72 Ω, and the loaded line impedance Z_o' is

$$Z_o' = \frac{Z_o}{\sqrt{1 + \frac{C_d}{C_o}}} \approx 50\ \Omega ,$$

with the intrinsic line capacitance C_o and the load capacitance C_d. The series resistance of the line with a strip electrode width of 60 μm is drastically reduced as compared with the previous design: It amounts to about 4 Ω for Al layer thickness of 1 μm.



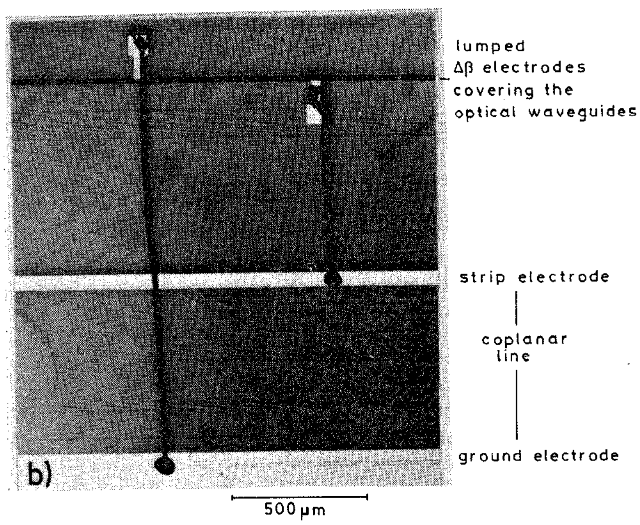


Fig. 1

a) Schematic view of the i.o. directional coupler switch with a loaded transmission line configuration (8 lumped electrode sections, 4 +Δβ-sections, 4 -Δβ-sections);

b) photomicrograph of the implemented structure (cf. circled area in Fig. 1a).

Fig. 1b is a photomicrograph of one section of the implemented structure showing the electrodes, the bonding wires, and the coplanar line.

TDR measurements of the line without (a) and with (b) the load electrodes are shown in Fig. 2. The measurements confirm that the line impedance before bonding is about 75 Ω ($\rho_a = +0.2$), in good agreement with the design, and after bonding about 52 Ω ($\rho_b = +0.025$). The peak value ρ_c associated with the coaxial-to-coplanar line transition shows that the transistion is not perfect and has to be improved.

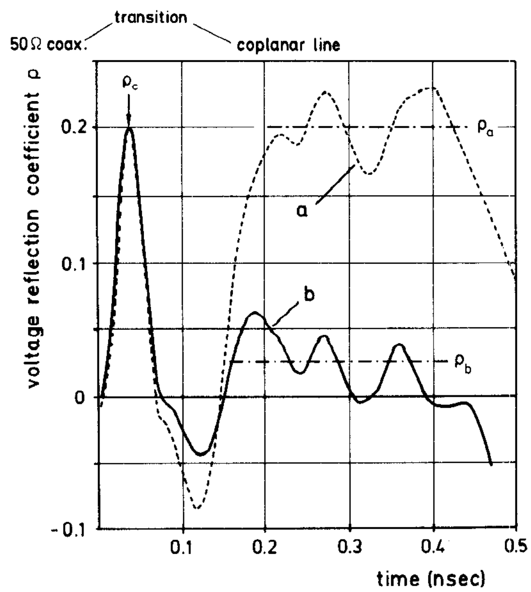


Fig. 2

TDR measurement of the transmission line, (a) prior to and (b) after bonding; $\rho_a = +0.2$ and $\rho_b = +0.025$ corresponding to 75 Ω and 52 Ω, respectively. ρ_c is due to the coaxial-to-coplanar waveguide transition.

An input pulse of about 160 psec rise time leads to an electrical pulse response of the line under investigation of about 220 psec rise time (10 to 90 percent values). This corresponds to an estimated line cut-off frequency of about 3 GHz, including waveguide transitions. Preliminary computer simulations of the loaded line, neglecting the transitions, yield a theoretical cut-off frequency of about 5 GHz. The computation considers the inductance of the bonding wires (0.5 nH) and the electrode capacitances and is based on a transmission line model (including series resistance) for each line section.

Optical pulse response of the directional coupler switch

End fire coupling by microscope objectives is used for launching optical power of several mW ($\lambda = 1.06$ µm, TM polarization) into one of the waveguides. Optical insertion loss is about 3 dB. The waveguides are implemented by Ti-indiffusion into c-cut $LiNbO_3$. Al electrodes and Al transmission line are deposited on a thin SiO_2 buffer layer.

Fig. 3 shows the optical pulse response (b) according to a preliminary experiment. The optical signal is detected by a fast Ge APD and amplified by a broadband amplifier (rise time 130 psec). The observed optical pulse rise time is about 300 psec. (10 to 90 percent value, the optical power is switched on). The corresponding driving pulse (a), measured at the end of the line, is displayed in Fig. 3, as well (pulse amplitude about 5 V). The pulse rise time is impaired by bias tees at the microwave input and output, required for adjusting a suitable dc operation point on the coupler characteristic. During the preliminary experiments, no special attempt was made to optimize the electrical and optical pulse response by an improved design.

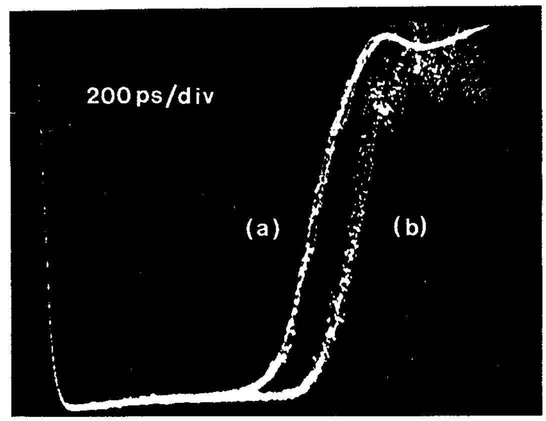


Fig. 3

Optical pulse response according to a preliminary experiment:

a) Driving pulse at the end of the line (amplitude about 5 V),
b) optical pulse (one output switched on) as detected by a fast Ge APD (exact rise time unknown) and a broadband amplifier (rise time 130 psec).

The load capacitances C_d lead to an increased propagation delay for the microwave signal, according to the relationship

$$t'_{pd} = t_{pd} \sqrt{1 + \frac{C_d}{C_o}} ,$$

with the intrinsic line delay t_{pd}. So, the inherent velocity mismatch between the optical and the microwave signal for $LiNbO_3$ substrates[3] is somewhat increased. (Calculations of the associated optical cut-off frequency will be given at the conference). However, the mismatch may be reduced, if the coplanar line is implemented on a suitable layer on the $LiNbO_3$ substrate.

Conclusion

The loaded transmission line concept represents a suitable approach for implementing fast integrated optical directional coupler switches. Low series resistances are combined with stepped $\Delta\beta$ electrode configurations. Preliminary experiments on $LiNbO_3$ substrates yield an optical pulse response of about 300 psec rise time. Moreover, this novel approach appears to be favourable for an improved velocity matching design.

Financial support by the German research council (DFG) is gratefully acknowledged.

References

1. Alferness R.C., "Guided-Wave Devices for Optical Communication", IEEE J. Quantum Electronics, QE-17, 946-959 (1981)

2. Kogelnik H. and Schmidt R.V., "Switched directional couplers with alternating $\Delta\beta$", IEEE J. Quantum Electronics, QE-12, 396-401 (1976)

3. Kubota K., Noda J., and Mikami O., " Traveling Wave Optical Modulator Using a Directional Coupler $LiNbO_3$ Waveguide", IEEE J. Quantum Electronics, QE-16, 754-760 (1980)