A 10 Gb/s traveling wave MZ-Modulator on InP

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We report a traveling wave Mach-Zehnder modulator on InP that is suitable for monolithical integration with SOA-based devices like a multi-wavelength laser. The V_π is lower than 10 V and the static extinction ratio is higher than 20 dB at 1550 nm. Microwave characteristics of the electrical lines were measured up to 40 GHz. The 3-dB bandwidth of 8 GHz allows for 10 Gb/s operation. Simulations predict a 3-dB bandwidth of 20 GHz after elimination of a design error (an impedance mismatch in the feed lines)

Introduction

The increasing demand for high-bandwidth digital communications and analog modulation requires fast electro-optic modulators. The most widely used materials for these devices are $LiNbO_3$ and III-V semiconductors, such as GaAs or InP. Lithium niobate devices have low insertion losses and high bandwidth [1], while InP ones can be integrated with optical amplifiers [2]. To avoid the bandwidth limitation imposed by the RC time constant of the electrical circuit, a traveling wave design can be implemented [3]. Several high-speed traveling wave modulators are reported in GaAs [4] and InP [5, 6], but little is published about the fabrication and the complete characterization of such devices.

In this paper we report about a traveling wave Mach-Zehnder modulator on InP. The device realization and a complete set of optical, electrical and electro-optical measurements are described and commented.

Design and fabrication

The modulator is based on a Mach-Zehnder interferometer. The 1-mm long phase shifters consist of a p-i-n diode InP/InGaAsP ridge. In the choice of thicknesses and doping levels of the various layers, many parameters had to be taken into account, such as optical and RF losses, velocity matching, modulation efficiency. The schematic layout is shown in Fig. 1. In the real device, the optical and the electrical axes are perpendicular, to facilitate the probing for the measurements. The optical waveguides in the phase-shifting sections are 4 μm wide, to relax fabrication tolerances and etched 100 nm in the film layer.

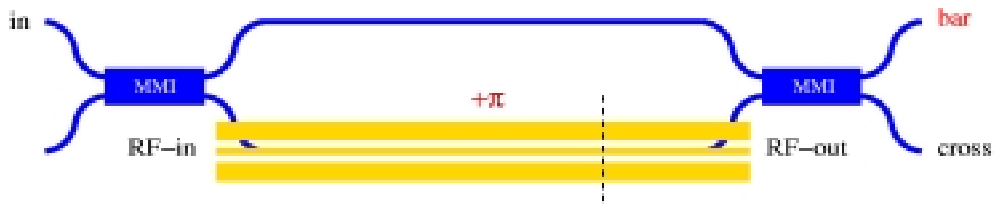

Fig. 1. Schematic top view of modulator

The signal and ground electrode widths are 12 µm and 30 µm, respectively, while the gap between signal and ground is 8 µm. The InP/InGaAsP layer stack was grown using MOVPE on a semi-insulating InP substrate. The composition of the InGaAsP layer corresponds to a photoluminescence wavelength of 1250 nm and the thickness is 500 nm. Subsequently, the optical waveguide etching mask was patterned with optical lithography in a 100 nm layer of SiN_x, using CHF_3 reactive ion etching. The waveguide mesas were created with an optimized CH_4/H_2 etching and O_2 descumming process [7]. SiN_x and polyimide were then used in the phase-shifters, for passivation and planarization purposes. Finally, 1.5 µm thick gold electrodes were plated. In Fig. 2 an SEM picture of a cross-section of a realized modulator is shown, as well as a schematic one.

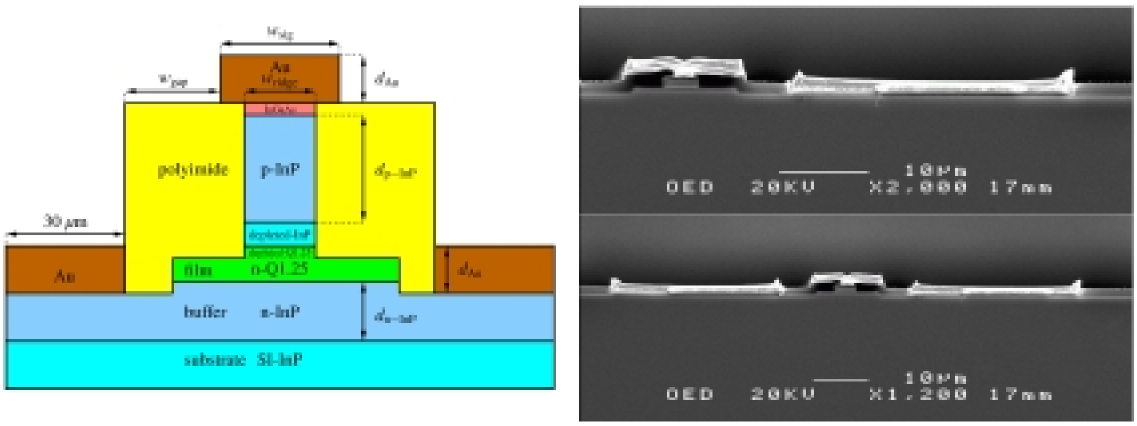

Fig. 2. Schematic cross-section (left) and SEM picture (right) of a realized modulator

Experiments

We performed three sets of measurements: the DC switching curves using an optical spectrum analyzer, the S-parameters of the modulator electrical lines, using an HP 8510 network analyzer, in the range 1-40 GHz, and the optical response.

For the last measurement, the following setup has been used: the laser beam from a tunable laser source is coupled in one of the modulator arms, by means of a lensed fiber and piezo-electric positioners. The Port 1 of a Network Analyzer provides the input RF signal for the modulator, while the output is connected to a 50 Ω termination load. The modulated optical output is then amplified by a Semiconductor Optical Amplifier and detected by a high bandwidth photo diode. Its electrical output is then connected to Port 2 of the Network Analyzer.

From the electrical S-parameters, the microwave effective index and the loss coefficient were computed [8]. The switching curves of the modulator are indicated in Fig. 3: the

V_π is lower than 9 V, the extinction ratio and the insertion losses are approximately 23 dB and 3 dB respectively. The extracted electrical losses and effective index are shown in Fig. 5: the values at high frequencies are considerable; the structure under analysis is commonly called a "slow-wave coplanar waveguide" [9]. Finally, the computed and measured modulation efficiencies are also presented in Fig. 4. The discrepancy between them is caused by an unintended impedance mismatch between the feed lines (89 Ω) and the phase-shifter section (21 Ω) (Fig. 5). The modulator 3-dB bandwidth is 8 GHz. If a good matching is achieved, a bandwidth higher than 20 GHz is predicted.

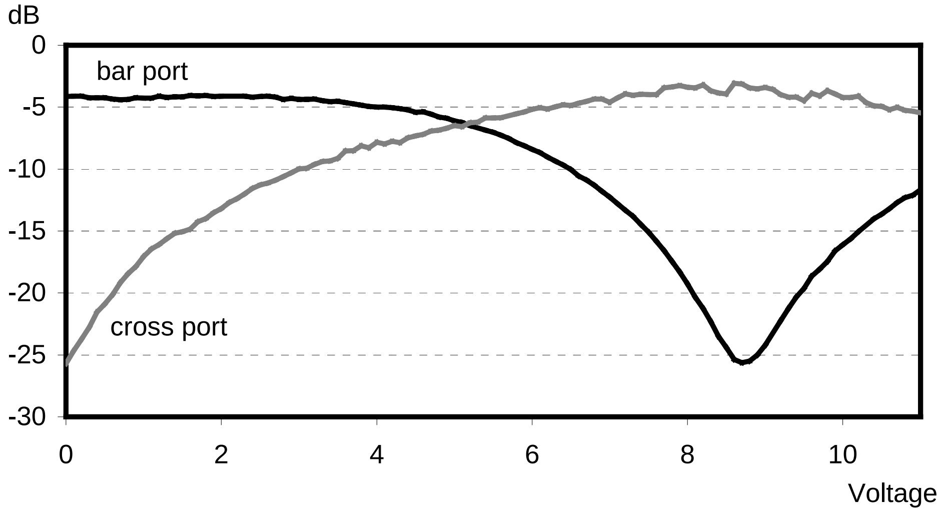

Fig. 3. Switching curves: optical insertion losses in dB as a function of applied negative voltage.

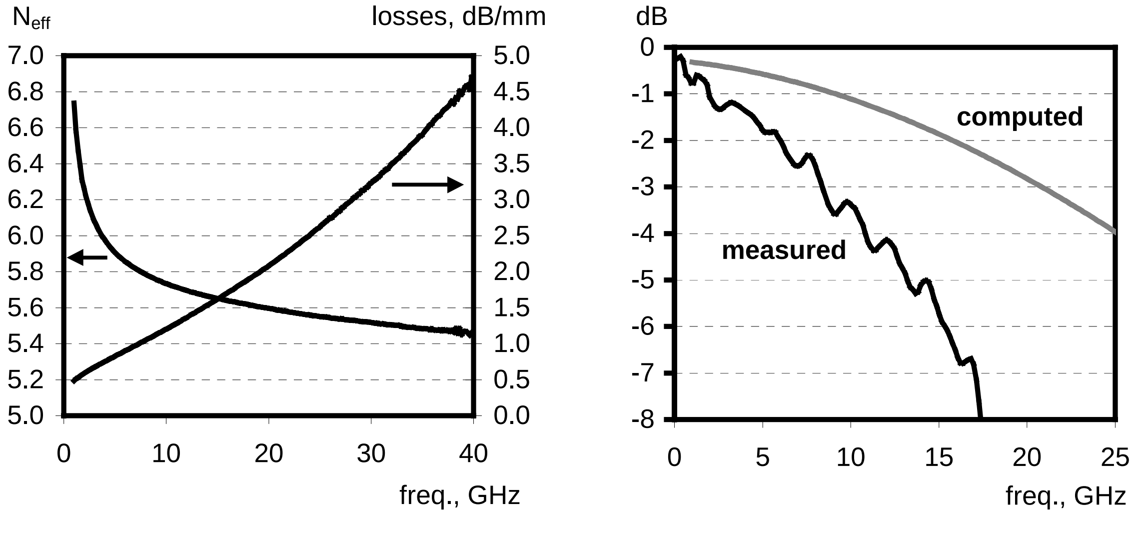

Fig. 4. Electrode effective index and losses, extracted from measured S-parameters (left) and computed and measured modulation efficiency (right)

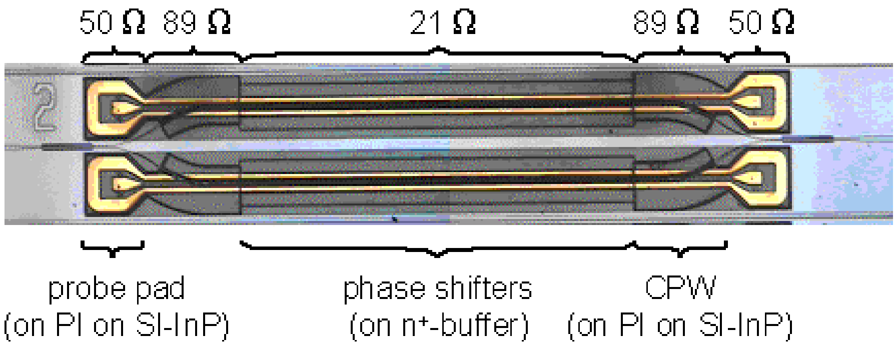

Fig. 5. Photograph of a realized optical modulator. The impedances of the various sections are shown.

Conclusions

We realized and characterized a traveling wave optical modulator in InP/InGaAsP. It shows good optical performance, 8 GHz bandwidth and potential for 20 GHz bandwidth after elimination of a design error (local impedance mismatch). It has the possibility for monolithic integration with semiconductor optical amplifiers, e.g. in a high-bit rate multi-wavelength transmitter. In a new design, we have changed the electrode structure in such a way that the impedance of the electrodes is matched as well as the velocity of the electrical and the optical waves, and that the electrical losses are reduced.

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