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LOW ABSORPTION InP/InGaAs-MQW PHASE SHIFTERS FOR OPTICAL SWITCHING

C.G.M. Vreeburg, M.K. Smit

Department of Electrical Engineering, Delft University of Technology,
P.O. Box 5031, NL-2600 GA, Delft, The Netherlands,
Phone +31-15-786106, Fax +31-15-784046

M. Bachmann, R. Kyburz, R. Krähenhühl, E. Gini, H. Melchior

Institute of Quantum Electronics, Swiss Federal Institute of Technology,
CH-8093 Zürich, Switzerland,
Phone +41-1-6332188, Fax +41-1-6331109

InP/InGaAs-MQW phase shifters with low absorption loss and low electro-absorption loss have been realized. Phase shift efficiency for TE-polarized light at λ=1.55 µm was 6.8 $^{o}V^{-1}mm^{-1}$ with negligible absorption loss and at λ=1.51 µm the efficiency was 8.9 $^{o}V^{-1}mm^{-1}$ with 5 dB/cm absorption loss.

Introduction

Optical switches can be made by using a Mach-Zehnder interferometer (MZI) [1,2]. For this type of switch, phase shifters with high efficiency and low absorption loss are required. For phase shifters the guiding layer is embedded in a p-i-n diode. Phase shift can be obtained by reverse biasing of the diode. High efficiency has been reported by using multiple quantum well (MQW) waveguides employing the quantum confined Stark effect [1,4], also the absorption loss are often high for MQW. For system applications polarization independence is also desired. In a bulk InGaAsP filmlayer polarization independence can be obtained by specially oriented waveguides [2]. With MQW the polarization dependence of the phase shift can be controlled by tensile strain in the quantum wells [1,3].

Our prime goal was to design an InP/InGaAs MQW layer with low absorption loss and electro-absorption loss (change in absorption due to applied voltages) at λ=1.53 µm. This guiding layer will be used for passive optical components and an integrated Mach-Zehnder interferometer. Wavelength dependence of absorption loss and phase shift efficiency have been determined.

Design and Fabrication

The difference between the signal wavelength and the band-edge of the MQW filmlayer determines the phase shift efficiency and the absorption loss. If the signal wavelength comes closer to the band edge of the material both the electro-optical efficiency and the absorption loss increase. Earlier experiments showed that we can expect low absorption loss if the wavelength difference is more than 140 nm. For a signal wavelength of λ=1.53 µm the bandgap wavelength of the material should be smaller than 1.39 µm.

Hence, the designed waveguide layer consists of a MQW structure with 4 nm lattice matched InGaAs quantum wells and 8 nm InP barriers. The calculated room temperature photoluminescence (PL)-wavelength of this structure is λ_{pl}=1.39 µm. Experiments revealed that the PL-wavelength was red shifted (1.48 µm) and that compressive strain occurred in the MQW-region. This is thought to be due to interfacial problems during the growth. Optimization of growth time and InGaAs composition resulted in the desired PL-wavelength with 4 nm tensile strained $In_{0.50}Ga_{0.50}As$ quantum wells.

Fig.1 gives the cross-sectional view of the phase shifting waveguides oriented in the $[0\bar{1}1]$ direction. The layers were grown by LP-MOCVD on a n^+ (100) wafer.

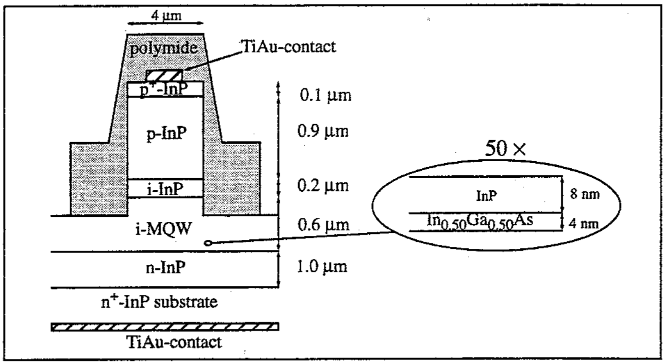

Fig 1. Cross sectional view of the phase shifting waveguides.

In order to measure the phase shift efficiency of the waveguide it has been integrated in a 2×2 Mach-Zehnder interferometer structure, as shown in Fig. 2. The efficiency can be easily inferred from the switching curves. As a splitting and a combining element, MMI-couplers [5] were used.

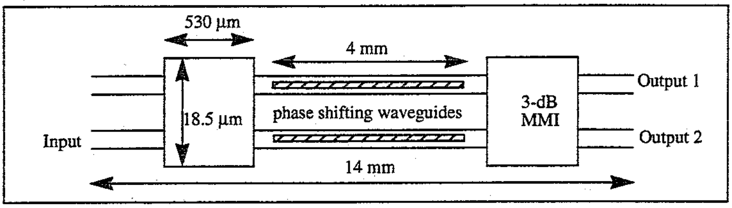

Fig. 2. Top view of the 2×2 Mach-Zehnder interferometer.

A 140 nm SiO_2 layer served as an etching mask for the waveguides. After contact lithography, we transferred the mask in the SiO_2 layer by CHF_3/Ar reactive ion etching. For etching InP we used a CH_4/H_2 etching process. Afterwards the electrodes on the waveguide rib were fabricated by a lift-off process, for passivation we used a polyimide film. Electrical isolation between the two electrodes was obtained by partly removing the p-InP between the electrodes and the MMI-couplers.

Measurements

The optical measurements have been performed between 20× AR-coated microscope objectives. The laser source was a λ=1.53 µm Fabry-Perot laser. Light emanating from the waveguides was imaged onto an InGaAs-diode. Electro-absorption was measured with a 5 mm long electrode on a 4 µm wide waveguide. The TE-light intensity as a function of the applied reverse bias is depicted in Fig. 3. Between 0 and -20 V the electro-absorption is lower than 3 dB/cm.

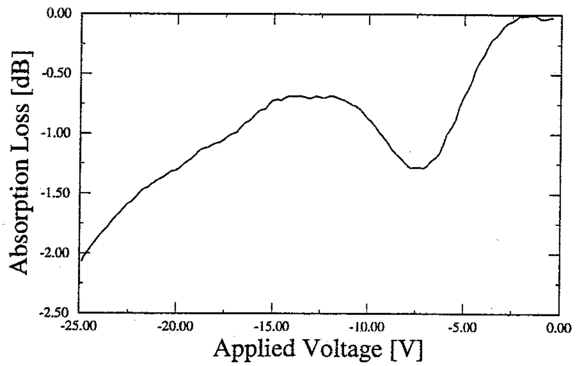

Fig. 3. Measured electro-absorption of a waveguide with 5 mm long electrode for TE-polarization.

The absorption peak between -5 and -10 V was measured for different waveguides. Probably it is caused by an absorption resonance in the transparent region of the MQW layer.

The measurement results of the 2×2 MZI (see Fig. 2) for TE-polarization are depicted in Fig. 4. Light was coupled in one of the input waveguides and the light intensity of the two output waveguides was recorded as a function of the applied reverse bias. The loss with respect to a reference waveguide is 12.5 dB and the crosstalk is -7.5 dB. The high loss and low crosstalk are caused by non optimized MMI-couplers as has been confirmed by measurements on single MMI-couplers. For the determination of the phase shift efficiency the poor performance poses no problems.

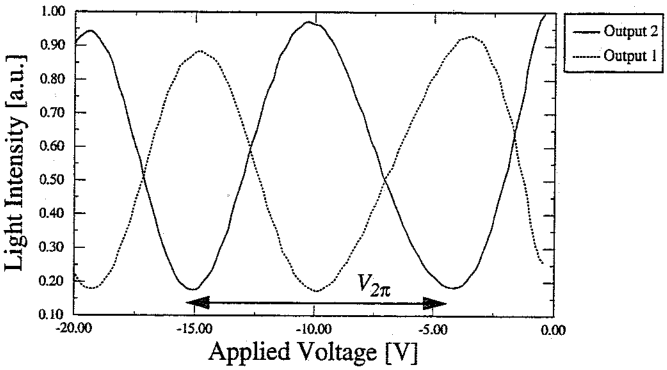

Fig. 4. Switching curve for TE-polarization with 4 mm electrode length at λ=1.53 μm.

Wavelength dependence has been measured with a tunable external cavity laser. Results for switching voltage and absorption loss are summarized in Table 1. $V_{2\pi}$ is the voltage needed to induce a phase shift of 2π with an electrode length of 4 mm.

Table 1: Wavelength dependence of switching voltage and absorption loss

λ (μm)	$V_{2\pi}$ (V)	Efficiency ($^o V^{-1} mm^{-1}$)	Absorption (dB/cm)
1.51	10.1	8.9	5
1.53	11.8	7.9	1
1.55	13.2	6.8	0
1.57	14.8	6.1	0

For shorter wavelengths both an increase in phase shift efficiency and absorption loss can be seen. The metallization of the electrodes caused high loss for TM-polarization. A new design has been made to solve this problem.

Discussion and Conclusions

For the integration with other passive optical components low absorption loss is required. This low loss can be obtained by using a wavelength longer than λ=1.53 μm. Also the electro-absorption is low at this wavelength, which is desired for low loss phase shifting. The fabricated structure opens the opportunity to integrate passive waveguide structure and phase shifters in a low loss InP/InGaAs MQW structure.

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