Crosstalk reduction in dilated MZI-based switches on InP by stray light removal

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Dilated space switches on InP have a crosstalk level of about -28 dB, which is too low for application in large WDM networks. In this contribution the influence of stray light in the wafer on the crosstalk level of the dilated switch is investigated. By placing titanium absorbers at both sides of the waveguiding structure of the switch, the stray light is removed from the wafer, resulting in a crosstalk reduction of 3 dB in this type of switch. In switches with lower crosstalk levels the reduction is even larger (6 dB).

Introduction

Optical space switches are key components in advanced wavelength-division-multiplexed (WDM) or time-division-multiplexed (TDM) optical networks. The demands that are imposed to these switches with respect to their crosstalk level, in e.g. WDM systems, are high: crosstalk levels below -35 dB are required for a proper functioning of the optical network [1].
The space switches presented in this paper, are based on a Mach-Zehnder interferometer (MZI) and are fabricated on a InP/InGaAsP layer stack. This switch type has a fabrication tolerant and polarisation insensitive waveguiding structure, it is suitable for high speed switching and is integrable with many different components like detectors, amplifiers, and demultiplexers.

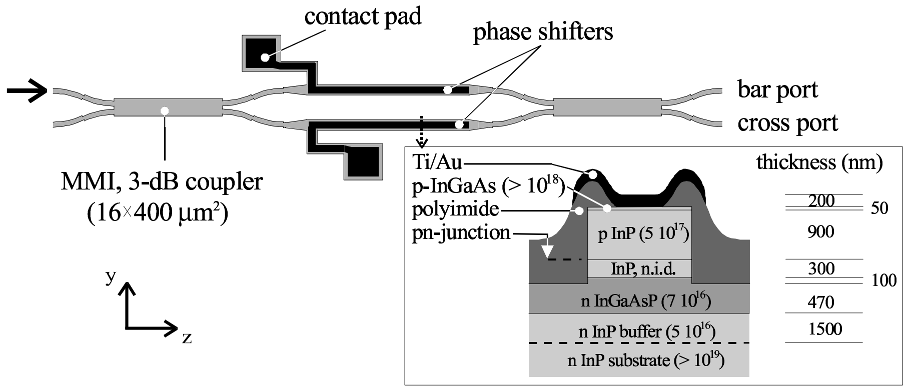

Figure 1 *The schematic layout of the MZI-based switch. The grey areas represent the waveguiding structure, the black regions represent the metal contacts on top of the phase shifting sections and the contact pads. In the inset a cross section of a phase shifter is depicted.*

The crosstalk level of our MZI-based switches is about -20 dB. If these switches are placed in a dilated scheme, a crosstalk level reduction of -20 dB is expected, however, in practice its crosstalk level is only reduced to about -28 dB, necessitating further research for the reduction of the switch crosstalk level.
Since our switch employs waveguides which have an etch depth of only 100 nm in the guiding (InGaAsP) layer, a 500 nm InGaAsP layer is present at both sides of the waveguides (see Fig. 1). In this layer light is guided that is clearly visible at the output side of the wafer with the use of an infrared camera. This light is introduced by scattering at imperfections in the waveguiding structure of the switch, and might be reintroduced into this waveguiding structure, thus disturbing the performance of the switch, which results in an increase of its crosstalk level. By removing this stray light a reduction of the switch crosstalk level might be obtained.

Stray light removal

The stray light is removed from the wafer with the use of a 20 nm thick titanium layer on top of the layer stack at both sides of the waveguiding structure (Fig. 2). The light underneath this titanium layer will be attenuated, since the imaginary part of the effective refractive index of this stack is non-zero due to the presence of the titanium (n_{ti} = 4.3 + 4.3i). In this way an optical attenuation is obtained of 3.1×10^{-3} dB/cm for TE polarisation and of 1.7×10^{-5} dB/cm for TM polarisation.
Special attention is paid to the shape of the edge of the titanium layer. The calculated amount of reflected stray light at the edge of the titanium absorbers exceeds 0.1 % for an angle of incidence larger than 75°. If a sawtooth shaped edge is employed (Fig. 2) with θ_{st} = 30°, less than 0.1% of the stray light is reflected at the absorber edge, which is acceptable. By taking l_{st} = 25 µm and $d_{ti\text{-}wvg}$ = 3 µm, the waveguide losses due to the titanium absorbers can be neglected and an easy fabrication of the sawtooth shaped edge is obtained.

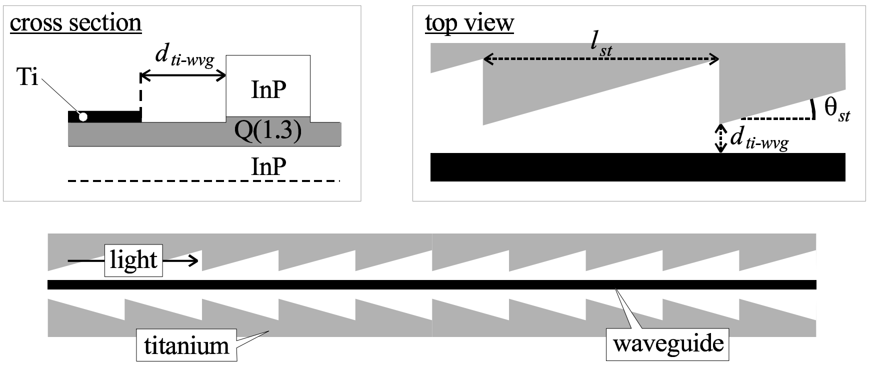

Figure 2 *A topview of a waveguide in combination with titanium absorbers. In the insets a cross section and a magnified topview of this structure is depicted in which the design parameters of the sawtooth edge of the titanium absorbers are defined.*

Design and fabrication

Our MZI-based switch consists of two MMI couplers which act as 3-dB splitting and combining sections and two, 2 mm long, phase shifting sections in between (Fig. 1).

Switching from the cross state to the bar state is obtained by reverse biasing the pin-diode in one of the phase shifting sections up to the switching voltage. Polarisation independent switching is obtained by a proper orientation of the phase shifters on the (001) substrate [2].
The dilated switch, depicted in Fig. 3, consists of four single switches. Since the two inner waveguides at the in- and output of the dilated switch are idle, this switch type is used as a regular 2×2 switch. The titanium pads are placed around the entire waveguiding structure of the switch except for the phase shifters, because there a polyimide layer, used for passivation of the pn-junctions, is present. In the waveguides that connect switch 1 and 2 with switch 3 and 4, phase shifters are inserted, that function as electro-optical attenuators. If a reverse bias substantially larger than the switching voltage is applied to the phase shifters in the crosstalk path of the dilated switch, the crosstalk signal will be attenuated, thus reducing the switch crosstalk [3].

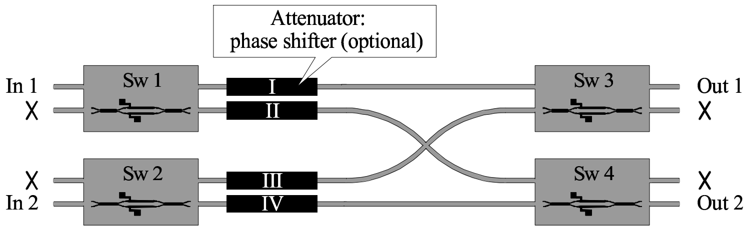

***Figure 3** The schematic layout of the dilated switch with electro-optical attenuators.*

The InGaAsP/InP/InGaAs layer stack was MOVPE-grown on a (001) oriented n+ substrate. The thickness and doping levels of the various layers are given in Fig. 1.
The waveguiding pattern of the switch is defined using contact exposure and is transferred into a 100 nm (PECVD) silicon-nitride layer using a CHF_3 reactive ion etch process. The waveguiding structure is realised employing an optimised CH_4-H_2/O_2 RIE/descum process. After removal of the silicon-nitride, metallisation windows are defined in polyimide, that is also used to passivate the pn-junctions. In the two final production steps the Ti/Au contacts on the phase shifting sections and the titanium absorbers are put on the chip using vacuum evaporation and a lift-off technique.

Measurement results

The measurements are performed at a wavelength of 1530 nm. At the input side of the wafer a microscope objective is used to couple light into the waveguides. At the output side of the wafer a tapered and lensed single mode fibre is employed.
Measurements of the crosstalk level of two types of dilated switches (without and with electro-optical attenuators: Switch A and Switch B respectively) are performed, both with and without the titanium absorbers. For Switch A a reduction of the crosstalk level is measured, thanks to the titanium absorbers, of 3 dB for TE and of 5 dB for TM polarisation to about -30 dB for both polarisation states.
The influence of the titanium absorbers at lower crosstalk levels is found in a similar experiment, by employing a dilated switch in which electro-optical crosstalk attenuators are applied, as shown in Fig. 3 (Switch B).
In Fig. 4 the switching curves of this dilated switch without the titanium absorbers are depicted for four different reverse bias levels applied to the electro-optical attenuators.

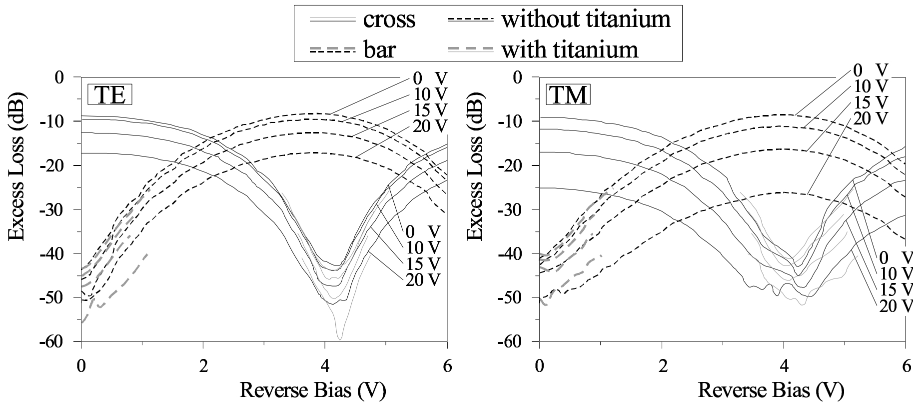

Figure 4 *The switching curves of the dilated switch (Switch B) without and with the titanium absorbers, for both TE and TM polarisation and for four different reverse bias levels applied to the electro-optical attenuators.*

The minimum crosstalk level for the cross state is given by the difference between the top cross-port curve (no attenuation) and the lowest bar-port curve (maximum attenuation). The bar state crosstalk is found in a similar way. The minimum crosstalk level that is obtained in this way for the switch without titanium is -41.6 dB for TE and -40.1 dB for TM polarisation [3]. The loss of this switch is about 9 dB. By introducing the titanium absorbers the optical power of the crosstalk signal, depicted in Fig. 4 by the grey lines, is reduced for the TE polarisation by 6 dB and for TM by 2 dB, the absorbers do not introduce additional signal loss. Due to an imperfect titanium absorber lithography the sawtooth shape of its edge is disrupted causing an increase of the crosstalk, especially for the TM polarisation when no reverse bias is applied to the crosstalk attenuators.

Discussion and conclusions

By applying titanium absorbers in (dilated) switches, their crosstalk is reduced for TE polarisation by 3 dB and for TM polarisation by 5 dB to about -30 dB. At lower crosstalk levels of -40 dB, titanium absorbers cause a crosstalk reduction of 6 dB for TE and 2 dB for TM. Comparison of the results depicted in Fig. 4 with the measurement results from switch A with properly shaped titanium absorbers reveals that a much larger crosstalk reduction (~6 dB) can be achieved for TM polarisation in Switch B when proper titanium absorbers are employed. The measurements show that the influence of the titanium absorbers on the crosstalk level of the switch gets stronger at lower crosstalk levels.

References

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