A Compact Integrated InP-Based Single-Phasar Optical Crossconnect

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***Abstract*—The first integrated InP-based polarization independent optical crossconnect is reported. The device can crossconnect signals at four wavelengths independently from two input fibers to two output fibers. Total on-chip loss is less then 16 dB. Device size is 7 × 9 mm^2.**

***Index Terms*—Integrated optics, PHASAR, photonic integrated circuits, semiconductor waveguides, wavelength-division multiplexing (WDM).**

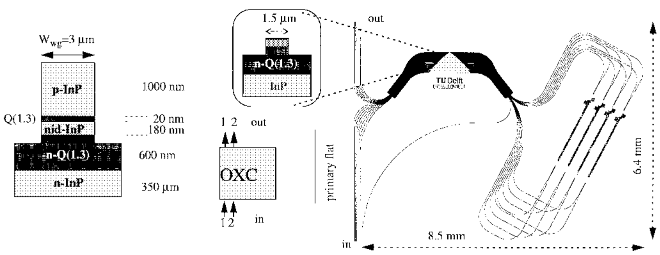

Fig. 1. Layout of the OXC and dimensions of the waveguide structures used.

I. Introduction

KEY COMPONENTS in advanced wavelength-division-multiplexed (WDM) networks are wavelength selective switches such as optical crossconnects (OXC's) and add–drop multiplexers (ADM's) [1], [2]. Presently, devices used in network experiments consist of a large number of discrete components, which makes them costly and voluminous. To reduce both cost and dimensions, integration will be necessary. First integrated wavelength selective switches reported were based on silica technology [3]. On InP, we have reported the first reconfigurable ADM [4] consisting of a PHASAR demultiplexer integrated with electrooptical Mach–Zehnder interferometer (MZI) switches. This device showed good loss and crosstalk performance, but it was not polarization independent. To obtain a polarization independent wavelength selective switch both the PHASAR and the switches have to be insensitive to the polarization state.

In this letter, we report the first integrated InP-based polarization independent optical crossconnect. The device, which can crossconnect signals at four wavelengths independently from two input fibers to two output fibers, has been realized by integrating a polarization dispersion compensated 16×16 PHASAR, as reported by Vreeburg *et al.* [5], with four polarization independent electrooptical MZI switches [6], [7]. Experimental results are found to be in good agreement with simulation results obtained with an advanced photonic circuit simulator [8].

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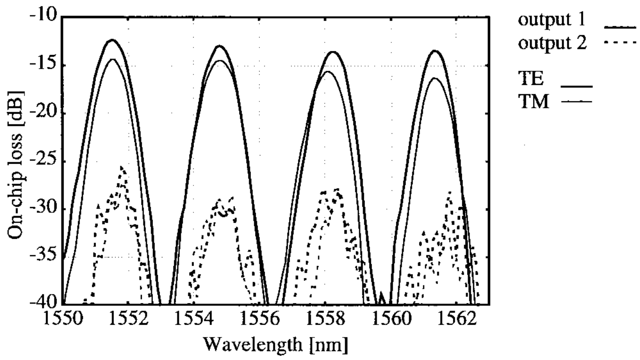
II. Design

The OXC consists of a single 16-channel polarization dispersion compensated PHASAR [5] and four MZI space switches connected in a foldback configuration. The foldback configuration using a single PHASAR has been chosen to avoid additional losses caused by misalignment of the wavelength responses of the demultiplexer and multiplexer due to nonuniformities of the wafer. Small nonuniformities in thicknesses and composition will change the central wavelength of the PHASAR, a 2% variation in the layer thicknesses results in a shift of the central wavelength of a few tenths of a nanometer, yielding a loss penalty of about 1 dB [9].

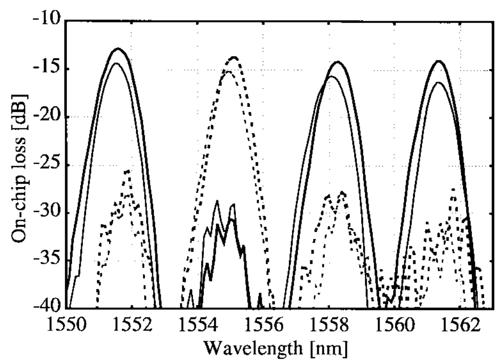
The 2×2 electrooptical Mach–Zehnder switches have phase sections orientated 28° form the $[01]$-direction (perpendicular to the small flat of the wafer) toward the $[0\bar{1}1]$-direction to obtain polarization independent operation [7]. In Fig. 1, the layout of the device and the layer stack are depicted. The four channels are spaced by 400 GHz (3.2 nm) and the first channel is designed to be at 1551 nm. The total device size is 8.5×6.4 mm^2.

III. Fabrication

The OXC was fabricated in a metal–organic vapor phase epitaxy (MOVPE) grown layer stack as shown in Fig. 1. A 100-nm-thick PECVD-SiN layer served as an etching mask for the waveguides. The pattern was defined using contact



(a)



(b)

Fig. 2. Measured response for both polarization states (a) with all switches off and (b) with switch 2 on.

illumination with positive photoresist and transferred in the SiN-layer by CHF_3 reactive ion etching. The waveguides were etched employing an optimized CH_4/H_2 etching and O_2 descumming process [10]. After removal of the SiN-layer, metallization windows in photosensitive polyimide were made on the phase shifting sections of the switches. TiAu contacts on top of the phase shifting sections were fabricated by vacuum evaporation and lift off with image reversal photoresist. The PHASAR has been made polarization insensitive by removing part of the InP top layer of the waveguides in the triangular birefringence compensation section (see Fig. 1) down to a InGaAsP etch-stop-layer using a selective wet chemical etch (HCL/H_3PO_4) [5]. After removal of the photoresist, the wafer processing was finished.

IV. Experiments and Simulations

The OXC was measured using the spontaneous emission spectrum of an EDFA as a broad-band light source and a polarizer to select the polarization state. Light was coupled into the chip using microscope objectives, coupled out of the waveguides by a single-mode lensed fiber and analyzed using an HP optical spectrum analyzer. Straight reference waveguides with a width of 3 μm showed a propagation loss of 1.5 dB/cm for TE-polarization (1.7 dB/cm for TM). Fig. 2 shows the measured response for the four channels for both polarization states.

The total on-chip loss was only 13 dB for TE and 16 dB for TM polarization. It is composed as follows: PHASAR (which is passed twice) 2×2 and 2×3 dB (2×2.5 to 2×3.5 dB), MZI-switch 1.5 dB (2.5 dB), crossings 6×0.3 dB, 3-cm waveguide 3×1.5 dB (3×1.7 dB). (Values between brackets are for TM-polarization.)

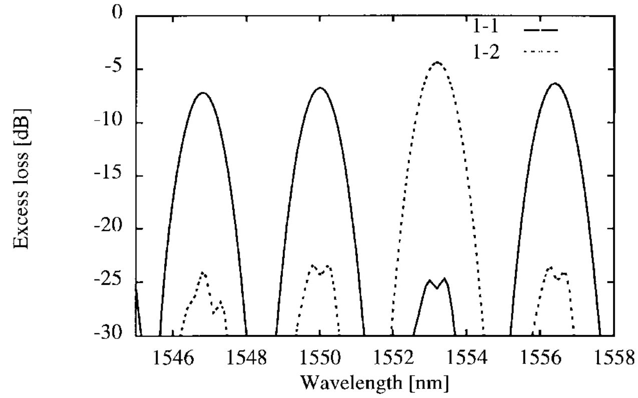


Fig. 3. Simulated response of the OXC for TE polarization with switch 3 on.

The absolute wavelength position is 1551.5 nm for the first channel. This is only 0.5 nm from the desired wavelength, and can be corrected by cooling the chip by approximately 5° in temperature. The interband crosstalk level is low: < -40 dB, indicating good performance of the PHASAR.

The main problem in the performance is the high intraband crosstalk level of -13 dB. We analyzed the origin of this crosstalk using the recently developed 16×16 PHASAR simulation module of our photonic circuit simulator [8]. Analysis of the results reveals that in this single PHASAR configuration the crosstalk consists of three main contributions; one from the switch, one from the PHASAR as demultiplexer (pass 1) and one from the PHASAR as multiplexer (pass 2). Because signals originate from the same source and are routed through the same PHASAR they will interfere coherently with each other, which is visible in the oscillating character of the response. Using a value of -20 dB for the switch crosstalk, which is typical for our devices, simulations predict that coherent interference results in a crosstalk penalty of about 5 dB (see Fig 3).

V. Discussion and Conclusion

A compact polarization independent integrated four channel 2×2 optical crossconnect on InP is reported. This OXC is realized integrating a single low-loss polarization dispersion compensated PHASAR [5] and electrooptical MZI space switches with special oriented phase shifting sections to cancel the polarization dependence of earlier designs [6]. The use of a single PHASAR both as demultiplexer and multiplexer was chosen to avoid loss penalties originating from misaligned wavelength responses of separate (de)multiplexers. Simulations and experimental results show however that this configuration results in a crosstalk penalty of about 5 dB caused by coherent interference.

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