Polarization Independent Dilated WDM Cross-Connect on InP

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***Abstract*— A four wavelength 2 $\times$ 2 optical wavelength-division-multiplexed cross-connect with dilated switches is reported. The device is monolithically integrated on InP and consist of two eight-channel PHASAR's combined with 16 electrooptic Mach–Zehnder interferometer switches. On-chip loss is less than -17 dB and crosstalk is better than -20 dB.**

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

I. INTRODUCTION

ADVANCED wavelength-division multiplexed networks contain wavelength selective switching nodes, that can cross-connect multiple wavelengths independently. Monolithic integration of these wavelength selective switches was first reported in silica technology [1]–[4] and more recently also on InP [5]–[7]. These devices usually consist of a combination of wavelength (de)multiplexers or routers (PHASAR's) combined with either thermooptic (in silica technology) or electrooptic (InP technology) space switches.

The first InP polarization independent WDM optical cross-connect (OXC) was reported by us [6] and used a single PHASAR for all (de)multiplex operations to prevent losses due to mismatch of the PHASAR responses. In this configuration however the performance of the device is limited by coherent signal-crosstalk beat noise [8] (worst case TM crosstalk -11 dB). At the ECOC'98, we reported an OXC using two PHASAR's and demonstrated that the crosstalk of this configuration was determined by that of the switches [7] (worst case TM crosstalk -16 dB). This device did however suffer from wavelength mismatch between the two PHASAR's, caused by wafer nonuniformities.

Here, we present an improved OXC processed on a CBE-grown wafer which is much more uniform than the MOVPE-grown wafers we used in our earlier OXC's [6], [7]. By using a dilated (or double-gate) switch scheme we also demonstrate an improvement of the crosstalk performance to better than -20 dB for both polarization states. To our knowledge this is the best performance reported so far on InP.

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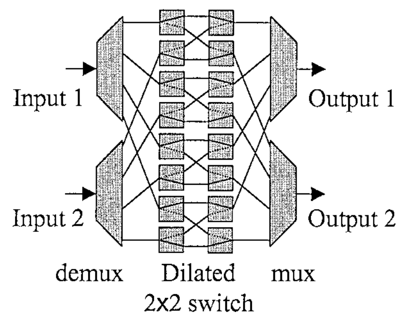


Fig. 1. Schematic representation of the dilated WDM cross-connect.

II. DESIGN

In Fig. 1 the mask layout of the realized OXC is depicted. It consists of two 2 8 polarization dispersion compensated PHASAR (de)multiplexers (each is a 1 4 DEMUX and a MUX combined in one) connected with four dilated electrooptic space switches. Each dilated switch contains four Mach–Zehnder interferometer (MZI) switches. The switches are operated by applying an electric field to one of the arms of the interferometer. The advantage of using a revere bias instead of current injection is the negligible power consumption, moreover the use of electrooptic effects makes the switches potentially very fast. Contrary to current injection however, the field induced electrooptic effects are not polarization independent. Thanks to the orientation sensitive Pockels' effect which occurs only for TE, a polarization insensitive switching is possible. As depicted in the figure, the phase shifting sections are at an angle of 28° relative to the [011]-crystallographic orientation to obtain polarization independent operation [10]. Variations in the process or wafer specifications can shift the polarization independent angle. A short phase shifting section in the [0-11] direction is therefore present to adjust the effective angle, if necessary. The two PHASAR's have been placed as close together as possible to reduce wavelength mismatch due to possible wafer inhomogeneities. The switches have been arranged in such a way that the total number of crossings is minimized. All possible paths have an equal number of crossings to avoid nonuniformities in the response due to crossing losses. The device is designed for 4 $\times$ 400 GHz (3.2 nm). Total device size is 11 $\times$ 6.5 mm^2.

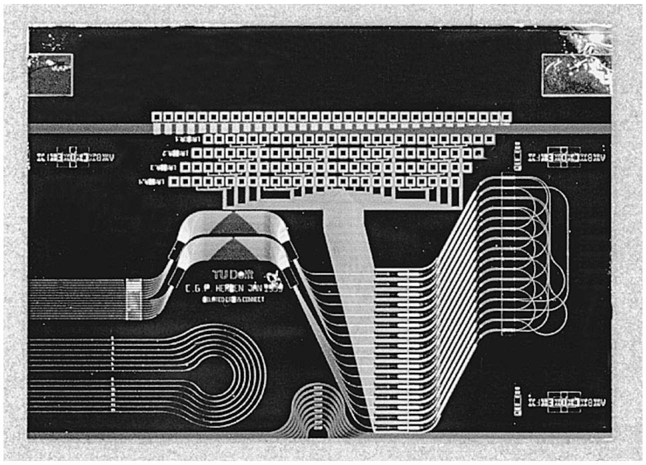
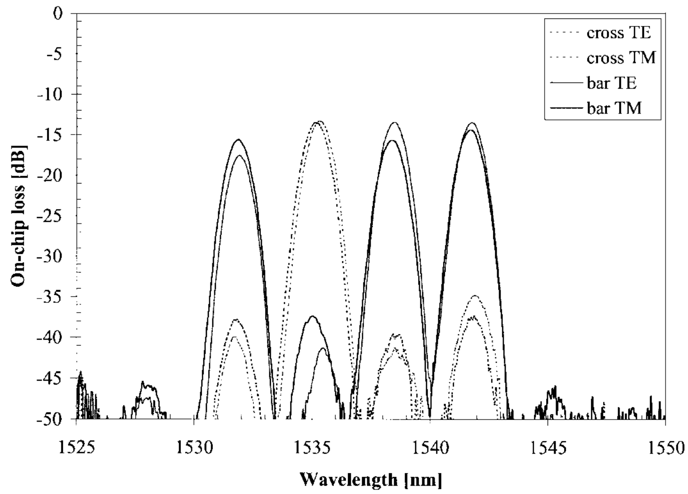
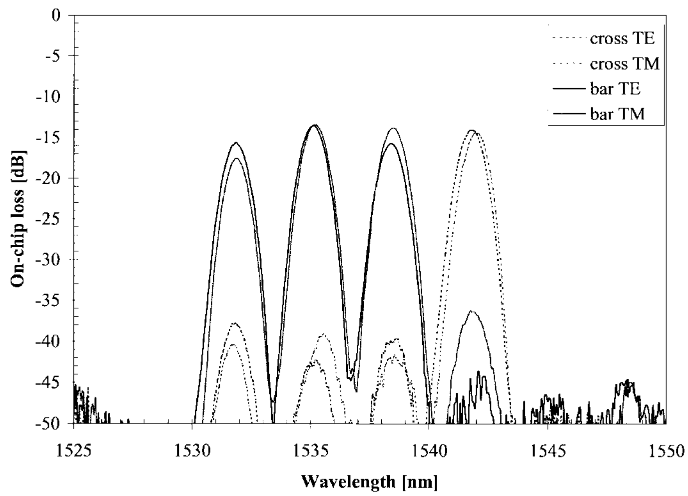


Fig. 2. Photograph of the realized chip



(a)



(b)

Fig. 3. Measured wavelength response for both polarization states. (a) Second wavelength channel is switched. (b) Fourth wavelength channel is switched.

III. Fabrication

The OXC was fabricated on a chemical beam epitaxy (CBE) grown InP–InGaAsP ($\lambda_{\rm gap} = 1.25$ μm)/InP layer-stack. The film-layer has a thickness of 720 nm and is covered by a 200-nm undoped InP cladding layer, followed by a 1000-nm p-doped InP cladding and a 50-nm heavily p-doped contact layer. The waveguide pattern was etched 100 nm into the film layer employing an optimized CH_4/H_2 etching and O_2 descumming process [11] with a PECVD-SiN mask. The p-doped part of the InP top cladding layer was locally removed wet chemically down to an etch stop layer. In the polarization compensating regions of the PHASAR's, this was done to obtain polarization independent operation and in the switches, between both arms of the Mach-Zehnder interferometer, for electric isolation. Photosensitive polyimide was used both for planarization and definition of metallization windows on top of the phase shifters. TiAu contacts were defined by liftoff. In Fig. 2 a photograph of the realized chip is depicted.

IV. Experiments

The wavelength response of the OXC was measured using the spontaneous emission spectrum of an EDFA as a broadband light source and a polarizer to select the polarization. The light was coupled into the waveguides using microscope objectives and collected at the output using a single-mode lensed fiber. The spectrum was recorded using an HP optical spectrum analyzer. Straight reference waveguides showed propagation losses of 1.5 dB/cm for TE and 1.3 dB/cm for TM.

In Fig. 3, the wavelength response of the OXC is depicted for both polarization states. The total on-chip loss is 15–17 dB, which can be explained as follows: a PHASAR is passed twice ($2 \times$ 2.50–3 dB) and two MZI switches ($2 \times$ 1.5–2 dB), six crossings (60.3 dB) and about 3 cm of waveguide ($3 \times$ 1.3–1.5 dB).

Measurements of the performance of single MZI switches showed a crosstalk of only about -12 dB. The cause of these problems is the lower contrast of the Q1.25 CBE-material (as compared to our previously used Q1.3 MOVPE-material) which gives rise to an increased asymmetry in the curved waveguide leads of the switches. The MMI-couplers in the switches are based on restricted interference, which means that the inputs are located in such a way that some modes in the MMI are not excited, among which is the first order mode [12]. Since the length of an MMI-coupler is determined by the beat-length of the two lowest order modes, a coupler based on restricted interference can be more compact than a nonrestricted one. When the field in the inputs is asymmetric however, the restricted interference principle no longer holds resulting in a deteriorated switch performance. Thanks to the use of the dilated switch scheme the crosstalk of the OXC is still better than -20 dB for all switching and polarization states even though the single switches had only -12 dB. Crosstalk values of -40 dB for a dilated switch in our waveguide structure were recently demonstrated by Maat *et al.* [13] showing the potential for future process runs.

V. Conclusion

A polarization independent dilated WDM optical cross-connect is reported. The device has only -15–17 dB on-chip loss and a crosstalk of better than −20 dB for both polarization states, despite of poor switch performance. It is demonstrated that the crosstalk of the OXC is improved by using the dilated switch scheme. To our knowledge these are the best results reported so far for InP-based OXC's.

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