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AN IMPROVED TECHNOLOGY FOR ELIMINATING POLARIZATION DISPERSION IN INTEGRATED PHASAR DEMULTIPLEXERS

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I. Abstract

An improved technology for realizing high quality PHASARs is reported compatible with the integration of electro-optical switches. This technology is demonstrated in a 16-channel polarization independent low loss (<1.7 dB) PHASAR.

II. Introduction

Recently we reported a 4-channel reconfigurable add-drop multiplexer (ADM) [1], consisting of a single PHASAR demultiplexer integrated with four Mach-Zehnder interferometer switches. This component, which was the first ADM realized on InP, combined a compact device size ($3 \times 6 \text{ mm}^2$) with good loss and crosstalk figures. However, the ADM was not polarization-independent. In this paper we report an improved technology, compatible with the fabrication of the ADM, to realize a polarization dispersion compensated PHASAR demultiplexer. Earlier we reported a polarization dispersion compensated PHASAR [4] based on the approach proposed by Takahashi [2] and Zirngibl [3]. For the specific waveguide structure of the ADM, required for our integration scheme, this approach introduced low loss for TE-polarization but an additional 2 dB loss for TM-polarization [4]. In this device the whole InP cladding layer was removed in the polarization dispersion compensation region. Our improved approach combines a local reduction in waveguide width with removal of part of the InP top layer. This gives lower loss and reduced sensitivity to the InP top layer thickness. We demonstrate this technology for a 16-channel PHASAR on InP. On-chip losses are as low as 1.2 dB and 1.7 dB for TE- and TM-polarization, crosstalk is better than -20 dB and residual polarization dispersion is <0.2 nm.

III. Design

In a polarisation dispersion compensated PHASAR, part of the original array waveguide structure is replaced by a second waveguide structure with a different polarization dispersion. By properly choosing the incremental path

length difference δl between two adjacent compensating waveguides, the polarization dispersion in this section can compensate the dispersion in the original waveguide structure [2], [3]. The incremental length δl of the compensating waveguide is given by:

$$\delta l = \frac{\Delta\lambda_N}{\Delta\lambda_n - \Delta\lambda_N} \cdot \Delta L,$$

in which $\Delta\lambda_n$ and $\Delta\lambda_N$ are the polarization dispersion in the normal and compensating waveguides and ΔL is the incremental arm length difference in the PHASAR. Due to the linear increase in arm length the compensating waveguides form a triangular shaped region, see Fig. 1.

The length of the triangular section and thus the dimension of the PHASAR can be minimized by using two waveguide structures with a large difference in polarization dispersion. The starting point is the original waveguide structure required for our integration scheme, see Fig. 1. A large difference in polarization dispersion can be obtained by removing the whole InP top layer. However, this results in an increased loss for the PHASAR, especially for TM-polarization [4]. Our improved technology avoids this loss by combining removal of part of the InP top layer with a reduction in waveguide width.

The polarization dispersion in the compensating waveguide is increased by reducing the waveguide width from $3.0\ \mu\text{m}$ to $1.5\ \mu\text{m}$ with a linear taper of $50\ \mu\text{m}$ length. The polarization dispersion of the compensating waveguides is further increased by removing part of the InP top layer at the price of coupling loss at the transition between the two waveguide sections. The polarization dispersion and this coupling loss as a function of the InP top layer thickness in the compensating waveguides are shown in Fig. 2. Both the polarization dispersion and the coupling loss increases for decreasing InP top layer thickness.

As a compromise between low coupling loss and sufficient polarization dispersion we have chosen a $0.2\ \mu\text{m}$ thick InP top layer in the compensating waveguides. Measured polarization dispersion of the normal waveguide structure ($3.0\ \mu\text{m}$ wide and $1.2\ \mu\text{m}$ thick InP top layer) and of the triangular section ($1.5\ \mu\text{m}$ wide and $0.2\ \mu\text{m}$ thick InP top layer) were $3.1\ \text{nm}$ and $5.7\ \text{nm}$, respectively. For a 16-channel PHASAR with $3.2\ \text{nm}$ channel spacing we have chosen a free spectral range of $51.2\ \text{nm}$ ($\Delta L=12.07\ \mu\text{m}$), which results in an incremental length of $\delta l=15\ \mu\text{m}$ for the compensating waveguides. Total device size of the PHASAR, excluding access waveguides, is $3.3\times 1.3\ \text{mm}^2$.

An important loss contribution in a PHASAR is the transition between the free propagation region and the array of waveguides. Loss dependence on the gap between the $3\ \mu\text{m}$ wide array waveguides is depicted in Fig. 3. This loss includes coupling loss between the free propagation region and the array waveguides, losses caused by offsets between straight and curved waveguides and radiation loss in the curved waveguides. Offset loss and radiation loss can be very low ($<0.2\ \text{dB}$). Coupling loss between the free propagation region and the array guides is calculated by diffraction of the input field with a Rayleigh-Sommerfeld approximation, overlapping of the diffracted field with the supermodi in the array-waveguides and finally overlapping of the supermodi with the modi in the separate array waveguides [6]. Due to the restricted lithographic resolution we have chosen a gap of $0.6\ \mu\text{m}$, which results in a simulated excess loss of $1\ \text{dB}$.

IV. Fabrication

The PHASAR was fabricated in a MOVPE grown layer stack as shown in Fig. 1. A $100\ \text{nm}$ thick PECVD-SiN layer served as an etching mask for the waveguides. The pattern was defined using contact 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 as described by [5]. The top layer of the waveguides in the compensating waveguides was etched through an opening in photoresist. First the SiN mask

was removed by CHF_3 reactive ion etching and then the InP was wet chemically etched with a selective etch ($\text{HCl}:\text{H}_3\text{PO}_4=1:4$) up to the Q(1.3) etch stop layer. After removal of photoresist the wafer processing was finished.

V. Experimental Results

The PHASAR was measured using an EDFA as a broadband light source and a polarizer to select the polarization. Light was coupled in the anti-reflection coated chip using microscope objectives and coupled out of the waveguides by a single mode tapered fiber. The light was analyzed using an optical spectrum analyzer. Propagation loss of $3.0\text{ }\mu\text{m}$ wide straight reference waveguides was 1.5 dB/cm for both polarizations. Fig. 3 shows the response of all sixteen channels of the PHASAR for both polarization. Average channel loss for TE- and TM-polarization was 1.3 dB and 1.7 dB , respectively. Channel uniformity is better than 0.5 dB and measured excess losses are slightly higher than simulated losses. Polarization dispersion of all channels was smaller than 0.2 nm , channel crosstalk was better than -20 dB . Channel spacing of 3.3 nm is slightly larger than the design value of 3.2 nm (400 GHz).

VI. Conclusions and Discussions

A 16-channel polarization independent PHASAR demultiplexer with good performance has been realized. Layer structure and fabrication process are compatible with the fabrication of wavelength routing devices such as ADM or OXC, reported earlier by us [1]. Excess loss is lower than 1.7 dB for both polarizations and the polarization dependence is smaller than 0.2 nm . This type of PHASAR, in combination with polarization independent Mach-Zehnder Interferometer switches [7] allows for the realization of polarization independent ADMs.

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VIII. References

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Fig. 1. Layout of the PHASAR demultiplexer and dimensions of the two waveguide structures in the array arms of the PHASAR.

Fig. 2. (a) Polarization dispersion and (b) coupling loss between the two waveguide structures as a function of the InP toplayer thickness of the compensating waveguides (width=1.5 μm).

Fig. 3. (a) Simulated loss for the central channel of a PHASAR as a function of the gap between the array waveguides. (b) Spectral response of the PHASAR for all sixteen channels; TE- (solid) and TM-polarization (dashed).