Performance analysis of polarization transformation waveguide structures for planar light circuits

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Abstract- **In this paper we analyze different approaches reported for polarization management in optical systems and also introduce a polarization rotator based on bending waveguides promising no additional fabrication step and high conversion efficiency.**

I. INTRODUCTION

With expansion of the channel capacity and increasing data rate requirements of optical communication systems, complexity and the number of components in the optical transceivers and receivers have increased towards reducing the cost and size of such highly complicated systems and more advanced coherent modulation formats. Polarization management is of great importance in such polarization diversity systems and polarization division multiplexed devices to maximize spectral and power efficiency.[1,2,3]

In this paper we review and analyze different approaches reported in literature promising reduction of cost, size and fabrication complexity for polarization conversion. The asymmetrical stepped waveguide approach with only one additional fabrication step is discussed in SOI and InP substrates for polarization rotators and polarization splitters and rotator (PSR) devices using mode evolution and mode coupling methods respectively.

Also a new approach to polarization management applicable to Mach-Zehnder Interferometer (MZI) based Variable Optical Attenuation (VOA) units will be proposed. This approach which introduces no additional fabrication step is aimed to solve the polarization dependency loss (PDL) problem in such devices in deeply attenuated working states.

II. DISCUSSION

1. Stepped waveguide polarization rotator on SOI

All approaches proposed to implement polarization rotation are based on waveguide geometries that support modes that are tilted with respect to those of the interconnection waveguides.Aa 45° tilt of modes is aimed to obtain hybrid TE/TM modes at the conversion section. The most typical approach on a rib waveguide is the use of an asymmetrically slanted waveguide, Fig.1.b, which has interconnection incompatibility with other devices in the circuit, Fig.1.a and

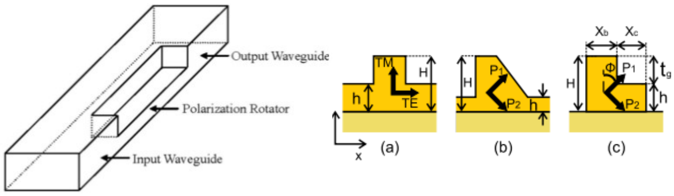

Fig.1. The stepped waveguide polarization rotator presented by Wang [3] (left), Transverse geometries of (a) interconnection waveguide, (b) slanted waveguide rotator, (c) stepped waveguide rotator. [1]

fabrication complexity. Wang [4] proposes an ultrasmall Si-based polarization rotator with an asymmetrical two-step cross-section that can be fabricated by using the process of dry etching. This geometry could be seen as a first order approximation of a slanted wall. The transversal geometry of the proposed waveguide is shown in Fig.1c.

It is reported that in this design over a small length of only ~10 um, more than 97% conversion can be obtained. Our simulations also show a perfect TE/TM hybridization in the asymmetric section (50-50) resulting in conversion efficiency of 99% .

2. Stepped Waveguide Polarization Rotator on InP

The approach proposed by Wang is interesting for polarization rotation on InP substrates, but the geometry cannot be directly applied due to the lower index contrast of this technology and its larger dimensions. Alonso proposes a polarization rotator base on a rib waveguide using the stepped waveguide approach on InP substrates.

Alonso[1] reports a 40 dB extinction ratio, contributing to a conversion efficiency of about 97.5% over a length of 924 um including rotator section and tapered interconnection waveguides. Although an InP cladding layer is not mentioned in this paper, our results show that, without this layer this rotation is not possible. A 45° tilt of modes at rotator section promises a hybrid mode (50% TE and 50 % TM),but our simulations with FIMMWAVE show that without including the cladding layer TE/TM first order modes has a fraction of 98-2. While by including the upper cladding we will obtain a 52-48 fraction leading to the high extinction ratio reported.

Zaitsu [3], using the method proposed by Alonso, also has reported modeling, fabrication and measurement of a polarization rotator based on mentioned stepped waveguide method except a deeply etched high-mesa profile on one side. Despite the close resemblance to Alonso's model, Zaitsu claims a 96 % conversion over only 190 um device including conversion sector and two 20 um tapered waveguide in their proposed model.
Our investigations show that the simulations of the model proposed has TE/TM contributions of only 84-16 in the conversion section which is far from ideal 50-50 fraction. Unless we take account for the fabrication defect reported in the paper. As shown in Fig. 3 SEM results show that the ridge etching profile is not perfectly rectangular, but has a residual slope with an angle of 54.7^{o}. Considering this defect in simulations, we obtain TE/TM fraction of 56-44 which shows a near 45^{o} tilt of mode in conversion sector. Our simulations on the proposed model show that although it promises a more compact device than Alonso's, but functionality of this model depends on predicted fabrication defects and residual slops, which resembles the basic slanted wall method.

3. *Stepped Waveguide PSR on SOI*

Polarization rotators discussed so far can be categorized as polarization rotators based on mode evolution. The stepped waveguide method for polarization conversion can also be applied to convert polarizations using mode-coupling methods. Xiong[4] has designed polarization rotator and splitters (PSR) based on tapered etched directional coupler. Fig.4.a represents schematic of the proposed design. It is reported that over a length of 120 um a conversion efficiency of -0.26 dB can be achieved which our simulations using FIMMWAVE admits this claim.
Fig.4.b reported by Xiong which represents dependency of conversion efficiency on the tip width, Dt, from 0 to 120 nm, shows a high fabrication tolerance for this design. But our simulations on height of 110 nm for the ridge (green line in the reported diagram) show that by increasing this Dt to its maximum which is half of the width of the waveguide, 180 nm, the results are not as predictable as it looks in the reported figure. As it can be seen, unlike the interpretation one might get from the reported figure, after about 100 nm we face drastic change in CE (Conversion Efficiency).

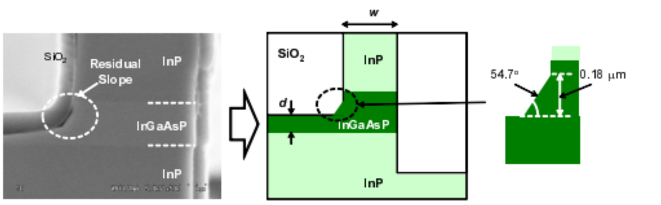

Fig.3. SEM result for the etching profile (left) and cross-sectional model based on actual structure of the fabricated device (right) [4]

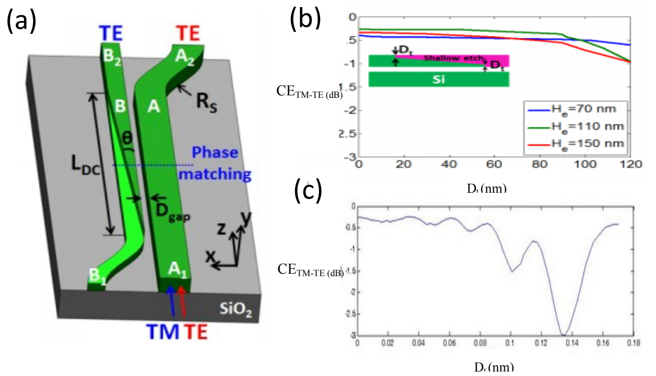

Fig.4. (a)Schematic of the PSR based on the taper-etched directional coupler, (b) Dependence of the polarization conversion efficiency to tip width D_t sweeping from 0 to 120 nm reported by Xiong[2], (c) Investigation on dependence of the polarization conversion efficiency to tip width D_t sweeping form 0 to 180 nm

Polarization Rotation using periodic curved waveguides

Here we discuss using polarization convertors convenient to use for better performance of PLC-VOA s and solving their Polarization Dependent Loss (PDL) by adding a polarization compensative effect upon the difference of two optical polarization states of Mach-Zehnder interferometer MZI) type VOA. We investigate efficiency of a polarization conversion using periodic curved waveguides. The principle of converting using curves relies on variation of refractive index by radius of the curve at each point, imposing asymmetry to waveguide structure without any additional fabrication process.

III. Conclusion

In this paper we review the most promising techniques for polarization rotation based on stepped ridge waveguides and analyze them in both mode evolution and mode coupling mechanisms on different substrates. At the end we discuss a new approach for polarization rotation which promises low insertion loss, high conversion efficiency and most importantly, no additional fabrication step.

IV. References

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