Polarization Converter on InP/InGaAsP Fabricated with Optical Reduction Wafer Stepper

U. Khalique[1], Y.C. Zhu[1], J.J.G.M. van der Tol[1], L. M. Augustin[1], R. Hanfoug[1], F. H. Groen[1], M. van de Moosdijk[2], W. de Laat[2], K. Simon[2], P. J. van Veldhoven[1], M.K Smit[1]

[1]COBRA Research Institute, Technische Universiteit Eindhoven,
Postbus 513, 5600 MB Eindhoven, The Netherlands
U.Khalique@tue.nl

[2]ASML De Run 6501, 5504 DR Veldhoven, The Netherlands

The shortest integrated polarization converter realized by a fully optical lithography is reported. It uses a single waveguide with one slanted side and one vertical wall. An optical 5x reduction wafer stepper with high numerical aperture (≥ 0.48) is used for exposure at 365 nm wavelength. Specified resolution is 0.4μm and overlay-accuracy is ≤60 nm. Vertical side of the converter is realized by reactive ion etching and slanted side by wet chemical etching. The polarization converter length is 125 μm and conversion efficiency is higher than 95%, which is better than the best known polarization converters on InP/InGaAsP until now.

Introduction

A typical photonic integrated circuit includes many components that can be polarization sensitive, e.g. integrated switches, interferometers, amplifiers, receivers etc. Thus, it is important to manipulate or convert optical polarization. A simple passive polarization converter is a satisfactory solution in cases that require a fixed polarization rotation like conversion from transverse electric (TE) to transverse magnetic (TM) or vice versa.

One of the ways to fabricate such a waveguide structure is to concatenate pairs of oppositely loaded waveguide sections [1,2]. Converters can also be fabricated using integrated bends [3]. Such designs result in a component length on the order of mm and excess losses at the interfaces between alternating sections. An alternative to periodic loading is a single section waveguide with one vertical wall and one slanted wall [4]. The vertical wall can be achieved by dry etch and the slanted side, oriented along the (111) crystal plane, by a selective wet chemical etch. Such a converter has been fabricated [5] with device length of 330 μm. An integrated converter on GaAs/AlGaAs has also been reported in [6], where the device length is 724 μm.

Previously we reported [7] an integrated polarization converter of 500 μm device length with 150 μm converter length. The width of the converter, which has a tolerance of 100 nm, is quite small to be realized by standard contact optical lithography. Alignment accuracy to realize vertical and slanted walls is also critical. It has been realized by e-beam exposure to satisfy these fabrication constraints. Here we report on an integrated converter on InP/InGaAsP material fabricated using high-resolution optical lithography. An optical 5x reduction wafer stepper is used for exposure at 365 nm wavelength. The converter length is 125 μm and the total device length, including incoupling waveguides and input and output tapers, is 325 μm.

Design and Fabrication

The device consists an asymmetric waveguide as the converter section, 1.1 μm wide input and output waveguides, coupled to 3 μm wide waveguides via 50 μm long tapers at both sides, as shown in Fig. 1. The vertical wall of the converter, the waveguides and the tapers are deeply etched by reactive ion etching. The slanted wall is realized by non-selective wet chemical etching with bromine methanol. SiN_x and Ti are used as masking materials.

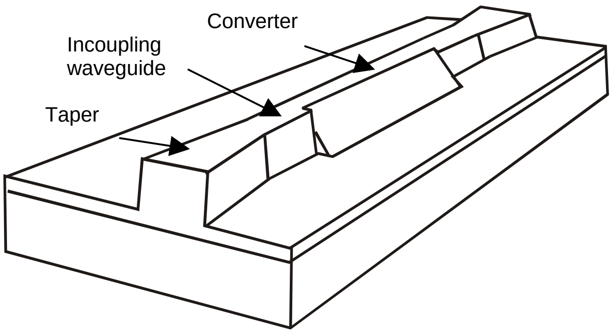

Fig. 1: Schematic of a single section polarization converter based on an asymmetric waveguide.

The layer structure consists of an InP substrate, 600 nm InGaAsP[Q(1.25 μm)] waveguiding layer and a 300 nm cladding layer of InP. Simulation by FIMMWAVE [8] showed that conversion efficiency of TE to TM is around 95% for a 0.82 μm wide and 112 μm long converter. We designed a mask for length variations of 50 μm to 300 μm in steps of 50 μm, for fixed width of 0.82 μm. The width is varied from 0.78 um to 0.9 μm for each of three lengths of 110, 120, 130 μm. Each device is put twice on the mask to supply sufficient measurement data.

The three exposures, respectively to define waveguides, to realize vertical and to define the slanted sides were made with a 5x reduction wafer stepper. It is an ASML PAS5500/100D i-line tool with a variable numerical aperture (NA=0.48-0.60), overlay-accuracy of ≤ 60 nm (99.7% 2-point global alignment) and specified resolution 0.4 μm. Light of wavelength 365 nm is used to expose the wafer through a projection lens, as is shown schematically in Fig. 2. Basically it is a step and repeat system for multiple exposures on four to eight inch wafers. However, we used a quarter of a two-inch wafer. To align and expose on the

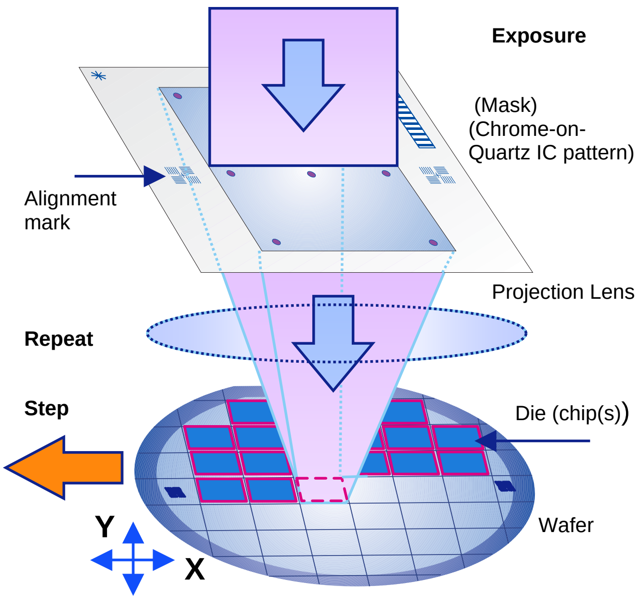

Fig.2: An optical 5x reduction wafer stepper at ASML

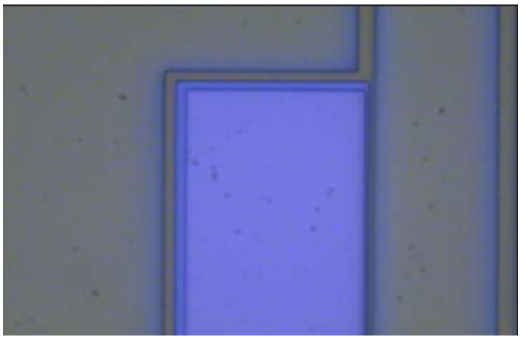

Fig. 3a: Top view of the converter section after third exposure. The alignment accuracy ≤ 0.4 μm.

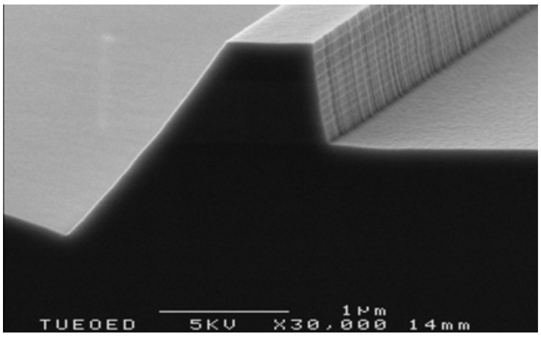

Fig. 3b: Cross-sectional view of the converter section after complete fabrication.

PAS5500/100D, a special mounting technique is developed. To align the quarters on this system phase grating alignment marks designed by ASML were made with standard optical contact lithography.

The photographs of the chip after different processing steps are shown in Fig.3. Fig. 3a shows a part of the top view of the converter section and the incoupling waveguide. The rectangular region on the left hand side of the converter is to limit the wet etch area. To define the waveguides the line width, which is the critical parameter, varies less than 20 nm. Fig. 2b is the cross sectional view of the realized converter section. The slanted side is etched somewhat deeper than the vertical wall, but that has no influence on the mode since we etched completely through the guiding layer.

Results and Discussion

Measurements have been performed with a transmission set up. Polarization was defined by polarizers in the input and the output optical lines and was very stable throughout the measurements. Fig. 4 shows the conversion efficiency as a function of length of the converter for TE input polarization. Maximum conversion from TE to TM polarization occurs at 125 μm conversion length, corresponding to half beat length between the modes of the converter section, and back to zero at full beat length that is 250 μm length. The conversion efficiency, for these particular converter's parameters (125 μm length and 0.82 μm width) is 95%.

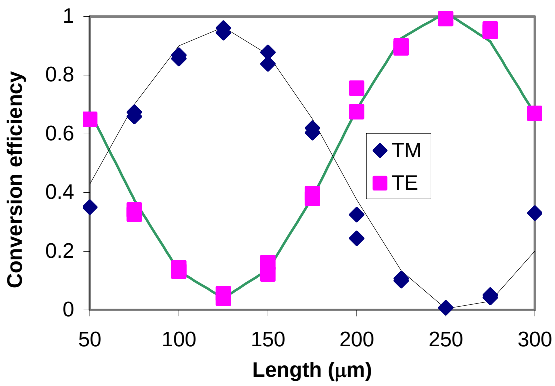

Fig. 4: For TE input the conversion efficiency as a function of length for a width of 0.82 μm.

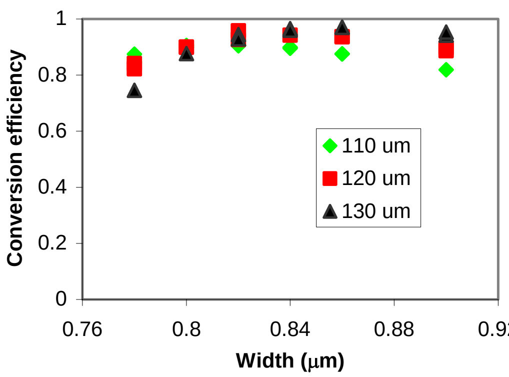

Fig. 5: For TE input the conversion efficiency as a function of width for three sets of lengths.

The same measurements have been done with TM polarization as input. They showed the same trend and 92% maximum conversion efficiency. Fig. 5 shows the maximum conversion efficiency as a function of width for three different lengths. Here the best point is for 0.86 μm width and 130 μm length, the maximum conversion efficiency is 97% for TE polarization and for TM input polarization it is 95%. The window for width tolerance is 100 nm to keep the efficiency above 90%. For the TM polarization the measurement showed the same width tolerance for conversion efficiency above 86%.

Loss measurements have been carried out with a Fabry Perot set up. The deep etched 3 μm wide waveguides showed losses of 1.6 dB/cm to 2.4 dB/cm at different positions on the chip for TE polarization; this variation is within the measurement accuracy of the set up. For TM it is 1.5 dB/cm to 2.7 dB/cm. Tapers have also been characterized. There were 16 tapers sequentially connected between 1.1 μm 3 μm wide waveguides and their total loss was less than 0.4 dB. Thus loss per taper is negligibly small. For the loss of the converter section, 250 μm length was chosen which is the full beat length, i.e. at output polarization is back to the initial state. Comparing the losses through these sections to the waveguide losses, the loss of the slanted waveguide of 250 μm length is less than 1 dB, including the coupling losses between waveguide sections.

Conclusion

A compact integrated polarization converter on InP/InGaAsP material has been realized by complete optical lithography for the first time. The critical steps are exposed on ASML 5x reduction stepper. The conversion efficiencies are higher than 95% for both TE and TM polarization. Excess loss of the converter is very low for the two polarizations. Conversion length is very small that is 125 μm. The best device parameters until now are achieved.

References

[1] J.J.G.M. van der Tol, F. Hakimzadeh, J.W. Pedersen, D.Li and H. Van Brug, "A new short and low-loss passive polarization converter on InP", IEEE Photonics Technology Letters, vol. 7, no. 1, pp. 32-34, 1995

[2] J.J.G.M. van der Tol, J.W. Pedersen, E.G. Metaal, F. Hakimzadeh, Y.S. Oei, F. H. Groen and I. Morman, "Realization of a short integrated optic passive polarization converter", IEEE Photonics Technology Letters, vol. 7, no. 8, pp. 893-895, 1995.

[3] C.van Dam, L.H. Spiekman, F.P.G.M. van Ham, F. H. Groen, J.J.G.M. van der Tol, I. Morman, W.W. pascher, m. Hamacher, H. Heidrich, C.M. Weinert and M.K. Smit, "Noval compact polarization converter based on ultra short bends", IEEE Photonics Technology Letters, vol. 8, no 10, pp. 1346-1348, 1996.

[4] H. el Refaei and D. Yevick, "An optimized InGaAsP/InP polarization converter employing asymmetric waveguides", Journal of Lightwave Technology, vol. 21, no. 6, pp. 1544-1548, 2003.

[5] H. el Refaei and D. Yevick, "Slanted-rib waveguide InGaAsP-InP polarization converters", Journal of Lightwave Technology, vol. 22, no. 5, pp. 1544-1548, 2004.

[6] Huang, R. Scarmozzino, G. Nagy, M.J Steel and R.M. Osgood, "Realization of a compact and single-mode optical passive polarization converter", IEEE Photonics Technology Letters, vol. 12, no. 3, pp. 317-319, 2000.

[7] F.H. Groen., Y.C. Zhu, J.J.G.M. van der Tol, "Compact polarization converter on InGaAsP/InP using an asymmetrical waveguide ", in Proceedings of the 11th European Conference on Integrated Optics, 2003, pp. 141-144.

[8] Y.C. Zhu, U. Khalique, J.J.G.M. van der Tol, E.J. Geluk, F. H. Groen, F. Karouta, M.K Smit, "Ultrashort polarization converter on InGaAsP/InP", accepted in this conference.