Polarization Splitting Based on Planar Photonic Crystals

V. Rinnerbauer[1,2], J. Schermer[2], and K. Hingerl[1]

[1]Christian Doppler Labor für oberflächenoptische Methoden, Johannes-Kepler-Universität Linz, A-4040 Linz
[2]Photeon Technologies, A-6900 Bregenz

Planar polarization splitting devices based on photonic crystal slabs have been developed, their main advantages being the planar design and their possible integration into PLCs. Three different principles are demonstrated and results from numerical simulations shown.

Introduction

The use of polarization multiplexing to double the existing fibre capacity has been demonstrated successfully in a recent field trial on an installed DWDM metropolitan area network in Berlin, Germany [1]. Together with the growing number of polarization preserving devices, in particular photonic crystal (PhC) devices, this experiment shows us the importance of effective polarization demultiplexers.

Due to their inherent polarization sensitivity, photonic crystals offer convenient solutions on a length scale of several tens of micrometers in silicon-based or other high index material systems. In a 2D photonic crystal slab, the presence of a horizontal symmetry plane allows us to decompose the guided modes into TE-like and TM-like polarization states, which are even and odd with respect to reflections through this plane [2]. In this paper, we will show three different principles that exploit the polarization dependency of these guided modes.

Polarization spitter design

Reflection at a photonic crystal interface

At the interface of a photonic crystal, an impinging wave is either transmitted or reflected, depending on whether there are allowed states for its frequency. The absence of allowed states can result either from a bandgap for this frequency, or else for symmetry reasons, which prohibit the excitation of the photonic crystal modes. Therefore reflection and transmission depend on the photonic crystal structure and the wavelength, the polarization and the incident angle of the impinging wave.

For this polarization splitter we have designed a photonic crystal structure that reflects one polarization while transmitting the other. The reflection and transmission spectra of a photonic crystal have been calculated using a plane wave expansion technique [3] based on a method proposed by K. Sakoda [4]. The results for a hexagonal lattice with 16 rows of air holes in silicon with a radius to period ratio r/a = 0.29 are shown in figure 1.

The effective refractive index of the silicon background was set to n_{eff} = 2.76, which corresponds to a slab height h of h/a = 0.6. This effective index was derived using the scaling laws, preserving the position of the bandgap for the transition from 2D to 3D

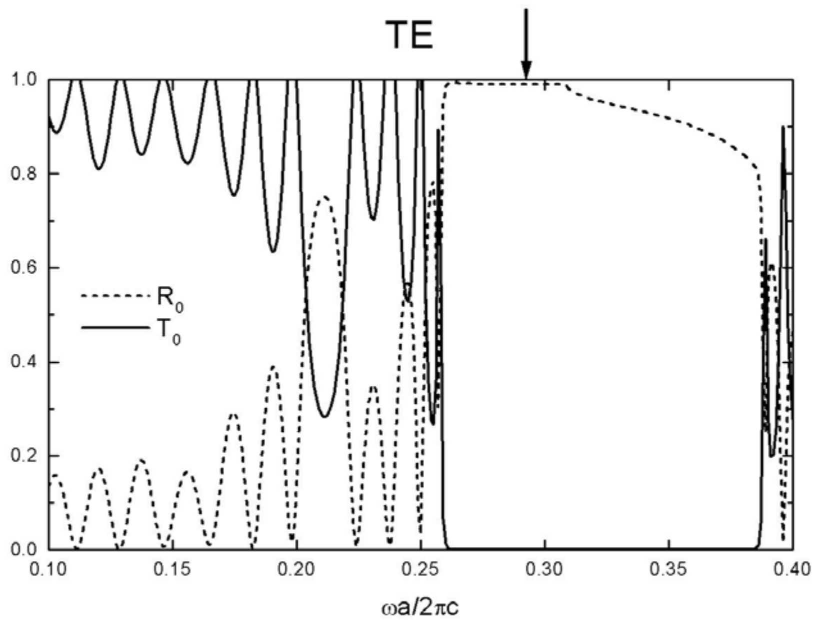


Fig. 1: Reflection at and transmission through a photonic crystal for TE (above) and TM polarization (below) as a function of normalized frequency

cases. The angle of incidence in this example is 10 degrees. It can be seen that for these parameters there are frequency regions where one polarization is transmitted but the other is reflected. We use the parameter ωa/2πc = 0.293. In figure 1 this parameter, whereby the power reflection is 0.990 for TE and the power transmission for TM is 0.998, is indicated by an arrow. The plane wave calculations were performed with 5 plane waves (n) parallel to the interface and 50 plane waves (m) perpendicular to it [notation of 4]. The results have been verified with 2D and 3D FDTD simulations of PhC slabs.

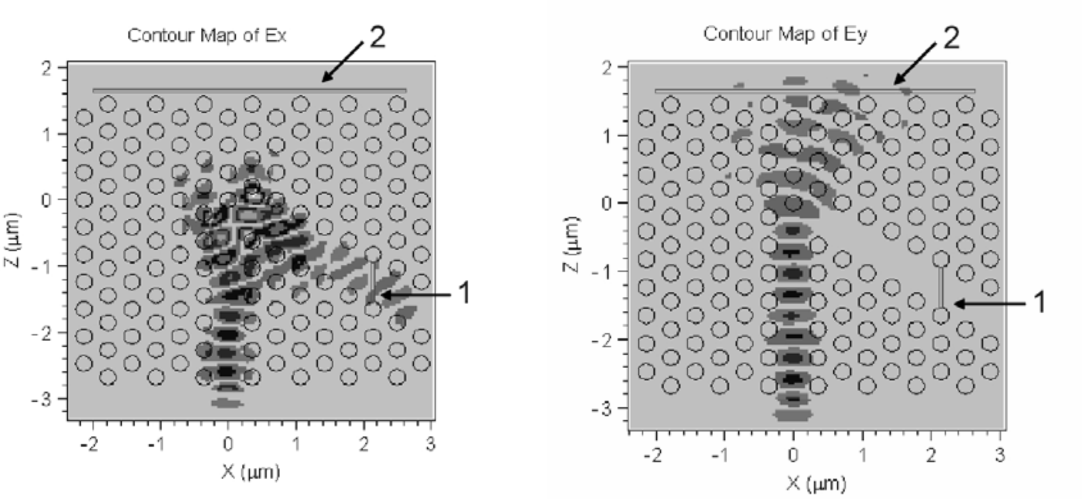
Guided modes and free propagation

In this example, a defect waveguide is introduced into a photonic crystal structure exhibiting a bandgap for TE polarization only. Because the bandgap prohibits propagation in the bulk, a bend in this photonic crystal waveguide redirects TE light with frequencies in the bandgap. However, the other polarization is not guided around the bend by the defect waveguide, and continues propagating straight through the crystal.

Once again, a hexagonal lattice of air holes in silicon with r/a = 0.29 is used. The period a is 415 nm and the height of the slab is 320 nm. This lattice has a bandgap for TE polarization for normalized frequencies of about 0.24 ≤ ωa/2πc ≤ 0.31.

The results of 3D FDTD simulations with a wavelength of 1.55 µm for such a structure are shown in figure 2. The time evolution of power is monitored at positions 1, 2 and the results shown below the picture of the field are a measure of the output power at the waveguide output on the right (position 1, dark gray) and at the top edge of the photonic crystal (position 2, light gray). The power output for TE polarization is about 90% (insertion loss of 0.45 dB), and 75% (1.25 dB) for TM.

The geometry of the bend was then optimised to obtain maximum output for both polarizations for a broad bandwidth. Simulations of the optimised bend show an output power of 93% (insertion loss of 0.3dB) for both polarizations at 1.55 mm, with a crosstalk below 16 dB for TM and below 24 dB for TE. The non-uniformity in the C-band is less than 0.5 dB for both polarizations.



(a) (b)

Fig. 2: FDTD simulation of a PhC bend for (a) TE and (b) TM polarization

Polarization-dependent defect modes

In this case the polarizations are separated at a Y branch in a photonic crystal connecting three defect waveguides with polarization-dependent modes. The defect modes of the photonic crystal waveguides are designed in such a way that each output waveguide of the Y-branch supports only one polarization whilst the input waveguide supports both.

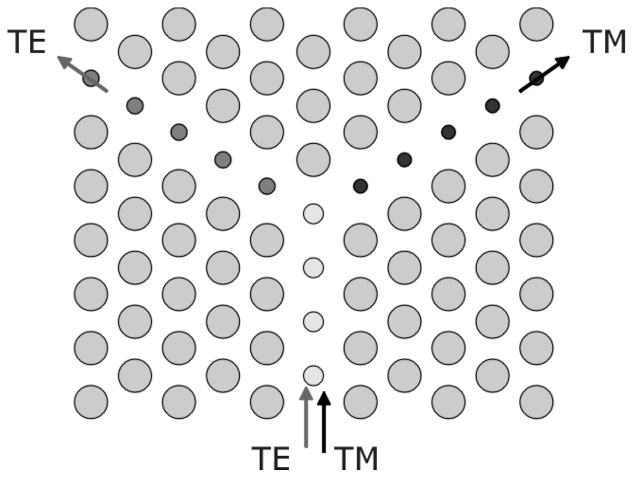
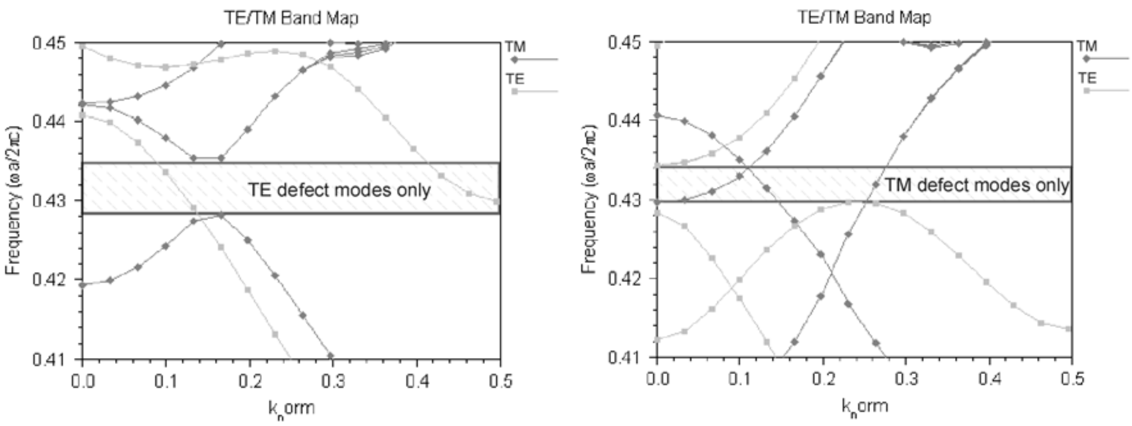


Fig. 3: Y-branch structure with polarization-dependent defect modes in the branches

In a 2D example we use a hexagonal lattice of air holes in silicon with r/a = 0.45. The lattice exhibits a bandgap for both polarizations for normalized frequencies of about 0.41 ≤ ωa/2πc ≤ 0.45.

Line defect waveguides are formed in this lattice by reducing the radius of the holes in one row. The input waveguide has a defect radius r/a = 0.33, which supports modes of both polarizations in the bandgap, whereas one output waveguide with a defect radius of r/a = 0. 2365 supports only TE modes (figure 3a) in a frequency region of about 0.430 ≤ ωa/2πc ≤ 0.434, and the other output waveguide with r/a = 0.1925 supports only TM modes in this frequency region (figure 3b).



(a) (b)

Fig. 3: Defect bands for (a) r/a = 0. 2365 and (b) r/a = 0.1925, parameters as explained in the text

In this example, the design of the Y-branch junction is of crucial importance for good transmission.

Conclusion

We have demonstrated three different designs of polarization splitting devices in photonic crystal slabs, exploiting the inherent polarization sensitivity of 2D photonic crystal slabs. The main advantages of all designs are the planar geometry and the ability to be integrated into PLCs with high integration density.

References

[1] N.E.Hecker-Denschlag, W. Schairer, W. Fischler, A. Richter, T. Auernhammer, B. Lankl: “Polarization multiplexing in a remotely-configureable photonic network”, ECOC 2002, Vol.3, 6.4.5

[2] S.G. Johnson, Shanhui-Fan, P.R. Villeneuve, J.D. Joannopoulos, L.A. Kolodziejski: “Guided modes in photonic crystal slabs”, Phys. Rev. B, Vol. 60(8), 1999, pp 5751-8

[3] K. Hingerl, L. Mao, V. Holy,V. Rinnerbauer, J. Schermer: “Reflection and Transmission of Finite 2D Photonic Crystals”, ECOC 2003, Vol.3, pp 672-3

[4] K. Sakoda: “Optical Properties of Photonic Crystals”, Springer, Berlin 2001, Chapter 4