3D SIMULATION ON A NOVEL LINBO$_3$-BASED SPLITTERS FABRICATED BY COMBINING PHOTONIC CRYSTAL AND CHANNNEL STRUCTURES

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Introduction

Lithium Niobate (LN) is a well-known material because of its strong Pockels effect and applications in many optical devices, such as high-speed optical switches, phase modulators and even nonlinear optics. In addition to bulk optics, LN has been extensively used for fabricating planar waveguides via introducing proton (H+) or metal (such as Ti) into beneath-surface or buried regions [1].

Among those integrated photonic devices, photonic crystals (PhCs) are attractive for their distinguished optical characteristics, for example, the ability of engineering waveguide dispersion or confining light in a small volume. If LN is applied in PhC-based devices, more sophisticated optical functions can be realized by taking advantage of the prominent electro-optic effect (Pockels effect). However, making LN photonic devices is very difficult, and typically requires long processing time and advanced equipment. Therefore, it will be desirable to analyze the LN PhCs prior to real fabrication. Finite-Difference Time-Domain (FDTD) has been extensively used for simulating optical wave propagating inside PhCs. Unlike conventional PhCs made of isotropic media, the optical birefringence of LN PhCs needs to be considered. Roussey *et al.* have analyzed theoretically the PhC-based superprism on LN [2, 3]. Fourati [4] used 2D FDTD method to calculate band structure of LN PhCs and the correlation between the bandgap and the refraction index. However, most works are based on a 2D model without considering the anisotropic nature of LN.

In this work, we present our design of waveguide splitter as shown in Fig. 1. Compared to Y-branch splitters, PhC splitters are much more compact due to the strong optical confinement. Two channel waveguides with electrodes are combined with the PhC splitter for modulating the optical phase on the two arms via electro-optics. We used a packaged Suite RSoft to simulate the PhC splitter for 1550-nm wavelength. PhCs consist of hexagonal lattices of holes in a LN slab with one lattice spacing in thickness. Thus the light is confined laterally by Bragg reflection. An air gap between the PhC slab and the substrate is assumed in our model for vertically confining light within the PhC slab.

The bandgap and waveguide mode are calculated by a 3D FDTD method taking into account the anisotropic nature of LN. To reduce scattering and reflection losses at the splitting and bending regions of PhCs, some modified structures with optimal design are proposed to effectively guide light at these regions.

Device description

Fig.1 is the scheme of the device. On the left is PhCs (holes in red and LN slab in dark gray) and on the right are two arms of channel waveguides (in dark gray) with electrode (in yellow). This PhCs have hexagonal lattices of holes with a lattice constant of 680 nm and a fill factor of 0.3. This PhCs are fabricated on an X-cut LN with refractive indices equal to 2.138 in X and Y direction and 2.21 in Z direction, respectively. The PhC slab is separated from the substrate by an air gap of one period thick. The top cladding material is the air. The PhC waveguide splitter is made by removing lines along the GK directions. The channel waveguides have metal electrodes on the two sides for EO modulation. With this design, the splitter is expected to have low insertion loss and low voltage Vπ (Voltage that makes phase changed 180 degree), compared with APE waveguide [5].

Results and discussion

3D FDTD are used for simulating optical wave propagating in this device. Fig. 2 shows the band structures of the LN PhC slab as well as the dispersion curves of the PhC waveguide modes for TM-like polarization. The propagation direction is along the K point. Clearly, the waveguide modes lie inside the photonic bandgap, corresponding to a good confinement factor.

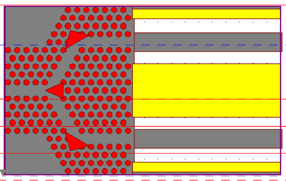

Fig. 1 LN PhC waveguide splitter as well as channel waveguides.

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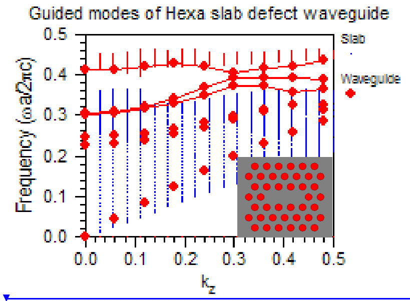

Fig. 2 Band structures of the LN PhC slab as well as the dispersion curves of the PhC waveguide modes. The inset shows the lattice with one line defect being a waveguide on GK direction.

Fig. 3 shows simulated light propagation from the left to the right in the splitter. With a triangle hole at the central splitting position and two others, rotated by 30^0 with respect to the horizontal line, at the bending positions, the insertion loss of PhC waveguides is estimated to be 4.56 dB. Moreover, the air gap under channel waveguides is able to eliminate vertical coupling to the substrate, especially for the transition from the PhC waveguide to the channel waveguide. The simulation results are shown in Fig. 4. With an air gap, the coupling loss reduces to 1.37 dB at outputs.

The EO effect on phase/power modulation is also estimated with two splitters combined together in a Mach-Zehnder configuration. Taking the advantage of high r_{33} of pure LN, electrodes pairs were placed along the channel waveguides in distance of 1 μm far from waveguides. For the channel arm with length of 200 μm mm, Vμ is 0.4 V, as shown in the Fig. 4.

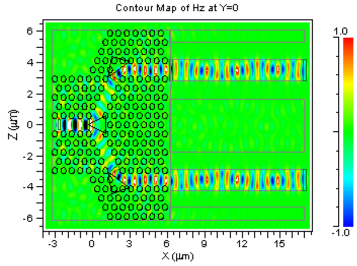

Fig. 3 Simulated optical waves in the splitter (top view). The optical waves propagate from the left to the right.

Conclusion

We used 3D FDTD method and consider the anisotropic nature of LN to design and a photonic splitter based on PhCs and channel waveguides for wavelength of 1550 nm. The splitter is realized on 10x13 μm hexagonal lattice of holes and channel waveguides of 200x1.32 μm^2. Thank to PhC properties and the addition of wave manipulation structures at splitting and bending points, the total loss was as low as 1.37 dB at outputs, with Vπ is 0.4 V.

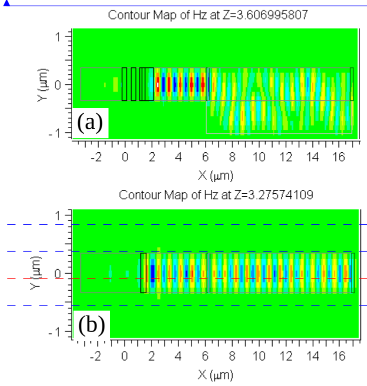

Fig. 4 Simulated optical waves from the PhC waveguide to the channel waveguide (side view): (a) without air gap and (b) with air gap.

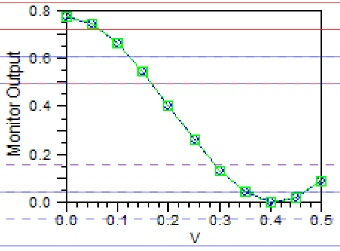

Fig. 4 EO effect on power spitting.

References

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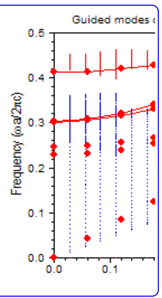

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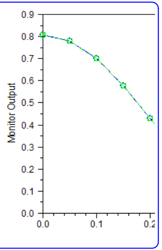

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optical applications such as low loss, compact, and surprising effects, that are going to be studied. Owning good properties as mentioned above, LN also draws attention as a promising material for fabrication and application of PhC structures in optical and optical related fields.

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, for example, Focused Ion Beam (FIB), Ion implanter, Ebeam Writer, etc. Thus, processes for LN structures usually cost time

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Some works also simulated LN as a potential material for PhC structures.

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with 2D FDTD (Finite-Difference Time-Domain) method

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Though working with LN, an anisotropic material, all these works used only unique RI for their calculations. Moreover, practically, these PhC structures are 2D with the depth of slab of about or less than 2 µm. However, without considering anisotropic nature, and with 2D FDTD simulation, the simulated results more or less would be different from practical problems.

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Small RI difference resulting high loss (a) and suspended structure minimizing vertical loss (b)

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K. Gallo, J. Prawiharjo, “Proton-exchanged LiNbO3 waveguides for photonic applications”, http://eprints. soton.ac.uk/41703/01/2938.pdf

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With this consideration, the simulated results would be close to realistic problem.