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Three- and Four-Fort Integrated Optical Circulators Based on Photonic Crystals: Theoretical Analysis and Numerical Simulations

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Abstract –We investigate in this work some possibilities of construction of compact nonreciprocal components for integrated optics. These components are based on 2D photonic crystals. The nonreciprocal materials which can be used for such components are magnetized ferrites semiconductors. Our aim are three- and four-port circulators. The physical principle of functioning of such devices is a combination of the volume resonances of gyrotropic cylindrical elements and of the corresponding junction. We show that to achieve the circulation regime, different types of resonances can be used. Some simulation results are presented as well. At 1550 nm, the circulators typically have 20 dB isolation in the frequency band of tens GHz.

Nonreciprocal devices are very important for large scale integrated optics. They permit to mitigate the influence of parasitic reflections of electromagnetic signals from nonideally matched components because the reflected light causes instabilities of lasers and amplifiers. However, the traditional optical isolators and circulators [1] have rather large dimensions, for example, the ferrite isolators based on Faraday effect have the length of several millimeters. Besides they not always permit integration with other optical elements.

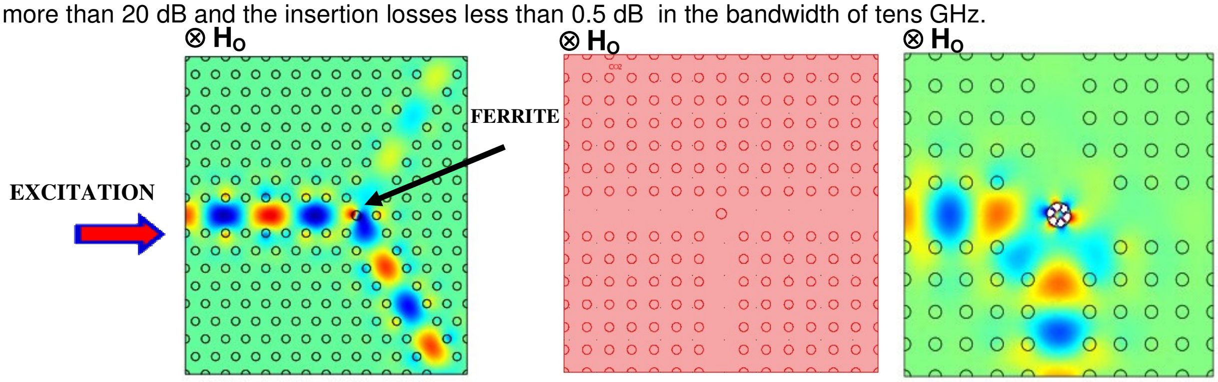
Our aim is a theoretical investigation of new compact circulators based on 2D photonic crystal waveguides. The nonreciprocity of such circulators is defined by Time-reversal asymetry of gyrotropic media, for example, of the tensor of permeability of magnetized ferrites and of the tensor of permittivity of semiconductors [2].

It is known that magneto-optic activity of the ferrites and magnetized semiconductors is very small. One of the ways to overcome this difficulty is the use of some resonant effects. The circulators suggested in our work are very compact because the physical principle of their functioning is a combination of different resonances of a nonreciprocal resonator and of corresponding junctions. The linear dimensions of them can be of several wavelengths.

Three examples of such devices are given in Fig, 1. In Fig. 1a, an Y-circulator is shown, in Fig.1b- a T-circulator, and in Fig. 1c, a four-port X-circulator is presented. Choosing the diameter of the gyrotropic cylinder and the surrounding junction, one can adjust the circulation regime of the circulators.

We show, that different resonant modes of the gyrotropic cylinder can be used to achieve this regime. For the tree-port circulators, one can use the lowest n=±1 or n=±2 azimuthal modes of the magnetized cylinder. But for the four-port circulators, at least two modes of the cylinder with different n should be used. Choosing resonant modes, one can take into account that higher modes will lead to higher insertion losses.

Our simulation results show that these circulators at the wavelength 1550 nm can have isolation of more than 20 dB and the insertion losses less than 0.5 dB in the bandwidth of tens GHz.



(a) (b) (c)

Figure 1: Examples of three- and four-port circulators. In Fig. 1a: Y-circulator is shown, Fig.1b - T-circulator, and Fig. 1c, four-port X-circulator.

References

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