

aggregated transmission to Port 2 for the three-port circulator (Fig. 4d) and the aggregated transmission to Port 2 for the four-port circulator (Fig. 5d) are both close to unity, the performance limitation is largely dominated by the waveguide coupler. There is also a trade-off between the bandwidth and the length of the waveguide coupler in this proof-of-concept structure. However, given the large degree of freedom in dispersion engineering for photonic crystals, by varying the dimension and the shape of the nearest unit cells to the waveguides, one could in principle match the uncoupled dispersion relations of the two waveguides, over a much broader range of the frequency. In other words, equalizing the propagation constant and the frequency of the two waveguides could allow us to create ideal circulators over a frequency range close to the entire photonic bandgap. Moreover, increasing the coupling coefficient κ by physically merging the two-way waveguide and the one-way waveguide could reduce the interaction length, thereby reducing the overall device dimension significantly. With the emergence of novel infrared magneto-optical materials featuring the Voigt parameter comparable to microwave ferrites [32,33] envision the experimental demonstration of such broadband circulator at optical frequencies.

5. Concluding Remarks

In this paper, we proposed a novel optical circulator based on directional couplers between a one-way waveguide and a two-way waveguide. We examined the bandwidth limit of such a waveguide coupler and its impact on the derived three-port circulators and four-port circulators. The bandwidth is not limited by the resonant linewidth and a three-port circulator and a four-port circulator are implemented numerically to feature a relative 1dB -bandwidth of 2% and 1.3% respectively. While our discussion has been restricted to two-dimensional structures, the operational principle and design procedures can be readily extended to three-dimensional structures at microwave, THz and optical frequencies, using out-of-plane confinement employed in experimental three-dimensional chiral edge state systems [25].

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