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A unidirectional air waveguide basing on coupling of two self-guiding edge modes

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ABSTRACT

Nonreciprocal waveguide plays the key role in optical communication devices because of the robustness of one-way transport along the edge. We present a 2D honeycomb magnetic-optical photonic crystal frame and realize a unidirectional air waveguide based on the coupling effect of two self-guiding one-way edge modes in proper the waveguide width. A great ideal nonreciprocal air waveguide with condensed-energy, strong stability, great nonreciprocity is achieved, and its transmission features of superiority over others configuration are demonstrated.

1. Introduction

The study of one-way electromagnetic (EM) edge modes of the two-dimensional (2D) magneto-optical photonic crystals (MOPCs) had been aroused intently attention in the integration optics communication devices based on the integer quantum Hall effect (IQHE) edge states in photonic crystals (PCs) [1–6]. Based on unique feature of one-way electromagnetic edge modes that backscattering in the unidirectional edge modes is completely suppressed and robust against imperfections or disruptions along the edge, they had been widely used in optics information transport for nonreciprocal optical waveguide devices, including isolators [7,8], circulators [9] and crossing waveguides [10]. We can achieve some particular waveguides in the Refs. [11,13] via studying the coupling effect between unidirectional edge modes deriving from the waveguide coupling theory [12,14], Fang et al. realized an ideal unidirectional air waveguide with the capability of broad working bandwidth, high extinction ratio, single-mode feature at the coupling width of 1.5a (a is lattice constant) and slow-light waveguide through coupling of two unidirectional edge modes. However, realization of one-way edge states transport requires an ancillary cladding layer made of either a perfect metal or PCs [4] to confine the radiation for rectangular or triangle lattices, since the prediction of edge states in honeycomb plasmonic lattices [14], experimental realization and observation of self-guiding unidirectional EM edge states with honeycomb MOPC [15], their self-guiding features may great benefit condensed-energy for applications in the field of unidirectional light propagation. Here we present a coupling structure with two semi-infinite 2D honeycomb MPOCs based on self-guiding features.

In this work, we design a waveguide coupling structure, and study waveguide coupling effect of self-guiding edge states motivated by the upper and lower edges via modifying the waveguide width. We demonstrate that unidirectional air waveguide inspired with advantages of condensed-energy, strong stability, great nonreciprocity, modes conversion, and operation bandwidth changing by varying the waveguide coupling width. Finally, we quantificationally illustrate relative features of the unidirectional air waveguide with good beam qualities applying in optical integrated circuit. The study we perform will open up new avenues for applications in the optical communication field.

2. Theory and modeling

Here a line-defect waveguide in a PC structure with a honeycomb lattice array of cylinders, with a lattice constant$a$ ($a = 1000$ nm) and r radius 0.2a, is proposed and shown in Fig. 1. The material of the upper and lower parts of the configuration is magnetic YIG (in green). According to the reports on YIG characteristics [13], its permeability tensor form satisfied with the Landau–Lifschitz equation [10,16] because of an external dc

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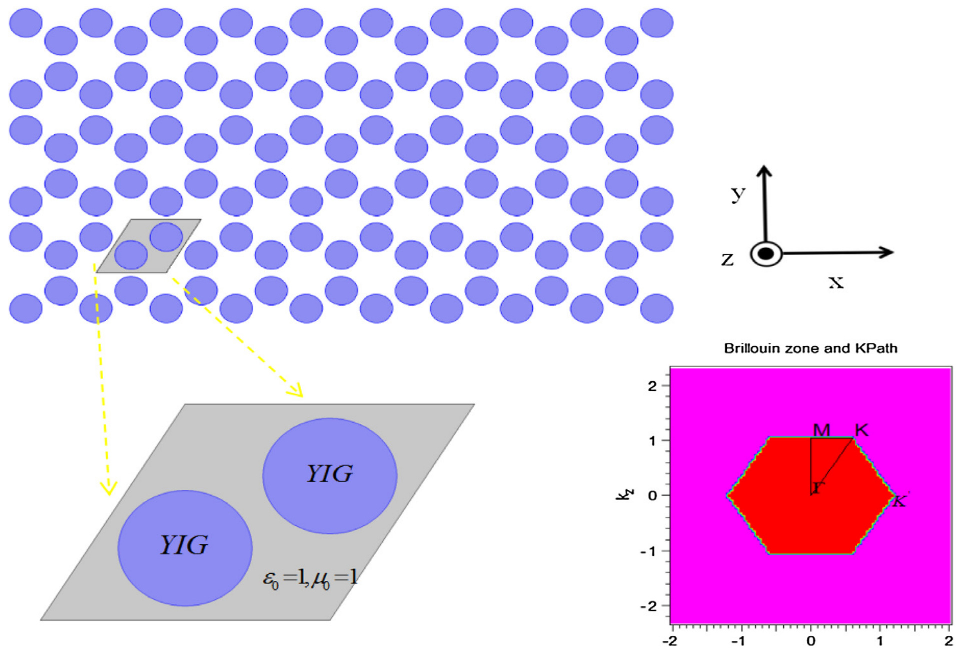

Fig. 1. Schematic of a honeycomb 2D MOPCs. Below panel: enlarged view of the rhombic unit cell of two sites, where green circle denotes cylinders of YIG, gray plane denotes background environment. Bottom right panel: view of Brillouin zone (BZ) and Kpath for a honeycomb photonic crystal, where red hexagon denotes the first Brillouin zone (1BZ). The coordinate axis setting is the same as shown. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

magnetic field applied in the out-of-plane (+z) direction inducing strong gyromagnetic anisotropy. As is described in the following form: $\mu(\mathrm{r})=\begin{bmatrix}\mu' & \mathrm{j}\mu'' & 0\\ -\mathrm{j}\mu'' & \mu' & 0\\ 0 & 0 & \mu'''\end{bmatrix}$ where $\mu'=1+(\omega_0\omega_\mathrm{m}/\omega_0^2-\omega^2)$, $\mu''=-(\omega\omega_\mathrm{m}/\omega_0^2-\omega^2)$, $\omega_0=2\pi\gamma\mathrm{H}_0$, $\omega_\mathrm{m}=2\pi\gamma=2.8\times10^6\ \mathrm{rad}^{-1}\ \mathrm{G}^{-1}$, $4\pi\mathrm{m_s}=1780\mathrm{G}$ and H_0 is the external magnetic field along the z-axis [10]. The structure parameters in this paper are refer to Refs. [10–13], as discussed $\epsilon=15$, $\mu=\begin{bmatrix}14 & 12.4\mathrm{j} & 0\\ -12.4\mathrm{j} & 14 & 0\\ 0 & 0 & 1\end{bmatrix}$, where this ignores the material dispersion and loss. Let us consider harmonic

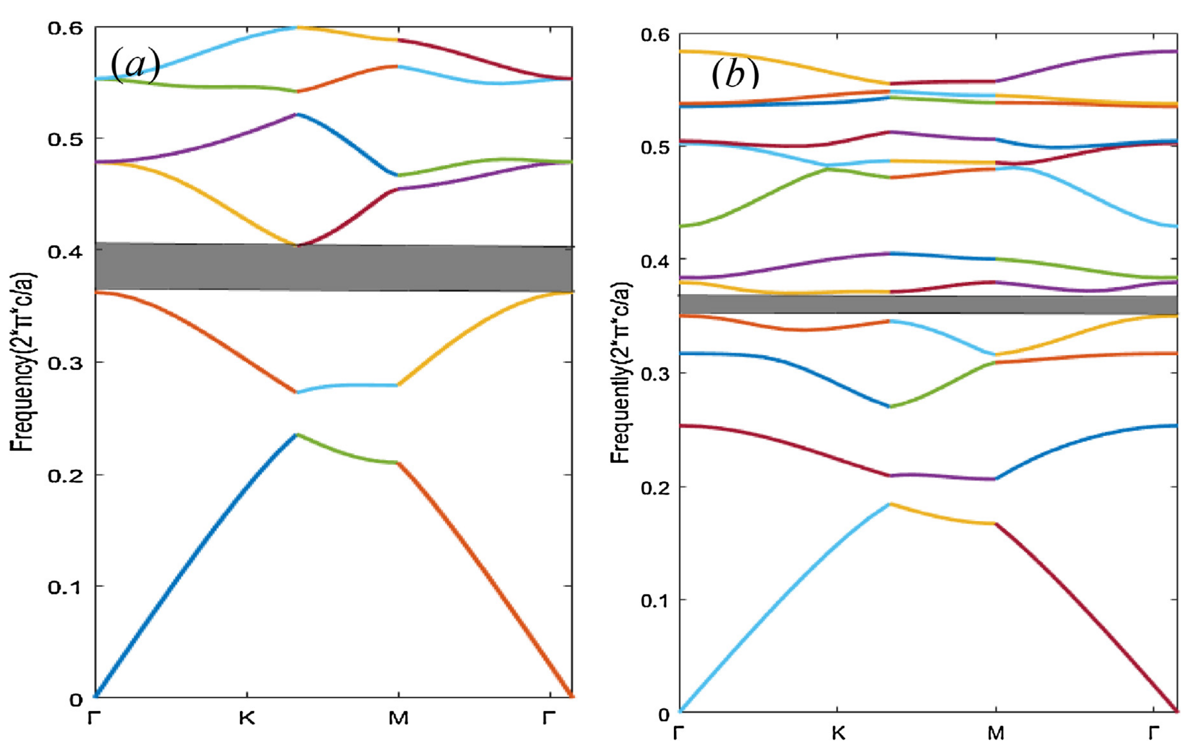

Fig. 2. Bulk TM mode band structures of the rod honeycomb lattice. (a) Without an external bias magnetic field applied for the structure. (b) With an external bias magnetic field applied for the structure.