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Magneto-optical isolators with flat-top responses based on one-dimensional magneto-photonic crystals

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Abstract

We propose two composite structures based on a one-dimensional magneto-photonic crystal basic structure and employ the 4 × 4 transfer matrix to investigate their transmission properties. One composite structure with total thickness of 15.09 μm achieves flat-top width of 3.5 nm and possesses Faraday rotation angle and transmittance waving at 45–53.50° and 98.75–99.73%, respectively. The other composite structure with the total thickness of 22.71 μm makes the flat-top width to 2.5 nm, and in the area of this bandwidth, Faraday rotation angle and transmittance fluctuate from 45° to 48.55° and 99.61% to 99.87%, respectively. Moreover, both of them are thin enough and show acceptable transmission bandwidths. These two structures can efficiently reduce the size of optical isolators and thus applying to the achievement of the integrated devices.

Keywords: Flat-top response; Magneto-photonic crystal; Magneto-optical isolator; 4 × 4 transfer matrix

1. Introduction

Optical isolators are critical components in optical communication systems, which are used to eliminate unwanted back-reflections that typically create instabilities such as frequency shifts, mode hop and amplitude modulation. As the widely used optical isolator in our daily life, the magneto-optical isolator (MOI) consists of two linear polarizers with polarization axes offset equal to 45° and a Faraday rotation material inserted between them. Generally, bulk magneto-optical material is being used as Faraday rotation material. However, the bulk magneto-optical material has commonly a length on the order of few millimeters [1]. This induces a large size of the optical isolators so that it is not suitable for the application in the integrated devices.

On the other hand, one-dimensional (1-D) magneto-photonic crystal (MPC) film, a PC [2–8] contains magnetic substances, possesses these characteristics of high transmittance and a large Faraday rotation due to the multiple interferences of light within the magnetic defect layers. Inoue and Fujii found that multilayer films composed of

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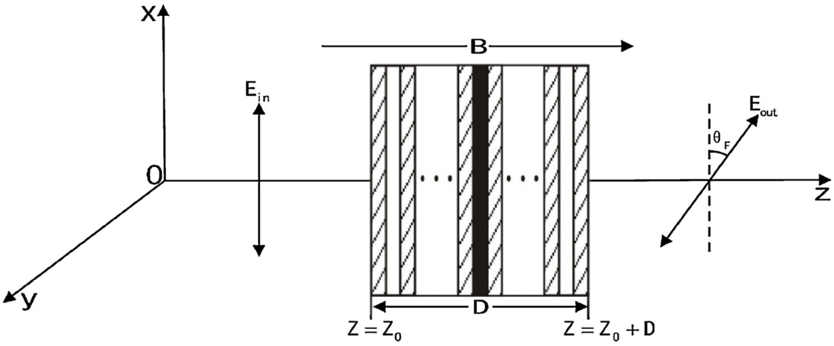

Fig. 1. The propagation of light in one-dimensional magneto-photonic crystal.

magneto-optical and dielectric materials exhibit great Faraday rotation effect [9]. Kato et al., reported that when the 1-D MPC is operated at multicavity (double- and triple-cavity), very high transmittance reaching 100% and very large Faraday rotation of 45° can be realized simultaneously [10]. Subsequently, Kato et al. fabricated experimentally a 1-D MPC, and confirmed theoretical calculation and the measured value for the Faraday rotation were in close agreement [11]. After this, Scientists have made a lot of work to find the optimization of 1-D MPC structures [12–20]. The introduction of 1-D MPC film as Faraday rotation material can efficiently reduce the size of the MOI, but conventional MPC inevitably suffer from narrow bandwidths [13–18]. That is, MPC isolator can work normally only at the central wavelength. Once these structures encounter instabilities induced by wavelength or temperature fluctuations, they will lose effectiveness.

We note that, Levy and co-workers introduced the use of multiple magnetic garnet (Ce:YIG) defect quarter-wave phase-shifts as a means for attaining a the flat-top response [21]. The flat-top response could be yielded by adjusting interdefect spacing. Zamani et al. more recently proposed and demonstrated several novel MPC structures with flat-top responses [22]. In the best case, they have achieved a 19.42 μm-thick perfect MOI with the flat-top width of 7.2 nm. These structures can effectively overcome the limitation of narrow bandwidths. However, they simultaneously suffer from new shortcomings such as more layers or larger fluctuation of Faraday rotation angle in transmission bandwidth.

As we know, Faraday rotation requires that the magnetization be along the direction of propagation. Its rotation away from the longitudinal direction introduces new off-diagonal components in the dielectric permittivity tensor, then results in the Faraday rotation. In this paper, we propose new structures and introduce the rotation of magnetization in order to avoid these defects mentioned above. First, we propose a new basic structure, and based on the basic structure, we obtain two composite structures with flat-top responses. Then, by tuning the applied magnetic field, we get perfect MOIs which the Faraday rotation angle $\theta_F = 45°$ and the transmittance $T \approx 100\%$.

2. Theory

To describe the propagation of light in 1-D MPC, 4×4 transfer matrix method can be applied. The linearly polarized TM light ($E//X$), having a plane wave for $\exp[i(kz - \omega t)]$ with wave number k and angular frequency ω, enters perpendicularly to the film plane at $Z = Z_0$, as shown in Fig. 1.

By solving the Maxwell equations and combining with the transfer theory, we can give the 4×4 transfer matrix for dielectric layer:

$$\Phi_D = \begin{vmatrix} \cos\delta & 0 & 0 & \frac{i}{\sqrt{\varepsilon_D}}\sin\delta \\ 0 & \cos\delta & -\frac{i}{\sqrt{\varepsilon_D}}\sin\delta & 0 \\ 0 & -i\sqrt{\varepsilon_D}\sin\delta & \cos\delta & 0 \\ i\sqrt{\varepsilon_D}\sin\delta & 0 & 0 & \cos\delta \end{vmatrix} \quad (1)$$