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One-dimensional tunable magnetic photonic band-gap materials at microwave frequency

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Abstract

The microwave transmission characteristics of one-dimensional magnetic photonic band-gap (MPBG) materials, in which a ferromagnetic composite layer is sandwiched by periodic dielectric layers, are studied. The magnetic photonic band gaps (MBPGs) are obtained related to the existence of ferromagnetic resonance (FMR) in the vicinity of the band-gap frequency. We investigate the effects of period structure and the applied magnetic field on the MPBGs as well as the ferromagnetic resonance. The photonic band gaps of the TE mode shift to lower frequencies. The MPBG effect is strongly dependent on the periodic structure of the MPBG materials. While the FMR effect is dominated by the applied magnetic field.

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1. Introduction

Recently, there has been much attention paid to the photonic band-gap (PBG) materials, the artificial matter which consists of periodic dielectric components in the nano- and micrometer scale regions [1–4]. It is well known that the periodic variation of dielectric constant or refractive index can give rise to the photonic band gaps (PBGs). Due to the unique photonic band gaps (an optical analogy to the electric band gap), where the electromagnetic waves cannot propagate in any direction, the photonic band-gap materials are promising as useful media for future photonic devices.

Up to now, magnetic materials have not attracted much attention for PBG materials, since the relative permeability μ_r for most of magnetic material is equal to 1.0 in the optical range. However, μ_r of most fer-

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rites is quite different from 1.0 in the microwave range and thus can be exploited for PBG materials. The effects of magnetic permeability on PBGs have been investigated theoretically by Sigalas et al. [5]. They found the PBG effect can be obtained when both the dielectric permittivity ϵ and magnetic permeability μ vary in the periodic materials. Therefore, a growing interest in magnetic photonic band-gap (MPBG) materials has resulted from their PBG effect and the large Kerr and Faraday effects [6–10].

An experimental investigation of a MPBG material has been presented [11]. It consists of an array of alternating layers of insulating polycarbonate and ferromagnetic composite made of an array of parallel ferromagnetic nanowires electrodeposited into a porous polycarbonate membrane. Classical ferrites are not suitable for MPBG materials at several gigaherz because of their low resonance frequencies. While ferromagnetic materials have higher resonance frequencies than most ferrites. Compared to the skin depth, the diameter of the nanowires is small, therefore the electromagnetic waves can propagate in the nanowires, as well as the insulating polycarbonate membrane.

Our recent calculation [12] have predicted that there exhibit the MPBG effect accompanied by the ferromagnetic resonance (FMR) in the vicinity of the band-gap frequency. In this Letter, we present an theoretical investigation of a MPBG material, in which a ferromagnetic composite layer is sandwiched by a couple of dielectric multilayers. The effects of the applied magnetic field as well as the periodic structure on the PBGs have been discussed in detail.

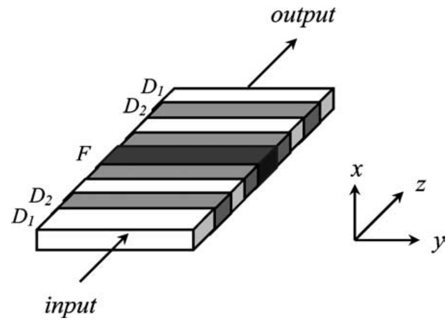

Fig. 1. Schematic description of the MPBG structure.

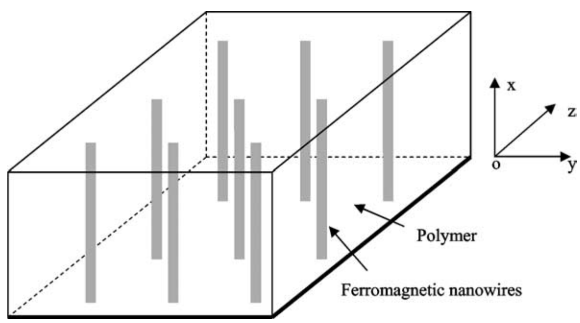

Fig. 2. Top-view picture of F layer of the MPBG sample, an insulating polycarbonate membrane filled with ferromagnetic nanowires.

2. Model and theory

According to the previous studies, the recent developments in manufacturing of materials permit the fabrication of magnetic nanowires of small diameter in a polymer background [13,14]. We suppose the magnetic layer is sandwiched between the periodic arrays of dielectric layers. The one-dimensional MPBG materials have multilayers expressed as $(D_1/D_2)^n/F/(D_2/D_1)^n$, where D_1 and D_2 are dielectric materials with high refractive index and low refractive index respectively, and F is a ferromagnetic composite. The film structure is shown in Fig. 1. Fig. 2 gives a schematic description of F layer. Because of the structural simplicity and the easiness of fabrication, the one-dimensional MPBG materials are very attractive for practical application.

The periodicity parameters d_1, d_2 and d_f are the thickness of two kinds of dielectric layer and ferromagnetic composite layer. The refractive indices of the dielectric layers are n_1 and n_2, while n_f is the effective refractive index of the polycarbonate membrane with ferromagnetic nanowires. In this configuration, the electromagnetic waves propagate along the OZ-axis and the direction of electric field is along the OX-axis and parallel to the nanowires. The applied static magnetic field H_{dc} is parallel to OX-axis. The microwave field H_{ac} and H_{dc} are perpendicular to each other meeting the requirements for a ferromagnetic resonance (FMR).

The transmission characteristics of one-dimensional periodic structure can be evaluated by the transfer matrix method [15]. The electromagnetic fields in adjacent layers are linked by a matrix M_i which depends