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Review

Magneto-phonon polaritons in two-dimension antiferromagnetic/ion-crystalic photonic crystals

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Abstract

Magneto-phonon polaritons in a two-dimension photonic crystal (PC) are discussed. This PC is constructed by embedding a periodical square lattice of ionic-crystal cylinders into an antiferromagnet. The two media are dispersive, with their individual resonant frequencies near each other. We first set up an effective-medium method to obtain the effective magnetic permeability and dielectric permittivity of the PC, followed by the dispersion relations of surface and bulk polaritons. There are a number of new surface polaritons, and two new distinctive bulk polariton bands in which the negative refraction and left-handedness can appear. The numerical calculations are based on the example, FeF_2/TlBr PC.

Keywords: Magneto-phonon polaritons; Photonic crystal; Antiferromagnet; Ionic-crystal; Negative refraction

Contents

1. Introduction

In recent decades, magnetic polaritons [1–8] and magnetostatic waves [9–16] in magnetic superlattices and magnetic photonic crystals have attracted considerable attention. Their dispersion features determine electromagnetic or optical properties of these structures at frequencies near magnetic resonant frequencies. Ferromagnetic materials can be used to engineer microwave devices, and one was immersed in magnetostatic modes [9–12,17] of the superlattices and magnonic crystals to incorporate them. The resonant frequencies of antiferromagnets (AFs) distribute from the millimeter to far infrared, so they have potential

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applications to process the millimeter and far infrared signals. Among the typical uniaxial AFs applied previously, MnF_2 [18,19] has resonant frequencies in the millimeter regime, but the resonant frequencies of CoF_2 and FeF_2 [20,21] lie in the far infrared region. The transverse optical (TO) phonon modes of ionic crystals (ICs) can directly couple with the electric fields in electromagnetic waves. This coupling absolutely changes optical properties of the ionic crystals through their dielectric function. The TO resonant frequencies generally distribute over the middle and near infrared frequency regions, but some ionic semiconductors possess lower TO phonon-resonant frequencies situated in the far infrared region [22]. One can find an AF and an IC, which have a common frequency range, where the AF has a negative magnetic permeability and the IC has negative dielectric permittivity. From the structures including such constitutive materials, we expect to obtain distinctive polariton features. In previous works [23] on the magnetic photonic crystals (MPCs), the nonmagnetic media generally are ordinary dielectrics, so the electromagnetic wave modes in the MPCs are just magnetic polaritons. The effect of magnetic permeability and dielectric permittivity of two component materials in MPCs on the photonic band gaps were discussed, where the permeability and permittivity were considered as scalar quantities [24].

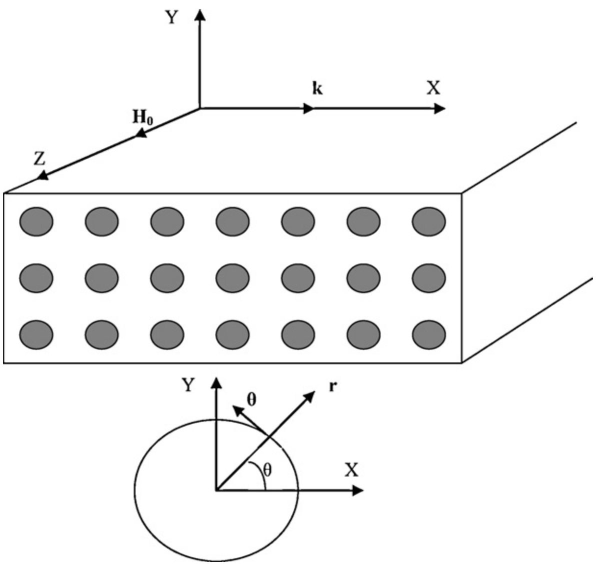

Fig. 1. Geometry configuration and coordinate system. The external magnetic field and the AF sublattice magnetizations are aligned along the z-axis, and the surface waves propagate along the x-axis. The bottom one is offered to the coordinate transformation between the xyz and $r\theta z$ systems.

2. Geometry and theoretical derivation

We consider such an MPC constructed by periodically embedding cylinders of ionic crystal into an AF, as shown in Fig. 1. We focus our attention on the situation where the external magnetic field and the AF anisotropy axis both are along the cylinder axis, or the z-axis. The surface of the MPC is parallel to the x–z plane. L and R indicate the lattice constant and cylindrical radius, respectively. We introduce the AF filling ratio, $f_a = 1 - \pi R^2/L^2$, and the IC filling ratio, $f_i = \pi R^2/L^2$. Our aim is to determine general characteristics of the surface and bulk polaritons with an effective-medium method under the condition of $\lambda \gg 1$ (λ is the polariton wavelength).

We first present the AF physics quantities to be applied. In the external magnetic field H_0, the magnetic permeability, $\overleftrightarrow{\mu}'_a$, is well-known, with its nonzero elements [2,20]

$$\mu'_{xx} = \mu'_{yy} = 1 + \omega_m\omega_a\left[\frac{1}{\omega_r^2 - (\omega_0 - \omega - i\tau)^2} + \frac{1}{\omega_r^2 - (\omega_0 + \omega + i\tau)^2}\right], \quad (1a)$$

$$\mu'_{xy} = -\mu'_{yx} = i\omega_m\omega_a\left[\frac{1}{\omega_r^2 - (\omega_0 - \omega - i\tau)^2} - \frac{1}{\omega_r^2 - (\omega_0 + \omega + i\tau)^2}\right], \quad (1b)$$

$$\mu'_{zz} = 1, \quad (1c)$$

with $\omega_0 = \gamma H_0$, $\omega_m = 4\pi\gamma M_0$, $\omega_a = \gamma H_a$, $\omega_e = \gamma H_e$, and $\omega_r = [\omega_a(2\omega_e + \omega_a)]^{1/2}$, where M_0 is the sublattice magnetization, H_a represents the anisotropy field, and H_e is the exchange field. ω_r is the AF resonant frequency, γ is the gyromagnetic ratio, and τ is the magnetic damping constant. We use ε_a as the dielectric constant of the AF. Subsequently, we present the dielectric function of the IC [22]

$$\varepsilon_i = \varepsilon_h + \frac{(\varepsilon_l - \varepsilon_h)\omega_T^2}{\omega_T^2 - \omega^2 - i\eta\omega}, \quad (2)$$

where ε_h and ε_l are the high- and low-frequency dielectric constants, but ω_T is the TO resonant frequency of $k = 0$ and η is the phonon damping coefficient. The IC is nonmagnetic, so its magnetic permeability is taken as $\mu_i = 1$.

When the MPC cell size is much shorter than the wavelength of electromagnetic wave, an effective-