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EXPERIMENTAL STUDY OF THE FARADAY EFFECT IN 1D -PHOTONIC CRYSTAL IN MILLIMETER WAVEBAND

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Abstract. The paper is devoted to experimental study of Faraday Effect enhancement. The experimental structure consists of photonic crystal, loaded with ferrite, which in turn is covered by thin metal layer or wire medium. An analysis of the transmission/reflection spectra for both unloaded and loaded photonic crystals shows that the surface oscillation mode (the surface state) is formed in the crystal band gap. A good agreement exists between experimental data and numerical calculations.

Introduction

A significant Faraday effect enhancement (FEE) in the case when magneto-optical media presents in resonant multilayer structure was described theoretically in [1, 3]. The effect of the enhancement was calculated for photonic crystals with defects [1] and for photonic crystals, bounded by strongly reflecting medium. The appearance of Tamm surface state (Tamm peak) [2, 4] in transmission spectrum of the structure should be considered as manifestation of the FEE. Unfortunately, a numerous side effects can appear by experimental realization of this idea.

The objective of the article is experimental and numerical demonstration, analysis of the FEE for the case of gyrotropic magnetic layer inserted into special one-dimensional (1D) photonic crystal.

Experiment details

The experimental structure under study consists of photonic crystal (air-teflon-quartz), loaded with ferrite (Fig. 1), which in turn is covered by thin metal layer or by wire medium. The permittivity of the teflon layer is ε_t=2.1, its thickness is d_t=1.25*mm*. Correspondingly for the quartz layer we have ε_q=4.5, d_q=2*mm*; and for the ferrite layer ε_f=11.1+0.0008*i*, d_f=2*mm*. The ferrite saturation magnetization is 4π*Ms*=4800*G*, and the damping coefficient is $\alpha = 0.024$. The value of the air gap between teflon and quartz layers is 1.5 mm. The electromagnetic wave propagates along *0Z* axis as it is shown in Fig. 1a. The structure is placed into a cylindrical metal hollow waveguide (Fig. 1b). The static magnetic field H_{st} is directed along *0Z* axis its magnitude varies in the range of 0–8400 Oe. The basic mode, which is the TE_{11} mode, is excited in the structure. The transmission coefficient was measured at the 22-40 GHz range. Main details of the experimental technique are presented in [4, 5].

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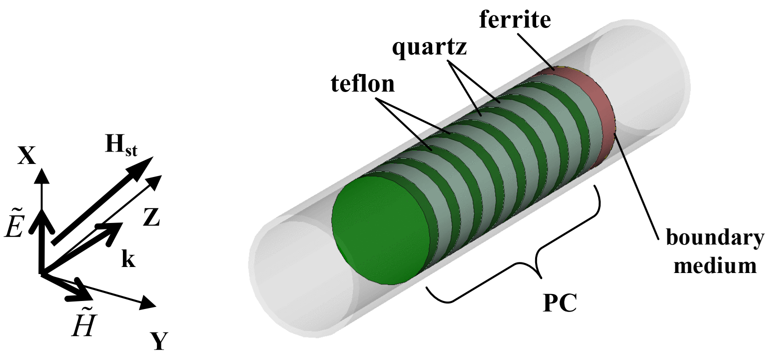


Fig. 1 – The model of the structure under research: the photonic crystal loaded with ferrite and "boundary medium".

Results and analysis

The structures with two types of "boundary medium", which close the ferrite layer, were investigated.

The case (a): the boundary medium - is a thin metal film (Fig. 2). An analysis of the transmission spectrum (Fig. 2) for unloaded photonic crystal and for photonic crystal loaded with ferrite and metal layer, shows that in the last case a surface oscillation mode is formed in the crystal band gap. In the figure 2 this mode appears as a "surface peak". The peak has a common origin with known Tamm peak [2, 5], so it will be called the Tamm peak too.

Detailed analysis allows to identify this peak as a peak connected with excitation of TE_{11} mode, which in turn appears because of FEE in the ferrite layer. Naturally one can see (Fig. 2) that when the angle between polarizing waveguide sections is $\theta = 90^0$ we observe sufficiently more intensive signal as compared to the case $\theta = 0^0$. The experimental data agree in the first approximation with results of numerical calculations.

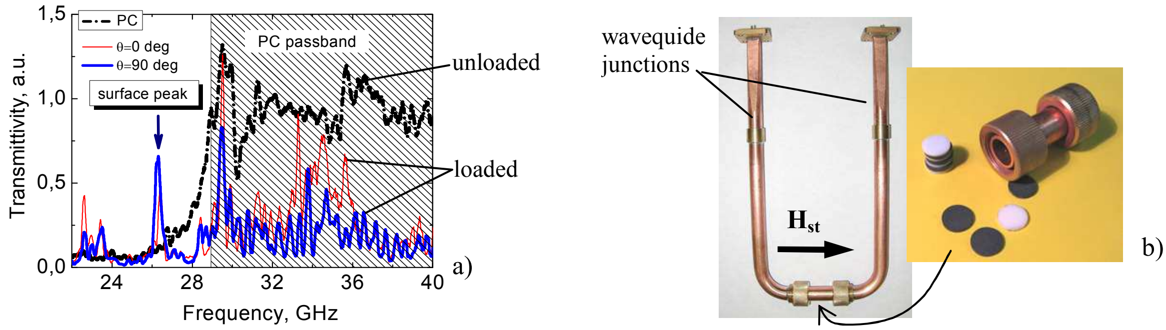


Fig. 2 – The transmission spectrum of the structure for various polarization angles (a); the measuring unit for studying the structure (b).

The case (b): the boundary medium – is a wire-medium structure [5]. Fig. 3(a) reveals a bandgap in the photonic crystal (PC). When PC is loaded with ferrite/wire-medium a clearly defined surface peak (the Tamm-peak) appears in the bandgap. A good correspondence between experimental data and numerical results is demonstrated in Fig. 3(b). The behavior of the peak and the mode transformation can be explained in the following manner.

It is known, that the wire medium is more transparent to the waves with $\vec{E}$-component, directed normally to the wires. This condition favors the exciting of electromagnetic wave with $\vec{E}$-component, directed normally to the incident wave in the space behind the boundary medium. This component in turn determines the enhancement of the Faraday Effect.

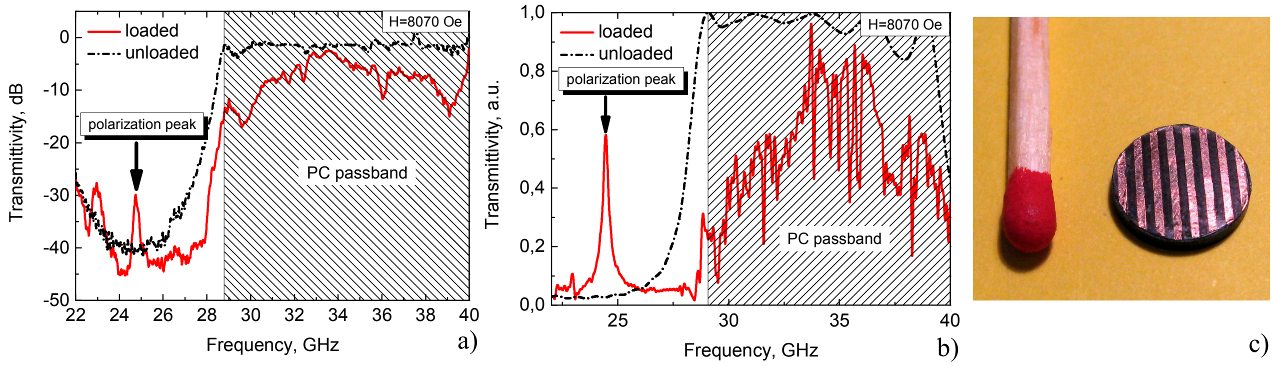
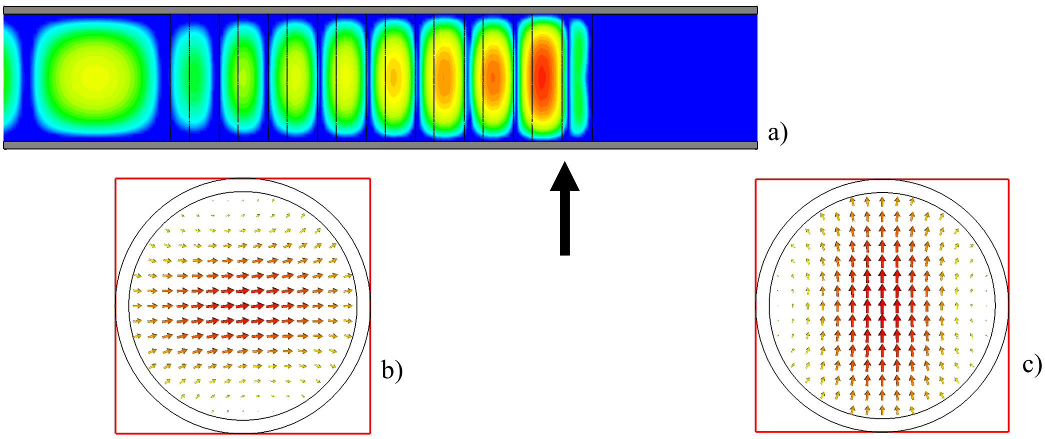


Fig. 3 – The transmission spectrum of the structure for magnetic field intensity H=8070 Oe: experiment (a) numerical simulation (b); the wire medium boundary (c)

To provide detailed investigation of this phenomenon, we calculated with FDTD method the spatial distribution of electromagnetic field in the photonic crystal structure at the resonance frequency. Figure 4 shows a spatial distribution of $\vec{E}$-component of the EHF-field (a) and the polarization at the input (b) and output (c) cross sections of the structure.



In **Out**

Fig. 4 – The distribution of E-component of the EHF-field for whole structure (a). The arrow shows the area of the field concentration for the Tamm-peak. The cross section of the structure for the: input (b) and output (c) waveguide polarization.

From Fig. 4(a) it follows that the concentration of electromagnetic energy occurs in the ferrite layer near the wire-medium (the metal lattice). This suggests the presence of surface oscillation at the interface between ferrite and wire-medium. The polarizations at the input and output of the waveguide, which are mutually orthogonal, are shown correspondingly in Fig. 4(b) and Fig. 4(c).

In order to verify the nature of the Tamm-peak in (Fig. 5). we analyzed the dependence of the peak position on the applied magnetic field.

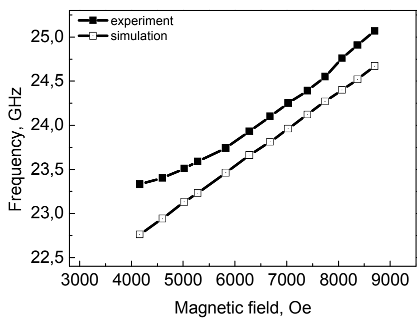


Fig. 5 – The frequency surface state peak position versus the static magnetic field

It is easy to see, that if the appearing peak is related to the Faraday Effect (if it has the magnetoresonance nature) then the increasing magnetic field will shift it to higher frequencies. In (Fig. 5) both experimental and calculated peaks demonstrate the similar magnetic field dependence.

Conclusion

To conclude, we investigated the enhancement of the Faraday Effect for the ferrite layer, inserted into special PC. The surface state peak, identified as the Tamm-peak for TE_{11} mode was observed experimentally and analyzed theoretically both for thin layer metal and wire-medium boundaries of ferrite layer. The magnetic field dependence of the characteristic peak frequency was found and analyzed.

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