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The mmW band Tamm states in one-dimensional magnetophotonic crystals

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Abstract. The mmW band photonic Tamm states in 1D magnetophotonic crystals are studied. It is shown the possibility to manipulate the eigenfrequencies of such states by an external magnetic field. Our experimental results are in a good agreement with theoretical prediction.

Introduction

The existence of the optical Tamm surface states (TS), in particular, TS localized at the interface of two adjoining 1D photonic crystals, was theoretically predicted in [1-9]. The frequency of such a state lies inside the overlap of band gaps of these photonic crystals, hence the amplitude of this state decreases exponentially with a distance from the interface.

The presence of optical TS was first experimentally demonstrated at visible wavelengths for 1D magnetophotonic crystal (MPC) composed by nonmagnetic (SiO2) and magnetic (Bi:YIG) materials [10]. The existence of TS was shown by the observation of the associated effects, such as an enhancement of the Faraday rotation and a sharp transmission peak through the sample, which is caused by the resonance tunneling of light through the TS. The latter effect may be used for a fabrication of a band-pass filter. Unfortunately, the influence of an external magnetic field on both diagonal and off-diagonal components of the dielectric tensor at optical frequencies is extremely small and therefore an external magnetic field does not markedly change the spectral position of the TS. Thus at optical frequencies we cannot consider such a filter as a tunable device.

In this paper we consider TS within 20-40 GHz frequency band (mmW band). In this case, on the one hand it is much easier to fabricate MPC because of relatively large wavelength, and on the other hand magnetic permeability of ferrite layers in the MPC strongly depends on magnetic field. Thus, one may expect a significant shift of the TS spectral position in external magnetic field that makes possible to develop miniature electronically-controlled elements for mmW band.

Experiment

The structure under investigation consists from two adjoining photonic crystals (Fig.1) The first one, which is MPC, consists of two periods; each period is made of ferrite disk of thickness $d_F = 1.00 \pm 0.03$ mm and air spacer of thickness $d_{S1} = 1.00 \pm 0.03$ mm. The second photonic crystal consists of five periods; each period is made of polystyrene disk of thickness $d_P = 1.59 \pm 0.03$ mm and an air spacer of thickness $d_{S2} = 2.00 \pm 0.03$ mm.

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The diameter of each disk is $D = 30$ mm. We use a nickel-based ferrite NiO Fe_2O_3 with magnetization $M_s = 4800$ gauss and the permittivity $\varepsilon = 11.0$ (dielectric loss tangent $\tan\Delta_\varepsilon = 8.1\cdot10^{-4}$). The permittivity of polystyrene is $\varepsilon = 2.42$ ($\tan\Delta_\varepsilon = 3.0\cdot10^{-3}$).

The structure under consideration was placed inside ebonite cylinder and then was fixed inside the air-gap of electromagnet, which creates the external magnetic field in parallel to the polarization of incident wave (Fig.1). The vector analyzer Agilent N5230A was used as a generator and detector of spectra.

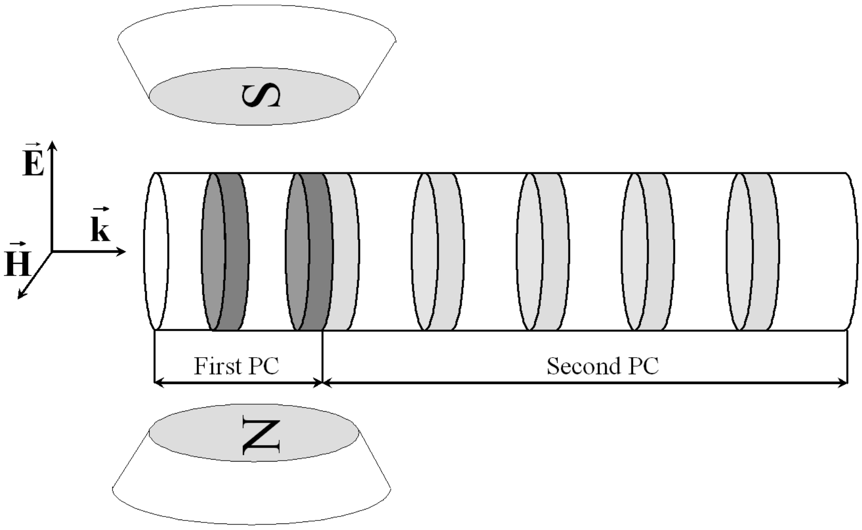

Fig.1 The scheme of experiment.

Results and Discussion

In the absence of the external field (zero magnetization) one can see the peak in transmission spectra (Fig. 2). This peak appears only for adjoining structure of two photonic crystals and does not exists for each of them or then they are not in a contact. Calculation shows that the frequency of this peak corresponds to the frequency f_T of the TS. While the theoretical prediction of the frequency of TS is in a good agreement with experimental data, there is some disagreement in the amplitude of the peak. This disagreement is caused by the diffraction, which appears due to the finite diameters of the disks and the finite aperture of the incident wave. Theoretical calculations were made by T-matrix method and did not take the diffraction into account.

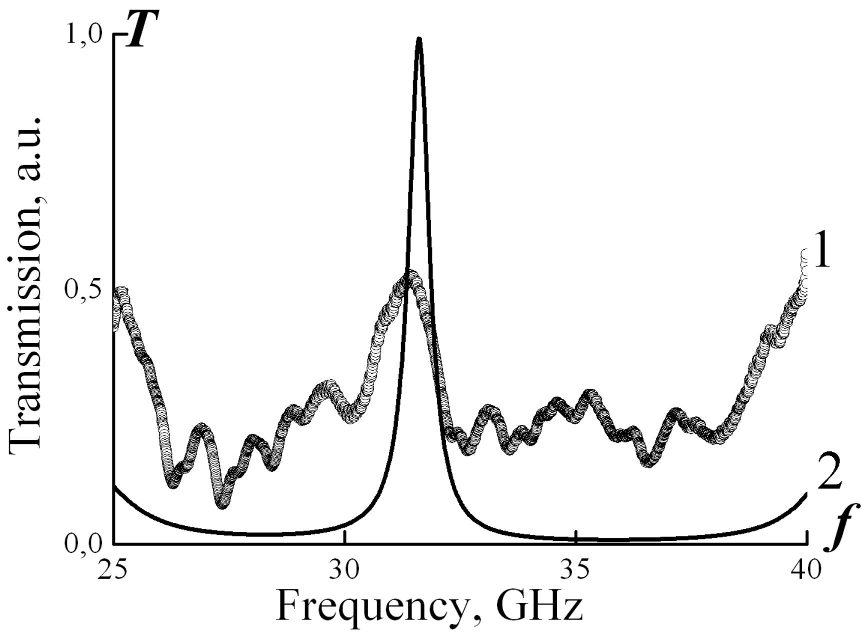

Fig.2 The transmission of adjoining photonic crystals at zero magnetization: 1 - experimental data, 2 - the theoretical evaluation.

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The frequency of TS f_T monotonically increases with the external magnetic field H_{ex} from 31 GHz at H_{ex}=0 up to 34 GHz at H_{ex}=5 kOe (Fig. 3). This phenomenon is due to the magnetic permeability dependence on magnetization.

To theoretically evaluate the field dependence $f_T(H_{ex})$ we used the experimental data on the tensor of magnetic permeability at $H_{ex} \leq 1000$ Oe [11] and the well-known expressions from the theory of FMR at $H_{ex} \geq 1000$ Oe [12]. One can see in Fig.3 a good agreement between theoretical and experimental data.

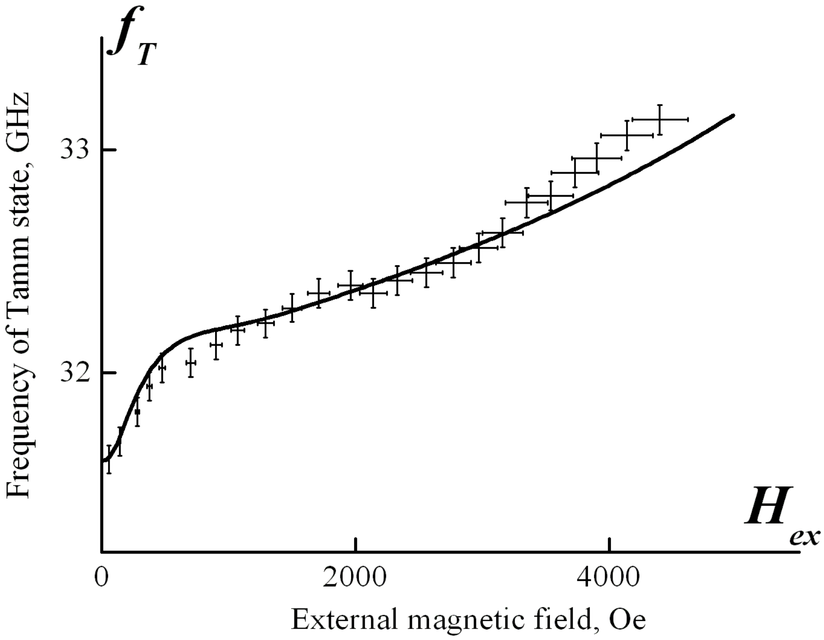

Fig.3 The dependence of the frequency of Tamm state f_T with respect to external magnetic field H_{ex}

Conclusion

We observed the additional peak in transmission spectra of adjoining MPC and photonic crystal in GHz band and the shift of this peak spectral position under MPC magnetization. These observations can be considered as a clear evidence of existence of photonic TS at high frequencies. The frequency of mmW band TS in MPC significantly and monotonically depends on the applied external magnetic field. It opens a new avenue for development tunable by magnetic field band-pass filters and other devices operating within mmW band.

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