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A PLANAR PHOTONIC CRYSTAL-BASED RESONANCE CELL FOR FERROMAGNETIC RESONANCE SPECTROMETER

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A design is suggested for the planar photonic crystal-based resonance cell of ferromagnetic resonance spectrometer. The improved sensitivity of the cell is attained owing to formation of a local concentration of the microwave field on the planar photonic crystal-signal stripline gap interface. Results of experimental investigations aimed at estimating the resonance cell sensitivity are presented.

KEY WORDS: *ferromagnetic resonance, resonance cell, planar photonic crystal, microwave Tamm state*

1. INTRODUCTION

As is known [1], the ferromagnetic resonance method, which is a particular case of the electron spin resonance technique, is among the most sensitive tools for investigating the atomic magnetic structure of various materials. The basic element of the spectrometers of the kind is the so called resonance cell of the waveguide or resonance type which provides, to the extent possible, the maximum efficient interaction of the magnetic component of the high-frequency field with the matter [2]. The main disadvantages of the currently available resonance cells of the ferromagnetic resonance spectrometers on the basis of hollow metal waveguides and cavity, coaxial and open resonators are their relatively large sizes, low factor of resonance filling by the specimen, narrow operation frequency band and complexity of prompt changing of the specimen. The planar resonance cell suggested in the paper to be used in ferromagnetic resonance spectrometers has been developed on the basis of a planar photonic crystal and is free, to in many respect, of these shortcomings.

As is known, the photonic crystals represent artificial periodic structures whose transmission spectrum contains a domain forbidden for electromagnetic wave propagation similarly to the forbidden energy band in natural crystals. Photonic crystals for microwave frequencies can be implemented either in the form of a hollow metal waveguide with periodic dielectric filling or on the basis of a planar transmission line [3-5].

The authors of paper [6] investigated a planar photonic crystal in which the microwave field had been concentrated on the interface between two photonic crystals with different periods. The narrow transmission range located in the forbidden band of the transmission spectrum of the given structure has been explained in the frame of an analogy with the Tamm state [7].

In this paper we investigate a planar resonance cell for ferromagnetic resonance spectrometers, which is formed by a planar photonic crystal on the basis of a microstrip waveguide and a chain of gaps in the signal stratum of the microstrip line (see Fig. 1). The section of the microstrip line containing the sequence of the gaps imitates the a domain with a negative permittivity (a planar analog of the wire medium [8]) to create the necessary and sufficient conditions for occurrence of microwave analogs of the so-called Tamm surface states (Tamm surface oscillations) [6,7]. The essence of the phenomenon is reduced to the fact that the microwave field is concentrated near the photonic crystal-“wire” medium interface [9] and the transmission spectrum of a structure of the kind show the presence of a transmission range (Tamm “peak” for a planar photonic crystal) in the forbidden band.

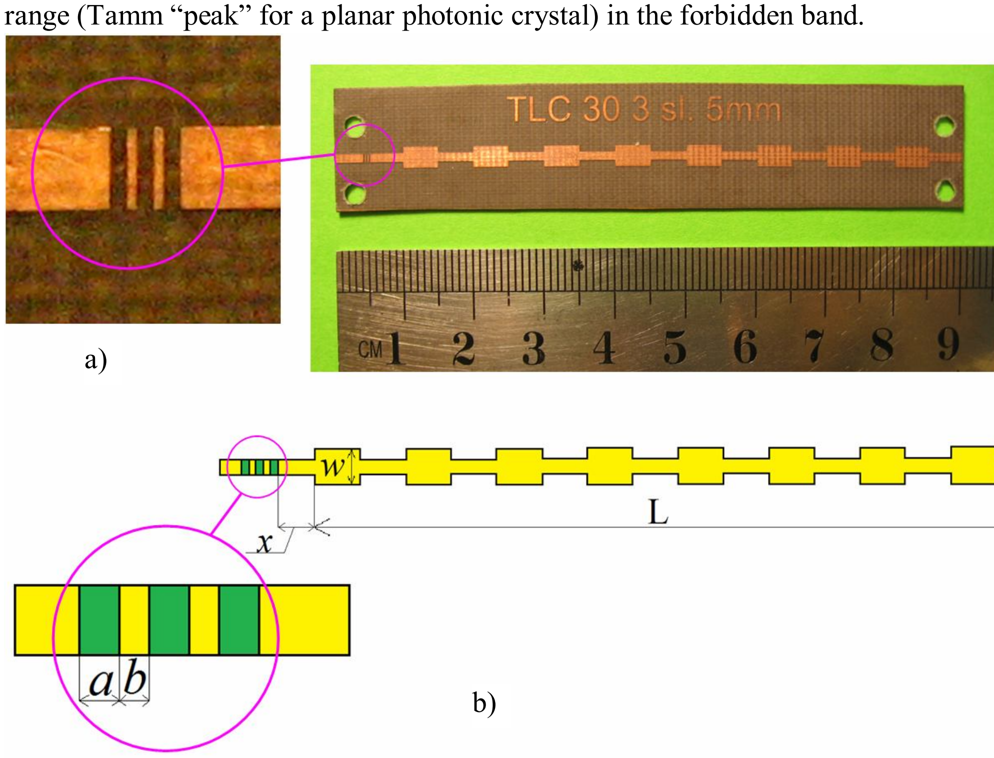

FIG. 1: Photo (a) and schematic representation (b) of the planar photonic crystal with a wire medium: $L = 80$ mm, $w = 3$ mm, $x = 5$ mm, $a = 2.5$ mm, $a = 2.5$ mm, and $b = 1.5$ mm

Simultaneously, the problem of location of the magnetic specimen under investigation within the range of microwave field concentration, namely, in the area where the microwave field-specimen interaction would be optimum.

2. RESULTS AND DISCUSSION

For the experimental study a resonance cell of ferromagnetic resonance spectrometers has been produced on the basis of a planar photonic crystal contacting a "wire" medium (see Fig. 1). The structure has been manufactured by the chemical etching method on a plate of a double-sided foil-coated laminated plastic Taconic TLC 30. The planar photonic crystal represents sixteen concatenated sections of a microstrip line with periodically alternating widths, specifically, the even sections are 3 mm in width, while the odd ones are 1.2 mm in width. The length of all the sections is 5 mm. Three breaks have been etched at the 5 mm distance from the photonic crystal such that adjacent breaks are spaced by 1.5 mm. The gaps imitate a "wire" medium.

The transmission spectra of the planar photonic crystals contacting the "wire" medium were measured within the frequency range 1 to 20 GHZ using a vector network analyzer Agilent PNA-L Network Analyzer N5230A at the room temperature. The structure to be investigated was connected to the device using coaxial microstrip junctions.

Comparison of the results of numerical modeling of the transmission spectrum of the planar photonic crystal with the "wire" medium with the experimental measurements of this spectrum shows a satisfactory agreement (see Fig. 2).

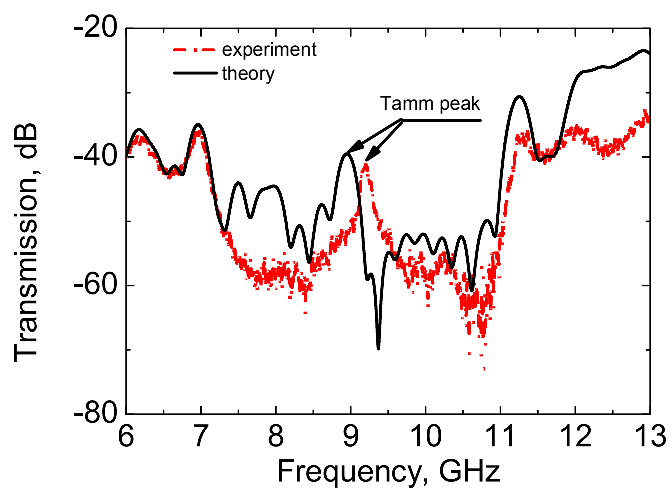

FIG. 2: Calculated and measured transmission factor spectra of the planar photonic crystal with a "wire" medium

As can be seen from the plot, a “Tamm peak” of transmission (with the Q-factor equal to 65) indeed arises in the forbidden band of the planar photonic crystal spectrum.

Note that the method of using a strip line for measuring ferromagnetic resonance transmission spectra, when to investigate the ferromagnetic resonance effect a ferromagnetic specimen is placed on the surface of a strip line connected to a microwave radiation source, is already known [10]. However, in that case the specimen under investigation interacts with the magnetic component of the high-frequency field propagating through the strip line operating practically in the traveling wave regime. The interaction like that is not optimum and results in a low sensitivity of the strip line as a cell of the ferromagnetic resonance spectrometer.

For optimizing the ferromagnetic resonance observation conditions, we applied a numerical modeling to calculate the high-frequency magnetic field distribution in the planar photonic crystal contacting a “wire” medium (see Fig. 3). Test specimens of various dimensions (see Table 1) made of the 1СЧ4 ferrite material were placed within the range of the high-frequency magnetic field concentration in the planar photonic crystal. Then the planar photonic crystal was positioned between electromagnet poles. To create the favorable conditions for the ferromagnetic resonance, the external magnetic field was oriented perpendicularly to the high-frequency magnetic field, i.e., perpendicularly to the strip line plane.

TABLE 1: Dimensions of the ferrite specimens under investigation

Specimen number	Length	Width	Height
1	1.0 mm	0.5 mm	0.31 mm
2	1.5 mm	1.5 mm	0.31 mm
3	3.2 mm	3.1 mm	0.31 mm

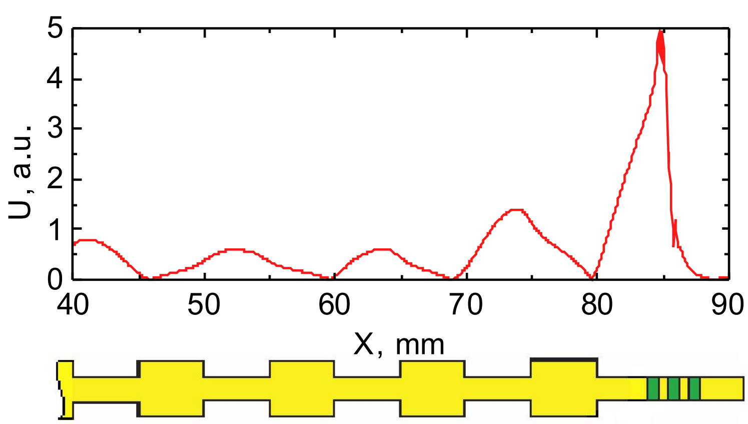

FIG. 3: Distribution of the high-frequency magnetic field in the planar photonic crystal contacting a “wire” medium

Results of investigating the ferromagnetic resonance in the ferrite test specimens obtained with the use of a microstrip transmission line with no width modulation are presented in Fig. 4. As can be seen, the ferromagnetic resonance peak (pointed by arrows) shifted toward higher frequencies (from 1 to 20 GHz) as the magnetic field magnitude was changed from 1 to 10 kOe. It should be noted that the ferromagnetic resonance was observed only for the largest specimen number 3.

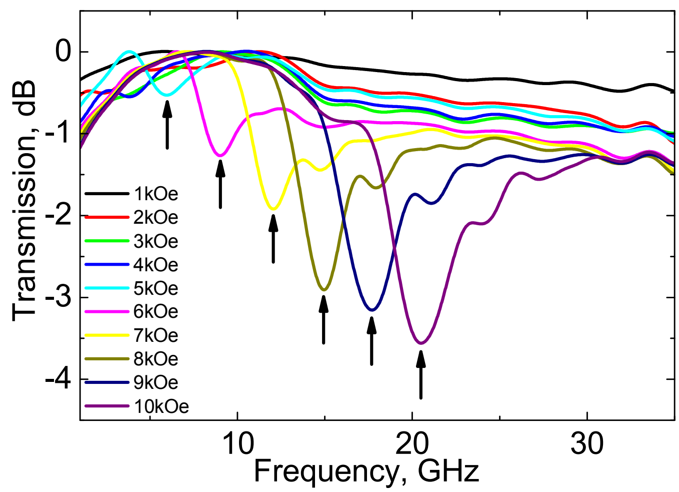

FIG. 4: Changes in the position of the magnetic resonance absorption peak on the frequency axis for ferrite specimen number 3 observed with the use of a microstrip transmission line with no width modulation

For comparison Fig. 5 presents experimental results on observation of the ferromagnetic resonance for the same specimens while placed in the resonance cell of the ferromagnetic resonance spectrometer on the basis of a planar photonic crystal with a "wire" medium. The measurements were carried out in the regime of magnetic field scanning at the "Tamm peak" frequency $f_{TR} = 9.2$ GHz. The use of the given cell made it possible to observe the ferromagnetic resonance for all three specimens.

In this case the specimens were placed in the area of concentration of the microwave field magnetic component associated with generation of the Tamm surface oscillation on the interface planar photonic crystal-"wire" medium. The existence of the localized in space node of the high-frequency field, i.e., actually conversion of the super-high frequency wave in the standing wave regime at the "Tamm peak" frequency, makes it possible to increase the ferromagnetic resonance spectrometer resonance cell on the basis of a planar photonic crystal with a "wire" medium.

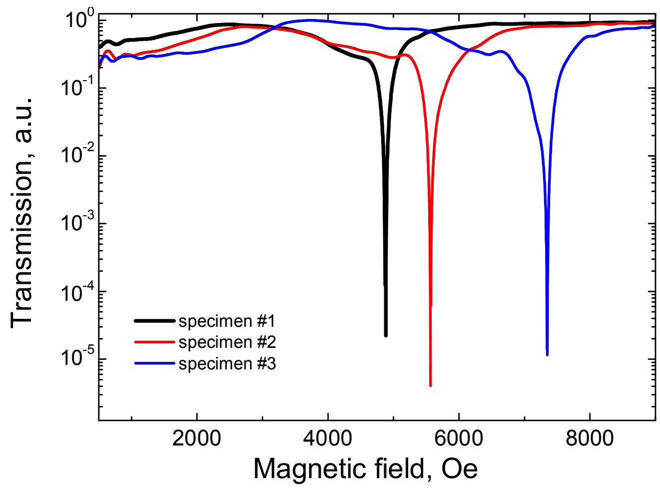

FIG. 5: Signals of the ferromagnetic resonance absorption observed in the test ferrite specimens at $f_{TR} = 9.2\,\text{GHz}$ with the use of a resonance cell of the ferromagnetic resonance spectrometer on the basis of a planar photonic crystal with a "wire" medium

The shift of the magnetic resonance absorption peak observed in Fig. 5 for different specimens is due to the difference in the specimen geometrical sizes. As is known, the difference leads to change in the internal demagnetizing field from one specimen to another. The estimates obtained with the use of the well-known Kittel formula confirm this fact.

For further development of the concept of using planar photonic crystals in the capacity of the resonance cells for ferromagnetic resonance spectrometers it is necessary to improve the design of the element in question in order to obtain greater concentration of the high-frequency field and increase the overall sensitivity.

3. CONCLUSIONS

It is shown in the paper that the Tamm surface oscillation arising in the area of the photonic crystal-"wire" medium interface can be efficiently used for the construction of resonance cells for the ferromagnetic resonance spectrometers.

Advantages of the suggested planar resonance cell consist in the possibility of quick replacing specimens in the course of experiments and its smaller sizes along the direction perpendicular to the microwave propagation as compared with the conventional resonance cells on the basis of hollow and coaxial metal waveguides and open resonant cavities. This makes it possible to use more compact magnetic systems to provide the operation magnitudes of the external magnetic field since it is applied perpendicularly to the strip line plane, i.e., along the minimum size of the suggested planar resonance cell. As compared with the conventional planar transmission line, the ferromagnetic resonance spectrometer resonance cell on the basis of a planar photonic crystal with a "wire" medium is characterized by the improved sensitivity which is determined by the Q-factor of the Tamm surface oscillation.

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