DETERMINATION OF THE PARAMETERS OF ONE-DIMENSIONAL GLOBULAR DIELECTRIC STRUCTURES IN THE MICROWAVE RANGE USING A BICONICAL RESONATOR

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The application of a biconical resonator for determining the parameters of one-dimensional globular periodic dielectric structures is considered. The HE_{111} resonant mode provides an effective estimate of the permittivity of the material from which the globules are made. The procedure for estimating the parameters includes the use of a fractional-rational approximation of the analyzed frequency characteristic. A numerical simulation of the electromagnetic field for a biconical resonator with the studied structure was implemented. The possibility of obtaining estimates of effective dielectric constant is verified using experimental data for a one-dimensional structure of contacting spheres placed in a dielectric tube.

Keywords: globular dielectric structure, photonic crystal, dielectric constant, biconical resonator, microwave measurements, machine learning, fractional-rational approximation.

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1. Introduction

Globular dielectric structures represent ordered assemblies of dielectric objects with a spherical shape (globules) arranged in a volume or along a specific direction [1]. Such structures are used in optics for the creation of photonic crystals [1-2]. At Oles Honchar Dnipro National University, a significant contribution to the physics of globular structures was made by a group headed by Prof. V. Moiseyenko [3]. In radio engineering and microwave systems such structures serve as elements of slow-wave structures, filters, antennas with tunable characteristics, and wave transformation devices. There is particular interest in these structures due to their potential use in the development of materials with artificially controlled electromagnetic properties, including radio camouflage technologies for reducing radar visibility. Their electrodynamic characteristics are determined by both geometric parameters (such as globule size and packing density) and the electrophysical properties of the material from which the globules are made. Accurate calculation and prediction of the behavior of such structures in electromagnetic fields is only possible if the dielectric permittivity of the material is known. However, in real-world conditions, this parameter is often unknown due to the specifics of the manufacturing process. This makes the problem of experimentally determining the dielectric permittivity of the globules within such structures especially relevant. One approach to solving this problem is based on obtaining a physical model for the microwave range and using resonant measurement methods, which allow for accurate detection of changes in the resonance frequency when the samples under study are introduced into the measuring resonator. The purpose of this article is to develop a resonance technique for obtaining the values of the effective permittivity of materials for a physical model of a one-dimensional globular structure in the microwave range.

2. Experimental equipment for determining the values of effective parameters of globular dielectric structures

A biconical resonator was selected for the measurements due to its design, which allows samples under test to be placed inside the measurement setup without requiring disassembly of a sample [3]. A biconical resonator operating in the 3-cm wavelength range was used, with a cone height of 33.25 mm, a lower base radius of $a_0 = 25$ mm, an upper base radius of $b = 5.75$ mm, and a cone apex half-angle of Φ=30°. The resonator was incorporated into a transmission-type measurement circuit using rectangular waveguides with cross-sectional dimensions of 23×10 mm², coupled through apertures with diameters d_1 = 8 mm and d_2 = 6.5 mm. Measurements were carried out in the 3-cm wavelength range using a panoramic meter R2-61.

The test samples were placed in a polyethylene tube with an outer diameter of 4.5 mm, an inner diameter of 2.5 mm, and a wall thickness of 1 mm. The design of the biconical resonator with the sample-holding tube is shown in Fig. 1a. The globules under investigation were positioned inside the tube at the center of the resonator; the total number of globules was 18, and their average diameter was d = 2.5 mm.To compare with the experimental data, a numerical electromagnetic simulation of this structure, including the coupling elements (Fig. 1b), was implemented using the finite element method to obtain its electrodynamic characteristics numerically.

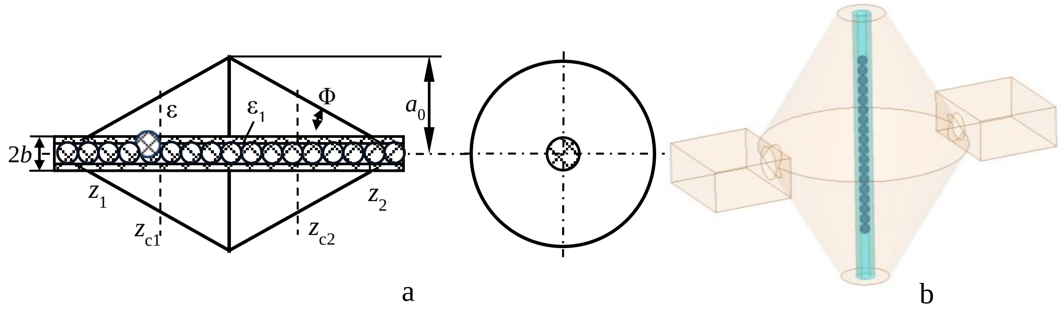

Fig. 1. Biconical resonator with the sample under study (a) and the electromagnetic model of the resonator with a tube containing the studied globules (b).

Since the experimental setup may exhibit a greater error in determining the absolute frequency value than the frequency shift caused by introducing the test samples into the tube, the dielectric permittivity of the samples was determined based on the relative shift of the resonance frequency. The frequency shift caused by the insertion of the globules into the tube was considered relative to the resonance frequency of the empty biconical resonator and that of the resonator with an empty tube. The measurements were carried out using the HE_{111} resonance mode, which has an eigenfrequency of 9.099 GHz.

3. The results of estimating the value of the dielectric permittivity of globules by the resonator method

Using the measurement setup, it was determined that the resonance occurred at a frequency of 9.028 GHz in the empty biconical resonator (Fig. 2a), at 8.959 GHz in the resonator with an empty tube (Fig. 2b), and at 8.938 GHz in the biconical resonator with globules placed inside the tube (Fig. 2c) correspondingly.

To estimate the dielectric permittivity of the globules, computer simulations were carried out for the transmission characteristics of the empty biconical resonator (Fig. 3), the biconical resonator with an empty tube (Fig. 4), and the biconical resonator with a tube filled with globules for several values of the globules' dielectric permittivity (Fig. 5 shows the case for ε = 4).

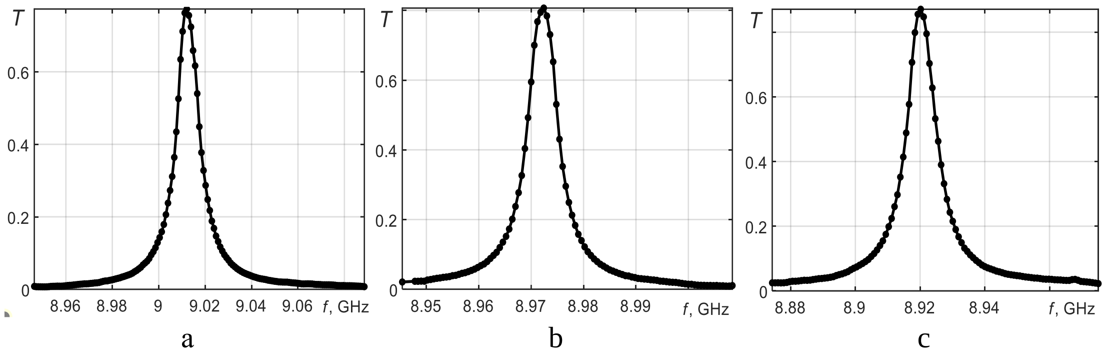

Fig.2. Experimental transmission characteristics of the empty biconical resonator (a), the biconical resonator with the tube (b), and the biconical resonator with globules (c).

As evident from the presented frequency responses, in all three cases a resonance is observed near 9 GHz (the insets in Figs. 3-5 show a zoomed–in view of the frequency response in the vicinity of this resonance). According to the field distribution analysis, this corresponds to the HE_{111} resonant mode, which is the most suitable for estimating ε [4].The other resonance peaks observed in the three cases correspond to different wave types and cannot be used to assess the resonance frequency shift caused by the insertion of globules into the resonator.

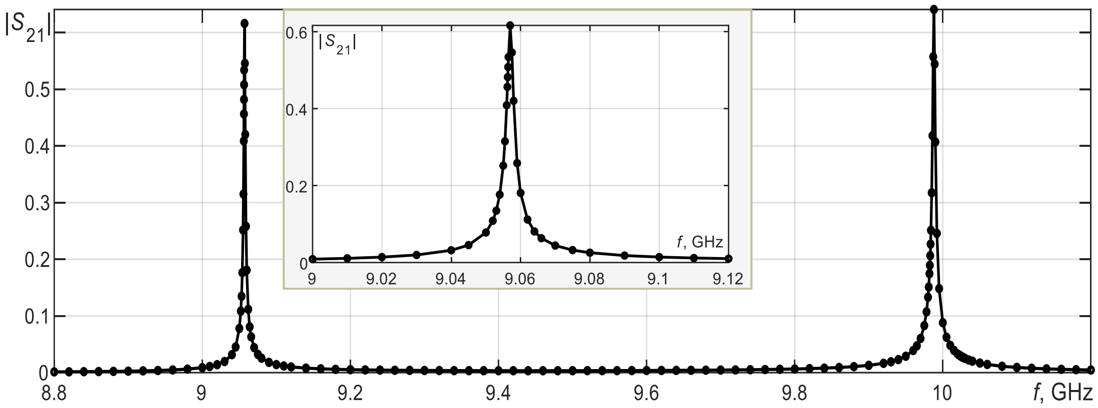

Fig. 3. Frequency response of the empty biconical resonator.

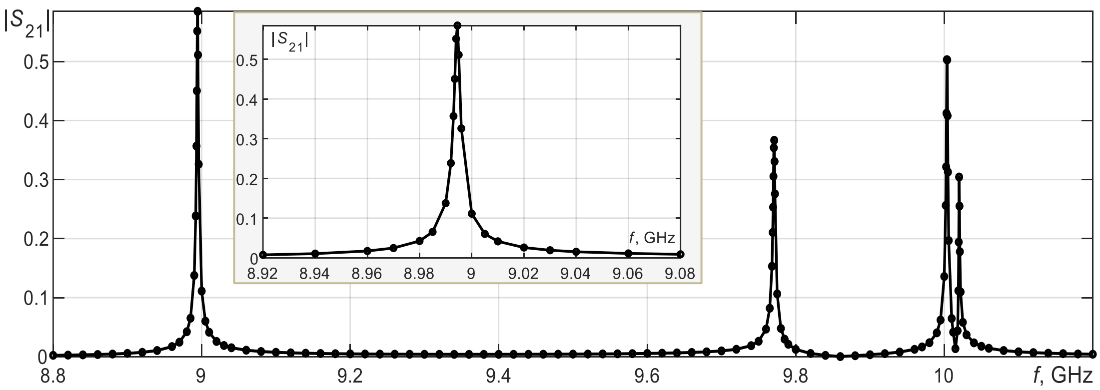

Fig. 4. Frequency response of the biconical resonator with an empty tube.

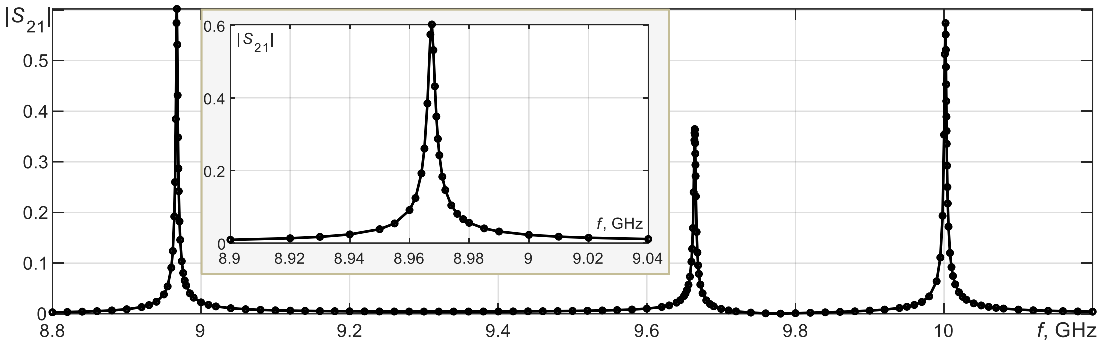

Fig. 5. Frequency response of the biconical resonator with a tube containing the test globules with ε=4.

To determine the resonance frequency f_0 from the obtained frequency characteristics, machine learning based on parametric fractional-rational approximation [4] was used, which allows the complex pole of the analyzed frequency characteristics to be determined with minimal error. According to the simulation results, the resonance frequency of the empty resonator was f_0=9.056 GHz, and for the biconical resonator with an empty tube, it was f_0 = 8.994 GHz. The shift in the resonance frequency due to the insertion of the tube was 0.062 GHz, while the experimental data showed a shift of 0.069 GHz. The obtained resonance frequency values f_0 for the biconical resonator with globules for different values of the dielectric permittivity ε of the globules were accumulated in a specialized database.

Using the experimentally determined values from this specialized database for the resonance frequency differences Δf_1 = 0.021 GHz for the resonator with an empty tube and the resonator with globules, and Δf_2 = 0.09 GHz for the empty resonator and the resonator with globules it can be estimated that the dielectric permittivity of the globules is close to 4.

4. Conclusions

The obtained results confirm the possibility of experimentally determining the dielectric permittivity of the globules in a photonic structure using a biconical resonator. The accuracy of the results is validated by the closeness of the estimated ε values to the known dielectric permittivity of the material from which the globular structure was formed.

Acknowledgments

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