INVESTIGATION OF PROPERTIES OF A SPATIAL LATTICE FORMED BY RESONANCE DIELECTRIC SPHERES

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The artificial dielectric model is used in creation of a material with the negative ε and μ and in describing electromagnetic wave interactions with vital tissues. The paper presents the theoretical study of the frequency properties and electric field distributions in the spatial cubic lattice at sites of which 216 identical dielectric spheres are placed. Basic oscillation frequencies in the lattice have been defined. Splitting of the frequency performance into bands corresponding to the resonance values of the negative or positive value of ε_{eff} is observed. The method for determining the negative values of medium penetrations has been proposed.

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The artificial dielectric model is often used in different theoretical considerations [1,2,3], though the systematic comparison between calculated and experimentally measured values of effective permittivity had been carried out only for the simplest lattices formed by infinite thin ideally conducting discs [4].

In papers [2,3] it was shown that dispersive properties of an artificial dielectric formed by the regular lattice of spherical particles can take any large positive and negative values, .if dispersion is caused by the dependence of a scattering coefficient on the frequency, values of ε_p and μ_p characterizing electromagnetic wave scattering on spherical particles. It means that in the artificial dielectric lattice in cases when particles themselves have a high permittivity, the resonance frequencies are possible, for that permittivity convert into infinity. These frequencies are found from the following transcendental equations

$$\frac{\varepsilon_p(\omega)+2\varepsilon_1}{\varepsilon_p(\omega)-\varepsilon_1}=\delta_{ii}C\,, \qquad (1)$$

where C is the particle concentration, ε_1 is the permittivity of a particle material, δ_{ii} are the components of the tensor of penetrations of the spatial lattice formed by spherical particles.

In this paper the dispersive performances of spatial lattices formed by dielectric spheres, and the electrical field distribution are experimentally studied. Firstly, the simple method has been proposed to define the negative value of effective permittivity.

The experimental research of electrodynamical parameters of cubic lattices at the sites of which there were spherical dielectric scatters, was carried out. From 216 dielectric spheres in foam rubber holders the cubic spatial structure of 6×6×6 elements is formed. The distance between spheres was chosen equal to 10 mm. The dielectric sphere material is ceramics based on titanium dioxide with the permittivity ε≈80, $\text{tg}\delta\approx 1\cdot 10^{-3}$. Spheres of about 10 mm in diameter were prepared with deflection from the sphericity ≈1...2 μm. In the process of sphere choice according to the frequency their tuning was carried out by decreasing in diameter so that the nominal frequency was equal to 3075 MHz with the accuracy of choosing ±2.5 MHz. The resonance frequency was defined according to the maximal value of the reflection coefficient of the H_{10} wave from the sphere placed in the center of the cross section of 32×72 mm waveguide. The resonance frequency corresponded to the first magnetic resonance and structure of TE_{101} electromagnetic oscillations in the dielectric sphere. The measuring section was placed between the waveguide reflectometer and matched waveguide load. The power supply was delivered from the high frequency generator by the pin vibrator the axis of which was in the E vector plane of excited in the structure oscillations corresponding to TE_{101}, TM_{101} and TM_{201} modes of oscillations in the separate sphere. The probe in the shape of the pin vibrator placed on the opposite lattice side recorded a signal.

The electrical field intensity distribution in the space between dielectric spheres by scatters was measured using the small perturbation method [5]. The method is based on the measurement of resonance wavelength in the structure during introducing a perturbating body of a small volume Δτ in the region under study. This shift of a resonance wavelength is defined by the Slater perturbation theorem that can be expressed by the equation

$$\frac{\Delta\lambda}{\lambda}=-k\frac{\int\limits_{\Delta\tau}\varepsilon\bar{E}^2dr-\int\limits_{\Delta\tau}\mu\bar{H}^2dr}{2\int\limits_V(\mu\bar{H}^2+\varepsilon\bar{E}^2)dV}=-k\frac{\Delta W_E-\Delta W_H}{W_{cp}}\,, \qquad (2)$$

where ΔW_E and ΔW_H are the variations of a stored energy in the electrical and magnetic fields of the cavity during introducing the perturbating body, W_{cp} is the average energy stored in the cavity at a high frequency oscillation period, k is the proportionality factor defined by the geometry and electromagnetic properties of the perturbating body material ($k\to 1$ for $\Delta\tau\to 0$).

For the resonance structure with the positive value of the effective permittivity the measured frequency shift will be directed to the side of resonance frequency decreasing. Fig.1,a shows the resonance curve shifted to the left side $F_p\to F_{p1}$ at introducing the perturbating body in the $\bar{E}$-field region, and the signal amplitude at the operating point 1 will increase (the arrow direction 1→1′). On the high frequency slope at the operating point 2 the signal amplitude will decrease (2→2′). If the effective permittivity will vary its sign then the sign W_{cp} of the stored energy in the electrical field of the resonance structure will vary. It will result in the resonance curve shift to the right side $F_p \rightarrow F_{p2}$, as it is shown in Fig. 1b. The signal amplitude decrease will be observed at the operating point 1 (1→1′), and the increase will be at the operating point 2 (2→2′). Thus, we shall define resonance frequency bands with positive and negative values of the effective permittivity.

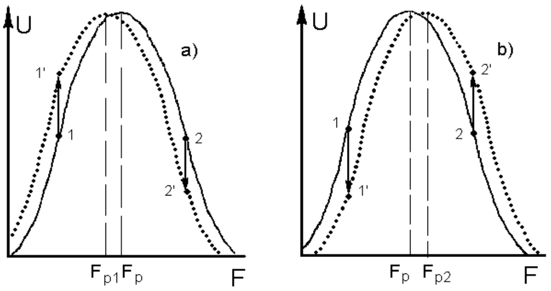

Fig.1. Resonance frequency shift F_p of a structure during introducing a perturbating body in the E-field region: a – the effective permittivity of a structure is positive, b – the effective permittivity of a structure is negative

In our case for the reliable recording of the frequency shift we have used the perturbating body in a shape of the thin copper cylinder 10 mm long and 3 mm in diameter. The signal from the output probe was detected and amplified by the correlated amplifier B8-6 and synchronously with the movement of the perturbating body recorded by the recorder.

The lattice passbands for the first magnetic resonance corresponding to the TE_{101} mode were defined in the single spherical dielectric cavity. It is the band of 2960...3130 MHz. The amplitude – frequency performance in this passband of a lattice is presented in Fig.2. The second passband corresponding to the first electrical resonance and TM_{101} mode in the single dielectric sphere equals to 4328...4390 MHz. The third passband corresponding to the TE_{201} mode equals to 6040...6280 MHz.

In general case the dispersion equation for TE modes of the single sphere has two groups of roots [3]. The first group of roots determines dielectric sphere electromagnetic oscillations concentrated in the internal sphere region. They have been named as internal or "input" modes of oscillations. The second group of roots determines proper dielectric sphere oscillations concentrated basically outside the sphere volume in the space around it, therefore such oscillations have been named "output" modes of oscillations of the dielectric cavity. "Input" and "output" modes are intercollected and have the similar structure of the electromagnetic field. They do not exist separately. We observed it during measurements of the amplitude – frequency performance of a lattice. Each resonance splits into two ones corresponding to "input" and "output" modes. These resonances are without fail overlapped in the frequency providing

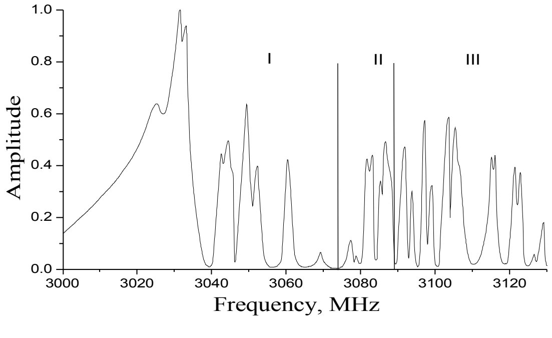

Fig.2. Amplitude – frequency performance of an artificial dielectric with the cubic structure of a lattice at sites of these dielectric spheres of 10 mm in diameter and distance between them 10 mm are placed. Power supply is in the E – field plane of the TE_{101} mode

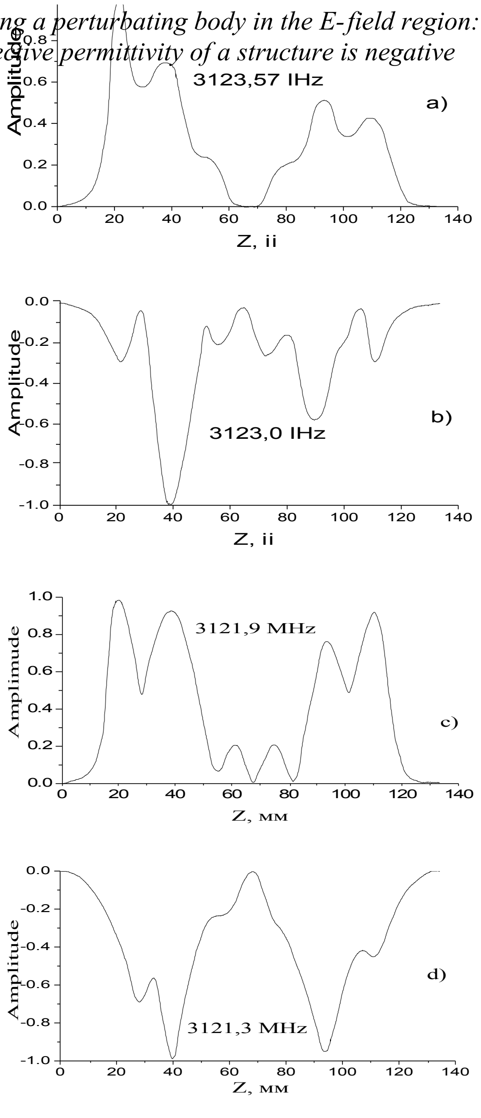

Fig.3. Electrical field distribution in a cubic lattice between spheres along the Z coordinate at frequencies of apexes of the double resonance curve: a,c – on high frequency slope; b,d - on the low frequency slope. The coordinate of the first sphere center is 18 mm

intermode coupling. Fig.3 shows the structure of an electric field distribution in the lattice along the Z direction, when the cylinder axis of a perturbating body coincides with the plane of the E – field of a single sphere. Fields have been measured on slopes of apexes of the double resonance with frequencies F_{p1}=3121.5 MHz and F_{p2}=3123,3 MHz. Frequency values of an operating point on slopes of the resonance curve without perturbating body are given in the figure. We observe the frequency increase during introducing the perturbating body both on left – hand and right – hand apexes of resonances. The signal decreases on low frequency slopes and increases on high frequency ones. This is the evidence of the negative value of the effective permittivity of a spatial lattice in this resonance band. Fields of all lattice resonances shown in Fig.2 have been researched. Resonances in the region I have positive values of ε_{eff}. Resonances in the region III have negative values of ε_{eff}. Resonances in the region II have both positive and negative values of ε_{eff} at various distances of the perturbating body motion, i.e. in separate layers of the spatial lattice.

The thin copper disc has measured the direction and value of magnetic fields in a lattice for one from resonance bands of 3120...3123 MHz. Obtained values of fields correspond to negative values of permittivity. Since the permittivity of this band is also negative then these preliminary results allow to say about the simultaneous existence of negative values of ε and μ.

The electrical field distribution along the Z coordinate has shown that together with modulation by spheres there is the spatial modulation by structure boundaries. Thus, for the resonance frequency of 3129 MHz there is one sinusoidal variation modulated by six layers of a sphere. The double resonance 3121.5 MHz and 3123.3 MHz has two spatial variations modulated by six layers of spheres, and so on. The maximum number of observed variants of a field equals to six. There is such a number of double resonances in I and III frequency bands. There are three double resonances in the frequency band II.

The investigation of the electrical field distribution between lattice spheres along X and Y coordinates has shown that each resonance is due to basic resonances on one from three mutually perpendicular planes and resonances in two other ones. It is the evidence of anisotropy of properties of the cubic lattice at sites of that spherical dielectric scatters are placed.

Studies of the lattice fields for TM_{101} and TE_{201} modes in the single sphere have also shown the presence of passbands with negative and positive values of ε_{eff}. In case if the number of spheres in a lattice increases then the frequency spectrum is condensed and separate resonances form one band.

Thus, studies of electromagnetic properties of a cubic lattice at sites of which the resonance spherical dielectric scatters are placed, where the TE_{101} mode is excited, have shown that the lattice has passbands corresponding to positive and negative values of permittivity. Resonance bands have been defined, in which the alternation of positive and negative values of permittivity is observed in lattice layers. Preliminary measured results demonstrating the simultaneous presence of negative values of ε and μ have been obtained. These effects may be used for the creation of novel artificial dielectrics with negative ε and μ and for researching electromagnetic wave interactions with tissues in vivo, sells of which form the regular spatial lattice, and their nuclei are the resonance scatters. The simple and effective method has been proposed to define the negative value of medium penetrations.

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ИССЛЕДОВАНИЕ СВОЙСТВ ПРОСТРАНСТВЕННОЙ РЕШЕТКИ, ОБРАЗОВАННОЙ РЕЗОНАНСНЫМИ ДИЭЛЕКТРИЧЕСКИМИ СФЕРАМИ

Г.А. Брызгалов

Модель искусственного диэлектрика используется при создании материалов с отрицательными ε и μ, а также при описании взаимодействия электромагнитных волн с живыми тканями. Экспериментально исследуются частотные свойства и распределение электрических полей в пространственной кубической решетке, и узлах которой размещены 216 одинаковых диэлектрических сфер. Определены частоты основных видов колебаний в решетке. Наблюдается расщепление частотной характеристики на полосы, соответствующие резонансным значениям отрицательной или положительной величины $\varepsilon_{\text{эфф}}$. Предложен метод определения отрицательного значения проницаемостей среды.

ДОСЛІДЖЕННЯ ВЛАСТИВОСТЕЙ ПРОСТОРОВИХ РЕШІТОК, УТВОРЕНИХ РЕЗОНАНСНИМИ ДІЕЛЕКТРИЧНИМИ СФЕРАМИ

Г.О. Бризгалов

Модель штучного діелектрика використовується при створенні матеріалів з негативними ε і μ, а також при описі взаємодії електромагнітних хвиль з живими тканинами. Експериментально досліджуються частотні властивості і

розподіл електричних полів в просторових кубічних гратках, у вузлах якої розміщено 216 однакових діелектричних сфер. Визначені частоти основних видів коливань в гратках. Спостерігається розщеплювання частотної характеристики на смуги, що відповідають резонансним значенням негативної або позитивної величини $\varepsilon_{эфф}$. Запропонований метод визначення негативного значення проникностей середовища.