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PERTURBATION THEORY OF COUPLED OSCILLATION OF RESONATORS WITH ACTIVE AND ABSORBING DIELECTRIC

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ТЕОРІЯ ЗБУРЕНЬ ЗВЯЗАНИХ КОЛИВАНЬ РЕЗОНАТОРІВ
З АКТИВНИМ ТА ПОГЛИНАЮЧИМ ДІЕЛЕКТРІКОМ

Розвивається теорія збурень, придатна для опису зв'язаних коливань діелектричних резонаторів, виконаних з активних діелектриків та діелектриків із втратами. Знайдена система рівнянь яка визначає амплітуди та частоти резонаторів та в окремих випадках збігається зі знайденою раніше.

Досліджуються зв'язані коливання діелектричних резонаторів різних видів. Отримані закономірності добре согласуються з результатами, знайденими в інших публікаціях на основі застосування чисельних методів та експериментальних досліджень. Представлені результати є основою для розрахунку та побудови широкого класу різноманітних оптичних модуляторів, перемикачів потужності, та сенсорів для систем оптичного зв'язку і інтернету речей.

It is known that the physical conditions in the DR can be implemented in such a way that energy from an external source is transferred to the field excited in its material. It is convenient to describe such resonators by introducing into consideration the concept of active dielectrics, materials in which the imaginary part of the dielectric constant can take positive values. In works [1 - 4], coupled systems of similar waveguides and resonators have already been considered, carried out using numerical methods, simulation and experimentally.

Previously [5], we considered dielectric resonators made of an ideal lossless dielectric whose dielectric constant is a purely real quantity. In this report, using perturbation theory for Maxwell's equations, coupled oscillations of resonators, the material of which is a complex function $\tilde{\varepsilon}_n = \varepsilon_n' + i\varepsilon_n''$, are studied, the imaginary part of which can take both positive and negative values. The resulting system of equations is used to study coupled oscillations of DRs made of an active dielectric and a dielectric with power losses. The found system of equations coincides with that obtained earlier [5] for $\varepsilon_n'' = 0$.

The simplest systems are considered, consisting of two coupled resonators, the material of one of the resonators is absorbing $\varepsilon_n'' < 0$, and the second is active $\varepsilon_n'' > 0$. Resonators with fundamental magnetic oscillations, as well as resonators with whispering gallery oscillations are investigated. (Fig. 1, 2).

On Fig. 1 shows the solutions of the equation systems for coupled oscillations of the absorbing and active DR with variation of the imaginary part of the dielectric constant of the second resonator.

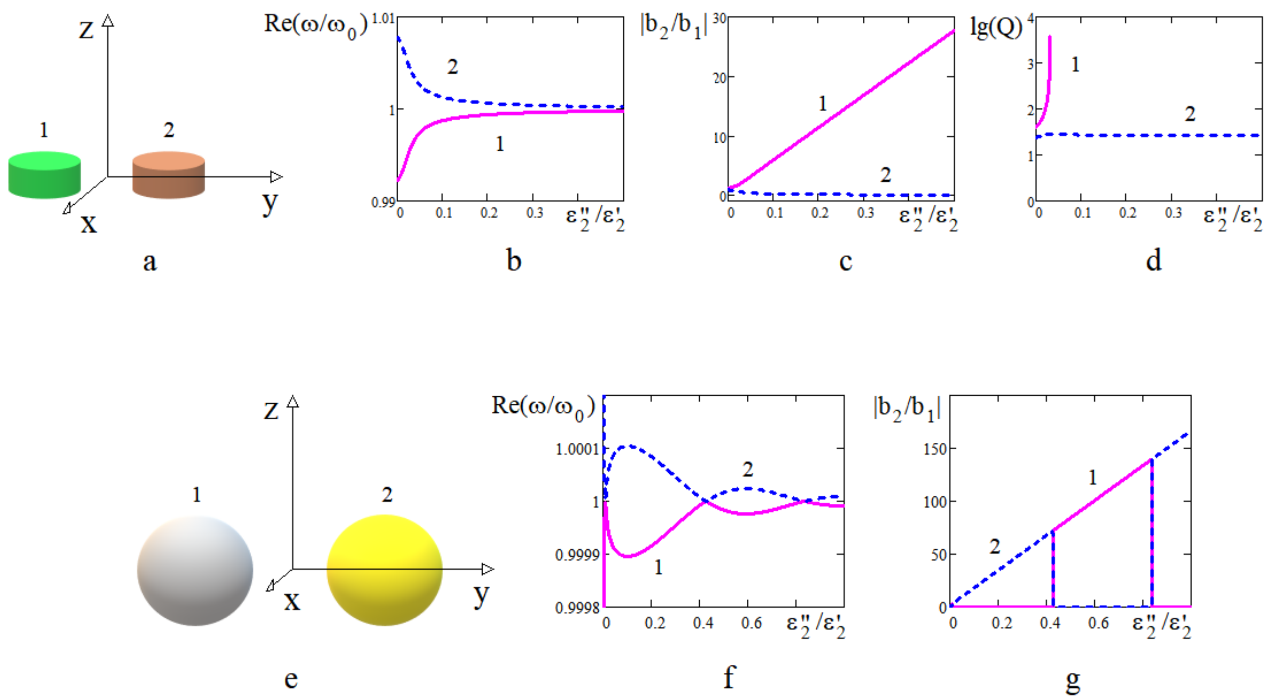

Fig. 1. Different cylindrical DR with main oscillations H_{101} (a) ($\varepsilon_1''/\varepsilon_1' = -0,01$; $\varepsilon_{1r}' = \varepsilon_{2r}' = 36$; $\Delta_1 = \Delta_2 = 0,4$; $f_0 = 10$ GHz; $\Delta x = \Delta z = 0$; $\Delta y = 10$ mm). Different spherical DR with a whispering gallery mode $H_{26,26,1}$ (e) ($\varepsilon_{1r}' = \varepsilon_{2r}' = 2,4$. $\Delta x = \Delta z = 0$; $k_0 \Delta y = 40$). The coupling frequencies (b, f); amplitude ratio (c, g) quality factor of coupled oscillations (d) as functions of the complex dielectric constant tangent function of the second DR (a) ($\varepsilon_1''/\varepsilon_1' = -0,01$).

As follows from the data obtained, an increase in the imaginary part of the dielectric constant for resonator 2 leads to a decrease in the detuning between frequencies (Fig. 1, b, f). The amplitudes of coupled oscillations are distributed in such a way that only one of the resonators of the system is excited (c, g). In this case, the quality factor of one of the coupled oscillations increases exponentially, and the quality factor of the other coupled oscillation remains approximately constant (d).

When using resonators with whispering gallery mods, the noted qualitative patterns of changes in the parameters of coupled oscillations are preserved (Fig. 1, e - g), however, the dependences of the frequencies become more complex functions of the dielectric parameters (Fig. 1, f).

On Fig. 2 shows the results of calculating the frequencies, amplitudes and quality factors of coupled oscillations of 3 cylindrical DRs with a whispering galery oscillations $EH_{1,20,1}$.

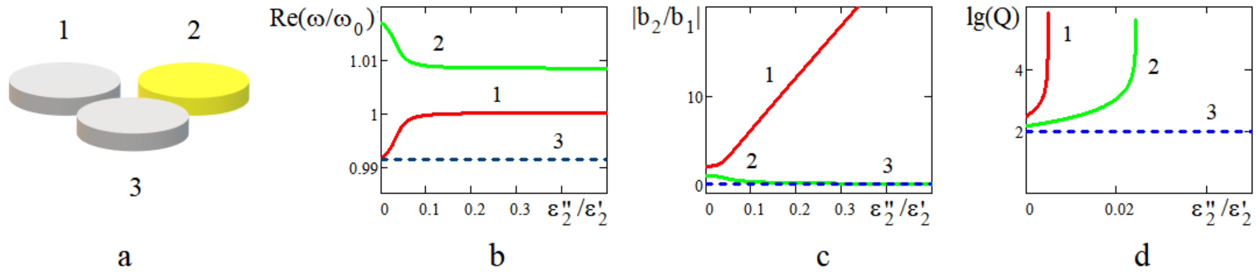

Fig. 2. 3 different cylindrical DR with a whispering gallery mode $EH_{1,20,1}$ (a) ($\varepsilon'_{1r} = \varepsilon'_{2r} = \varepsilon'_{3r} = 9$; $k_0\Delta r = 22$ $\Delta_1 = \Delta_2 = \Delta_3 = 0,2$). The coupling frequencies (b); amplitude ratio (c) quality factor of coupled oscillations as functions of the complex dielectric constant tangent function of the second DR (a) ($\varepsilon''_1 / \varepsilon'_1 = \varepsilon''_3 / \varepsilon'_3 = -0,01$).

The obtained patterns of amplitude distribution confirm the previously discovered effect [6, 7], the essence of which is that coupled oscillations in complex lattices consisting of various types of DR are broken down into oscillations of individual sublattices. All resonators in each individual sublattice are characterized by the same shape and the same parameter values.

Thus, using perturbation theory, we have obtained a new system of equations that describes the general patterns of behavior of multi-element lattices with DR performed by their various dielectrics. Considered DR lattices can find practical application in multiplexers, amplifiers, channel switches and other devices of infrared and optical communication systems.

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