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MODELING OPTICAL TOPOLOGICAL INSULATORS ON LATTICES OF COUPLED DIELECTRIC RESONATORS

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МОДЕЛЮВАННЯ ОПТИЧНИХ ТОПОЛОГІЧНИХ ІЗОЛЯТОРІВ НА РЕШІТКАХ ЗВ'ЯЗАНИХ ДІЕЛЕКТРИЧНИХ РЕЗОНАТОРІВ

Побудовані електродинамічні моделі складних решіток, що характеризуються властивостями топологічних ізоляторів. Досліджені матриці розсіювання. Аналізуються фізичні властивості, смуги частот, та розподіл амплітуд вимушених коливань, які обумовлюють специфічні властивості топологічних ізоляторів.

As shown by the results of studies carried out in recent years, some lattices of dielectric microcavities with whispering gallery oscillations have a number of exotic physical properties [1 - 3]. One of these unusual properties is the possibility of propagation of electromagnetic oscillations (photons) along the "surface" of the lattice. Such structures in optics and solid state physics are called topological insulators. The nature of optical topological insulators is not fully understood. To clarify the physical mechanisms of surface propagation of photons, in the proposed work an electromagnetic model of the lattice is constructed, based on the concept of degenerate oscillations of its constituent microcavities. In works [2, 3], similar effects have already been considered, but based on the use of numerical modeling methods, which does not allow judging the nature of this phenomenon. Confirmation of the effects of surface propagation of electromagnetic waves in resonators with degenerate oscillations will make it possible to speak more confidently about the possible mechanism of wave propagation in optical topological insulators of this type.

In order to clarify in more detail the properties of topological insulators, we built electromagnetic models of the currently known arrays of coupled dielectric ring resonators, shown in Fig. 1, a. It was assumed that these gratings are connected to the input 1-2 and output 3-4 optical transmission lines. First, we considered the transfer coefficients between ports 1-2, 1-3, 1-4 (Figs. 1, b), then the distribution of the amplitudes of forced oscillations of the resonators was calculated in each passband of the structure.

It was assumed that the coefficients of mutual coupling between adjacent microresonators are known; not adjacent microresonators are not coupled. In each of the microresonators, two types of degenerate natural oscillations are excited, characterized by different parity with respect to a given coordinate system. To calculate the scattered field by the lattice, we used the perturbation theory [6].

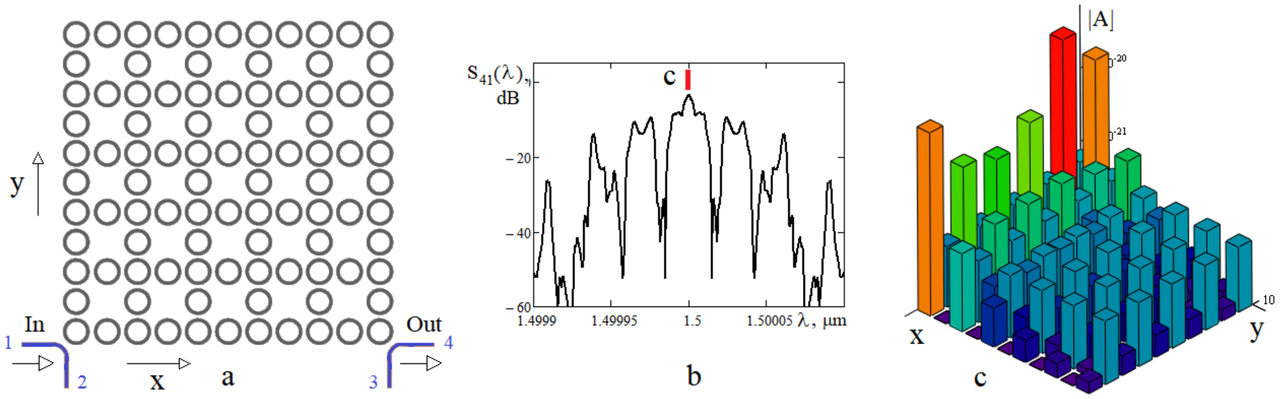

Fig. 1. Square lattice of optical microcavities with whispering gallery oscillations (a). Attenuation between ports 1 - 4 of the lattice (b). Distribution modulus amplitudes of the forced oscillations of the lattice at the central wavelength (c).

Q-factor of dielectric of resonators $Q_D = 10^{10}$; open space coupling coefficients $\tilde{k}_{OS} = 10^{-6}$; coupling coefficients of microresonators with lines $\tilde{k}^e = \tilde{k}^o = 3 \cdot 10^{-4}$; mutual coupling coefficients between resonators with even types of oscillations $k^e_{s,s+1} = 5 \cdot 10^{-5}$; with odd types of oscillations $k^o_{s,s+1} = -2 \cdot 10^{-5}$.

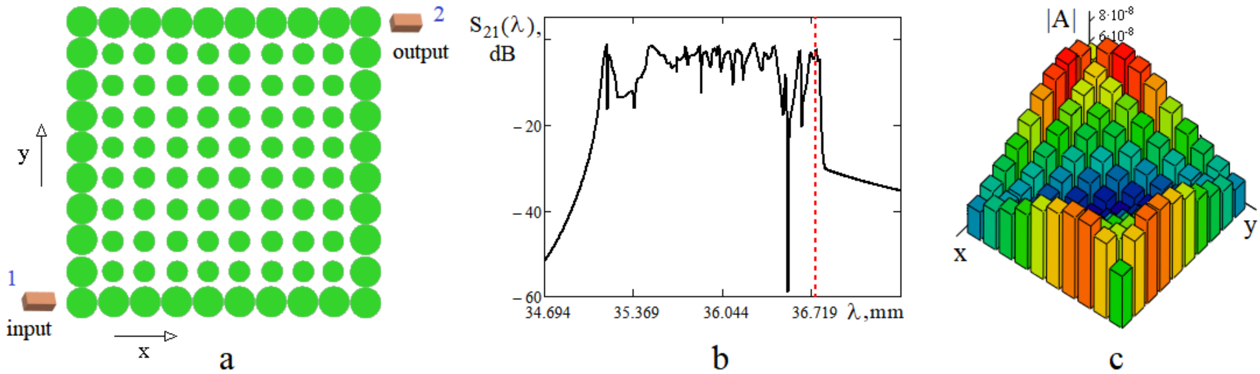

Fig. 2. Square lattice of various cylindrical DRs with main types of oscillations $H_{01\delta}$ and different compression ratios (a) ($\varepsilon_{1r} = 36$; $Q_D = 10^5$; $\Delta_1 = L_1 / 2r_1 = 0{,}3$; $\Delta_2 = L_2 / 2r_2 = 1$; L_s - height; $2r_s$ - DR diameter ($s = 1, 2$)). Attenuation between ports 1 - 2 of the lattice (a). Distribution modulus amplitudes (c) of the forced oscillations of the lattice at the wavelength 36,72 mm (b).

The obtained simulation results showed that at the wavelength of natural oscillations $\lambda_0 = 1{,}5\,\mu m$ shown by the red line in Fig. 1, c, the distributions of the amplitudes of the field of microcavities approximately correspond to the wave propagation characteristic of optical topological insulators (Figs. 1, c). However, already at detuning from the central transmission band, the distribution of the amplitudes of the microcavities becomes chaotic. For gratings of the considered type, the bands of surface wave propagation are relatively narrow (Figs. 1, b), but losses during surface propagation are minimal.

At present, gratings with the properties of optical topological insulators are known only with resonator vacancies at the sites (Fig. 1, a). The presence of such vacancies inside the lattice suggests its spatial inhomogeneities.

As noted earlier in [4, 5], spatially inhomogeneous lattices also have unusual electromagnetic properties, somewhat similar to those of topological insulators (see figs. 2, 3). In contrast to topological insulators, resonators of spatially inhomogeneous lattices can also exhibit no degenerate oscillations. The propagation of oscillations in such gratings is determined only by the inhomogeneity of their structure.

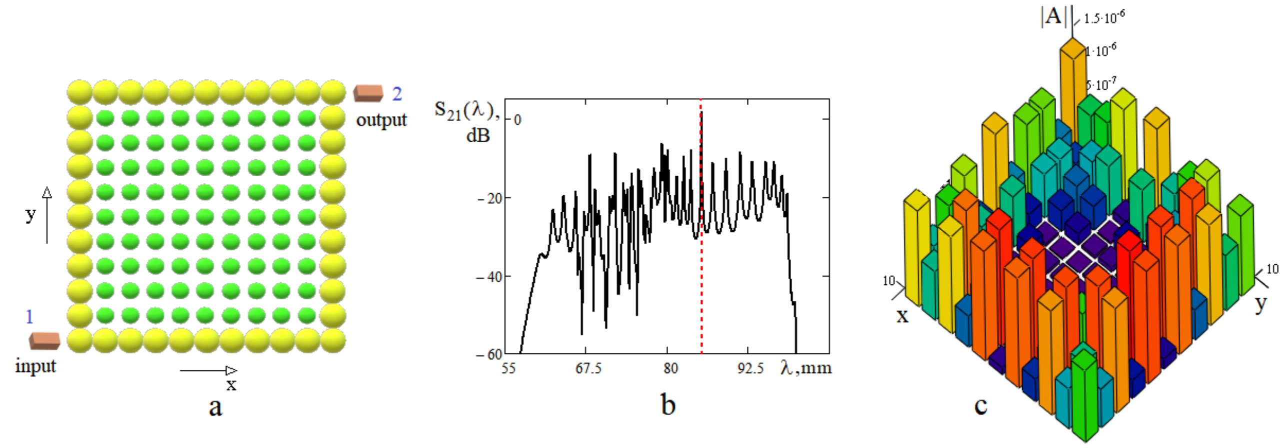

Fig. 3. Square lattice of various spherical DRs with main types of nondegenerate oscillations H_{101} (a) ($\varepsilon_{1r} = 81; \varepsilon_{1r} = 36$). Attenuation between ports 1 - 2 of the lattice (a). Distribution modulus amplitudes (c) of the forced oscillations at the wavelength 85,35 mm (b).

Thus, the simulation data obtained makes it possible to assert with a high degree of confidence that the unusual properties of optical topological insulators of this type are due to the effects of the interaction of degenerate oscillations that occur in dielectric resonators with whispering gallery waves, as well as the possible inhomogeneities of their structure. It should be noted that we have identified only one passband with minimal losses, on which the effect of surface wave propagation takes place.

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