EFFECT OF RANDOM VARIATIONS OF BOTH COMPOSITION AND THICKNESS OF 1D PHOTONIC CRYSTAL WITH ADMIXTURE PLASMA LAYERS ON PHOTONIC BAND GAP

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Investigation of disorder effects in an imperfect superlattice allowing modeling the properties of photonic crystal containing the plasma layers is still of a great interest [1]. Development of the theory of photonic structures requires consideration of model systems such as photonic superlattice with plasma layers. Using the virtual crystal approximation [2] we study 1D-superlattice, which is a topologically ordered ensemble (such as a Si/liquid crystal or SiO_2/Si system) with randomly included admixture plasma layers. The superlattice is modeled as a set of macroscopically homogeneous layered system with randomly included extrinsic (with respect to the ideal superlattice) layers of variable composition and thickness. Corresponding configuration-dependent material tensors in our model [3] of the imperfect superlattice are represented in terms of random quantities. After configuration-averaging the translational symmetry of the considered system is "restored" that allows us obtain the system of equations which define normal modes of electromagnetic waves, propagating in one-dimensional “periodic” medium.

To specify the results, let’s firstly consider the propagation of electromagnetic excitation in an imperfect Si/LC 1D superlattice with two elements (layers) in the cell, namely, with the first layer of silicon ($\varepsilon_1 = 11.7$) and the second layer of liquid crystal ($\varepsilon_2^{(1)} = 5.5$).Then we study SiO_2/Si 1D superlattice (with $\varepsilon_1 = 3.7$). The concentration, thickness and permittivity of the basic material layer in the first and second sublattices are denoted as $C_1^{(1)}$, $a_1^{(1)} = a_1, \varepsilon_1^{(1)} \equiv \varepsilon_1$ and $C_2^{(1)}, a_2^{(1)}, \varepsilon_2^{(1)} \equiv \varepsilon_2$, and the corresponding parameters of impurity layers with a different composition $C_{2C}^{(2)} \equiv C_C$ and thickness $C_{1T}^{(2)} \equiv C_T$, as well as $a_2^{(2)}, \varepsilon_2^{(2)}$. Note that the permittivity profile for inhomogeneous plasma is $\varepsilon_2^{(2)}(z) = 1 - \omega_e^2(z)/\omega^2$. For considered model plasma frequency is $\omega_e << \omega$ (collisions in plasma are neglected) and plasma density for $a_{n\alpha}$-th layer varies exponentially:

$$n(z) = n_{cr}\left\{\begin{aligned} &\exp\left[-\delta\left[z-(n-1)d-\sum_{j=1}^{\alpha}a_{nj}+a_{n\alpha}\right]/a_{n\alpha}\right]+ \\ &+\exp\left[-\delta\left(-z+(n-1)d+\sum_{j=1}^{\alpha}a_{nj}\right)/a_{n\alpha}\right]\end{aligned}\right\}/2 \quad (1)$$

Gradation parameter δ corresponds to the volume average plasma permittivity $<\varepsilon_2^{(2)}>= 0.9$. Below we are considered the case of admixture plasma layers only in LC-sublattice for Si/LC superlattice and in Si-sublattice for SiO_2/Si system. Simple calculations [4] yield the dependence the lowest photonic band gap width $\Delta\omega$ on plasma concentration of the systems studied:

$$\Delta\omega_1/\omega = (\varepsilon_1 - f_d f_{1C})^{-1}\sqrt{f_{1C}^2 f_{1T} + f_{2C} f_{2T} + f_{3C} f_{3T}}\,,$$
$$f_d = a_2\left[a_1 + a_2 + C_T\left(a_1^{(2)} - a_1\right)\right]^{-1},\ f_{1T} = \pi^{-2} Sin^2\pi\ f_d\,, \quad (2)$$
$$f_{2T} = f_d\frac{\pi^{-1}\delta\ Sin2\pi\ f_d + 4 f_d Sin^2\pi\ f_d}{\delta^2 + (2\pi\ f_d)^2},\ f_{3T} = f_d^2\frac{Sin^2\pi\ f_d}{\delta^2 + (2\pi\ f_d)^2},$$
$$f_{1C}^2 = \left[C_C(\varepsilon_2 - 1) + \varepsilon_1 - \varepsilon_2\right]^2,\ f_{2C} = C_C f_{1C},\ f_{3C} \equiv C_C.$$

The dependence $\Delta\omega(C_C, C_T)$ is shown in Fig. 1 for Si/LC superlattice and in Fig. 2 for SiO_2/Si system for different relative both composition and thickness of layers. Surface 1 in

Fig. 1 refers the case of $a_1 / a_2 = 0.1$ and $a_1^{(2)} / a_2 = 0.5$, surface 2 corresponds to the case of $a_1 / a_2 = 0.5$ and $a_1^{(2)} / a_2 = 0.1$. In Fig. 2 photonic band gap $\Delta\omega_1 / \omega$ corresponds to the values $a_1^{(2)} / a_2$ and a_1 / a_2 that are equal to 0,1; 10 (surface 1) and 10; 0,1(surface 2).

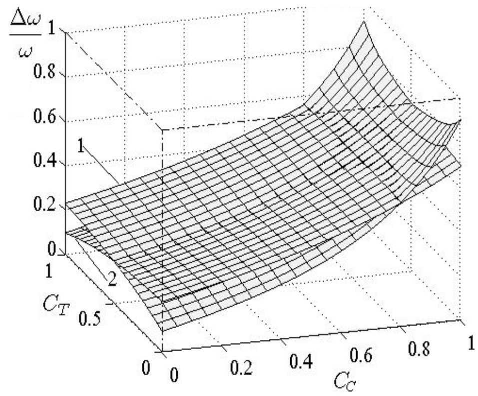

Fig. 1. Concentration dependence for a nonideal Si/LC 1D superlattice which contains plasma layers in LC-sublattice.

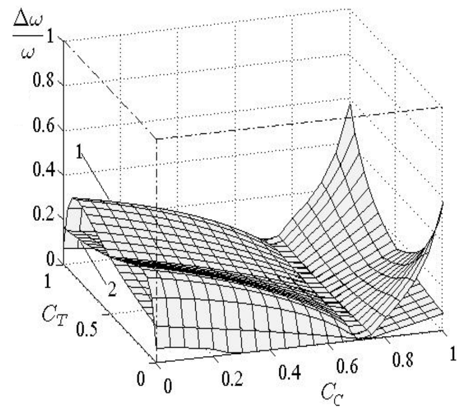

Fig. 2. Concentration dependence for a nonideal SiO_2/Si 1D superlattice which contains plasma layers in Si-sublattice.

Our results show that the optical characteristics of imperfect 1D superlattice may be significantly altered owing to transformation of their photon mode spectrum resulting a presence of admixture layers. Graphic representation $\Delta\omega(C_C, C_T)$ proves that the concentration dependence for the binary systems considered above differs for different relative composition of plasma layers. The case of nonideal multilayered systems with a larger number of sublattices and components of alien layers supposes a wide variety of specific behaviors of the photonic gap width. This circumstance extends considerably the promises of modeling composite materials with predetermined properties.

References

1. *Xiang-kun Kong, Shao-bin Liu, Hai-feng Zhang, He-lan Guan*. The effect of random variations of structure parameters on photonic band gaps of one-dimensional plasms photonic crystal // Optics Communications. 2011. V. 284. No.12. P.2915-2918.
2. *Parmenter R.H.* Energy Levels of a Disordered Alloy// Phys. Rev. 1955. V. 97. P.587-698.
3. *Rumyantsev V.V., Fedorov S.A., Gumennyk K.V.* Peculiarities of band gap width dependence upon concentration of admixtures randomly included in 1D photonic crystal // Photonic Crystals: Optical Properties, Fabrication and Applications / ed. William L. Dahl, NY: Nova Science Publishers, Inc., 2011. P. 183-200.
4. *Rumyantsev V.V., Fedorov S.A.* Effect of random variations of both the composition and thickness on photonic band gap of one-dimensional plasma photonic crystal // Proceeding of PIERS 2012. The Electromagnetic Academy, 2012. P. 1411-1414