ELECTRICALLY CONTROLLABLE OPTICAL SWITCH BASED ON ONE-DIMENSIONAL PHOTONIC CRYSTAL

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Abstract: Electrooptical switch within narrow spectral range has been demonstrated. The switch consisting of one-dimensional photonic crystal with a nematic liquid crystal defect layer was placed between two crossed polarizers. Principle of operation is based on the interference of the ordinary and extraordinary light waves passed across the device due to the electric-field induced coincidence of their wavelengths.
Keywords: photonic crystal, defect mode, photonic band gap, liquid crystal

The development of new control methods of optical properties of photonic crystal (PC) materials is very important for their application in optoelectronics and nanophotonics [1-3]. Multilayer PC systems with a wide photonic band gap (PBG) are of great interest, especially in visible spectral region, where the liquid crystals (LC) are used as active structural elements for tuning of spectral parameters within PBG. Liquid crystals are known to have a wide range of optical transparency, high birefringence, large optical nonlinearity and high susceptibility to external perturbations (temperature, electric and magnetic fields). All this makes them very promising candidates for effective control of spectral and optical properties of PCs [2-4]. To date some methods of spectral tuning of multilayer PC with nematic defect layer have been studied theoretically [5] and experimentally [6-8]. It makes possible to use them for designing of new methods of switching between optically transparent and opaque states of PC elements.

In this paper we propose electrooptical one-dimensional PC/LC switching based on an interference of ordinary (*o*) and extraordinary (*e*) light waves passed through the cell and two crossed polarizers due to the electric-field induced coincidence of their wavelengths.

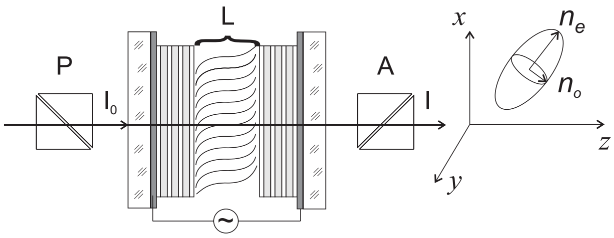

Fig. 1. Experimental cell of the one-dimensional photonic crystal with liquid crystal defect layer in crossed polarizers: P –the polarizer, A – the analyzer

The PC lattice under study has the $(HL)^N H(D)H(LH)^N$ structure. Here H and L are the various dielectric layers with the high n_1 and low n_2 refractive indices and the thicknesses t_1 and t_2, respectively. A lattice spacing is $t = t_1 + t_2$. The symbol D denotes the defect layer with the refractive index n_d and the thickness L. N is the number of the HL and LH bilayers. Fig. 1 shows an experimental device. Two identical multilayer mirrors are combined so that a sandwich-like cell with a gap of about L=7.4 μm is fabricated. Each mirror consists of six zirconium dioxide (ZrO_2) layers with the refractive index n_1 =2.04 and the thickness t_1 =55 nm of each layer and five silicon dioxide (SiO_2) layers with the refractive index n_2 =1.45 and the thickness t_2 =102 nm. The nematic liquid crystal 4-n-pentyl-4'-cyanobiphenyl (5CB) was

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infiltrated between mirrors. The refractive indices of 5CB are $n_{\|}$= 1.720, $n_{\perp}$=°1.536, where subscripts (||) and (⊥) refer to the direction parallel or perpendicular to the nematic director **n,** respectively. The electro-optical cell was placed between two crossed polarizers. The initial orientation of **n** was along the *x*-axes, while the probe radiation was polarized at 45° to the *x*-axes. To reorient the liquid crystal 800-Hz AC voltage was applied to the ITO electrodes. Two-dimensional (in *xz*-plane) *S*-deformation of the nematic results in decrease of the extraordinary refractive index $n_e = n_{\perp} n_{\|} \cdot [n_{\|}^2 \cos^2 \theta(z) + n_{\perp}^2 \sin^2 \theta(z)]^{-1/2}$, where θ(*z*) is the angle between the wave vector of the extraordinary beam **k**||*z* and the local direction of **n**. Ordinary refractive index $n_o = n_{\perp}$ is independent of the director tilt angle θ. According to the known relation $\lambda_e = 2n_e L / N_e$, where integer *N* is number of defect mode, the change of n_e under the action of external field results in the shift of the spectral position of defect mode λ_e. At the same time, the position of λ_o defect modes remains invariable. At spectral coincidence of the defect modes λ_e=λ_o the phase modulation of light passed across the PC/LC will depend on the difference of the defect mode numbers [9]

$$I = I_0 \sin^2 \pi (n_e - n_o) \frac{L}{\lambda} = \sin^2 \pi (N_e - N_o) / 2 . \quad (1)$$

Fig. 2 shows the transmission spectra of the tunable PC/LC cell placed between crossed polarizers at U_1 = 0.95 V (dashed curve) and U_2 = 1.23 V (solid curve) applied voltage. The transmission of sample within long-wave spectral range is the result of interference 42-th and 41-th λ_e-modes with 38-th fixed mode λ_o=588 nm. The states T_{OFF} and T_{ON} correspond

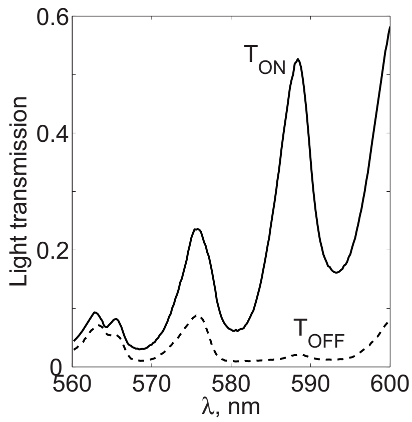

Fig. 2. Light transmission of PC/LC at interference of 42-th (U_1 = 0.95 V, dashed curve) and 41-th (U_2 = 1.23 V, solid curve) λ_e-modes with 38-th λ_o-mode .

to the destructive and constructive interference, respectively. Thus, at spectral coincidence of orthogonally polarized defect modes of PC it can be realized both an amplification and quenching of probe radiation. According to Eq. 1 the result of interference (maximum or minimum) depends on difference of mode serial numbers N_e - N_o. The transmission has minimum when $N_e - N_o = 2k$ is even and maximum when $N_e - N_o = 2k + 1$ is odd.

Fig. 3 shows both experimental and theoretical field-induced transmission oscillations of PC/LC cell at a fixed wavelength λ_o=453.4 nm. According to the specific feature of Freedericksz transition [10], the transmission doesn't change up to the threshold voltage which is U_c=0.74 V in our case. With further increasing of voltage the transmission of the cell is oscillating function of the applied voltage moreover a width of oscillations increases with growth of voltage. Maxima and minima of the transmission correspond to coincidence of resonance wavelength of λ_e-modes with wavelength λ_o=453.4 nm. Broadening of oscillations is connected with decreasing of refractive index of extraordinary wave at increasing of voltage. The theoretical simulation (solid curve) was made using the recurrent relations method [11]. One can see quality agreement between the experimental and computed values.

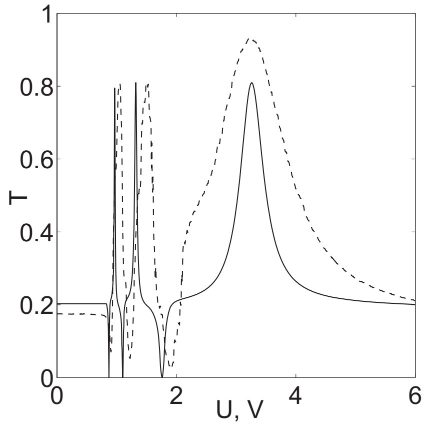

Fig. 3. The field-induced transmission oscillations of 1D-PC/LC cell placed between crossed polarizers at a fixed wavelength: dashed curve is experimental, solid curve is theoretical simulations

It has been experimentally and theoretically demonstrated that the 1D-PC/LC cell placed between crossed polarizers is able to switch over transmittance in the defect modes. It is related to the interference of the *o*- and *e*-waves passed across the cell due to the electric-field induced coincidence of their wavelengths. Thus, the 1D-PC cell with the switchable nematic liquid crystal defect layer and crossed polarizers can be effectively used as a light valve in the whole spectral range of the photonic band gap.

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1. J.D. Joannopoulos, R.D. Meade, and J.N. Winn, *Photonic Crystals: Molding the Flow of Light*, Princeton: Princeton University Press, 1995.
2. K. Busch, R.B. Wehrspohn, S. Lölkes et al., *Photonic Crystals: Advances in Design, Fabrication, and Characterization,* John Wiley&Sons, 2004.
3. V.F. Shabanov, S.Ya. Vetrov, A.V. Shabanov, *Optics of Real Photonic Crystals: Liquid Crystal Defects, Irregularities* SB RAS Publisher, Novosibirsk, 2005.
4. H. Kitzerow, *Liq. Cryst. Today*, vol. 11, p. 3, 2002.
5. S.Ya. Vetrov, A.V. Shabanov, E.V. Shustitskii, *Opt. Spectrosc*., vol. 100, p.409, 2006.
6. R. Ozaki, M. Ozaki, and K. Yoshino, *Electr. Commun. Jpn.* P. 2, vol. 88, p. 46, 2005.
7. V.A. Gunyakov, V.P. Gerasimov, S.A. Myslivets et al., *Tech. Phys. Lett.,* vol. 32, p. 951, 2006.
8. V.G. Arkhipkin, V.A. Gunyakov, S.A. Myslivets et al., *JETP*, vol. 106, p. 388, 2008.
9. V.Ya.Zyryanov, V.A. Gunyakov, S.A. Myslivets et.al., *Nanotech. Rus.*, vol. 3, 2008.
10. L.M. Blinov *Electro- and Magnetooptics of Liquid Crystals*, Nauka, Moscow, 1978, p. 384.
11. V.A. Bushuev, A.D. Pryamikov, *Quant. Electron.* ,vol. 33, p. 515, 2003.