Experimental and Theoretical Investigation of Polarization Plane Rotation of Light in Nanoparticle-Enriched Chiral Liquid-Crystalline Photonic Structures with an Anisotropic Defect Layer

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The possibility of defect induction controlled by external electric field in nanoparticle-enriched cholesteric liquid-crystalline (CLC) cell with selective reflection in visible range of light and controlling the rotation of polarization plane of light by induced defect was experimentally and theoretically demonstrated. Three cases of induced defects were examined: defect was induced near the input substrate of the cell, in the center of CLC cell and near the exit substrate of the cell. The CLC layer parameters are: ε_1= 2,47, ε_2= 2,85, σ= 0,324, where σ is pitch of helical structure. Our estimations show that non-locality of the field results in induction of the defect with the thickness of 2,27μm. Consequently, it was experimentally confirmed that the rotation of polarization plane has maximum value when light at first propagates through cholesteric liquid-crystalline photonic structure and then falls to the anisotropic layer. The main result of the experiment is the fact that the rotation of the polarization plane of light occurs at lower voltages when the cholesteric liquid crystal is enriched by nanoparticles. In order to simulate our experimental results, we used Ambartsumian's layer addition modified method [1] adjusted to solution of such problems. A *CLC layer* with a defect can be treated as a multi-layer system: ***CLC(1)-Defect Layer (DL)-CLC(2)***. Let us present the solution of the boundary problem of light transmission through the multi-layer system in the form:

$$\vec{E}_r = \hat{R}\vec{E}_i, \quad \vec{E}_t = \hat{T}\vec{E}_i, \tag{1}$$

where the indices *i*, *r* and *t* denote the incident, reflected and transmitted waves' fields, $\hat{R}$ and $\hat{T}$ are the reflection and transmission matrices.

$$\vec{E}_{i,r,t} = E^p_{i,r,t}\vec{n}_p + E^s_{i,r,t}\vec{n}_s = \begin{bmatrix} E^p_{i,r,t} \\ E^s_{i,r,t} \end{bmatrix}, \tag{2}$$

where $\vec{n}_p$ and $\vec{n}_s$ are the unit vectors of orthogonal linear polarizations, $E^p_{i,r,t}$ and $E^s_{i,r,t}$ are corresponding amplitudes of the incident, reflected and

transmitted waves. According to Ambartsumian's layer addition modified method, if there is a system consisting of two adjacent (from left to right) layers, *A* and *B*, then the reflection transmission matrices of the system, $A+B$, viz. $\hat{R}_{A+B}$ and $\hat{T}_{A+B}$, are determined in terms of similar matrices of its component layers by the matrix equations:

$$\begin{aligned} \hat{R}_{A+B} &= \hat{R}_A + \tilde{\hat{T}}_A\hat{R}_B\left[\hat{I} - \tilde{\hat{R}}_A\hat{R}_B\right]^{-1}\hat{T}_A, \\ \hat{T}_{A+B} &= \hat{T}_B\left[\hat{I} - \tilde{\hat{R}}_A\hat{R}_B\right]^{-1}\hat{T}_A, \end{aligned} \tag{3}$$

where the tilde denotes the corresponding reflection and transmission matrices for the reverse direction of light propagation, and $\hat{I}$ is the unit matrix. The exact reflection and transmission matrices for a finite ***CLC layer*** (at normal incidence) and a defect (isotropic or anisotropic) layer are well known. First, we attach the ***DL*** with the ***CLC Layer (2)*** from the left side. In the second stage, we attach the ***CLC Layer (1)*** with the obtained ***DL-CLC Layer (2)*** system.

The ellipticity e and the azimuth ψ of the transmitted light are expressed by $\chi = E^s_t / E^p_t$ through the following formulas:

$$\psi = \frac{1}{2}arctg\left(\frac{2\,\mathrm{Re}(\chi)}{1-|\chi|^2}\right), \quad e = tg\left(\frac{1}{2}\arcsin\left(\frac{2\,\mathrm{Im}(\chi)}{1+|\chi|^2}\right)\right).$$

The comparison of experimental results with the theoretical predictions confirms the validity of the approach. We present a new configuration of liquid crystal device that performs as a tunable linear polarizer for both polarized and unpolarized lights. Our results can be used in systems as a broad band optical diode for circularly polarized incident light, as well as in the sources of elliptically polarized light with tunable ellipticity.

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References

[1] A. H. Gevorgyan, Phys. Rev. E., **83(1)**, 011702(1–12), (2011).