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CHIRAL PHOTONIC STRUCTURES WITH ANISOTROPIC DEFECT CONTROLLED BY HYDRODYNAMIC FLOW

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Abstract–For the first time it is experimentally shown the possibility of planar defect induction in chiral liquid crystalline plane structure by means of hydrodynamic flow. The behavior of unpolarized light reflection spectrum from chiral liquid crystalline plane structure with planar defect induced by hydrodynamic flow is studied. The possible applications of observed phenomena are discussed.

1. Introduction

The investigation of optical properties of Photonic Crystals (PC) is one of the most interesting problems, because the results of these studies can find wide applications in optoelectronic devices of new generation. Thanks to variety of optical properties the chiral photonic crystals, i.e. the Cholesteric Liquid Crystals (CLC), Chiral Smectics and crystals with artificial chirality are of special interest. The main difference of Chiral PC-s and other PC-s is the fact that the Chiral PC-s show Photonic Band Gap (PBG) only for circular polarized (CP) light with the same sense of handedness as the chirality of the PC. For these crystals the Bragg reflection takes place for the light with wavelength in $n_0 p < \lambda < n_e p$ spectral range, where p is the helical pitch, n_0 and n_e are the ordinary and extraordinary local refractive indices. The light with opposite circular polarization does not undergo diffractive reflection.

The perfect periodic PC-s have found many practical applications. But the PC-s with defect are much more interesting because the presence of defect inside the periodic PC structure causes the origin of additional resonance modes inside PBG. This enables the control of PBG optical characteristics, in particular, the spectral position, width, structure, etc. The defect modes could be exploited to create narrow bandpass tunable filters, polarizers, low threshold lasers, etc. The defect in the Chiral PC structure could be induced in several ways: by thin isotropic layer sandwiched between two Chiral PC-s [1-3], by helical pitch phase jump at the boundary of two Chiral PC-s [4], by local change of the helical pitch [5], by helical pitch gradient of Chiral PC [6,7], by external electric field perpendicular to the helical axis of PC and parallel to the cell substrates [8,9], etc. In [10,11] the properties of Chiral PC with anisotropic defect layer are studied.

Liquid Crystals (LC) as well as CLC-s are sensitive to such external influences as static electric and magnetic, acoustic fields, light, mechanical vibrations, temperature and hydrodynamic flows. Thanks to this property it is possible to induce and control various types of defects inside the

CLC layer by means of the same fields. In particular, in the case of appropriate geometry of experiment by means of hydrodynamic flow parallel to the surface of the cell substrates, the planar defects could be induced. It is important to note that the parameters of defects induced by this method could be controlled by means of same flows and also by other external influences.

In our experiment the planar defect was induced in a special designed rectangular CLC cell by applying pressure difference between the ends of the cell. This system with some exceptions could be interpreted as three-layered structure. It consists of two CLC layers with undistorted pitch at the cell substrates (thanks to strong coupling between CLC molecules and the cell substrates) and an anisotropic layer sandwiched between them with distortions of molecule alignment caused by hydrodynamic flow. Above some threshold value of the flow velocity the change of the helical pitch of CLC layer localized in the middle part of the cell thickness takes place creating planar anisotropic defect.

We have experimentally confirmed the possibility of planar defect induction in the CLC layer by means of hydrodynamic flow. We study the behavior of light reflection coefficient when the planar defect is induced by means of hydrodynamic flow. Also we discuss possible applications of this system.

2. Results of the Experiments and Discussion

A CLC cell of special construction was designed for the experiments [12] (Fig.1). The glass substrates (1, 2) of the cell were coated with polymeric alignment layer, which was rubbed to align the director of LC along the hydrodynamic flow direction. By means of spacers a 35μm thick gap between cell substrates was created forming plane capillary. The capillary and supportive volumes 3 and 4 were filled with CLC, which was a 4-component mixture of two CLC-s with opposite chirality and two Nematic Liquid Crystals (NLC). The CLC-s Cholesteryl Pelargonate and Cholesteryl Oleate, and NLC-s MBBA and 5CB with 45:5:30:20 wt% ratio were used. Such composition of CLC was selected mainly by two reasons. The first was the necessity to obtain the smallest possible viscosity, to provide velocity of hydrodynamic flow sufficient for reorientation of LC molecules at small pressure difference between the ends of the cell. The second reason was the necessity of obtaining selective reflection band in the visible part of spectrum at room temperature and possibly small temperature shift rate. The CLC mixture had selective reflection band for Right CP light at normal incidence in the visible part of spectrum in 20°C-40°C temperature range. The cholesteric–isotropic phase transition temperature was measured to be approximately 43°C.

The reflection was measured by means of fiber spectrometer Stellar Net: Black comet, with optical resolution about 1 nm. The measurements were carried out by means of reflection measurement probe which had two channels of fibers. One of these channels, consisting of 7 fibers was delivering light to the sample from krypton-tungsten lamp. The reflected light was collected by a central fiber, with 600 μm and delivered to the spectrometer. More details of experimental setup are described in [2].

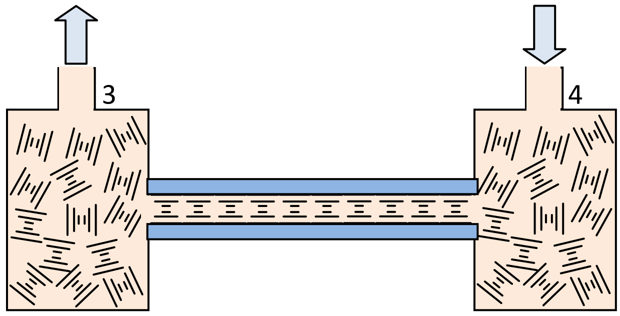

Fig.1. Sketch of CLC cell. 1,2 – glass substrates. 3,4 – supportive volumes for CLC. Arrows denote the air pressure. The reflection was measured using reflection measurement fiber probe described in [10].

Figure 2 represents temperature dependence of the wavelength corresponding to reflection maximum for samples of various thicknesses. As could be seen from the graph the PBG of CLC shows small temperature shift rate ($\partial p/\partial T \sim 1$ nm) in 20–25°C temperature range. As the measurements were carried out at room temperature (23°C) without CLC temperature stabilization, the temperature shift of PBG during experiment could be neglected. Also from Fig.2 it could be concluded that the wavelength corresponding to the maximum of selective reflection shows almost negligible dependence on the cell thickness.

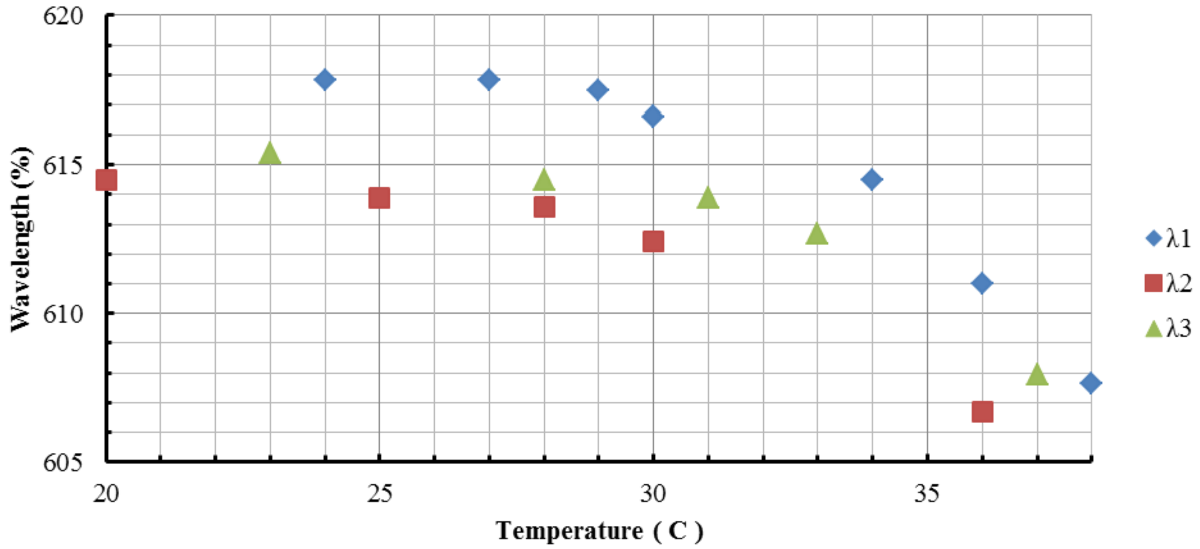

Fig.2. Temperature dependence of wavelength corresponding to the maximum of selective reflection. λ1, λ2, λ3 are corresponding to the CLC cell with thickness 10, 20 and 30 μm, respectively.

The reflection coefficient of light at the wavelength corresponding to the maximum of selective reflection ($\lambda_{max} \sim 610$ nm) increases when the pressure difference is created between the ends of the CLC cell (Fig.3). In particular, at $\Delta P = 10^5$ Pa the reflection coefficient at mentioned wavelength increases almost two times. This fact is in a good agreement with theoretical calculations in [10].

Such behavior of reflection coefficient could be qualitatively explained as follows. The presence of pressure difference between the ends of the cell gives rise to Poiseuille hydrodynamic flow parallel to the substrates of the cell and perpendicular to the helical axis of CLC. When the pressure difference exceeds certain threshold value the hydrodynamic flow reorients the LC molecules in the middle layer of the cell thickness along its direction. Such reorientation for NLC is reported in [12]. This reorientation results in CLC pitch deformation and formation of anisotropic planar defect in the middle of the CLC film thickness. As it was mentioned, this system could be interpreted as 3-layered. Thanks to strong coupling between the LC molecules and cell substrates the deformation of CLC helix will be smaller at the surface of the substrates than in the middle of CLC film thickness, where the flow velocity is also higher. By increasing the pressure difference and as a consequence the velocity of the flow (which is the same as controlling the parameters of defect layer) it is possible to obtain layer with optical thickness equal to thickness of half-wave phase retarder for certain wavelength. This anisotropic defect layer will produce additional phase difference equal to π between the components of transmitted light. It is well known that in this case the vector of polarization of light with elliptic or circular polarization (CP) will change the direction of rotation to opposite.

In case of light with linear polarization at normal incidence, one of the CP components will be reflected from the “first” undistorted CLC layer and the opposite CP component will transmit through defect layer and change the handedness of polarization to opposite. Then this wave will be reflected by the “second” undistorted CLC layer and again change the handedness of polarization when is transmitted through the defect layer. This wave will pass through the “first” CLC layer and increase the reflection coefficient. It is obvious that in the same way could be interpreted the behavior of unpolarized light, if it is assumed as interference of chaotically distributed waves with linear polarization.

Figure 3 depicts the dependence of reflection coefficient at 610 nm on pressure difference applied to the ends of the cell. As seen, a drastic change of reflection occurs when the pressure difference exceeds 0.14×10^5 Pa. When ΔP reaches 10^5 Pa the magnitude of reflection coefficient increases almost two times compared to initial reflection in the beginning of the experiment. Most probably at this value of pressure difference the defect layer acts as half-wave phase retarder for incident light. During further increase of ΔP the reflection coefficient decreases which indicates that the optical thickness of defect layer is not $\lambda/2$ anymore and additional phase difference is more than π.

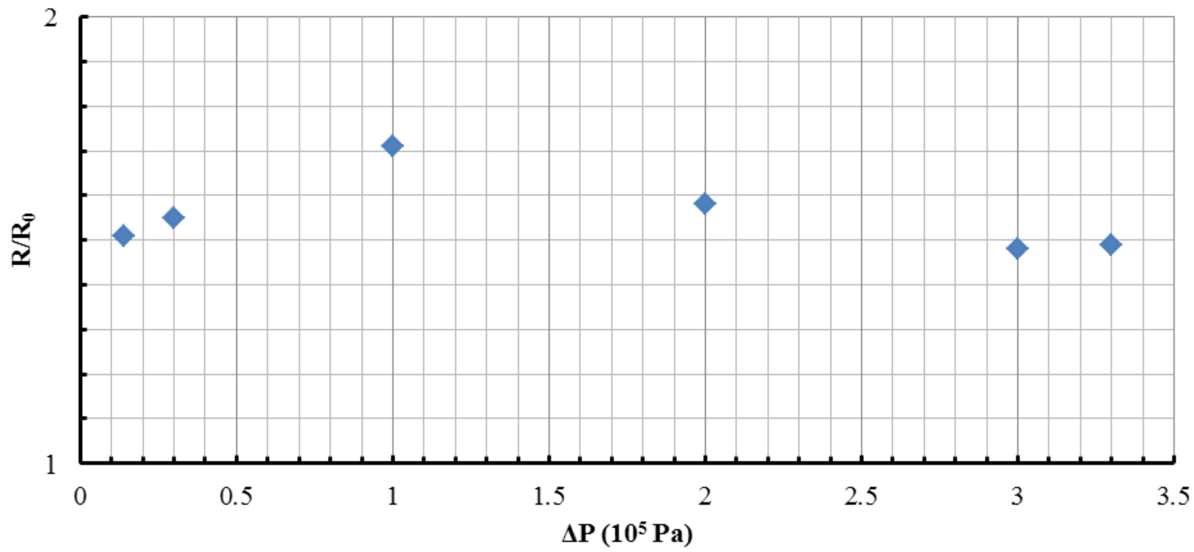

Fig.3. Coefficient of reflection of light at 610 nm vs. pressure difference. The coefficient of reflection is normalized to the initial value of the reflection at the beginning of experiment.

From this viewpoint it would be interesting to measure the reflection at higher ΔP. Theoretically the reflection coefficient must show oscillations but in the experiment we observe chaotic behavior, which could be explained by non-Poiseuille flows. At these ΔP the system becomes highly scattering.

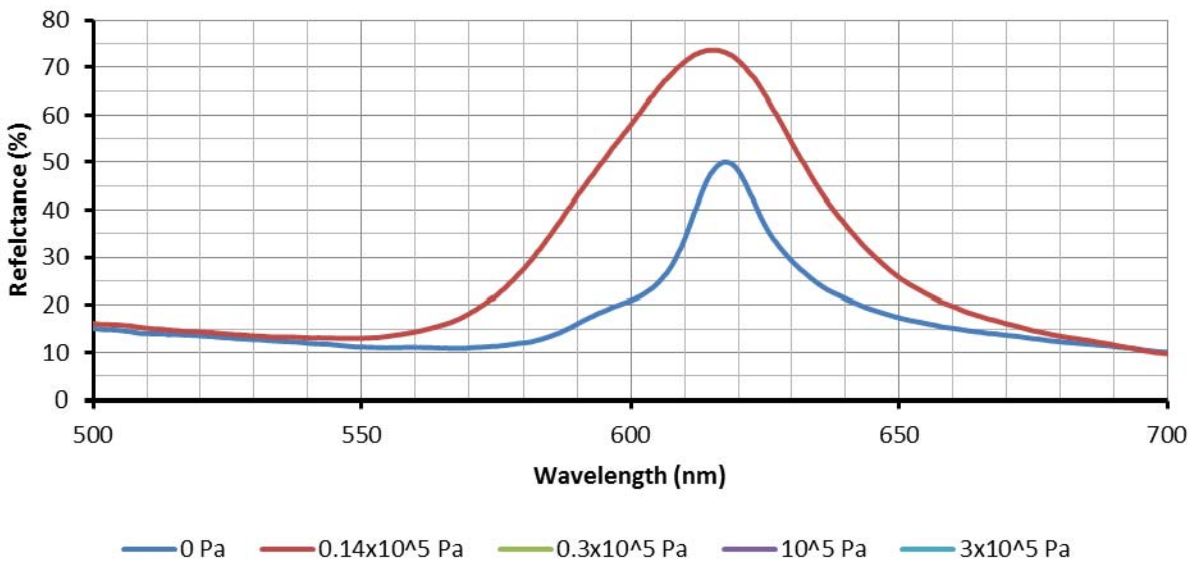

Fig.4. Spectra of unpolarized light reflection at various pressure differences.

Also we have experimentally studied the behavior of reflection spectrum of unpolarized light at various values of ΔP (Fig.4). The results show a small shift of selective reflection maximum wavelength to the shorter wavelengths. This confirms that at the surfaces of the cell substrates the pitch of CLC is not subject to strong distortions. From Fig.4 a change of FHWM of PBG could be noticed which occurs mainly due to PBG short-wavelength edge shift. This indicates the CLC helical pitch gradient formation due to hydrodynamic flow.

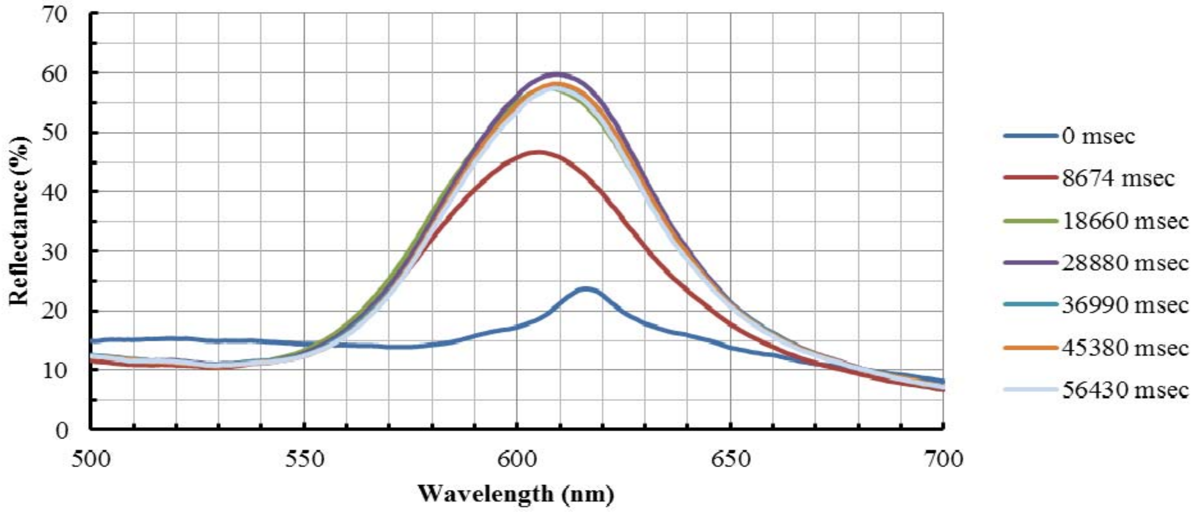

Fig.5. Reflection spectra of unpolarized light at 10^5Pa pressure difference measured after equal intervals of time.

It should be noted that the pitch deformation takes place during few tens of seconds. Figure 5 shows temporal behavior of reflection spectrum at $\Delta P = 10^5$ Pa. The characteristic time of stabilization of pitch deformation is about 30–35 sec.

3. Conclusions

Concluding we can say that for the first time the possibility of planar defect induction by means of hydrodynamic flow in a CLC is experimentally shown. It is also shown that by varying the pressure difference between the ends of CLC cell it is possible to control optical characteristics of the defect layer. This could be used in tunable filters, defect mode microresonators, etc. The observed phenomena can be interpreted by 3-layer model described in [8,10].

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