PROCEEDINGS OF THE YEREVAN STATE UNIVERSITY

Physical and Mathematical Sciences 2018, **52**(1), p. 55–59

Physics

FORMATION OF THE DISCLINATION DEFECTS IN THE DYE-DOPED CHOLESTERIC LIQUID CRYSTALLINE STRUCTURE UNDER THE INFLUENCE OF THE LASER BEAM

Zh. V. NINOYAN *

Chair of Optics YSU, Armenia

In the work the influence of the laser beam on the optical properties of highly absorbing dye-doped cholesteric liquid crystalline (CLC) structure is investigated. By means of polarizing microscope studies step-like variation of the CLC helical pitch and formation of the disclination defect lines (oily streaks) is observed.

MSC2010: Primary 81V80; Secondary 81V65, 82D15.

***Keywords*:** chirality, pitch, lasing, defects, dye, domain.

Introduction. Cholesteric liquid crystals (CLC) have unique optical properties and due to their periodic helical structure and large optical anisotropy have found many applications. One of the properties of CLC is the ability of selective reflection of the circularly polarized light within certain wavelength range with the same handedness of polarization as the helical structure. In other terms the CLC are photonic band gap (PBG) materials [1, 2].

The presence of PBG makes it possible to obtain mirrorless, wavelength tunable laser emission in the visible part of spectrum from fluorescent dye-doped CLC (DDCLC) structures [3,4]. Lasing emerges from the edges of the PBG when its spectral position overlaps with the luminescence spectrum of the laser dye [5]. Conventionally the CLC bandedge lasers are pumped by nanosecond laser pulses which are absorbed by the laser dye [6–8]. The influence of the pump beam on the optical properties of the DDCLC structures was studied in several works. In [9, 10] the step-like variation of the CLC pitch was observed as a result of non-linear reorientation of the LC molecules under the influence of the electric field vector of the laser beam. In [11] the spectral position of the PBG of the DDCLC structure as a result of the local heating was studied. However, in these works there were no microscopic studies conducted and the variation of the CLC helical pitch was observed by means of registering bandedge lasing wavelength and defocusing of the laser beam.

* E-mail: zhirayr.ninoyan@gmail.com

Another characteristic property of the CLC structure is the formation of disclination line defects, which are separating two CLC domains, where the number of the pitches in the helical structure differs by 0.5. Disclination defects were observed in the Cano-Grandjean wedge cells or during the formation of the CLC structure when the LC mixture is cooled from the isotropic state to cholesteric [12]. The latter one are called oily streaks. The density of the oily streaks depends on the cooling velocity of the LC mixture. Disclination defect lines of the first and second order were observed in the CLC structure unwinded by means of inhomogeneous electric field [13]. However, to the best of our knowledge there are no studies, which report on the formation of the oily streaks in the CLC structure under the influence of the laser beam.

In the present work the influence of the laser beam on the optical properties of the DDCLC structures is investigated. The laser beam is strongly absorbed by the dye. By means of polarizing microscope studies a step-like dialation of the CLC pitch and formation of the disclination defect lines were observed.

Experimental Part. For the experiments conventional LC cells of two parallel glass substrates glued at a certain distance from each other was used. The CLC mixture was sandwiched between two glass substrates coated by alignment layers and rubbed in anti-parallel directions in order to obtain planar CLC structure. The gap between the glass substrates and as a consequence the thickness of LC cell was 6.3 μm. The CLC is a mixture of nematic liquid crystal E7 and chiral dopant BDH 1305. In the experiments pure and fluorescent dye-doped CLC mixtures was used.

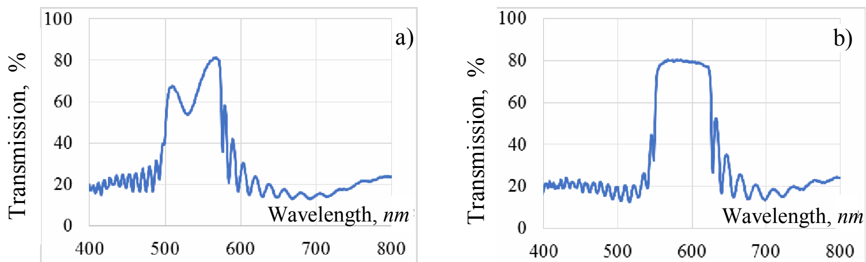

Fig. 1. The reflection spectra of a) **M1** (PBG 550–620 *nm*); b) **M2** (PBG 500–570 *nm*).
The thickness of the samples is 6.3 μm

The concentration of the nematic liquid crystal and chiral dopant was 94 : 6 in the first mixture (**M1**) and was 95 : 5 in the second mixture (**M2**). Later 1 wt. % of fluorescent laser dye Pyrromethene597 (PM597) was added into both CLC mixtures. PM597 has an absorption band in the 450 – 560 *nm* wavelength range and fluorescence within the 550 – 650 *nm*. The mixtures were heated to isotropic phase and capillary filled into the cells and slowly cooled to room temperature. The reflection spectra of DDCLC mixtures are shown in the Fig. 1. On both spectra we can observe selective reflection bands 500 – 574 *nm* for **M1** and 550 – 626 *nm* for **M2**. As we can see, the PBG of **M2** is shifted towards long wavelength comparing to PBG of **M1**. The reflection band of the **M1** is overlapping with the absorption band of the PM597, which could be seen on the spectrum. The helical pitches of **M1** and **M2** are estimated to be 331 *nm* and 361 *nm* respectively.

The experimental setup is shown in Fig. 2. We used a pulsed laser with 532 *nm* wavelength for optical pumping of the samples. The laser emits pulses of 12 *ns* duration and 12.5 *Hz* repetition rate. The power of the pump beam was controlled by half-wave retarder and the polarizing beam splitter. Pumping beam was focused onto the sample by a lens with 100 *mm* focal length at an angle of 45° with respect to the cell normal. We have used a CCD camera placed above the sample to investigate changes in DDCLC structure.

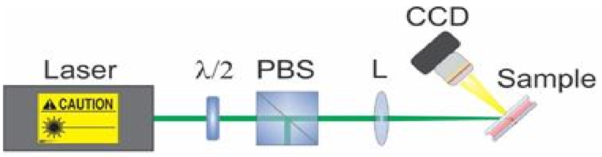

Fig. 2. Scheme of the experimental set-up with pump laser (532 *nm*, 300 *ps* and 7 *ns* pulse width); $\lambda/2$ (half wave plate for 532 *nm*); PBS (polarizing beam splitter); L (lens with 100 *mm* focal length); CCD (CCD camera).

Results and Discussion. Under the influence of the pump beam, the helical pitch of the DDCLC varies which could be observed in the form of reflectivity color change, which in its turn corresponds to the shift of the selective reflection band. On the Fig. 3 there are shown structural changes in the **M2** DDCLC layer under the influence of the pump beam of different powers.

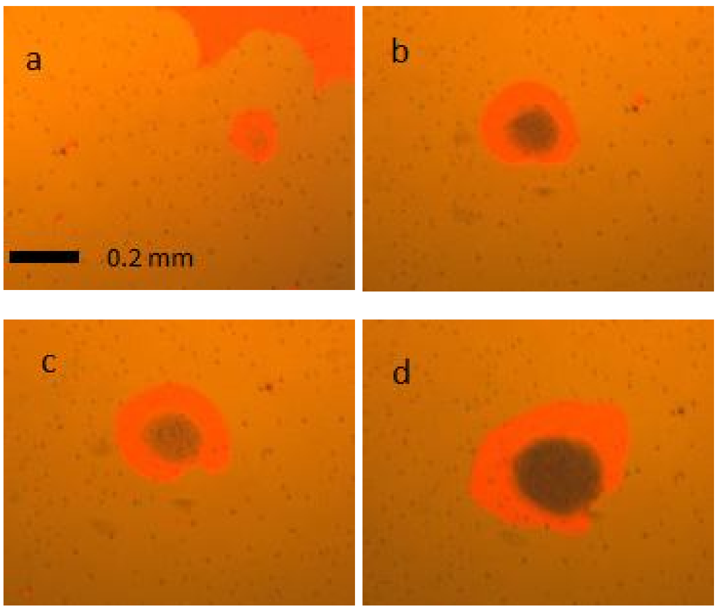

Fig. 3. **M1** DDCLC structural changes under the influence of pumping beam of different energies: (a) 96, (b) 144, (c) 192, (d) 288 μJ/pulse. Images were taken 15 *s* after launching the pump beam.

The images were captured after 15 *s* of launching the pump beam. The pump beam energies were 96, 144, 192, 288 μJ/pulse (Fig. 3, a, b, c and d respectively). There is a clear vision of helical pitch change area which changes its color to red under the influence of pumping laser beam. As we can see the pitch change area increases after setting a higher pumping laser beam energy.

Results for DDCLC **M1** layer are shown on Fig. 4. The pump beam energy was 4, 12, 24, 48 μJ/pulse (Fig. 4, a, b, c and d respectively). From the Fig. 4, a we can notice that pumping beam energy 4 μJ/pulse is not enough to cause visible changes in the DDCLC structure. Further increase of the pump beam energy leads to a variation of the DDCLC helical pitch and appearance of domains with different color reflectivity. On the Fig. 4, c besides of domains with different color reflectivity we can observe also disclination defect lines.

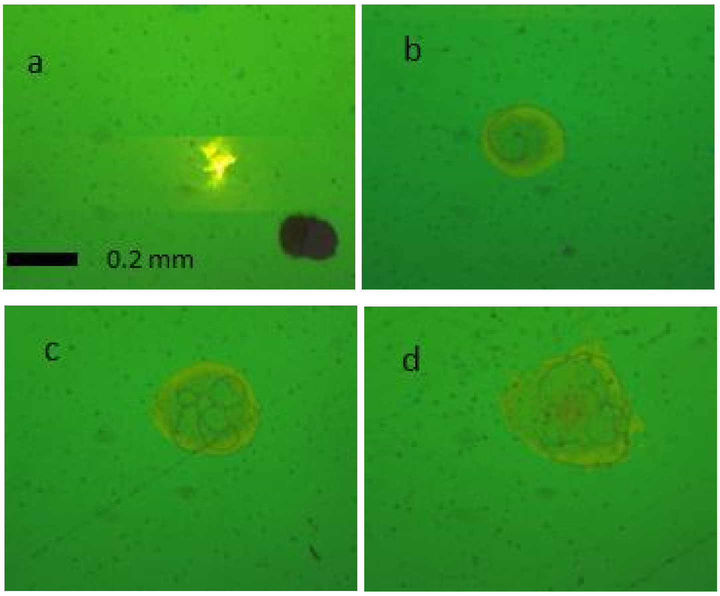

Fig. 4. CLC helical pitch step-like changes and Cano-Grandjean disclination defect lines for M2 for laser beam energy (a) 4, (b) 12, (c) 24, (d) 48 μJ/pulse. Images are taken after 15 s of laser pumping.

Under the influence of the electric field vector of the pump beam, the molecules of the CLC are being reoriented, which leads to unwinding of the CLC helical structure [14, 15]. The strong anchoring forces stipulate CLC to deform in such a manner to have an integer number of the half pitches. This leads to step-like dialation of the CLC pitch. Such behavior was observed for both DDCLC mixtures, while for pure ones we were not able to register any significant change in the CLC structure. On the Fig. 3, a we can see two areas with brighter red color, one of which emerged after the influence of the pump beam, while the larger one existed before the start of the experiment (upper right corner), during the sample fabrication process. The emergence of the defect lines in the DDCLC layer with **M1** under the influence of the pump beam with 24 and 48 μJ/pulse demonstrates total unwinding of the CLC structure which led to the formation of Cano-Grandjean disclination lines. These defect lines are separating domains with a difference of the number of the pitches equal to 0.5.

Conclusion. In the present work, we have studied the influence of the laser beam on the CLC structure. Experimentally it was shown that under the influence of the nanosecond laser pulses the helical structure of the DDCLC is unwinded step-like. In one of the mixtures, we were able to generate Cano-Grandjean disclination defect lines, which creates possibility of the DDCLC layers micro--structuring for further applications. The experiments have shown that in pure CLC structures it was not possible to cause any significant change using pump beam of the same order of energy as was used in DDCLC structures.

Author would like to acknowledge Professor R. Alaverdyan and T. Dadalyan for support and helpful discussions.

Received 22.12.2017

REFERENCES

1. **Funamoto K., Ozaki M.I., Yoshino K.** Discontinuous Shift of Lasing Wavelength with Temperature in Cholesteric Liquid Crystal. // Jpn. J. Appl. Phys., 2003, part 2, v. 42, № 12B, p. L 1523–L 1525.
2. **Schmidtke J., Jünnemann G., Keuker–Baumann S.** et al. Electrical Fine Tuning of Liquid Crystal Lasers. // Appl Phys Lett., 2012, v. 101, p. 051117.
3. **Kopp V.I.** et al. Low-Threshold Lasing at the Edge of a Photonic Stop Band in Cholesteric Liquid Crystals. // Optics Letters, 1998, v. 23, № 21, p. 1707–1709.
4. **Dadalyan T., Ninoyan Zh., Nys I., Alaverdyan R., Beeckman J., Neyts K., Willekens O.** Tuning the Lasing Wavelength of Dye-Doped Chiral Nematic Liquid Crystal by Fluid Flow. // Liquid Crystals, 2017, v. 44, p. 372–378.
5. **Coles H., Morris S.** Liquid-Crystal Lasers. // Nat. Photonics, 2010, v. 4, p. 676–685.
6. **Belyakov V.A., Gevorgian A.A., Eritsian O.S., Sipov N.V.** Effect of Anomalously Strong Absorption in Cholesterics. // Sov. Phys. Technical Physics, 1987, v. 32, № 7, p. 843–845.
7. **Gevorgyan A.H.** Mechanisms of Anomalous Absorption of Radiation in Media with Periodical Structure. // Mol. Cryst. Liquid Cryst., 2002, v. 378, p. 129–146.
8. **Gevorgyan A.H.** Resonant Interaction of Light with a Stack of Alternating Layers of a Cholesteric Liquid Crystal and an Isotropic Medium. // Phys. Rev. E, 2015, v. 92, p. 062501.
9. **Morris S.M., Ford A.D., Pivnenko M.N., Coles H.J.** The Effects of Reorientation on the Emission Prop. of a Photonic Band Edge Liquid Crystal Laser. // J. Opt. A: Pure Appl. Opt., 2005, v. 7, p. 215–223.
10. **Lukishova S.G.** et al. Nonlinear "Brightening" of a Film of Nonabsorbing Chiral Nematic Under Selective Reflection Conditions. // Pis'ma Zh. Eksp. Teor. Fiz., 1996, v. 63, № 6, p. 403–407.
11. **Alaverdyan R.B., Arakelyan S.M., Chilingaryan Yu.S.** Optical Bistability in a Nonlinear System with Distributed Feedback (Experiment). // Pis'ma Zh. Eksp. Teor. Fiz., v. 42, № 9, p. 366–369.
12. **de Gennes P.G., Prost J.** The Physics of Liquid Crystals. Oxford University Press, 1993.
13. **Belyaev S.V., Blinov L.M.** Step Unwinding of a Spiral in a Cholesteric Liquid Crystal. // JETP Lett., 1979, v. 30, № 2.
14. **Lukishova S.G., Magulariya E.A., Lebedev K.S.** Experimental Observation of Nd: YAG Laser Field Induced Nonlinear Frustration of Selective Bragg Reflection in the Cholestric Liquid Crystal. // ProcSPIE, 1996.
DOI: 2800:2800-2800-9
15. **Dadalyan T., Ninoyan Zh., Nys I., Alaverdyan R., Beeckman J., Neyts K.** Light-Induced Multi-Wavelength Lasing in Dye-Doped Chiral Nematic Liquid Crystals Due to Strong Pumping Illumination. // Liquid Crystals, 2018.
DOI: 10.1080/02678292.2018.1429680