The investigation of the behaviour of polarization of light passing through chiral liquid–crystalline photonic structures

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ABSTRACT

The possibility of defects induction controlled by external electric field was experimentally demonstrated in the cholesteric liquid-crystalline films with selective reflection in visible range of light. It was verified that due to the induced defect it is possible to control the rotation of polarization plane of light propagating through liquid-crystalline structure. The investigation of three types of defects induced near the input substrate, in the centre and near the exit substrate of the film was done. The basic result of the experiment is that the maximum value of the polarization plane rotation was observed when light after propagating through chiral liquid-crystalline photonic structure passes through the anisotropic defect layer.

Keywords: Cholesteric Liquid Crystals, Chiral Photonic Crystals, Selective Reflection, Defect Structures.

1. INTRODUCTION

The behaviour of polarization of light, propagating through the medium is directly connected with the optical characteristics of the medium and, therefore, provides a lot of information about medium. Apart from a merely fundamental interest, the investigation of the spatial dynamics of the light polarization state in different mediums has also great practical importance. For example, application of polarization methods is used in biomedical research, industry and optoelectronics[1]. During the last decade photonic crystals and various photonic structures became one of the most interesting objects of physics[2]. Liquid crystals, containing chiral molecules have a self-organizing helicoidal structure and a range of Bragg reflection. These mediums are called chiral photonic crystals (CPCs)[3,4]. The main difference between CPCs and usual photonic crystals lies in the fact that the photonic band gap in CPCs exists only for one circular polarization (for the case of normal light incidence), coinciding with the chiral medium helix sign. Based on them it is possible to create simply controlled light elements. CPCs such as: cholesteric liquid crystals, artificial chiral-made crystals etc., can function as tunable filters, switchers, and lasing devices. One of the main advantages of using liquid crystals over photonic crystals is the spontaneously formed periodic structure, without the need for complex fabrication procedures and the pecularity of such soft matter which may be readily deformed to achieve facile wavelength tuning. So, CLCs are now well established in basic research as well as in development for applications and commercial use. Cholesteric liquid crystals (CLCs) are particularly interesting one-dimensional materials because of their spontaneous self-assembly into periodic structures and the fact that the photonic band gap can be tuned over a broad range of frequencies. In terms of their optical properties, a prominent feature of cholesterics is the helical structure of their director axes. Such helicity gives rise to selective reflection and transmission of circularly polarized light [5,6]. CLCs are also optically active structures. Several studies on chiral photonic crystals showed that it is possible to create localized additional modes within the photonic band gap by inducing a defect into the periodic structure [7,8]. Thus it is extremely interesting to examine the liquid-crystalline mediums, if we take into account the broad possibility to control them by external field (including optical [9]).

The aim of this work is the experimental investigation of characteristics of the light polarization behaviour in the planar cholesteric liquid-crystalline mediums in the presence of defects, induced by electric field. We have observed the influence of the defect layer's location in the chiral photonic structure. We experimentally discovered some new features of CPCs taking into account the polarization characteristics of light for the case of normal light incidence.

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2. EXPERIMENT

2.1 Sample preparation

In order to investigate polarization plane rotation of light, we prepared cholesteric liquid-crystalline cells. A mixture of right-handed pelargonium(*X –17*), left-handed oleate (*X –26*) and *E-7* nematic liquid crystals in the ratio of 30:60:10 was prepared. The mixture was green in colour and the wavelength λ_R of laser radiation, illuminating the mixture was centered at 0,53μm. Our sample has 40μm thickness. The thickness of electrodes was 1μm and the distance between them was 1mm . The inner surfaces of glass substrates were first coated with thin polymide layer and then they were rubbed with special material. As a result the orientation of CLCs director was parallel to the surfaces, which means that the helix axis were perpendicular to the surfaces of the cell. The mixture was introduced into the empty cell by capillary action. One side of electrodes was conducting and the other side was non-conducting. By applying a voltage to different pairs of electrodes, we changed the defect location inside the system. Sandwiched cholesteric liquid-crystalline cell used in our experiment is represented in Figure 1.

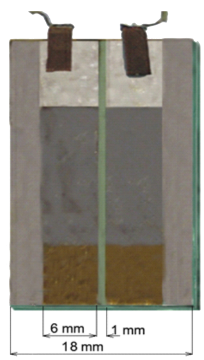

Figure 1. Sandwiched CLC cell (the light of laser radiation propagates perpendicular to the surface of CLC cell).

2.2. Experimental set-up

By applying electric field to the planar oriented cholesteric liquid-crystalline layer, we have observed the rotation of polarization plane of light. The voltage applied to the CLC cell changes the direction of molecular orientation (direction of director). Our estimations show that non-locality of the field results in the induction of the defect with the thickness of 2μm. As represented in Figure 2 we focused on three interesting cases: the first one concerns to the case when defect was induced near the input substrate of the film (a), the second one corresponds to the case when defect was induced in the centre of CLC film (b) and the last one concerns to the case when defect was induced near the exit substrate of the film (c). By applying a voltage to different pairs of electrodes, we changed the defect location inside the system. At certain values of applied voltage the induced anisotropic layer acts as a half-wavelength plate, which changes handedness of polarization[10]:

$$d \sim \frac{\lambda}{2(n_e - n_o)}, \tag{1}$$

where d is thickness of defect layer, λ is wavelength, n_e and n_0 are extraordinary and ordinary refractive indices, respectively. As it is known circularly polarized light reflecting from the CLC cell does not change its polarization direction. If defect locates in the centre of the film, band gap for both polarizations becomes prohibited due to the right-handed and left-handed polarizations reflection. If defect locates near the one substrate, one of the polarizations transmits and the other polarization reflects.

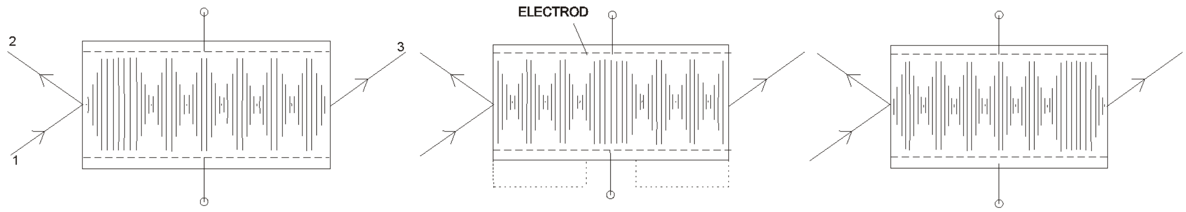

Figure 2. Schematic diagram of a CLC cell model with an anisotropic defect: a) defect was induced near the input substrate of the film, b) defect was induced in the centre of CLC film , c) defect was induced near the exit substrate of the film (1-incident light, 2-reflected light and 3-transmitted light).

We want to emphasize some peculiarities of the polarization plane rotation of light, which arises under the influence of the electric field. In order to investigate polarization plane rotation at first we found the selective reflection gap and just for this range we investigated rotation of polarization plane. For our sample selective reflection gap lies in the range of 15-25°C. Figure 3 illustrates the scheme of our experimental set-up. Light of laser radiation (diode pumping semiconductor laser with 0,53μm wavelength and 30mW power in CW regime) after passing through the prism and polarizer becomes plane-polarized, then it passes through quarter-wave plate and becomes circularly polarized. We use modulator in order to obtain discontinuous regime of laser radiation. Subsequently light falls on the microrefrigerator (the temperature of microrefrigerator was smoothly changed by temperature controller) and propagates into CLC cell after which it passes through second polarizer (our polarizers were crossed) and photodiode. Eventually we have observed the impulse on the screen of the oscillograph. Below we will discuss the phenomenon of polarization plane rotation of light for these three cases.

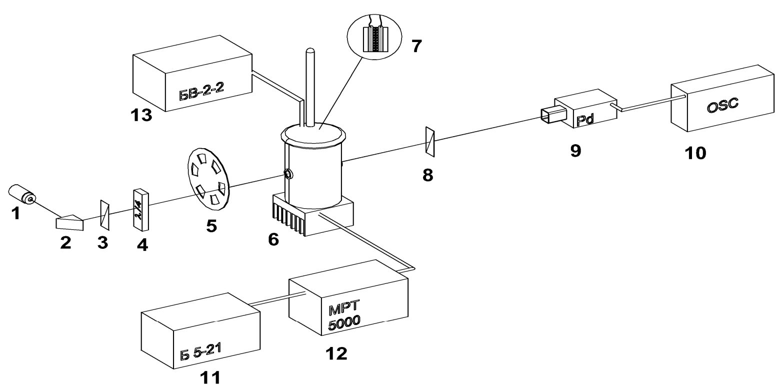

Figure 3. Scheme of experimental set-up: 1. Source of laser emission, 2. Prism, 3. Polarizer, 4. λ /4 wavelength-plate, 5. Modulator, 6. Microrefrigerator, 7. CLC cell, 8. Polarizer, 9. Photodiode, 10. Oscillograph, 11. Source of constant current, 12. Controller of temperature, 13. Source of constant voltage.

3. RESULTS AND DISCUSSION

External electric field was varied between 500-950V. We have measured rotation angles of polarized ellipse in respect to the primary direction. In order to define the primary direction at first we rotated exit polarizer by *π/4* from the crossed position of polarizers. For each measurement it was determined ellipticity $\sqrt{I_{\min} / I_{\max}}$ of transmitted light and then it was determined rotation of ellipse. The Fig.4 corresponds to the case when defect was induced near the input substrate of the film, in this case light falls directly to the anisotropic defect layer and the polarization plane rotates only by some degrees. Low temperature corresponds to the short wavelength boundary and high temperature corresponds to the long wavelength boundary. t =17°C is the peak temperature for the gap of selective reflection.

t=17°C

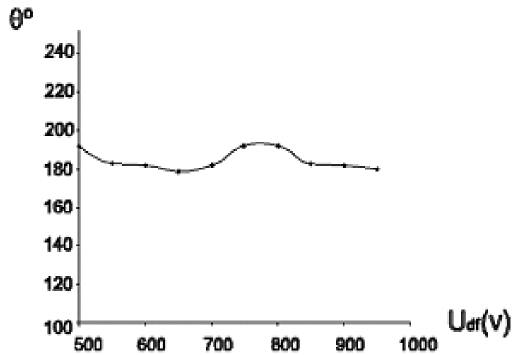

Figure 4. The dependence of the rotation of polarization plane from the applied voltage, when defect was induced near the input substrate of the film (for the case of peak temperature of selective reflection gap).

Figure 5 shows the dependences of the polarization plane rotation from the applied voltage when defect was induced in the centre of CLC film. In this case polarization plane rotates obviously. Our experimental result shows that at the boundary of selective reflection range the polarization plane almost didn't rotate. On the contrary, in the peak temperature, which coinciding t=19,8°C, the polarization plane rotation is large enough.

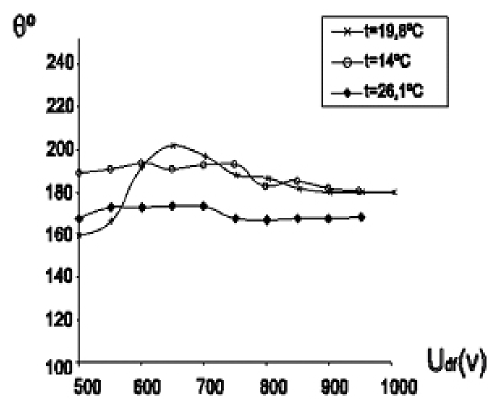

Figure 5. The dependences of the rotation of polarization plane from the applied voltage when defect was induced in the centre of the cholesteric liquid-crystalline film.

In Figure 6 similar dependences are presented. The measurements were performed at the temperatures 14,9°C, 20,9°C and 17°C. Our experimental results show that when defect was induced near the exit substrate of the film, the polarization plane rotation has maximum value. The similar measurements were performed in the absence of electric field and we noticed that in this case the rotation of polarization plane is less than in the presence of induced defect. Theoretical calculations are under way and we will publish elsewhere.

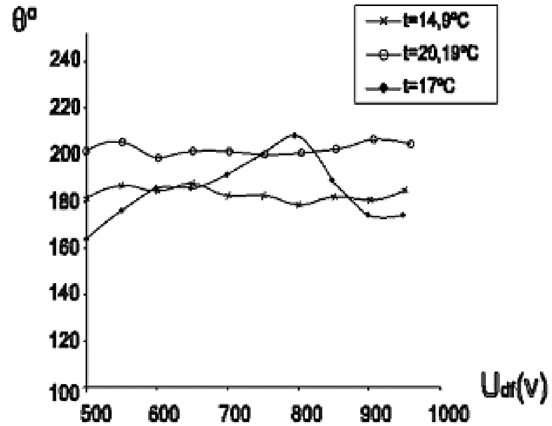

Figure 6. The dependences of the rotation of polarization plane from the applied voltage when defect was induced near the exit substrate of the film.

4. CONCLUSION

Concluding, let us note that when defect was induced on the input substrate of the film, the polarization plane rotates by about 15-20 degrees. In the second case, when defect was induced in the centre of the film, the polarization plane rotates 30-35degrees. The third case is when light propagates through the CLC film and then falls to the defect, in this case the polarization plane rotates by about 40-45 degrees. The main trend here is to obtain large rotation with small loss. The basic result of the experiment is the fact that the polarization plane rotation has maximum value when light firstly propagates through chiral liquid-crystalline photonic structure and then falls to the anisotropic layer. So, we have experimentally demonstrated that in the chiral liquid-crystalline photonic structures, which have property of selective reflection in visible range of light, it is possible to induce defect, which can be controlled by external electric field. We have investigated the influence of the defect layer's location in the CLC cells. We have also shown that due to induced defect it became possible to control the rotation of polarization plane of light. Our results can be used in the systems as a band optical diode for circularly polarized incident light as well as in sources of elliptically polarized light with tunable ellipticity.

ACKNOWLEDGMENTS

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