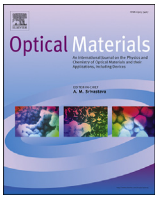
Optical Materials 69 (2017) 259–264

Contents lists available at ScienceDirect

Optical Materials

journal homepage: www.elsevier.com/locate/optmat



Polarization properties of cubic blue phases of a cholesteric liquid crystal

Kamil Orzechowski [a], [*], Marek W. Sierakowski [a], Marzena Sala-Tefelska [a], Pankaj Joshi [b], Tomasz R. Woliński [a], Herbert De Smet [c]

[a] Faculty of Physics, Warsaw University of Technology, Koszykowa 75 Str., Warsaw, Poland
[b] Schaeffler Technologies, Herzogenaurach, Germany
[c] Centre for Microsystems Technology (CMST), imec and Ghent University, 9000 Gent, Belgium

ARTICLE INFO

Article history:
Received 18 January 2017
Received in revised form
5 April 2017
Accepted 20 April 2017

Keywords:
Liquid crystal
Chiral media
Blue phase liquid crystal
Optical properties

ABSTRACT

In this paper, we have experimentally investigated polarization properties of the blue phase of a cholesteric liquid crystal in polycrystalline cells with different alignment layers. Experiments were carried out by various temperatures and wavelengths within the spectral range covering Bragg reflection. It was conclusively demonstrated that the change of polarization state of transmitted light through polycrystalline BP-cell is mainly due to Bragg reflection, while optical activity is relatively small. Besides, the linear birefringence was not observed, as expected. It was shown that the ellipticity of the outgoing polarization state can change from almost linear (1.33%) to elliptic (7.33%), depending on sample orientation, with negligible changing of optical rotatory power (for BP I at 470 nm). The results indicate that also polycrystalline BPLC structure, although locally anisotropic, is macroscopically isotropic showing non-negligible optical activity only for resonant wavelengths, although being much lower than that in a typical cholesteric phase. It was also shown that different alignment layers in BP-cell may shift Bragg reflection spectral range, so influencing the outgoing polarization state for particular wavelength.

1. Introduction

Blue Phase Liquid Crystal (BPLC) is a very promising material for prospective applications in novel displays and future photonic technology. BPLC is composed of chiral molecules, creating a self-assembling nanostructure in two levels of molecular arrangement: double-twist cylinders (DTCs) and supramolecular cubic structure made by regularly ordered DTCs (Fig. 1) [1–5]. At present, three structurally distinct types of the blue phase are identified: BP III, BP II, and BP I, appearing in order of decreasing temperature from the isotropic phase and naturally existing in comparatively narrow temperature ranges of 0.5–2 K. However, *in situ* polymerization technique proposed by Kikuchi et al. [6] allows to extend the temperature range of BP occurrence over tens of Kelvins. BP I has a body centered unity cell formed of DTCs, BP II is simple cubic, and BP III is a foggy phase whose structure is considered as an amorphous network of disclinations [7]. Due to its complex structure, BPLC possesses a few advantageous properties for photonic applications, such as ultra-fast switching speeds [8–10], existence of 3D photonic band gap manifesting in Bragg reflections related to cubic lattice structure [11,12], no need of alignment layers in display devices [13–15], induced birefringence by an external electric field (Kerr-like effect) [16], optical isotropy and polarization insensitivity on a macroscopic scale. Nevertheless, owing to intrinsic DTC twist BPLC is locally anisotropic, also in the absence of external fields and exhibits optical activity, albeit much lower than that in a typical cholesteric phase [17,18]. Additionally, BPLC can change the polarization state of the linearly polarized light into the elliptical one. This change was theoretically predicted in the subject literature [19,20] and by our measurements was confirmed experimentally. The rotation of the polarization azimuth i.e. optical rotatory power of monocrystalline BPLC was also reported to be of the order of a few degrees per micrometer [21,22].

This paper reports on polarization effects of BPLC for various temperatures and for different wavelengths within the spectral range covering Bragg reflection in polycrystalline BP-cells. Polycrystalline texture of BPLC, consisting of BP platelets of different orientations, is easily obtained and is more stable compared to a

---

* Corresponding author.
E-mail address: orzechowski@if.pw.edu.pl (K. Orzechowski).

http://dx.doi.org/10.1016/j.optmat.2017.04.051
0925-3467/

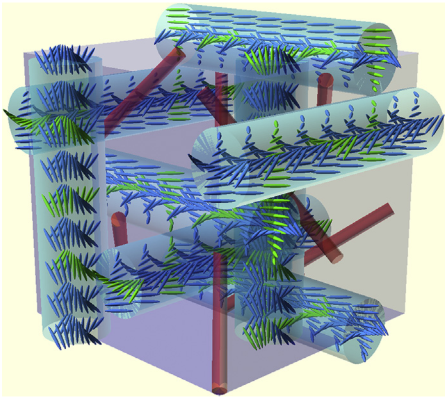


Fig. 1. Ordered DTCs forming a body centered cubic structure as unit cell of BP I. Green molecules correspond to connected helices, and red rods are related to array of liquid-crystalline disclinations in unit cell. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

monodomain cell. Since our measurements are aimed to recognize the polarization properties of BPLC for further applications in photonic structures, including optical fibers, we focus our measurements on polydomain samples, which we can expect in our applications. In our measurements different alignment layers (ALs) in BP-cells are used. ALs can create a BP structure with a very vivid colors of reflection and may change a range of selective reflections, even in polycrystalline samples. To the best of our knowledge, the influence of ALs on selective reflections in BP phases was not reported in literature [23–26], except one [27]. Joshi et al. showed that homogeneous ALs in LC-cell selectively influence BP II domains by reorienting and assisting them to get larger, resulting in sharp Bragg reflection in the visible range. The presented work shows the novel experimental results on the influence of different ALs on the polarization properties in BP-cell, extending earlier observations.

2. Material and methods

BPLC used in our experiment was a mixture consisting of nematics JC1041-XX (JNC Japan) (48.04% by wt.) and 5CB (38.41% by wt.), chiral dopant R5011 (3.15% by wt.), monomers EHA (3.39% by wt.) and RM257 (6.49% by wt.), and photoinitiator DMPAP (0.52% by wt.). The material was ready to polymer-stabilization, but the polymerization process was not carried out.

The experimental setup is shown in Fig. 2. A white-light source and four broadband LEDs were used as a light source. The LEDs operate with peak wavelength for Red = 635 nm (FWHM = 16 nm), Yellow = 590 nm (FWHM = 12 nm), Green = 518 nm (FWHM = 46 nm), and Blue = 470 nm (FWHM = 13 nm). In this study two 20 μm-thick LC-cells were used. The cells were prepared of high-quality float glass plates with thickness 0.7 mm. Polyimides SE-130 and SE-1211 (Nissan Chemical Industries, Ltd.) were used as orienting coatings for homogeneous (HG) and homeotropic (HT) alignment, respectively [28,29].

The BP-cell was placed on a heating stage with accuracy of 0.1 °C between crossed polarizers. It allows for (i) direct measurement the transmitted light attenuation due to selective reflections from BP structure in different temperatures, and (ii) examination the polarization properties of the BPLC. Each sample was heated over the temperature of BP–isotropic phase transition and then was cooled gradually at the rate of 0.1 °C/min passing through the subsequent phases of the LC. The spectra of transmitted light in all appearing phases were analyzed by using the Ocean Optics HR4000 spectrometer and the images of phase textures were recorded by using a polarizing microscope with a digital camera (not shown here). The geometrical cross-section area of the detected probe beam (2500 μm^2) was significantly larger (100:1) than the size of the BP platelets (~25 μm^2) in the samples.

We have noticed that ALs used in LC-cells have a significant influence on the textures of BP (Fig. 3).

3. Experimental results

Initially, the spectra of linearly polarized light (using a white-light source) transmitted through the BP-structure in the LC-cell for various temperatures were measured. It allows us to determine exact position of the Bragg reflection peak for each BP phase. The dots presented in Fig. 4 show the values of wavelengths for maximum intensity of light transmitted through the samples (for crossed polarizers) in various temperatures covering all the considered LC phases. The values indicated by dots in Fig. 4 correspond directly to the wavelengths of Bragg reflection maxima and show the temperature shift of reflection spectra in particular phases. In Fig. 4a the peak spectral positions are shown for sample with homogeneous (HG) AL, and in Fig. 4b for sample with homeotropic (HT) AL. Note the dramatic changes in peak position for the two ALs in chiral nematic phase (N*) and BP II phases as well as the double-maximum spectrum for HG AL (Fig. 4a). For HG AL, for which a uniform green texture in BP II was obtained, the Bragg reflection maximum was at ~550 nm (Fig. 4a). However, for HT AL the reflection was very weak in this region. In the latter case the reflection was more distinct at ~460 nm (Fig. 4b). In lower temperatures in BP I phase the Bragg reflection was observed at ~630 nm for both ALs, although for HT was more distinct than for HG. This implies that ALs have an essential impact on the orientation of BP domains, so that the incident light is reflected from different planes of the BP-structure. In BP I phase with HG AL we have observed also the second reflection at ~460 nm. It may be interesting that for polydomain BP samples one can obtain spectra with more than one transmission maximum. In lower temperatures

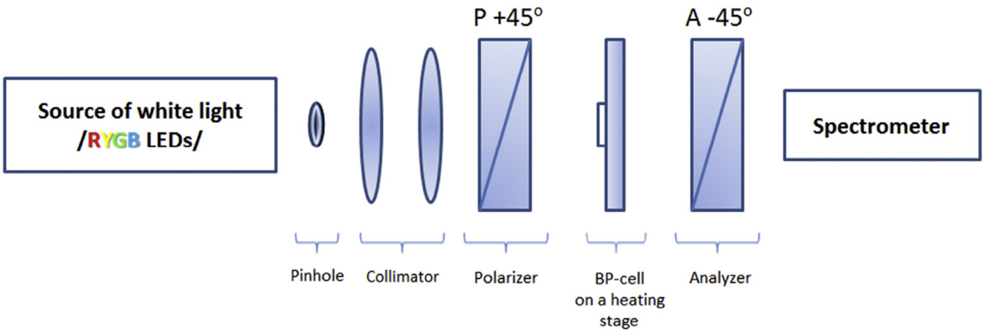


Fig. 2. Experimental setup to characterize of BPLC.