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Influence of cylindrical geometry and alignment layers on the growth process and selective reflection of blue phase domains

M.M. Sala-Tefelska [a, *], K. Orzechowski [a], M. Sierakowski [a], A. Siarkowska [a], T.R. Woliński [a], O. Strzeżysz [b], P. Kula [b]

[a] *Warsaw University of Technology, Faculty of Physics, 00-662, Warsaw, Poland*
[b] *Military University of Technology, Institute of Chemistry, 00-908, Warsaw, Poland*

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ABSTRACT

In this work we demonstrate the influence of cylindrical shape and alignment layers on light reflection in Blue Phase Liquid Crystals (BPLCs). The process of blue phase (BP) domains growth was observed in a microcapillary for the first time. The cylindrical structure, its diameter and alignment layers influence the orientations of cubic BP domains and affect their growth. A homogeneous BP structure was obtained in a cylindrical tube by changing the temperature and by using external electric field. This study also shows the ability of switching between BP I and chiral phase, in a capillary under the influence of the electric field.

1. Introduction

The blue phase (BP) is a liquid crystal (LC) state between isotropic and chiral phase. It usually exists in a narrow range of temperatures in chiral nematic LC with a small helix pitch. Half of the helix pitch p of the chiral nematic LC is shown in Fig. 1a. The BP consists of double twisted cylinders (Fig. 1b) which are placed on the cubic lattice in various directions. The double twisted cylinders are separated by the network of disclination lines which stabilize the 3-dimensional periodic BP structure. This is a metastable state with local minimum energy, which explains the very narrow temperature range in which the BP phase occurs. The double twisted chiral nematic LC in the BP phase resembles the chiral nematic phase in capillaries, which was mentioned in Refs. [1,2]. The BP can exist in three distinct sub-phases called: BP I, BP II and BP III, which is also known as a fog phase. BP I and BP II (Fig. 1c and d) have a cubic symmetry and exhibit Bragg reflections. The frequencies of the reflected light are in visible and UV ranges. BP III has the same symmetry as the isotropic phase and has a foggy, uniform consistency [3,4]. Although, the blue phase was discovered already in 1888 by the Austrian botanist and chemist Reinitzer [5], its properties were described years later at the end of the 20th century. Currently, the new technology of observation and analysis allows to get more information about the structure of BP domains, their growth [6–8], optical properties and potential applications [9–18]. The temperature range of BP appearance can be extended by addition of bimesogenic molecules or nanoparticles [19–21] and stabilized by using a polymer [22]. Therefore, it is easier to observe and use the BP phase in many experimental configurations. Recently, in paper [23] thermal tuning of guided light was demonstrated by using photonic crystal fiber (PCF) filled with BPLC. This kind of structure can be used as an optical filter. While, M. Wahle et al. [24] showed experimental and modal analyses of the electric field applied to photonic crystal fiber filled with BPLC. They observed that the asymmetric shift of photonic band gaps is a result of mixed polarization. The BP does not need orientation layers, which is a huge advantage for liquid crystal photonics and display technology. In spite of this, alignment layers can force a certain arrangement of BP cubes that can be used for other purposes. Recently, it was noticed that alignment layers change Bragg reflection in BP cells [14,17,25]. Also the stimuli-responsive blue phases were observed upon the addition of nanoparticles and dopants in the presence of alignment layer [26–28]. It is not obvious how BP behaves in different geometries and how the orientation layer influences the liquid-crystal configuration. Continuing research activities in this field we decided to examine cholesteric LC with the BP phase in microcapillaries. In this work,

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* Corresponding author.
E-mail address: martef@if.pw.edu.pl (M.M. Sala-Tefelska).

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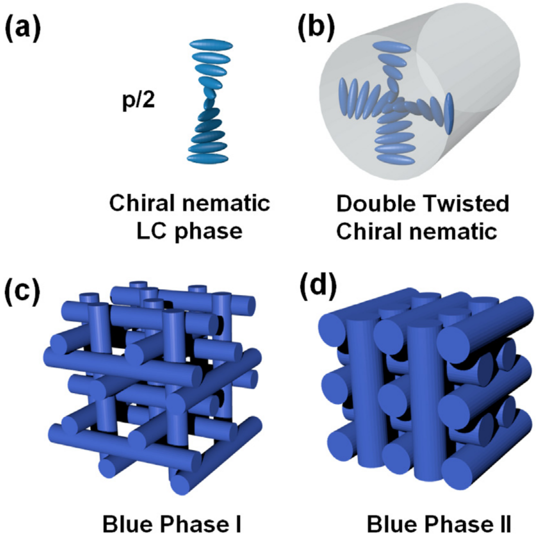


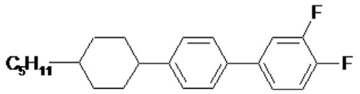
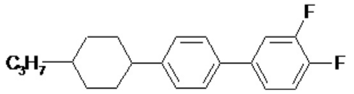
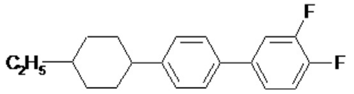
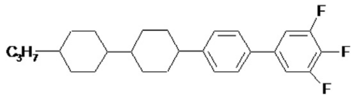
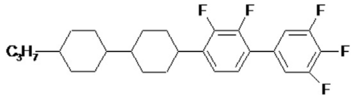
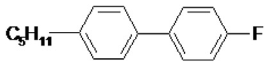
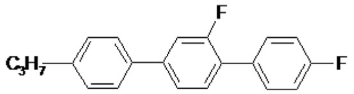
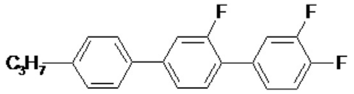
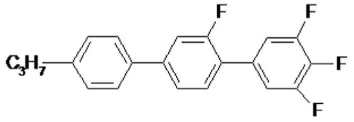
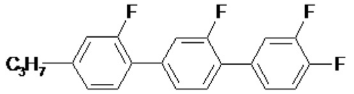
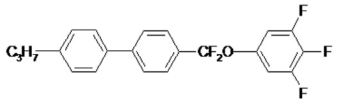
Fig. 1. (a) Single helical structure (half of pitch *p*) of the chiral nematic LC (b) One of the BP cube components - cylinder with double twisted chiral nematic (c) Cubic structures of Blue Phase I and (d) Blue Phase II.

the BP domains growth, in a single cylinder structure, was observed. Also, the influence of alignment layers and electric field on selective Bragg reflection was presented.

2. Materials and setup

The BPLC material used in the experiment is composed of nematic LC host - 1912 mixture mixed with two chiral dopants [29]. The major compositions of the 1912 mixture are photochemically stable fluorinated oligophenyls with fluorinated cyclohexyl- and bicyclohexylbiphenyls [30]. The compound structures and concentrations are listed in Table 1. Compounds 4–10 were synthesized at the Military University of Technology. Compounds 1–3 and 11 were provided by Valiant Fine Chemicals. The 1912 mixture has the melting point below −20 °C, clearing point at 78 °C and medium birefringence $\Delta n = 0.178$ at 589 nm. It has relatively low electric anisotropy $\Delta\varepsilon = 12.6$ at 1 kHz, and medium rotational viscosity $\gamma = 305$ mPa•s. All parameters were measured at 20 °C. To obtain the chiral nematic mixture with the BP phase, two optical active dopants (OADs) were added to the 1912 mixture: biphenyl-4,4-dicarboxylic acid bis-(1-methylheptyl) ester and [1,1;4,1] terphenyl-4,4-dicarboxylic acid bis-(1-methylheptyl) ester, both synthesized at the Military University of Technology [29]. Both structural formulas are presented in Fig. 2. The concentration of each optically active compound was 7.0 wt%. The measured macroscopic helical twisting power (HTP) of biphenyl and terphenyl ester is 25 μm^{-1} and 30 μm^{-1}, respectively and the helical pitch was 571 nm and 476 nm, respectively. The parameters were measured at 20 °C in a mixture of fluorinated compounds analogous to the components of the 1912 mixture. In this composition BP II appears in a range of temperatures from 60.5 °C to 59 °C and BP I appears from 58.9 °C to 54 °C, in a cooling process. The BP domains in the capillaries were observed with Nikon Eclipse Ts2R-FL polarized light microscope and Linkam THMS600 heating stage. The capillary was made of a pure silica glass and had 60 μm inner diameter with about 200 μm outer diameter and was manufactured at Maria Curie-Skłodowska University (MCSU) in Lublin. Cylinders were filled with the chiral nematic mixture by capillary action. The capillary with BPLC was put into the heating chamber and placed in the polarizing microscope. The inner surface of the capillaries was covered with SE130 and SE1211 polyimides (produced by Nissan Chemical Industries, Ltd.) to obtain planar and homeotropic alignment layers, respectively.

Table 1
Composition of the 1912 nematic mixture.

No.	Formula	Concentration in weight [%]
1		19.8
2		7.2
3		6.5
4		10.8
5		2.5
6		12.5
7		7.1
8		6.1
9		12.9
10		8.4
11		6.3

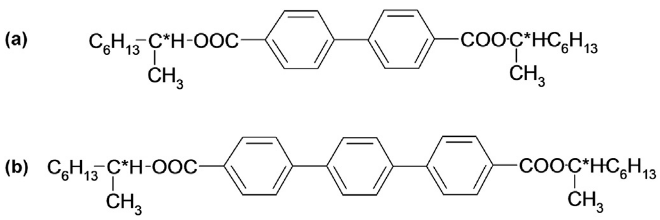


Fig. 2. (a) OAD1 - biphenyl-4,4-dicarboxylic acid bis-(1-methylheptyl) ester (b) OAD2 - [1,1;4,1]terphenyl-4,4-dicarboxylic acid bis-(1-methylheptyl) ester.