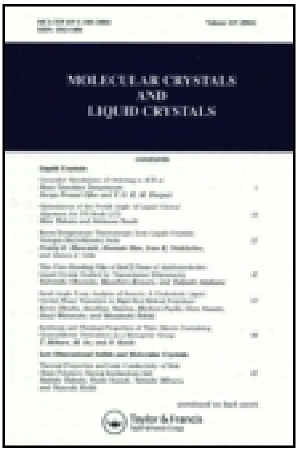

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Version of record first published: 18 Apr 2012.

Mol. Cryst. Liq. Cryst., Vol. 558: pp. 28–36, 2012

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2011.653676

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Recently introduced photonic liquid crystal fibers (PLCFs) prove to be excellent materials as all fiber devices in optic fiber telecommunication. PLCFs are a perfect complement the optic communication technology by actively controlled all-fiber devices such as attenuators, polarization or PMD controllers or phase shifters. The control is based on molecular orientation of an liquid crystal (LC) in a PLCF. The most research is devoted to an active control of LC orientation by external fields. A passive control is mostly omitted or assumed to be planar.

In this paper we investigate the passive control of LC molecules by using an aligning material between an LC and the inner surface of photonic crystal fiber (PCF) air holes. In the experiment we used commercially available polyimide—SE1211 to induce homeotropic anchoring condition in two different LCs: a 6CHBT nematic LC (NLC) and PW700 chiral nematic LC (CNLC). The aligning material increases and ensures the stability of initial orientation and without external fields the orientation is well defined in photonic liquid crystal fiber-based devices

Keywords Liquid crystals; photonic crystal fiber; photonic liquid crystal fiber; chiral nematic; orietation of liquid crystals

1. Introduction

Optical fiber technology has been well studied for a half a century and since its successful application in telecommunications the interest has been growing rapidly. Research has focused not only on communication technologies but has extended to be the field of sensors. This development of optical fibers continues and opens up great possibilities, one of them being a photonic crystal fiber (PCF) [1–4]. PCFs introduced about 15 years ago, enabled to achieve a new mechanism of light propagation governed by photonic band gap (PBG) in which light is trapped and propagated due to a defect of the 2D structure in comparison to tradition total internal reflection TIR [5]. The PCF structure bases on 2D lattice which is commonly created by a lattice of air holes around the defect, e.g. solid core. The latest

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achievement in PCF technology is to introduce a material into air holes. The filling material changes the refractive index of the PCF structure inducing a change of PCF properties. The materials whose properties can be changed by an external factor enable active control of PCF properties. One type of suitable materials and additionally anisotropic are LCs [6, 7]. The other advantage of an LC is that the it has been well examined as a material for LC displays technology. PLCFs, as a combination of two LCs and PCFs, have a great potential to improve and extend the range of application of all-fiber devices [8–12]. PLCFs can be dynamically tuned by e.g. temperature and electric field, but also PLCF technological process can also significantly influence their properties and has to be taken into account while designing such a device. Tuning of PLCF properties can be achieved in the same way as in LC cells by using an electric field or by a change of temperature, some systems can be controlled by an optical or magnetic field [13–16].

2. LC Orientation Control Techniques

A commonly used technique to induce alignment in an LC cell is rubbing [7, 17], due to the confined surface of PCF air holes, this technique cannot be applied, similarly, all other direct contact methods such lithography or particle bombarding [7, 17–21]. Indirect alignment control methods require additional material or treatment [7, 17, 19, 21–25]. Two most appropriate for alignment control inside PCF air holes are photo-activated and thermally-activated polymers [17, 21–26]. These two methods are based on placing an extra layer of monomer solution on the inner surface of each air hole in a PCF lattice. Polymerization in a high temperature creates an aligning layer, for photo-activated materials, additionally, the layer is irradiated by polarized UV light to finish the process.

Preliminary research on orientation control was conducted on a single element of the periodic PCF structure, a capillary, to enable observation samples under polarizing microscope. We used capillaries of 8 and 13 μm inner diameters and an external diameter of about 125 μm, and their total length was 15 cm (manufactured at the Maria Curie-Skłodowska University (Lublin, Poland)). These studies consisted in observing of two types of liquid crystal with induced homeotropic aligning conditions. We used a SE-1211 polymer (Nissan Chemical Industries, Ltd.) [27] by filling and removing excess solution from the PCF by different pressure applied at both ends of the capillary. We removed the solvent at 90 degrees (C) and then baked the polymide at 180 degrees (C) for about 45 minutes. The sample prepared with an aligning material was filled with an LC.

Initially NLC 4-(trans-4′-n-hexylcyclohexyl)-isothiocyanatobenzene (6CHBT) (manufactured at the Military University of Technology-MUT, Warsaw, Poland) [28–30] was measured.

Figure 1 shows that there is a color change in the transmittance caused by molecules configuration inside the capillary tube (Fig. 2) since a more complex LC molecules structure influences the transmitting light.

To confirm molecules arrangement, we used an interferometric polarizing microscope (Fig. 3). The shift of the fringes confirms LC escaped radial configuration. The fringe shift at the center of the capillary differs from the one at the inner edge of the capillary. We calculated birefringence changes for the maximal fringe shifts. Birefringence can be described (1).

$$\Delta n = \frac{\lambda}{L} \cdot \frac{d}{h} \tag{1}$$

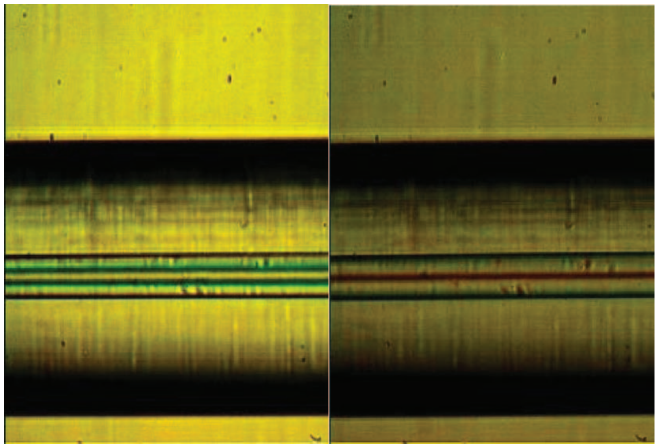

Figure 1. LC escaped radial configuration in the capillary under a polarizing microsope with parallel polarizers on the left capillary is parallel to polarization axis, and on the right it is tilted for 45°.

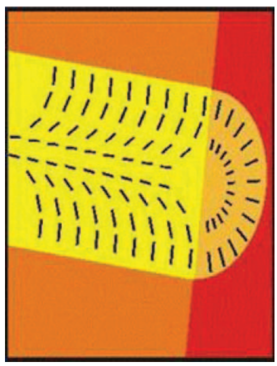

Figure 2. LC splay configuration.

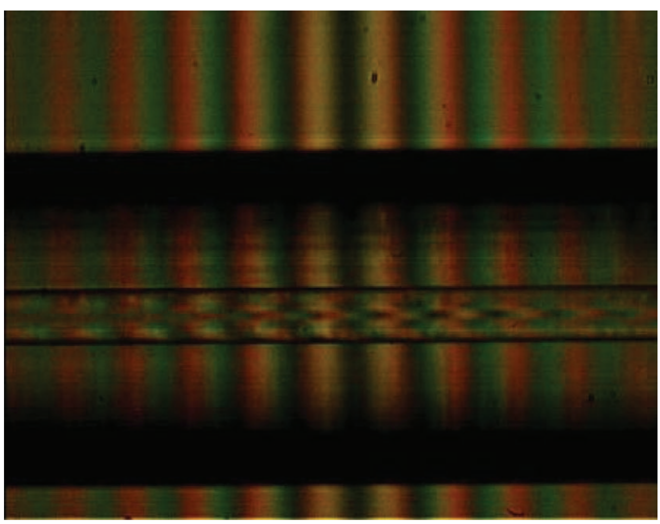

Figure 3. Image of the LC escaped radial configuration observed under interferometric polarizing microscope.

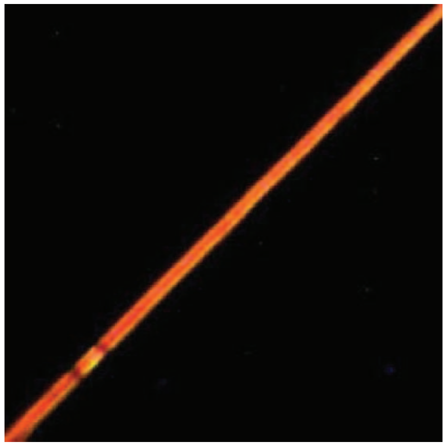

Figure 4. LC planar configuration in the capillary under the polarizing microsope with crossed polarizers the capillary is tilted for 45°.

where Δn is the LC birefringence, L is the thickness of the capillary and of the changes in a distance from the capillary axis, λ is the average wavelength (550 nm), h is the distance between two fringes, and d is the shift of the fringe. We calculated 0.2 birefringence based on two external shifts, to the left and right.

We compared results with capillary without an orienting material which caused a planar LC configuration (Fig. 4). Similar measurement was done under interferometric polarizing microscope (Fig. 5).

Preliminary studies were done for a CNLC mixture (PW700) (manufactured at the Military University of Technology-MUT, Warsaw, Poland) characterized by a helical pitch of 400 nm. No particular orientation is evident for samples with no aligning materials (Fig. 6). By contrast, the sample with a homeotropical aligning layer (Fig. 7) exhibits stable LC

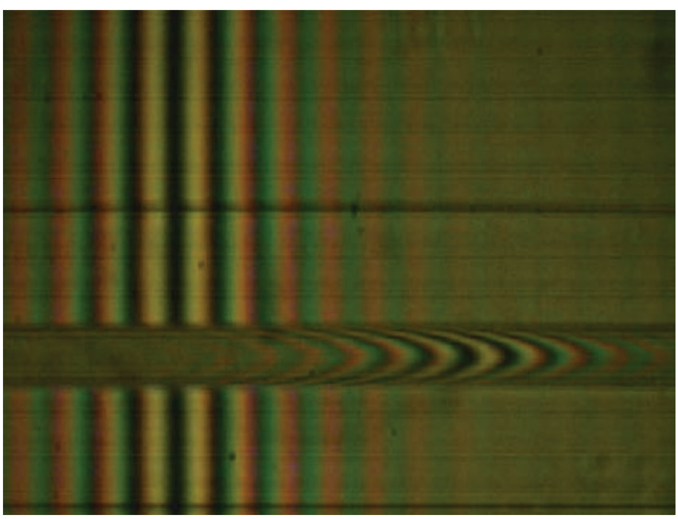

Figure 5. Image of the LC planar configuration observed under interferometric polarizing microscope.

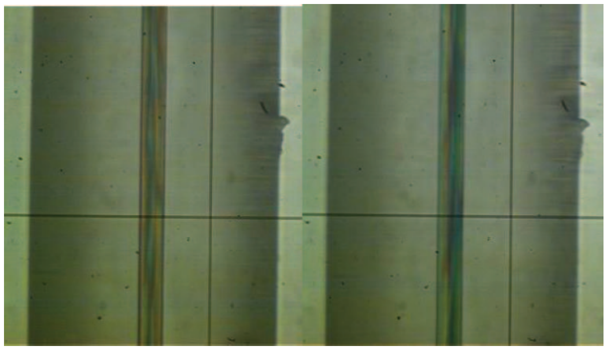

Figure 6. CNLC without any alignment material on the inner surface of the capillary under polarizing microscope, with parallel polarizers on the left capillary long axis parallel to the polarization axis, and on the right, the capillary long axis being at 45° to the polarization axis.

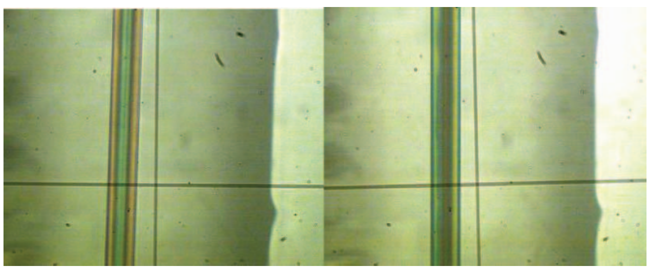

Figure 7. CNLC with homeotropic alignment material on the inner surface of the capillary under polarizing microscope, with parallel polarizers on the left capillary long axis parallel to the polarization axis, and on the right- the capillary long axis being at 45° to the polarization axis.

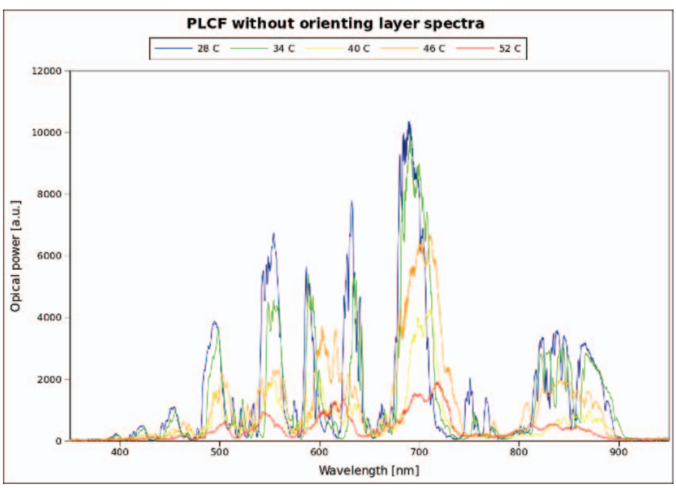

Figure 8. Changes of the spectra of PLCF filled with NLC without orienting layer under increasing temperature.

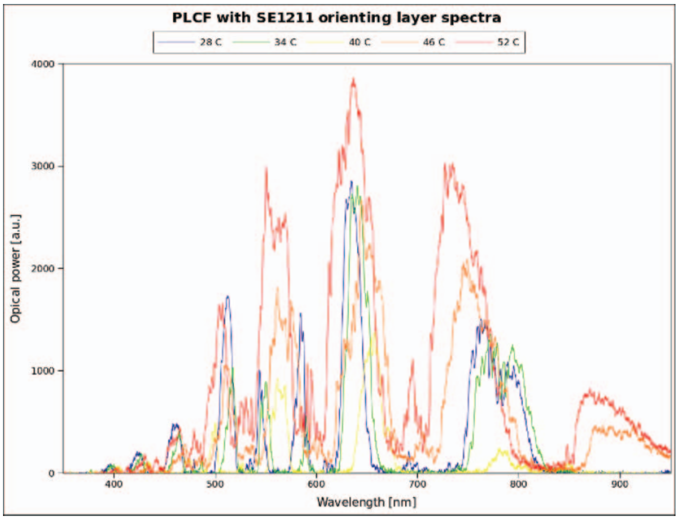

Figure 9. Changes of the spectra of PLCF filled with NLC with homeotropicaly orienting layer under increasing temperature.

molecules orientation similar to an NLC. The complex structure of a CNLC forces us to include the twist factor to account for the orientation structure of this LC.

3. Orientation Control in PLCF

LC orientation measurement was indirect for PLCF samples—by analysis of spectral transmission and response to the temperature change. PLCF samples were prepared in the same procedure as a capillary, except that we used the PCF of 3 and 6 rings of air holes external diameters of 125 μm (manufactured at the Maria Curie-Skłodowska University (Lublin,

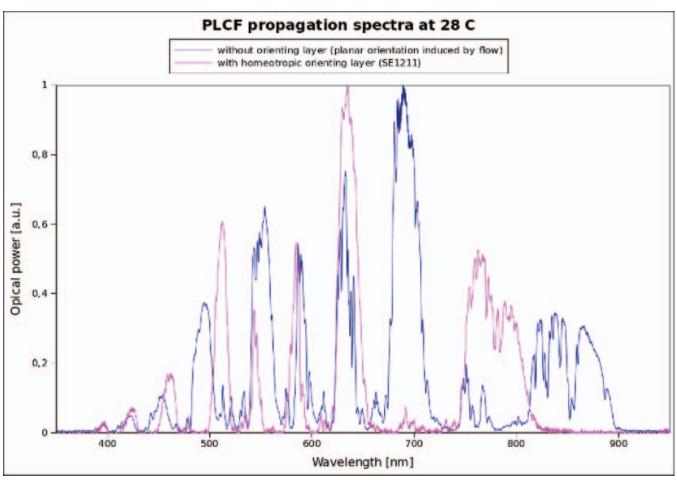

Figure 10. Comparison of the spectra of PLCFs filled with NLC for samples with and without homeotropically aligning material.

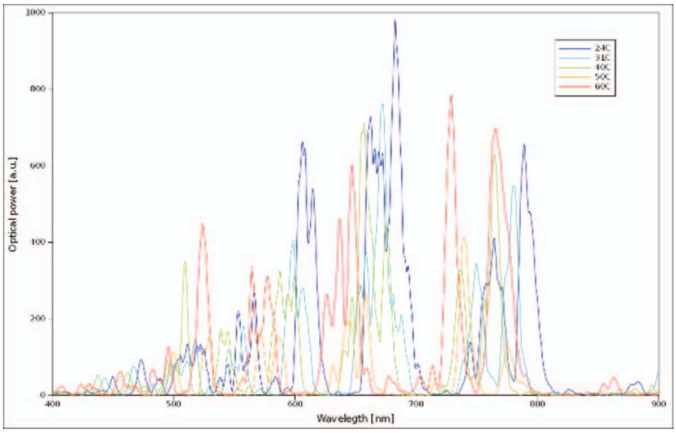

Figure 11. Changes of the spectra of a PLCF filled with a CNLC without orienting the layer under increasing temperature.

Poland)). The PLCF without an orienting layer has the typical behavior of a red- or blue-shifting PBG (Fig. 8). The PLCF with a homeotropically aligning layer (Fig. 9) represents a different behavior—from room temperature to 40 degrees, two PBGs (at 650 nm and 750 nm) are characterized by the red-shift, further heating up the reversing peak shift direction into the blue-shift.

The experimental results of a PLCF filled with a CNLC (Figs. 11 and 12) show similar behavior—the blueshift during an increase of temperature, however, the division of PBGs for PLCF without additional layers suggest that the LC orientation is not uniform along the sample, which is the consequence of a random orientation presented in Fig. 6.

Comparison for both types of LC at low temperature presents major influence of anchoring conditions on propagating light (Figs. 10 and 13).

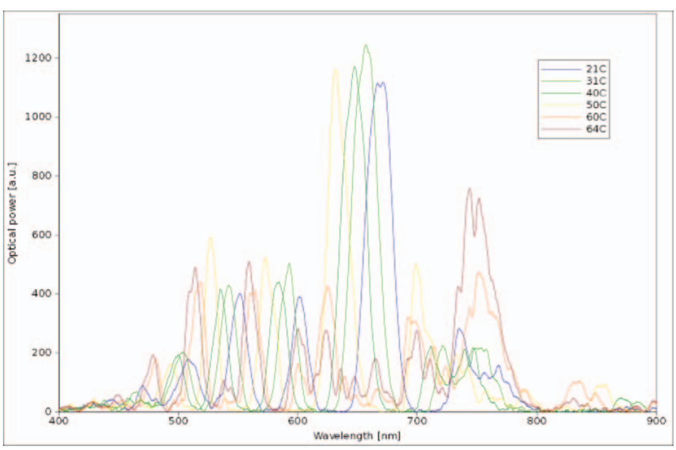

Figure 12. Changes of the spectra of a PLCF filled with a CNLC with homeotropicaly orienting the layer under increasing temperature.

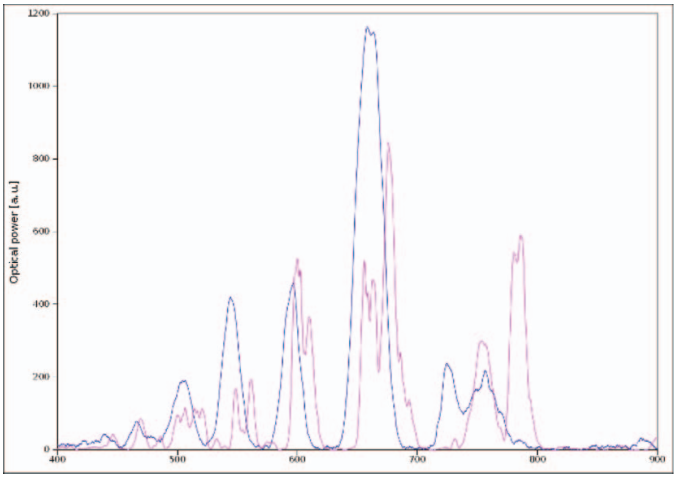

Figure 13. Comparison of the spectra of PLCFs filled with NLC for samples with and without homeotropically aligning material.

4. Conclusion

We presented various spectral PLCF responses to changing temperature. We have proved that the type of LC anchoring conditions plays a crucial role in performance of the potential PLCF device. In this paper we have presented selected spectral characteristics of the PCFs infiltrated either with NLC or CNLC under the influence of temperature. We have proved that specific LC anchoring conditions play a predominat role in performance of the prospective PLCF-based devices. It appeared that in CNLCs the issue of orientation control in PCFs is even more critical than pure NLCs.

Acknowledgment

This work was supported by the Polish Ministry of Science and Education under the grants N N517 554139 and N N507 439539 and partially by the "Master" Programme of the Polish Science Foundation. M. Chychłowski acknowledges the European Social Fund through the Warsaw University of Technology Development Programme granted by the European Union and partially by the MISTRZ Programme of the Polish Science Foundation.

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