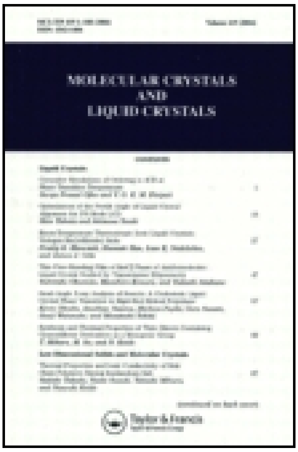

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Escaped Radial and Planar Liquid Crystal Orientation Inside Capillaries

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In this paper we present the experimental results of two configurations of liquid crystals (LCs) in capillaries: escaped radial and planar induced by thermally activated anchoring conditions. 6CHBT nematic LC was filled into silica glass capillaries with inner diameters of 13 and 8 μm. The homeotropic and planar boundary conditions were realized by using commercially available alignment materials.

Keywords liquid crystals; LC orientation; aligning materials; photonic crystal fibers

1. Introduction

Photonic crystal fibers (PCFs) have focused increasing research interests over the last decade and they constitute the next step in the development of optic fiber technology [1, 2]. PCFs are two-dimensional periodical structures and are characterized by new physical properties. Recent advances in this field are photonic liquid crystal fibers (PLCFs) that, by combining PCFs and LCs, can greatly increase optical fiber tuning possibilities. Prospective devices based on PLCFs can be used in optical telecommunication as all-optical controlling devices improving optical transmission quality as well as sensors of various physical quantities [3–9].

Due to special properties of both LCs and PCFs there is a great need to control the alignment of LC molecules [10–12] within a PCF. LC orientation in the PCF can be modeled by LC orientation in a single capillary. Since classical alignment techniques such as rubbing or particle beam deposition are rather impossible, other indirect methods should be used, e.g., the methods based on an additional layer created on the inner surfaces of PCF holes or within a capillary tube [13, 14].

Both the escaped radial and planar orientations of LC molecules inside capillary tubes can be achieved due to using either homeotropic or planar aligning materials. The homeotropic and planar boundary conditions were realized by using commercially available alignment materials. We chose an indirect method for LC orienting within capillary tubes. The method uses high temperature to create orienting structures at polymer layers. Inside the capillary tube, homeotropic boundary conditions result in the escaped-radial (splay)

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LC configuration that cannot be achieved without any orienting layer. However, planar boundary conditions enhance homogenous LC alignment quality in comparison to the flow-induced alignment. The results obtained related to the LC orientation control inside capillaries could be directly applied into more complex structures such as PCFs resulting in better performance of advanced PLCF-based devices.

2. Materials and Experimental Procedures

In the experimental, we used capillaries of 8 and 13 μm inner diameters made of silica glass. External diameters of these capillaries were about 125 μm and their total length was 15 cm. The capillaries were manufactured at the Maria Curie-Skłodowska University (Lublin, Poland).

Different boundary conditions were achieved by using appropriate aligning materials. The homeotropic boundary conditions were realized by using the SE-1211 polymer (Nissan Chemical Industries, Ltd.). Treatment of inner surface of capillary by this type of the aligning material and inner diameter of more than 1 μm causes the escaped-radial LC configuration. The planar boundary conditions were realized by using the SE-130 polymer (Nissan Chemical Industries, Ltd.) respectively [15]. This procedure enhanced planar LC orientation inside the capillary.

4-(trans-4′-n-hexylcyclohexyl)-isothiocyanatobenzene (6CHBT) nematic LC [16] was selected to test quality of the alignment induced by both polymers inside capillaries.

Filling of the dissolved aligning material and the LC as well as extracting of the dissolved aligning material excess were executed in the same setup. A high pressure system was used to induce materials flow due to pressure difference at both ends of the glass capillaries. During the whole infiltration process one end of the capillary and the liquid were subjected to pressure of 4 bars whereas the other one was subjected to 1 bar. During extraction of the excess of the dissolved aligning material both capillary ends were placed in air and the pressure was subjected similarly. Filling and extracting times varied within a range of a few minutes to an hour and a half, depending on the material and diameter of the capillary. Two additional steps were realized to make an aligning layer after filling and removing the excess of the dissolved orienting material. The first one comprised solvent evaporation by heating the sample to temperature about 90 degrees (C). The second involved heating the capillary with polymide at its inner surface at 180 degrees (C) for one hour to obtain material polymerization.

3. Measurement

The obtained LC molecules orientations within the capillary tubes were investigated under a polarizing microscope. The angle between the capillary axis and the input polarizer was modified during observations. It is evident that both planar and escaped-radial LC configurations are rotationally symmetrical along the longitudinal capillary axis.

Since the planar LC orientation has been previously investigated by us [13], we have concentrated our research efforts on the escaped-radial LC orientation measurements under the interferometric polarizing microscope and then on birefringence calculations for selected points of the capillary cross section.

4. Results

In this section we present the results of applying the aligning material to the inner surface of the capillary and then filled with the nematic liquid crystal.

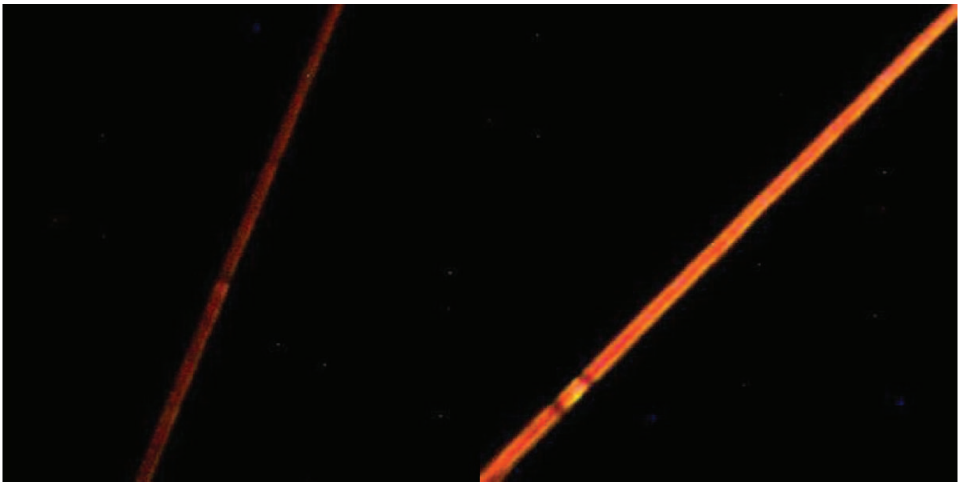

Figure 1. LC planar configuration in the capillary under the polarizing microscope with crossed polarizers. Capillary is at 45 and 22.5 degrees to the polarizer.

4.1. Planar Orientation

In Fig. 1 are presented images of 13-μm capillary with the planar 6CHBT alignment induced by the SE-130 polymide as observed under the polarizing microscope with crossed polarizers. The Images were taken at the same angle, showing changes in transmittance characteristic for this LC orientation type.

4.2. Escaped-Radial Orientation

In Figs. 2 and 3 are presented images of the 8-μm capillary with the splay 6CHBT alignment induced by the SE-1211 polymide as observed under the polarizing microscope with either

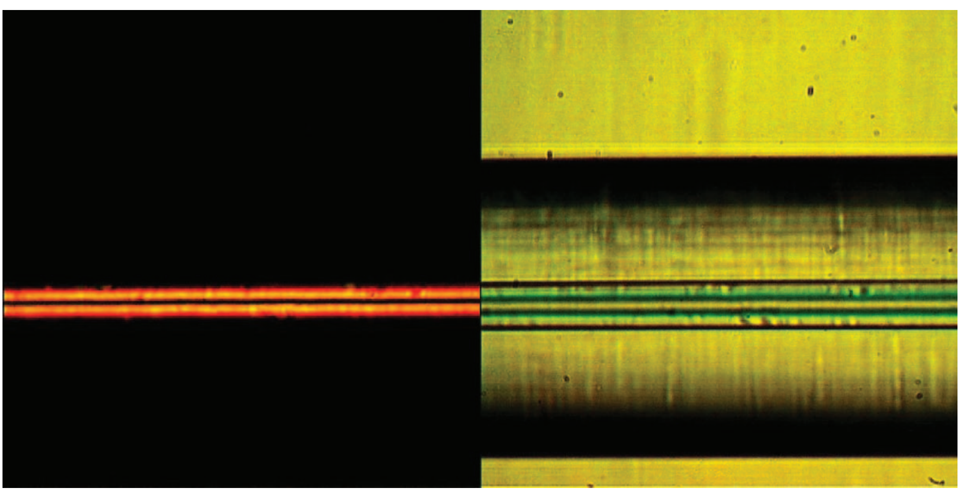

Figure 2. LC splay configuration in the capillary under the polarizing microscope. Polarizer is at 0 degrees to the sample axis. Both polarizers are either crossed (left), or parallel (right).

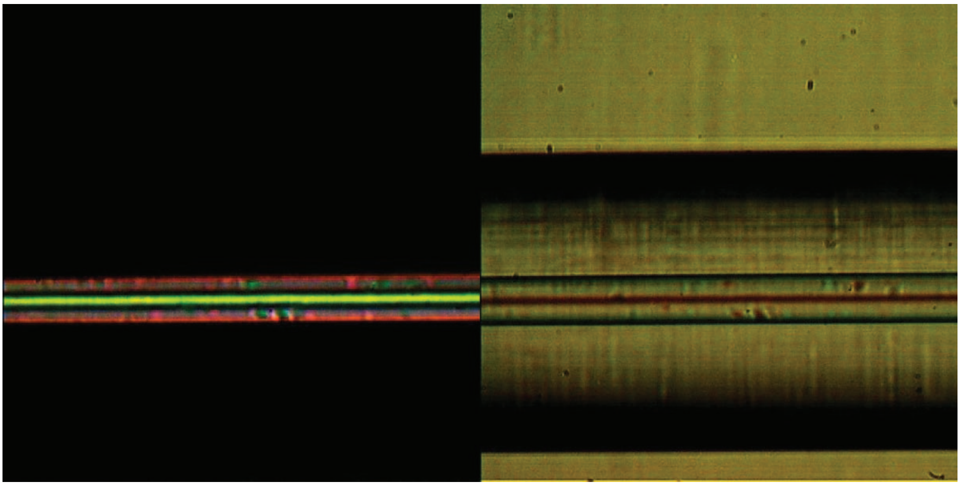

Figure 3. LC splay configuration in the capillary under the polarizing microscope. Polarizer is at 45 degrees to the sample axis. Both polarizers are either crossed (left), or parallel (right).

crossed or parallel polarizers. There is a characteristic color change and transmittance shift while the sample rotates in the polarizers plane. This color change is caused by molecules configuration inside the capillary tube (Fig. 4) since more complex LC molecules structure influences the transmitting light.

To be sure of the obtained splay configuration, we examined the sample by using the interferometric polarizing microscope (Fig. 5). The shift of the fringes confirms LC splay

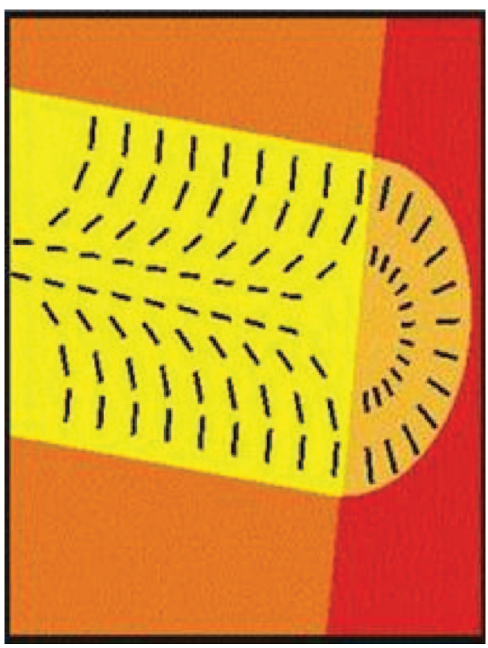

Figure 4. LC splay configuration.

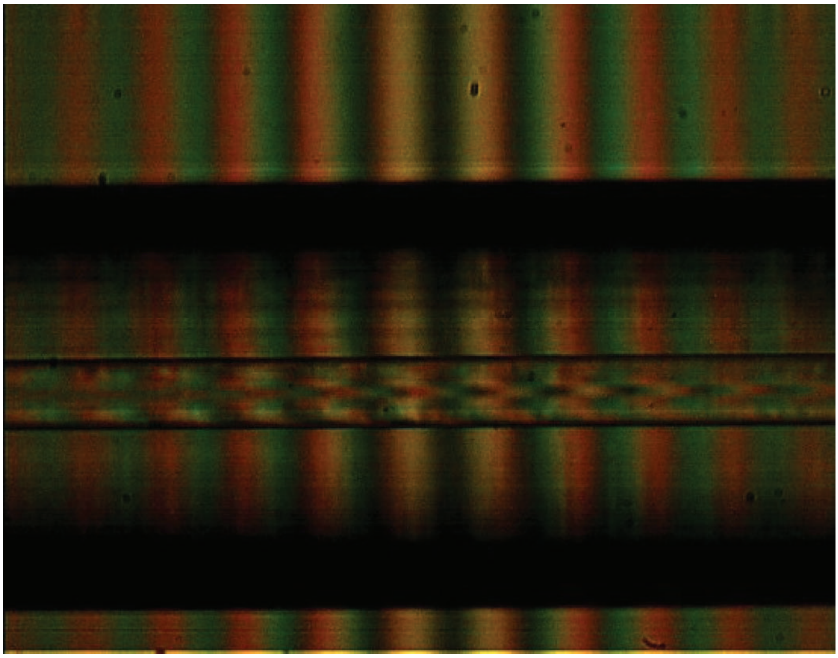

Figure 5. LC splay configuration in the capillary under the interferometric polarizing microscope. Both the polarizer and the analyzer are at 45 and 135 degrees to the sample axis.

configuration. The fringe shifts at the inner edge of the capillary differs from the one at the center of the capillary. Birefringence changes were calculated for the maximal fringe shifts. Birefringence can be described by the following equation:

$$\Delta n = \frac{\lambda}{L} \square \frac{d}{h}$$

where Δn is the LC birefringence, L is a thickness of the capillary and of the changes in a distance from the capillary axis, λ is an average wavelength (550 nm), h is a distance between two fringes, and d is a shift of the fringe.

The calculated birefringence for the maximal fringe left shift is 0.1, at the cross section center of the sample the fringe shift to the right is maximal and also is equal to 0.1. Since both shifts are in opposite directions, the total birefringence between these fringe shifts is equal to 0.2.

5. Conclusions

Planar and escaped-radial LC configurations were realized by using thermally activated aligning materials. Measurements of the samples with applied homeotropic boundary conditions under the interferometric polarizing microscope indicate direction of birefringence changes that confirms splay-type of the molecular orientation.

The experimental results obtained along with the alignment method created by thermal treatment of the material that was successfully realized in a single capillary can be straightforwardly applied to sets of capillaries in the form of the PCF to improve or extend PLCF-based devices.

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