Analysis of liquid crystals orientation in microcapillaries

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Abstract—Growing interest in photonic liquid crystal fibers, as relatively easily controllable optical fiber devices, force us to examine the quality of orientation of liquid crystals infiltrating a photonic crystal fiber. In this letter, we present a novel method of orientation analysis of liquid crystals in microcapillaries.

Photonic liquid crystal fibers (PLCFs) can find various applications in tunable photonic devices. To the most promising applications belong fiber-optic sensors of various physical quantities such as temperature, pressure, electric and/or magnetic fields[1-3]. Other applications include light beam propagation control in all-optical telecommunication systems such as polarizers, attenuators, polarization mode dispersion compensators, and filters. All these devices are based on PLCFs in which an arrangement of liquid crystal (LC) molecules is a crucial factor.

The examination of LCs orientation within a PLCF can be done by using a standard polarimetric approach for LC quality orientation testing in LC cells[4]. However, difference in the complexity of PLCFs and LC cells structures force us to study the LC arrangement in basic elements of PLCFs i.e. capillaries. Polarimetric measurement is sufficient to determine the type and quality of molecular orientation in LC cells.

Our previous research [5] of orientation induced by an additional layer in capillaries proved a good agreement with the experiment. It appeared that the LC molecules orientation measurement under a polarizing microscope can be used to identify the type of orientation of an LC in a capillary.

However, this approach is not sufficient for testing the quality of LC molecular alignment in LC-infiltrated capillaries in which thin orienting polymer layers play the major role in the arrangement of LCs molecules. In display-type LC cells a typical distance between both glass surfaces is from 1 µm to 20 µm, assuring that the surfaces can influence and control the arrangement of LC molecules. Since photonic crystal fibers (PCFs) have rod-like air holes, the major role on LC orientation will be attributed to microholes of the cylindrical shape instead of flat surfaces. One of the experimental methods of LC molecules orientation determination is to measure the birefringence of a liquid crystal in a capillary tube – the basic element of a PCF. Initially, to induce and control orientation within PLCFs capillaries with diameters of 25-µm have been chosen. Difficulties in controlling thickness of the orienting layer were the main reason for using these relatively high diameters of the capillaries. The other reason is that a typical air-hole diameter of the side-hole fibers is about 20-30 µm and our orientation technique can be applied to the side-hole fibers

In experimental birefringence measurement, we used a 25-µm capillary filled with a 6CHBT nematic liquid crystal (NLC) and with an additional pVCi planar orienting layer. Then the birefringence of the sample was measured by using the interferometric polarizing microscope (Fig. 1). The main difference between a polarizing microscope and an interferometric polarizing microscope is additional prisms splitting polarization before an analyser. These two beams travel with different velocities because of the birefringence of the prisms. Finally, the interference occurs at the analyser.

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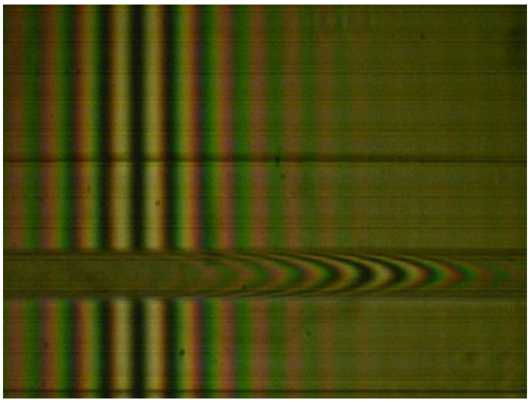

Fig. 1: Interferometric image of a capillary with NLC placed in an immersive liquid

The birefringence of a 6CHBT in a planar (homogenous) orientation within the capillary was measured perpendicular to the capillary axis plane and can be described by the following equation[6]:

$$\Delta n \cdot L = \left(n_e - n_o\right) L = \lambda \frac{d}{h} \qquad (1)$$

$$\Delta n=\lambda\frac{d}{hL} \tag{2}$$

$$\Delta n(x)=const\,\frac{d(x)}{L(x)} \tag{3}$$

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

In the central part of the capillary, the ratio d/h is equal to 8.8. Hence, the measured birefringence of the 6CHBT LC in the capillary based on the formulae (2) is equal to 0.19.

Precise study of the curvature of a fringe pattern on an interferometric image induced by the birefringence of the NLC in the capillary corresponds to the birefringence and to the thickness of the sample in function of the distance from the capillary axis (central part of the capillary). In an ideal planar orientation of the LC in a cylindrical-shaped container, birefringence is constant (Δn), which implies that the ratio d/L would be also constant (3). L as the thickness of a capillary in function of the distance from capillary axis x is given by the equation:

$$L(x)=2\cdot\sqrt{(r^2-x^2)} \tag{4}$$

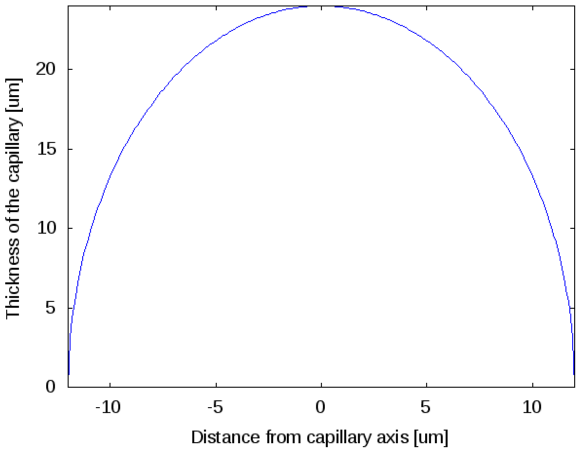

Fig. 2: Thickness of the sample

A shift of maximum in function of the distance from capillary axis x should be described by the same type of function, as shown in Figure 2, to fulfil the constant ratio condition. Analysis shows a certain deviation of the ratio between the interferometric shift and the thickness of the sample. This deviation is caused by the difference of the best fitting function describing the interferometric shift in comparison to a change in thickness in an ideally cylindrical tube. Several types of functions were considered to fit the experimental data of the interferometric shift; two approximations are presented in Fig. 3: second order polynomial function and the square root of the second order polynomial function. The second order polynomial function is the best fitting function. However, the square root of the second order polynomial function could be the only fitting function to fulfil the ratio constant condition (d/L = const.).

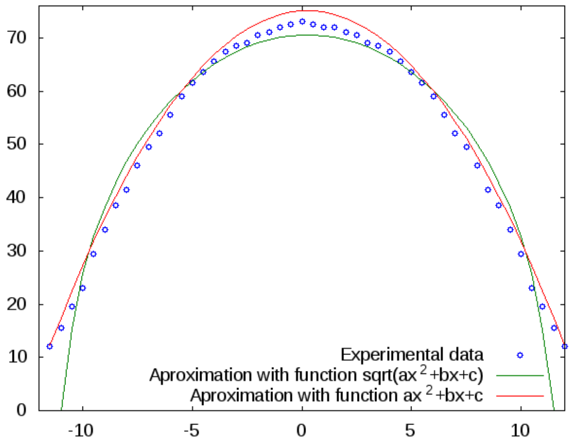

Fig. 3: Approximations for experimental data of interferometric shift

The polynomial function is equal to:

$$d(x)=a\cdot x^2+b\cdot x+c \tag{5}$$

and the square root of the polynomial function is given by:

$$d(x)=\sqrt{(a\cdot x^2+b\cdot x+c)} \tag{6}$$

Fig. 4 presents the following functions: the sample thickness vs. distance from the capillary axis (4) and the best fitting approximation of the interferometric shift (5).

This change in ratio proves that the birefringence of the measured sample is not constant and can be written as a ratio of the approximated shift function to the thickness function (Fig. 5). The calculated change of the NLC birefringence in the capillary is about 0.06, which is 30% of its maximal value. Assuming the ideal cylindrically capillary, this birefringence change can be caused by not ideally planar orientation of the LC molecules.

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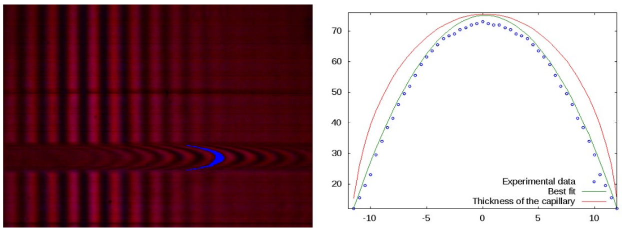

Fig. 4: Interferometric shift a) image from the microscope with the marked shift b) aproximation of the interferometric shift and the function of the sample thickness

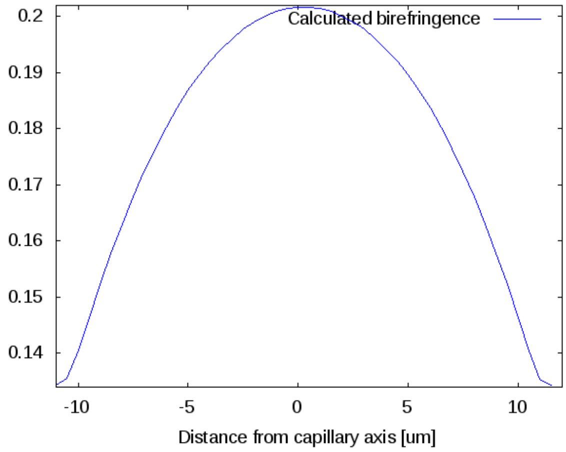

Fig. 5: Change of birefringence with thickness of the sample

This change in birefringence can be caused either by a tilt angle induced on the capillary surface, or by an additional effect introduced by the orienting layer. Alternatively, they can be caused by both of these factors. This analysis does confirm the observed effect of NLC birefringence lowering with a decreasing thickness of the sample. The decreasing value of birefringence observed at the "edges" of the capillary suggests that NLC molecules could have a tilt angle. This tilt angle can be attributed to the manufacturing procedure of the sample.

To conclude, the main objective of this analysis was to compare experimental results with theoretical assumptions. An experimental data were obtained from the polarizing microscope interferometric images of a microcapillary filled with a nematic liquid crystal and two approximation functions were proposed. Since the best fitting function did not match the theoretical model based on an ideally cylindrical tube, the observed mismatch can be the result of NLC deviation from planar (homeogenic) orientation.

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