A Single Step Method for Characterizing Blue Phase LCs at Various Temperatures

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ABSTRACT

Characterization of Blue Phase liquid crystals (BPLC) at different temperatures is an interesting but time consuming research activity. We present a quick and efficient one step method to record the Polarization optical micrograph (POM) depicting texture of BPLC at various temperatures simultaneously and also support our case with COMSOL simulations.

1. INTRODUCTION

Blue phase (BP) are frustrated thermodynamic phases existing in chiral liquid crystals between isotropic and chiral nematic (N*) phases. Three distinct types of BP have been identified, viz. BP-I, BP-II and BP-III in order of increasing temperature. BP-I and BP-II are known to possess body centered and simple cubic structures respectively, whereas BP-III is amorphous. Owing to the inherent 3D periodicity in arrangement of disclinations (defects) BP possesses photonic band gaps. In nature BP only exists in a very small temperature range (~1° C) severely limiting their use in practical applications. It was only after the stability range was drastically enhanced by polymer stabilization [1] they started to attract attention of the display research community. Some of the features which make BPLC a promising candidate material for future displays are:

- Sub-millisecond grey-to-grey response times
- No requirement of alignment layers
- Optically isotropic dark state

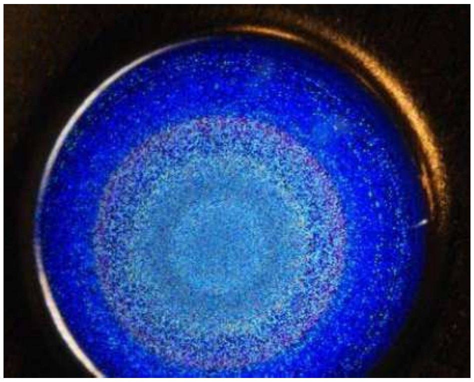

Fig 1. Polarization Optical Microscope image (POM) showing variation in texture of Blue Phases.

The first step of optical characterization of BPLC consists of recording its texture under a polarization optical microscope (POM). The liquid crystal cell is mounted on an accurate heating stage and placed between crossed polarizers to observe the texture either in transmission or reflection mode. The circular opening in the metal heating stage which facilitates light transmission also results in a temperature gradient in the opening. Since BP is very sensitive to temperature, this variation howsoever small, manifests in the POM as can be clearly seen form Fig. 1. The outermost ring is the edge of the circular opening of the heating stage. As we proceed radially inwards the temperature falls and this results in a slightly different texture of the BP platelets. While the temperature gradient might seem to be an unwanted artifact of the observation setup, it can be used at our advantage provided we have an accurate mapping of the temperature distribution. We performed finite element method (FEM) based simulations in COMSOL's "heat transfer in solids" module to calculate this variation in temperature. To corroborate this variation we also measure the transmission spectra at various spots, and a shift in peak reflection wavelength was observed.

2. EXPERIMENTAL RESULTS

2.1 Polarization Optics Micrographs

Although on a macroscopic scale BPLCs are isotropic, they possess a photonic band gap for one of the two circularly polarized lights, depending upon the handedness of the chiral dopant or liquid crystal itself. The LC cell with BPLC is placed between crossed polarizers. The linearly polarized light can be seen as a sum or equal amount of Left and Right circular polarizations. Hence the light crossing the second polarizer will be confined to those wavelengths which satisfy the Bragg reflection condition [2]. This wavelength will be different for differently oriented crystals, resulting in distinctly colored platelets as shown in Fig. 2.

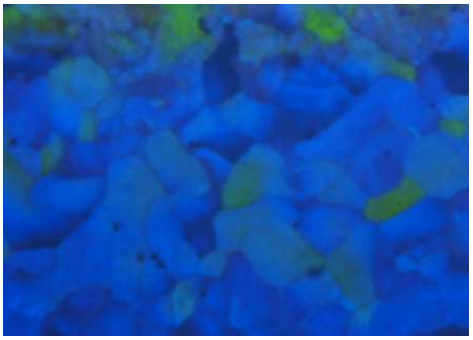

Fig 2. POM: clearly showing different platelets and grain boundaries.

2.2 Bragg reflection and transmission spectrum

A typical transmission spectrum of polymer stabilized blue phase at two spots is shown in Fig. 3. We used a Xenon lamp (Hamamatsu E7536) as a broadband white light source, and the spectrum was recorded using a fiber spectrometer (OceanOptics USB2000). The Bragg reflection wavelength is related to the crystalline plains as:

$$\lambda = \frac{2na}{\sqrt{h^2 + k^2 + l^2}} \qquad (1)$$

Where, *n* is the average refractive index of BP, *a* is the lattice constant and *h, k, l* are Miller's indices of the crystal plane.

The variation in temperature in the circular opening also reflects in the shift of the central reflection wavelength as we go outwards form the center of the cell.

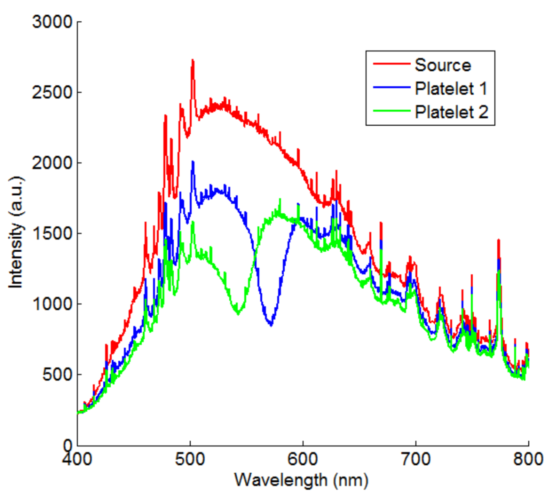

Fig 3. Spectrum showing the dip in transmission owing to Bragg reflection for two platelets, with central wavelengths at 543 nm and 572 nm.

3. COMSOL SIMULATION

3.1 Mathematical description of the simulation

The design of the heating stage is such that the part where the liquid crystal cell is mounted is connected to the heating element only at one of its edges, as can be seen from Fig 4-(b). We are interested in the variation of temperature in this region of the LC Cell. The stage is made up of Nickel coated copper. The temperature profile in the opening, obtained from COMSOL [3] is depicted in Fig. 4-(a). Two modes of heat transfer involved are conduction and radiation, which have been modeled in COMSOL's-heat transfer in solids module.
Heat conduction in solids is governed by Fourier's law of heat conduction:

$$q = -k\nabla T \qquad (2)$$

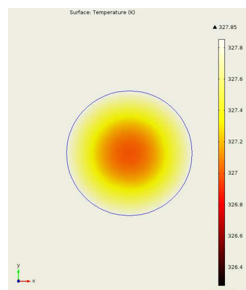

Fig 4-(a). Simulation results, showing variation of temperature in the circular opening.

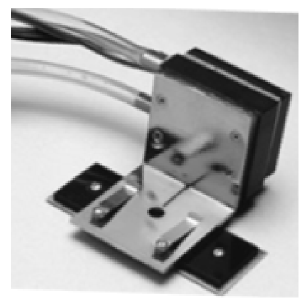

Fig 4-(b). Picture of the heating stage used in this study.

where, *q* is heat flux and *k* is thermal conductivity. The heat loss due to radiation is governed by Stefan's-Boltzmann's law:

$$q = -\epsilon\sigma(T^4 - T_0^4) \qquad (3)$$

where, ϵ is the emissivity and σ is Stefan's constant.

4. RESULTS AND DISCUSSION

4.1 Temperature profile

The variation in the temperature caused by the presence of the circular opening can be seen from Fig. 4. By carefully observing the texture of the liquid crystal at a certain spot, while cooling down from the isotropic to the Cholesteric phase (N*), the appearing of BP and subsequent phase transition to the N* phase, gives a good measure of the range of existence of BP. For this study we use a mixture of JC-1041xx, 5CB and ZLI4572 and the temperature range of stability is found to be 0.9℃.

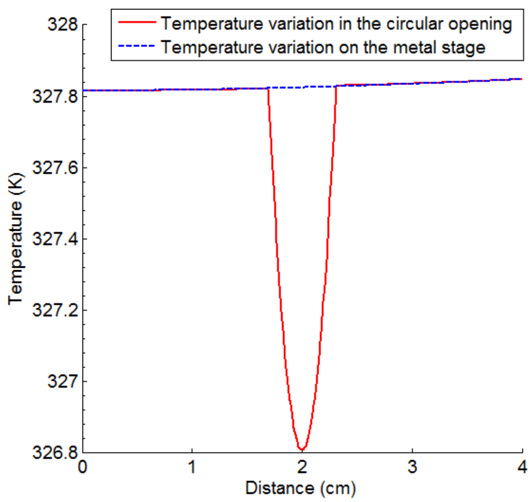

Fig 4. Variation in temperature on the stage and in the circular opening.

4.2 A Better design of the heating stage for BP

Taking cue from the success of the Grandjean–Cano cell [4] for the study of Cholesteric liquid crystals (CLC), we also propose that a heating stage with a rectangular opening is even more suitable for the study of BPLC. We foresee that instead of obtaining similar textures with circular symmetry we will obtain parallel strips which will make optical characterization considerably more convenient.

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REFERENCES

[1]. Hirotsugu kikuchi, Masayuki Yokota, Yoshiaki Hisakado, Huai Yang and Tisato Kajiyama, “Polymer-stabilized liquid crystal blue phases”, Nature Materials 1.1 (2002): 64-68

[2]. Wright, David C., and N. David Mermin. "Crystalline liquids: the blue phases." *Reviews of Modern physics* 61.2 (1989): 385.

[3] http://www.comsol.com/

[4] Podolskyy, Dmytro, Oluleke Banji, and Per Rudquist. "Simple method for accurate measurements of the cholesteric pitch using a “stripe–wedge” Grandjean–Cano cell." *Liquid Crystals* 35.7 (2008): 789-791.

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