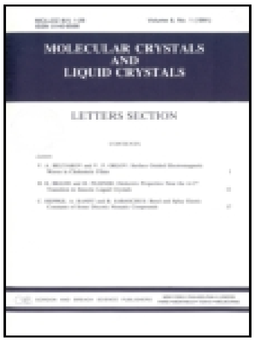

Taylor & Francis
Taylor & Francis Group

Molecular Crystals and Liquid Crystals

ISSN: 1542-1406 (Print) 1563-5287 (Online) Journal homepage: http://www.tandfonline.com/loi/gmcl20

Studies of Image Processing and Refractive Index in Blue Phase

D. D. Luders, K. C. Camargo, A. R. Sampaio, A. J. Palangana & N. M. Kimura

To cite this article: D. D. Luders, K. C. Camargo, A. R. Sampaio, A. J. Palangana & N. M. Kimura (2015) Studies of Image Processing and Refractive Index in Blue Phase, Molecular Crystals and Liquid Crystals, 611:1, 192-196, DOI: 10.1080/15421406.2015.1030258

To link to this article: http://dx.doi.org/10.1080/15421406.2015.1030258

Published online: 06 Jul 2015.

Mol. Cryst. Liq. Cryst., Vol. 611: pp. 192–196, 2015

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2015.1030258

Studies of Image Processing and Refractive Index in Blue Phase

D. D. LUDERS, K. C. CAMARGO, A. R. SAMPAIO, A. J. PALANGANA, AND N. M. KIMURA*

Departamento de Física, Universidade Estadual de Maringá, Maringá, Paraná, Brazil

The isotropic - blue phases - cholesteric phase transitions are studied in a thermotropic (COC) by image processing and refractive index measurements. Textures of blue phases are optically characterized as well as their transition points. The experimental investigation employed here is sensitive to detect changes in the structural configuration of blue phases as a consequence of our refractive index data. In this context the experimental results are presented and discussed.

Keywords image processing; refractometry; phase transition; blue phase

I. Introduction

The phase transitions study in liquid crystals (*LC*) and in particular the identification of their respective transition points constitutes a fundamental aspect of research with these materials. Therefore this is not always an easy task since there is a diversity of liquid crystal phases that exhibit distinct optical textures [1]. Several experimental techniques have been employed in this context and each one has its own peculiarity [1–3]. In this way, it is important to mention that the image processing technique has been used as a powerful tool for the identification of phase transition points especially in *LC* systems [4–7]. It is further indicated in LC materials that exhibit phase transitions weakly first order [4, 8, 9]. The mean square deviation (σ) for the mean values of the image frame color tones is a fundamental statistical parameter determined by means of this technique. The parameter σ plays an important role in the identification of phase transition points in agreement with other experimental techniques [6, 8–12]. The polarized light optical microscopy connected to the CCD camera is used to observe the isotropic (*I*), blue phases (*BP*) and cholesteric (N^*) phases for cholesteryl oleyl carbonate (*COC*). Liquid crystal textures of $I - BP$ – N^* phase transitions and their respective transition points are studied here through image processing. Textures of two blue phases (*BPI* and *BPII*) are optically characterized via image processing as well as the $I - BPI - BPII$ – N^* transition points. Refractive index measurements obtained with a refractometer (high resolution) are also reported as a function of temperature near these phase transitions. In this context, our experimental results are presented and discussed.

*Address correspondence to N. M. Kimura, Departamento de Física, Universidade Estadual de Maringá Av. Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. E-mail: newller@dfi.uem.br

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/gmcl.

II. Fundamentals

Thermotropic liquid crystal compound, cholesteryl oleyl carbonate (*COC*), investigated in the current work was purchased from the Sigma-Aldrich Chemical Company. The isotropic, blue phases and cholesteric phases are characterized by means of optical microscopy, image processing and refractometry techniques. The phase sequence, as a function of the temperature, is determined as following: $I - BPI$ ($36.65^\circ C$), $BPI - BPII$ ($36.45^\circ C$) and $BPII - N^*$ ($35.75^\circ C$), respectively. The *COC* sample was prepared in sealed glass cells and placed in a hot stage device connected to the circulating temperature bath stable within $0.01\ K$. The digital image of liquid crystal (*COC*) textures, detected by the CCD camera connected to the polarized light optical microscope, is directly stored in a file driven by a computer with a resolution of 1280×1024 pixels, and a Delphi program was utilized to analyze these image frames. In this context, the mean intensity of the colour tones is given by $M_0 = 1/l_x l_y \int_0^{l_x} \int_0^{l_y} b(x, y) dx dy$, where l_x and l_y are the dimensions of the image frame and the function *b(x, y)*, represent the *32 bits* true colour pixel, with range from *0* to *255* in red, green or blue colors (RGB image). In this way, the 2-rank statistical moments of the image frame is written by $M_2 = 1/l_x l_y \int_0^{l_x} \int_0^{l_y} [b(x, y) - M_0]^2 dx dy$. The root square $(M_2)^{1/2}$ is known as the mean square deviation (σ). The parameter σ is determined (Delphi program) as a function of the temperature, for each *RGB* component of liquid crystal (*COC*) textures, in the range of *BP* and N^* phases. A cooling rate of $\sim 8\ mK/s$ was used during the acquisition of the experimental image frames. Refractive index measurements were determined through the digital refractometer (Atago RX) with an accuracy of 2×10^{-5}, are based on the internal reflection of light at the interface between the COC sample and the surface of an optical glass prism. We remember that the cholesteric phase presents optical anisotropy while the blue phases are optically isotropic [13, 14].

III. Results and Discussion

The blue phase range between the *I* and N^* phases is investigated via image processing and refractive index measurements. Figure 1 shows the blue phases and N^* textures obtained upon cooling from the isotropic near the $I - BP - N^*$ phase transitions. The black texture in the I phase is transformed into a dark blue texture at the $I - BPI$ phase transition as exhibited in Fig. 1, and, after the transition is completed, the *BPI* phase is characterized by the presence of smooth light blue texture. The light blue texture transforms to a greenish texture at the $BPI - BPII$ phase transition. This texture, in the small range of *BPII* phase, disappears only near the $BPII - N^*$ phase transition. From this transition point predominates cholesteric texture. This texture disappears only in the vicinity of the crystalline phase. Figure 2 shows the mean square deviation (σ) versus temperature near the $I - BPI - BPII - N^*$ phase transitions for the cooling cycle. In the temperature range of blue phases, σ increases and becomes maximum and then decreases as the temperature decreases toward the N^* phase. Observe in the figure 2 clearly the occurrence of three well pronounced peaks (σ) between *I* and N^* phases. The peaks (blue, green and red colors are the most sensitive) correspond to $I - BPI - BPII - N^*$ phase transitions, respectively. Temperature dependence of the refractive index, in the range of the blue phases between N^* and *I* phases, are presented in Fig. 3 where, near the $N^* - BPII$ transition, n_{eff} ("effective" refractive index of the cholesteric phase), increases and becomes maximum ($N^* - BPII$ transition), just one refractive index ($n_{eff} = n$) was determined and subsequently decreases as the temperature increases toward the *BPI* phase. In addition, there is a small jump in the refractive index values in the vicinity of $BPII - BPI$ and $BPI - I$ transitions [14]. Linear fit of these refractive

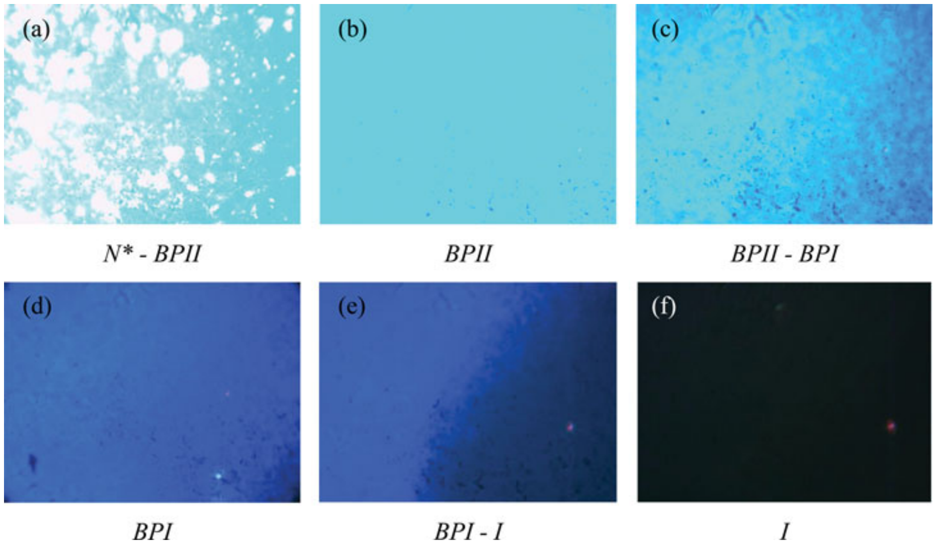

Figure 1. Textures for cholesteric, blue phases and isotropic phase sequence, where, *N**, *BPII, BPI* and *I* are respectively cholesteric, blue phase two, blue phase one and isotropic phases. (a) 35.75°C, (b) 36.17°C, (c) 36.45°C, (d) 36.52°C, (e) 36.65°C and (f) 36.81°C.

index data, in the domain of blue phases, showed that the slope (a) of this linear range satisfies the relation $a_{BPI} > a_{BPII} > a_I$. This is an important result which reflects a change in the structural configuration of blue phases in each phase transition detected by refractive index data [15].

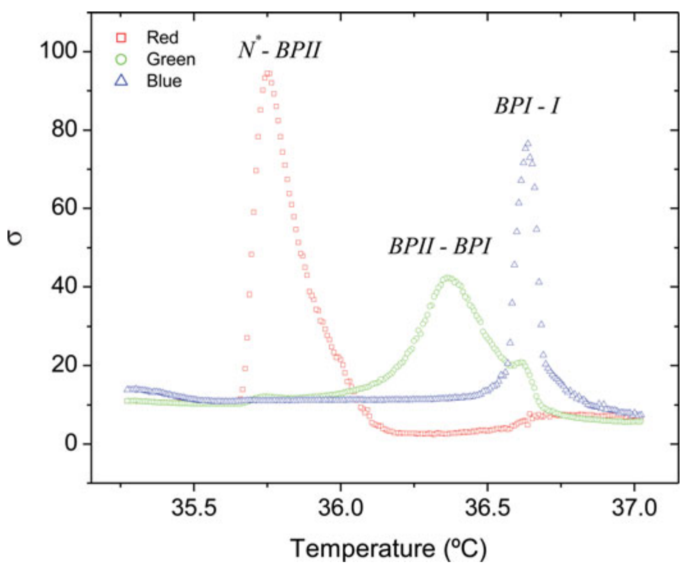

Figure 2. Mean square deviation versus temperature in the N^*−BPI −$BPII$ −I phase sequence, obtained from red, green and blue colors.

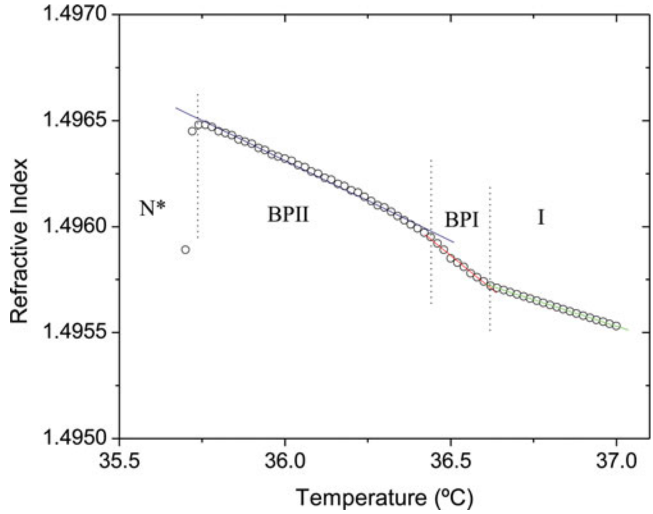

Figure 3. Refractive index as a function of the temperature. The solid line corresponds to a linear fit.

To sum up, we have carried out studies of image processing and refractive index near the isotropic - blue phases - cholesteric phase transitions of a thermotropic (*COC*). The investigation method utilized here is sensitive to detect changes in the topological configuration of blue phases [16, 17]. It can be decisive for the recognition of the transition points connected to the isotropic and cholesteric phases. In fact, the obtained results are consistent with the occurrence of blue phases between the isotropic and cholesteric phases. As a final remark, we mention that these experimental results presented and discussed in this work may stimulate further investigations focused on other liquid crystal materials or complex fluids.

Funding

We are thankful to the Brazilian Agencies CAPES, Fundação Araucária (PR) and CNPq (MCT) for the financial support.

References

[1] Dierking, I. (2003). *Textures of Liquid Crystals*, Universit of Manchester, Manchester.
[2] de Gennes, P. G., Prost, J. (1993). *The Physics of Liquid Crystals,* 2nd ed. Clarendon Press, Oxford.
[3] Khoo, I. C. (2007). *Liquid Crystals,* 2nd ed. Wiley.
[4] Montrucchio, B., Sparavigna, A., & Strigazzi, A. (1998). *Liq. Cryst. 24*, 841.
[5] Montrucchio, B., Sparavigna, A., Torgova, S., & Strigazzi, A. (1998). *Liq. Cryst. 25*, 613.
[6] Sampaio, A. R., Palangana, A. J., & Visccovini, R. C. (2004). *Mol. Cryst. Liq. Cryst. 408*, 45.
[7] Sampaio, A. R., Kimura, N. M., Visccovini, R. C., Fernandes, P. R. G., & Palangana, A. J. (2004). *Mol. Cryst. Liq. Cryst. 422*, 57.
[8] Eccher, J., Sampaio, A. R. , Viscovini, R.C., Conte, G., Westphal, E., Gallardo, H., & Bechtold, I.H. (2010). *J. of Mol. Liq. 153*, 162.
[9] Braga, W. S., Santos, O. R., Luders, D. D., Sampaio, A. R., Kimura, N. M., Simões, M., & Palangana, A. J. (2013). *J. Mol. Liq. 187*, 20.
[10] Hluchow, E., Santoro, P. A., Evangelista, L. R., Palangana, A. J. (2007). *J. Mol. Liq. 43*, 133.

[11] Sastry, S. S., Mallika, K., Gowri, B., Rao, S., Tiong, H. S., & Lakshminarayana, S. (2012). *Liq. Cryst. 39*, 695.
[12] Freire, F. M. C, Kimura, N. M., Luders, D. D., Palangana , A. J., & Simões, M. (2013). *Phys. Rev. E*, *88*, 064502.
[13] Crooker, P.P. *Chirality in Liquid Crystals*, Springuer, (Kitzerow, New York 2001).
[14] Manohar, R., & Shukla, J.P. (2004). *J. of Phys. and Chem. of Solids*, *65*, 1643.
[15] Chen, Chun-Wei, Jau, Hung-Chang, Lee, Chun-Hong, Li, Cheng-Chang, Hou, Chien-Tsung, Wu, Chih-Wei, Lin, Tsung-Hsien, & Khoo, I. C. (2013). *Opt. Mat. Exp. 3*, 532.
[16] Meiboom, S., & Sammon, M. (1980). *Phys. Rev. Lett. 44*, 882.
[17] Seidelman, T. *Rep. Prog. Phys. 53*, 659 (1990).