Images Intensity Analysis of Thermochromic Liquid Crystal near Critical Temperature

Risti Suryantari*, Flaviana
Department of Physics, Parahyangan Catholic University, Indonesia.

* Corresponding author. Email: ristisuryantari@unpar.ac.id
Manuscript submitted July 26, 2019; accepted January 7, 2020.
doi: 10.17706/ijmse.2020.8.1.26-31.

Abstract: In this paper, the thermal-optical analysis based on images intensity distribution of thermochromic liquid crystals sample near critical temperature under crossed polarizer microscope is discussed. Thermochomic liquid crystals (TLCs) is composed from chiral nematic liquid crystals which have twisted molecular structure and optically active. TLCs show the blue-red colorplay at critical temperatures which color changes occured. According to experimental result, crossed-twist pattern appears when the temperature approaches a higher critical temperature of sample at 32 °C . The different of the molecules orientation cause uneven of intensity distribution along the twist-line. According to measurement, the length of a twist-line is equivalent to half of the pitch ($p/2$), which mean that the molecules twist at 180°, and also equivalent to half of sample thickness ($h/2$). Moreover, the consistency of twist-line length measurement at various temperatures shows the stability of twist-line near higher critical temperature.

Key words: Thermochromic liquid crystals, chiral nematic, intensity, thermal-optical, critical temperature, twist-line, stability.

1. Introduction

Thermochromic liquid crystals (TLCs) illustrate a color-play depend on selective visible light wavelength reflection at different temperatures [1]. It shows stable blue color at higher temperature, for instance, a TLCs R30C5W will reflect dominant red color started at 30°C, and at higher temperature, TLCs reflect shorter wavelength (blue-green), the blue color started at 35°C. Blue color still appear over 35°C until a clearing point up to 45°C. The colors vary with the nature composition of the sample, the temperature, and the angles of incidence and observation [1], [2].

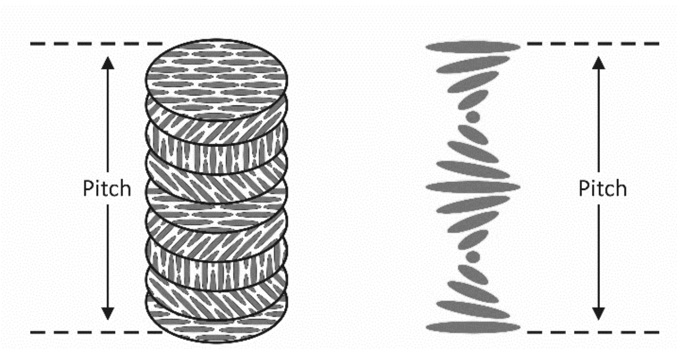
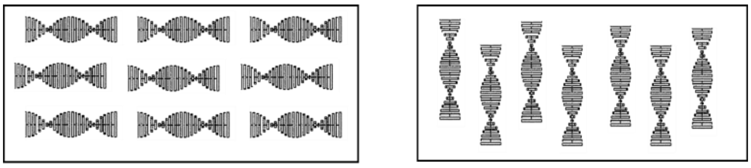


Fig. 1. Molecules alignment of chiral nematic liquid crystal structure.

The main component of TLCs is chiral nematic liquid crystals and having twisted molecular structure. It consists of nematic layers whose particular directors. Each layer has different molecular direction that turned by an different angle from one layer to the next layer. The distance of two layers with the same orientation is equivalent to 2π and namely pitch (*p*) as shown in Fig. 1 [2].

There are two types of chiral nematic sample alignment namely focal conic and planar as shown in Fig. 2. The focal conic and planar textures differ basically in the direction of ordering relative to the observer [2], [3].



(a) (b)

Fig. 2. (a) Focal conic texture and (b) planar texture [2].

Chiral nematic liquid crystal has a number of optical properties because of anisotropic characteristic [4], [5]. For any anisotropic materials, different orientations respect to the molecular alignment may cause the incident light be transmitted with different velocities, and cause birefringence effect. When unpolarized light enters to chiral nematic liquid crystal, incident light selectively polarized, commonly become two directions namely ordinary polarized ray and extraordinary ray polarized [2], [3], [6].

The optical active properties of cholesteric liquid crystal are result of circularly polarized light. The molecules rotate quickly along the pitch. The greater in rotational speed of the molecule cause the shorter of pitch and shorter wavelength will be reflected. In TLCs, the reflected wavelength also depend on the temperature. At higher temperature the molecule will move faster, and the layer will be more twisted, resulting in shorter pitch then it reflects shorter wavelength. A typical wavelength as temperature responses shown in Fig. 3 [2].

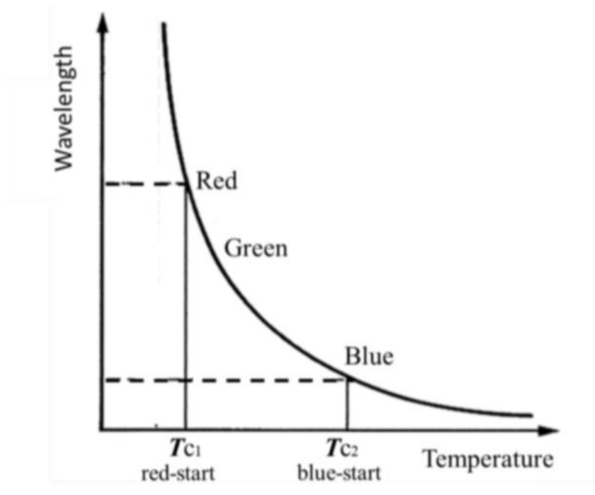


Fig. 3. Graph of reflected wavelengths at various temperatures. Critical temperature notated by T_c representing red-start at lower temperature Tc_1 and blue start at higher temperature Tc_2 [2].

The magnitude of the reflected wavelength approached by the principle of scattering Bragg. The periodic layered structures of chiral nematic allow it behave as a three-dimensional diffraction grating for visible light and similar to Bragg scattering effects that observed in crystalline solids with shorter than x-rays wavelength. This Bragg-type scattering gives rise to the characteristic iridescent colors as shown in Fig. 4 [2], [6], [7].

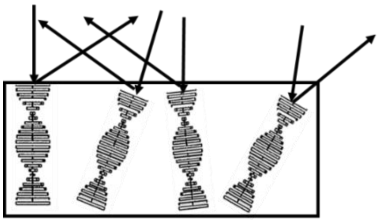


Fig. 4. Bragg scattering illustration of non-normal incident light in chiral nematic.

The relation between wavelength reflected and the angle of the incident beam normal to the surface approximately described by the Bragg diffraction in equation 1.

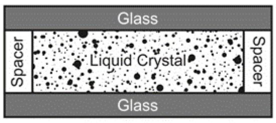
$$\lambda = 2d\, n \sin\phi \quad (1)$$

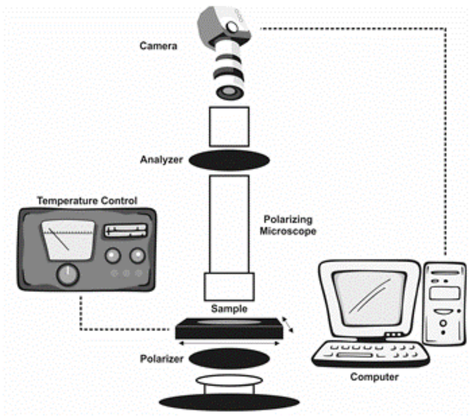
Here n is the refractive index of the material, d is Bragg layers, ϕ is the normal angle that comes to the surface of the chiral nematic liquid crystal, and λ is the reflected wavelength. Here, $2d$ is equal to the length of the pitch, p [2], [6], [7].

The purpose of this study is to observe the thermo-optical effect of thermochromic liquid crystal sample near critical temperature of sample over high critical temperature. The sample has the temperature activation range of 24-29 °C , then the higher critical temperature at 29 °C. Using polarizer microscope, we get the images of each sample, then analyze these images over higher critical temperature by applying some method in image processing using Matlab [8].

2. Material and Methods

TLCs sample from Hallcrest inc without any treatment of orientation ordering was used here. A sample with 50 µm of thickness was prepared to be observed under polarizing microscope. It was placed on the hot stage as a temperature controller. The experimental set up shown in Fig. 5. The active temperature range of the sample is 24-29 °C, it will show the blue color over 29 °C, so that the temperatures of observation were set from 22 °C to 35 °C.





(a) (b)

Fig. 5. (a) Side view of sample. (b) Instrumentation set-up.

To analyze and simplify the images, RGB images were converted to HSV (hue, saturation, value). This study is focused to observe the intensity of the image, so we just took the component V (value) and then called V-image [8]. Using the improfile-technique that applied in along the twist-line on V-image using Matlab then we get more information about the intensity related the pitch and the orientation of molecules [8][9].

3. Results and Discussion

A crossed pattern obtained near high critical temperatures, as shown in Fig. 6. These patterns thought to be a double twist [10], and started appear at 32 °C, over the high critical temperature [10]-[13]. When the temperature increases, the chiral nematic liquid crystal molecules will more twisted with larger rotational angle and speed [2], [3], [6].

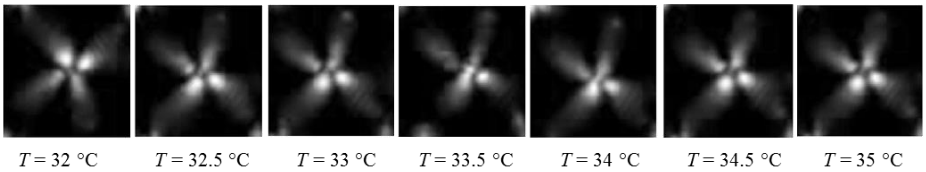


Fig. 6. Crossed-twist pattern images at over higher critical temperature of TLCs sample.

The RGB images that has been converted into HSV image by taking the "V" component only (called V-image) shown in Fig. 6. The brightness values, sometimes called intensity, I, in HSI image (hue, saturation, and intensity), are in the range of 0-1. Then, we plot the intensity along twist-line using improfile technique as shown in Fig. 7 [8], [9].

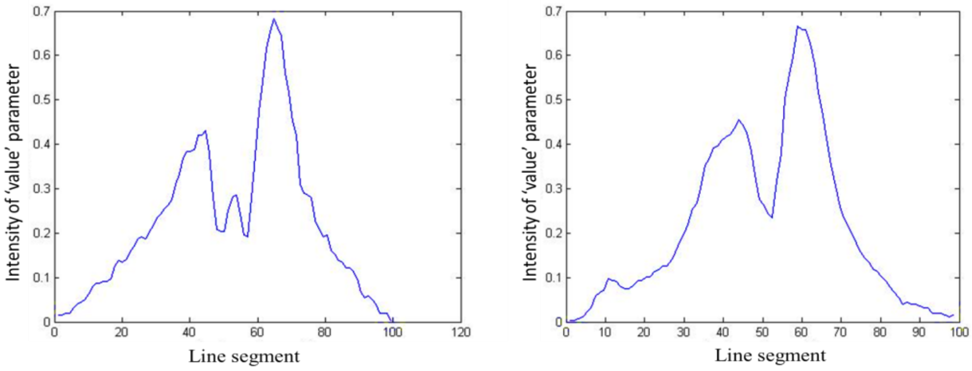


Fig. 7. Plot profile of (a) twist-line 1 and (b) twist-line 2.

Based on Fig. 7, it can be shown the distribution of image intensity, which proportional to the intensity of the light being transmitted, along the two crossing line namely twist-line 1 and twist-line 2 at 34.5 °C. The example of these line segmentation shown in Fig. 8. Figure 7 shows obviously the uneven of intensity distribution along twist-line at 34.5 °C. This is due to the rectification of the molecules along different twist lines as shown in figure 8. High image intensity occurs when the direction of the molecules almost equal to the direction of the analyzer, on the other hand the intensity depends on the angle of the director, the different orientations cause different the image intensity.

The results of the measurement of the twist axis length shown in Fig. 8.b which the average measurement result is 25 μm. It is equivalent to half of the sample thickness ($h/2$), noted that in this experiment we use 50 μm of sample thickness. The consistency of the twist axis length approximately 25 μm for each temperature shows that the molecules tend to be stable after obtain its high critical temperature represented by the same patterns from 32 °C to 35°C as shown in Fig. 7.

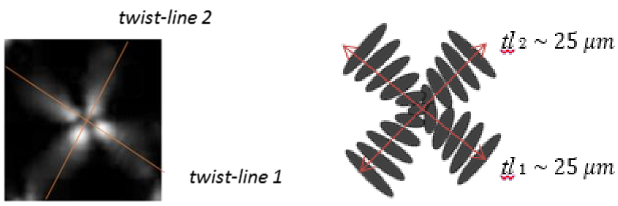


Fig. 8. An example of line segmentation along a twist pattern.

Moreover, according to pitch definition also shown in Fig. 1, the twist-line length is predicted to be equivalent to half of the pitch ($p/2$), which the molecule twisted at 180°. It is because we argue that it will obtain the same intensity at same molecules directions, so that it cannot be differed at π and 2π of rotation. (In chiral nematic liquid crystals, the pitch will determines a reflected wavelength by layers consisting of a set of molecules with the same director n. Noted that director n is the tendency of aligning the direction of molecules in a layer, or the resultant of all directions of the molecules. In fact the direction of each molecule can be vary) [2].

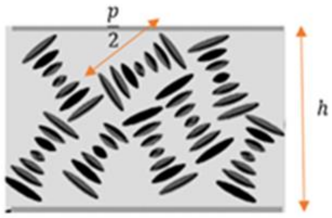


Fig. 9. Visualization of oblique alignment in chiral nematic sample [14].

The magnitude of the reflected wavelength can be approached through the Bragg scattering principle through the equation 1, which $d = \frac{p}{2}$, here d is the distance between the Bragg layers. According to experimental result, it could be concluded that $\frac{p}{2} = \frac{h}{2}$, so that $p = h$, however because the molecular alignment of sample not being oriented, the patterns obtained here seems an oblique pattern as visualized in figure 9. On the space of sample with a sample thickness h, the pitch will shorten with increasing molecular rotation during an increasing in temperatures so that shorter wavelength would be reflected at higher temperature. Otherwise, it cannot be concluding about the value of the wavelength based on Bragg scattering principle only, because the range of reflected wavelength here is in the range of visible light.

4. Conclusion

Two crossed twist-line patterns appear at high temperatures over the higher critical temperature in thermochromic liquid crystal (TLC) sample with 50 μm of thickness. By plotting the image intensity along the two crossed twist-line of each images from 32 °C to 35 °C, it shows uneven intensity because of the different of molecules orientation along the twist-line. According to the measurement, the twist-line length average is equivalent to half the sample thickness ($h/2$) and also equivalent to half of the pitch ($p/2$) which the molecules twist at 180°, so that we can conclude that $h = p$. Because the molecular alignment of sample not being oriented well, the patterns obtained here seems an oblique pattern. Moreover, the consistency of the twist axis length for each temperatures shows that the molecules tend to be stable after obtain its higher critical temperature.

Acknowledgment

The authors would like to thank to Research Department of Parahyangan Catholic University for the financial support and Material Laboratory of Gadjah Mada University for the facilities of research.

References

[1] Ferrara, M., & Bengisu, M. (2014). *Materials that Change Color, Smart Materials, Intelligent Design*. Springer.

[2] Hallcrest. (1991). *Handbook of Thermochromic Liquid Crystal*. Glenview, IL, Hallcrest.

[3] Chandrasekhar, S. (1992). *Liquid Crystal*. Cambridge University Press. New York.

[4] Pasechnik, S. V., Chigrinov, V. G., & Shmeliova, D. V. (2009). *Liquid Crystals Viscous and Elastic Properties*. Wiley-VCH Verlag GmbH & Co.

[5] Whitfield, C. A., *et al*. (2017). Hydrodynamic instabilities in active cholesteric liquid crystals. *The European Physical Journal E. 40(50)*.

[6] Yang, D.-K., & Wu, S.-T. (2006). *Fundamentals of Liquid Crystal Devices*. John Wiley&Son Ltd.

[7] Zheng, Z., Li, Y., Bisoyi, H. K., Wang, L., Bunning, T. J., & Li, Q. (2016). Three-dimensional control of the helical axis of a cholesteric liquid crystal by light. Nature, *531*, 352-357

[8] Gonzales, R. C., & Woods, R. E. (2002). *Digital Image Processing*, 2nd ed. Prentice Hall.

[9] Information. Retrieved from https://www.mathworks.com/help

[10] Tanaka, S., *et al*. (2015). Double-twist cylinders in liquid crystalline cholesteric blue phases observed by transmission electron microscopy. Scientific Report.

[11] Kikuchi H. (2008). Liquid crystalline blue phases. *Liquid Crystalline Functional Assemblies and Their Supramolecular Structures*. *128*, 99–117.

[12] Rahman, M. D. A., *et al*. (2015). Blue phase liquid crystal: Strategies for phase stabilization and device development. *Sci. Technol. Adv. Mater., 16*, 033501.

[13] Sala-Tefelskaa, M. M., *et al.* (2018). Influence of cylindrical geometry and alignment layers on growth process and selective reflection of blue phase domains. *arXiv:1707.06641v2.*

[14] Panjasan. Retrieved from http://en.wikipedia.org/wiki/Blue_phase_mode_LCD

Risti Suryantari was born in Yogyakarta on May 22, 1986. She received the S.Si (bachelor of science) in 2008 and the M.Sc. (master of science) from the Physics Department of Gadjah Mada University, Indonesia. Currently, she is a lecturer at Physics Department, Sciences Faculty, Parahyangan Catholic University. Her fields of interest including liquid crystal material, image processing, and education physics. Risti Suryantari is a member of the International Liquid Crystal Society (ILCS) and Physical Society of Indonesia (PSI).

Flaviana was born in Jakarta, Indonesia, on October 17th, 1984. Flaviana received the S.Si. (bachelor of science) degree in physics from Parahyangan Catholic University, Bandung, Indonesia, in 2006, and the M.T. (master of engineering) degree in electrical engineering from Bandung Institute of Technology (ITB), Indonesia, in 2012. Since 2012, she has joined the Department of Physics, Parahyangan Catholic University, Bandung, Indonesia, as a lecturer until now. Ms. Flaviana is a member of Physical Society of Indonesia (PSI) since 2015.