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Identification of polymer stabilized blue-phase liquid crystal display by chromaticity diagram

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We reported an identification method of blue phase liquid crystal (BPLC) display status by using Commission International de l'Éclairage (CIE) chromaticity diagram. The BPLC was injected into in-plane-switch (IPS) cell, polymer stabilized (PS) by ultraviolet cured process and analyzed by luminance colorimeter. The results of CIE chromaticity diagram showed a remarkable turning point when polymer stabilized blue phase liquid crystal II (PSBPLC-II) formed in the IPS cell. A mechanism of CIE chromaticity diagram identify PSBPLC display status was proposed, and we believe this finding will be useful to application and production of PSBPLC display. © *2012 American Institute of Physics*. [http://dx.doi.org/10.1063/1.4705432]

Blue phase liquid crystal (BPLC) was discovered by Reinitzer and described the appearance of blue phases in 1888. The fundamental behaviors of blue phase were well studied in 1970 s, and the BP generally was consisted of chiral dopant and cholesteric liquid crystal. However, BPLC appeared in narrow temperature range of 1 °C and hindered its further development and application.[1,2] The problem of narrow stable temperature range has been overcome by using the polymeric stabilization,[3] nanoparticles,[4] and T-shaped compound.[5] Therefore, various innovational applications were proposed,[3,6–9] and BPLC display is one of the most popular applications.[10]

The performance of BPLC display was greatly dominated by BPLC materials which have three different types: blue phase I (BP-I), blue phase II (BP-II), and blue phase III (BP-III). Wu *et al*. reported that BP-II exhibited a small hysteresis than BP-I (Ref. 11), and Kikuchi *et al*. also found BP-II had faster response time than BP-I.[12] Yoshizawa reported that BP-III has greatly improved response time in microsecond scale.[13] These three BP types were differentiated with the assembled structure of the double twist cylinders (DTCs).[2,14–16] The DTC assembly of the BP-I was body-centered cubic, BP-II is simple cubic, and BP-III is an arbitrary orientation (amorphous).[2,17] The assembled structures of BPLC can be examined by polarized optical microscope (POM),[18] x-ray diffraction (XRD),[19] differential scanning calorimeter (DSC),[20,21] optical spectroscope,[12] and confocal laser scanning microscope (CLSM).[22] However, these characterizations which described above were not satisfied the requirement of manufacturing BPLC display. For example, practical BPLC displays have the optical spectrum in ultraviolet range, and BPLCs are difficult to be observed by POM. For another example, XRD, DSC, CLSM, and optical spectroscope are complicated processes and time consumption for manufacturing examination.

Commission International de l'Éclairage (CIE) was widely applied in measurement of liquid crystal display. The color shift[23] and color reproduction[24] can be precisely defined by CIE. However, the identification of liquid crystal assembly or alignment, especially in BPLC, has not ever been reported. Herein, we demonstrated an approach to identify the status of BPLC in the in-plane-switch (IPS) cell. BPLC display could be directly analyzed by luminance colorimeter, and the CIE chromaticity diagram revealed an obvious change when BPLC assembled or aligned from BP-I into BP-II. A series of control experiments were prepared to realize the identification mechanism of CIE approach.

BPLC was consisted of host liquid crystals (4-cyano-4′-pentyl biphenyl, 5CB, 41.94 mol. %; JC1041XX, 45.02 mol. %) and chiral dopant (ISO-DF, 2.44 mol. %). The BPLC was polymeric stabilized by monomer (ethyl hexyl acrylate, EHA, 3.74 mol. %), reactive mesogen (RM257, 2.45 mol. %), and photo initiator (DMPAP, 0.34 mol. %).[3] The phase-transition sequence of the BPLC was ISO (48.8 °C) and BP (41.3 °C) N*. The BPLC were filled into an IPS cell (line/space/gap = 10 μm/10 μm/10 μm), and polymeric stabilized by ultraviolet (UV) cured process (UV wavelength at 365 nm, intensity at 2 mW/cm^2, exposure time at 30 min). In order to obtain polymer stabilized blue phase I (PSBP-I) or PSBP-II formation in the IPS cell, BPLC was heated to 29.3, 30.3, 31.3, 32.3, 34.3, and 36.3 °C, respectively, and then polymer stabilized by the UV cured process. After UV curing, BPLC-IPS cells were measured by luminance colorimeter (Topcon, BM5A, CIE resolution: ±0.03, Nit resolution: ±4%). The luminance colorimeter was operated at room temperature without application of bias voltage. The whole apparatus was showed in Figure 1.

As shown in Figure 2, the CIE chromaticity diagram reveals large variation at different curing temperatures. However, the CIE curve renders a remarkable turning around 31.3 °C, and we conjectured that turning point means the transition point from PSBP-I into PSBP-II. For example, when BPLC was cured at 29.3 or 30.3 °C, the BP was assembled into body-center cubic and PSBP-I was obtained. On contrary, when BPLC was cured at 34.3 or 36.3 °C, the PSBP was assembled into simple cubic and PSBP-II was obtained.

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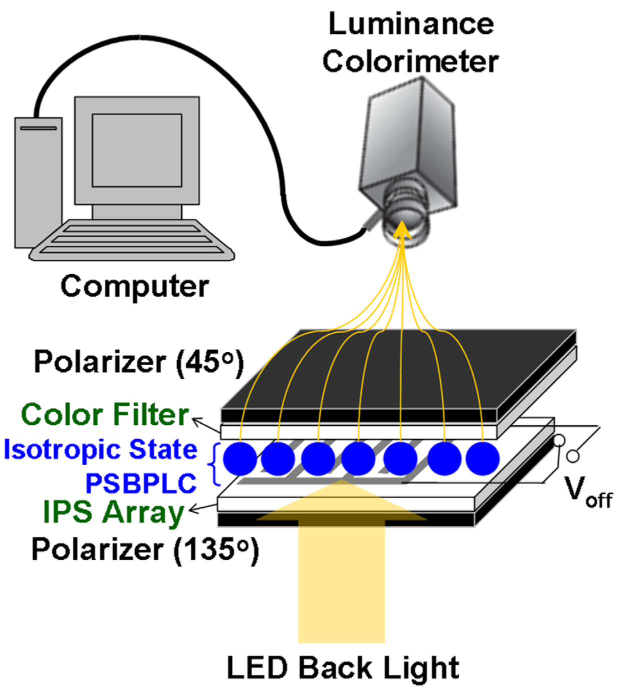


FIG. 1. The whole apparatus of luminance colorimeter in a dark room.

In order to confirm result of CIE chromaticity diagram, the conventional analysis of optical spectroscope (Perkinelmer, Lambda 800) was used. The six test cells were delaminated in order to collect the pure polymer stabilized blue phase liquid crystal (PSBPLC) for further verification. In Figure 3(a), the result of reflected spectrum revealed left shift between 29.3 and 31.3 °C, and the variation of spectrum indicated the formation of PSBP-I due to the DTC assembly.[12] The reflected spectrum revealed right shift between 31.3 and 36.3 °C, and the PSBP-II was obtained due to the assembly of simple cubic. The reflected spectrum can be further evaluated by the plot of peak wavelength against the curing temperature.[6] As shown in Figure 3(b), the curve rendered a remarkable turning point at 31.3 °C. The turning point indicated the transition of PSBP status, and the result is well correlated with the CIE chromaticity diagram. However, CIE shows more easy, convenient, and effective than the conventional analyses. Besides the analysis of optical spectroscope, polarized optical microscope (Olympus BX51)

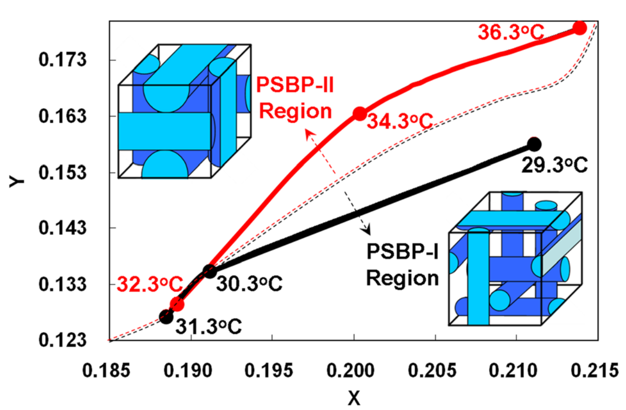


FIG. 2. CIE chromaticity diagram of BPLC and their blue phase regions.

was selected to double confirm the formation of PSBPLC. Figure 3(c) is a typical plate texture of PSBP-I after cured at 30.3 °C. However, when PSBPLC was cured at 34.3 °C, the POM revealed another texture of spot feature (Figure 3(d)). Regarding to the spot texture, the liquid crystal was characterized as the PSBP-II.

In the following control experiments, we showed how the CIE identify BP status (Figure 4). Initially, the incident back light was analyzed by luminance colorimeter (Figure 4(a)), and it had luminance of 2134 nit and CIE of (0.279, 0.256). In the second setup (Figure 4(b)), the incident back light passed through one polarizer (135°), and it revealed the luminance of 845 nit and CIE of (0.294, 0.274). The nit decreased due to the polarization film. In the third setup (Figure 4(c)), the incident back light passed through one polarizer (135°) and one PSBP cell, the colorimeter revealed luminance of 744 nit and CIE of (0.300, 0.281). In the fourth setup (Figure 4(d)), the incident back light passed through one polarizer (135°), one PSBP cell, and another polarizer (45°), and the luminance revealed dramatically decrease from 744 nit to 3.10 nit. However, CIE was still detectable and revealed obviously change from (0.300, 0.281) to (0.233, 0.196). The result of nit indicated the PSBPLC was not a perfect isotropic state, and the linear polarization of incident light would interact with PSBPLC. After incident light interacted with PSBPLC, it formed a projected light and would be detected by the colorimeter. The CIE chromaticity diagram would change with the variation of blue phase status as well as DTH assemblies of BPLC which were correlated to the Bragg's reflected spectrum.[12] The final setup in Figure 4(e) was the incident back light pass through two polarizer and had luminance of 0.107 nit and CIE of (0.300, 0.246). This result revealed that the colorimeter has high sensitivity and resolution to detect projected light in an extreme condition of small luminance.

Because of the IPS cell designation and the host/chiral composition of BPLC, the PSBPLC display revealed light leakage at dark state. The detail optical mechanism was described as following (Figure 4(f)). When the incident light polarized by the 45° polarizer, most of the linear polarized light will be absorbed by BPLC. However, a little linear polarized light was depolarized by the IPS cell and host/chiral composition of BPLC, and then light leakage was occurred. The light leakage was detected by the luminescence colorimeter. The colorimeter was so sensitive that the variation of CIE can be effectively measured. The color space of the CIE result can be transfer into the optical spectrum due to the CIE chromaticity was calculated from the spectral power distribution. The different phases of PSBP showed different color spaces, and optical spectrum due to the PSBP-I and PSBP-II has different assemblies or alignments. For example, the PSBP-I reveals a blue shift in reflectance and left-down shift on CIE coordination. According to the color engineering, the left-down shift of CIE coordination also means blue shift of transmittance. The variations of PSBP color space are well correlated with the analysis of reflected spectrum. On contrary, the PSBP-II has a red shift in reflectance and right-up shift on CIE coordination. The right-up shift of CIE coordination means red shift of

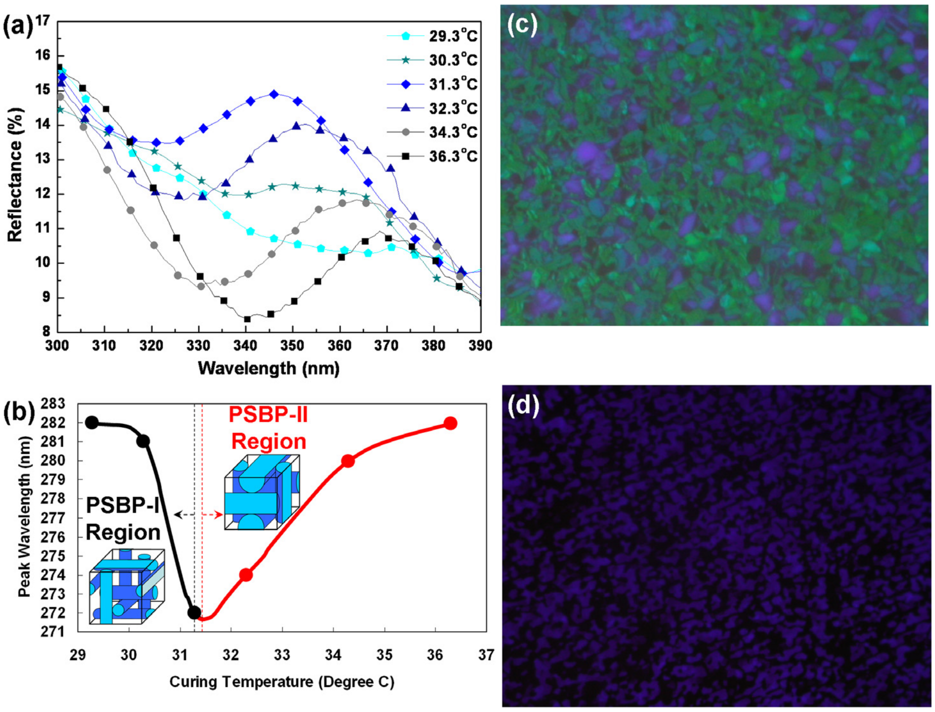
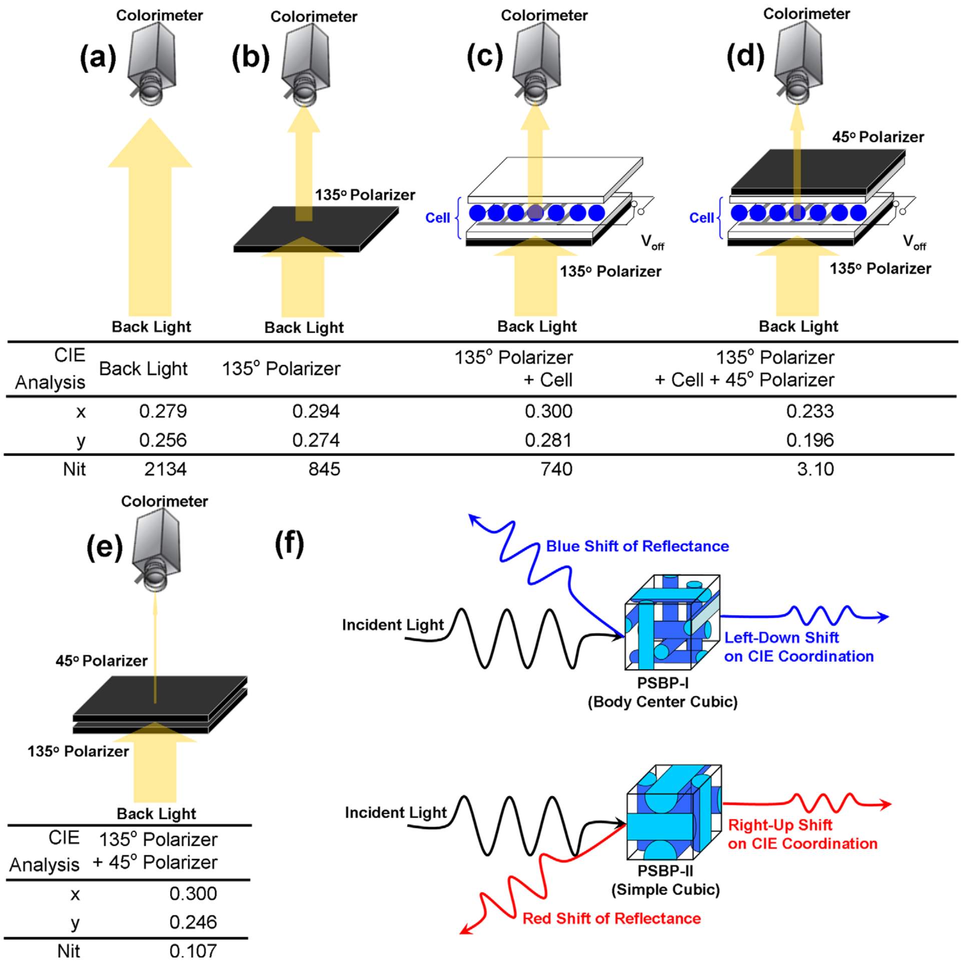


FIG. 3. Optical spectrum of BPLC: (a) reflectance and (b) peak wavelength against curing temperature. POM images after PSBPLC cured at 30.3 °C (c) and 34.3 °C (d).

transmittance, and the result is consisted with the analysis of reflected spectrum.

In conclusion, an identification method of BPLC was proposed. By using luminance colorimeter, the CIE chromaticity diagram rendered a turning point when PSBP assembled from BP-I to BP-II. Compared to the conventional measurements, the CIE chromaticity diagram is an efficient, precise, and convenient method to characterized PSBPL status. The analyzed mechanism was described by the PSBPLCs which have different assemblies at BP-I and BP-II. The BP assemblies are well correlated with the variation of color space. We think the findings will be useful in manufacturing



CIE Analysis	Back Light	135° Polarizer	135° Polarizer + Cell	135° Polarizer + Cell + 45° Polarizer
x	0.279	0.294	0.300	0.233
y	0.256	0.274	0.281	0.196
Nit	2134	845	740	3.10

CIE Analysis	135° Polarizer + 45° Polarizer
x	0.300
y	0.246
Nit	0.107

FIG. 4. Mechanism of CIE chromaticity diagram identify BP status.

and production of polymer stabilized blue phase liquid crystal displays in the future.

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