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In a nematic liquid crystal (LC), the excitation energy of an ultraviolet light (360 nm) is efficiently transferred to yellow fluorescent dye via blue fluorescent sensitizer, to enhance yellow fluorescence of the dichroic dye. The LC can emit white fluorescence when yellow and blue fluorescent dyes are mixed at suitable concentrations. In the homogeneously aligned cell with the fluorescent nematic LC, fluorescent dye molecules reorient along the applied electric field with LC molecules when the voltage is applied to the LC cell. With the increase of the voltage, the fluorescent intensity decreases without changing the fluorescent color. The contrast ratio at 0 and 8 V is about 6.5.

Keywords: dichroic ratio; electro optical property; fluorescent dichroic dye; guest host mode; nematic liquid crystal; sensitizing effect; white fluorescence

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INTRODUCTION

Emissive type liquid crystal displays (LCDs) of fluorescent guest host (GH) mode have been proposed [1–3]. The fluorescence intensity of the GH LC cell can be controlled by applying a voltage across the LC cell. We have demonstrated on a multi-fluorescent-color switching in the fluorescent GH LCD in which the cell with different fluorescence colors are stacked [4–10]. We have also reported that fluorescence intensity can be increased using a sensitizing effect in nematic liquid crystals. Green and red fluorescence can be enhanced by single and multiple energy transfers under the UV excitation [10,11].

In this study, sensitizing effects in the LC cell dissolving blue and yellow fluorescent dichroic dyes are investigated. A suitable concentration of dyes to emit the white fluorescence is clarified and the electro-optical properties and the contrast ratio are also discussed.

EXPERIMENTAL

Blue fluorescent dye of 2,5-Bis(5-*tert*-butyl-2-benzoxazolyl)-thiophene (BBOT) and yellow fluorescent dye of 4,7-bis(4-(2-(*p*-butylphenyl) ethen-1-yl)phenyl)-2,1,3-benzothiadiazole (BPEP-BTD) were prepared. A UV fluorescent lamp ($\lambda_{max} = 360\,nm$, FWHM $= 40\,nm$) was used as an excitation light source. Dyes were dissolved in a nematic LC of phenyl-cyclohexane compounds (ZLI-1083) which was almost transparent in the wavelength range of the excitation UV light. Homogeneously aligned LC cells were prepared with the fluorescent LC and ITO-coated glass substrates. The cell thickness was $10\,\mu m$. In the measurement of an electro-optical property, the LC cell is exited unpolarized UV light and the fluorescence intensity whose polarization direction is parallel to the LC is detected.

RESULTS AND DISCUSSION

Absorption spectra of the BBOT and BPEP-BTD fluorescent LC cells for the incident polarized light parallel and perpendicular to the LC alignment direction (rubbing direction in the cell) are shown in Figures 1(a) and (b), respectively. The concentration of BBOT and BPEP-BTD dye in the LC is 0.5 wt%. Absorption dichroic ratios of BBOT and BPEP-BTD fluorescent LC cells are 5.6 and 8.7, respectively. Polarized fluorescence spectra of the LC cells excited with unpolarized UV light are also shown in Figure 1. Fluorescent dichroic ratios are almost the same as each absorption dichroic ratios.

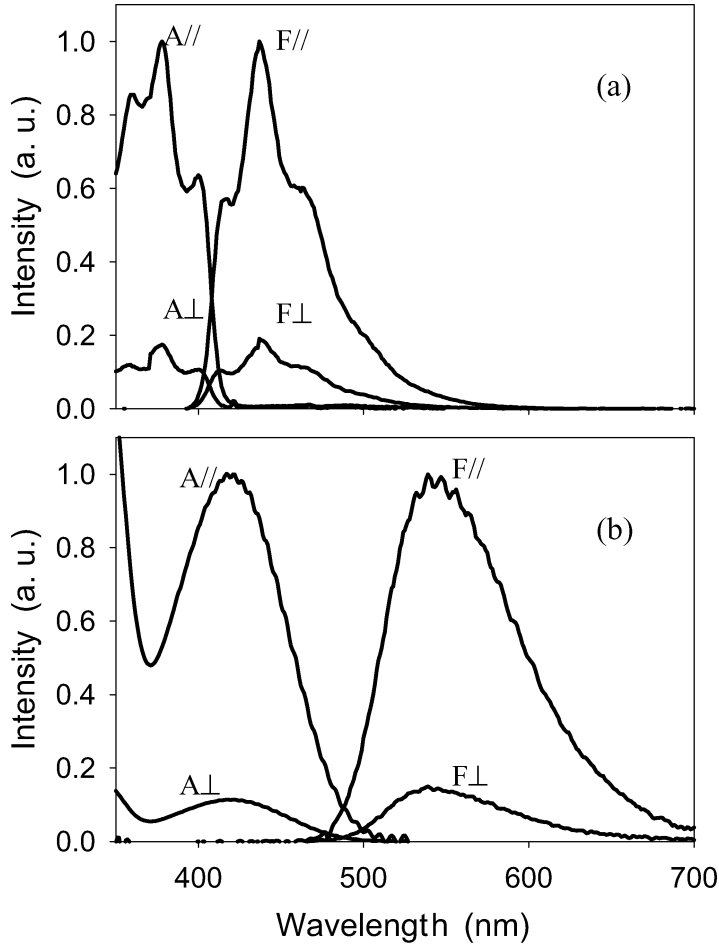

FIGURE 1 Polarized absorption and fluorescence spectra of (a) BBOT and (b) BPEP-BTD of 0.5 wt% dissolved in the LC. The peak intensities of polarized spectra parallel to the LC direction are normalized.

It is seen that the fluorescence intensity of BBOT is larger than that of BPEP-BTD as shown in Figure 2, since the absorption spectrum of BBOT widely overlaps with the emission spectrum of the excitation lamp and the absorption of BPEP-BTD however shows minimum around the peak wavelength of the emission spectrum of the excitation lamp. When BBOT of 0.5 wt% and BPEP-BTD of 0.5 wt% are dessolved together in the LC, the fluorescence intensity of BPEP-BTD increases by 1.8 times and the emission of BBOT decreases to

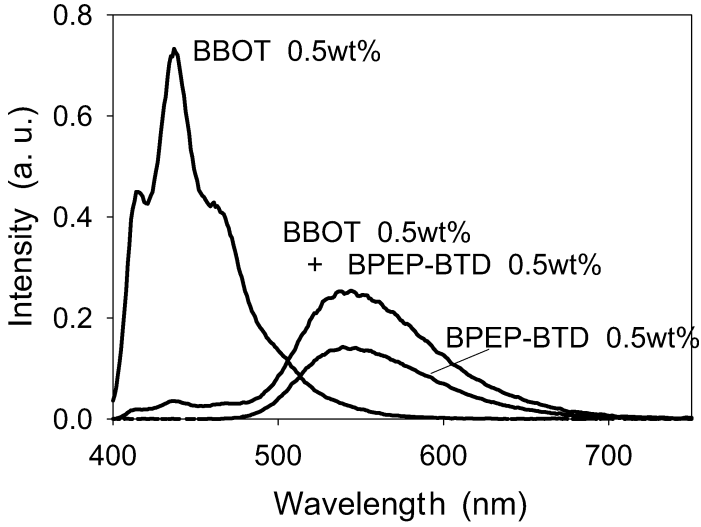

FIGURE 2 (a) Fluorescence spectra of BBOT, BPEP-BTD and sensitized BPEP-BTD.

the low level, as also shown in Figure 2. This result suggests that the excitation energy is transferred from BBOT to BPEP-BTD in the host LC.

The fluorescence intensity in the GH mode can be controlled by applying an external voltage, as well as the transmission light intensity in the case of conventional GH LC cell. We measured the sensitized fluorescence intensity of BPEP-BTD whose polarization direction was parallel to the LC director under the voltage application to the LC cell. The peak intensity of BPEP-BTD (545 nm) decreases as increasing the applied voltage, as shown in Figure 3. On the other hand, the small peak intensity of BBOT (473 nm) hardly changes. The contrast ratio of yellow fluorescent intensity I(0V)/I(8V) is about 4.7 which is lower than that in the fluorescent LC cell without the sensitizing dye of BBOT, since the absorption dichroic ratio of BBOT is lower than that of BPEP-BTD.

When both BBOT of 0.1 wt% and BPEP-BTD of 0.1 wt% are dissolved in the LC, peak intensity of BBOT fluorescence becomes almost the same level as that of BPEP-BTD, as shown in Figure 4(a), and the white fluorescence color is realized. This fact indicates that the intermolecular energy transfer between BBOT and BPEP-BTD molecules occurs less-efficiently in LC with dilute concentrations of the dyes. If the concentration of BBOT increases to 0.2 wt%, both peak intensities

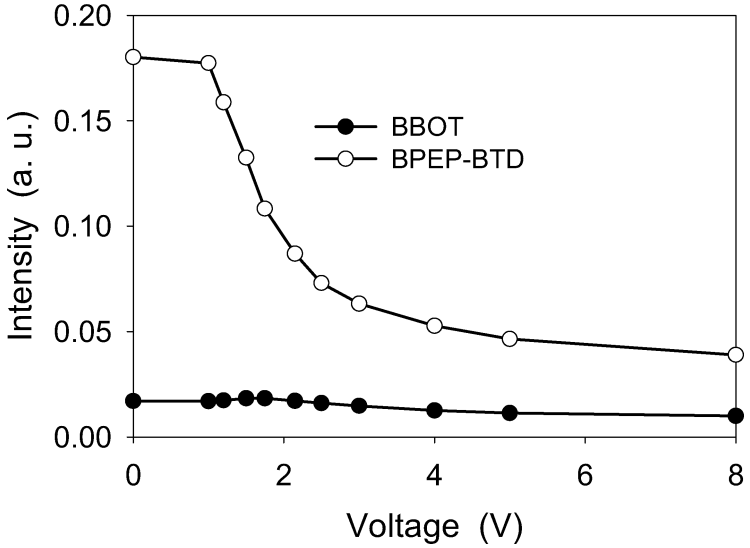

FIGURE 3 Fluorescence peak intensities of BBOT and BPEP-BTD as a function of applied voltage in the LC cell with BBOT of 0.5 wt% and BPEP-BTD of 0.5 wt%.

of BBOT and BPEP-BTD increase. However, the fluorescence intensity of BPEP-BTD tends to saturate if BBOT of 0.3 wt% is added. Figure 4(b) shows color coordinates of each spectrum shown in Figure 4(a).

Fluorescence spectra of the LC cell containing BBTO (0.2 wt%) and BPEP-BTD (0.1 wt%) at the different applied voltages are shown in Figure 5(a). The fluorescence peak intensities of BBTO and BPEP-BTD decrease with increasing the applied voltage, as shown in Figure 5(b). The contrast ratios of BBOT and BPEP-BTD peak intensities are respectively 5.0 and 7.6 correspondingly with their dichroic ratios. Therefore, the white fluorescence color slightly becomes bluish under the higher voltage application, as shown in Figure 5(c). The contrast ratio of the white fluorescence intensity is about 6.5 when the voltage of 8 V is applied to the LC cell.

Next, we increase the concentration of BPEP-BTD to 0.2 wt% to improve the white fluorescent color. When BBTO of 0.2 wt% and BPEP-BTD of 0.2 wt% are dissolved in the LC, the peak intensity of BPEP-BTD becomes about three times larger than that of BBOT, as shown in Figure 6(a). We further add BBOT to increase the BBOT peak intensity. However, the peak intensity saturates at the BBOT concentration of 0.6 wt%. On the other hand, that of BPEP-BTD

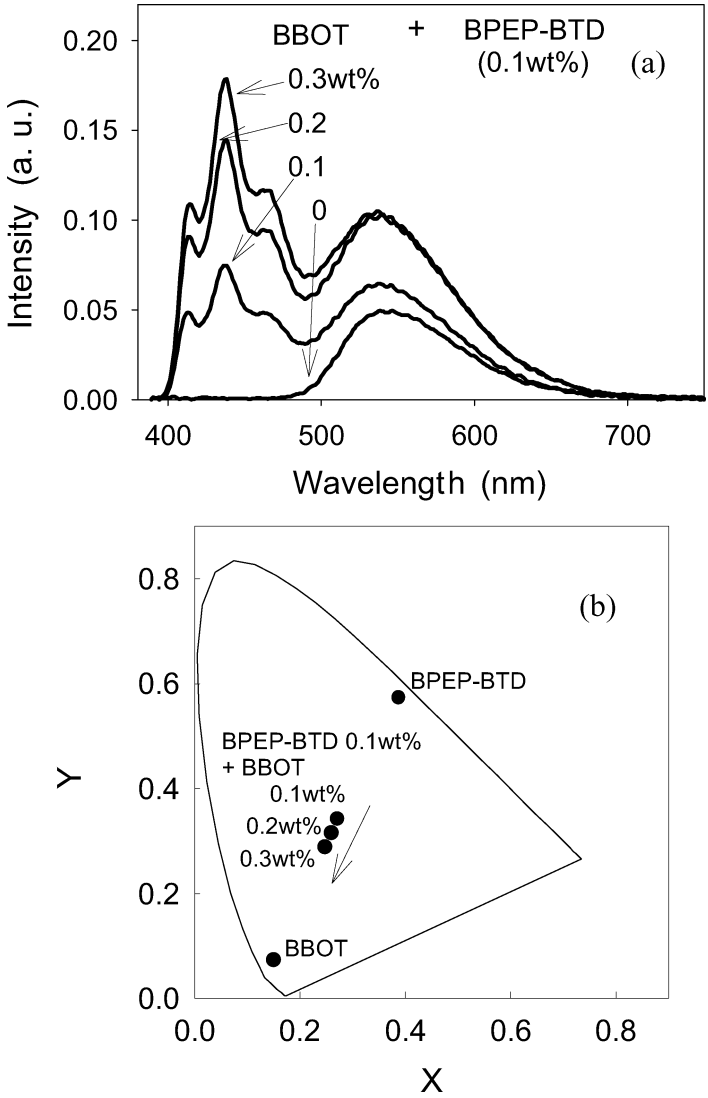

FIGURE 4 (a) Fluorescence spectra in LC cells with BPEP-BTD of 0.1 wt% and BBOT of 0.1 ~ 0.3 wt%, and (b) the chromaticity diagram.

increases with increase of the BBOT concentration, therefore the fluorescence color becomes slightly yellowish with the increase of the BBOT concentration, as shown in Figure 6(b). Moreover the density quenching effect occurs for the BBOT fluorescence more than 1 wt%,

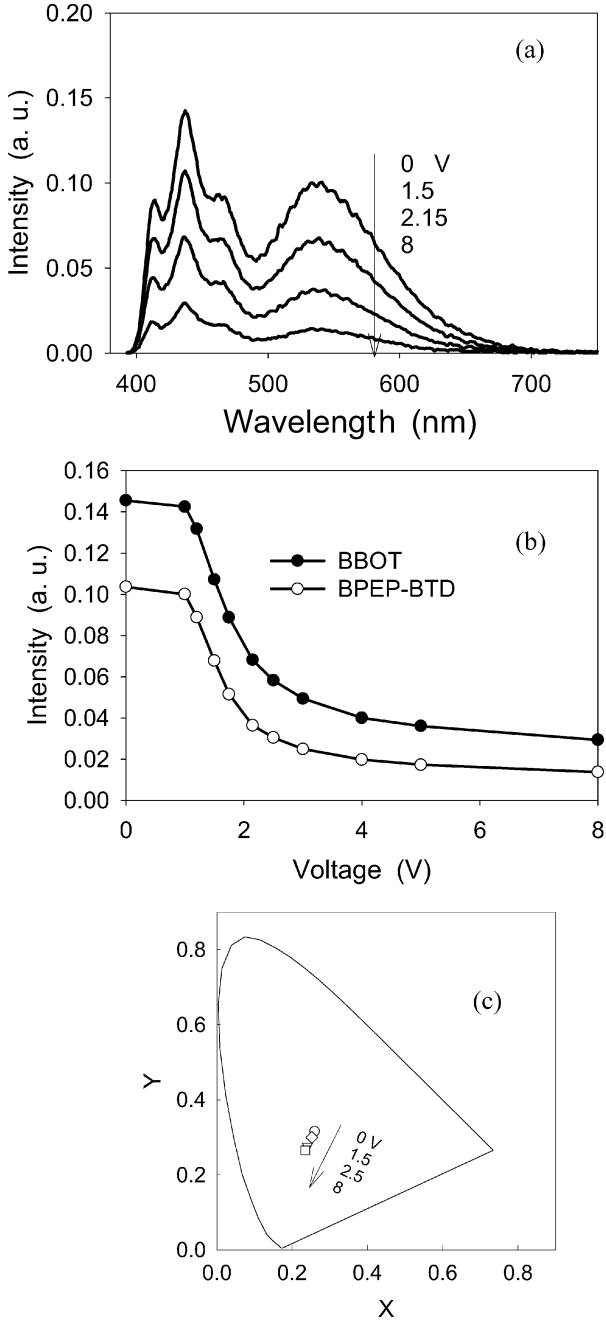

FIGURE 5 (a) Voltage dependence of fluorescence spectra in the LC cell with BPEP-BTD of 0.1 wt% and BBOT of 0.2 wt%, (b) fluorescence peak intensities of BBOT and BPEP-BTD, and (c) the chromaticity diagram.

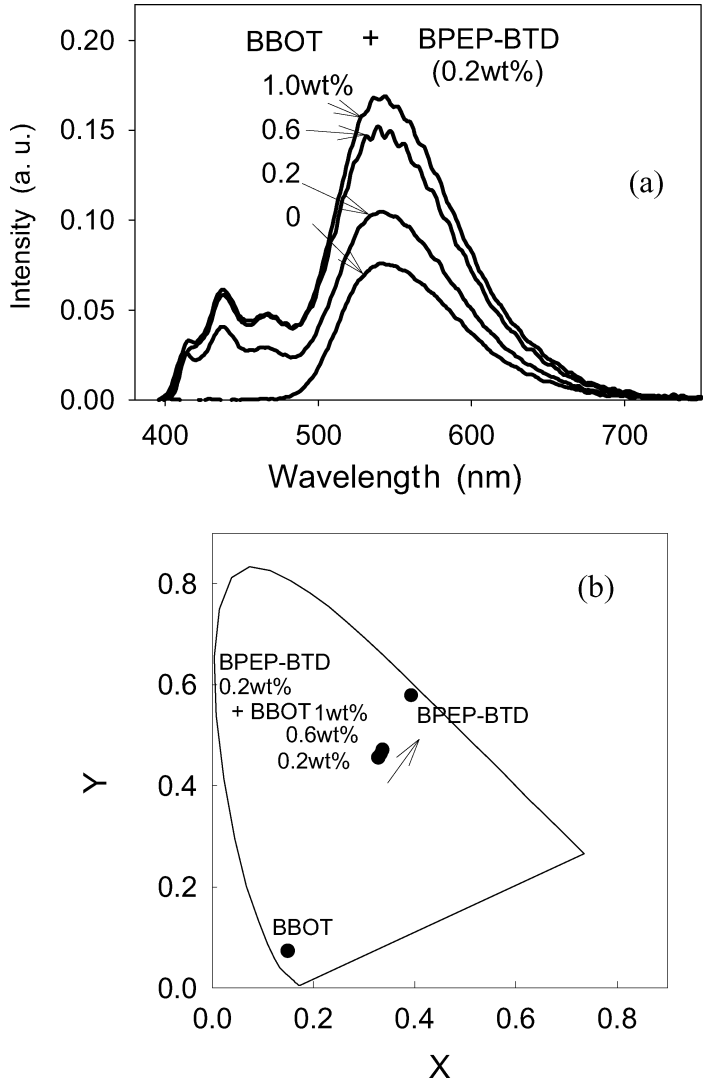

FIGURE 6 (a) Fluorescence spectra in LC cells with BPEP-BTD of 0.2 wt% and BBOT of 0.2 ∼ 1 wt%, and (b) the chromaticity diagram.

so we can not obtain the white fluorescence by adding BBOT in the LC with BPEP-BTD of 0.2 wt%. When the voltage is applied to these LC cells, the fluorescence intensities decrease as well as other fluorescent LC cells and the color shift is hardly observed.

SUMMARY

We can obtain the white fluorescence in the LC cell by mixing the blue and yellow fluorescence dichroic dyes and irradiating the UV light, and control the fluorescence intensity by applying the voltage. When blue fluorescent dye BBTO of 0.2 wt% and yellow fluorescent dye BPEP-BTD of 0.1 wt% are dissolved in the LC, the blight white fluorescence can be observed and the contrast ratio of the intensity is about 6.5 at the applied voltage of 8 V. When the concentration of BPEP-BTD is 0.2 wt%, the white fluorescence color can not be obtained any longer by even if adjusting the BBOT concentration. The combination of cyan and red fluorescence dyes also has a potential to realize the white fluorescence in the LC cell, and the experiment is in progress.

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