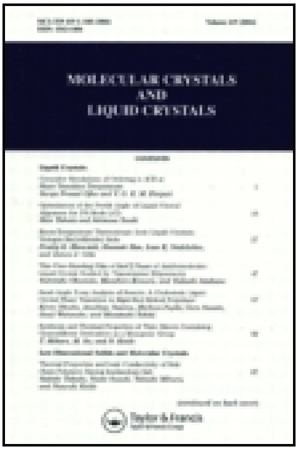

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Multicolor Fluorescent Liquid Crystal Display using a UV Light Emitting Diode

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Multicolor Fluorescent Liquid Crystal Display using a UV Light Emitting Diode

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Multicolor fluorescent liquid crystal (LC) displays using a newly developed UV light emitting diode (UV-LED) as an excitation source are proposed. The fluorescent LC cells are prepared by mixing a cholesteric LC and a blue or green dichroic guest fluorescent dye. A green or red fluorescent film is stacked on the LC cell. The LC cells work as both a UV shutter and a fluorescent emitter, therefore the fluorescence color can be electrically switched between two fluorescent layers. The multicolor fluorescence switch is also demonstrated in the triple-layered cell; two LC layers (blue and green) and one fluorescent film (red).

Keywords: liquid crystal display; multicolor fluorescent display; UV light emitting diode; anisotropic phosphor

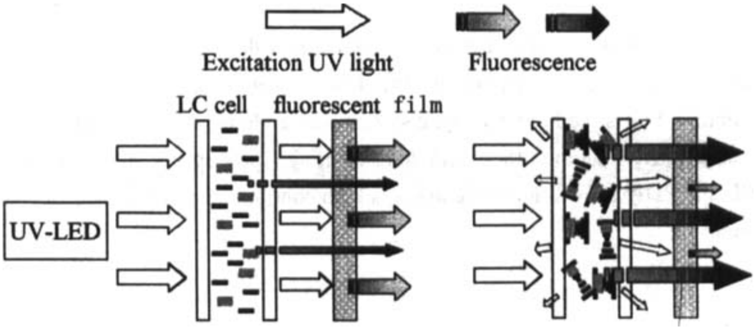
INTRODUCTION

Currently, liquid crystal displays (LCDs) are widely utilized as a portable information display because of the low power consumption. However, common LCDs require a backlight system with a Hg fluorescent lamp for high image quality. On the other hand, light-emitting type displays, such as a CRT, EL and PDP, show a high brightness, a high contrast ratio and a wide viewing angle.

A fluorescent LCD might be expected to have some advantages; the display color would be brilliant and could be viewed from any angle. Larrabee reported the first fluorescent LCD[1], however its contrast ratio was low. The fluorescent LCD with high contrast was demonstrated by Labes where the fluorescence was emitted from a LC irradiated with a UV source by switching from a scattering texture to a non-scattering texture[2,3]. In addition, two color fluorescent LCDs were reported in which a fluorescent element was placed external to a LC cell which functioned as both a tunable UV shutter and as a tunable fluorescent emitter[4,5].

Another type of fluorescent LCD in which a guest-host (GH) or twisted nematic (TN) LC cell was used as a tunable UV shutter to control the photoluminescent intensity from the phosphor film was proposed[6]. Recently, a similar mode LCD using the TN LC cell has also been reported[7].

A full-color fluorescent display has also been proposed[8,9],where fluorescent films of three pure primary colors are exited using a near-UV light-emitting diode (LED)[9] or a newly developed UV-LED. In this paper, multicolor fluorescent LCDs are proposed using the UV-LED as an excitation source. Fluorescent LC cells and fluorescent films are stacked and changes of the fluorescence color are measured as a function of applying voltage across the LC cell.



(a) on-state (b) off-state

Fig. 1 The principle of the multicolor fluorescence switching.

OPERATING PRINCIPLE

The principle of the fluorescence color switching is shown in Fig. 1. A small amount of an anisotropic fluorescent guest dye is added in the cholesteric-nematic phase transition LC. The color of an external fluorescent film is different from the fluorescence color of the LC cell. When a voltage above threshold is applied to the LC cell, that is in the on-state, the absorbance of the UV light becomes minimum in the homeotropically aligned LC cell and its fluorescent intensity is also minimum. Then, the UV light passing through the LC cell can excite the external fluorescent film, and the fluorescent intensity of the film becomes maximum. On the other hand, when removing the applied voltage, that is in the off-state, the UV light is scattered due to the focal conic texture and is effectively absorbed by the guest dye in the LC cell, and the UV light intensity which would excite the external film becomes minimum. Therefore, we can see the fluorescence color mainly emitted from the LC cell.

EXPERIMENTAL

The liquid crystals used in our experiment were a nematic LC ZLI-5092 (Δn=0.0821, clearing point Tc=90℃) and chiral LC dopants CB-15 and S-811. The cholesteric LCs were prepared by mixing 10wt% of CB-15 or 5 wt% of

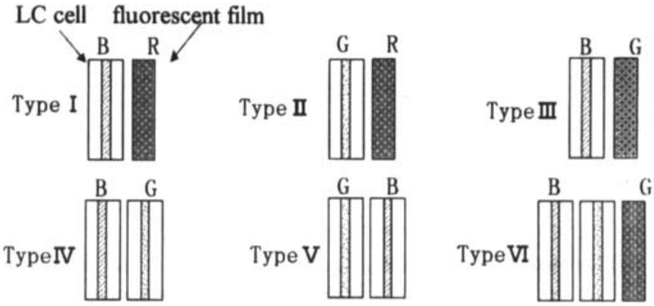


Fig. 2 Combinations of stacked fluorescent layers

S-811 with ZLI-5092. The selective reflection wavelength of these cholesteric LCs was in the infrared region. Anisotropic fluorescent dye, 2,5-bis(5′-tertbutyl-2′-benzoxazolyl)-thiophene (BBOT) and a triphenylamine derivative (NSD) were employed as guest molecules in the cholesteric LCs, where their concentrations were 0.5 wt% and 1.0 wt%, respectively. The cell thickness was about 5 μm. As the external phosphor film, polymer solutions of NSD and europium thenoyltrifluoroacetonate (EuTTA) were used. BBOT, NSD and EuTTA respectively show purplish-blue, blue-green and red fluorescence under the UV excitation. Combinations of stacked fluorescent layers investigated in this study are shown in Fig. 2.

A newly developed UV-LED (Nichia Chemical Industries) was used as an excitation light source. The UV-LED was driven with a DC current. When the driving current is 10 mA, the peak wavelength is 372 nm with 11.5 nm of FWHM. A color glass filter of UVD-33S (Toshiba) was utilized to cut the weak visible light from the UV-LED.

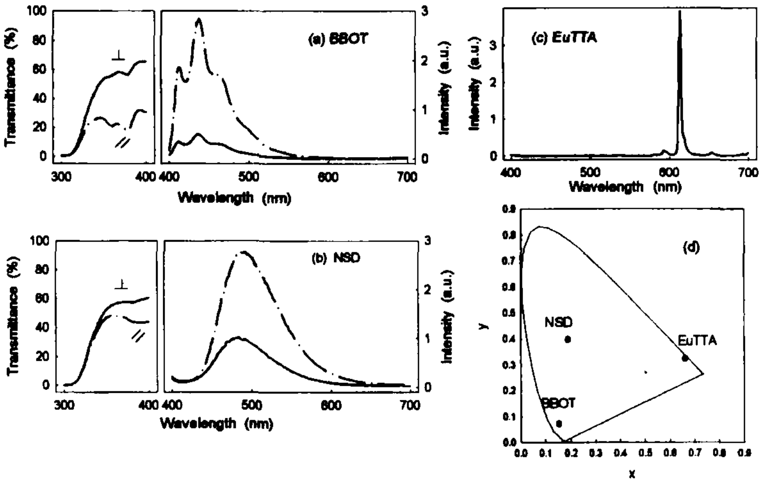


Fig. 3 Dichroic properties and fluorescence spectra of (a) BBOT and (b) NSD in homogeneous guest-host cells, (c) fluorescence spectrum of EuTTA film and (d) their chromaticity coordinates (CIE 1931).

RESULTS AND DISCUSSION

Figs. 3(a) and 3(b) show transmission spectra in the UV light range and fluorescence spectra which are measured in homogeneously aligned guest-host cells of BBOT and NSD. The dichroic ratio (DR) of BBOT in ZLI-5092 is about 2.3 at 370 nm. When the incident UV light is polarized parallel to the LC direction (dash-dot line), the fluorescent intensity, as well as the UV light absorption, becomes maximum. The fluorescent intensity at 435 nm of the peak wavelength is about 5.7 times stronger than that for the excitation by UV light polarized perpendicular to the LC direction (solid line). The DR of NSD is 1.4 and the ratio of the fluorescent intensity at 490 nm of the peak wavelength is also low comparing to that in BBOT guest-host cells, that is about 3:1. In Fig. 3(c), a sharp fluorescence spectrum around 612 nm of the EuTTA polymer film is shown and it has no anisotropy for the UV light absorption. The CIE (1931) chromaticity coordinates of three fluorescence colors are shown in Fig. 3(d).

Fig. 4(a) shows the change of the spectrum by applying a voltage across the LC cell in Type I. The blue fluorescent intensity decreases and the red one increases with increasing applied voltage, as shown in Figs. 4(b). Therefore the fluorescence color changes can be obtained from purple to purplish red, whose chromaticity coordinates are shown in Fig. 4(c).

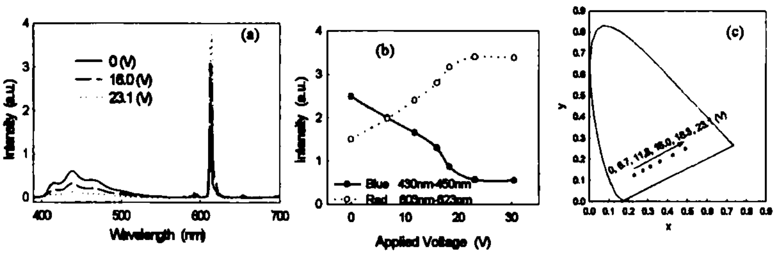


Fig. 4 (a) Fluorescence spectrum and (b) the intensities of blue and red light and (c) chromaticity coordinates in the stacked cell of Type I, as a function of applied voltage.

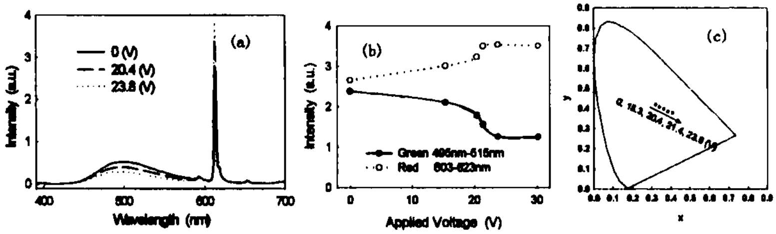


Fig. 5 (a) Fluorescence spectrum and (b) the intensities of green and red light and (c) chromaticity coordinates in the stacked cell of Type II, as a function of applied voltage.

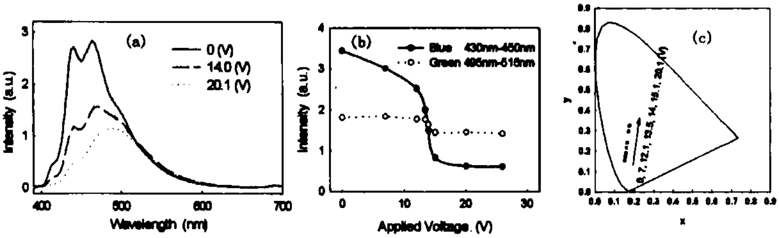


Fig. 6 (a) Fluorescence spectrum and (b) the intensities of blue and green light and (c) chromaticity coordinates in the stacked cell of Type III, as a function of applied voltage.

In the case of Type II, the spectrum variation and the intensities of green and red light are shown in Figs. 5(a) and 5(b), as a function of applied voltage. The green fluorescent intensity of the LC cell decreases but the red one of the external film increases with increasing applied voltage, as well as those of Type I, however the difference between the color in the off- and on-state is relatively small. Therefore, the hue variation in the chromaticity diagram is narrow and the chroma is also low, as shown in Fig. 5(c). The low DR of NSD results in these poor properties.

Fig. 6(a) shows the fluorescence spectra in the stacked cell of Type III. The blue fluorescent intensity of BBOT decreases with increasing applied voltage, however the intensity of NSD around 500 nm of the peak wavelength also slightly decreases, as shown in Fig. 6(b), since BBOT and NSD fluorescence spectra overlap between about 450 nm to 510 nm. Their chromatic coordinates are shown in Fig. 6(c). The fluorescence color changes from purplish blue to bluish green are observed.

Next, we have tried to stack two fluorescent LC cells and they are illustrated in Fig. 2 as Type IV and V, and the LC cells are driven by each other. When the LC cell on the incident side of the UV light (LC1) is in the off-state and another LC cell (LC2) is in the on-state, most UV light is absorbed by the LC1 and the fluorescence from the LC1 is observed. Since the UV light passed through the LC1 is weak and the absorbance of the LC2 is small, the fluorescent intensity of the LC2 becomes minimum. In addition, the fluorescence of the LC1 fully passes through the transparent LC2 without been scattered. On the other hand, when the LC1 is in the on-state and the LC2 is in the off-state, the absorption of UV light and fluorescent intensity of LC1 are minimum. Furthermore, the weak fluorescence of the LC1 is scattered by the LC2 in the off-state and can hardly pass through the LC2. As a result, the fluorescent emitted mainly from the LC2 can be obtained. The fluorescence switches in the case of type IV and V are shown in Figs. 7(a) and 7(b), respectively. The hue difference by electrically switching in these double-layered LC cells as shown in Fig. 7(c) is larger than that of the type III.

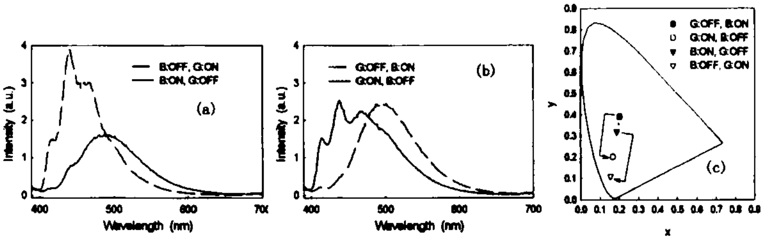


Fig. 7 Fluorescence spectrum switching in the double-layered LC cells of (a) Type IV and (b) Type V, and (c) chromaticity coordinates.

Moreover, the multicolor switching properties are investigated in the triple-layered structure, that is shown in Fig. 2 as Type VI with two LC cells and one external fluorescent film. Blue and green fluorescence can be achieved by the same operation as in the type IV. When both LC cells are in the on-state, the absorption of the UV light through two LC cells is minimum. Therefore, the fluorescent intensity of the external film becomes maximum. Figs. 8(a) and 8(b) show the switching results in the triple-layered cell. Fig. 8(a) shows the changes of fluorescence spectra with the combination of the

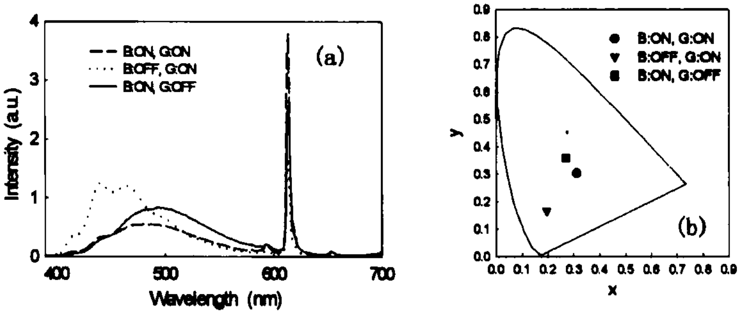


Fig. 8 (a) Fluorescence spectrum switching in the triple-layered LC cells of Type VI and (b) chromaticity coordinates, with each applied voltage combination.

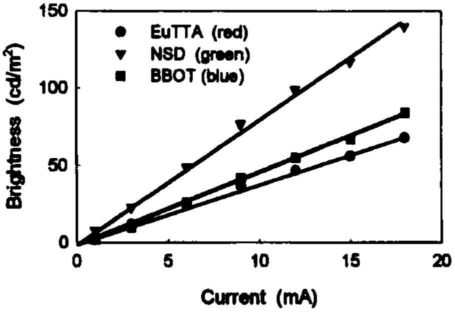


Fig. 9 Fluorescent brightness of BBOT and NSD LC cells and EuTTA polymer film as a function of driving current of the UV-LED.

applied voltage. However, a clear green and red fluorescence color can not be obtained, as shown in Fig. 8(b). This is because the second LC cell of NSD has low dichroic ratio.

Fig. 9 shows the fluorescent brightness of BBOT and NSD LC cells and EuTTA polymer film, as a function of driving current of the UV-LED. The brightness increases linearly with increasing driving current of the UV-LED. The driving power is about 40 mW at the current of 10 mA.

CONCLUSIONS

Multicolor fluorescent LCDs using the UV-LED as an excitation source are investigated. The fluorescence color can be electrically switched between two or three fluorescent layers.

Comparing to the usual LCD backlight systems using a Hg fluorescent lamp, the backlight using the newly developed UV-LED have the advantages: they are lighter, thinner and a Hg-free, and have noiseless properties. Moreover, the fluorescent emissive LCDs have a high coefficient of the light utilization and a wide viewing angle, compared to the conventional LCDs using color filters and polarizers.

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