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Optical Color Compensation Film for Plasma Display Panels

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Abstract. *An optical filter providing color compensation for plasma display panel modules was prepared using a cyanine dye that was designed to attenuate visible light from neon plasma discharge. Two types of the optical filters were devised and their effect on the image quality was evaluated. A film optical filter eliminated the double image or reflection observed using glass filters and provided a greater bright room contrast ratio. Our results indicated the overall color purity was improved by 12.7% with a red color purity correction and that the color temperature was increased by 2500 K using the film. © 2010 Society for Imaging Science and Technology.*
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INTRODUCTION

Color compensation is one important aspect of the engineering of plasma display panel (PDP) devices. For color plasma displays, each pixel is composed of three discharge cells where plasma is turned on and off by applying the appropriate voltage to the display electrodes. When a high voltage is applied across the two electrodes, a mixture of neon and xenon gas is excited and energy is released as ultraviolet (UV) radiation. The UV wavelengths excite the phosphors in the panel to emit red, green, or blue. Neon atoms are excited and, upon returning to the ground state, also emit neon spectral lines around 580–700 nm with a strong peak at 585 nm.[1] On the other hand, when excited xenon atoms return to the ground state, near infrared light of 800–1100 nm is generated, in addition to the UV emission.[1,2]

Therefore, a filter locally reducing the transmittance of orange neon and near-infrared light is added to the face of plasma displays.[3–5] This filter can also be endowed with properties correcting the color balance of an image or improving the color purity by regulating the transmittance in the visible range. Because the orange light emitted during the neon discharge is mainly responsible for color purity degradation in PDP devices, we devised an optical color compensation filter to optimize the color spectrum of visible light emitted from the panel by attenuating unwanted spectral emissions having a wavelength 585 nm.

To provide better image quality, a cyanine dye was designed to meet the optical properties of a filter. Cyanine dyes are used in many optical signal-recording processes such as photography, laser printing, xerography, and optical memory systems.[6,7] Because they are easily tuned they are also important for display applications such as near infrared absorbance filters for PDPs.[8] By varying the number of carbons in the cyanine dye methine-bridge or by modifying the cyanine ring structure, it is possible to synthesize dyes absorbing particular wavelengths and having particular solvent solubility.

EXPERIMENTAL PROCEDURES

Synthesis of Cyanine Dye and Film Preparation

The dye selected for this study was synthesized by condensation of 3-ethyl-2,4-dimethylpyrrole (kryptopyrrole) and 1,1,3,3-tetramethoxypropane (TMOP) with perchloric acid. The novel production setup was composed of a slit interdigital micromixer with a hasteloy high pressure mixer inlay having a 45 μm channel width, and a 250 μm channel depth (IMM GmbH, Germany) that was followed by an extension loop. A microchannel device was employed for the production of cyanine dye because the microchannel reaction provided higher yields and productivity when compared with the same reaction in a larger batch type apparatus.

Kryptopyrrole was fed into one side of the micromixer at a flow rate of 1 mol/h and TMOP was fed into the other side of the inlet at a flow rate of 0.44 mol/h. The TMOP feeding solution was composed of 9.6% w/w TMOP, 18.5% w/w perchloric acid, 57.7% w/w chloroform, and 14.2% w/w ethanol. After mixing in the micromixer, the temperature of the resulting solution was maintained at 55°C at a flow rate of 0.7 L/h. It was possible to increase the scale of the production scale to 1 kg/day by increasing the feed flow rate. The cyanine dye suspension was collected in a 2 L jacketed filter reactor, washed with octane and water, and then dried. The resulting product yield and purity were 95% and 99.5%, respectively. The dye was also characterized by NMR spectroscopy. ^{1}H NMR ($CDCl_3$, 600 MHz) 10.70 (s, 2H), 7.31

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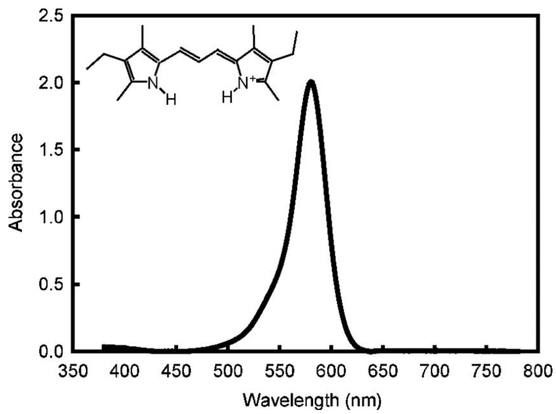

Figure 1. Absorption spectrum of a dilute solution of cyanine dye.

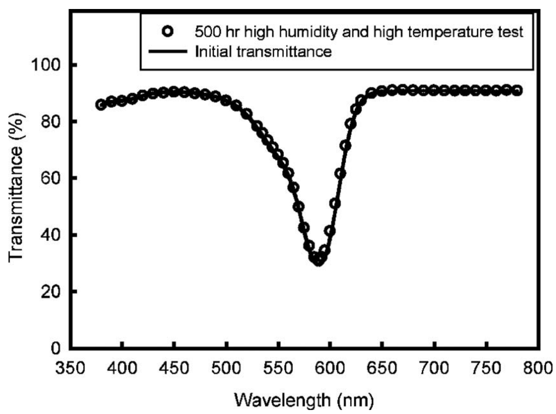

Figure 2. Optical filter durability test.

(dd, J=9.5, 7.5 Hz, 1H), 7.24 (d, J=9.5 Hz, 1H), 7.23 (d, J=7.5 Hz, 1H), 2.40 (s, 6H), 2.37 (q, J=6.5 Hz, 4H), 2.17 (s, 6H), 1.04 (t, J=6.5 Hz, 6H). ^{13}C NMR ($CDCl_3$, 150.9 MHz) δ 149.67, 138.64, 137.97, 131.51, 130.65, 114.28, 17.33, 14.48, 12.62, 9.66.

A coating solution to be used for color compensation was prepared by dissolving the cyanine dye (0.04% w/w) in a binder resin solution of poly(methylmethacrylate) in 2-butanone (30% w/w). This mixture was bar coated on a transparent polyethylene terephthalate (PET) film.

RESULTS AND DISCUSSION

The structure of the cyanine dye used in this study is shown in Figure 1. When dissolved in 2-butanone the cyanine dye had a sharp absorption band at 580 nm with a half bandwidth of 36 nm as shown in Fig. 1. The molar absorptivity was measured as 1.36×10^4 M^{-1} cm^{-1}. Due to its high molar absorptivity, the amount of dye required could be reduced by 75% with the same performance, compared with a conventional dye. The cyanine dye layer was 15 μm thick when bar coated on a transparent PET film and had a minimum transmittance at the orange wavelength of 587 nm as observed in Figure 2. The cyanine-coated layer efficiently removed the emitted neon orange light having an emission wavelength of 585 nm from the PDP devices tested.

Our cyanine dye proved advantageous both in terms of its optical absorption characteristics and its solubility in a

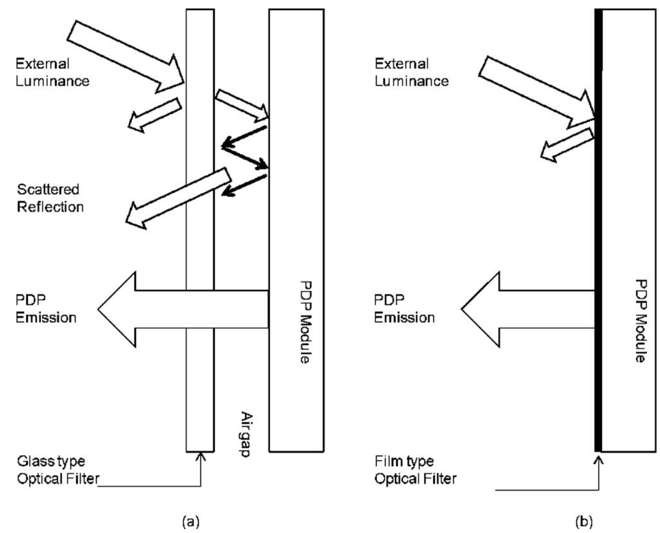

Figure 3. A schematic illustration of light path of PDP TV set: (a) glass-type optical filter; (b) film-type optical filter.

binder solvent. In addition, the dye was stable when subjected to the heat generated by the PDP module. A durability test showed that the absorbance of the dye deteriorated less than 1% after both a 500 h high temperature test at 80°C, and a 500 h high humidity test using 90% relative humidity, at 80°C (554.49 g water/kg air) as shown in Fig. 2.

The reflection caused by the 3 mm air gap between the front of a plasma display panel and a conventional tempered glass filter leads to a double reflection effect in the images as shown in Figure 3(a). The color compensation filter was applied to the filter film as shown in Fig. 3(b). Because the filter was directly attached to the front surface of the plasma display panel, the 0.5 mm filter film both minimized the dullness of the image and eliminated the double image reflection of glass filter PDPs. The film filter could also save weight and thickness in PDP TV and give a cost reduction of 10–20 % with respect to devices using the tempered glass.

The main absorption wavelength, intensity and half bandwidth of a dye can also influence the black image quality of a PDP. This effect can be represented as the bright room contrast ratio. The bright room contrast ratio is proportional to the luminescence of a bare PDP emission and inversely proportional to both the transmittance of the optical filter and to the reflected external illuminant light from the PDP set as shown in Fig. 3(b). Therefore, to enhance the quality of the black image a filter needs to have a low transmittance, allowing the panel to absorb external light and reduce reflection without blocking the three primary colors (red, green, and blue) from the PDP phosphor. The color compensation filter can improve the contrast ratio without reducing the luminance. It does so by reducing the transmittance in the wavelength region having weak bare PDP luminance and strong external light intensity. Table I shows the optical behavior of the PDP set when the cyanine dye was applied both as a film and to the glass filter. The film-based color compensation filter had superior bright room contrast ratio and higher transmittance when compared to glass filters.

Table I. Optical color compensation filter comparison.

	Module	Film filter	Glass filter
Transmittance (%)	100	47.2	46.8
Peak luminance (cd/m^2)	1349	658	644
Black luminance (cd/m^2)	10.7	2.41	2.65
Bright room contrast ratio (100 lx)	126:1	273:1	246:1

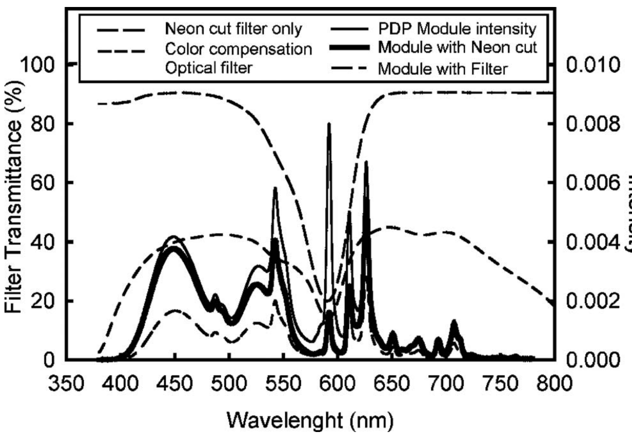

Figure 4. The emission spectrum of a PDP and the transmission spectrum of the optical filter.

Our color compensation filter was designed to absorb visible light emitted from 570 to 600 nm. Figure 4 shows that unwanted spectral emissions at 585 nm were effectively reduced, thereby enhancing red color purity and improving bright room contrast ratio of PDP TV modules. Figure 5 shows that the coordinates in the Commission Internationale de l'Eclairage (CIE) chromaticity diagram of the PDP device spectrum and the National Television Standard Committee standard. The color coordinates of red, green, and blue were shifted from $(x=0.640, y=0.354)$, $(x=0.283, y=0.659)$, $(x=0.152, y=0.058)$ to $(x=0.663, y=0.325)$, $(x=0.246, y=0.678)$, $(x=0.149, y=0.054)$ when the cyanine dye coated film was applied. The color reproducibility was increased by 12.7% overall and the red color purity was greatly enhanced with the cyanine dye coated color compensation filter. When the filter was equipped with UV, infrared, electromagnetic interference (EMI) shielding functions along with the color compensation, the center of color coordinates, i.e., the white light emission, moved from $(x=0.301, y=0.310)$ to $(x=0.273, y=0.290)$ and corresponded to an increase in color temperature from 7800 to 10,300 K.

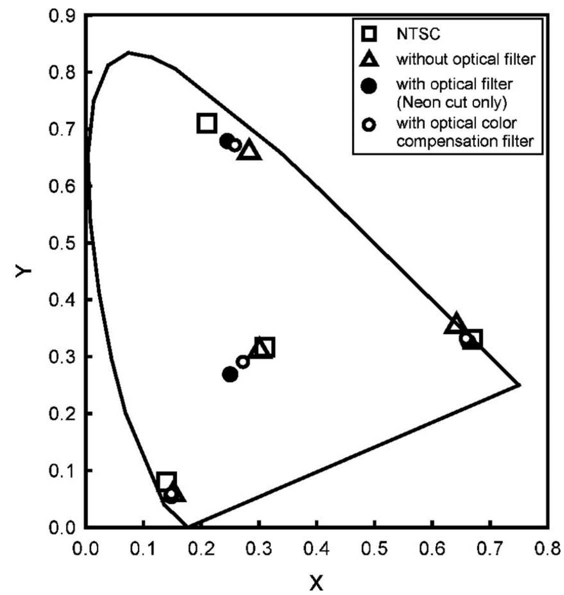

Figure 5. Color coordinates of the CIE chromaticity diagram.

CONCLUSIONS

A color compensation filter was applied to 42 in. PDP TV sets in order to enhance color purity and black image quality. The filter was coated with a cyanine dye and passed rigorous high temperature and high humidity durability tests. The filter was tested with both glass and film-coated filters. The film filter showed improved black image quality without the double image reflection of glass filters. Our filter effectively reduced the amount of 585 nm light emitted as a result of the neon excitation that takes place during plasma discharge. The color purity was enhanced by 12.7%, and the color temperature increased from 7800 to 10,300 K. The absorption of the external illuminant and reflected light from the PDP passed through the color compensation filter twice, resulting in a colorless black or nonreddish black image.

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