High performance color conversion polymer films and their application to OLED devices

Masaru Nagai
Fuji Electric Advanced technology Co., Ltd.
Japan

1. Introduction

When dye molecules absorb light, they emit light at a different, generally red-shifted, wavelength. This is a principal characteristic of dye molecules and is applied in many fields, such as laser systems, lighting, and displays. In this article, we report highly efficient color-conversion polymer films and their application to full-color, active-matrix (AM), organic light emitting diode (OLED) displays.

Since they were first reported by Tang and van-Slyke [1], OLEDs have attracted much attention for application to next-generation displays. During the past decade, several commercial products have been developed using small OLEDs fabricated by vacuum evaporation. However, OLED manufacturing is still problematic, especially for full-color displays. Figure 1 outlines three typical methods for fabricating full-color, OLED displays. Side-by-side patterning for red-green-blue (RGB) using shadow masks has been the most commonly used method [2], but using shadow masks is costly. Moreover, the substrate size and display resolution are limited.

Using OLEDs with color filters (CFs) eliminates the need for shadow masks and is suitable for large-scale high-resolution displays [3, 4]. The CFs are used with white OLEDs to attain full-color functionality. However, the transparent spectral band of the CFs must be narrowed to expand color gamut, leading to a reduction in the amount of light emitted by the white OLEDs. Therefore, balancing high efficiency with a wide color gamut is difficult. A good way to overcome this trade-off without losing the advantages of the color filter method is to use a color conversion material (CCM) that converts the blue spectrum of the OLED emission into red and green spectra [5-7]. If a polymer is used as the CCM, patterning can be achieved using a low-cost printing technology, such as ink jetting.

Use of a CCM is thus a promising alternative for manufacturing large-scale, full-color OLED displays. In this article, we report high-efficiency CCM films made using various polymers and their application to AM-OLED displays.

2. Proposed CCM systems

Several types of CCM films have been proposed for OLED use. The simplest type is a thin solid film composed of single-dye molecules. This is a single-step conversion system of single-dye molecules. With such films; there should be sufficient overlap between the

absorbance spectrum of the material and the emission spectrum of the backlight OLED, the emission spectrum of the material should have a wide color gamut, and the films should have high photoluminescence quantum efficiency (PL_{eff}). Finding a suitable CCM is thus difficult, particularly with respect to the requirement for high-photoluminescence quantum efficiency. With most fluorescent dyes, the PL_{eff} in film is considerably smaller than that in solution due to the concentration quenching effect.

A photo-resist-dispersion-type CCM was proposed to overcome this problem. In this system, fluorescent dyes are dispersed in photoresist polymers with a dispersion density sufficiently low to avoid concentration quenching. Photolithography is used for the material patterning. However, when the dispersion density is reduced, the film thickness increases to more than 10 μm in order to obtain sufficient backlight absorption. This increased thickness creates various types of defects in the OLED device, such as current leakage [8]. The photosensitivity of the photoresist polymer is another problem. The photo-initiators react with the dyes and degrade the PL_{eff} [9].

To overcome these drawbacks, we have developed an advanced CCM system that uses host materials and guest dyes. The host material absorbs OLED-emitted light, and the excited energy is transferred from the host to the guest dye in a Förster fashion, resulting in radiation from the guest dyes. Using a low concentration (~1%) of guest dyes prevents concentration quenching. Since a photoresist polymer is not used, durability is improved compared to the systems that do use one. In short, this advanced CCM system results in both high PL_{eff} and improved durability without increasing the film thickness significantly.

3. Experiments

In the experiments we used to evaluate the use of various polymers as a CCM, we dissolved the polymer in tetrahydrofuran (THF) to 1.0 wt% and coated it on a glass substrate by spinning (500 rpm for 5 s; then 800 rpm for 20 s). The coating was done in dry N2 atmosphere (due point < −40□). The oxygen concentration was less than 50 ppm. The film samples were encapsulated with glass covers in dry N2 atmosphere. The photoluminescence (PL) and absorbance spectra of the samples were measured. The PL_{eff} of the samples and solutions was measured using an integrating sphere with a diffraction grating and a Xe lamp as an excitation source [10]. The excitation wavelength for the measurement was 470 nm, corresponding to the backlight peaking. To evaluate advanced CCM systems, a mixture of small dye molecules and host polymers in THF was used. The host/guest ratio was tuned so as to obtain the maximum PL_{eff}. American Dye Source (ADS) Co., Ltd supplied the polymers used in this research.

4. Materials

4.1 CCM-green conversion

There are severe restrictions with CCM green conversion (CCM-G). Sufficient overlapping between the absorbance spectrum of the material and the emission spectrum of the backlight OLED is required to achieve sufficient photon transfer. If blue OLEDs are used for the backlight, the CCM-G should have a very short Stokes' shift (~ 50 nm). Since achievement of an advanced CCM host/guest energy transfer system is impossible when blue OLEDs are used for the backlight, single-step color conversion using a single-dye system may be the only way to implement CCM-G. Reducing concentration quenching in

dye films is thus very important for using CCM-G. We examined the use of various types of polymers for CCM-G. We focused on polyfluorene derivatives, which are well known for their high PL_{eff} [11, 12].

Figure 2 diagrams the chemical structures of potential candidates for CCM-G polymers, and Table 1 summarizes their performances. For most fluorescent polymers, the PL_{eff} in film is much less than that in solution. Few polymers result in a PL_{eff} in film higher than 60%. Moreover, the maximum PL peak in film is red-shifted 20-30 nm compared to that in solution.

A comprehensive evaluation of the performances showed that fluorene/MEH-PPV copolymer (CCM(G)-1) is the best polymer for our purpose. This polymer has a very short Stokes' shift and a very high PL_{eff} (70%) in film, the same as that in solution. This strongly suggests that concentration quenching would not occur in film.

Figure 3 plots the PL and absorbance spectra of a film fabricated using CCM(G)-1. There was an absorbance peak around 480 nm, which is nearly identical to the emission peak of the backlight blue OLEDs. Moreover, the film showed bright green emission peaking at 510 nm.

The absorbance and PL peaks for polyfluorene, 370 and 420 nm, respectively, are much shorter than the excitation wavelength. Thus, the absorption and emission of CCM(G)-1 arose mainly due to the MEH-PPV units in the chains. In other words, fluorene units in the chains acted as "spacers" between MEH-PPV units and reduced their mutual interactions. This apparently caused higher PL_{eff} in film made of CCM(G)-1.

CCM(G)-2 exhibited an even higher PL_{eff} in film—90%. This excellent PL_{eff} is also explained in the same manner. Unlike the CCM(G)-1 structure, a phenyl unit is connected to each side of the fluorene units. These phenyl units further weakened the MEH-PPV units—MEH-PPV units interaction. Thus, use of this polymer resulted in even higher PL_{eff} than using CCM(G)-1. Unfortunately, its absorbance and PL peaks do not match our target values.

4.2 Drying conditions for CCM(G) films

In the experiments using CCM(G), THF was used as a solvent since it is easily removed by spinning due to its low boiling point (66°C). A low-boiling-point solvent, however, is hard to use for ink-jet printing because it can clog the nozzles. Generally speaking, solvents used for ink-jet printing should have a boiling point higher than 150°C. If a high-boiling-point solvent were used for patterning the CCM, a drying process would be needed after spinning to remove the solvent residue. Our experiments showed that the PL_{eff} of CCM films is significantly affected by the drying conditions. Using a tetralin solution, which is typically used as an ink-jetting solvent, we investigated the relationship between the PL_{eff} of CCM(G)-1 films and the drying conditions.

CCM(G)-1 was dissolved in tetralin to 1.0 wt% and coated on a glass substrate by spinning in the same way as described above. Next, it was heat dried using a hot plate in dry N_2 atmosphere. The temperature was varied between 25°C (room temperature) and 200°C, and the drying time was 30 minutes.

As shown in Fig. 4, the PL_{eff} of the CCM(G)-1 films decreased as the drying temperature was increased. The films dried at room temperature had the same order of PL_{eff} as that of THF films. However, they had some fluidity due to insufficient solvent removal. The films dried at 100°C had the same PL_{eff} as those dried at room temperature and were stiff. The PL_{eff} of

films dried above this temperature decreased as the temperature was increased. Films made of a polyfluorene derivative aggregate when heated, and the decrease in PL$_{eff}$ was apparently caused by polymer aggregation and the resultant strengthened interactions between MEH-PPV units [13-15]. The stronger interactions promoted the transfer of exited energy to other units without radiation.

We also investigated the effect of the processing atmosphere on the PL$_{eff}$ of CCM-G films. From the manufacturing point of view, fabrication of CCM films in air is preferable. We thus first performed all processes and measurements in air for CCM(G)-1 films. Unfortunately, this significantly reduced the PL$_{eff}$ (to 30%).

We further investigated the effect of air exposure on the PL$_{eff}$. As shown in Table 2, air exposure during spin coating and drying had little effect on the PL$_{eff}$. However, once the films had been dried, air exposure significantly degraded the PL$_{eff}$.

Moisture and oxygen adversely affect the characteristics of MEH-PPV derivatives [16-18]. Moisture and oxygen on the non-dried films had trouble diffusing and penetrating the films due to the presence of residual solvent. In contrast, they easily penetrated the dried films and thus degraded them.

4.3 Monomer diffusion method

To enhance the PL$_{eff}$ of the CCM(G) films, we developed a "monomer diffusion method". This method can be used for any type of CCM polymer film. Thermosetting acrylate monomers are used to reduce concentration quenching in the film.

Figure 5 schematically illustrates the four steps in this method. 1) A CCM polymer film is formed on a substrate. 2) Liquid-state acrylate monomers are coated on the substrate without using a solvent. The substrate is then heated in two steps: 3) at a temperature lower than the thermosetting point and 4) at a higher temperature. In the first heating step, the monomers diffuse into the CCM polymer film and act as spacers in the polymer chains. In the second heating step, cross-links are formed between the remaining monomers. The acrylate monomers used must have sufficient transparency and an adequate refractive index, both of which depend on the adjacent CCM film.

The PL$_{eff}$'s of the CCM(G)-1 films with and without monomer diffusion are compared in Fig. 6 for three drying temperatures. The weight of the acrylate monomers was 1200, and their refractive index was 1.65. The thicknesses of the films and acrylate-monomer layers were 0.80 and 1.0 μm, respectively. Using this method substantially improved the PL$_{eff}$ for each drying temperature. The highest PL$_{eff}$ was 80% for the film dried at 100°C. Interestingly, this method restored the PL$_{eff}$ of degraded films. Acrylate monomers apparently diffused into the aggregated portion of the films and separated the adjacent units, thereby reducing the strength of their interactions.

Cross-sectional images obtained by focused ion beam (FIB) analysis of CCM(G)-1 films without and with an acrylate layer and dried at 100°C are shown in Fig. 7. The white layer on the films is a carbon protection layer that was formed to minimize ion-beam damage. Comparison of the two images reveals that diffusion of the acrylate monomers doubled the thickness of the CCM(G)-1 film.

In another experiment, we investigated the effect of preliminary mixing of the acrylate monomers in the CCM polymer solution on the PL$_{eff}$ in film. As shown in Table 3, increasing the fraction of acrylate monomers to 30:1 had little effect on the PL$_{eff}$ for CCM(G)-1 film. Only when the fraction was increased to 40:1 there was a substantial effect. However, such a thick film would adversely affect device performance, and it would be difficult to form by

ink-jet printing. The acrylate monomers and CCM polymers were apparently separated in the preliminary mixed solution and also in the films, so the monomers did not act as spacers and thus did not reduce the interaction between the CCM polymer units. In contrast, when the monomers were added to the CCM solid films, the individual monomers diffused into the CCM polymers and acted as spacers.

We also examined the use of epoxy monomers, another typical thermosetting material. However, they significantly degraded the CCM(G) films. These monomers apparently have an adverse chemical effect on polyfluorene-MEH-PPV derivatives.

4.4 Durability of CCM(G) films

We examined the durability of CCM(G) polymer films by encapsulating the CCM substrate with a glass cover and placing a sharp-cut filter (Hoya Co., Ltd.; L42) on the cover. The light from a Xe lamp was passed through the filter, and the light irradiated the target film with a luminance of 10,000 cd/m². The filter had a transmission wavelength of 420 nm, and most of the light shorter than this wavelength was removed from the irradiation. During the irradiation, the substrate was kept at 60°C to accelerate film degradation. These test conditions accelerated CCM film degradation ten-fold compared to OLED device driving with 1,000-cd/m² backlight luminescence.

As shown in Fig. 8, the cyano-substituted polymers, CCM(G)-4 and -5, showed a rapid decrease in PL_{eff} over time. Cyano groups seem to be sensitive to light irradiation. The fluorene/MEH-PPV derivatives with no cyano units showed better light durability. For CCM(G)-1, the decrease in PL_{eff} was only 20%.

To investigate the effect of impurities on durability, we further purified the CCM(G)-1 polymer using the reprecipitation method, with THF as the good solvent and acetonitrile as the poor solvent. The reprecipitation was continued until all traces of impurities had been removed, as measured using liquid chromatography. As shown in Fig. 8, the durability of CCM(G)-1 was greatly improved following this further purification—the PL_{eff} remained unchanged for the duration of the test.

These fluorene/MEH-PPV derivatives, however, had absorbance durability problems. Their absorbance was significantly degraded by light irradiation, and material purification did nothing to alleviate this. As shown in Fig. 9, the absorbance of CCM(G)-1 film decreased as irradiation proceeded, and the peak was blue shifted.

As shown in Fig. 10, the absorption constant of the films depended on the film thickness. The thinner the film, the larger the decrease. Therefore, this problem can be alleviated by increasing the film thickness.

4.5 CCM-red conversion

If blue to red conversions are to done with a single-step process, the material must have a very long Stokes' shift (>150 nm). Few fluorescent polymers have such a long Stokes' shift.

Figure 11 shows the chemical structures for candidate single-step CCM-R polymers, and Table 4 summarizes their performances. All of them had unacceptable performance. The PL_{eff} was 20% at best in solution and in film.

The long Stokes' shift reflects the higher potential of radiation-less deactivation of excited polymers. Therefore, the poor PL_{eff} is not surprising. In short, the single-step CCM-R system is not particularly suitable.

An advanced CCM system should be more suitable for red conversion. In this system, the two functions of a CCM, absorption and emission are achieved using two different materials, a host polymer and a guest dye, respectively. This leads to a significant advantage: the restrictions mentioned in section 2 are greatly eased, so there are more candidate materials that can be used. There are two steps in selecting the two materials to use. First, candidates for the guest dye are selected on the basis of their emission spectra without considering their absorbance peaks. Next, candidates for the host polymer are identified on the basis of their absorbance spectra. The transfer of excited energy from the host polymer to the guest dye is another factor in the selection process. This transfer is strongly related to the energy alignment between the host polymer and guest dye.

Pyrromethene derivatives are potentially suitable as a guest dye. They have a narrow emission spectrum, so their use results in a sufficiently wide color gamut without excessive emission losses [19]. The chemical structure and emission spectrum of a possibly useful pyrromethene derivative (650) are shown in Fig. 12.

We examined the use of five CCM-G polymers as the host material for this guest dye. Table 5 summarizes the PL_{eff}'s of the host/guest mixture films, and Fig. 13 shows the energy diagrams. The HOMO level of the material was determined by photoelectron spectroscopy measurement (AC2, Riken Keiki Co., Ltd.). The LUMO level was determined by using the HOMO value and the band gap energy. The CCM(G)-4/guest system had an excellent PL_{eff} (as high as 80%). In this system, the guest-HOMO-LUMO level was completely confined within the host-HOMO-LUMO level. In this mixed film, emissions came from only the guest dye. The CCM(G)-1, and -2 had particularly low PL_{eff} values. In these systems, the host-HOMO level was higher than the guest-HOMO level. Therefore, to achieve sufficiently high performance with the advanced CCM system, the guest-HOMO-LUMO level must be completely confined within the host-HOMO-LUMO level.

5. CCM-OLED displays

5.1 Display preparation
We prepared top-emission, full-color, 2.8" QVGA (240×320), active-matrix (AM), OLED displays with CCM-R, and -G polymers. Figure 14 shows the process flow. The a-Si thin-film transistors (TFTs) and color filter substrates were fabricated independently. A blue OLED was fabricated on the TFT substrate, and CCM film was deposited on the color filter substrate by ink-jet printing. In the final stage, the two substrates were joined together using thermosetting acrylate polymer. This polymer was used both for the transparent adhesive filler and the diffusion layer.

5.2 Ink-jet printed CCM
Ink-jet printing is generally used for polymer OLEDs and color filters due to its cost advantages. Obtaining uniformly thick printed films is critical because their performance is strongly affected by their thickness. In contrast, it is not critical for CCM films. The photon conversion efficiency of CCM film is expressed as

$$Ec = Ea \times PL_{eff} = \{1-\exp(-\alpha T)\} \times PL_{eff}, \qquad (1)$$

where Ea is the absorptance, α is the absorption constant (per cm), and T is the film thickness. As T increases, Ec rapidly converges to a specific value. In other words, Ec is not affected by fluctuations in film thickness in thicker regions. As shown in Fig. 15, beyond a thickness of 400 nm, Ea was basically constant.

Images taken with a fluorescent microscope (NIKON INSTECH Co., Ltd.; TE2000-S) of ink-jetted CCM(G)-1 films illuminated by 470-nm light are shown in Fig. 16. The film thickness was significantly nonuniform due to the interaction between the CCM solution and the substrate/bank surfaces. The thickness tended to increase near the banks. The luminance of the insufficiently thick film (a) was not uniform, while that of the sufficiently thick film (b) was uniform. For CCM(G)-4 films, we obtained the same results.

In accordance with these results, we used a thickness of 400 nm for both the red (CCM(G)-4/pyrromethene-650) and green (CCM(G)-1) CCM films in the OLED device we prepared.

5.3 Backlight blue OLED

The schematic structure of the OLED is shown in Fig. 17. Common anode was connected to the a-Si TFT. A transparent oxide electrode made of indium-zinc-oxide (IZO) was used for the common anode. It was fabricated by plasma sputtering. To avoid damage to the OLED during sputtering, a buffer layer was fabricated under the electrode. Doping was used to reduce the driving voltage and to improve the injection performance of both the hole-injection layer and the electron-injection layer.

Figure 18 shows the EL spectrum of the OLED, and Figure 19 shows the a) current density-voltage and b) luminescence efficiency-current density curve of the pure blue emitting OLED, respectively.

5.4 Display performance

Figure 20 shows a photograph of the AM-OLED display. Uneven areas were not evident to the naked eye in any of the ink-jet-printed pixels.

Backlight conversion efficiency Eb was used an index of the color-conversion ability of the CCM films:

$$Eb = CCM\ efficiency\ (cd/A)/OLED\ efficiency\ (cd/A). \qquad (2)$$

For CCM-G, the Eb value was nearly constant at 1.9. This value was greater than 1.0 due to the luminosity effect. For CCM-R, the value was 0.53.

Figure 21 shows the color gamut of the OLED display. The pure blue emitting OLED and the better emission spectra of the CCM polymers enabled the achievement of an NTSC gamut ratio of 100%.

The display had a significantly wider viewing angle than that of the conventional side-by-side patterned displays, as shown in Fig. 22. This was mainly because the fluorescent light emitted from the CCM layer has Lambertian distribution.

6. Conclusion

High-performance, color-conversion polymer systems were identified: single-step CCM for green and advanced CCM for red. They have high PL quantum efficiencies (70–80% in film), and their PL and absorbance spectra are well suited for CCM-OLED devices. A monomer diffusion method was developed for enhancing the PL_{eff} in film. AM CCM-OLED displays were fabricated using ink-jet printing that had an NTSC gamut ratio of 100%. These polymers are promising color-conversion materials that can be used to fabricate efficient CCM-OLED devices.

7. References

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Technology	Side-by-side patterned RGB	White OLED with CFs	Blue OLED with CCMs
Schematics			
Efficiency	high	low	medium
Color Gamut	wide	narraw	wide
Resolution	<150ppi	>180ppi	>180ppi
Characteristic Manufacturing Process	OLED patterning by metal masks	OLED evaporation without patterning	CCM layers to be added
Mother Glass Size	G3	G4 available	G4 available
Production Yield	low	high	high

Fig. 1. Typical methods for fabricating full-color OLED displays.
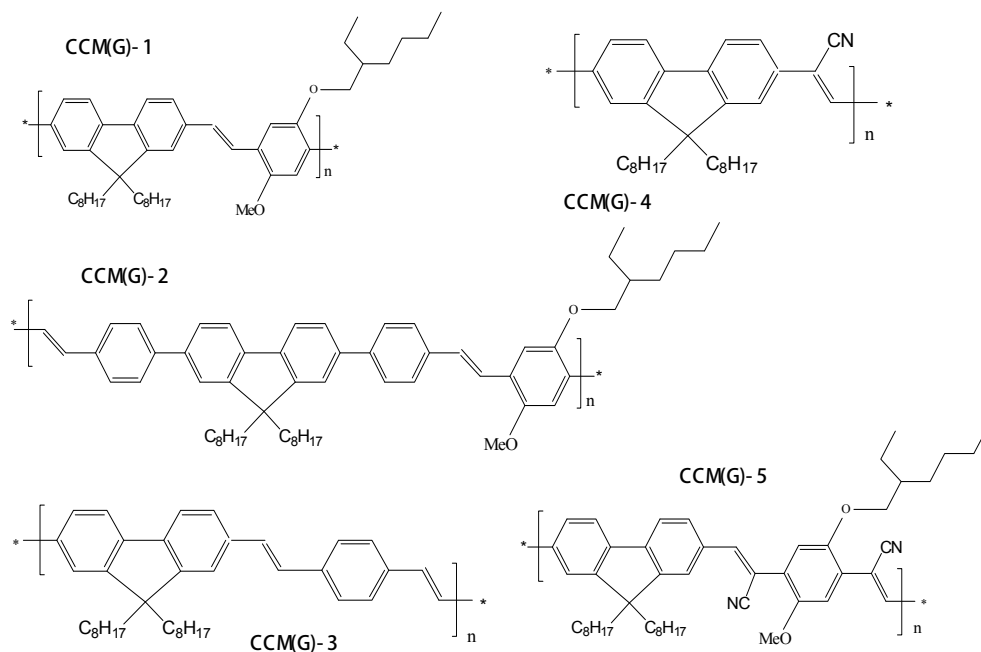
Fig. 2. Chemical structures of candidate CCM-G polymers.
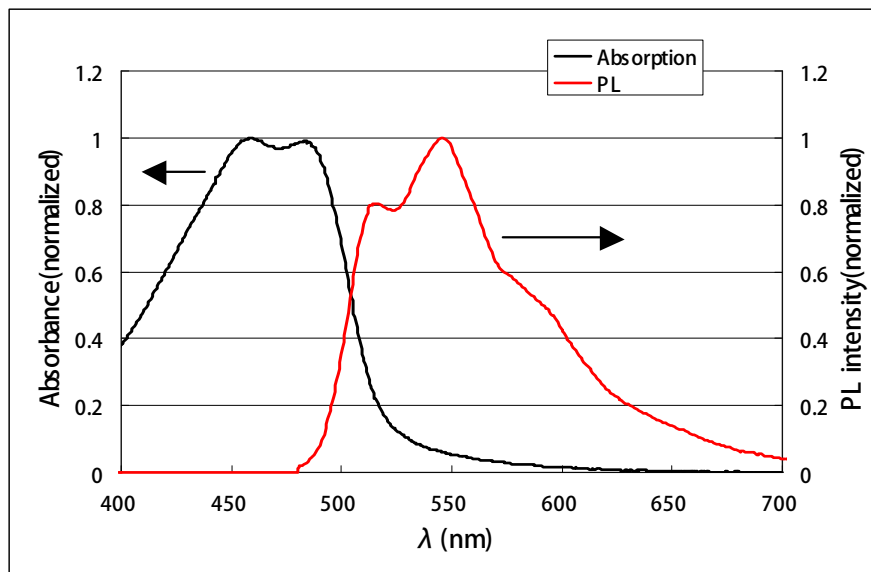
Fig. 3. Absorbance and PL spectra of CCM(G)-1 film.
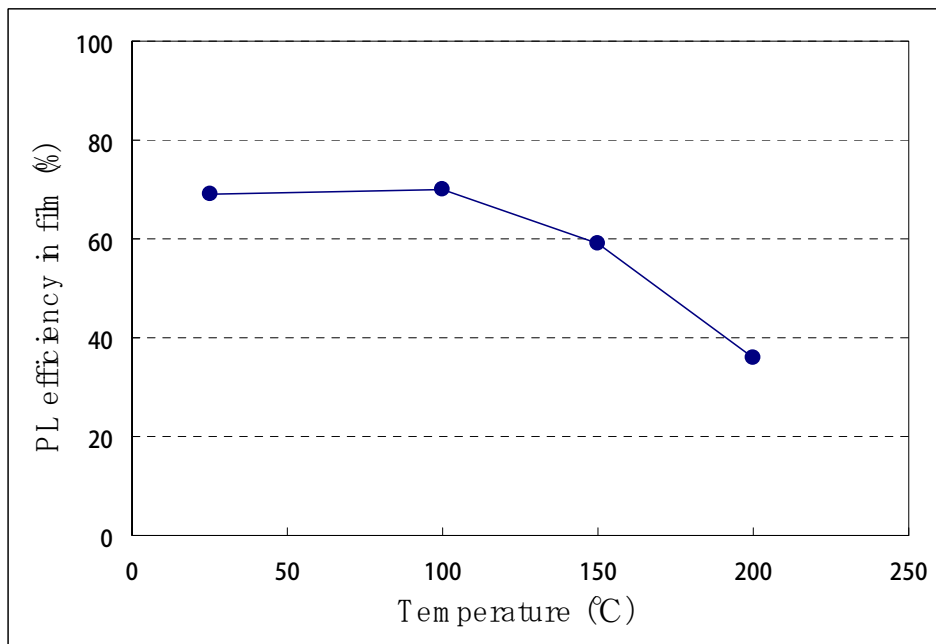
Fig. 4. PL efficiency of CCM(G)-1 film vs. drying temperature.

1) CCM film formation

2) Acrylate monomer coating

3) Diffusion process (100℃ × 60 min)

4) Cross-linking formation (200℃ × 60 min)
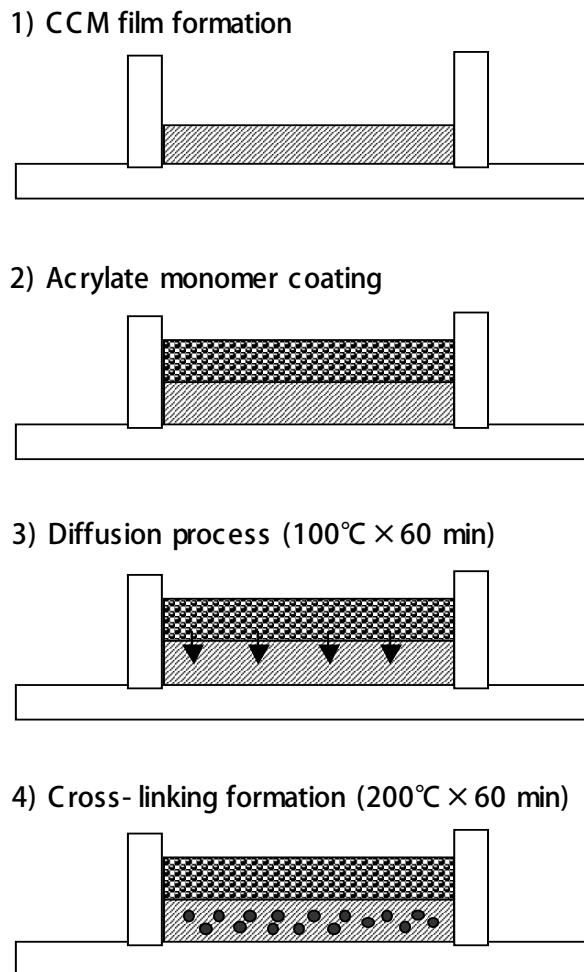
Fig. 5. Schematic showing steps in monomer diffusion method.
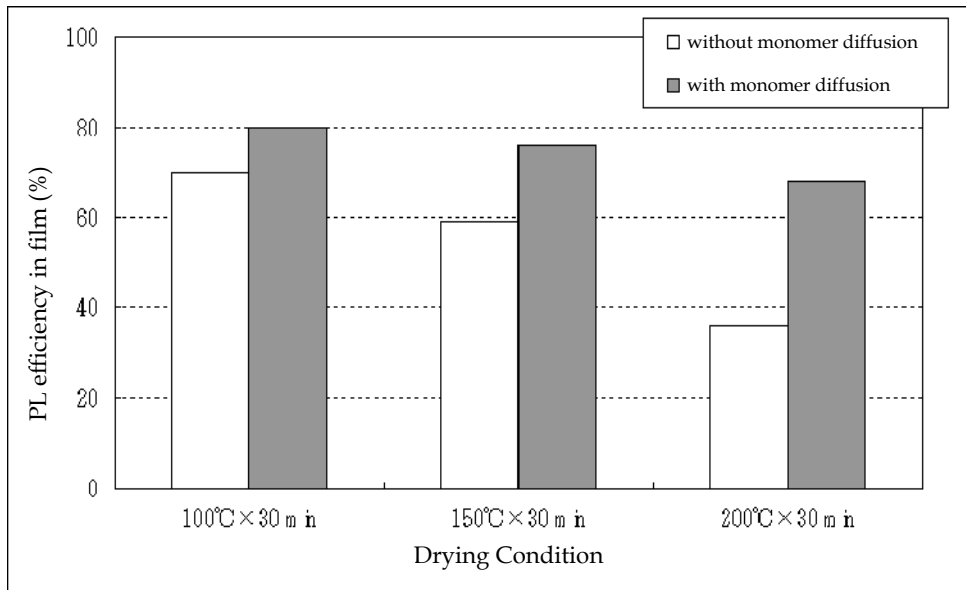
Fig. 6. Effect of monomer diffusion on PL efficiency of CCM(G)-1 film dried with various temperatures.
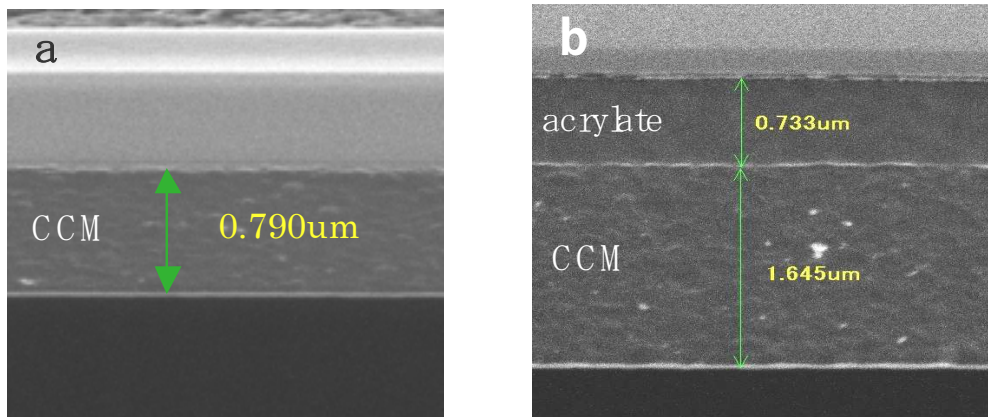
Fig. 7. Cross-sectional images of CCM(G)-1 film (a) without and (b) with acrylate layer.
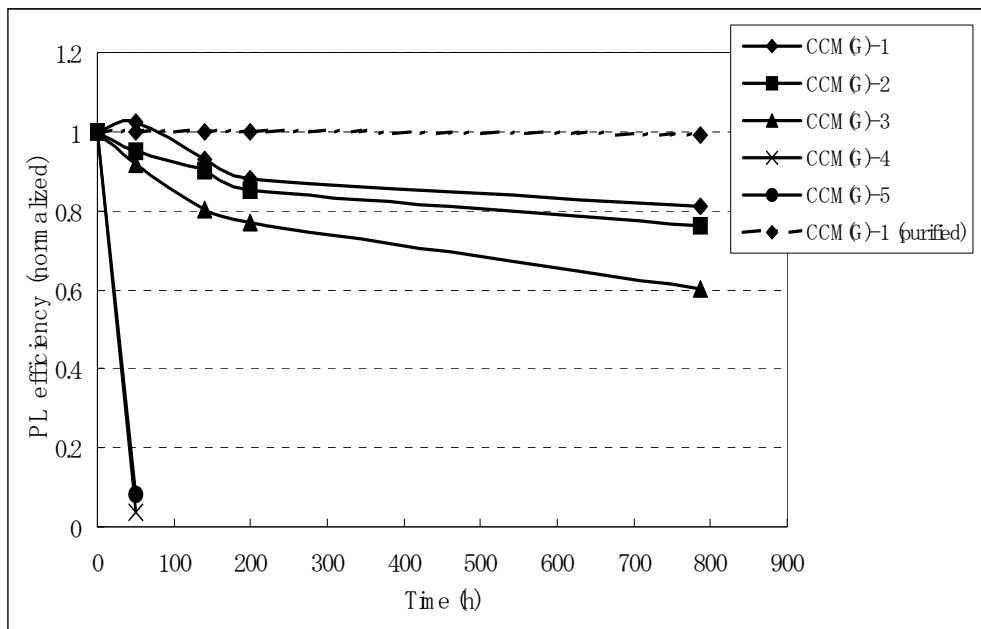
Fig. 8. Decrease in PL efficiency for CCM polymers.
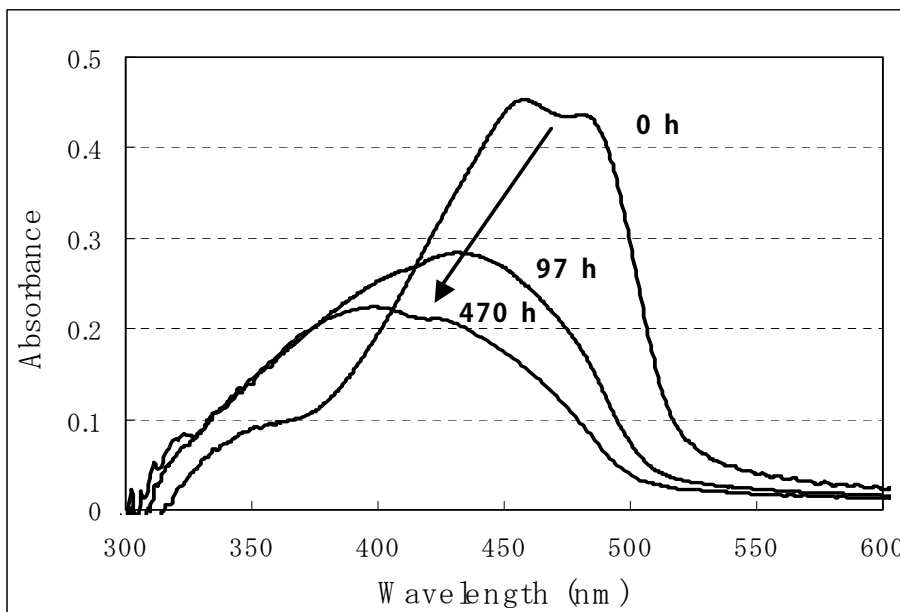
Fig. 9. Degradation in absorbance spectra for CCM(G)-1 film at 97 and 470 hours.
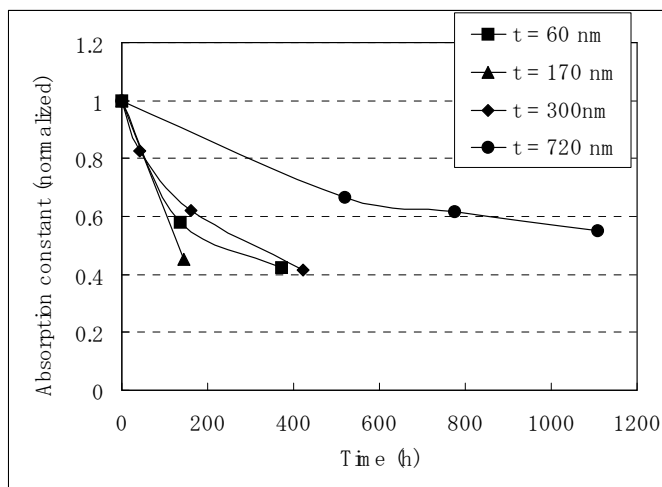
Fig. 10. Degradation in absorption constant over time for four CCM(G)-1 film thicknesses.
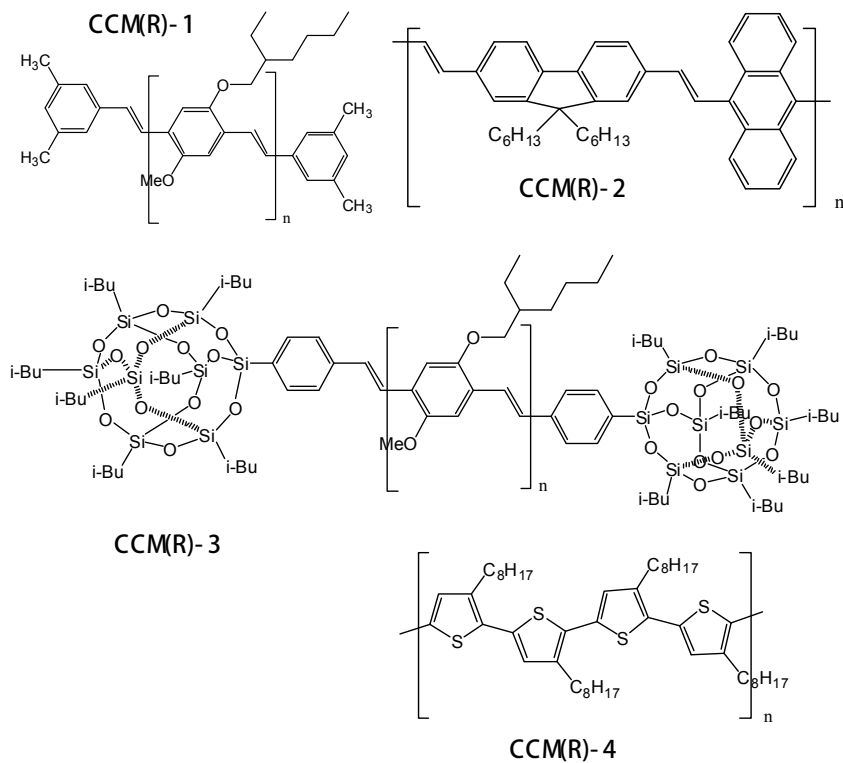
Fig. 11. Chemical structures of candidate CCM-R polymers.
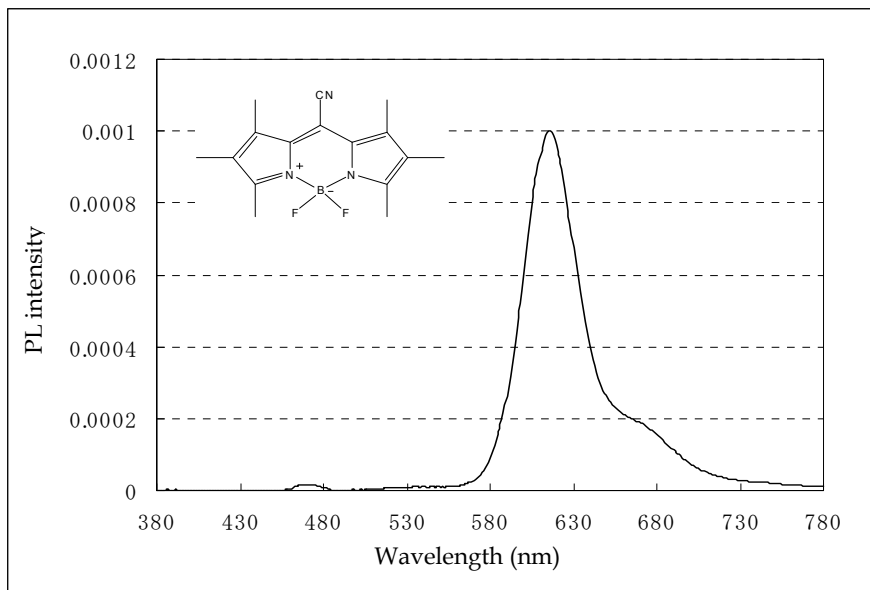
Fig. 12. PL spectrum and chemical structure of pyrromethene 650.
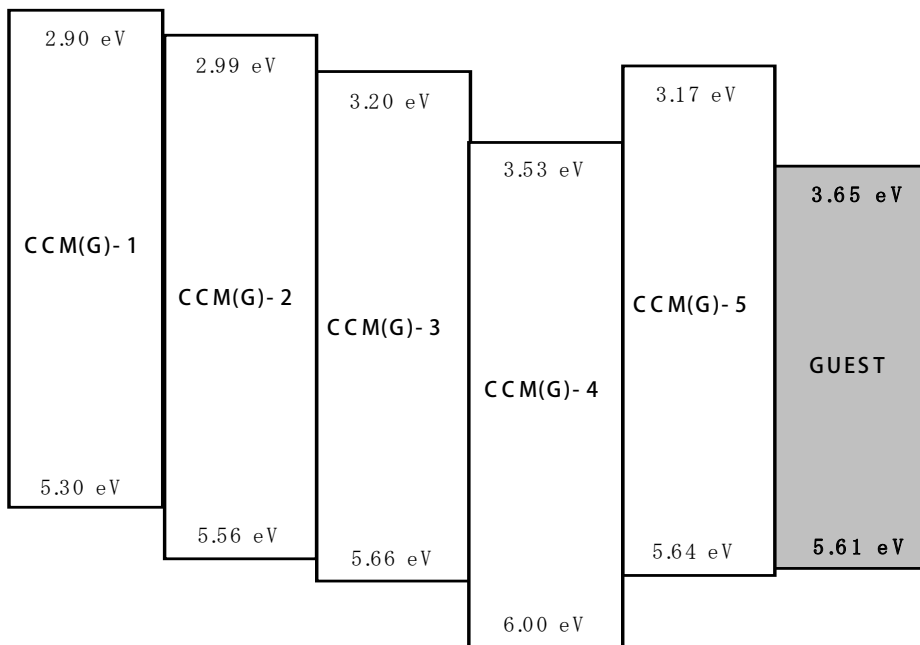
Fig. 13. Energy diagrams for advanced CCM(R) systems.
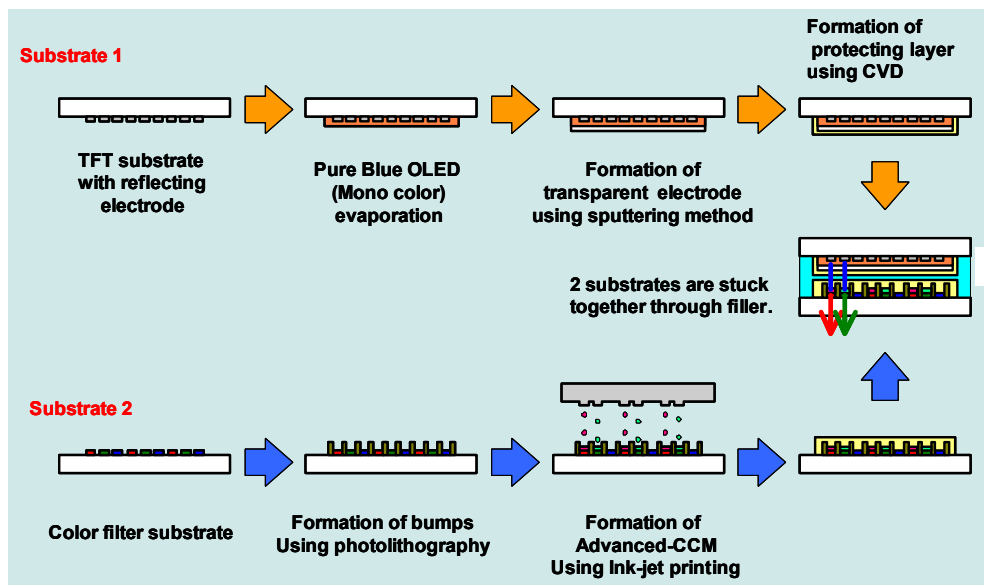
Fig. 14. Process flow for preparing CCM-OLED displays.
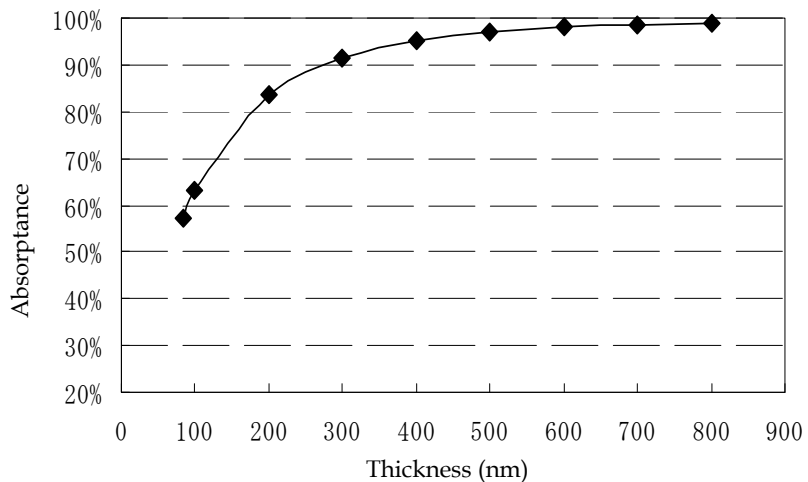
Fig. 15. Calculated Ea of CCM(G)-1 as a function of film thickness.
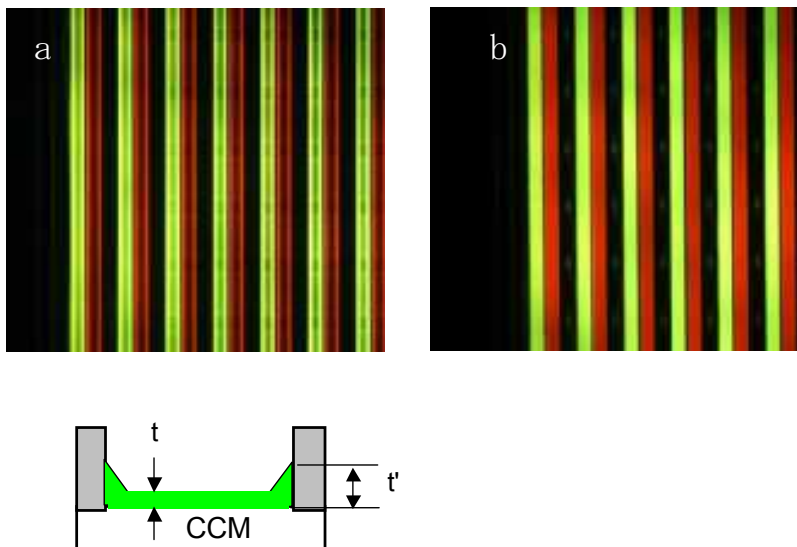
Fig. 16. Fluorescent-microscopy images of ink-jetted CCM films: (a) t, 500 nm; t′, 100 nm and (b) t, 1500 nm; t′, 400 nm.
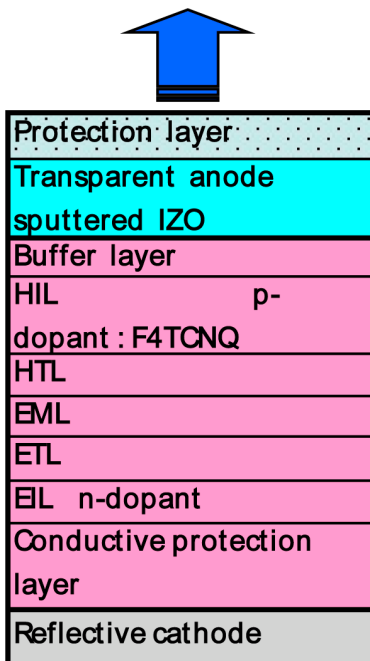
Fig. 17. Cross-sectional structure of backlight blue OLED. HIL: hole injection layer, HTL: hole transport layer, EML: emitting layer, ETL: electron transport layer, EIL: electron injection layer.
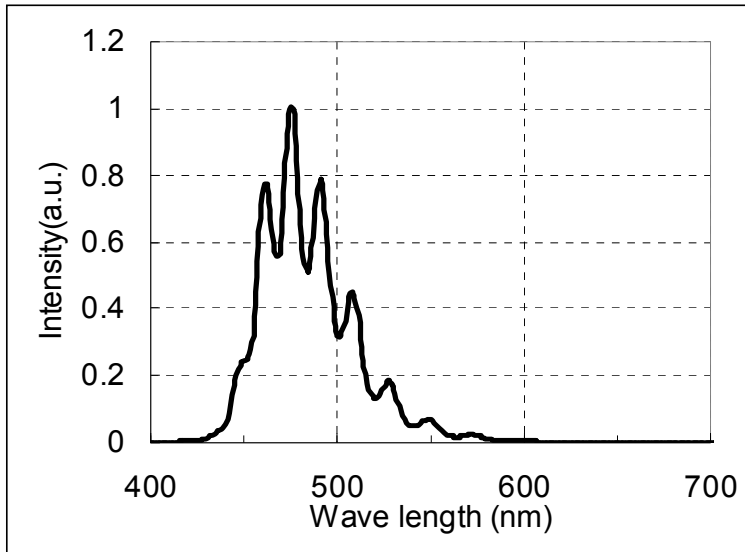
Fig. 18. EL spectrum of backlight blue OLED.
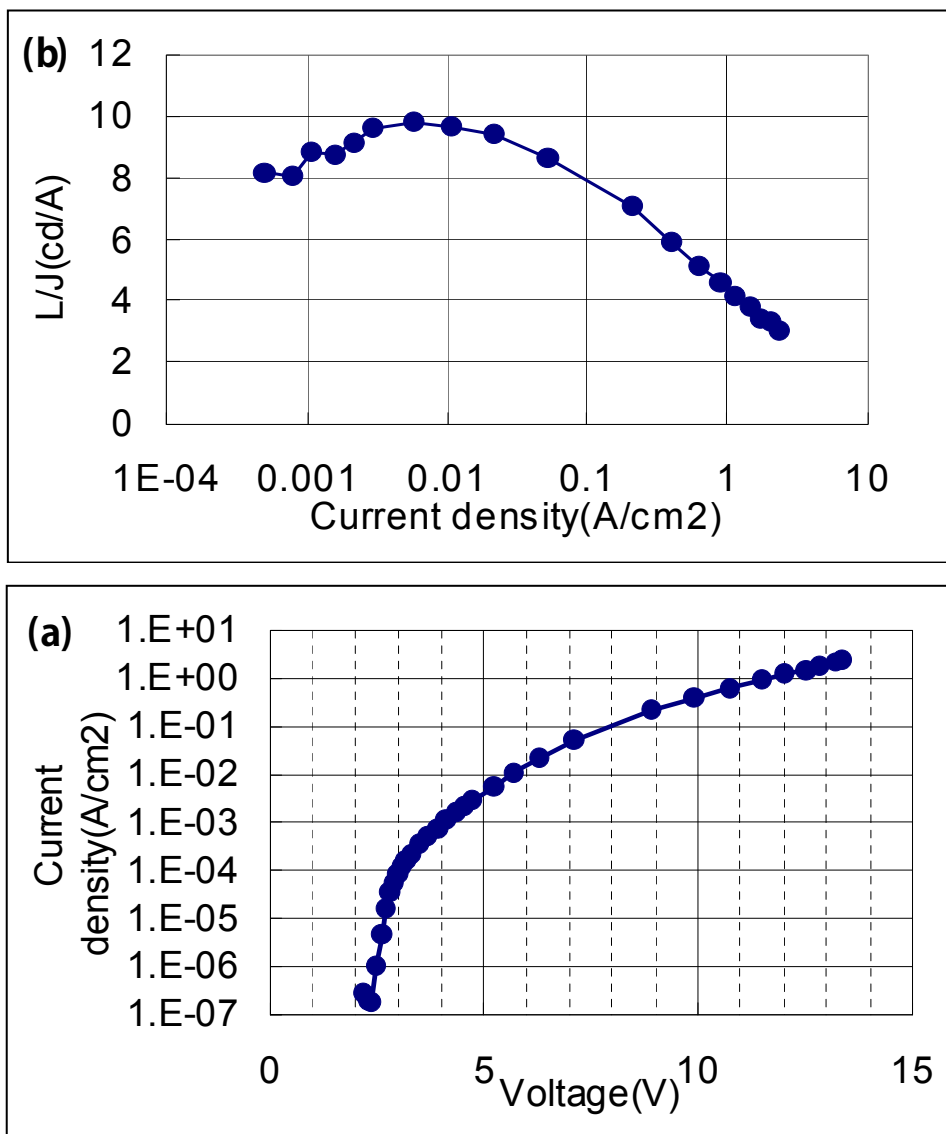
Fig. 19. (a) Current density (I) and (b) current efficiency (L)-voltage (V) characteristics of backlight blue OLED.
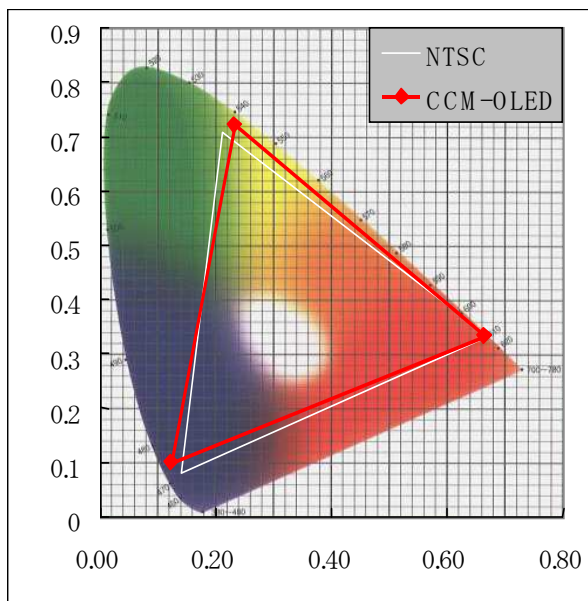
Fig. 20. 2.8″ a-Si TFT AM-OLED display.

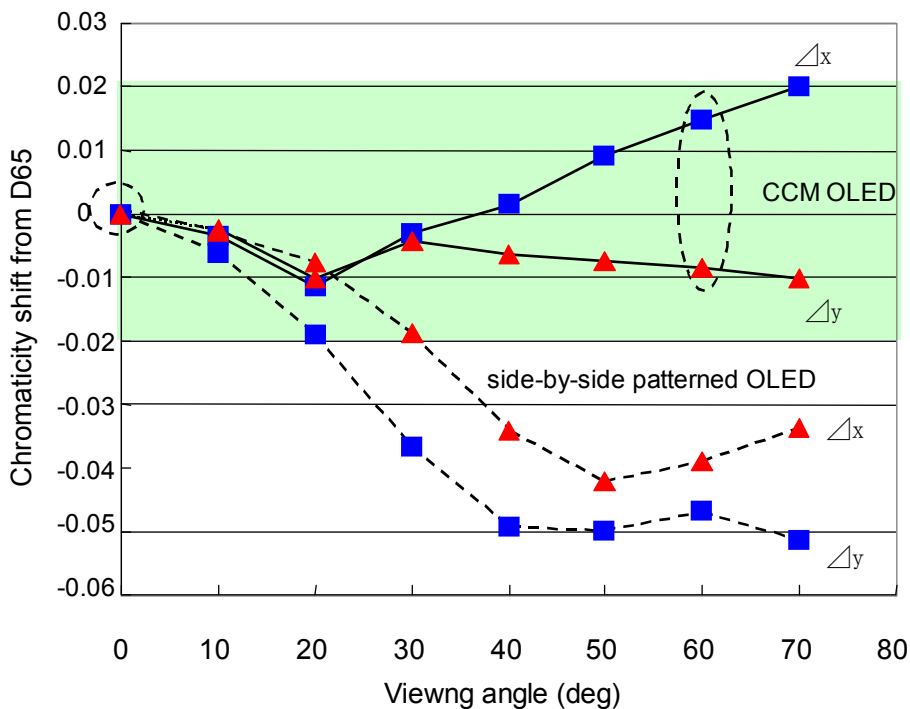Fig. 21. Color gamut of AM-OLED display.

Fig. 22. Shift in chromaticity with viewing angle of CCM and side-by-side patterned OLED displays.

*Tables

CCM-G	Molecular Weight (Mw)	Film			Solution		
		PL_{eff} (%)	Abs. Peak (nm)	PL Peak (nm)	PL_{eff} (%)	Abs. Peak (nm)	PL Peak (nm)
1	68,000	72	480	510	73	480	520
2	57,000	90	425	560	88	430	550
3	110,000	50	457	520	72	460	490
4	60,000	54	439	536	76	440	500
5	65,000	39	410	550	70	410	510

Table 1. Performance of CCM-G polymers.

PL$_{eff}$ (%)	Spin Coating	Drying (100°C × 30 min)	Substrate Handling (less than 30 min)	Measurement (less than 10 min)
72	dry N$_2$	dry N$_2$	dry N$_2$	dry N$_2$
71	in Air	dry N$_2$	dry N$_2$	dry N$_2$
68	dry N$_2$	in Air	dry N$_2$	dry N$_2$
33	dry N$_2$	dry N$_2$	in Air	dry N$_2$
30	dry N$_2$	dry N$_2$	dry N$_2$	in Air

Table 2. Degradation in PL efficiency of CCM(G)-1 film due to air exposure.

CCM: acrylate monomer : tetralin	1 : 0 : 100	1 : 10 :100	1 : 20 : 100	1 : 30 : 100	1 : 40 : 100
PL$_{eff}$ in film (%)	70	70	71	71	79

Table 3. PL efficiencies of CCM(G)-1 film and of CCM(G)-1 film made using acrylate monomer preliminary mixed solution.

CCM-R	Molecular Weight (Mw)	Film			Solution		
		PL$_{eff}$ (%)	Abs. Peak (nm)	PL Peak (nm)	PL$_{eff}$ (%)	Abs. Peak (nm)	PL Peak (nm)
1	42,000	21	485	638	22	485	597
2	33,000	5	462	616	4	460	574
3	50,000	19	492	634	19	460	601
4	49,000	6	563	731	16	624	500

Table 4. Performance of single-step CCM(R) polymers.

Guest	Pyromethene 650				
Host	CCM(G)-1	CCM(G)-2	CCM(G)-3	CCM(G)-4	CCM(G)-5
PL$_{eff}$ (%)	12	35	54	80	48

Table 5. Performance of advanced CCM(R) films.

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This book provides a timely overview of a current state of knowledge of the use of polymer thin film for important technological applications. Polymer thin film book covers the scientific principles and technologies that are necessary to implement the use of polymer electronic device. A wide-ranging and definitive coverage of this emerging field is provided for both academic and practicing scientists. The book is intended to enable readers with a specific background, e.g. polymer nanotechnology, to become acquainted with other specialist aspects of this multidisciplinary field. Part A of the book covers the fundamental of the key aspect related to the development and improvement of polymer thin film technology and part B covers more advanced aspects of the technology are dealt with nano-polymer layer which provide an up-to-date survey of current research directions in the area of polymer thin film and its application skills.

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