Study of image improvement for an organic light emitting diode using an iodide-polarizer

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An Organic Light Emitting Diode (OLED) can reduce visual reflective sensitivity and improve the contrast ratio, color saturation and view angle chromatism from ambient light. The presented application uses a mature and convenient method to examine the image improvement of an Organic Light Emitting Diode, which is an iodide-polarizer utilized on the panel of an OLED. In Flat Panel Displays (FPDs), many key vision indexes indicate the image performance including visual reflective sensitivity, contrast ratio, color saturation, view angle, pixel solution, brightness, response time and so on. In this study, an iodide-polarizer was applied to the panel of an OLED and experiments were conducted to examine the visual reflective sensitivity, contrast ratio, color chromatism and color saturation for the above relative key indexes of image performance. The results clearly show the excellent performance in reducing visual reflective sensitivity by 91.2% in the best sensitivity region of human eyes (525~580nm), improving the contrast ratio of the image 5.1 and 6.1 times in a simulated indoor ambience (490 cd/m^2) and a simulated outdoor ambience (1375 cd/m^2), retarding color chromatism decay from 48% to 27.5% in the simulated indoor ambient light (490 cd/m^2) and color chromatism decay from 69.9% to 38.1% in the simulated outdoor ambient light (1375 cd/m^2), and achieving 24% and 42.5% more color saturation when tilting a large degree view angle (at 70^o) for a simulated indoor ambience (490 cd/m^2) and a simulated outdoor ambience (1375 cd/m^2), respectively.

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1. Introduction

Daily life increasingly relies on electronic displays. Indeed, the information age is unimaginable without them. The display industry has been witnessing a rapid growth in recent years, spurred by the tremendous proliferation of communication and computing applications. New generation displays are required to process sufficient information content and operate in various applications with different criteria, such as a wide viewing angle, high contrast ratio, high color saturation, high brightness, high readability, high pixel resolution, rapid response time, portability, low color chromatism and high tolerance of environmental variations. In all electronic displays, the front on screen performance and physical dimensions (e.g., thickness and weight) are the most straightforward features users can feel and appreciate. The new generation flat panel displays (FPDs) such as liquid crystal displays (LCDs), field emission displays (FEDs), plasma display panels (PDPs) and organic light emitting diode panels (OLEDs) have progressed well technically, and are excellent at fulfilling the above mentioned criteria. Among these above candidates, organic light-emitting diodes (OLEDs) are used in commercial applications such as small screens for mobile phones and portable digital audio plays, car radios, digital cameras and so on [1]. Moreover, OLEDs are recognized to have the greatest potential to be the next generation display devices [2,3] and planar lighting source [4,5].

OLED research chiefly focused on the academic field until Dr. Tang and his coworkers at Kodak Chemical showed for the first time efficient organic light-emitting device in a multilayer configuration with significant performance improvement, and functional performance of multi-layer OLEDs was demonstrated by Tang and Vanslyke in 1987 [6]. They have therefore received much attention due to their many advantages. Nowadays, small molecule organic light-emitting diodes (SMOLED) made using a thermal deposition process have been utilized for commercial display products. The design of the multi-layers is combined in something like a sandwich, including the hole injection layer (HIL), hole transporting layer (HTL), emitting layer (EML), electron transporting layer (ETL), and electron injection layer (EIL), respectively. Each layer of the sandwich the design is between the whole injecting anode and the electron injecting cathode, and it can be chosen by the adaptive dopant, codopant and/or cohost mechanisms [7-9].

However, cathodes made of metals, such as Al, Ca and MgAg that are used in OLEDs, lead to strong ambient light reflection and decreased visible contrast, color saturation and view angle chromatism of the screen image. In the past, such portable applications favored the high light output of OLEDs for readability in strong ambient light. However, increasing the high light emission to compensate for reflection can lead to a short lifetime of the product and eyestrain. Therefore, methods for improving the out-coupling light efficiency of LEDs have also been applied to OLEDs. Many methods have been attempted to upgrade the optical performance of OLEDs. For example, from the late years, rough or textured surfaces, mesa structures, and lenses were manufactured to suppress the waveguide modes and reduce the reflectance [10-13]. Further, the thickness of the indium tin oxide (ITO) layer was controlled to reduce energy loss in the high-index layer [14]. A pyramidal array light-enhancing layer (pyramidal ALEL) on an organic light-emitting diode panel was optimized to enhance the luminance efficiency with a gain factor of 2.03 experimentally [15].

As a solution to promote the contrast ratio, various studies used the optical interference effect and utilized multilayers to develop black electrodes using vacuum deposition technology [16-21]. However, the black electrode is not part of the original OLED design, leading to extra fabrication complexity and costs. Another solution, which made the black matrixes of the pixels in lithography process technology reduce visual reflective sensitivity [22,23], for a similar reason also led to extra fabrication complexity and costs.

This study used an iodide polarizer to experimentally examine the image improvement of an OLED under different simulated ambient lights. These image improvements include visual reflective sensitivity, contrast ratio, color saturation and view angle chromatism under these different simulated ambient lights. The iodide-polarizer is a type of important optical film found in a wide array of applications in various FPD fields. The lamination skill of the iodide polarizer on the panel of the display is very mature [24,25]. Experiments were conducted in the present study to specifically examine the image improvement of OLED using an iodide-polarizer application. The experimental data can also provide information of great academic and practical significance.

2. Experimental studies

2.1. Experimental OLED manufacturing

The panel of a bottom emission of the passive-matrix OLED (PMOLED) was made in this experiment. The process flow of the panel followed the mass production procedure, as shown in Fig.1 [23,26]. According to Fig. 1, a 0.7mm thick mother glass substrate was used, and indium tin oxide (ITO) film with a thickness of 150nm was deposited on the mother glass, which has an optimal property between electricity and optic [21]. The average electro-optical property of the ITO substrate is greater than 85% transmittance in the visible region and less than 10 Ω/□ sheet resistance. The first step of the process flow included the patterns of four layers in the thin film, lithography and the etching processes of the ITO substrate.

The procedures in the first step included the metal alloy pattern of the external conductive line (e.g., Ag), the ITO pattern of the transparent electrode, the insulator pattern of the pixel definition pattern and the separator pattern of the cathode metal. In the second step, an evaporator technology was used to form the multi-organic layers and cathode metal layer (e.g., aluminum). The layer of hole injection material which reduces the energy barrier in between ITO and HTL is therefore beneficial to enhancing charge injection at the interfaces and ultimately improving power efficiency of the device, the materials of HIL are that starburst like amorphous materials, 4, 4', 4''-tris(3-methyl-phenyl-phenylamino)triphenylamine (m-MTDATA) can be doped by x% strong molecular acceptors like tetrafluoro-tetracyano-quinodimethane (F_4-TCNQ) in the controlled co-evaporation [27]. The material of HTL has a "bi-phenyl" center core that is like a N,N'-bis(1-naphthyl)-N,N'-diphenyl-1,1'-biphenyl-4,4'diamine (NPB). The materials of EML utilize the fluorescent dopants in the guest-host doped emitter system, the red emitting materials that are like y% 4-(dicyanomethylene)-2-tert-butyl-6(1,1,7,7-tetramethyljulolidin-4-yl-vinyl)-4H-pyran (DCJTB) to be doped in 5,6,11,12-tetraphenyl-naphthacene (Rubrene) and tris(8-hydroxyquinolinato)aluminum (Alq_3) of a cohost system, the green emitting materials that are like z% GD-206 of Idemitsu Kosan to be doped in BH-120 of Idemitsu Kosan, the blue emitting materials that are like w% BD-52 of Idemitsu Kosan to be doped in BH-120 of Idemitsu Kosan. The material of ETL is like a tris(8-hydroxyquinolinato)aluminum (Alq_3). The material of EIL is like a lithium fluoride (LiF), an effective cathode Al for OLEDs could be constructed by interposing a thin LiF layer between Al and Alq_3 [28,29]. These organic materials were purchased from Syntec GmbH (Germany), Aldrich (US), Eastman Kodak (US) and Idemitsu Kosan (Japan), respectively. In consideration of production yield, the greater thicknesses of the organic material layers and cathode metal-Al layer were considered to avoid the defect issues caused by the spike of ITO, pin hole of films, and the thermal stability of light-emitting and particles[30-32]. The HIL/HTL/EML/ETL/EIL thicknesses in the organic materials and cathode metal-Al were each controlled by 300nm. In the third step, the ITO substrate with patterns was encapsulated by an encapsulation glass substrate with getter to control the H_2O/oxygen-free environment. The final step is the module technology. The encapsulated substrate was scribed and broken according to the size of design, and assembled with the driver IC which was able to tune gamma curves in relation to grayscale and brightness [33]. This experimental PMOLED panel was formatted in the specification of 1.5''-128RGBx128 with 262,144 colors.

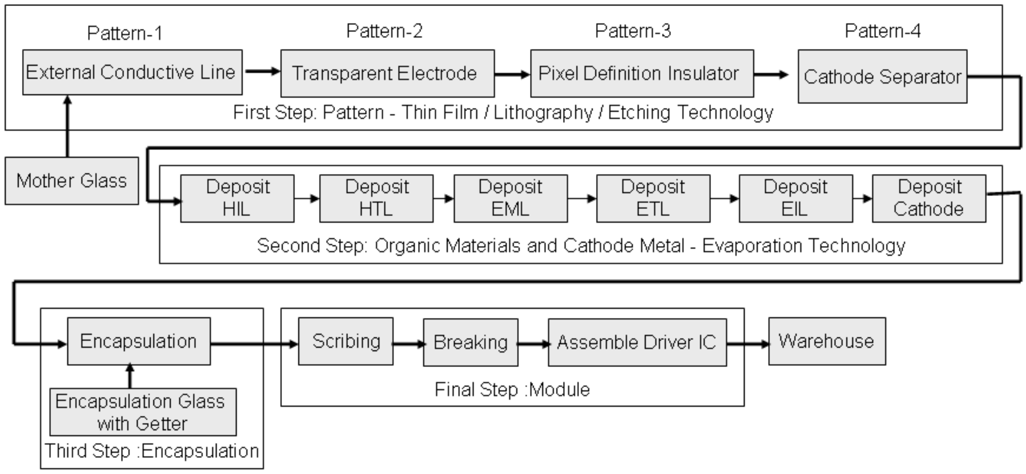


Fig. 1. The Process flow of panel in the PMOLED

2.2. The Iodide-polarizer property

High dichroic polarizers are desirable in many industrial applications such as thin-film transistor/liquid-crystal displays and high-precision optical devices. Conventional polarizers for these applications mostly use iodine as the dichroic chromophore because polyiodine molecules display much higher dichroism than other dyes. When polarizers are manufactured, the polyiodine molecules are absorbed into a semicrystalline polymer film, and the film is drawn to have a high degree of orientation. The polyiodine molecules are also oriented in agreement with the polymer, and the obtained film displays light absorption depend on the polarization direction of the incident light [34-36]. The iodide-polarizer is an important component of the liquid crystal display (LCD) fields. It can polarize the light from the blacklight source of the LCD. Conversion of a wave from linear to circular polarization may be affected by either transmission or reflection. In the free space at millimeter wavelengths, reflection circular polarizers are preferable to their less compact transmission counterparts [37]. The applied dye-polarizer is the combination of a linear polarizer and a quarter-wavelength phase retarder. A strong ambient light passes through the linear polarizer layer, thus turning into horizontal oriented light. As this light is reflected off the surface of an OLED it is now spinning in the opposite direction. This reverse spinning light reflected off the surface of the OLED is now 90 degree different than the transmission axis of only a linear polarizer. Because of its orientation the linear polarizer absorbs this reflected light, and cancels it out so it is not observed by the view [38,39]. Another function is that it is able to protect the panel and avoid scraping of the panel. The optical property of the iodide polarizers has been discussed [40]. A common iodide-polarizer with a convenient, laminated panel display is considered here.

2.3. Measurement inspection

We had to utilize some instruments and measurement inspections to verify and confirm the electro-optical performance of the panel of the experimental PMOLED. The experiment used the measurement inspections, including the color performances from the 1931 index of the Commission International de l'Eclairage (CIE_{1931}), color gamut (color saturation) and the current-luminance-voltage (ILV) curve of the experimental PMOLED. These performances were measured by a Minolta Chroma Meter CS-1000. It is able to simulate different light conditions of indoor ambience and outdoor ambience using the DMS-505 type of the autronic-MELCHERS GmbH. The transparent performance of the iodide-polarizer and the reflecting performance in the panel of the experimental PMOLED were measured by the Hitachi U4100 system.

3. Results and discussion

According to the above, the design of the organic layers of an OLED resembles a sandwich between the hole injecting anode and the electron injecting cathode, including a passive- matrix OLED (PMOLED) and an active-matrix OLED (AMOLED). The basic spectra properties of the experimental PMOLED are shown in Fig. 2. According to the spectra of Fig. 2, the red coordinates (x, y) of CIE_{1931} are (0.630, 0.354), green coordinates (x, y) of CIE_{1931} are (0.294, 0.630) and blue coordinates (x, y) of CIE_{1931} are (0.145, 0.193), color saturation compared with National Television System Committee (NTSC) is 59.4% and the synthetic white luminance is 145 (cd/m^2) when turning on red, green and blue simultaneously.

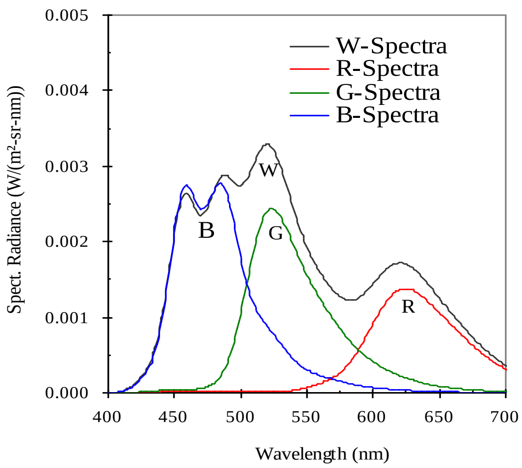


Fig. 2. The Spectra in the experimental PMOLED is turned on by driver IC @ 13.5V and measured by a Minolta Chroma Meter CS-1000 in a darkroom.

Due to the cathode metal of the OLED, it has strong reflection from the ambient light. In this study, an iodide-polarizer is used on the panel of the experimental PMOLED. The transmittance of the iodide-polarizer and reflectance of the panel of the OLED in the visible light region (400 ~ 700 nm) were measured by the Hitachi U4100 system, as shown in Fig. 3. According to Fig.3, it displays the results of utilizing an iodide-polarizer on the panel of the OLED; it has low reflectance in green region. Further, it appears the panel of the OLED is not specially designed to avoid a high amount of green specular reflection which affects the visual sensitivity of human eyes [25,40].

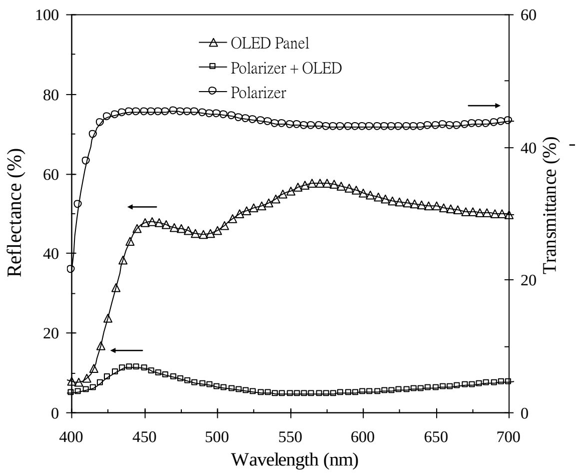


Fig. 3. Transmittance of an iodide-polarizer, reflectance of the OLED and applying an iodide-polarizer on the panel of the OLED. The transmittance and the reflectance are measured by Hitachi U4100 system.

3.1 Effects of the visual reflective sensitivity of human eyes

It is non-linear for the visual sensitivity of human eyes and it changes according to the wavelength. The green region (525~580nm) is the best sensitivity region for human eyes, both in daytime and nighttime light [40,41]. We can apply the optical transmittance property of an iodide-polarizer to reduce the effect of reflective light on human eyes in the visible wavelength caused by the ambient light. It shows the visual reflective sensitivity of human eyes in the visible wavelength when utilizing an iodide-polarizer on the panel of the OLED in Fig. 4. According to Fig. 4, the iodide polarizer can clearly reduce the visual reflective sensitivity by 91.2% in the best sensitivity region of human eyes when using an iodide-polarizer on the panel of the OLED.

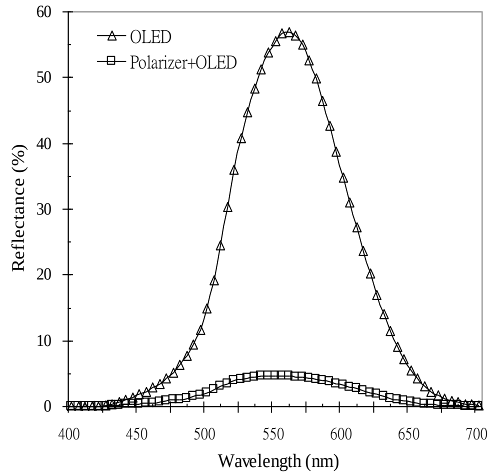


Fig. 4. The reflectance of the OLED with and w/o an iodide-polarizer for visual reflective senstivity of human eyes.

3.2 Effects of contrast ratio

In the visual reflective sensitivity of human eyes, we examine the contrast ratio (CR) in indoor ambience and an outdoor ambience. This is generally considered the most important visual characteristic of a display in the contrast ratio of an image. It conveys information by modifying an array of dots on a screen in the sole function of a display. The contrast ratio indicates the amount of difference that can be used to discriminate between a pixel that is fully on and that is off in the reflection of ambient light. It is a key vision index of display and is defined as [21,22]

$$CR=(L_{on}+R \text{ x } L_{amb}) / (L_{off}+R \text{ x } L_{amb}): \quad (1)$$

In which CR, L_{on}, L_{off} and L_{amb} are contrast ratios, the luminance of the OLED when turned on, the luminance of the OLED when turned off and the luminance of ambiance light, respectively. The ambient lights are simulated by the DMS-505 system of the autronic MELCHERS GmbH including a simulated indoor ambient light and a simulated outdoor ambient light. These simulated spectra are shown in Fig. 5. According to the spectra of Fig. 5, the panel of OLED is able to be applied to examine the contrast ratios under conditions of indoor ambience and outdoor ambience.

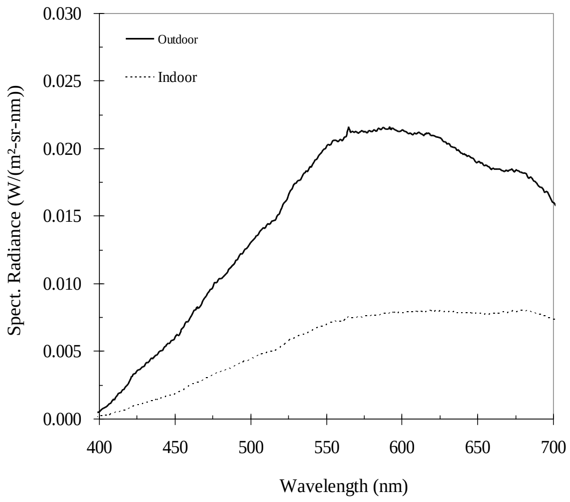


Fig. 5. The spectra of indoor ambience and outdoor ambience are simulated by the DMS-505 system of the autronic MELCHERS GmbH.

According to the calculation of equation (1), it gets a better CR value when utilizing an iodide-polarizer on the panel of an OLED for the different simulated ambient lights. These results are listed in Table 1. As shown in Table 1, the iodide -polarizer is able to increase the contrast ratio of the panel by 5.1 and 6.1 times in a simulated indoor ambience (490 cd/m^2) and a simulated outdoor ambience (1375 cd/m^2). The lamination function of the iodide-polarizer is easy to use and well developed for the production of displays. In the application of OLEDs, it clearly reduces the visual reflective sensitivity of human eyes, improves the contrast ratio of the display in the ambient lights, and protects the panel's surface from scraping. In utilizing the optical interface theory, depositing multilayers like black electrodes or making black matrixes, it is also possible to improve the contrast ratios of the displays. However, this increases costs, fabrication complexity and it is difficult to control the product uniformity, [to keep the production throughput and increase the product yield from the production of OLEDs [16-22]. Does the part of the last sentence within the brackets keep your intended meaning? For depositing the black cathodes or making the black matrixes of OLEDs, it is also necessary to laminate the protective film on the panel to avoid the scraping of the panels' surface of OLEDs.

Table 1. The comparison of CR value for utilizing an iodide-polarizer on the panel of the OLED or not

Simulating Ambiance	w/o dye-Polarizer	with dye-Polarizer
Indoor490 cd/m^2)	1	6.1
Outdoor (1375 cd/m^2)	1	5.1

3.3 Effects of CIE$_{1931}$ and color saturation

The CIE$_{1931}$ index and color saturation are able to indicate the representations of the hues. Larger hues or gamuts offer clearer discrimination for human vision. They are also key vision indexes of displays [24]. When utilizing an iodide-polarizer on the panel of an OLED, we measured the CIE$_{1931}$ index and color saturation in a darkroom using a Minolta Chroma Meter CS-1000, as shown in Fig. 6. According to Fig. 6, the proposed technique achieved a similar color performance (~ 59% color saturation) for utilizing an iodide-polarizer on the panel of the OLED.

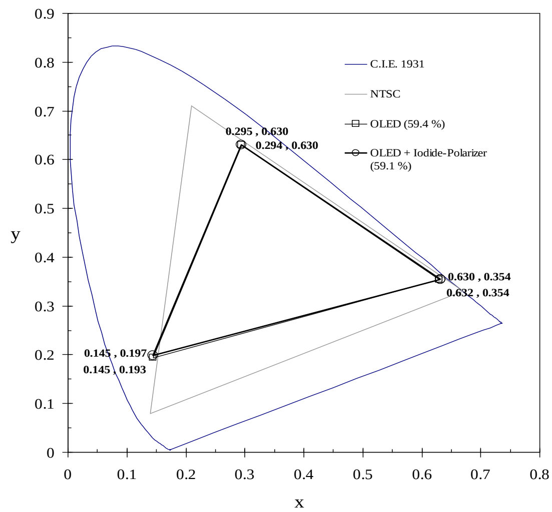
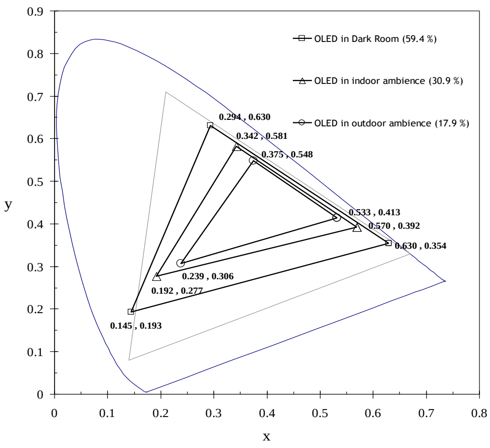


Fig. 6. The CIE$_{1931}$ Chromaticity Diagram displays the CIE$_{1931}$ index and color saturation of theOLED with and w/o an Iodide-Polarizer in the darkroom.

We also examine color saturation based on the color sensitivity of human eyes under different ambient light conditions and different viewing angles. The luminance of indoor ambient light (490 cd/m^2) and outdoor ambient light (1375 cd/m^2) are simulated by the DMS-505 system of the autronic MELCHERS GmbH. When utilizing an iodide-polarizer on the panel of the OLED in a simulated indoor ambience (490 cd/m^2) and a simulated outdoor ambience (1375 cd/m^2), their CIE$_{1931}$ index and color saturation are shown in Figs. 7(a) and (b). Figs. 7(a) and (b) clearly display the decay results of color saturation on the panel of the OLED without an iodide-polarizer for these simulated ambient lights. The laminated iodide-polarizer on the panel of OLED can clearly retard color chromatism decay from 48% to 27.5% for the simulated indoor ambient light (490 cd/m^2) and color chromatism decay from 69.9% to 38.1% for the simulated outdoor ambient light (1375 cd/m^2).



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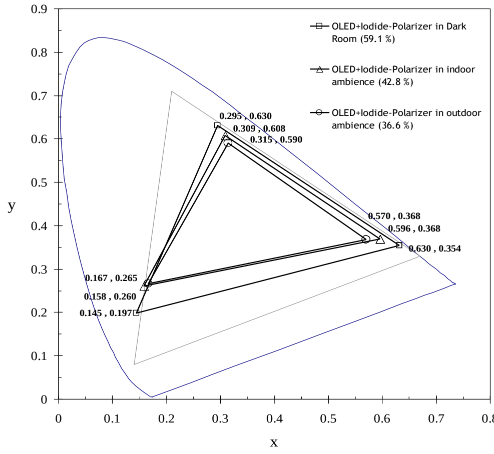

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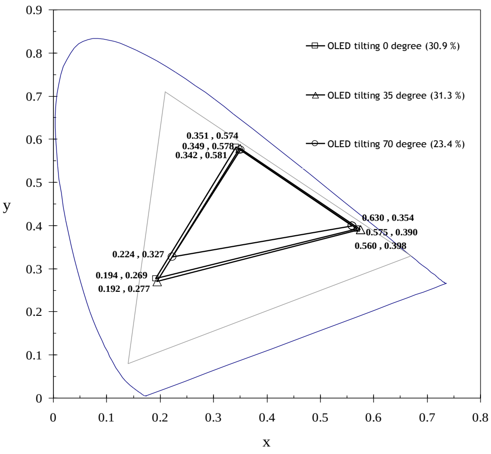

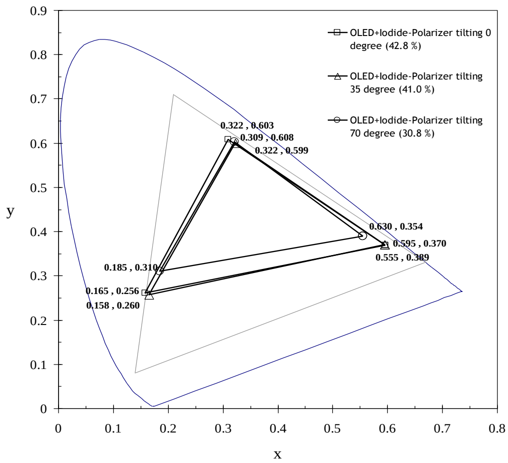

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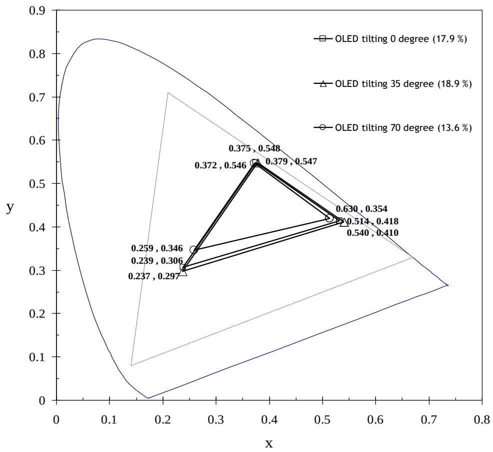

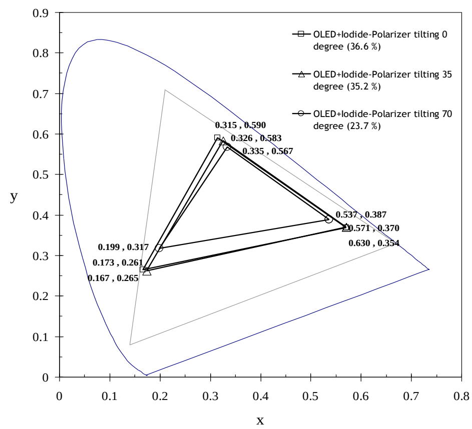

Fig. 7(a). The CIE_{1931} Chromaticity Diagram displays the CIE_{1931} index and color saturation of the OLED without an iodide-polarizer in a simulated indoor (or office) ambience (490 cd/m^2) and a simulated outdoor ambience (1375 cd/m^2).(b). The CIE_{1931} Chromaticity Diagram displays the CIE_{1931} index and color saturation of the OLED with an iodide-polarizer in a simulated indoor ambience (490 cd/m^2) and a simulated outdoor ambience (1375 cd/m^2). (c). The CIE_{1931} Chromaticity Diagram displays the CIE_{1931} index and color saturation of the OLED without an iodide-polarizer in a simulated indoor ambience (490 cd/m^2). (d). The CIE_{1931} Chromaticity Diagram displays the CIE_{1931} index and color saturation of the OLED with iodide-polarizer in a simulated indoor ambience (1375 cd/m^2). (e). The CIE_{1931} Chromaticity Diagram displays the CIE_{1931} index and color saturation of OLED without an iodide-polarizer in a simulated outdoor ambience (1375 cd/m^2). (f). The CIE_{1931} Chromaticity Diagram displays the CIE_{1931} index and color saturation of the OLED with iodide-polarizer in a simulated outdoor ambience (1375 cd/m^2).

For the laminated iodide-polarizer on the panel of the OLED and tilting at a larger angle (at 70^o) in the simulated indoor ambience (490 cd/m^2), the color saturations of the OLEDs are shown in Figs. 7(c) and (d). Figs. 7(c) and (d) clearly show 24% more color saturation when utilizing an iodide-polarizer on the panel of the OLED. Similarly, for the laminated iodide-polarizer on the panel of the OLED and tilting at a larger angle (at 70^o) in the simulated outdoor ambience (1375 cd/m^2), the color saturation of the OLEDs is shown in Figs 7(e) and 7(f). It can also clearly achieve 42.5% more color saturation when utilizing an iodide-polarizer on the panel of the OLED.

3.4 Discussion

Currently, the biggest obstacle to the development of OLEDs is the high cost and very immature supply chain compared with LCDs. The cost of OLEDs is almost 7 times as much as LCDs' [42].

At present, the most important step is to reduce the cost of OLEDs. Although depositing the black cathode or making the black matrixes improves the contrast ratio of the image, these improvements increase cost and fabrication complexity (e.g., the uniformity of thin film in the black cathode or black matrixes, the addition of throughput steps and the control of product yield in producing OLEDs). The proposed technique is a convenient and mature technique for utilization of an iodide-polarizer on the panels of OLEDs which does not require extra skill. It significantly improves the visual reflective sensitivity, contrast ratio and color saturation of strong ambient light conditions.

4. Conclusions

This study successfully demonstrates the proposed technique for the application of an iodide-polarizer to the panel of an OLED. At present, the proposed method is able to reduce the reflected light for the visual reflective sensitivity of the human eye by 91.2% under ambient light and improve the contrast ratio by 5.1 and 6.1 times for simulated indoor ambiance (490 cd/m^2) and simulated outdoor ambiance (1375 cd/m^2). It is also able to retard color chromatism decay from 48% to 27.5% under simulated indoor ambient light (490 cd/m^2) and color chromatism decay from 69.9% to 38.1% under simulated outdoor ambient light (1375 cd/m^2), and achieve 24% and 42.5% more color saturation when tilting at a large degree view angle (at 70^o) in a simulated indoor ambience (490 cd/m^2) and a simulated outdoor ambience (1375 cd/m^2).

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