

Introduction to Flat Panel Displays

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thickness direction without twist while the direction of each discotic molecule fluctuates. This hybrid alignment structure consists of splay and bend deformations.

The wide-view Fuji film markedly improves the viewing angle of TN LCDs without losing any light transmittance or degrading image quality. A TN LCD with $\sim 80^\circ$ viewing cone at CR > 10:1 has been demonstrated.⁷³ A significant advantage of film-compensated TN LCDs is that no change in the panel process is required because the conventional polarizer is simply replaced by a new polarizer laminated with the compensation film. The discotic film is also cost effective. These features enable TN to penetrate into the larger size LCD market segment, say 20- to 26-inch diagonal. However, grayscale inversion can still be observed in large-panel film-compensated TN LCDs which ultimately limits their competitiveness with IPS and MVA.

4.7 In-plane switching

To overcome the narrow viewing angle of TN LCDs, IPS was proposed in the 1970s^{74, 75} and implemented in TFT LCDs in the 1990s.^{76, 77} The interdigitated electrodes are in the same substrate and the top substrate has no electrode such that the generated fringing fields are in the transverse plane. As shown in Figure 4.16, the LC directors are rotated in the plane which results in a wide viewing angle.

4.7.1 Device structure

In an IPS system, the interdigitated electrodes are fabricated on the same substrate and LC directors are aligned homogeneously with a rubbing angle of $\sim 10^\circ$ with respect to the striped electrodes. The transmission axis of the polarizer can be set to be parallel (e-mode) or perpendicular (o-mode) to the LC directors while the analyzer is crossed to the polarizer. The in-plane electric fields induced by the electrodes twist the LC directors, as shown in Figure 4.17. The incoming linearly polarized light from the polarizer experiences a phase retardation so that its polarization state is changed, resulting in light transmission through the crossed analyzer. However, due to the strong vertical electric field existing above the electrode surface, the LC directors in these regions mainly tilt rather than twist. As a result, the transmittance above the electrodes is greatly reduced. Overall, the conventional IPS mode has a light efficiency $\sim 75\%$ of that of a TN LCD, when a positive $\Delta\epsilon$ LC material is used. Although using a negative $\Delta\epsilon$ LC in the IPS mode could enhance the light efficiency to $\sim 85\%$, the required on-state driving voltage is too high ($> 10 V_{rms}$).⁷⁸ This is because negative $\Delta\epsilon$ LC materials tend to have a smaller dielectric anisotropy. As a result, both threshold and on-state voltages are increased. For low power consumption, the preferred operating voltage is less than $5 V_{rms}$.

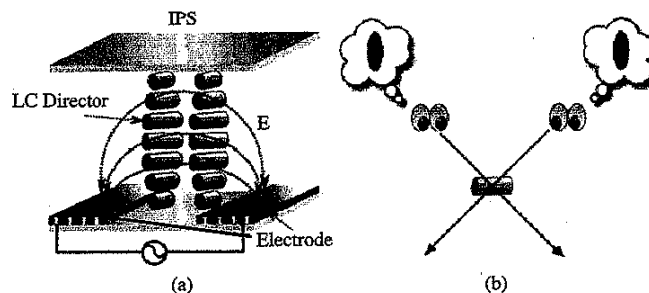


Figure 4.16 (a) IPS electrodes, electric fields and LC director orientations in a voltage-on state; (b) viewing angle characteristics of in-plane rotation of LC molecules.

Figure 4.17 LC director IPS cell at $V = 5 V_{rms}$. LC

4.7.2 Voltage-depe

Figure 4.18 depicts the IPS device structure sho at $\sim 5 V_{rms}$ for all three v (without LC cell) is 35.

4.7.3 Viewing angl

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Figure 4.18 Voltage-de

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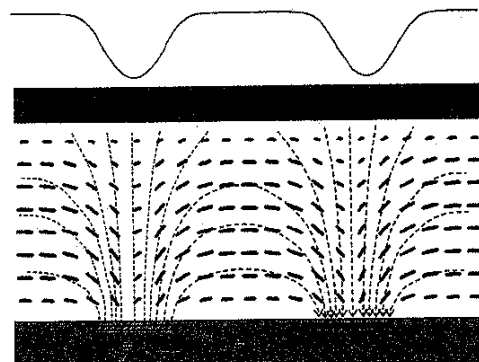


Figure 4.17 LC director distribution, electric field profile (dashed lines) and corresponding light transmission of an IPS cell at $V = 5 V_{rms}$. LC, MLC-6686; $\Delta\epsilon = 10$; electrode width $W = 4 \mu m$; gap $G = 8 \mu m$; cell gap $d = 3.6 \mu m$.

4.7.2 Voltage-dependent transmittance

Figure 4.18 depicts the voltage-dependent light transmittance at RGB wavelengths corresponding to the IPS device structure shown in Figure 4.17. The threshold is $\sim 1.5 V_{rms}$ and maximum transmittance occurs at $\sim 5 V_{rms}$ for all three wavelengths. Due to absorption, the maximum transmittance of the two polarizers (without LC cell) is 35.4, 33.7 and 31.4 % for R, G and B wavelengths, respectively.

4.7.3 Viewing angle

Figure 4.19 shows the calculated iso-contrast contours of an IPS LCD without any compensation films. The 10:1 iso-contrast extends beyond a 60° viewing cone. For mobile displays, this viewing angle is adequate because the display is mainly viewed by a single user. However, for large-size displays such as

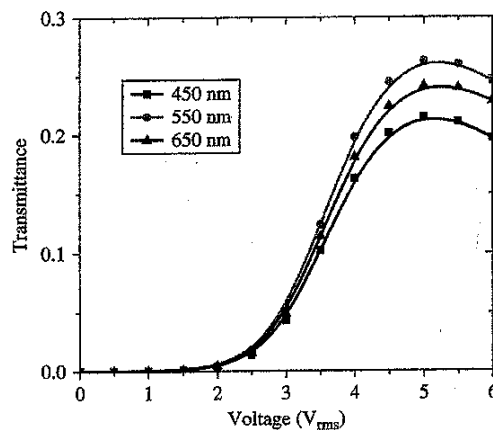


Figure 4.18 Voltage-dependent light transmittance of an IPS LCD. The device structure is shown in Figure 4.17.

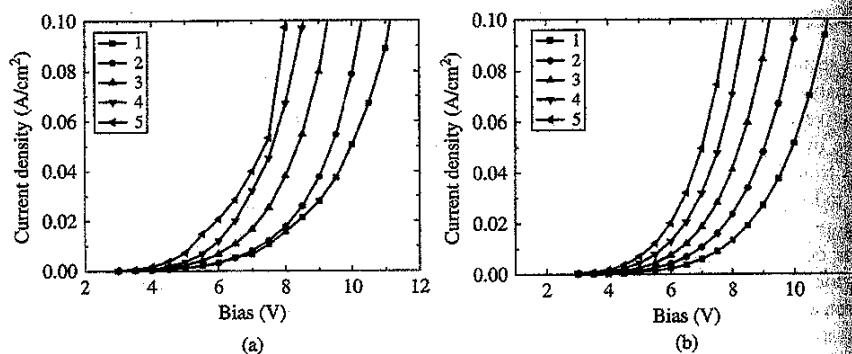


Figure 7.33 (a) Experimental and (b) simulated J - V characteristics of devices 1 to 5.

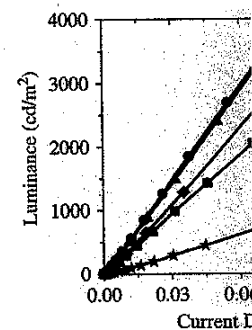


Figure 7.35 Measurement of luminance versus current density for devices 1 to 5.

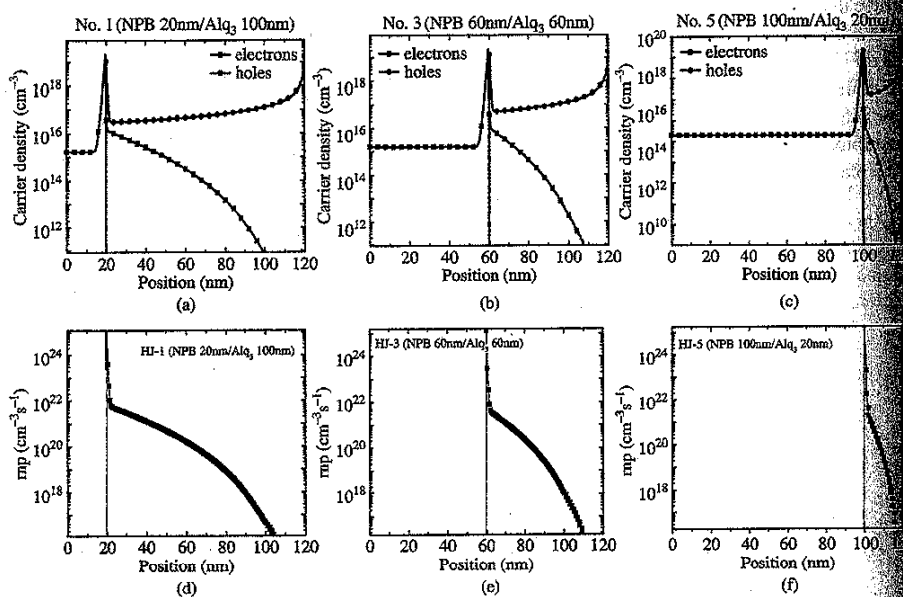


Figure 7.34 Simulated results of (a-c) carrier density and (d-f) recombination rate distributions of devices 1 to 5.

Figure 7.35(a) shows the luminance versus current density for devices 1 to 5. We can see that the luminance increases then decreases as the HTL thickness increases. As shown in Figure 7.34, maximum recombination occurs at the HTL-ETL interface. To have constructive wide-angle interference, the recombination position must be located at $\lambda/4n$ from the reflective cathode, derived from Equation (7.39). Considering the peak wavelength of PL emission at 530 nm and that the refractive index of the organic material is about 1.6, the $\lambda/4n$ value is about 82 nm, which means device 2 should be close to the optimization condition of the constructive wide-angle interference. Experimental spectra of the devices are shown in Figure 7.35(b). The EL emission spectral peaks are at 558, 544, 536, 534 and 526 nm for devices

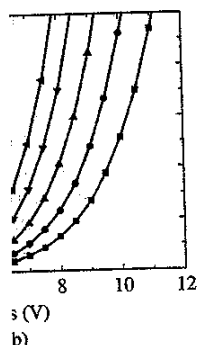
1 to 5. Such a blue shift can be wavelength dependent, the emission from the cathode, i.e. increasing the

7.5.5 Degradation mechanism

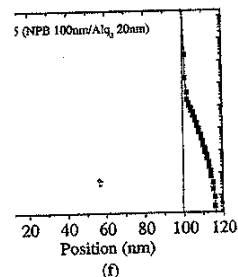
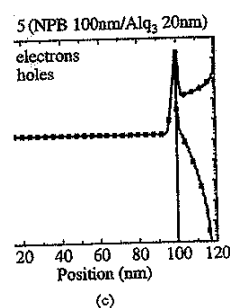
Lifetime is one of the major evaluation principles of LEDs and is much shorter (less than a tenth) than that of LEDs. Organic materials are semiconductors due to their band structure. There are two independent modes: (1) dark

Dark-spot formation is the result of the storage, and the growth of dark spots are electrochemical reactions. To prevent dark-spot formation, prevent oxygen and moisture from entering the device. The root causes of the structural degradation are bubble formation in the organic layer, which leads to the degradation of the device for water and oxygen diffusion and (3) intense decomposition of volatile species which leads to the degradation of the device during operation at 85 °C/100 % relative humidity. The device is fabricated, and the device is degraded.

Typically, control of the substrate density of structural defects, sealing of the OLED in an inert atmosphere, and the substrate between the organic layer character



devices 1 to 5.



distributions of devices 1, 3

to 5. We can see that the own in Figure 7.34, max-side-angle interference, the ved from Equation (7.39). ctive index of the organic ould be close to the optim-spectra of the devices are 34 and 526 nm for devices

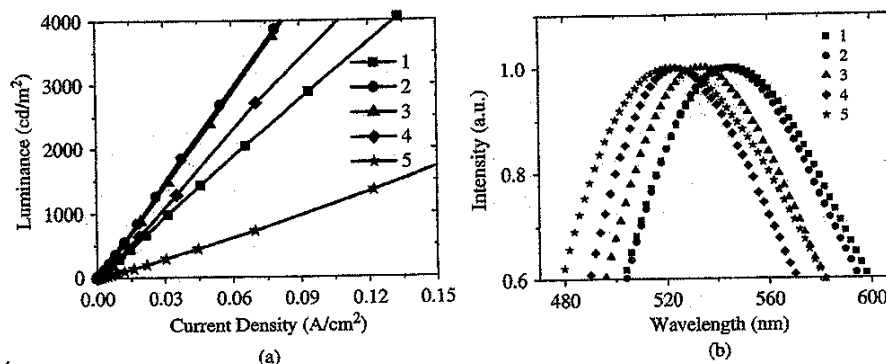


Figure 7.35 Measured (a) luminance versus current density and (b) EL spectra of devices 1 to 5.

1 to 5. Such a blue shift can be understood from the wide-angle interference. Since the interference is wavelength dependent, the enhancement ratio blue-shifts on increasing the recombination zone towards the cathode, i.e. increasing the HTL thicknesses.

7.5.5 Degradation mechanisms

Lifetime is one of the major obstacles to wide commercial applications for OLEDs. Although the operation principles of LEDs and OLEDs are similar, the lifetime of OLEDs is much shorter (typically less than a tenth) than that of LEDs. The main reasons are that (1) OLEDs have a thinner layer structure, (2) organic materials are sensitive to moisture and oxygen and (3) organic materials are not as robust as semiconductors due to larger vibration energy. Degradation in OLEDs can be categorized as three independent modes: (1) dark-spot formation, (2) catastrophic failure and (3) intrinsic degradation.

Dark-spot formation is the increase in nonemissive regions with time. This occurs even during OLED storage,⁸² and the growth rate may be accelerated by operation. The formation mechanisms of the dark spots are electrochemical reactions of the organic (or electrode) materials with environments. To slow down dark-spot formation, as described in Section 7.5.3.2, encapsulation or passivation is needed to prevent oxygen and moisture from attacking the OLED. There are many possible root causes which lead to the dark-spot phenomenon. Dark spot means nonemission at a certain area rather than luminance decrease in the whole emissive zone, which means structural defects in OLEDs produce the dark spot. The root causes of the structure defects include the following: (1) the layer between cathode and organic layers produces bubble structure which impedes electron injection and loses contact between the cathode and organic layer, which leads to a nonemissive zone;⁸³ (2) pinholes on the cathode provide a pathway for water and oxygen diffusion which oxidize the cathode metal and react with the organic materials;⁸⁴ and (3) intense decomposition of the ITO and organic film caused by local temperature rises releases volatile species which lead to local delamination and to oxidation of the cathode.⁸⁵ Figure 7.36 shows OLED images during operation taken under an optical microscope, just after device fabrication and after storage at 85 °C/100 % relative humidity for three hours. It is clear that the dark spots exist when the device is fabricated, and they grow with time.

Typically, control of substrate cleanliness and smoothness and device fabrication process reduces the density of structural defects, and the potential of dark spots is also reduced. Another way is using hermetic sealing of the OLED in an inert gas environment, which can control dark-spot degradation.⁸⁶ Heating the substrate between the organic evaporation⁸⁷ can also reduce the dark-spot area. But this can change some organic layer characteristic at the same time.