

Optoelectrical properties of four amorphous silicon thin-film transistors 200 dpi active-matrix organic polymer light-emitting display

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We report on opto-electrical properties of a current-driven 200 dpi active-matrix organic polymer red light-emitting display (AM-PLED) based on four hydrogenated amorphous silicon thin-film transistor pixel electrode circuits. The AM-PLED luminance and effective light-emission efficiency were 30 cd/m² and 0.3 cd/A, respectively, at the data current equal to 25 mA. The display electroluminescent spectrum has a peak located at and the full width at half maximum value of 644 and 95 nm, respectively, and Commission Internationale de l'Eclairage color coordinates of (0.66,0.33). © 2003 American Institute of Physics. [DOI: 10.1063/1.1617372]

Since hydrogenated amorphous silicon (*a*-Si:H) thin-film transistors (TFTs) active-matrix (AM) arrays can be fabricated at low cost and with a high uniformity over large areas, it is expected that one day this mature technology could become preferred in comparison with the polycrystalline silicon (poly-Si) TFTs technology¹⁻³ for the active-matrix organic light-emitting displays (AM-OLEDs). Furthermore, recent enhancements of the organic light-emitting device (OLED) performances⁴ have made it easier to extend the *a*-Si:H TFTs technology to AM-OLED. In AM-OLED, *a*-Si:H TFTs act as switching and driving devices in pixel electrode circuits. To drive light-emitting devices in AM-OLEDs, a continuous excitation during the whole frame period is needed. This can be a very demanding task for *a*-Si:H TFTs which can produce undesirable variations in their electrical properties. To compensate for these variations current driven pixel electrode circuits have been proposed for AM-OLEDs.^{1,5,6}

In this letter, we report on optoelectronic properties of a current-driven 4-*a*-Si:H TFTs AM-organic polymer light-emitting display (AM-PLED). Its properties are compared to typical characteristics of organic polymer light-emitting devices (PLEDs).

The fabrication of 4-*a*-Si:H TFTs 200 dpi active-matrix arrays consists of six masks process steps: chromium (2000 Å) gates and selection lines are defined on Coming 1737 glass substrates (mask No. 1); *a*-SiN_x:H (3000 Å)/*a*-Si:H (1000 Å)/*n*⁺*a*-Si:H (300 Å) trilayer is deposited by the plasma-enhanced chemical vapor deposition (PECVD) method, then device active islands are defined (mask No. 2); gate electrode via through gate insulator is formed (mask No. 3); molybdenum (2000 Å) source/drain and data lines are defined (mask No. 4); backchannel etching and thermal annealing are performed; benzocyclobutene (BCB) (1–1.5 μm) planarization layer is deposited and thermally cured; drain electrode via through the BCB layer is defined (mask No. 5); indium tin oxide (ITO) (1000 Å) is deposited and pixel electrodes are defined over the BCB layer (mask No. 6). The ITO

surface is UV-ozone treated for 10 min before a hole injection layer [poly (3,4-ethylene dioxythiophene) doped with poly (styrenesulfonate)] is deposited from a water solution by spin coating and is thermally cured. Next the red light-emissive poly-fluorene layer is deposited from solution by spin coating and is thermally cured. Finally a calcium (150 Å)/aluminum (2000 Å) bilayer cathode is thermally evaporated on top of the display. We removed the PLED active layers from display contact pads using organic solvents. A schematic cross section of the PLED is shown in the inset of Fig. 2. All the cathode electrodes for each pixel are connected in the AM-PLED. To compare the optoelectrical properties of the AM-PLED with those of typical PLEDs, we also fabricated a red light-emitting PLED (2×3 mm²) over the ITO-coated glass substrate, which has the same organic active layer structure as the AM-PLED.

To evaluate the AM-PLED properties we applied constant 30, 0, and 30 V to V_{select1} , V_{select2} , and V_{DD} lines, respectively.⁶ The data current ranging from 0 to 25 mA was applied to I_{data} lines to light up the display, and the display luminance was measured for each data current level. The light was emitted through the ITO electrode. Figure 1 shows an image of the red light-emitting 200 dpi AM-PLED for data current of 25 mA; the magnified image of the light-emitting pixels is also included in this figure. The fabrication yield of the AM-PLED light-emitting pixels was about 75%, the display size was 0.5×0.5 in.² (100×100 pixels) and the pixel aperture ratio (AR) was about 10%. The AR was defined as the ratio of the pixel PLED area (24×65 μm²) to the whole pixel area (127×127 μm²).

The total luminous flux of the AM-PLED and PLEDs have been measured in air at room temperature, using an integrating sphere and a calibrated photodetector connected to a radiometer.⁷ Figure 2 shows characteristic variation of the display luminous flux versus applied data current. We obtained up to 1.1×10⁻² lumen when the data current was equal to 25 mA. For a Lambertian emitter, we can calculate the luminance (L) from the measured luminous flux (Φ):

$$L = \frac{\Phi}{\pi \times A}, \quad (1)$$

where A is the area of the light emitter. By assuming that the

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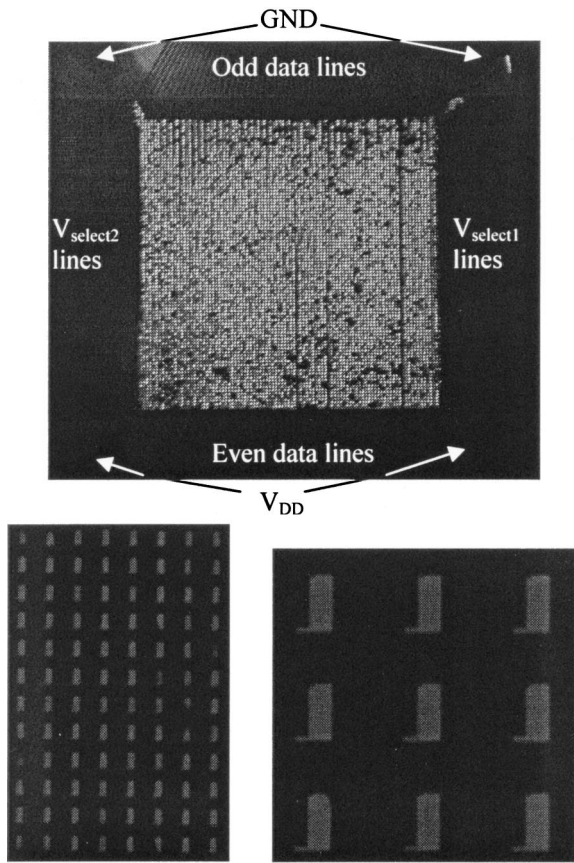


FIG. 1. Top view of illuminated 4-*a*-Si:H TFTs 200 dpi AM-PLED. Magnified images of the light-emitting pixels are also shown.

AM-PLED is a Lambertian emitter (which was verified experimentally), we calculated the display luminance (L_{Display}) by considering the display area and the fabrication yield of the light-emitting pixels: $A = 1.27 \text{ cm} \times 1.27 \text{ cm} \times 0.75 = 1.215 \times 10^{-4} \text{ m}^2$. Evolution of L_{Display} with the data current is shown in Fig. 2; and for data current of 25 mA we obtained $L_{\text{Display}} = 30 \text{ cd/m}^2$. In addition, if we take into consideration the pixel PLED area, e.g., pixel AR=10%, we can calculate the effective light-emission luminance (L_{Emission}) for $A = 1.27 \text{ cm} \times 1.27 \text{ cm} \times 0.75 \times 0.1 = 1.215 \times 10^{-5} \text{ m}^2$. The variation of L_{Emission} versus effective current density (defined as data current/total effective current-flowing area of the AM-PLED) is shown in Fig. 3; and

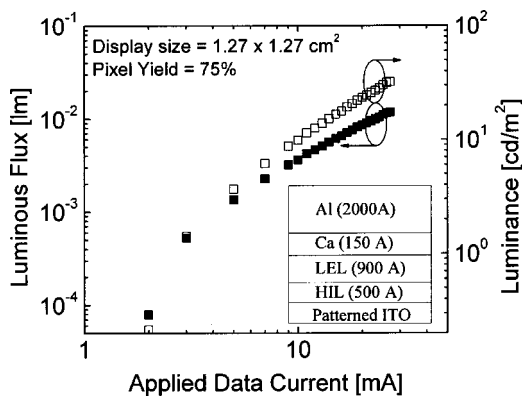


FIG. 2. The variations of luminous flux and luminance (L_{display}) vs applied data current of 4-*a*-Si:H TFTs 200 dpi AM-PLED are shown. The structure of the organic polymer light-emitting device is also included in this figure.

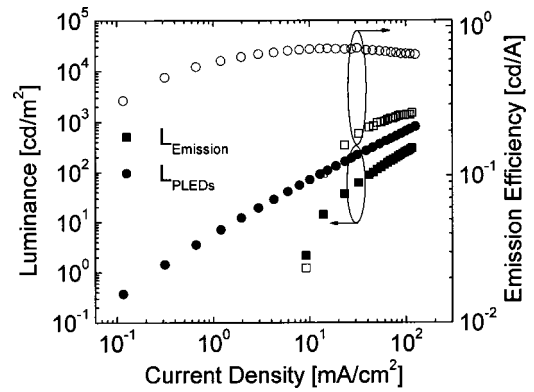


FIG. 3. The variations of effective light-emission luminance (solid square, L_{Emission}) and effective light-emission efficiency (open square) vs effective current density of 4-*a*-Si:H TFTs 200 dpi AM-PLED are shown. The evolution of luminance (solid circle, L_{PLEDs}) and light-emission efficiency (open circle) vs effective current density of the red PLED are also shown.

L_{Emission} up to 300 cd/m^2 was obtained for 115 mA/cm^2 . We have also defined the effective light-emission efficiency of the AM-PLED as the ratio of effective light-emission luminance to effective current density. Its variation with the current density is also shown in Fig. 3; and for the studied displays, we obtained a maximum effective light-emission efficiency of about 0.3 cd/A at 115 mA/cm^2 . In Fig. 3, the luminance and light-emission efficiency of the red PLEDs ($2 \times 3 \text{ mm}^2$) are also shown. The PLED had a luminance of about 720 cd/m^2 at 110 mA/cm^2 and a maximum light emission efficiency of about 0.71 cd/A at $31 \text{ mA/cm}^2 @ 220 \text{ cd/m}^2$. As shown in Fig. 3, the effective light-emission efficiency of the AM-PLED is lower in comparison with the light-emission efficiency of the PLEDs by a factor of 3–4 for the current density ranging from 80 to 110 mA/cm^2 . It is speculated that this difference is due to leakage current through defective AM-PLED pixels that do not contribute to light emission.

In Fig. 4, the electroluminescent (EL) spectra of the red light-emitting AM-PLED and PLEDs are shown. EL spectra were measured by mounting a charge coupled device based spectrometer on the detector port of the integrating sphere.^{7,8} The wavelength of the spectrometer was calibrated using a standard mercury lamp. From the EL spectra we extracted their peak positions located at 644 and 653 nm, and their full

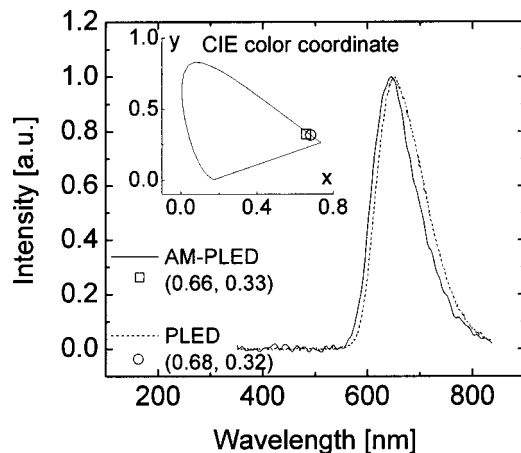


FIG. 4. EL spectra and CIE color coordinates of 4-*a*-Si:H TFTs 200 dpi AM-PLED (solid line) and PLED (dashed line) are shown.

width at half maximum (FWHM) values of 95 and 105 nm, for AM-PLED and PLEDs, respectively. From these spectra, we also calculated Commission Internationale de l'Eclairage (CIE) color coordinates for AM-PLED and PLEDs, which were (0.66,0.33) and (0.68,0.32), respectively, as shown in the inset of Fig. 4. The blueshift and smaller FWHM value of the AM-PLED EL spectrum is responsible for the decrease of CIE- x and the increase of CIE- y color coordinates, respectively.

In conclusion, we have fabricated and evaluated the optoelectrical properties of the current-driven 4-*a*-Si:H TFTs 200 dpi AM-PLED. The AM-PLED had luminescence of 30 cd/m² at 25 mA and its maximum effective light emission efficiency was about 0.3 cd/A at 115 mA/cm². The AM-PLED EL spectrum was blueshifted and narrower in comparison with the typical PLED EL spectrum. Overall the PLED showed better optical performance than the AM-PLED.

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