Integration of the 4.5" active matrix organic light-emitting display with organic transistors

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Abstract

We developed an 4.5" 192x64 active matrix organic light-emitting diode display on a glass using organic thin-film transistor (OTFT) switching-arrays with two transistors and a capacitor in each sub-pixel. The OTFTs has bottom contact structure with a unique gate insulator and pentacene for the active layer. The width and length of the switching OTFT is 800㎛ and 10㎛ respectively and the driving OTFT has 1200㎛ channel width with the same channel length. On/off ratio, mobility, on-current of switching OTFT and on-current of driving OTFT were 10^6,0.3~0.5 $cm^2/V{\cdot}sec$, order of 10 μA and over 100 μA, respectively. AMOLEDs composed of the OTFT switching arrays and OLEDs made using vacuum deposition method were fabricated and driven to make moving images, successfully.

1. Introduction

Since late 1940s, organic semiconductors (OSCs) have been continuously studied, and organic thin-film transistors (OTFTs) have recently been of great interest for several electronic applications such as active-matrix flat panel displays, electronic papers, and chemical sensors, replacing the traditional inorganic semiconductor-based transistors.[1] Among many developed OSCs, thermally evaporated pentacene exhibited carrier mobility reaching 3 to 5 $cm^2V^{-1}s^{-1}$, which exceeds mobility in thin-film transistors (TFTs) based on amorphous Si.[2] To realize the commercial applications of high performance and low coat OTFT, one of the key issues is to identify solution processible gate dielectric materials. Gate dielectric materials in OTFT should be pinhole free, long term stability, good insulation properties and also be compatible with organic semiconductors. There are few materials reported to be these requirements. Recently it was reported that high performance OTFT (mobility~5cm^2/Vs and on/off ratio~10^6) based on pentacene and Al_2O_3/polystyrene double layered gate dielectrics by 3M. However these approaches still require inorganic layer formed by vacuum process.

In this work, 4.5" OLED based on pentacene TFT array has been demonstrated. Organic thin-film transistor (OTFT) switching-arrays with 64 scan lines and 192 data lines were designed and fabricated to drive organic light-emitting diode (OLED) arrays. Pentacene was used as semiconductor material and an organic insulator was used as gate insulator material. On/off ratio, mobility, on-current of switching OTFT and on-current of driving OTFT were 10^6, ~0.5 $cm^2/V{\cdot}sec$, order of 10 μA and over 100 μA, respectively. These properties were enough to drive the active-matrix organic light-emitting diode (AMOLED) over 60 Hz frame rate. AMOLEDs composed of the OTFT switching arrays and OLEDs made using vacuum deposition method were fabricated and driven to make moving images, successfully.

2. Design and fabrication

In this work, we synthesized wet-processible gate dielectrics. organic-inorganic hybrid type materials such as mixture of organosilane and low temperature curable polymer are used. The dielectric properties are shown in Figure 1. After cured at 200°C, Au was deposited by thermal evaporation and patterned using standard photolithography process. Prior to Pentacene deposition, Au surface was treated with Self Assemble Monolayer (2-Mercapto 5-nitrogenzimidazole) to reduce the contact resistance. Pentacene was deposited though shadow mask and passivated using PVA (Polyvinyl Alcohol). Figure 2 shows the transistor performance. As shown, linear mobility was ~0.5 cm^2/Vs with 10^6 on/off ratio.

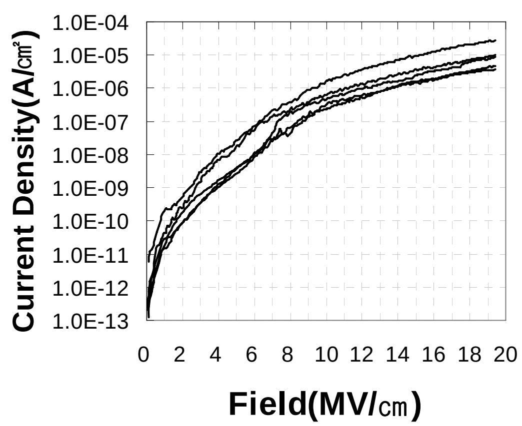

Figure 1. Current-Voltage characteristics of gate insulator

measured using Metal-insulator-metal structure

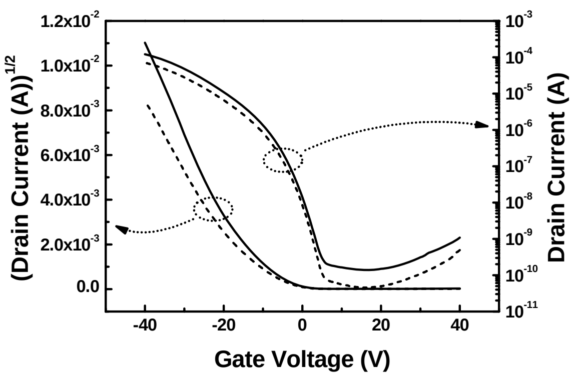

Figure 2. Drain current versus gate voltage at a drain voltage of -20 V; dashed line and solid line show the drain currents of switching transistor and driving transistor, respetively.

Active-matrix array of 4.4 inch square shape was designed to drive OLED array. 192×64 pixels were integrated in the array. Each sub-pixel had a pixel-circuit to drive an OLED.

Pixel-circuit had a storage capacitor and two transistors; one was a switching transistor and the other was a driving transistor. Fig. 3 shows the schematic diagram of pixel-circuit and Fig. 4 is the photograph of a sub-pixel. Switching TFT stored the data signal (Data in Fig. 4) into the storage capacitor (Cst in Fig. 4) during on-stage of the scan signal (Vgate in Fig. 4) and kept the stored data during off-stage of the scan signal. Driving TFT controlled the current of OLED according to the data stored in storage capacitor.

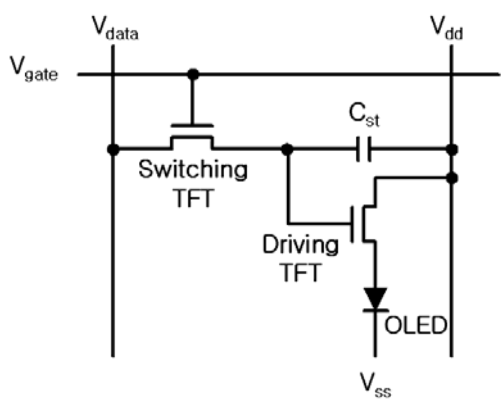

Figure 3. Schematic diagram of pixel-circuit of voltage writing scheme; Vgate is a scan signal, Vdata is a voltage writing data, Vdd is a power line for OLED and Vss is a cathode voltage for OLED.

The channel length was 10 μm for both transistors. The channel widths of switching TFT and driving TFT were 800 μm and 1200 μm, respectively. The capacitance of storage capacitor was 1 pF. Ratio of channel width over length (W/L) of driving TFT was chosen to guarantee on-state drain current large enough to lighten the OLED. Storage capacitor was designed to have enough capacitance to reduce the cross-talk owing to the parasitic capacitance of circuit. W/L of switching TFT was designed considering the charging time of the storage capacitor. As shown in Fig. 2, we used finger shaped TFTs to increase channel widths. The width of finger was 30 μm. The widths of gate line, data line and power line were 50 μm, 40 μm and 50 μm, respectively. Storage capacitor was designed to use the same layer of the gate insulator as its dielectric layer.

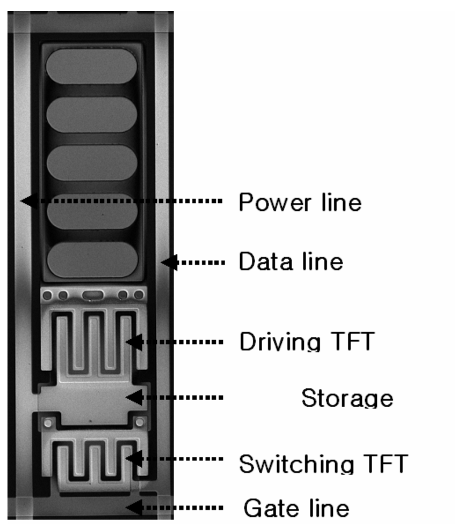

Figure 4. The photograph of sub-pixel.

Figure 5. A still cut of moving image displayed on an AMOLED.

OLED array was fabricated on the active-matrix switching-array after the measurement of characteristics of OTFTs. AMOLED was fabricated using low molecular weight materials and thermal deposition process with shadow mask. After the OLED process, devices were encapsulated using glass can and getter. After this, we made tap bonding on the devices and drove them with external electronics.

3. Summary

We designed and fabricated 192×64 active-matrix switching-array using OTFTs for driving of OLED array. In each sub-pixel, a pixel-circuit with two transistors and one capacitor was integrated. OTFTs gave on/off ratio of 10^6 and mobility of 0.5 $cm^2/V\cdot sec$. On-current were over 100 µA in case of driving TFT and order of 10 µA in case of switching TFT. Using this switching array, AMOLEDs with deposition process were fabricated and driven successfully. From these results, it was assured that AMOLED driven by organic TFTs can be fabricated; this was a drastic advance in making the all-organic display device with low-cost.

4. References

[1] C.D. Dimitrakopoulos and P.R.L. Malenfant, *Adv. Mater.* **14** (2002) p. 99.

[2] T.W. Kelley, D.V. Muyres, P.F. Baude, T.P. Smith, and T.D. Jones, *Mat. Res. Soc. Symp. Proc*. **771** (2003) L6.5.1.