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Organic and Printed Devices for Large Area Electronics

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1. Introduction

Organic thin-film transistors (OTFTs) based on π-conjugated polymers as soft channel materials have recently been of great attention for potential applications in organic/printed optoelectronic devices, such as active-matrix flat panel displays (AMFPDs), electronic papers, RFID tags, and chemical/bio-sensors.[1-3] In particular, up to now, unresolved issues of research which evolved from FPDs system are concerned with development of high-performance and low-cost OTFTs backplanes on desired surface by easy-to-process yet highly ordered system. Importantly, the solution-processability of π-conjugated polymers has stimulated much interest in their utilization as active electronic elements for low-cost, large-area, and flexible active matrix display backplane comparable to hydrogenated amorphous silicon (a-Si:H)-based thin-film transistors.[4-6]

In this paper, we report a novel charge-transfer type liquid-crystalline semiconducting copolymer (CT-LCSC) which contains both electron-donating and electron-accepting building blocks, and exhibits unprecedented electrical characteristics such as field-effect mobilities as high as 0.33 $cm^2/V\cdot s$ and good bias-stress driven electrical stability that is comparable to that of amorphous silicon (a-Si). Liquid-crystalline thin films with structural anisotropy form spontaneously through the self-organization of the individual polymer chains as a result of intermolecular interactions in the liquid-crystalline mesophase, and adopt preferential well-ordered inter-molecular π-π stacking parallel to the molecular surface. Furthermore, we developed AMOLEDs on a glass using two OTFTs and a capacitor in a pixel. OTFTs switching-arrays with 64 scan lines and 64 (RGB) data lines were designed and fabricated to drive OLED arrays. In this study, OTFT devices have bottom contact structures with an ink-jet printed liquid-crystalline polymer semiconductor and an organic insulator as a gate dielectric. The width and length of the switching OTFTs is 500 ㎛ and 10 ㎛, respectively and the driving OTFTs has 900 ㎛ channel width with the same channel length. The characteristics of the OTFTs were examined using test cells around display area. On/off ratio, mobility, on-current of switching OTFTs and on-current of driving OTFTs were 10^6, 0.1 $cm^2/V\cdot sec$, order of 8μA and over 70 μA, respectively. These properties were enough to drive the AMOLEDs over 60 Hz frame rate. AMOLEDs composed of the OTFTs switching arrays and OLEDs made with polymer materials were fabricated and driven to make moving images, successfully. In addition, we developed the 4-inch AM-EPD (electrophoretic display) with QVGA resolution.

2. Results and Discussion

In this work, we synthesized wet-processable gate dielectrics. Organic-inorganic hybrid type materials such as mixture of organosilane and low temperature curable polymer are used. After cured at 200°C, Au was deposited by thermal evaporation and patterned using standard photolithography process. Prior to ink-jet printing, Au surface was treated with self-assembled monolayer (pentafluorothiol) to reduce the contact resistance. Finally, tetrahydronaphthalene (THN) solution of CT-LCSC printed on prepared substrates. It was found that annealing printed films is essential to improving transistor performance. As discussed with UV-Vis absorption spectra and X-ray diffraction patterns, increased crystallinity and enhanced intermolecular π-π interactions after annealing facilitate carrier transport. Therefore, in this work, all printed CT-LCSC devices were annealed at 100°C for 1 h. CT-LCSC devices operate as standard p-type, field-effect transistors in an accumulation mode. The mobility was calculated from transfer curves by using the equation below,

$$I_{sd} = (W/L)\,\mu_{lin}\,C_i\,(V_g - V_T) \qquad \text{at linear regime}$$
$$I_{sd} = (W/2L)\,\mu_{sat}\,C_i\,(V_g - V_T)^2 \qquad \text{at saturation regime}$$

where I_{sd} is the source-drain current, W the channel width, L the channel length, μ_{lin} the carrier mobility in linear regions, μ_{sat} the carrier mobility in saturation regions, C_i the capacitance of the dielectric, V_g the gate voltage, and V_T the threshold voltage. Fig. 1 shows the transfer characteristics of printed thin-film transistor at a drain voltage of -10V and -40V. From this result, we can calculate the field-effect mobility (~ 0.1 cm^2/Vs) and on/off ratio (10^7).

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. 2 shows the schematic diagram of pixel-circuit. Switching OTFT stored the data signal into the storage capacitor during on-stage of the scan signal and kept the stored data during off-stage of the scan signal. Driving OTFT controlled the current of OLED according to the data stored in storage capacitor.

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 OTFT 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. 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.

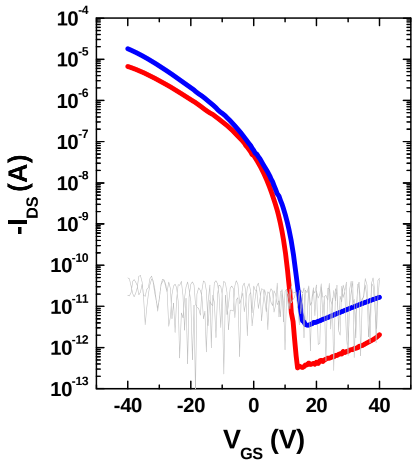

Figure 1. Transfer characteristics of printed organic thin-film transistor at a drain voltage of -10V (red line) and -40V (blue line).

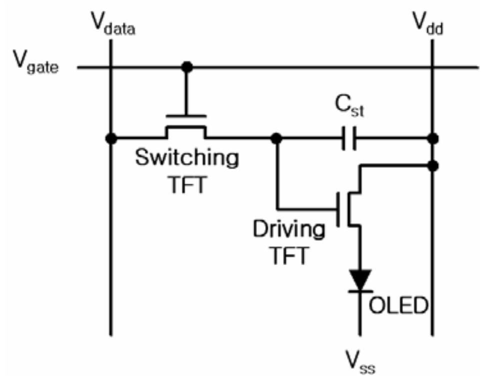

Figure 2. Schematic diagram of pixel-circuit of voltage writing scheme; V_{gate} is a scan signal, V_{data} is a voltage writing data, V_{dd} is a power line for OLED and V_{ss} is a cathode voltage for OLED.

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.

Figure 3. A still cut of moving image displayed on an AMOLED.

Figure 4. A still cut of moving image displayed on an AMEPD.

3. Conclusion

In conclusion, we designed and fabricated 192×64 active-matrix switching-array using ink-jet printed 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 10^7 and mobility of 0.1 $cm^2/V{\cdot}sec$. On-current were over 70 µA in case of driving OTFT and order of 8 µA in case of switching OTFT. Using this switching array, AMOLEDs with deposition process were fabricated and driven successfully. From these results, it was assured that AMOLED driven by ink-jet printed OTFTs can be fabricated; this was a drastic advance in making the low-cost, all-organic flexible display with high-performance.

4. References

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