Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp402-403

Printed OTFT-backplane for Electrophoretic Display Characterized by High Uniformity of Performance over a Large Area

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1. Introduction

The solution process for organic thin film transistors (OTFTs) has been an issue because of the low manufacturing cost, the large area application, and the low temperature process. Recently, there have been the numerous reports on high performance OTFTs based on solution process [1,2]. However, it is rare for these high performance materials to be applied to backplanes, especially employing solution process.

In this study, we report on the application of TIPS -pentacene using inkjet printing to backplane for EPD panel, characterized by the high performance and the high uniformity over the area of 6” panel with the resolution of 150 x 192 pixels.

2. Experimental

Ink-jet printing is an appropriate method to conserve the expensive organic semiconductor because it can jet droplets on a specific area only. TIPS-pentacene ink was used for semiconductor and TIPS-pentacene molecules were dissolved in anisole solvent with 3wt%.

Usually, a jetted droplet produces a coffee ring when it is naturally dried because the most of molecules is accumulated at the contact point due to the convective flow of solvent, and the contact point is pinned during drying. Thus, in the middle area of crystal with the coffee ring the number of molecules is not sufficient for carriers to transport, resulting in performance degradation.

Conceptually by moving the contact point toward the center during drying the coffee stain can be eliminated and thus a semiconductor layer with the uniform thickness produced. In order to make the contact point move we have applied heat to the substrate during jetting to forcefully evaporate the solvent near contact point [3].

We applied the heating process to TIPS-pentacene backplane. The appropriate temperature was figured out to be 46 ^{o}C in this case, which was extracted by varying the temperature and examining the morphology of TIPS-pentacene at each temperature. Also, the performance of backplane was examined by demonstrating the panel operation.

3. Results and discussion

In Fig.1 the microscopic pictures of TIPS-pentacene crystal were presented, which were formed at the different substrate temperatures of 36℃, 46℃ and 56℃ during ink-jetting droplet.

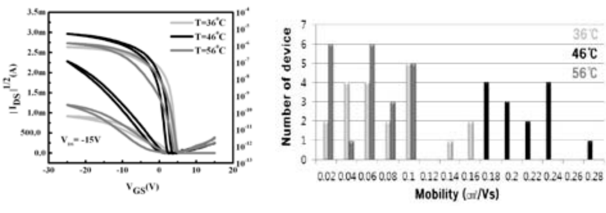
(a) (b) (c)

Fig. 1. The microscopic pictures of TIPS-pentacene crystal heated at (a) 36℃, (b) 46℃, (c)56℃ during jetting droplet.

In Fig.1a at 36℃ the coffee ring was clearly seen and the crystal grains were not appeared. Meanwhile at 56℃ of Fig.1c the coffee ring was not appeared and the gains were clearly seen but were not continually extended to the center. However, at 46℃ of Fig.1b the grains were clearly seen and continually extended from the contact to the center.

The reason for the above results was attributed to balance between the moving speed of contact point and the speed of crystal formation at the contact. When the two speeds were balanced, the longish grains extended from the contact to the center could be obtained. From the results we could determine that the temperature at 46℃ was an appropriate one for the uniform morphology.

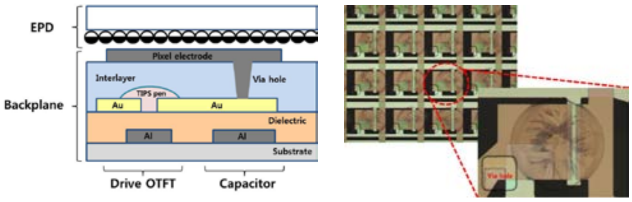
In Fig.2 the electrical characteristics at the above three different temperatures were compared. As we expected the transfer curve at 46℃ produced the best performance in terms of mobility, sub-threshold voltage, and turn-on voltage as shown in Fig.2a. In addition the uniformity presented by standard deviation was also high at 46℃ as shown in Fig.2b.



(a) (b)

Fig. 2. The performance comparison of TIPS-pentacene OTFT at the different temperatures; (a) the transfer characteristics, (b) the mobility with standard deviation.

Based on the heating process we fabricated OTFT backplane by using TIPS-pentacene as the semiconductor. The backplane contained 150 x 192 pixels on 6” area in which each pixel was consisted of 1 OTFT and 1 capacitor. The OTFT employed bottom contact structure with 20 ㎛ channel length and 310 ㎛ width. A schematic cross section of a pixel is illustrated in Fig.3.



(a) **(b)**

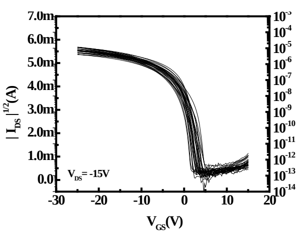
Fig. 3. (a) The cross-section of a pixel consisting of OTFT backplane and EPD panel, (b) the crystals of TIPS-pentacene on backplane

It was very important to make the substrate temperature be uniform at 46℃ over the entire large area. Thus we put the substrate at 46℃ for 30 min until the substrate temperature was uniform over the entire area. The details of the other fabrication processes can be found in [4].

The other important factor to obtain good performance was to locate the center of droplet to be out of channel area as shown in Fig.3b. Because at the center of droplet the grains with the different boundary direction met together so that lots of grain boundary traps formed, resulting in degrading performance

Since the turn-on time of EPD was 130msec, the frame frequency was selected to be 6.5Hz (t_{frame}=1/6.5Hz= 153msec > 130msec). Based on the design rule the OTFTs should supply a larger on-current than 0.5uA(I_{on}= $C_t x V_{on}/\tau$), where V_{on} is the on-voltage and τ the time constant which are of 30 V and 0.204msec respectively, in order to charge up the total capacitor C_t of 3.57 pF including the storage capacitance and the parasitic capacitance as well in a limited scanning time of 1.02 msec. And the off-state current should be less than 38 pA (I_{off}= $C_t x \Delta V/t_{frame}$), where ΔV is the allowed voltage loss and 1.63 V, in order to sustain the voltage across the storage capacitor during the frame time of 153 msec.

In Fig.4a the transfer curves of 20 OTFTs at the different locations from the backplane were depicted by overlapping. The on-current was 5uA at V_G= -10V which was sufficiently large to charge up the storage capacitor within 0.8 msec. And the off-state current was about 1 pA which was sufficiently small to keep the voltage across the capacitor sustainable.



	Uniformity
Mobility (cm^2/V·s)	0.21 (±0.05)
SS (V/dec)	0.47 (±0.17)
Ion/Ioff	3.96 (±1.45) × 10^7
Vth (V)	0.64 (±0.85)
Off-state current (pA/um)	6.61 (±3.08) × 10^{-4}

(a) **(b)**

Fig. 4. (a) The transfer curves of 20 OTFTS from backplane, (b) the summary of performance parameters.

Also, trasnfer curves indicate a unifom performance. They were in the vary narrow range meaning a good uniformity. The uniformity of parameters were summaried in Fig.4b. The mobility was 0.21 cm2/V.sec with the standard deviation of 25%, which was sufficient to display a good ptictures as shown in Fig.5.

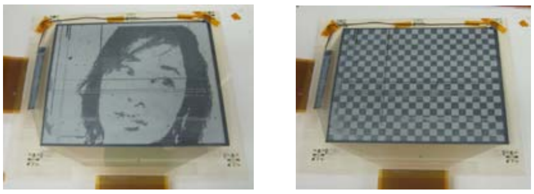


Fig. 5. The images of EPD panel driven by TIPS-pentacene-backplane.

4. Conclusions

We fabricated OTFT-backplane for EPD panel by using TIPS-pentacene as an organic semiconductor. In order to achieve high performance and high uniformity over a large area, we controlled the morphology of TIPS-pentacene crystal by heating substrate during ink-jetting the droplets. At T=46℃ substrate temperature the OTFTs produced the best performance. The average mobility was 0.21±0.05㎠/V·s with the deviation of 25% from 28,800 OTFTs on 6” area and the on/off current ratio 3.9±1.45×10 [7]. The OTFT-EPD panel worked successfully and demonstrated to display several images.

Acknowledgements

This research was supported by a grant(F0004020-2010-33) from information display R&D center, one of the knowledge economy frontier R&D program funded by the ministry of knowledge economy of Korean government

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