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4.4L: *Late-News Paper:* A High Resolution Flexible Electrophoretic Display Driven by OTFTs with Inkjet-Printed Organic Semiconductor

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Abstract
A 4.8-in. VGA (167 dpi) organic thin-film transistor (OTFT)-driven flexible electrophoretic display was demonstrated by developing inkjet printing of a small-molecule organic semiconductor (OSC) peri-xanthenoxanthene derivative. A passivation layer of OSC was also printed by the screen-printing method. Pixel OTFTs exhibited high mobility of 0.4 cm^2/Vs and high thermal stability after full integration of the field shielded pixel structure.

1. Introduction
In recent years, solution-processed organic thin-film transistors (OTFTs) have attracted much attention, due to feasible advantages such as low-cost, low-energy-consumption and effective material use in manufacturing processes. There are many reports on inkjet printing of organic semiconductors (OSC) as active layers of OTFTs, using polymer materials [1-4] and small-molecule materials [5-7]. OTFTs that use small-molecule OSCs have exhibited relatively high mobilities of approximately 1 cm^2/Vs [8-10]. These small-molecule OSCs materials have greater potential for high-resolution active matrix display application than polymer semiconductor materials. However, high-mobility small-molecule OSCs are generally more difficult to print uniformly than polymer OSCs, due to random crystallization of the molecules on the OTFT channel [11]. We have developed a soluble OSC, *peri*-xanthenoxanthene (PXX) derivative [12], and optimized the solution formulation, which has enabled uniform film formation on the polymer gate insulator by inkjet printing. We have also developed a hydrophobic bank with controlled surface energy that enables both precise patterning of the OSC for a high-resolution pixel array and interlayer dielectric formation on the bank layer. Consequently, a field shielded pixel OTFT cell with higher mobility of ca. 0.4 cm^2/Vs, and its application to a flexible 4.8-in. VGA (167 dpi) electrophoretic display (EPD) was successfully demonstrated.

2. Fabrication process of OTFT backplane
Figure 1 shows a schematic cross-section of the developed field shielded OTFT pixel with bottom-gate bottom-contact structure. During fabrication, Cu gate electrodes and the storage capacitor electrodes are first patterned by photolithography on a 200-μm thick polyethersulfone (PES) substrate. A polymer gate insulator with a thickness of 550 nm was then spin coated and annealed at 150 °C. After patterning of Au source-drain electrodes and the hydrophobic bank by photolithography, the OSC layer was patterned by inkjet printing under ambient conditions. We have developed a novel *peri*-xanthenoxanthene (PXX) derivative small-molecule OSC (see Fig. 2), which has high thermal stability and exhibits high mobility of 0.4 cm^2/Vs [12]. To formulate the OSC ink, an aromatic solvent with a high boiling point over 200 °C was used. Slow vaporization of the solvent improves the crystallinity of the OSC film and achieves stable inkjetting without clogging of the nozzle. The OSC ink concentration and ink droplet volume were approximately 0.5 wt% and 10 pL, respectively.

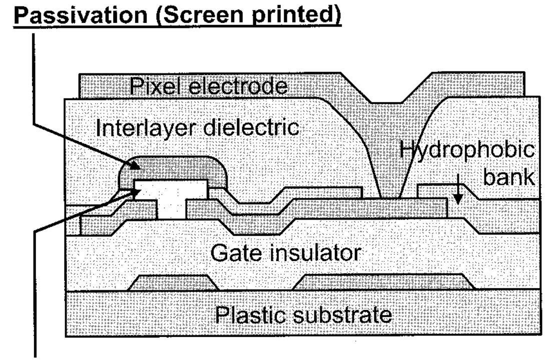

Figure 1. Schematic cross-section of the OTFT pixel.

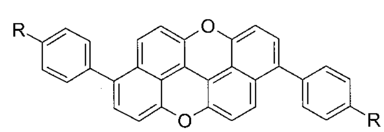

Figure 2. Molecular structure of the *peri*-xanthenoxanthene (PXX) derivative.

Although the as-inkjetted OSC droplets on the substrate were approximately 100 μm in diameter, the hydrophobicity of the bank layer assisted the precise patterning of a 25 × 80 μm OSC layer after drying (see Fig. 3). Formation of the bank layer requires control of the hydrophobic bank surface-energy, because the bank repels the OSC and an interlayer dielectric must also be uniformly coated on the hydrophobic surface at the same time. Therefore, a novel bank material was developed with optimized surface energy and was adopted instead of a conventional fluoropolymer (Fig. 4).

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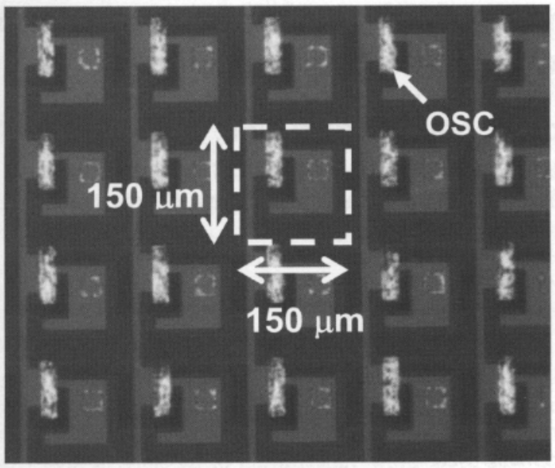
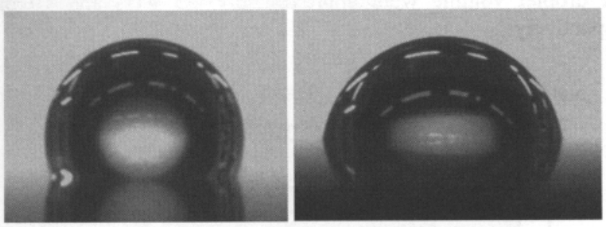


Figure 3. Optical micrograph of the OTFT array after OSC pattering.



Fluoropolymer bank (water c.a. =

Originally developed bank (water c.a. = 82°)

Figure 4. Water contact angles (c.a.) on the bank material.

After the formation of the OSC layer, the passivation layer was patterned by screen-printing on the OSC area using a high viscosity fluoropolymer ink. To evaporate the high boiling point solvent contained in the passivation layer, the OTFT backplane was annealed at 120 °C. The UV patternable interlayer dielectric was then spin coated and the contact holes were patterned by photolithography. Finally, the Cu pixel electrodes were formed by evaporation and photolithography processes to complete the field shielded pixel structure.

3. Characteristics of OSC-inkjetted OTFT

The morphology and molecular ordering of an inkjetted OSC film are determined by the solvent evaporation process, which depends on a variety of parameters, such as the surface energy of the solvent or the gate dielectric, the vapor pressure of the solvent and the substrate temperature. These conditions were optimized to obtain an OTFT mobility of around 0.4 cm^2/Vs. Figure 5 shows the transfer characteristics of the OSC inkjetted OTFT with W/L = 60 µm/5 µm. Along with a mobility of 0.4 cm^2/Vs, a threshold voltage of -1 V, subthreshold slope of 0.4 V/decade and a current on/off ratio of 10^7 were obtained.

The on- and off-current of the pixel OTFT was monitored at each step of the process, and the value were almost constant, even after integration, as shown in Fig. 6. The backplane was then exposed to thermal stress at 120 °C for 2 h. Although the pixel OTFT displayed only a slight reduction in the on-current, the mobility

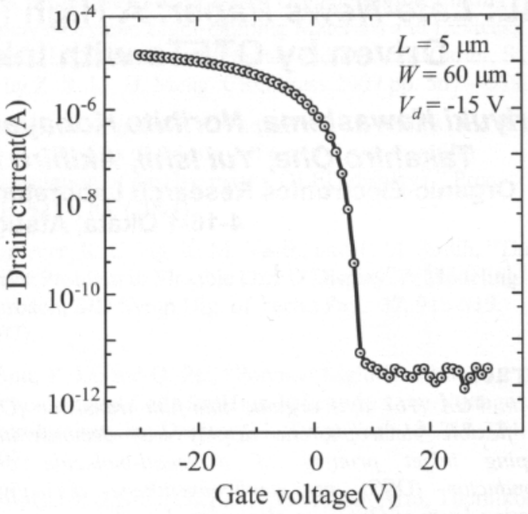


Figure 5. Transfer characteristics of the PXX derivative inkjetted OTFT.

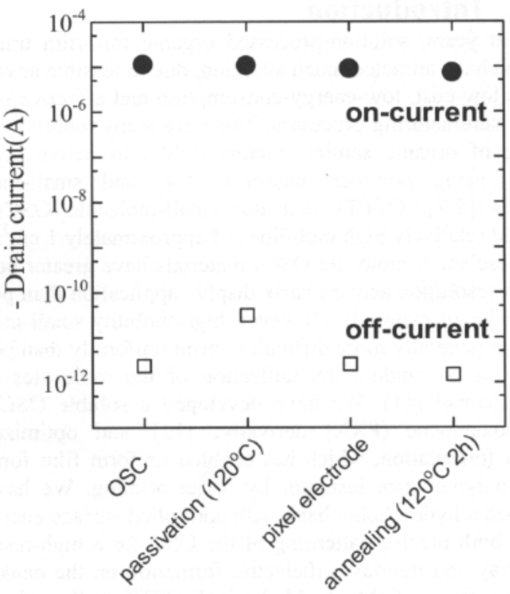


Figure 6. Evolution of the OTFT on-current and off-current during the fabrication process.

was still maintained at 0.25 cm^2/Vs, which is sufficiently high for high resolution EPD operation.

4. Application to a flexible EPD

A flexible EPD was fabricated after lamination of an E Ink® imaging film onto the developed active matrix TFT backplane. The specifications of the flexible electrophoretic display are summarized in Table 1. The size of this VGA display is 4.8 inch diagonal and the resolution is 167 dpi with pixel size of 150×150 µm. The gap of adjacent pixel electrodes is 5 µm and the aperture ratio is 93.4%. Figure 7 shows a 16-level grayscale image of the OTFT-driven EPD. The voltages applied to the data line and the scan line were 30 V_{p-p} and 42 V_{p-p}, respectively.

Table 1. Specifications of the OTFT-driven EPD.

Display size	4.8 inch diagonal
Resolution	167 dpi
Pixel number	480 × 640 (VGA)
Pixel size	150 × 150 μm
Aperture ratio	93.4%

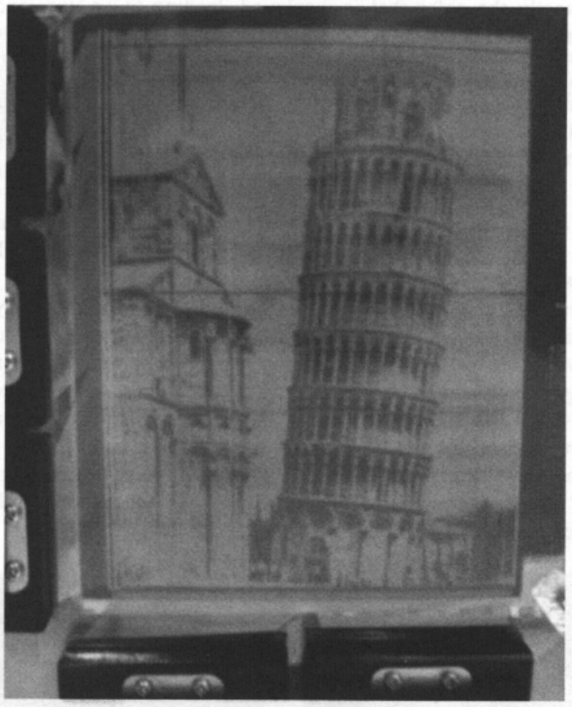


Figure 7. Image of inkjet printed OTFT-driven EPD.

5. Conclusions

An OTFT was developed using a high-mobility small-molecule OSC of *peri*-xanthenoxanthene (PXX) derivative, which was soluble in a common organic solvent, and precise patterning of PXX by inkjet printing with a surface-energy-controlled hydrophobic bank. Passivation of the PXX was achieved by screen printing with a fluoropolymer ink. Consequently, a 4.8-in VGA EPD driven by OTFT pixels with mobilities of 0.4 cm^2/Vs was successfully fabricated. This is promising technology for future high resolution printed-OTFT-driven displays.

6. Acknowledgements

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7. References

[1] A. C. Arias, S. E. Ready, R. Lujan, W. S. Wong, K. E. Paul, A. Salleo, M. Chabinyc, R. Apte, R. Street, Y. Wu, P. Liu and B. Ong, Appl. Phys. Lett., **85**, 3304 (2004).

[2] S. E. Burns, W. Reeves, B. H. Pui, K. Jacobs, S. Siddique, K. Reynolds, M. Banach, D. Barclay, K. Chalmers, N. Cousins, P. Cain, L. Dassas, M. Etchells, C. Hayton, S. Markham, A. Menon, P. Too, C. Ramsdale, J. Herod, K. Saynor, J. Watts, T. von Werne, J. Mills, C. J. Curling, H. Sirringhaus, K. Amundson and M. D. McCreary, SID'06 Digest, p. 74 (2006).

[3] S. Moriya, T. Miyamoto, T. Saeki, T. Kawase, S. Inoue and T. Shimoda, SID'06 Digest, p. 277 (2006).

[4] S. Lee, D. H. Kim, B. L. Lee, H. Moon, E. J. Jeong, J. I. Park, B. W. Yoo, B. W. Koo and J. Y. Kim, Etx. Abst. SSDM, pp. 1122-1123 (2008).

[5] H. Maeda, M. Matsuoka, M. Nagae, H. Honda and H. Kobayashi, SID'07 Digest, p. 1749 (2007).

[6] C. Harada, S. Ohta, T. Chuman, H. Ochi, H. Sato, S. Ishizuka and A. Yoshizawa, Proc. IDW'07, p. 1977 (2007).

[7] T.Okubo, K. Kokubo, K. Hatta, R. Matsubara, M. Ishizaki, Y. Ugajin, N. Sekine, N. Kawashima, T. Fukuda, A. Nomoto, T. Ohe, N. Kobayashi, K. Nomoto and J. Kasahara, Proc. IDW'07, p. 463 (2007).

[8] A. Afzali, C. Dimitrakopoulos, and T. Breen, J. Am. Chem. Soc., **124**, 8812 (2002).

[9] S. Park and T, Jackson, Appl. Phys. Lett. **91**, 063514 (2007).

[10] H. Ebata, T. Izawa, E. Miyazaki, K. Takimiya, M. Ikeda, H. Kuwabara and T. Yui, J. Am. Chem. Soc., **129**, 15732 (2007).

[11] D. H. Song, M. H. Choi, J. Y. Kim and J. Jang, Appl. Phys. Lett., **90**, 053504 (2007).

[12] N. Kobayashi, M. Sasaki and K. Nomoto, Chem. Mater. **21**, 552 (2009).