Flexible Electrophoretic Display with Inkjet Printed Active Matrix Backplane

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Abstract

A 9.6-inch, 25.7-ppi organic-TFT-driven active matrix display backplane was developed and fabricated by using an effective combination of inkjet printing and vacuum processes. This novel process, which consists of a single photolithography step for forming source and drain electrodes and two inkjet printing steps for forming semiconductor layer and gate electrode, is particularly compatible with flexible plastic substrates. The highest temperature in the process was 80°C, and the total processing time required to fabricate the panel was only 30 hours. An active matrix electrophoretic display device was fabricated by laminating an E-Ink Imaging Film on the organic TFT backplane, and was proven to operate stably in the air even without a passivation layer. Thus the effectiveness and adaptability of this hybrid process for e-paper applications was confirmed. The process also enables flexible displays to be produced easily and at low cost. Organic TFT active matrix backplanes fabricated using this process are considered to be viable for display devices used in e-papers, smart cards, and other products with high-volume, low-cost requirements.

1. Introduction

The build-out of network infrastructure is bringing us closer to a ubiquitously networked world in which devices of all kinds will be connected. This growth in networks is expected to trigger an explosion of products equipped with e-papers, e-poster, RFID tags, smart cards and similar devices. Such devices will require inexpensive, lightweight, unbreakable, flexible displays that are capable of easily displaying information downloaded from networks. Organic Thin Film transistors (OTFTs) have been considered as one of the candidates for achieving flexible active-matrix backplanes at low cost [1-3]. Polymer semiconductors are soluble in organic solvents and can be printed with a liquid solution, most typically by using an inkjet printing process [4-9]. A flexible active-matrix backplane can be fabricated at low temperature and in ambient air by using an inkjet process to fabricating these organic TFTs [10]. Inkjet printing is an additive process in which material deposition and patterning take place concurrently. Because polymer semiconductors are patterned in just a single step, the inkjet printing process has two important advantages over standard photolithography techniques. First, material consumption in inkjet printing is minimized because the material is deposited only in the locations and amounts required. Second, processing time can be reduced because no expensive masks are required and the process is completed in a single step. The foregoing advantages make an inkjet printing process exceedingly well suited for the fabrication of low-cost active-matrix backplanes. This paper describes the creation of a small, flexible, electrophoretic display prototype envisioned for applications in e-paper that uses an organic TFT active-matrix backplane fabricated by inkjet printing.

2-1. Flexible electrophoretic display fabrication process

A novel, high-throughput process for fabricating active-matrix backplanes with organic TFTs was developed by combining an inkjet process for printing solutions with a standard vacuum process [11,12]. The new process was used to form organic TFTs consisting of metal electrodes, polymer semiconductors, and a polymer gate insulator. Source and drain electrodes were formed by standard metal evaporation and photolithography techniques, but the remaining steps were performed via a liquid-phase process that included inkjet printing. This process has the following advantages over a standard process in which photolithography is used to form each layer:

(1) Accurate alignment is easy to achieve. Whereas it is difficult to achieve alignment with a multi-step photolithography process due to repeated thermal expansion and contraction of plastic substrates, the new process makes accurate alignment easy because all steps following the photolithographic formation of source and drain electrodes are performed using the inkjet technique. Inkjet printing is a noncontact and serial patterning method and it can easily adjust to the expansion and contraction of the plastic substrates.

(2) A photolithography process can be used to form source and drain electrodes as well as to simultaneously pattern complicated interconnects, pixel electrodes and contact pads, all of which require a high degree of accuracy.

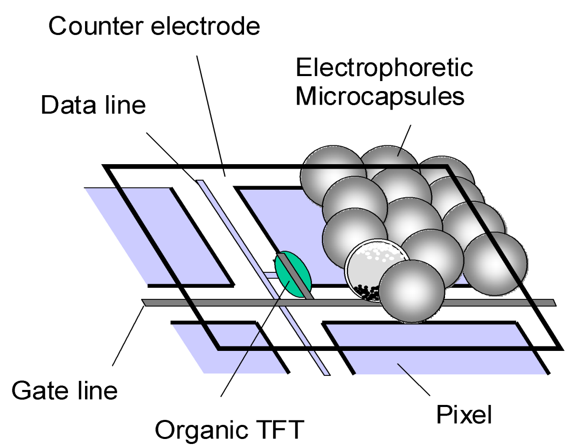

Figure 1 *Structure of electrophoretic display*

The active-matrix backplane fabricated by this process leverages the respective advantages of inkjet printing and photolithography to enable the low-cost, high volume production of flexible displays.

Figure 1 schematically illustrates the structure of the organic TFT active-matrix electrophoretic display that was fabricated using this process. The process was as follows. First, a metal layer was formed by vacuum evaporation on a 120-µm-thick plastic substrate. Source and drain electrodes were then formed by photolithographically patterning this metal layer. Data lines, pixel electrodes, and contact pads that connect to control signals from a driver substrate were formed at the same time as the source and drain electrodes are formed. The patterning of an organic semiconductor layer is critical for electrically isolating the transistors from one another [11]. To isolate the transistors, a 20-nm-thick fluorene-bithiophene copolymer (F8T2) layer was inkjet-printed onto the source and drain electrodes. Next, an insulating polymer was spin-coated to form a gate insulator, and gate lines and gate electrodes were printed with a metal dispersion. The metal interconnections and gate lines were connected to complete the active-matrix backplane. In this process for producing an electrophoretic display, all steps after the initial metal vacuum deposition were carried out in ambient air, including the process for producing microencapsulated electrophoretic material. Moreover, the highest process temperature was extremely low (80°C), and the total man-hours was less than 30 hours.

The electrophoretic display was prepared by laminating the organic TFT active-matrix backplane with electrophoretic film, trademarked “E Ink Imaging Film,” provided by E Ink Corporation on which the microencapsulated electrophoretic material and counter electrodes were provided.

2-2. Organic TFT performance

The basic structure of the organic TFT device using this active-matrix backplane is shown in the sectional view in Figure 2 and in the plane view in Figure 3.

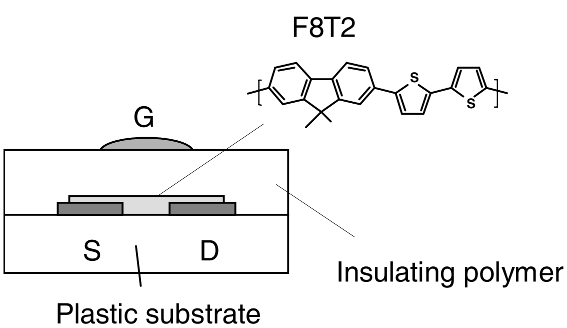

***Figure 2** Sectional view of the Polymer TFT*

No passivation layer or other protective sealing structure was provided for the organic TFTs. The transfer characteristics of this organic TFT were measured in ambient air. The results are shown in Figure 4. The field-effect mobility was 0.002 cm^2/V at a gate bias of –40V. The on-off ratio between 0V and –40V was 2×10^6. The degradation of the on-current and off-current as a function of exposure time to air is shown in Figure 5. The on-off ratio was on the order of 10^6 even after 1500 hours of air exposure, even though no passivation layer was provided.The high on-off ratio and outstanding air-stability are attributed to the relatively high ionization potential (5.3 to 5.4 eV) of the F8T2 used for the semiconductor layer, as well as to resistance to doping with airborne oxygen and water [12].

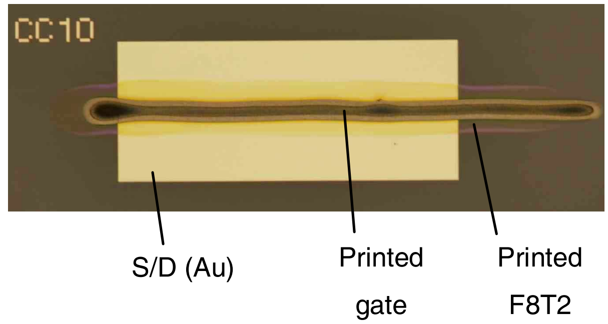

***Figure 3** Plane view of the polymer TFT*

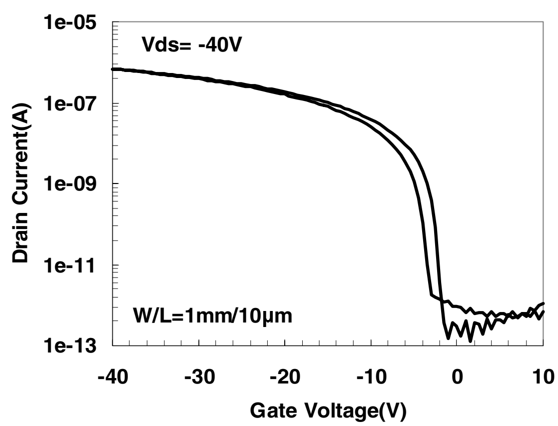

***Figure 4** Transfer characteristics of polymer TFT*

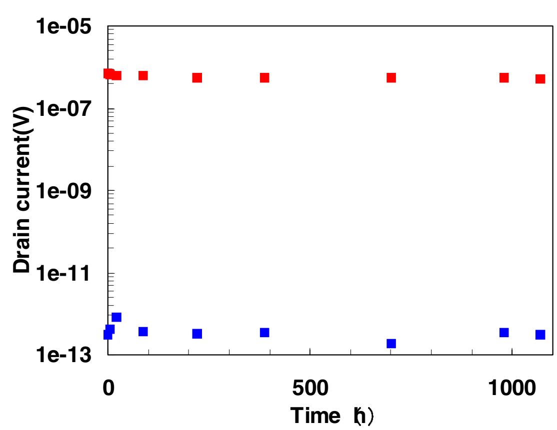

***Figure 5** Degradation of the on-current and off-current as function of exposure time to air*

2-3. Flexible electrophoretic display performance

The basic specifications of the electrophoretic display are shown in Table 1.

Table 1 Specifications of electrophoretic display

Panel size	146mm × 194mm
Num. of pixels	144 × 192
Resolution	1012 μm pitch (25.7ppi)
Thickness	250μm
Voltage	-40V
Contrast	~4

This 25.7-ppi electrophoretic display has a display area of 146mm × 194mm and a total thickness of 250 μm. It worked in air and exhibited uniform image contrast. Images on the display were not degraded even when the display was operated while bent as shown in Figure 6. The switching time of the display was about 500 ms, which is essentially equal to the response of the electrophoretic material. The electrophoretic display was exposed to air for about 6 months, and then operated again. No noticeable changes in display operation were observed despite the absence of a passivation layer or other protective sealing structure.

3. Summary

A 9.6-inch, 25.7-ppi active-matrix backplane was fabricated using a hybrid process that combined a vacuum process and an inkjet process. The highest temperature reached in any process was 80°C, and the total processing time required to fabricate the panel was only 30 hours. This electrophoretic display operated stably in air without a passivation layer being provided.

The effectiveness of this hybrid process was confirmed by fabricating a flexible electrophoretic display for envisioned applications in e-paper. The process enables flexible displays to be produced easily and at low cost. Organic TFT active-matrix backplanes fabricated using this process are considered to be viable for display devices used in e-papers, e-poster, RFID tags, smart cards, and other products with high-volume, low-cost requirements.

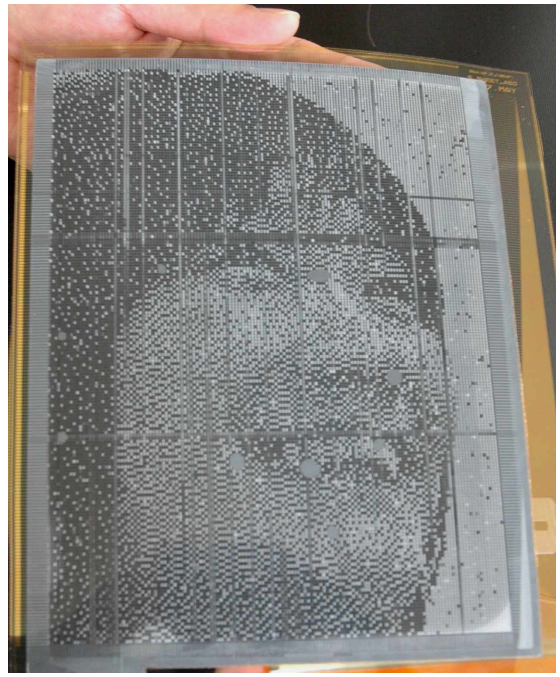

Figure 6 *9.6-inch, 25.7-ppi electrophoretic display*

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