A flexible, full-color OTFT-OLED display

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Abstract

We have demonstrated a flexible and full-color OTFT-OLED display. The display has a top-emitting pixel structure with a resolution of 80 ppi, which can be achieved by developed integration architecture of OTFTs. The 0.3-mm-thick flexible display exhibits peak brightness over 100 nit with a contrast ratio greater than 1000:1

1. Introduction

Organic light-emitting diodes (OLEDs) are self-emissive devices consisting of thin organic layers with a total thickness of a few hundreds of nanometers, indicating that OLEDs enable display devices to be thin and lightweight. In addition, OLED devices are typically fabricated by thermal evaporation, thus OLEDs can be fabricated on a several kinds of substrates at a reduced fabrication temperature. These features enable OLEDs to be formed even on a plastic substrate, and OLEDs on a plastic substrate exhibit mechanical flexibility[1]. It should be noted that OLEDs have all-solid-state structure showing a wide viewing angle, indicating that OLEDs are quite suitable for thin, lightweight and flexible display applications. Considering active-matrix (AM) operation of OLEDs on a plastic substrate, a flexible AM backplane is required.

Organic thin film transistors (OTFTs) are candidates for the pixel transistors of the flexible AM backplane, because OTFTs can be directly fabricated on a plastic substrate with a fabrication temperature below 200 °C. OTFTs fabricated on a plastic film exhibit not only a mechanical flexibility but also reasonable mobility for display driving.

To date, several pioneering works have demonstrated green-monochromic flexible AM-OLED displays driven by OTFTs (OTFT-OLED)[2,3]. Their displays employ a conventional bottom emission pixel structure, where OLED and OTFTs are arranged in a side-by-side configuration.

Here, if we employ a top-emission structure, where OTFT and OLED are arranged in a tandem configuration, resolution of OTFT-OLED can be increased enough for full-color imaging. We have developed integration architecture of OTFTs for achieving the top-emission structure, and demonstrated the world's first flexible and full-color OTFT-OLED display[4]. In this presentation, we would like to introduce key technologies to achieve this OTFT-OLED display and the display properties.

2. Display properties

Figure 1 shows a photograph of our flexible OTFT-OLED display. The specifications of the display are summarized in table 1. We employ a so-called top-emission structure in order to achieve such an increased resolution of 80 ppi for full-color imaging, and each pixel is controlled by 2T-1C pixel circuit constructed by pentacene OTFTs as shown in Fig. 2. The applied voltages for driving display are shown in Fig. 2, and these values are summarized in table 1.

Fig. 1. Photograph of our OTFT-OLED display

Table 1. Specifications of the OTFT-OLED display

Display size	2.5-inch diagonal
The number of pixel	160 × RGB × 120 (QQVGA)
Pixel size	318 μm × 318 μm
Resolution	80 ppi
The number of color	16,777,216
Peak luminance	> 100 cd/m²
Contrast ratio	> 1000:1
Operation scheme	2T-1C Voltage programming
Scan voltage(Vscan)	30 V p-p
Signal voltage (Vsig)	12 V p-p
Vcc – Vcath	20 V

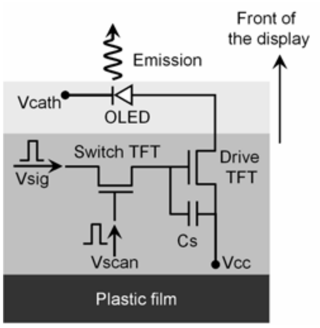

Fig. 2. Schematic cross section of the pixel

The thickness and the weight of the display are 0.3 mm and 1.5 g, respectively. We have confirmed that this thin and lightweight display can be operated at a bending radius of 20 mm.

3. Display structure

Figure 3 shows a schematic cross-section of our top-emission pixel structure. The 2T-1C pixel circuits using pentacene OTFTs are constructed on a plastic film. We use PES or PEN(Dupont-Teijin Film, Teonex Q65FA) as the base film. Each OTFT is in a so-called bottom gate and bottom contact configuration with a channel length of 5 microns[4-6]. Each active region of the TFT is patterned and isolated by utilizing disconnection of the evaporated pentacene film caused by a prefabricated insulating wall structure called OSC separator[4]. The OTFTs are encapsulated by dual-layered interlayer dielectrics consisting of chemical-vapor deposition (CVD) grown poly-para-xylyrene and a solution-processed photo-patternable organic insulator, on which the anode is fabricated. Emission areas of the OLEDs are defined by a window pattern fabricated on the anode. Electrical contacts between diferrent metal layers are achieved by contact holes fabricated in the organic insulators[4]. The above mentioned layers used for the OTFT backplane are all defined by a photolithography. Then RGB OLEDs, a cathode film, and a barrier film are continuously formed by a series of procedures conducted in vacuum.

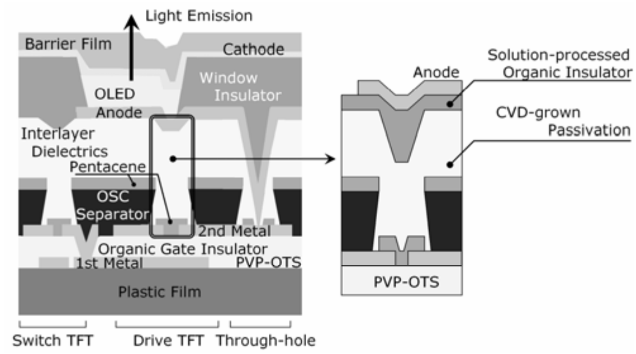

Fig. 3 Schematic cross section of our top-emission pixel structure

4. Electrical properties of the OTFTs

Because our OTFT is in a bottom-gate configuration, the upper anode can behave as a top-gate electrode. When the display is operated, the anode is negatively biased to the source electrode of the p-channel drive OTFT. These structural and electrical conditions induce unexpected charge accumulation in the drive OTFT. This phenomenon is referred to as a back-channel effect, and it decreases on/off ratio of the drive OTFT within a limited operation voltage.

Figure 4 shows typical transfer characteristics of the drive OTFT measured after the integration of the OTFT backplane. Current contrast ratio is estimated within a gate voltage swing of 12 V, which corresponds to the amplitude of the signal voltage (See table 1). For the estimation, 1 μA is assumed as a typical driving current required for OLEDs.

When drain-source bias (V_{DS}) is -12 V, the estimated current contrast ratio is about 10^4. Although the contrast ratio decreases with increasing $|V_{DS}|$ due to the mentioned back-channel effect, a contrast ratio of 1000: 1 is still obtained with an increased V_{DS} of -30 V.

Considering that the applied $|V_{DS}|$ for the display operation is smaller than |Vcc-Vcath| = 20 V, the drive OTFT promises current contrast greater than 1000:1 even when the back-channel effect is considered. Consequently, the OTFT-OLED display shows a corresponding contrast ratio (See table 1).

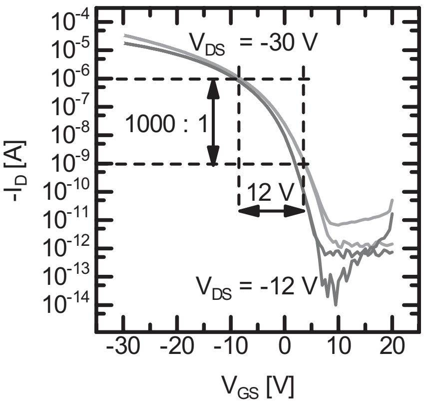

Fig. 4 Typical transfer characteristics of the drive OTFT

The degree of the back-channel effect depends on the overlapped capacitance between the anode and the channel. To reduce the capacitance, we carefully control the thickness of interlayer dielectrics utilizing the following planarization effect during the OTFT integration.

In our structure, the channel region of each OTFT is located in the depressed area which is surrounded by the separator walls. The depressed channel regions are covered with the previously mentioned multi-layered dielectrics. When the regions are finally covered with solution-processed organic layer, the depressed areas can be locally planarized (See Fig. 3). Meanwhile the thicker interlayer dielectrics can be formed above the channel regions than those on the other areas. Due to this planarization, the distance between the anode and the channel can be expanded, which contributes to reduce the stray capacitance and the back-channel effect. In other words, a series of fabrication procedures, which utilizes separator wall and its planarization, contributes to increase the thickness of the interlayer dielectrics, resulting in reduction of the back-channel effect.

5. OTFT fabrication on a plastic film

When OTFTs are fabricated on a plastic substrate, expansion or shrinkage of plastic films directly affect the accuracy of pattern alignment, especially in our case where finely-patterned OTFTs with a channel length of 5 microns are used. The fabrication contains thermal treatment and a wet processing, and both thermally-induced and solvent-induced expansion/shrinkage can be occurred in each fabrication step. We have controlled these factors, and managed the accuracy of pattern alignment.

Figure 5 shows typical alignment accuracy between gate and source-drain layers estimated on a PES film. These values were estimated by using the patterns designed for estimating alignment accuracy. The number of patterns is fourteen, and each pattern is placed around the pixel area. The typical alignment accuracy is estimated to be within 5 μm. Alignment accuracies between other layers are also in the same order.

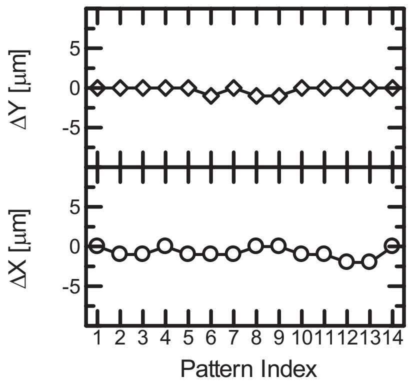

Fig. 5 Typical alignment accuracy between gate and source-drain layers estimated on a PES film

6. Summary

We have demonstrated a flexible and full-color OTFT-OLED display. The display employs a top-emission pixel structure, which can be achieved by developed integration architecture of pentacene OTFTs. The display achieves a pixel resolution of 80 ppi, and it shows peak brightness over 100 cd/m^2 with a contrast ratio greater than 1000:1. These properties of the display are supported by the management of each integration step of OTFTs on a plastic substrate.

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8. References

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