QVGA AMOLED Displays Using the Carbon Nanotube Enabled Vertical Organic Light Emitting Transistor

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Abstract

We present the first display panels exploiting the nVerPix CN-VOLET technology that reduces the pixel circuit of the conventional AMOLED display to two discrete components: the switching transistor and the CN-VOLET. This permits high aperture ratio bottom emission displays—as high as 70% here—and greatly simplifies the manufacturing. Mono-color QVGA AMOLED displays (6.4 cm diagonal) playing video will be shown.

Author Keywords

OLED; organic light emitting transistor; carbon nanotube; active matrix

1. Objective and Background

Increasing the size of active matrix organic light emitting diode (AMOLED) displays is a major goal for display makers. Great manufacturing challenges presently prevent medium and large size AMOLED displays from being produced at a cost competitive with existing display technologies. A key issue is the performance required from the thin film transistor (TFT) backplane. With the TFT materials presently available to display designers, the performance requirements lead to complex solutions lowering yields and driving up costs. A recently developed technology, presents a unique solution to the backplane problem through a novel transistor architecture that promises to simplify the manufacturing process, improve OLED lifetime and enable future display technologies such as flexible and transparent displays.

AMOLED displays require a TFT material with higher mobility and stability than that used in the TFTs of AMLCDs—amorphous silicon (a-Si). Low temperature polycrystalline silicon (LTPS) and indium gallium zinc oxide (IGZO) based TFTs are the two main candidates being explored by display manufactures, but LTPS has uniformity issues and IGZO has not demonstrated sufficient stability [1,2]. We have reported a new type of vertical light emitting transistor that has an organic channel with performance comparable to that of poly-Si based TFT driven OLEDs [3]. The device is based on the carbon nanotube enabled vertical organic field effect transistor (CN-VFET) [4]. The sub-micron channel length of the CN-VFET allows high currents to be realized at low voltages using organic semiconductors in the channel at low cost. Moreover, OLED layers can be inserted between the channel and drain layers turning the device into a vertical organic light emitting transistor (CN-VOLET, Fig. 1A) [3]. The stacked nature of this new device along with the high optical transmittance of the CNT source electrode (>98% across the visible spectrum) leads to a high aperture ratio for the CN-VOLET, which can reduce drive current densities, and in-turn, prolong OLED lifetime.

A significant benefit of the CN-VOLET is that it reduces the number of circuit components in the 2T + 1C conventional

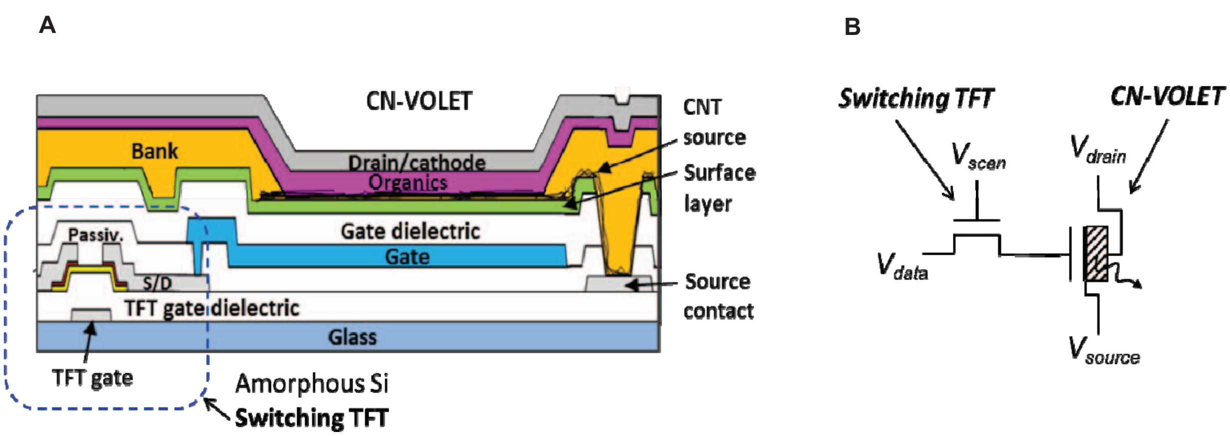

Figure 1. A) Pixel cross section of the QVGA AMOLET display consisting of a CN-VOLET and single switching TFT. B) Active matrix CN-VOLET pixel circuit. The CN-VOLET combines the driving TFT, storage capacitor and OLED into a single device.

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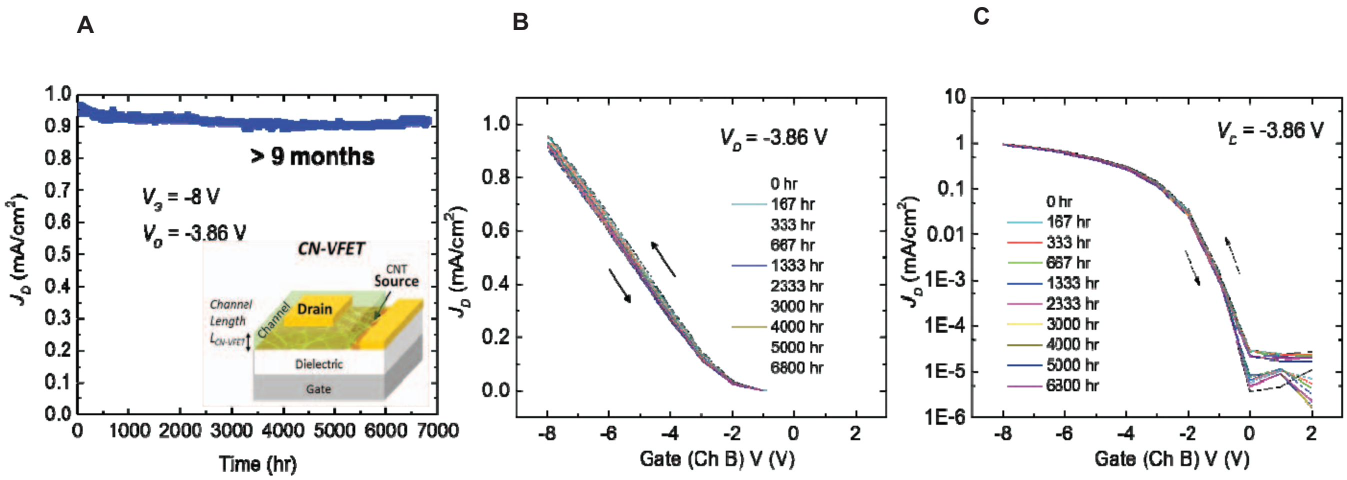

Figure 2. Stability data of the CN-VFET under constant bias stress for a period surpassing 9 months time. A) On-state current density vs. time. CN-VFET schematic inset. Transfer curves plotted on a linear (B) and log (C) y-axis current density scale.

AMOLED pixel circuit by combining the driving TFT, storage capacitor and OLED into a single vertically stacked device. Due to the large gated area of the device, the separate storage capacitor can be eliminated since the gate capacitance is sufficient to store the required charge between refresh cycles (without being so high as to limit high refresh rates) [5].

Some of these advantages of the CN-VOLET have already been demonstrated but others remain. Here we show the first display based on the CN-VOLET technology in a bottom emission, high aperture ratio (70%), mono-color, QVGA active matrix organic light emitting transistor (AMOLET) display showing 60 Hz video. An ongoing problem for the OLED display community remains bias stress instability. We also show bias stress stability data for a CN-VFET (the substructure of the CN-VOLET) biased for over 9 months, demonstrating a remarkably high level of stability.

2. Results and Discussion

Bias stress stability measurements on a CN-VFET with the structure shown inset in Fig. 2A were recorded in an argon glovebox. A constant gate voltage (V_G) of -8 V and drain voltage (V_D) of -3.86V were applied (source grounded) to the device and the on-state drain current was monitored over a period > 9 months (Fig. 2A). Transfer curves were taken once per hour through 2000hrs then once per day after 2000 hrs. Bi-directional transfer scans were taken to monitor any hysteresis; the voltage was scanned from ON (V_G = -8V) to OFF (V_G = +2V) and back to ON (V_G = -8V) over less than 30 s to minimally affect the bias stress. As seen in the data, negligible shifts in the threshold voltage and on-state drain current density were observed during this period.

The QVGA AMOLET was fabricated on a conventional amorphous silicon switching TFT backplane. Similar to the backplane of a liquid crystal display (LCD), there is only a single TFT—the switching TFT—in each pixel. The CN-VOLET takes care of the light emission and brightness control. A conventional back-channel-passivated amorphous silicon TFT process was used followed by the CN-VOLET process. The latter consisted of three lithographically patterned layers: the gate dielectric layer (a singularly patterned layer stack consisting of silicon nitride, silicon oxide and surface layer), the CNT source layer and the bank layer (Fig. 1A). The CNT source layer was deposited and patterned by conventional methods [3]. After the bank layer, the organic channel and light emitting layers were thermally evaporated through a shadow mask followed by an aluminum CN-VOLET drain electrode deposited in the same manner. The bottom emission, mono-color (green), QVGA AMOLET display has a: 2.5” diagonal, resolution of 320 x 240,

Figure 3. The QVGA AMOLET display in operation.

160um x 160um pixel size, 70% aperture ratio, contrast ratio of 10^5 to 10^6 and brightness of >500 Cd/m2. Fig. 3 shows the QVGA AMOLET in operation.

3. Impact

Given that conventional organic TFTs are generally susceptible to bias stress instability the observation of this remarkable stability in the CN-VFET is an exceptionally important and welcome result. The origin of this stability relative to that of conventional TFTs is thought to result from the vertical architecture which limits the time that injected charge spends in the immediate vicinity of the gate dielectric, where traps present a major source for the instability.

At present, between 4 to 7 additional transistors beyond the 2T+1C AMOLED pixel circuit are used because of the complex compensation methods required to correct for uniformity and stability issues with LTPS and IGZO. With the level of stability demonstrated here in the CN-VFET, combined with the demonstrated QVGA AMOLET display, these devices continue to show high promise to greatly reduce the manufacturing complexity, and associated costs, of AMOLED displays.

4. Acknowledgements

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