

# Novel Amorphous-Si AMOLED Pixels with OLED-independent Turn-on Voltage and Driving Current

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In Active Matrix Organic Light Emitting Diode (AMOLED) displays, a voltage data signal is converted in the pixel to an OLED driving current (and thus brightness) by a FET. Typically p-channel FET's are used, because with conventional "bottom-anode (ITO)" OLED's, only p-channel devices allow the direct programming of the FET gate-source voltage (and thus the driving current) independent of the OLED I-V curve (Fig. 1(a)). This excludes the use of low-cost amorphous-Si (a-Si) TFT technology (as used in AMLCD's) because no p-channel a-Si device exists for fundamental reasons [1] even though a-Si devices can easily provide sufficient current. Thus more expensive poly-Si technology must be used [2]. In this abstract, we present a novel integration approach that allows conventional bottom-anode OLEDs to be integrated with n-channel a-Si TFT's in such a way that programming becomes independent of the OLED I-V curve.

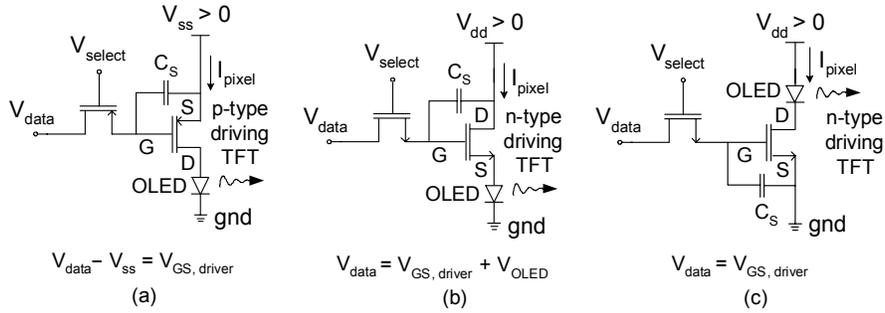
The circuit schematic of a conventional AMOLED pixel with p-channel poly-Si TFT's is shown in Fig. 1(a). The TFT is processed first with temperatures up to 300°C, followed by the OLED anode (patterned ITO, connected to the TFT drain), the organic (blanket) (Fig. 2(a)) and cathode (blanket) (Fig. 2(b)). Because the best OLED's are made with the anode (ITO) deposited first, and because processing (photolithography) of the organic is not feasible, p-channel devices are required for direct programming of the pixel. With the OLED at the drain (not source) of the driving FET, the data voltage appears directly across the gate-source of the driving TFT and therefore the pixel current depends only on the characteristics of the driving FET, independent of the OLED characteristics when the FET is in saturation. If n-channel FET's (such as a-Si TFT's) are used instead with the same integration process (Fig. 1(b)), since the only accessible contact is the anode of the OLED, the OLED will be connected to the source of the driving FET, and therefore the data voltage will be divided across the gate-source of the driving FET and the OLED, based on the TFT and OLED characteristics. This is undesirable because the gate-source voltage of the driving TFT (and thus the driving current) will depend on the OLED characteristics which vary with time and in manufacturing. Also, higher programming voltages will be required for the same gate-source voltages.

To enable the use of a-Si TFT technology with a-Si TFTs as n-channel devices, and achieving an OLED-independent performance, the OLED cathode must be connected to the drain of the driving TFT as shown in Fig. 1(c) which is not possible with the conventional integration process. To achieve this, a new integration technique is required (Fig. 3). In this approach the TFT is processed first as usual, followed by the OLED anode (patterned ITO, connected to the common  $V_{dd}$  line). Next, multi-layer resist is used to form a separator around the anode (ITO) area in such a way that its projection hangs over an interconnect line which is in contact with the drain of the driving TFT. This projection shadow masks the interconnect line when the organic is evaporated in the next step at normal incidence (Fig. 3(a)). A 2-layer TPD/ALQ organic was used for this purpose. Finally the cathode is evaporated at an angle to make a contact to the mentioned interconnect line and thus the drain of the driving TFT (Fig. 3(b)). The experimental output characteristics of the a-Si TFT pixels fabricated with the new process is compared with the conventional process in Fig. 4. As a result of connecting the OLED cathode to the drain of the driving TFT in the new structure, the turn-on voltage is reduced by several volts and the driving current is increased by a 10X factor (Fig. 4(b) with respect to Fig. 4(a)). This is because in the new structure the data voltage is converted directly to the gate-source voltage of the driving TFT, rather than being split between the gate-source of the driving TFT and the OLED. This was confirmed by comparing the experimental data to SPICE modeling (Fig. 4(b)). Active matrices of the inverted pixels have also been realized with QVGA timing (Fig. 5).

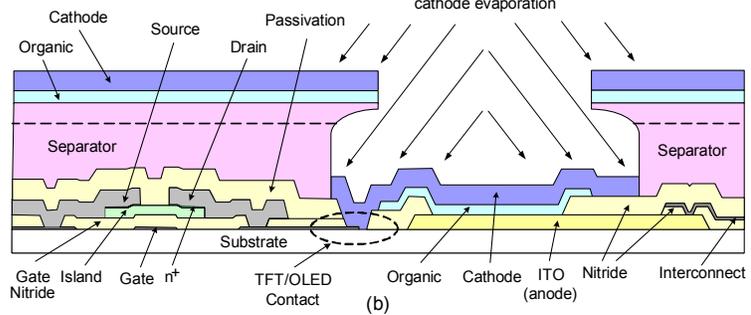
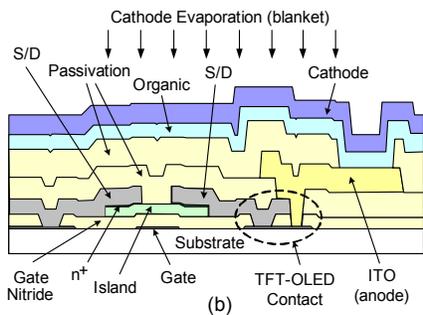
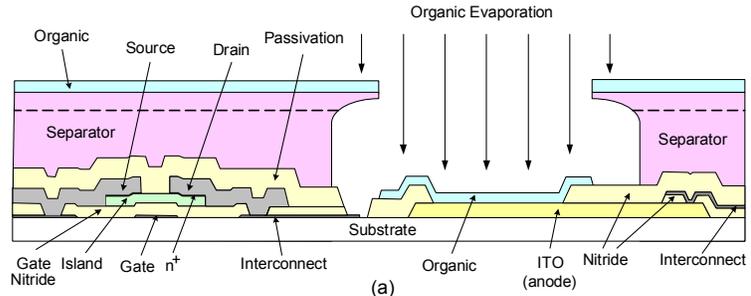
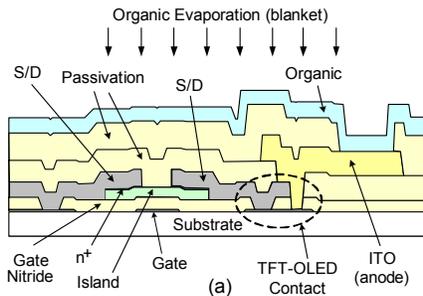
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[1] R. A. Street, *Hydrogenated Amorphous Silicon*, New York: Cambridge University Press, 2005, ch. 10.

[2] J. Lih et. al., *Journal of the Society for Information Display*, v. 12, n. 4, 2004, pp. 367-371

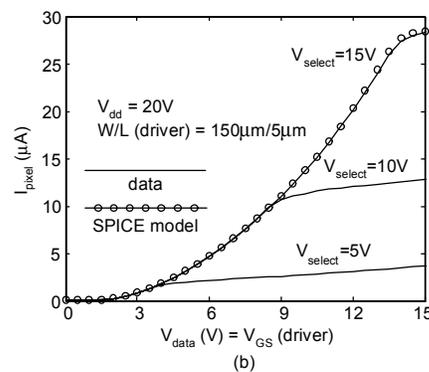
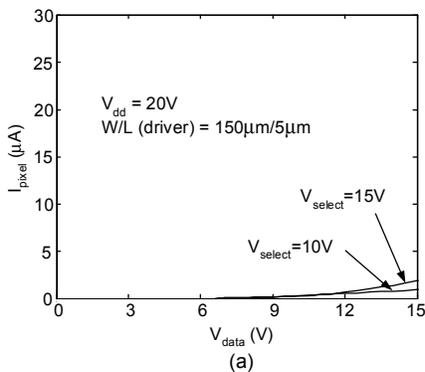


**Fig.1.** Circuit schematic of 2-TFT AMOLED pixels: (a) conventional structure with p-channel TFTs (poly-Si), (b) conventional structure with n-channel TFTs (a-Si) and (c) new “inverted” structure with n-channel TFTs (a-Si). In the p-channel design (a) and the inverted design (b), the data voltage programs the gate-source of the driving TFT directly, but in the design (c), the gate-source voltage of the driving TFT depends on the OLED characteristic. Realizing the inverted design (c) requires a technique for connecting the driving TFT to the OLED bottom contact (cathode).

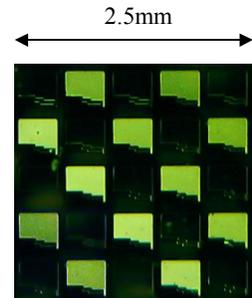


**Fig.2.** Schematic cross-section of the conventional AMOLED structure of Fig. 1(a), or 1(b) after the evaporation of (a) the organic and (b) cathode. The S/D electrode in contact with ITO is the drain for p-channel or the source for n-channel FETs.

**Fig.3.** Schematic cross-section of the inverted AMOLED structure of Fig. 1(c). Photoresist separators are used as shadow masks for evaporation of the organic layers with normal incidence (a) and evaporation of cathode at an angle (b) to form the OLEDs. Note that the drain of the driving TFT is now connected to the OLED top contact (cathode).



**Fig.4.** Experimental output characteristics of (a) a conventional a-Si AMOLED pixel of Fig. 1(b) and (b) an inverted a-Si AMOLED pixel of Fig. 1(c). A 10X improvement in the pixel current and a reduction of the turn-on voltage by several volts can be seen in the inverted pixels. This is because in the conventional design  $V_{data}$  is split between the OLED and the gate-source of the driving TFT, but in the inverted design it is converted directly to the gate-source voltage of the driving TFT.



**Fig.5.** image of active matrix in checkerboard test mode with QVGA timing. The pattern of emission is defined by the ITO area.