AMOLED Reliability with *a*-Si TFT's in Normal vs. Inverted TFT/OLED Integration Scheme

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An important technical issue associated with using a-Si for AMOLED displays is the direct voltage programming of the pixel by providing a constant current source to the OLED. Since only n-channel a-Si TFT's are available, this requires connecting the driver TFT to the OLED cathode rather than the OLED anode which is not conventionally possible without inverting the OLED stack. Previously, we proposed an "inverted" TFT/OLED integration technique for fabricating directly programmable pixels without inverting the OLED stack (so that conventional bottom-emission OLED's may be used) and demonstrated the technique on glass [1]. The circuit schematic and cross-section of the normal and the "inverted" AMOLED pixels are shown in Fig. 1. We showed that the inverted structure (i) lowers the typical pixel operation voltages by several volts and (ii) makes the pixel current independent of the OLED characteristics. This is because in the inverted structure the data voltage is transferred directly across the gate-source of the driver TFT rather than being split across the gate-source of the driver TFT and the OLED. In this abstract we show that (i) the luminance decay vs. time in either normal or inverted pixels may be predicted by measuring the drift in the characteristics of individual TFT and OLED components and (ii) the luminance decay is lower in the inverted structure, because of the lack of dependence on the OLED voltage rise.

The normal and inverted AMOLED pixels and individual test TFT's and OLED's (TPD/Alq_3 organic) were fabricated on clear plastic with a maximum TFT process temperature of 250°C using standard a-Si deposition. To predict the pixel reliability, we first measure the drift of individual test TFT's/OLED's at constant TFT gate voltages/OLED currents (Fig. 2). We assume a power law relation for the TFT threshold voltage shift [2] and a stretched-exponential decay of the OLED quantum efficiency [3]. We then apply the "rates" (time derivatives) of the measured TFT threshold voltage shift (as a function of TFT gate voltage) and OLED voltage rise/luminance drop (as a function of OLED current) to the pixel circuit where the bias conditions vary over time (Fig. 3). The prediction is in good consistency with the experimental data.

The pixel current drop and luminance decay presented in Fig. 3 shows that the inverted pixel has a higher operation lifetime. The reason is that in the normal structure the OLED voltage rise reduces the voltage across the gate-source of the driver TFT and therefore reduces the pixel current/brightness accordingly while the inverted pixel is not affected by the OLED voltage rise. Considering the linear dependence of the threshold voltage shift on the gate-source voltage of the driver TFT and assuming both pixels start operating at the same initial pixel current, $I_{pixel}(0)$, one may show by simple algebra:

$$\frac{I_{pixel,normal}(t)}{I_{pixel,inverted}(t)} = \left(1 - \frac{\Delta V_{OLED}(t)}{\sqrt{I_{pixel}(0)/k}}\right)^2 \qquad \text{where} \quad k = \frac{1}{2}\mu_n C_{SiNx}\left(\frac{W}{L}\right)_{driver}$$

which means the pixel current drops more in the normal pixel compared to the inverted pixel at all times unless the OLED voltage does not increase at all (i.e. unless the OLED is ideal). It is clear that pixel lifetime should improve in both structures by improving the stability of the individual TFT/OLED components, but the above argument remains the same. This shows the benefit of the inverted structure for improving the AMOLED pixel reliability.

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[1] B. Hekmatshoar et. al. *DRC Conf. Dig.* , p. 95, Jun. 07
[2] M. J. Powell et. al. *Phys. Rev. B*, v. 45, n. 8, p. 4160, Feb. 92
[3] W. E. Howard et. al. *IBM J. Res. Dev*. v. 45, p. 1, 2001

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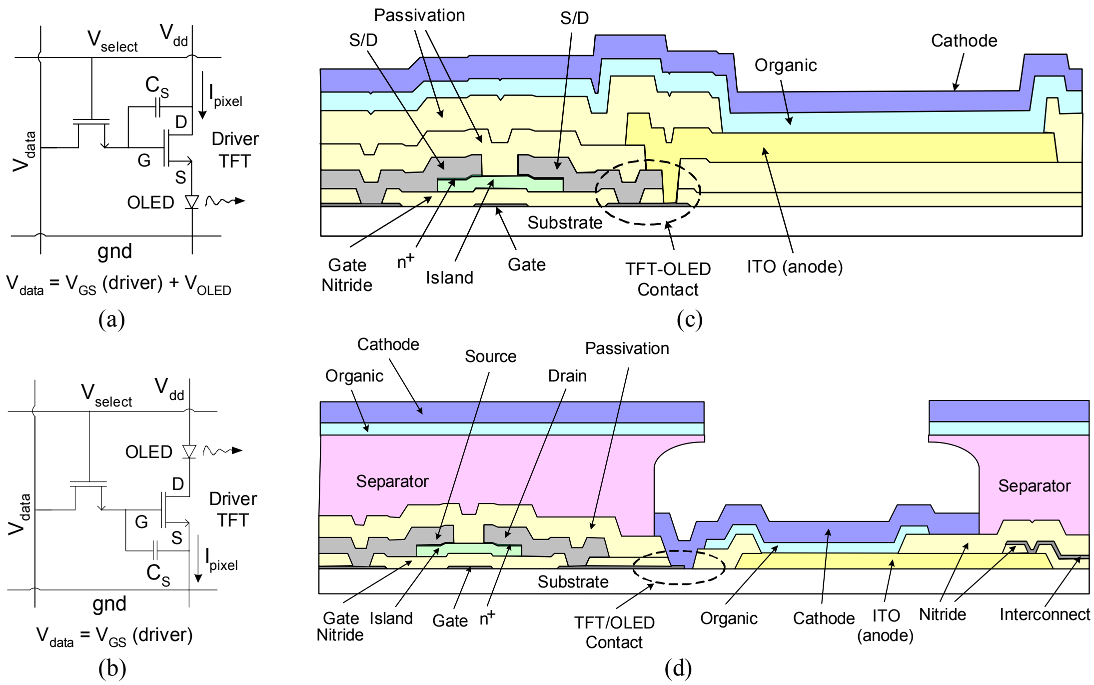
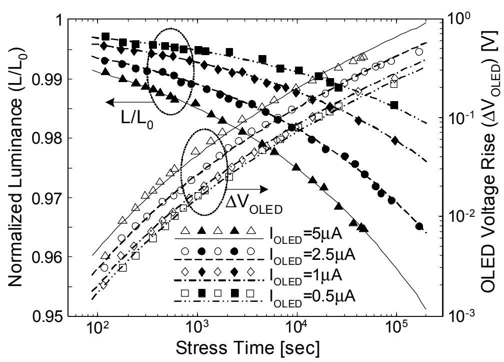


Fig. 1. Schematic circuit structure of a (a) normal and (b) a-Si AMOLED pixel. The cross section of the fabricated pixels is shown in (c) and (d) for the normal and inverted pixels, respectively.



$$\frac{L}{L_0} = \exp[-(t/\tau)^{\alpha}] \quad [2]$$

$$\tau = C(I_{OLED})^{\delta}$$

$$\Delta V_{OLED} = B(I_{OLED})^{\gamma}(\log t)^{\lambda}$$

$$\begin{cases} \alpha = 0.28 \\ C = 0.1\ \text{sec}(\mu\text{A})^{-\delta} \\ \delta = -2.0 \\ B = 16\ \text{mV}(\mu\text{A})^{-\gamma}[\log(\text{sec})]^{-\lambda} \\ \gamma = 0.33 \\ \lambda = 0.65 \end{cases}$$

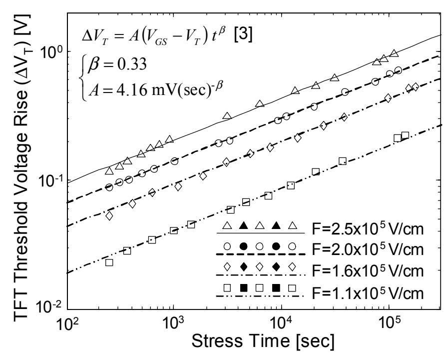
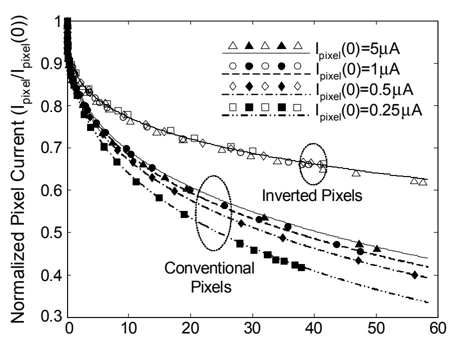


Fig. 2. Extraction of the individual TFT and OLED drifts. The OLED's are stressed at constant current densities and the TFT's at constant gate field (F = V_{GS}/t_{SiNx}, nitride thickness = 300nm) for predicting the pixel reliability (Fig. 3).



$$\frac{d(L/L_0)}{dt} = -\alpha\tau^{-\alpha}t^{\alpha-1}\exp[-(t/\tau)^{\alpha}]$$

$$\tau = C\left(I_{OLED}\right)^{\delta}$$

$$\frac{d\Delta V_{OLED}}{dt} = B(I_{OLED})^{\gamma}(\log e)\,t^{-1}(\log t)^{\lambda-1}$$

$$\frac{dV_T}{dt} = A\beta(V_{GS}-V_T)t^{\beta-1}$$

$$I_{OLED} = I_{pixel} = I_{TFT,\,driver}$$

$$I_{TFT,\,driver} = \frac{1}{2}\mu_n C_{SiNx}\frac{W}{L}(V_{GS}-V_T)^2$$

$$\begin{cases} V_T(0) = 2.5\text{V},\ \mu_n = 0.65\ \text{cm}^2/\text{Vs} \\ W/L = 30,\ C_{SiNx} = 2\times10^4\ \text{pF}/(\mu\text{m})^2 \end{cases}$$

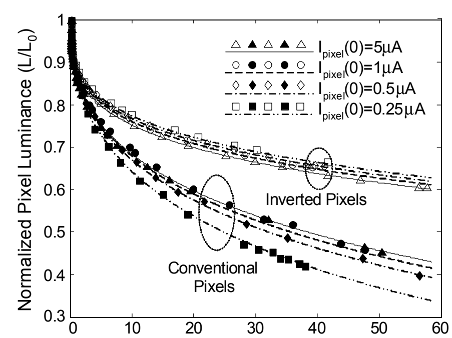


Fig. 3. Plots of the normalized pixel current drop and luminance decay for the normal and inverted pixels (symbols: data points, lines: predictions). The brightness decay is lower in the inverted pixels resulting in a higher pixel lifetime. The predictions are made by finding simultaneous solutions to the given set of differential equations (TFT/OLED decay rates). The fitting parameters are extracted by measuring TFT's and OLED's under constant DC stress (Fig. 2).