Novel Pixel Electrode Circuits and a-Si:H TFT Structures for AM-OLEDs

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ABSTRACT

We report on two novel pixel electrode circuits and a-Si:H TFT structures for top light-emitting AM-OLEDs. In the proposed current-driven pixel circuit, a high data-to-OLED current ratio can be achieved without increasing the a-Si:H TFT size in contrast to the conventional current-mirror pixel circuit, and also shows enhanced current-scaling function with the reduced number of signal lines. The proposed voltage-driven pixel circuit is composed of five a-Si:H TFTs, but does not require any complicated drive ICs. The compensation of the OLED current variation with the threshold voltage shift of driving a-Si:H TFT for both pixel circuits have been verified by SPICE simulations. Different a-Si:H TFT structures are also suggested to improve electrical stability of driving TFTs in AM-OLEDs.

1. INTRODUCTION

Recently amorphous silicon technology has drawn much attention as a possible candidate for active-matrix organic light-emitting display (AM-OLEDs) thanks to its maturity from 20 years of AM-LCD development. However, the amorphous silicon thin-film transistor (a-Si:H TFT) has a long term electrical stability problem associated with the threshold voltage shift due to gate bias stress, resulting in non uniform picture quality of AM-OLED [1]. To overcome threshold voltage (V_{TH}) shift, several solutions have been proposed based on either voltage-driven [2 - 4] or current- driven pixel circuits [5 - 7].

In this paper, we present two types of new pixel circuits capable of reducing the effect of V_{TH} shift (ΔV_{TH}) to enhance the AM-OLED electrical reliability. First a new voltage-driven circuit was proposed [8] to provide a full compensation for V_{TH} shift without developing complicated driver ICs. An improved current-driven pixel electrode circuit was also proposed [9] with an enhanced current scaling function. A current mirror circuit with a cascaded storage capacitor proposed here will allow to achieve a high data-to-OLED current ratio without increasing TFT size in comparison with the conventional current mirror pixel circuit. At the same time, by removing one control signal line, this circuit has a much simpler pixel circuit layout and driving scheme than the previous cascade capacitor pixel electrode circuit [7]. Finally, novel a-Si:H TFT structures were introduced for improving the stability of driving TFTs [13].

2. EXPERIMENTS AND RESULTS

2.1 Voltage-Driven Pixel Electrode Circuit

In the voltage-driven pixel circuit [8], we maintain constant OLED current regardless of drive TFT threshold voltage shift by compensating its gate node voltage. The schematic diagram of the proposed pixel circuit is shown in Figure 1. The pixel circuit is composed of a power line, 2 control lines, 2 capacitors and 5 TFTs; 2 switch TFTs (SW1, SW2), a precharge TFT (PC), a drive TFT (DR) and a mirror TFT (MR). The pixel circuit operates in 4 states; precharge, compensate, restore and drive. During the precharge state, previous gate2 (Gate2[n-1]) is high (*VGH*), which turns on the precharge TFT (PC). The precharge TFT has its drain and gate node connected, which act as a diode with turn-on voltage same as the TFT's

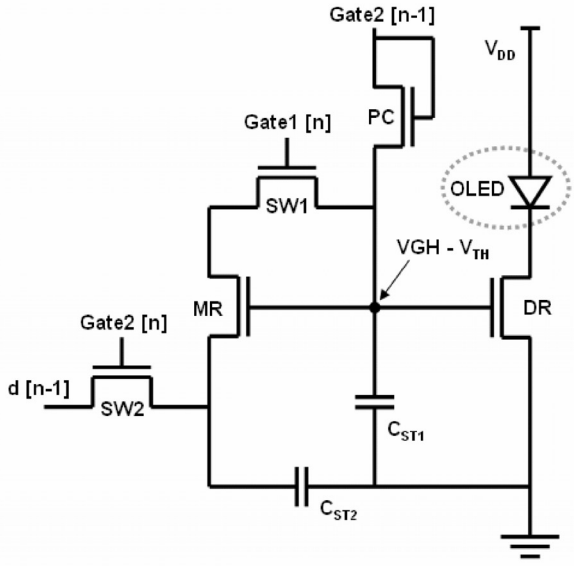

Figure 1 Schematic diagram of proposed voltage-driven pixel circuit [8].

threshold voltage (*Vto=Vth*). Since this diode is forward biased, the gate node of drive TFT (DR) is *precharged* to the gate high voltage minus the TFT's threshold voltage (*VGH-Vth*) and stored in the first storage capacitor (Cst1). During the compensate state, previous gate2 is turned off, whereas gate1 (Gate1[n]) and gate2 (Gate2[n]) are turned on, and the data signal (D[n]) voltage *Vd* is applied to the source node of the mirror TFT (MR). The first switch TFT (SW1) connects the gate and drain of mirror TFT to form a diode with turn-on voltage equal to the TFT's threshold voltage (*Vto=Vth*). Since *VGH-Vth* was precharged in C_{ST1} during precharge state, and this voltage is higher than *Vd*, MR diode is forward biased. The gate node voltage of DR (or the anode voltage of MR) is decreased as Cst1 is discharged by MR diode, which will converge to the data voltage plus the turn-on voltage of MR diode (*Vd+Vth*).

Assuming that the threshold voltage of MR and DR is identical ($Vth_{DR}=Vth_{MR}$), the voltage value now stored in Cst1 will *compensate* the OLED current by canceling out the threshold voltage of DR, as shown in the following equations.

$$I_{OLED} = \frac{k}{2}(Vgs - Vth_{DR})^2, Vgs = Vd + Vth_{MR}$$

$$I_{OLED} = \frac{k}{2}(Vd + Vth_{MR} - Vth_{DR})^2 = \frac{k}{2}Vd^2$$

During the restore state, gate1 signal is turned off, whereas gate2 is still on, and the data signal voltage is 0V (*Gnd*). While the gate voltage of DR and MR is held at *Vd+Vth*, the source voltage of MR is decreased from *Vd* to *Gnd*, and restored in the second storage capacitor (Cst2). Our recent studies convey that when the gate-to-source voltage of both DR and MR is identical, the amount of threshold voltage shift due to gate bias stress should also be identical. This corresponds to the previous assumption that the threshold voltage of DR and MR is the same. During drive state, gate2 signal is finally turned off, and DR *drives* the compensated OLED current. SPICE simulation results verify that the proposed pixel circuit compensates the OLED current reduction induced by TFT threshold voltage shift up to 5V, resulting in maximum OLED current reduction (= $\Delta I_{OLED}/ I_{OLED}$ [%] = $4\Delta Vth/(Vgs-Vth)$) of less than 14%, as shown in Figure 2.

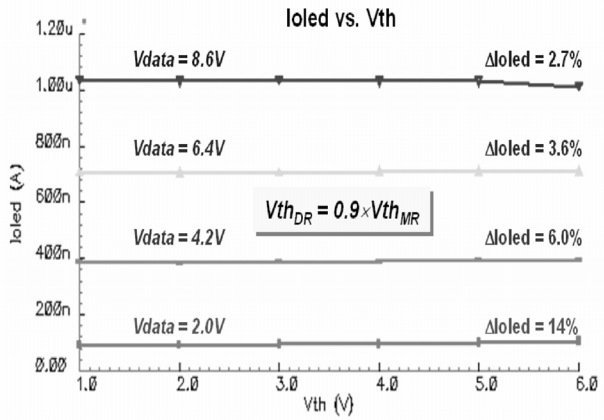

Figure 2 I_{OLED} reduction as function of TFT's Vth shift.

2.2 Current-Driven Pixel Electrode Circuit

The proposed current-driven pixel electrode circuit [9] consists of two switching TFTs (T1 and T2), one mirror TFT (T4), one driving TFT (T3), and two storage capacitors (C_{ST1}, C_{ST2}) connected between a scan line and ground with a cascade structure, Figure 3.

The pixel circuit operation mechanism can be described as follow: During the ON-state, V_{SCAN} turns on the T1 and T2, and I_{DATA} (=$I_{OLED-ON}$) passes through T1 and T4 shown as the solid line in Fig. 4, and sets up the voltage at T2 drain electrode (node V_A). At the same time, the voltage at T4 gate electrode (node V_B) is set by I_{DATA} passing through T4. Since I_{DATA} is current source, the gate voltage of T4 is automatically set high enough to allow the fixed I_{DATA} flowing through T1 and T4. In the pixel simulation, since the current-scaling is not controlled by the geometry ratio of the transistors, T3 and T4 are designed as having the same geometries. Since in the ideal case T3 and T4 are assumed identical and the gate bias (V_{B_ON}) is common to both TFTs, the same amount of current (I_{DATA}) is expected to flow through OLED to T3 by V_{DD}. The V_{B_ON} will be stored in both C_{ST1} and C_{ST2}, and the voltage across C_{ST2} is V_{SCAN} - V_{B_ON}. When the pixel changes from the ON- to OFF-state, V_{SCAN} turns off T1 and T2. Because C_{ST2} is connected between the scan line and the node B to form a cascade structure with C_{ST1}, the change of V_{SCAN} will reduce V_{B_ON} to V_{B_OFF} due to the feed-through effect of the capacitors. V_{B_OFF} can be derived from the charge conservation theory as $V_{B\_OFF} = V_{B\_ON} - \Delta V_{SCAN} \cdot C_{ST2} / (C_{ST1}+C_{ST2})$.

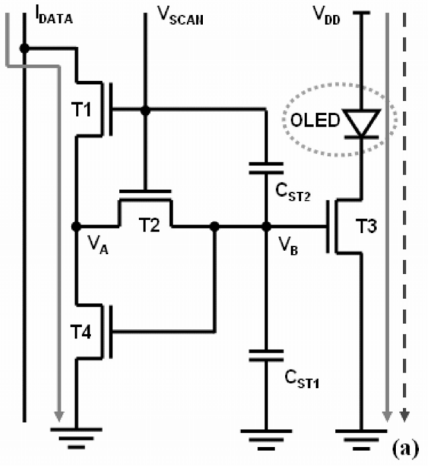

Figure 3 Schematic diagram of proposed current-driven pixel circuit [9].

A reduced T3 gate voltage (V_{B_OFF}) will be held in C_{ST1} and C_{ST2} and it will continuously turn on T3 during the OFF-state. Since gate bias of T3 (V_{B_ON}) is reduced to V_{B_OFF} by the ratio of cascaded capacitor, a scaled-down data current (I_{OLED_OFF}) from I_{OLED_ON} by ratio of C_{ST2}/C_{ST1} will flow through OLED, shown as the dashed line in Figure 4. Consequently, when a very large data current (I_{DATA}) can be used to charge the pixel electrode to shorten the pixel programming time, a smaller driving current (I_{OLED_OFF}) can be achieved for lower gray scales at the same time. To investigate the current scaling ratio of the proposed pixel electrode circuit, we changed the I_{DATA} from 0.2 to 5 μA and measured the corresponding I_{OLED_ON} and I_{OLED_OFF} flowing through the diode for different ratios of cascaded-capacitors. In ON-state, the I_{OLED_ON} is identical to the data current (I_{DATA}), Figure 4. When the pixel circuit operates in OFF-state, the diode current (I_{OLED_OFF}) is scaled-down by the ratio of cascade capacitor as discussed above. From Figure 4, it is obvious that the larger C_{ST2}/C_{ST1} results in significant decrease of the I_{OLED_OFF} at lower I_{DATA}. In the proposed pixel circuit, since $I_{OLED\text{-}ON}$ is not affected by the threshold voltage variation, the variation of $I_{OLED\text{-}OFF}$ with ΔV_{TH} is used to estimate its influence on the performance of pixel circuit. For

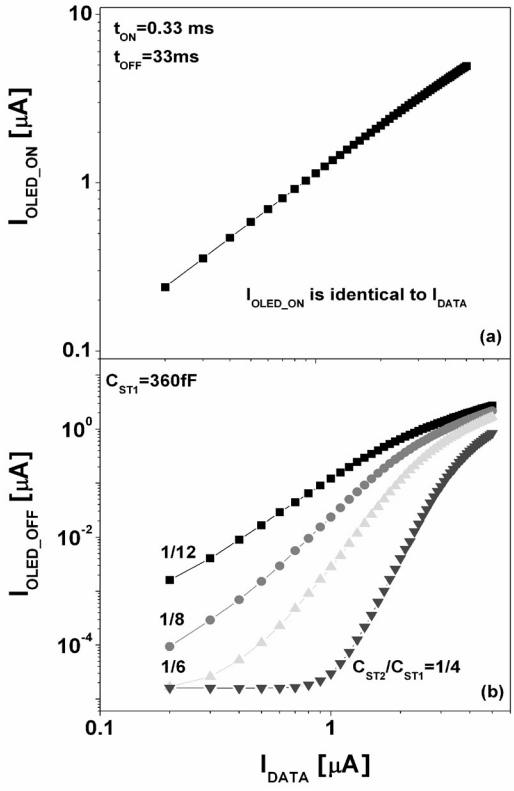

Figure 4 Variation of the simulated I_{OLED_ON}, I_{OLED_OFF}, and I_{AVE} as a function of I_{DATA} for various C_{ST2}/C_{ST1} ratios.

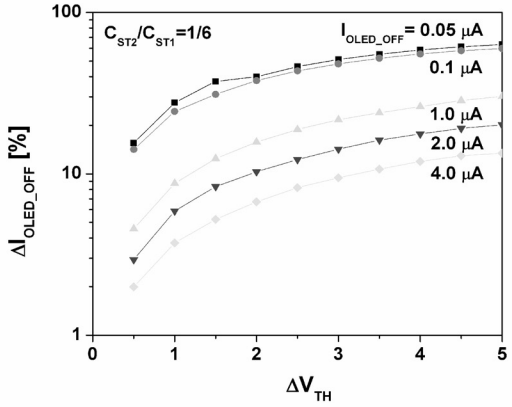

Figure 5 Variation of ΔI_{OLED_OFF} as a function of TFT threshold voltage shift.

given C_{ST2}/C_{ST1}, the variation of the $I_{OLED\text{-}OFF}$ with the ΔV_{TH} can be defined by,

The variation of $I_{OLED\text{-}OFF}$ as a function of the ΔV_{TH} is

$$\Delta I_{OLED-OFF} = \frac{I_{OLED-OFF}(\Delta V_{TH}) - I_{OLED-OFF}(\Delta V_{TH}=0)}{I_{OLED-OFF}(\Delta V_{TH}=0)}$$

shown in Figure 5. It should be noted that this $\Delta I_{OLED\text{-}OFF}$ increase corresponds to overall reduction of $I_{OLED\text{-}OFF}$ with the increase of ΔV_{TH}. As ΔV_{TH} increases up to 5V, $\Delta I_{OLED\text{-}OFF}$ also increases from 4 to 25% when $I_{OLED\text{-}OFF}$ is higher than 1.0μA; a larger increase of $\Delta I_{OLED\text{-}OFF}$ is observed when $I_{OLED\text{-}OFF}$ is lower than 100nA. From our data, we can conclude that a large C_{ST2}/C_{ST1} can achieve a high R_{SCALE} but will also result in a large $\Delta I_{OLED\text{-}OFF}$.

2.3 Driving a-Si:H TFT Structures

As discussed above, the pixel circuit performance is very sensitive to V_{TH} variation of driving a-Si:H TFTs. Therefore, suppressing device V_{TH} variation is the key to the future success of AM-OLEDs. Since a-Si:H TFT V_{TH} variation is mainly originated from a high gate bias [10] to supply a high OLED current, it is possible to reduce the gate bias level by using TFTs with larger channel width. However, due to reduction of pixel electrode aperture ratio, conventional TFT structure can not be enlarged enough to provide adequate level of OLED current. Alternatively, an interdigitated or fork-shaped TFT with a large channel width has been proposed for AM-OLEDs [11], Figure 6. However, it is known that a single transistor with a larger channel width results in a larger TFT threshold voltage shift in comparison with the normal (switching type) TFT [12], which was also experimentally verified in our laboratory. To address this critical problem, we propose, for example, Corbino a-Si:H TFT as driving device for AM-OLEDs [13], Figure 7. The Corbino a-Si:H TFT is composed of circle-shape inner electrode and ring-shaped

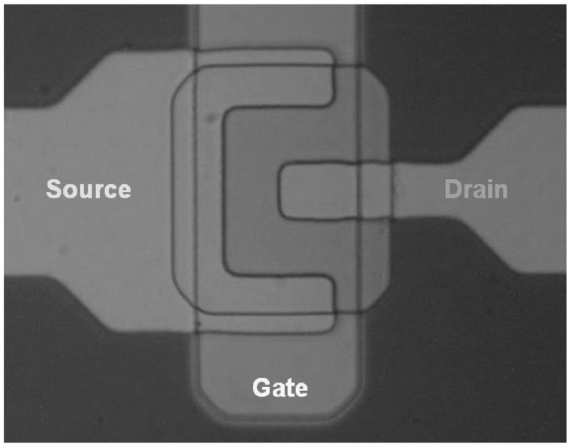

Figure 6 Top view of Fork a-Si:H TFT.

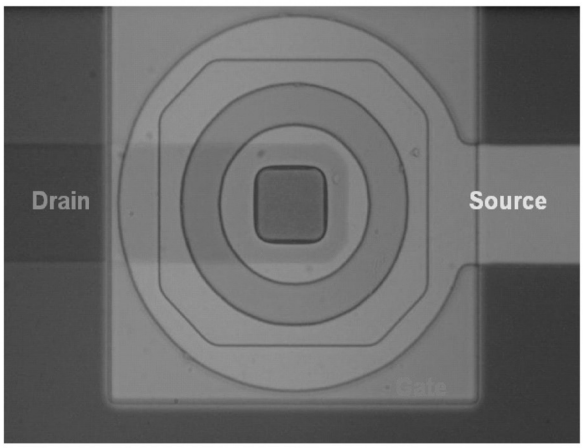

Figure 7 Top view of Corbino a-Si:H TFT.

outer electrode. Since the ring-shaped electrode provides a uniform electric field distribution in the channel and eliminates any local electric-field crowding due to sharp corners present in normal TFT, Corbino TFT shows better electrical stability even for larger W/L ratio in comparison to normal TFTs. Therefore, Corbino a-Si:H TFT is a good candidate to be used as a driving TFT for top light-emitting anode AM-OLEDs. Figure 8 shows an example of pixel circuit including driving Corbino a-Si:H TFT.

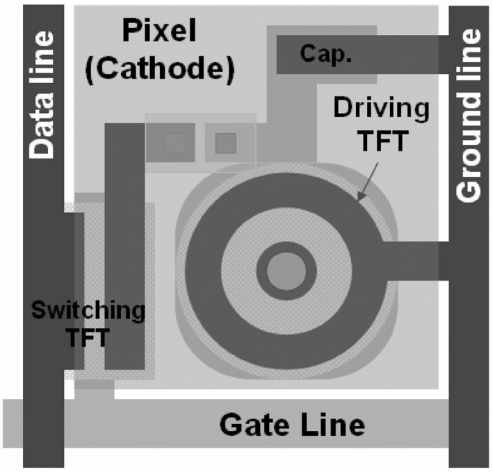

Figure 8 Top view of Corbino a-Si:H TFT for AM-OLED.

3. CONCLUSION

We described new a-Si:H TFT pixel circuits suitable for enhancing the electrical reliability of AM-OLED. Proposed pixel circuits are composed of a-Si:H TFTs and top-anode OLED structure. By using SPICE simulations, we verified that the voltage-driven circuit does not require any complicated drive ICs to compensate for OLED current reduction due to the TFT threshold voltage shift. In the current-driven circuit, by employing the cascaded capacitors connected to the driving TFT, we produce better non-linear scaling-function than the cascade capacitor circuit, which has a high scaling ratio at low current levels and a low scaling ratio at high current levels. Further more, by using novel Corbino a-Si:H TFTs as a driving TFT, the pixel electrode circuit electrical stability is further enhanced, which relax stability demands on pixel circuits. The pixel design value [$\mu\epsilon_{OX}W/(2t_{OX}L)$] must be very carefully chosen to satisfy both spatial and temporal reliability requirements of the AM-OLEDs.

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