

# A Self-compensated Voltage Programming Pixel Structure for Active-Matrix Organic Light Emitting Diodes

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## ABSTRACT

We propose a new pixel structure for voltage programming Active Matrix OLED (AMOLED). The proposed pixel structure can display full color images by compensating threshold voltage ( $V_{th}$ ) variation of driving TFTs. It also solves the mismatch problem of TFT characteristics in the same pixel, which can make display degradation. In this paper, we describe the operating principle and characteristics of the pixel structure. And we verify that it is possible to realize good image quality with proposed pixel structure by HSPICE simulation and implemented 2.2" QCIF panel using LTPS (Low Temperature Poly-Si) process.

## 1. Introduction

Liquid-crystal display(LCD) is currently the dominant flat-panel display(FPD) technology because of its portability, low power consumption and mature manufacturing technology. But LCD needs back-light and it is difficult to realize fast moving video images due to slow response time of liquid crystal. To overcome above limitations, organic light-emitting diodes (OLED) for FPD applications has been studied. OLED is a monolithic and semi-conductive device that emits light when current is flown to it. It has various advantages such as simple structure, fast response time, emissive nature and wide viewing angle.

There are two kinds of pixel addressing method for OLED. One is passive matrix addressing method and the other is active matrix addressing method. In case of active matrix OLED

(AMOLED) display, because light is emitted during frame time, emission current is lower than that of passive matrix OLED[1] so that large size, high resolution AMOLED display can be realized. However, it still has non-uniformity problems of display images because of the threshold voltage and mobility variations of poly-Si TFTs among pixels.

Recently, AMOLED displays demonstrated with several solutions to obtain uniform images, such as  $V_{th}$  compensated voltage programming methods [2-5], current programming methods [6,7] and digital driving methods [8-10]. Even though the current programming method can compensate almost all non-uniformity factors of AMOLED display, slow charging speed of this method makes it difficult to be applied for large size and gray scale panels. Digital driving method can reduce the threshold voltage sensitivity of displayed images, but it needs very fast addressing speed so that may not be the good solution for high resolution and large size panels. The voltage programming method, reported by Dawson et al. [2], can compensate the threshold voltage variation of TFTs. But this structure requires two pixel capacitors and three control signal lines with complex control signals for driving. Our previous work about voltage programming method suggested another compensating method [3]. However, it is encountered to the mismatch problem between driving TFT and compensating TFT in the same pixel. Therefore, we couldn't achieve enough compensating ability for the threshold voltage

variation. And these drawback must also be considered for other modified structures[4,5].

So, we propose a new voltage programming AMOLED pixel structure that can compensate  $V_{th}$  variations of poly-Si TFTs by itself with simple driving method, and without additional mirror-type compensating TFTs.

## 2. Proposed pixel structure

Figure 1 shows the proposed pixel structure of AMOLED having 6 TFTs, 1 capacitor and 2 horizontal control lines. M2, M3, M4, M5 and M6 are switching TFTs, and M1 is driving TFT, which supplies emission current to OLED during a frame time. M4 makes discharging path to initialize the gate voltage of driving TFT, M1. C1 is a storage capacitor, which stores gate voltage of M1. As you see in Figure 2, it needs two row line time to complete data programming operation. So we apply not only 'scan[n]' (current

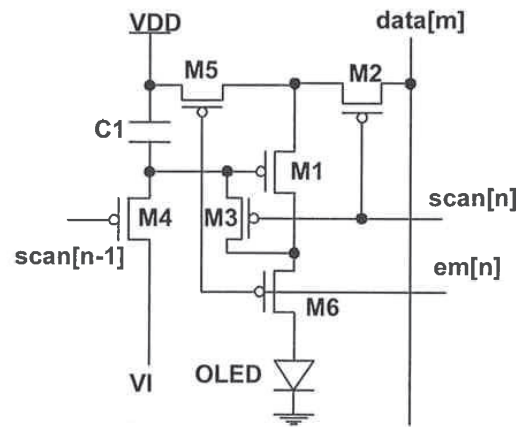


Figure 1. Proposed pixel structure.

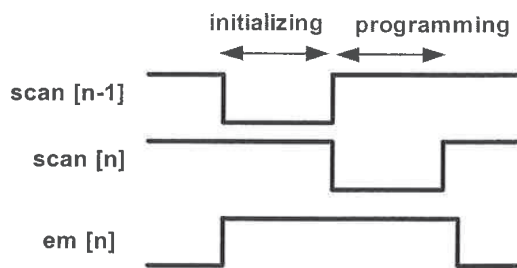


Figure 2. Timing diagram of proposed structure.

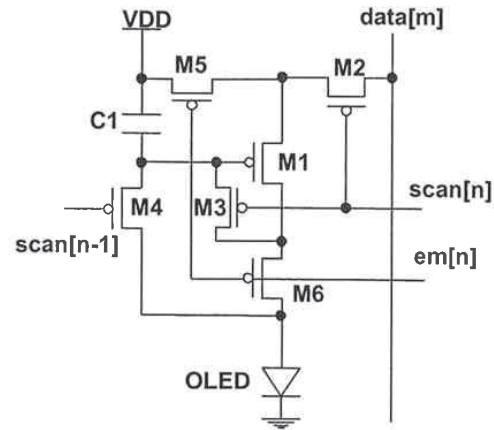


Figure 3. Modified example A of proposed pixel structure.

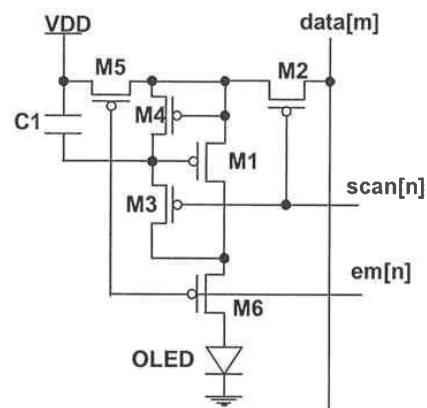


Figure 4. Modified example B of proposed pixel structure.

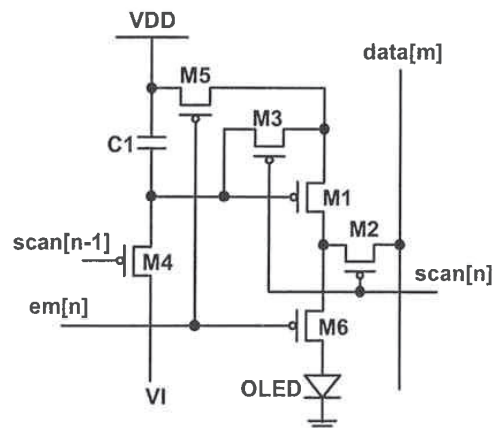


Figure 5. Modified example C of proposed pixel structure.

row scan signal), but also 'scan[n-1]' (previous row scan signal) to program one pixel. During previous scan line time (when 'scan[n-1]' signal is logic low), the gate voltage of M1 is discharged down to V<sub>L</sub>. And during current scan line time (when 'scan[n]' signal is logic low), M2 and M3 are turned on so that data voltage is programmed to the gate node of M1 through diode connected M1. At that time, the programmed data voltage is automatically reduced to 'V<sub>data[m]</sub> - V<sub>th,M1</sub>', V<sub>data[m]</sub> and V<sub>th,M1</sub> are programmed data voltage and threshold voltage of M1, respectively. After two line time, previous and current one, M5 and M6 are turned on by em[n] signal, then OLED emission current of programmed data, which is independent on the threshold voltage of M1, flows through M5, M1, and M6, as shown in equation (1).

$$I_{OLED} = \frac{\beta}{2} (|V_{GS,M1} - V_{th,M1}|)^2 = \frac{\beta}{2} ((VDD - (V_{DATA} - V_{th,M1})) - V_{th,M1})^2 = \frac{\beta}{2} (VDD - V_{DATA})^2 \quad (1)$$

The gate voltage of M1 already contains the information of its threshold voltage. Therefore, the threshold voltage mismatch of TFTs in the same pixel is no more our considerations. Figure 3 and figure 4 shows modified structure of figure 1. Each one takes a different method to initialize the gate voltage of M1. Modified example A structure, as shown in figure 3, discharges C1 through OLED when M4 is turned on. Modified example B structure, as shown in figure 4, discharges C1 through data line, when M2 is

turned on and data voltage is fallen down to the level that is enough to make M4 turned on. By means of using modified structure, higher aperture ratio can be obtained. Especially for modified example B, only one scan signal(scan[n]) is needed for driving, by replacing M5 and M6 to n-channel TFTs. Figure 5 shows another modified structure which make diode connected M1 by M3 placed above M1. This configuration can reduce light leak due to the leakage current of M3 and M4.

### 3. Simulation results

We verified the performance of proposed pixel structure by using HSPICE simulation. As simulation results, when the variation of V<sub>th</sub> in the same pixel is 0.1 V, the variation of display gray level is over 28 gray level of 8bit gray scale in case of conventional structure [3]. But proposed pixel structure is free from that problem. When the threshold voltage variations, row line time and peak OLED current are  $\pm 0.5$  V, 30  $\mu$ sec (for VGA resolution) and 2.5  $\mu$ A, respectively, we can observe that the variation of emission current is under 9 nA, 0.9 gray level of 8bit gray scale. Detailed simulation results for several conditions of threshold voltage fluctuation are handled by another paper of this conference [11]. Those results show that the threshold voltage variation among pixel TFTs is properly compensated.

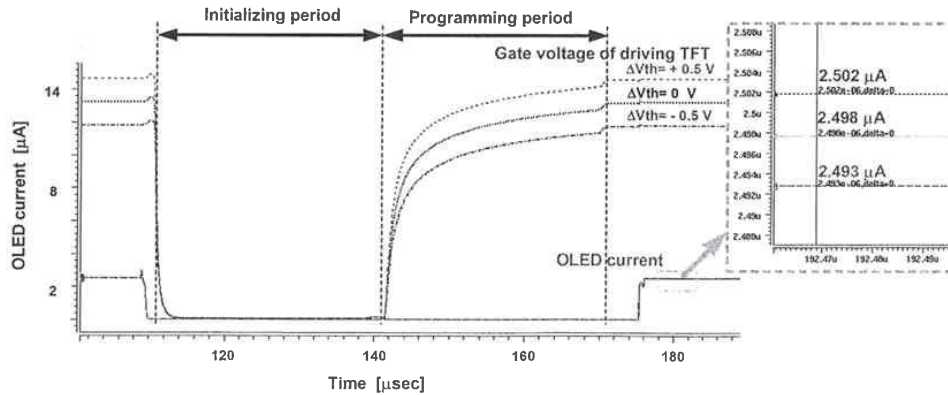


Figure 6. HSPICE simulation waveforms when I<sub>OLED</sub> is maximum value.

#### 4. Experimental results

We verify the proposed pixel structure by panel implementation with LTPS TFT process. And this experiment shows that the compensating performance of proposed structure makes it possible to implement 6bit gray scale with LTPS AMOLED panel. Figure 6 shows the photograph of 2.2" QCIF AMOLED panel and table 1 shows panel specifications.

#### 5. Conclusions

We propose the new pixel structure and its several modifications for voltage programmed AMOLED display, which is composed of six TFTs and one capacitor. With proposed structure, we can implement enhanced good display images, compared with previously reported structures. It



Figure 7. Panel demonstration.

Table 1. Panel specification.

|                   |                                   |
|-------------------|-----------------------------------|
| Panel size        | 2.2-inch                          |
| Resolution        | QCIF(176XRGBX220)                 |
| (Sub)Pixel pitch  | 66 x 198 mm <sup>2</sup> (128ppi) |
| Scan driver       | Integrated                        |
| Peak luminescence | > 100 Cd/m2                       |

is enough to display 6bit gray scale and may be possible to implement 8bit gray scale according to simulation results. By means of our research, it is able to realize uniform AMOLED display which is based on LTPS TFT process and driven by simple driving method.

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