유기박막트랜지스터(OTFT)를 이용한 AMOLED 픽셀 보상회로 연구

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A New Organic Thin-Film Transistor based Current-driving Pixel Circuit for Active-Matrix Organic Light-Emitting Displays

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Abstract - A new current-driving pixel circuit for active-matrix organic light-emitting diodes (AMOLEDs), composed of four organic thin-film transistors (OTFTs) and one capacitor, is proposed using a current scaling method. Designing pixel circuits with OTFTs has many problems due to the instability of the OTFT parameters with still unknown characteristics of the material. Despite the problems in using OTFTs to drive the pixel circuit, our work could be set as a goal for future OTFT development. The simulation results show enhanced linearity between input data and OLED luminescence at low current levels as well as successfully compensating the variation of the OTFTs, such as the threshold voltage and mobility.

1. Introduction

Organic thin-film transistors (OTFTs) have gained much attention due to the low temperature process and low cost manufacturing, which allow the use of large-area, lightweight, and flexible plastic substrates. Also, the integration of OTFTs with OLEDs can lead to an all-organic display which would have the possibility of realizing low cost electronics for large area applications. Since organic light-emitting displays are current driven devices, stable output current is needed for uniform luminescence. However, the unstable characteristics of the OTFT such as large threshold voltage variation(ΔVth) and large sizes(W/L) cause unstable current flow, hence resulting in non-uniform brightness of OLED. In order to guarantee reliable output current, pixel compensation circuits, making the large variation of OTFTs less sensitive to the circuit, is essential in Active-Matrix OLED displays. In this work, we have made some progress in driving AMOLED displays less sensitive to the highly unstable OTFT characteristics, using four transistors and one capacitor. This will be set as basic studies on using OTFTs in AMOLED displays with some problems and its solution mentioned. The results are based on the current state-of-the-art performance OTFTs to drive the elements in OLED displays. With further improvements to be made on OTFT devices, we can expect the performance and design margins to be improved. This work could be both set as a goal and as basic research information for future OTFT development.

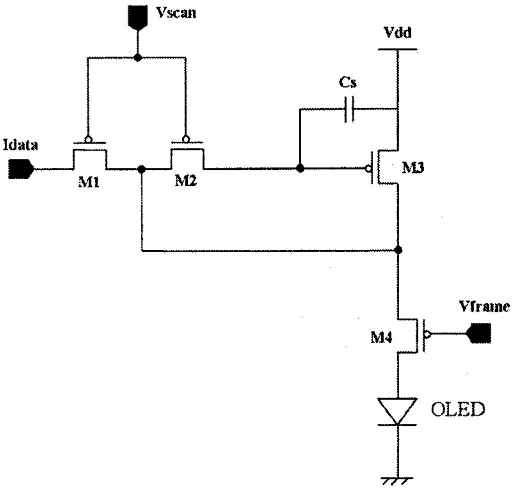
2. Subject

2.1 Modelling of OTFT and OLED

OTFT model parameters were extracted based on the state-of-the-art performance values for pentacene on glass substrates. Since pentacene thin-film transistors are p-type transistors, the applied value of hole mobility was 0.5 cm^{2}V^{-1}s^{-1}. While hole mobility for pentacene TFTs higher than 1 cm^{2}V^{-1}s^{-1} has been reported[1], we have selected a lower value for a more conventional reasons. The threshold voltage of -2.5 V with maximum drift velocity of 5.0×10^4 ms^{-1} was reasonable. The I_{ON} / I_{OFF} ratio of 10^7 and dielectric thickness of 200 nm was based on former literature. Also, the gate-drain and gate-source overlap capacitance was selected to 87.3pF, respectively. The mobility modulation coefficient of -0.007 V^{-1} was selected considering the short channel effects. For HSPICE simulations we have used the level 3 MOSFET model.

For OLEDs, among the various equivalent circuit models[5,6,7], we have selected a parallel connected capacitor to an NMOS transistor model for simulation. The OLED parameters were obtained by fitting experimental work based on recent literature[2]. The parameters are typical for an OLED with area of 150×150 um with organic layer thickness of 80 nm. The scanning time for QVGA(320×240) resolution with frame rate of 60 Hz is around 50 us. A typical value for the external quantum efficiency, η, is 1 % where the current density for a luminance of 100 cd/m^2 is about 20 mA/cm^2 for red and blue OLEDs[1]. Therefore, the maximum current is formed below 10 uA for an OLED with an area of 225×225 um. Finally, considering the size of the pixel, the capacitance(C0) of the OLED was calculated to be larger than 2.5 pF. Therefore, we have used a value of 3 pF for reliability with a power supply of 25 V.

2.2 Proposed pixel circuit using OTFTs



<Fig. 1> Schematic of proposed pixel circuit using OTFTs

Here we propose a new current programmed pixel circuit based on the conventional circuit presented by Hattori et al. [3]. As can bee seen in Fig. 1, the circuit is designed by aligning the two switching transistors together to reduce voltage instability of the gate of driving transistor M3. Also, an improvement of the linearity between input current and luminescence at low current levels (2 uA~8 uA) is obtained. Finally, compensation of the threshold voltage shift(ΔVth) of the TFTs were improved compared to the conventional structure. We also figured out that by aligning the two transistors the whole pixel application become less sensitive to the sizes(W/L) of transistors.

Direct application of OTFTs to conventional circuits has many problems since the operation of pixel circuits depend largely on the width/length, threshold voltage, and mobility of OTFTs. Also, the storage capacitance is influenced by these parameters, so it is important to figure out the charging time considering the parameter values. Optimization is a difficult process because the activation of the pixel circuit is highly sensitive to these parameters. Finally, the interaction between the sizes of the OTFT influence the output OLED current significantly. The optimization results for the simulation are listed in Table 1.

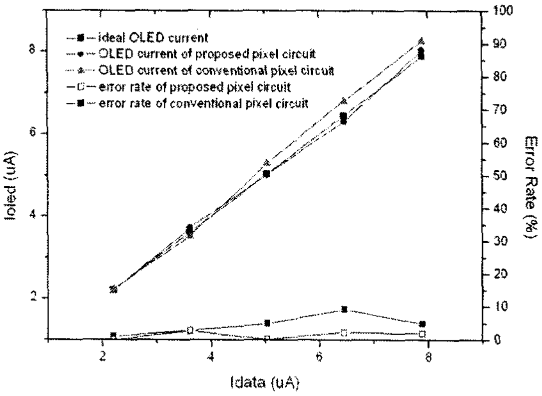
<Table 1> Optimized parameters used for the proposed pixel circuit

Device	Value	Role
M1	W/L=150um/5um	Switching Transistor
M2	W/L=7um/5um	Switching Transistor
M3	W/L=575um/5um	Driving Transistor
M4	W/L=100um/5um	Switching Transistor
Cs	5 pF	Storage Capacitor

The operating principle of proposed pixel circuit is the programming of driving transistor M3 by input current(Idata). This current is supplied from the source driver circuit outside the pixel. Since the sizes of the OTFTs are as large as 500um/5um, the transistors act as a capacitor when input pulses are applied and hence, capacitive coupling is dominated during the operation. When the driving transistor is biased in the saturation region, the OLED current will be determined only be the gate-source voltage of driving transistor M3 and becomes,

$$I_{OLED} = \frac{1}{2} C_{ox} \frac{W}{L} \left(V_{GS_{M3}} - V_{TH_{M3}} \right)^2 \qquad (1)$$

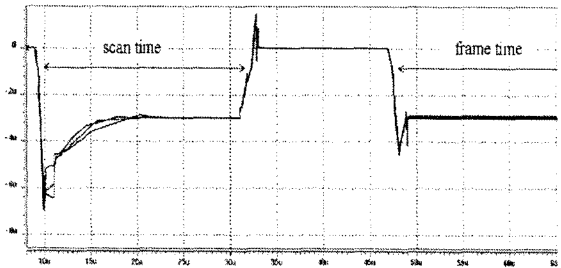
This will ensure constant OLED current as long as stable voltage between the gate and source of transistor M3 is guaranteed.



<Fig. 2> Linearity between Idata and Ioled for optimized W/L values, with difference from the ideal for the proposed and conventional pixel circuits.

Fig. 2. represents the linearity between input current and OLED current(Ioled) for optimized values of W/L. We have taken the small current level of 2 uA~8 uA since low current levels are more difficult to control in AMOLED displays. Error rate is measured with the optimized values of the proposed and conventional pixel circuits' sizes(W/L). As can be seen from the figure, the error rate has improved significantly to as low as 1%.

Simulation was conducted with stress induced, by modifying the parameters of the OTFT, due to unexpected changes. The results of modifying the mobility and operating temperature had insignificant influence to the output currents of the OLED. Therefore, we conclude that the threshold voltage shift(ΔVth) of the OTFT will have the most influence on the operation and therefore, focus on the compensation of the threshold voltage shift of the transistors. The threshold voltage deviation is reported to be around 0.33 V[2], however, in this work we have set the values to 0.5 V for more practical reasons.



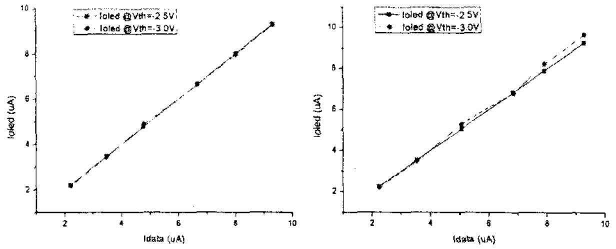
<Fig. 3> Threshold voltage compensation of the proposed pixel circuit for Vth of -3.0 V, -2.5 V, and -2.0 V at Idata of 3 uA.

Fig. 3 represents the threshold compensation scheme at frame time for Idata of 3 uA. The threshold voltage for the OTFTs was set to -3.0 V, -2.5 V, and -2.0 V, respectively. As can be seen from the figure, the current at frame time had small variation with respect to threshold voltage variation, and it can be concluded that the threshold voltage shift was well compensated.

Generally the threshold voltage of the OTFT is expected to decrease with time according to eq. (2).

$$\Delta V_{th} = A V_G{}^{\beta} t^{\gamma} \exp\left(-\frac{E_A}{kT}\right) \qquad (2)$$

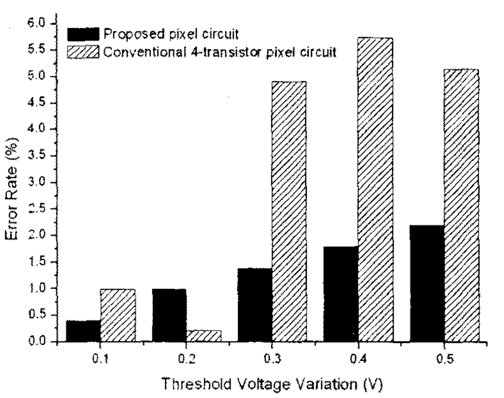
Since the transistor for driving the current to the OLED is M3, and under the assumption that the gate voltage of the transistor M3 is constant through the whole frame time, the threshold voltage decreases with increasing temperature. Thus, having measured the Ioled with Vth decrease of 0.5 V, the non-uniformity of the proposed circuit is under 2 % compared to that of the conventional circuit which is over 5 %.



(a) Proposed pixel circuit (b) Conventional pixel circuit

<Fig. 4> Uniformity of Idata vs. Ioled for the conventional and proposed pixel circuit.

Fig. 4(a) and Fig.4(b) represent the uniformity of the proposed pixel circuit and the conventional circuit with decrease of the threshold voltage by 0.5 V, respectively. As can be seen from the data, the uniformity of the proposed pixel circuit is much more preserved compared to the conventional pixel circuit. Fig. 5 represents the error rate of OLED current of the proposed pixel circuit compared to the conventional pixel circuit with threshold voltage variation. It can be seen that the error rate of the proposed pixel circuit is much lower than the conventional pixel circuit by more than 60 %.



<Fig. 5> Error rate of OLED current in proposed pixel current compared to conventional pixel current.

3. Conclusion

A new current scaling AMOLED pixel design driven by Organic Thin-Film Transistors (OTFTs) was proposed and verified by SPICE simulation. The parameters for the OTFTs were extracted using SPICE Model level 3 on the basis of current studies on OTFTs. The pixel circuit consists of four OTFTs, one storage capacitor, and an additional control signal to enhance the linearity between the input data and luminescence. The proposed pixel circuit shows high immunity to the threshold voltage variation of the OTFT compared to the conventional circuit which will lead to uniform display image for large scale displays.

[References]

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[3] R. Hattori, T. Tsukamizu, et al., "Current-writing active-matrix circuit for organic light-emitting diode display using a-Si:H thin-film transistors," IEICE Trans. Electron., vol. E83-C, pp. 779-782, 2000.