Micro-LED Pixel Circuit with n-type LTPS TFTs for Pulse Width Modulation Operation

Yong-Hoo Hong[1], Eun Kyo Jung[1], Jungwoo Lee[1], KeeChan Park[2], Jae-Hong Jeon[3], Soo-Yeon Lee[4] and Yong-Sang Kim[1]

yongsang@skku.edu
[1]Department of Electrical and Computer Engineering, Sungkyunkwan University, Suwon 16419, Korea
[2]Department of Electronics Engineering, Konkuk University, Seoul, 05029, Korea
[3]School of Electronics and Information Engineering, Korea Aerospace University, Goyang, 10540, Korea
[4]Department of Electrical and Computer Engineering, Seoul National University, Seoul, 08826, Korea
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ABSTRACT

This paper proposes a novel micro-LED pixel circuit using Pulse Width Modulation (PWM) operation method for preventing wavelength shifts generated by current density. In addition, the proposed circuit applies the internal V_{th} compensation method to remove external sensing structure.

1 INTRODUCTION

Liquid Crystal Display (LCD) is a flat panel display with liquid crystal as its core material. However, LCD products have major drawbacks such as slow response time, poor conversion efficiency and low saturation, which is compensated by the organic light emitting diode (OLED). OLED is a self-illuminating display in which the device that represents the screen in the display emitting light by itself, not through an external light source [1], [2]. LCD can display the screen only when all the backlights are turned on, whereas OLED only needs to supply power to desired pixels, so power consumption can be used very efficiently. It is also significant advantage in mobile environments that the LCD does not need a complicated structure such as an essential backlight, which reduces the thickness and weight. However, OLED also has a serious burn-in problem due to organic materials and the disadvantage that the normal OLED structure is forced in the pixel circuit design. It is the micro-light emitting diode (micro-LED) that compensates for shortcomings of LCD and OLED [3], [4].

Micro-LED is a technology that manufactures a display panel by using tiny LEDs of about 1 to 10 μm as pixels. Similar to OLED, since RGB sub-pixels emit light themselves, they have excellent viewing angles, good luminous efficiency, and vivid colors. Unlike LCD, it can completely turn off the pixels, so it is possible to implement an infinite contrast ratio, and the response speed is also very fast. In addition, it is attracting attention in many ways because it uses silicon-based LEDs instead of OLEDs and, like OLEDs, has good power and contrast ratios as it can turn off unused devices [5]-[7].

Micro-LED displays have an electrical characteristic in that the wavelength of emitted light is shifted according to the density of the current flowing through the micro-LED [8]. At the higher current density level, a red-shift of the wavelength is observed [9]. Therefore, micro-LED displays need to apply a pixel driving circuit that uses analog PWM for gray scale control [10]. The proposed PWM driving circuit uses the PAM method of the conventional AMLCD and AMOLED driving circuits, while the PWM operation is also applied.

2 PROPOSED PWM PIXEL CIRCUIT

Fig. 1 (a) shows the proposed pixel circuit with PWM operation using n-type LTPS TFTs. The proposed circuit is composed of PWM unit, CCG unit, driving TFT, storage capacitor and micro-LED. The PWM unit and CCG unit each take on the roles of emission time control and emission current level control of micro-LED. The proposed circuit consists of 11 TFTs and 2 capacitors, including the PWM unit driving TFT and the CCG unit driving TFT. It can be seen that the anode of the micro-LED is connected to the VDD side with an Inverted micro-LED structure.

2.1 Operation Process

Fig. 1 (b) is a timing diagram showing the operation process of the proposed circuit. It is composed of V_{th} compensation with PWM data, V_{th} compensation with CCG data and emission based on 1 frame time (8.3ms).

First, in the V_{th} compensation with PWM data period, the Vth deviation between TFTs is removed by an internal compensation method. As PWM data is progressively input for each scan line, the gate voltage of PWM driving TFT becomes $V_{data\_PWM} + V_{th\_PWM}$.

Secondly, in the V_{th} compensation with CCG data period, the Vth deviation between TFTs is also removed by an internal compensation method. As CCG data is simultaneously input for all scan line, the gate voltage of CCG driving TFT becomes $V_{data\_CCG} + V_{th\_CCG}$. The emission time and emission current level are set accordingly.

Finally, micro-LEDs emit light from all pixels simultaneously. As light emission continues, the voltage level of sweep signal increases, and the gate voltage of PWM driving TFT increases due to the coupling effect of Capacitor. When the PWM driving TFT becomes on-state, the gate voltage of CCG driving TFT becomes VGL of V_{OFF} and CCG driving TFT becomes off-state, then the light emission ends.

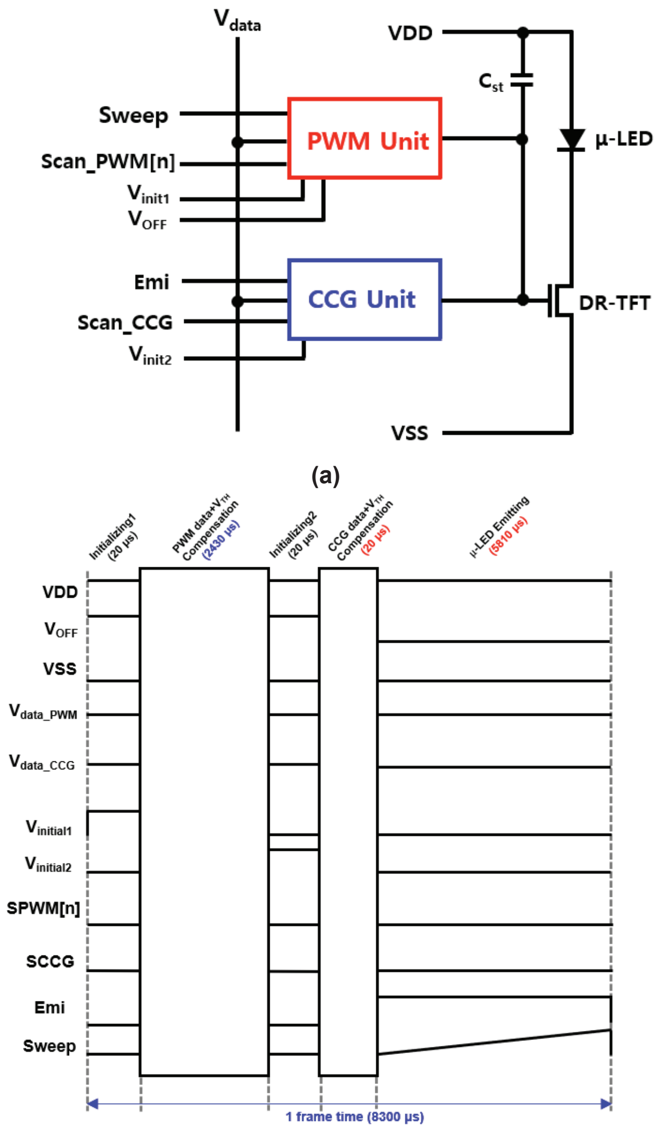


Fig. 1 Proposed pixel circuit : (a) One pixel circuit schematic and (b) timing diagram.

2.2 Simulation

We set up the n-type LTPS TFT model through the SmartSpice simulation program. The initial V_{th} of a n-type LTPS TFT is +1 V, the value of width/length is 20/5 μm. We set the micro-LED display panel (480 (horizontal) × RGB × 270 (vertical)) of a modular type and the frame rate of 120 Hz. Table. 1 shows the specifications of the proposed PWM pixel circuit simulation using n-type LTPS TFTs. Fig. 2 is the I-V transfer characteristics of the n-type LTPS TFT used in the simulation.

Table. 1 The specifications of the proposed pixel circuit

Parameter	Value
VDD	+5 V
VSS	0 V
V_{OFF}	-1.9 V to +6 V
PWM data (V_{data_PWM})	-7.3 V to -1.9 V
CCG data (V_{data_CCG})	1.9 V
Sweep	0 V to +6 V
Scan_PWM [n]	-5 V to +10 V
Scan_CCG	-5 V to +10 V
$V_{initial1}$	-5 V to +10 V
$V_{initial2}$	-5 V to +10 V
Emi	-5 V to +10 V
Model	**Value**
V_{th}	+1 V
Width/Length of T7, T10	20/5 [μm/μm]
Width/Length of T1-T6, T8, T9, T11	20/5 [μm/μm]

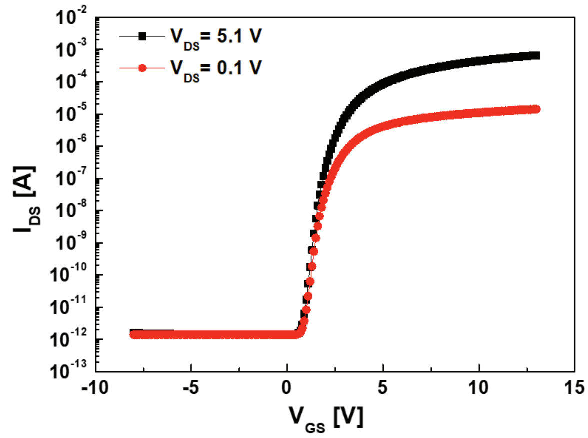
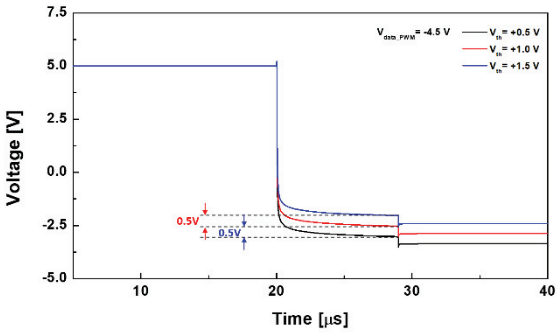


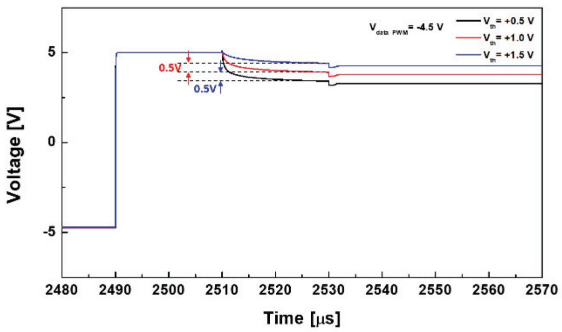
Fig. 2 I-V transfer characteristics of n-type LTPS TFT in simulation.

3 RESULTS AND DISCUSSION

In order to fix the level of the current flowing through the micro-LED at 10 μA, the CCG data was fixed at +1.9 V. The PWM operation of the proposed circuit controls the current driving time according to the gray scale. As the V_{data_PWM} increases, the light emission time of the micro-LED increases. The PWM data voltage was divided into -2.5, -3.5, -4.5, -5.5, and -6.5 V, respectively. The emission times of PWM data voltages -2.5, -3.5, -4.5, -5.5 and -6.5 V are 1.02, 1.95, 2.96, 3.97 and 5.07 ms, respectively. Therefore, it was confirmed that we could control the emission current level through control of CCG data and control the gray scale through control of PWM data by SmartSpice simulation. Fig. 3 (a) and (b) are the simulation results of the V_{th} compensation. We gave a V_{th} variation of ±0.5 V in both compensation periods, performed the simulation with the PWM data fixed at -4.5 V and confirmed that the compensation worked well.



(a)



(b)

Fig. 3 The simulation results for (a) V_{th} compensation of the PWM unit and (b) V_{th} compensation of the CCG unit of the proposed pixel circuit.

4 CONCLUSIONS

We propose a novel pixel driving circuit using n-type LTPS TFTs to implement the PWM operation. To improve the wavelength shift characteristic in micro-LED, we applied PWM operation to the proposed pixel circuit to fix micro-LED current density. As the PWM data voltage decreases, the emission time of the micro-LED becomes longer as shown in the simulation results. We confirmed that the grayscale representations of the micro-LED according PWM data (V_{data_PWM}, -7.3 V to -1.9 V) and CCG data (V_{data_CCG}, +1.9 V) in SmartSpice simulation. In addition, it was confirmed that the proposed circuit performs well internal compensation of the threshold voltage in the PWM unit and the CCG unit.

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