# A Novel Pixel Circuit Based on Oxide TFT for µLED Display Using Pulse Width Modulation Method

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**ABSTRACT**

*This paper introduces the novel pixel circuit for µLED display. In order to improve screen distortion, when grayscale representation of µLED is generated, we use the Pulse Width Modulation (PWM) method in which the amount of emission current of µLED is fixed and the emission time of µLED is controlled.*

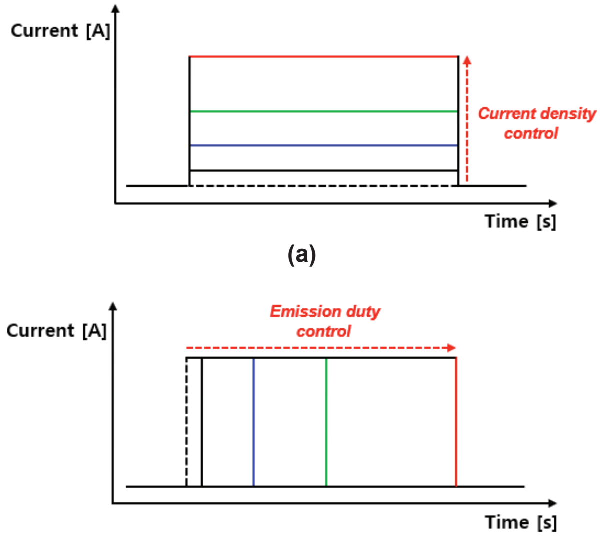
## 1 INTRODUCTION

Micro light-emitting diodes (µLEDs) refers to an ultra-miniature LED of less than 100 µm, and has the advantage of realizing low power consumption, miniaturization, and light weight of the display due to its small size and low power consumption. In addition, unlike organic light-emitting diodes (OLEDs), which show weaknesses in luminous efficiency and lifespan, it has excellent efficiency and lifespan and can operate in extreme conditions below -20°C and over 100°C [1]-[2]. Due to this possibility as a next-generation display, many domestic and foreign companies are currently strengthening their technology investment in µLED [3]-[5]. In general, the OLED pixel circuits use a Pulse Amplitude Modulation (PAM) method that represents grayscale levels by the amount of current flowing through the OLED as shown in Fig.1 (a). At this time, the amount of current flowing through the OLED is controlled through the driving Thin Film Transistor (TFT) of the pixel circuit [6]-[7]. However, when a conventional OLED pixel circuit is applied to the µLED, realizing a grayscale representation is impossible because of the wavelength shift in the µLED as PAM changes the current density in µLEDs [8]-[9]. In particular, when modular µLED display panels are connected to each other to realize a larger display, a difference in color wavelengths occurs between each modulator. To solve the wavelength shift problem, driving current of the µLED should have a constant value regardless of the grayscale and control driving time of the µLED according to grayscale. Therefore, when the µLEDs emit light, it is essential to apply the Pulse Width Modulation (PWM) method that fixes the amount of emission current and controls the emission time as shown in Fig1. (b) [10].

However, a color shift may be also generated when the electrical characteristics of TFTs are changed upon continuous bias stress or deviation in characteristics [11]-[12]. In particular, when the electrical characteristics such as the threshold voltage ($V_{TH}$) of driving transistors are changed, circuit malfunction occurs. Accordingly, $V_{TH}$ compensation structure is required to prevent the degradation of electrical characteristics.

Meanwhile, Oxide TFTs have high mobility and low production cost. It is widely used in large-area display panels because of its high uniformity between TFTs compared to Low Temperature Poly-silicon (LTPS) TFTs. In addition, since Oxide TFTs have a low off-current characteristic, it is possible to realize low power consumption. In general, Oxide TFTs are composed of a channel layer by adjusting the ratio of Amorphous Indium Gallium Zinc Oxide (a-IGZO), and the ratio of indium is increased to improve electron mobility. However, when the ratio of indium increases, oxygen vacancy of the channel layer increases and the $V_{TH}$ of the oxide TFT has a negative value [13]-[14]. Even if a voltage is not applied to the gate node of the TFT, a channel of the TFT is formed and is turned on normally. Accordingly, a leakage current flows through the Oxide TFT and it is resulted in high power consumption. In addition, the $V_{TH}$ variation of the driving TFT may occur due to continuous gate bias stress and hysteresis. it can lead to serious malfunction in grayscale representation of display [15]-[16].

Therefore, we propose a novel pixel circuit based on Oxide TFT using the PWM driving method that can solve wavelength shift problem of the µLEDs. The proposed circuit is applied to fix the amount of current density flowing through the µLED and control the light emission time. The circuit driving is possible regardless of the operation of the enhancement mode and the depletion mode of the Oxide TFT. In addition, the proposed circuit compensates the $V_{TH}$ of the driving transistor through the source follower method in consideration of the operation in the depletion region. So, it is possible to secure stability for grayscale representation during µLED light emission.




(b)

**Fig. 1 Two driving methods to represent grayscale (a) PAM method (OLED) (b) PWM method (μLED)**

## 2 EXPERIMENT

In simulation, we set Oxide TFT model and designed a novel 10T4C pixel circuit using the PWM method. Fig. 2 exhibits the I-V transfer characteristics of the Oxide TFT model using a-IGZO as the channel layer in the SmartSpice simulation. The initial $V_{TH}$ of a-IGZO TFT is +1 V, the width/length of the channel is 20/5 μm, and the electron mobility is 15 $cm^2$/V·s. We considered the μLED display panel (480 (horizontal) × RGB × 270 (vertical)) of a modular type and the frame rate of 120 Hz. Fig 3. (a) shows the proposed circuit consists of the PWM part, CCG part, driving TFT (DR-TFT), storage capacitor ($C_{ST}$), and μLED. The PWM part plays a role of controlling the light emission time of the μLED and the CCG part is responsible for fixing the emission current of μLED. Therefore, when the μLEDs emit light, stability for grayscale representation can be secured.

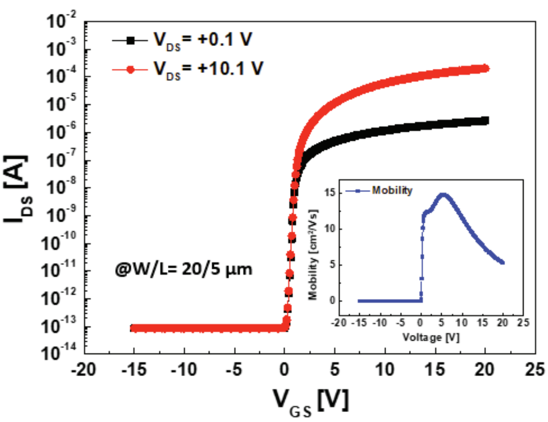
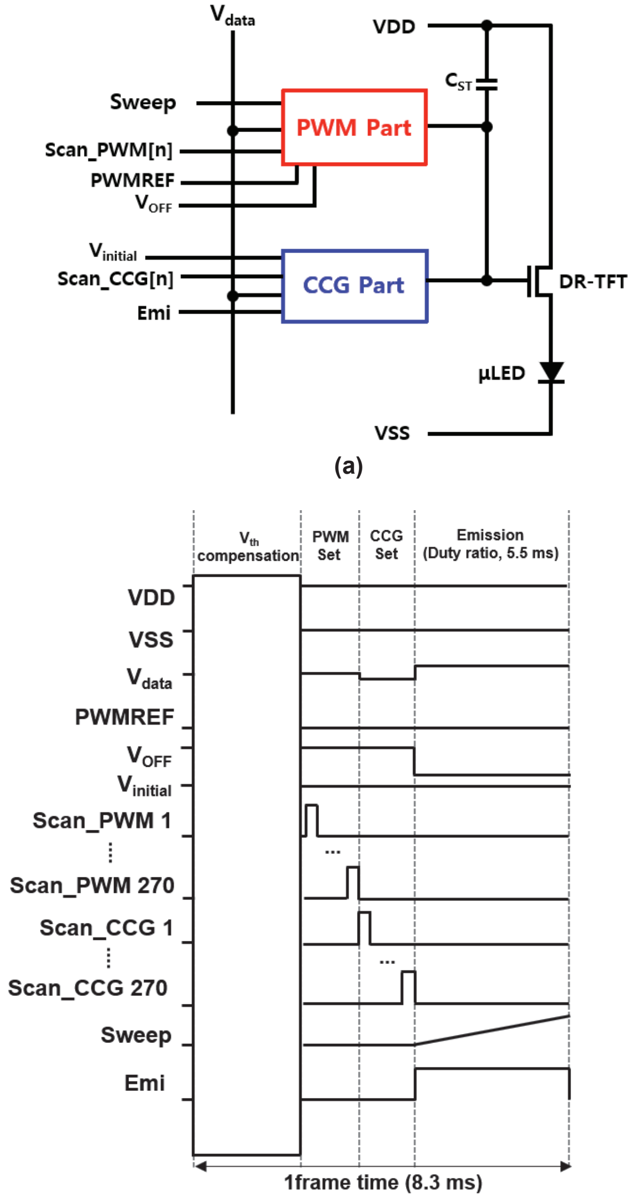



**Fig. 2 I-V transfer characteristics of a-IGZO TFT in simulation**



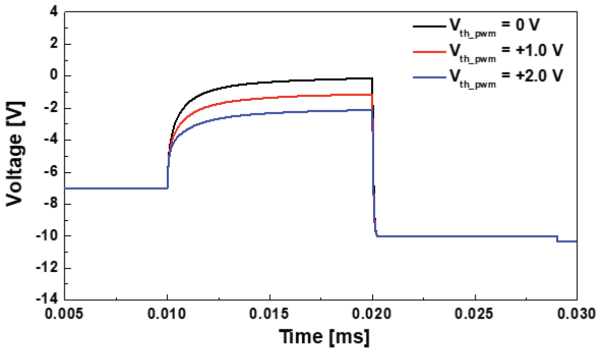

(b)

**Fig. 3 Proposed pixel circuit structure : (a) circuit schematic (b) timing diagram**

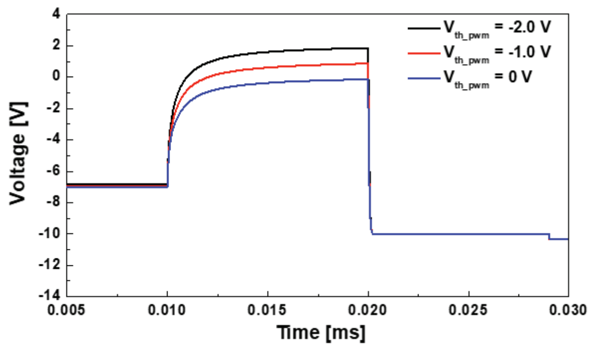
The operation sequences of the proposed circuit are composed of the $V_{TH}$ compensation of driving TFT, PWM set, CCG set, and μLED emission as shown in Fig. 3 (b). First, the $V_{TH}$ of driving TFT of all pixels is simultaneously compensated to solve $V_{TH}$ deviation between transistors. Second, the PWM data and CCG data is progressively input to the gate node of driving TFT through all 270 lines for adjusting the grayscale representation time of μLED and fixing the amount of current flowing through μLED, respectively. At last, the μLED of all pixels simultaneously emits light. Therefore, the grayscale representation of the μLED are implemented through the light emission time according to the PWM data value.

Table. 1 The driving voltages of proposed circuit

| Parameter | Value |
|---|---|
| VDD | +7 V |
| VSS | -5 V |
| $V_{OFF}$ | -5 V to +7 V |
| PWM data ($V_{data}$) | -4.9 V to -10.3 V |
| CCG data ($V_{data}$) | -5.5 V |
| PWMREF | -10 V to +10 V |
| Scan_PWM[n] | -20 V to +10 V |
| Scan_CCG[n] | -20 V to +10 V |
| $V_{initial}$ | -10 V to +10 V |
| Emi | -10 V to +10 V |
| Sweep | 0 V to +6 V |




(a)

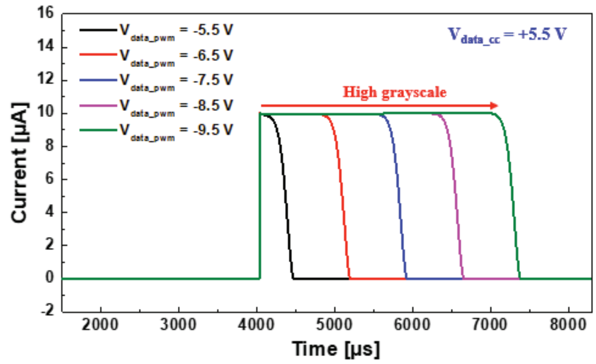



(b)

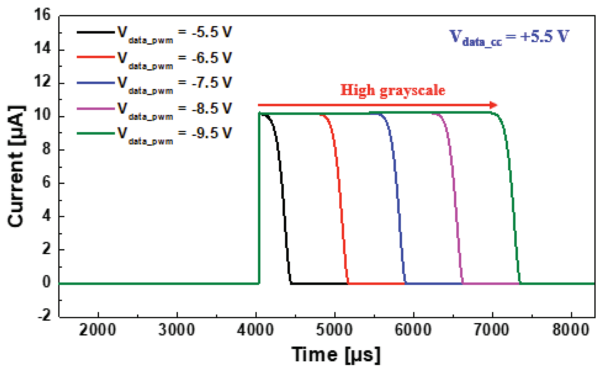
**Fig. 4 Simulated voltage waveform according to $V_{th\_pwm}$ compensation (a) in enhancement mode (b) in depletion mode**

## 3 RESULTS AND DISCUSSION

To prove $V_{TH}$ compensation of driving TFT, we simulated for voltage waveform according to $V_{TH}$ variation of driving TFT consisting of PWM part in the enhancement mode ($V_{th\_pwm}$ = +1.0 V, +2.0 V) and depletion mode ($V_{th\_pwm}$ = -2.0 V, -1.0 V) as shown in Fig. 4. Fig. 5 shows the simulated current waveforms for grayscale representation of µLED according to PWM data ($V_{data\_pwm}$, -5.5 V to -9.5 V). To fix the current flowing through µLED, CCG data ($V_{data\_cc}$) was set to +5.5 V (10 µA). As the value of PWM data decreases, the µLED off time according to the Sweep signal became longer because the low voltage




(a)




(b)

**Fig. 5 Simulated current waveform for grayscale representation according to PWM data (a) in enhancement mode and (b) in depletion mode**

was written in the data period. Fig. 5 (a) exhibits the grayscale representations according to the PWM data when the operation of the proposed circuit is in the enhancement mode ($V_{TH}$ = +1 V of all TFTs). In addition, in order to consider the operation of the Oxide TFT in depletion mode, it was confirmed that the grayscale representations of the µLED according PWM data ($V_{data\_pwm}$, -5.5 V to -9.5 V) and CCG data ($V_{data\_cc}$, +5.5 V) can be implemented when the $V_{TH}$ of all TFTs is -1 V as shown in Fig. 5 (b).

## 4 CONCLUSIONS

In this paper, we proposed a novel pixel circuit based on Oxide TFT for µLED display using the PWM method. To improve the wavelength shift problem in µLED, we applied PWM method to the proposed pixel circuit to fix µLED current density. To verify $V_{TH}$ compensation, we simulated voltage waveform according to $V_{th\_pwm}$ variation of PWM part in the enhancement mode and the depletion mode, respectively. In addition, we confirmed that the grayscale representations of the µLED according PWM data ($V_{data\_pwm}$, -5.5 V to -9.5 V) and CCG data ($V_{data\_cc}$, +5.5 V) in SmartSpice simulation. So as to consider characteristics of Oxide TFT, we also simulated current waveforms regardless of operation of the enhancement mode ($V_{TH}$ of all TFTs is +1 V) and depletion mode ($V_{TH}$ of all TFTs is -1 V).

## REFERENCES


[1] C.-L. Lin and Y.-C. Chen, "A Novel LTPS-TFT Pixel Circuit Compensating for TFT Threshold-Voltage Shift and OLED Degradation for AMOLED," IEEE Electron Device Lett., Vol. 28, pp. 129-131 (2007).

[2] J. Kim, J. Ko, J. Park, G. Jeong, H. Maeng, S. Park, and W. Choe, "A compensation algorithm for degradation in AMOLED displays," SID Symp. Dig. Tech. Papers, Vol. 49, pp. 445-448 (2018).

[3] A. Beckers, D. Fahle, C. Mauder, T. Kruecken, A. R. Boyd, and M. Heuken, "Enabling the next era of display technologies by micro LED MOCVD processing," SID Symp. Dig. Tech. Papers, Vol. 49, pp. 601-603 (2018).

[4] C.-J. Chen, H.-C. Chen, J.-H. Liao, C.-J. Yu, and M.-C. Wu, "Fabrication and Characterization of Active-Matrix 960×540 Blue GaN-based Micro-LED Display," IEEE J. Quantum Electron., Vol. 55, pp. 3300106 (2019).

[5] H.-M. Kim, J. G. Um, S. Lee, D. Y. Jeong, Y. Jung, S. H. Lee, T. Jeong, J. Joo, J. Hur, J. H. Choi, J. S. Kwak, and J. Jang, "High brightness active matrix micro-LEDs with LTPS TFT backplane," SID Symp. Dig. Tech. Papers, Vol. 49, pp. 880-883 (2018).

[6] C.-L. Fan, M.-C. Shang, W.-C. Lin, H.-C. Chang, K.-C. Chao, and B.-L. Guo, "LTPS-TFT Pixel Circuit Compensating for TFT Threshold Voltage Shift and IR-Drop on the Power Line for AMOLED Displays," Advance in Materials and Engineering, Vol. 2012, pp. 1-5 (2012).

[7] C.-L. Lin, P.-C. Lai, L.-W. Shih, C.-C. Hung, P.-C. Lai, T.-Y. Lin, K.-H. Liu, and T.-H. Wang, "Compensation Pixel Circuit to Improve Image Quality for Mobile AMOLED Displays," IEEE J. Solid-State Circuit, Vol. 54, pp 489-500 (2018).

[8] Z. Gong, S. Jin, Y. Chen, J. McKendry, D. Massoubre, L.-M. Waston, E. Gu, and M. D. Dawson, "Size-dependent light output, spectral shift, and self-heating of 400 nm InGaN light emitting diodes," J. Appl. Phys., Vol. 107, pp. 013103 (2010).

[9] S. Chhajed, Y. Xi, Y.-L. Li, Th. Gessmann, and E. F. Schubert, "Influence of junction temperature on chromaticity and color-rendering properties of trichromatic white-light sources based on light-emitting diodes," J. Applied Physics, Vol. 97, pp. 054506 (2005).

[10] M. Kimura, D. Suzuki, M. Koike, S. Sawamura, and M. Kato, "Pulsewidth Modulation with Current Uniformization for TFT-OLEDs," IEEE Tran Electron. Dev., Vol. 57, pp 2624-2630 (2010).

[11] J.-H. Lee, J.-H. Kim, and M.-K. Han, "A new a-Si:H TFT pixel circuit compensating the threshold voltage shift of a-Si:H TFT and OLED for active matrix OLED," IEEE Electron Device Lett., Vol. 26, pp. 897-899 (2005).

[12] Y.-S. Kim and M.-K. Han, "Degradation due to electrical stress of poly-Si thin film transistors with various LDD lengths," IEEE Electron Device Lett., Vol. 16, pp. 245-247 (1995).

[13] B. Kim, H. N. Cho, W. S. Choi, S.-H. Kuk, Y. H. Jang, J.-S. Yoo, S. Y. Yoon, M. C. Jun, Y.-K. Hwang, and M. K. Han, "Highly Reliable Depletion-Mode a-IGZO TFT Gate Driver Circuits for High-Frequency Display Applications Under Light Illumination," IEEE Electron Dev. Lett., Vol. 33, pp. 528-530 (2012).

[14] J.-H. Kim, J. S. Oh, K. C. Pack, J.-H, Jeon, and Y.-S. Kim, "IGZO TFT Gate Driver Circuit with Improved Output Pulse," IEEE Electron Dev. Lett., Vol. 7, pp. 309-314 (2018).

[15] Y. K. Jang, and J. K. Jeong, "Recent progress in high performance and reliable n-type transition metal oxide-based thin film transistors," Semicond. Sci. Technol., Vol. 19, pp. 024002 (2015).

[16] K. H. Ji, J.-I. Kim, H. Y. Jung, S. Y. Park, R. N. Choi, U. K. Kim, C. S. Hwang, D. S. Lee, H. S. Hwang, and J. K. Jeong, "Effect of high-pressure oxygen annealing on negative bias illumination stress-induced instability of InGaZnO thin film transistors," Appl. Phys. Lett., Vol.98, pp. 103509 (2011).