# A Micro Light-Emitting Diode Pixel Circuit Based on Metal Oxide Thin-Film Transistor with Progressive Emission Using Pulse Width Modulation

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**ABSTRACT**

*The pixel circuit was proposed for the µLED displays. The PWM and progressive emission were applied to use tens of µA current and hundreds of us emission time in considering EQE characteristics. The proposed circuit was proved to operate stably in depletion mode of a-IGZO TFT.*

## 1 Introduction

Micro light-emitting diode (µLED) displays have the advantages of low power consumption, lightweight, and miniaturization [1]. In addition, the µLED displays have a long lifetime and high luminous efficiency compared to organic light-emitting diodes (OLEDs). However, it is impossible due to the wavelength shift of µLEDs when pulse amplitude modulation (PAM) is applied to the µLED pixel circuit [2]. Accordingly, the µLED current should have a constant value regardless of the gray-level and control emission time for gray-level expression. In other words, it is essential to apply the pulse width modulation (PWM) with constant current. The region, which have excellent external quantum efficiency (EQE) of µLEDs exists in high current [3]. The progressive emission is possible to easily control the emission time of µLEDs than the simultaneous emission. The number of pixels, which emit light at the same time is reduced in progressive emission compared to simultaneous emission [4]. Consequently, the power consumption is decreased when the µLEDs emit light using PWM and high current in the progressive emission-based pixel circuit. The amorphous indium-gallium-zinc oxide (a-IGZO) thin-film transistors (TFTs) have a threshold voltage ($V_{TH}$) of negative value. So, it leads to high power consumption in circuit of display panel because a channel of the a-IGZO TFT is formed and leakage current flows itself in the off-state. Therefore, it is essential to develop the new driving circuits considered depletion mode of a-IGZO TFT in the display panel. Besides, the $V_{TH}$ variation occurs due to continuous bias stress and hysteresis [5]. Thus, it is necessary to compensate for the $V_{TH}$ of the driving-TFT in the pixel circuit. Herein, we proposed the µLED pixel circuit with progressive emission using PWM based on a-IGZO TFT. The PWM was applied to overcome the wavelength shift of µLED by controlling emission time according to gray-level. The proposed circuit was applied to internal compensation through the source-follower method. The proposed µLED pixel circuit adjusted gray-level and fixed the constant µLED current, respectively. We utilized the progressive emission to use tens of µA current and hundreds of us emission time in high EQE of µLED.

## 2 Proposed µLED Pixel Circuit

Fig 1. (a) exhibits the proposed µLED pixel circuit based on a-IGZO TFT. The proposed circuit is composed of PWM and constant current generation (CCG) units. The T1 and T2 are the driving-TFT of PWM and CCG unit, respectively. The PWM unit decides the gray-level of the µLEDs. The CCG unit set to constant current level of µLEDs. Fig 1. (b) indicates the timing diagram of the progressive emission applied to the proposed circuit during 1 frame time.

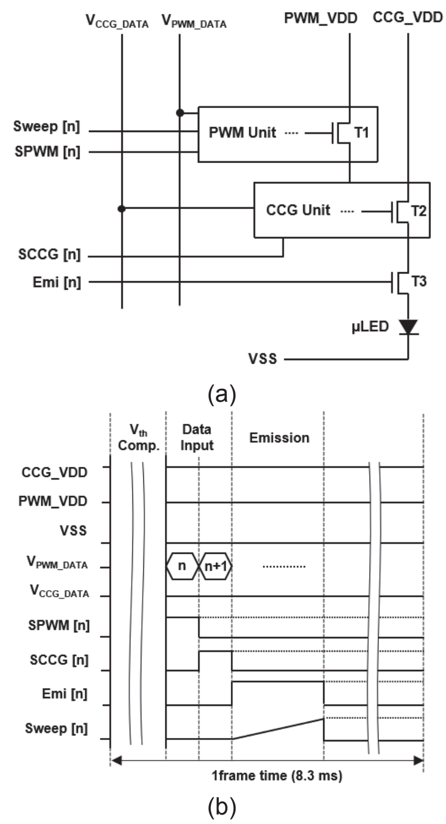
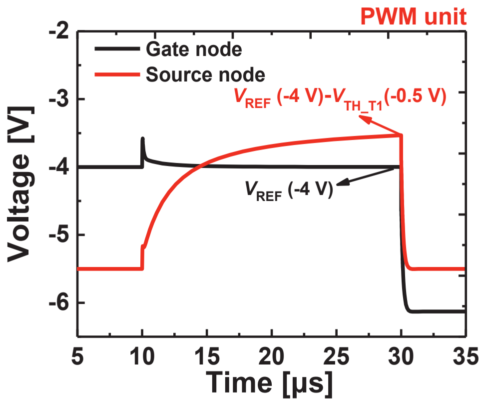


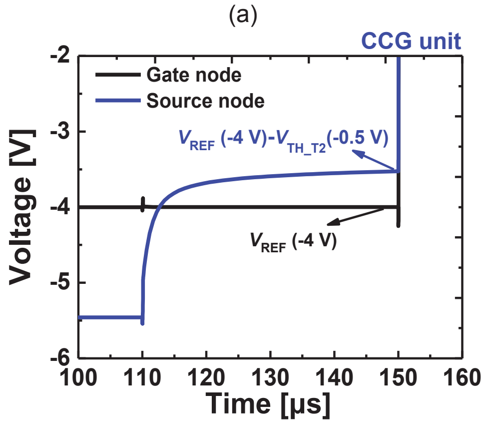

**Fig. 1 Proposed pixel circuit (a) schematic and (b) timing diagram**

## 3 Results and Discussion

We investigated the operation of proposed pixel circuit using the circuit simulation (SmartSpice, Silvaco). Fig. 2 exhibit the simulated voltages during the $V_{TH\_T1}$ compensation period in the PWM and CCG units for 1st scan line. As shown in Fig. 2(a), when a $V_{REF}$ of -4 V was applied to the gate node of T1, the source node of T1 was charged as $V_{REF}$-$V_{TH\_T1}$ of -3.5 V by the source follower method of PWM unit during the 10 to 30 μs (1H time). The T1 was turned off and the $V_{TH\_T1}$ of -0.5 V is stored in PWM unit. After that, Fig. 2(b) shows the simulated voltage waveforms for gate and source node of T2 during 110 μs to 150 μs (2H time). The $V_{TH\_T2}$ compensation were applied to the T2 of the CCG unit. When a $V_{REF}$ of -4 V was applied to the gate node of T2, the source node of T2 was charged to $V_{REF}$-$V_{TH\_T2}$ of -3.5 V by the source follower method until the T2 is turned off. Finally, the $V_{TH\_T2}$ of -0.5 V is stored in CCG unit. Fig. 3 represents the μLED gray-level expression at $V_{th}$ of -0.5 V. Fig. 3(a) indicates the μLED current waveform according to $V_{PWM\_DATA}$ (-5.9 V, -6.4 V, -6.9 V, -7.4 V, and -7.9 V) for gray-level expression. The μLED peak current of 50 μA was determined by $V_{CCG\_DATA}$ of 4.8V. Therefore, these simulation results were proved to represent gray-level through PWM with a μLED current of 50 μA for high EQE characteristics. The gray-level is 255G,

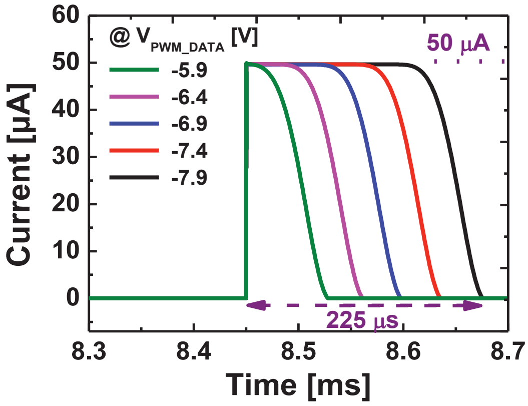



(a)

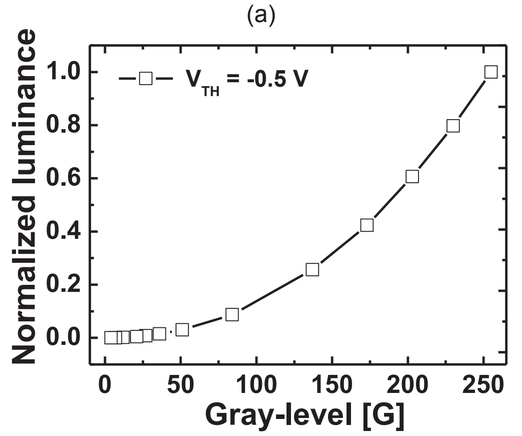



(b)

**Fig. 2 Simulated voltage waveforms: $V_{TH}$ compensation in (a) PWM and (b) CCG units.**




(a)




(b)

**Fig. 3 Simulated (a) current waveforms by varying $V_{PWM\_DATA}$ (-5.9 V, -6.4 V, -6.9 V, -7.4 V, -7.9 V). (b) normalized luminance of gray-level using 2.2 gamma correction.**

230G, 203G, 173G, and 137G from -7.9 V to -5.9 V, respectively. The proposed μLED pixel circuit was based on an 8-bit gray-level (256G) using the PWM method at a 2.2 gamma correction. The maximum emission time is set to 225 μs at 255 gray-level in the target luminance. The value of the luminance was regarded by integrating the μLED current multiplied by the emission time. Thus, we defined the normalized luminance as dividing the luminance value of the corresponding gray-level by that of the 255 gray-level. As shown in Fig. 3(b), we confirmed the normalized luminance according to gray-level. The gray-level expression well was achieved based on 2.2 gamma correction.

## 4 Conclusion

In this paper, a-IGZO TFT-based pixel circuit was proposed for μLED display. The source follower method was used to compensate the $V_{TH}$ in depletion mode operation of driving-TFTs (T1, T2). We verified the source node was charged as $V_{REF}$-$V_{TH\_T1}$ of -3.5 V through the source follower method in PWM and CCG units when $V_{TH}$ is -0.5 V and a $V_{REF}$ of -4 V was applied to the gate node. The PWM was applied to overcome the color shift of μLEDs by fixing the constant current of μLED regardless of gray-level. The emission time for gray-level was adjusted depending on $V_{DATA\_PWM}$. We applied the progressive emission method to use emission current of 50 μA and emission time of 225 μs in considering of high EQE and luminance of μLED. In addition, we verified the gray-level expression through normalized luminance by $V_{PWM\_DATA}$ variation. It is well achieved based on 2.2 gamma correction. As a results, the proposed μLED pixel circuit is possible to stable operation using the PWM in depletion mode of a-IGZO TFTs.

**Acknowledgement**

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