*Proceedings of 6th Thin Film Materials & Devices Meeting*
*November 2-3, 2009, Kyoto, Japan*
*http://www.tfmd.jp/*

# Pulse-Width Modulation with Current Uniformization using Reduced Pixel Circuit for TFT-OLEDs

Daisuke Suzuki[1], Masamichi Koike[1], Shigeki Sawamura[2],
Masakazu Kato[3] and Mutsumi Kimura[1,4]

[1] Ryukoku University, Seta, Otsu, 520-2194, Japan, mutsu@rins.ryukoku.ac.jp
[2] Nara Institute of Science and Technology, Takayama, Ikoma 630-0192, Japan
[3] Osaka University, Yamadaoka, Suita 565-0871, Japan
[4] Innovative Materials and Processing Research Center, Seta, Otsu 520-2194, Japan

**Keywords:** Pulse-Width Modulation, Current Uniformization, Pixel Circuit, TFT-OLED

**Abstract.** We have proposed a novel driving concept for TFT-OLEDs, pulse-width modulation with current uniformization. This driving method can simultaneously achieve precise grayscale and exceedingly improve luminance uniformity. Lately, we succeeded to reduce the number of TFTs in a pixel circuit from nine to seven. Especially in this paper, its working and tolerance against characteristic deviations of TFTs and OLEDs are confirmed using circuit simulation.

## Introduction

TFT-OLEDs have been highlighted for a next generation of flat-panel displays [1-2]. One of the most critical issues for TFT-OLEDs is luminance uniformity between neighboring pixels. In order to improve the luminance uniformity, many kinds of driving method were proposed [3-11].

Formerly, we and another group presented pulse-width modulations with self-biased inverter [6-7]. These driving methods can compensate characteristic deviation of TFTs. However, they cannot compensate characteristic deviation of OLEDs. On the other hand, recently, we presented a time-ratio grayscale with current uniformization [11]. This driving method can compensate characteristic deviations of both TFTs and OLEDs. However, it needs high-speed scanning for high-resolution and many-grayscale displays.

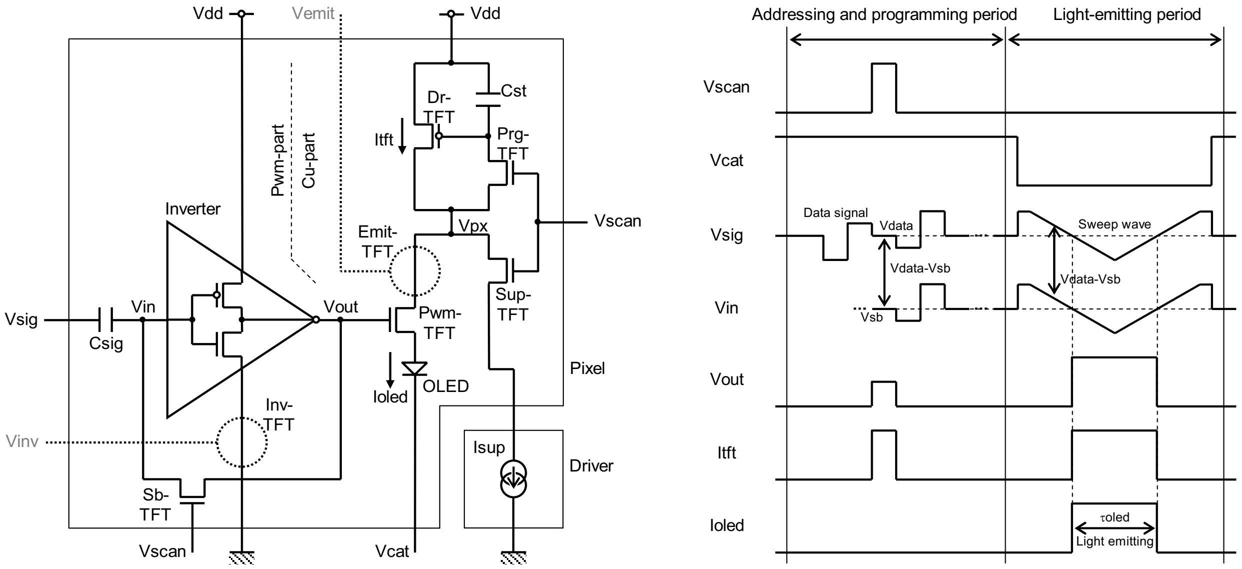
We have proposed a novel driving concept for TFT-OLEDs, pulse-width modulation with current uniformization [12]. This driving method can simultaneously achieve precise grayscale and exceedingly improve luminance uniformity. Lately, we succeeded to reduce the number of TFTs in a pixel circuit from nine to seven [13]. Especially in this paper, its working and tolerance against characteristic deviations of TFTs and OLEDs are confirmed using circuit simulation [14].

## Pulse-width modulation with current uniformization

This driving method can simultaneously achieve precise grayscale using the pulse-width modulation and exceedingly improve luminance uniformity using the current uniformization. The pixel circuit consists of the Pwm-part, pulse-width modulation part, and Cu-part, current uniformization part, as shown in Fig. 1. Here, the reduced TFTs and buslines that exist in the conventional pixel circuit of the pulse-width modulation with current uniformization are shown using the dotted lines.

The working of the Pwm-part is explained as follows. First, during an addressing period, data-addressing operation is executed. Since Vin and Vout are connected, the voltage difference between Vdata and Vsb, Vth of the inverter, can be stored in the Csig. Next, during a light-emitting period, pulse-width-modulation operation is executed. Since a sweep wave is applied and coupled to Vin through the Csig, and the voltage difference between Vdata and Vsb is already stored in the Csig, the Pwm-TFT can be correctly turned on, and τoled, light-emitting time, can be exactly controlled.

On the other hand, the working of the Cu-part is explained as follows. First, during a programming period, current-programming operation is executed. Since the Prg-TFT and Sup-TFT are turned on, the proper voltage for Itft=Isup can be stored in the Cst. Since Isup is enough to charge the Cst and whole pixel circuit, Vpx is settled, and Itft is asymptotical to Isup. Next, during a light-emitting period, current-reproduce operation is executed. Since Vgs of the Dr-TFT is already stored in the Cst, Itft is unchangedly kept, and Ioled can be roughly equal to



(a) Pixel circuit

(b) Timing chart

| | |
|---|---|
| Pwm-part | Pulse-width modulation part |
| Cu-part | Current uniformization part |

| | |
|---|---|
| Sb-TFT | TFT to connect input and output of self-biased inverter |
| Inv-TFT | TFT to power inverter |
| Csig | Capacitor to store Vdata and Vsb |
| Dr-TFT | TFT to drive OLED with constant current |
| Prg-TFT | TFT to program proper voltage in Cst |
| Sup-TFT | TFT to supply constant current from Isup |
| Pwm-TFT | TFT to control light emitting time by pulse-width modulation |
| Emit-TFT | TFT to define light-emitting period |
| Cst | Capacitor to store Vgs of Dr-TFT |

| | |
|---|---|
| Vscan | Scanning voltage |
| Vsig | Signal voltage |
| Vdata | Data voltage related to data signal |
| Vin | Input voltage inputted to inverter |
| Vout | Output voltage outputted from inverter |
| Vsb | Vth of inverter detected by self-biased inverter |
| Vinv | Voltage applied to Inv-TFT |
| Vcat | Cathode voltage |
| Vpx | Pixel voltage between Dr-TFT and OLED |
| Vemit | Voltage applied to Emit-TFT |
| Isup | Current from constant current supply |
| Itft | Current through Dr-TFT |
| Ioled | Current through OLED |
| τoled | Light-emitting time |

Fig. 1
Pulse-width modulation with current uniformization.

Isup. Since only one operating point is used in the current-programming operation, and it can coincide with the operating point in the current-reproduce operation, the current variation due to the shift of the operating points does not occur.

Recently, we succeeded to reduce the number of TFTs in a pixel circuit from nine to seven. First, the Inv-TFT to power off the inverter can be reduced because it does not matter whether the inverter is powered on or off when the pixel circuit is not selected during the addressing and programming period. Next, the Emit-TFT to define the light-emitting period can be also reduced because the same function is obtained when the cathode voltage is varied. As a result, we also reduce the number of buslines in an array panel from six to four.

## Simulation results

We confirm the working of this driving method using circuit simulation as shown in Fig. 2. Here, typical characteristics and optimized designs are used, the addressing and programming period is 16 μs per one scan line, the light-emitting period is 8 ms, and Vdata is 2.5 V by assuming that the pixel pitch is 200 μm, the maximum luminance is 100 Cd·m$^{-2}$, the scan-line number is 500, and the halftone grayscale is displayed. An original TFT model is implemented in the circuit simulation [15]

It is found in the simulated voltage and current waveforms shown in Fig. 2(b) that τoled can be exactly controlled, whose value of 3.94 ms is almost similar to the required value of 4 ms, and Ioled can be roughly equal to Isup, whose value of 0.998 μA is almost similar to the required value of 1 μA.

We also confirm the tolerance against ΔVth of TFTs and OLEDs using circuit simulation as shown in Fig. 3. Here, the variations of τoled, Ioled and Loled, light-emitting brightness, whose

**Pwm-part**

| | Type | W (μm) | L (μm) | LDD (μm) |
|---|---|---|---|---|
| Inverter -TFT | p | 2 | 2 | S/A |
| Inverter -TFT | n | 2 | 2 | 0.75 |
| Sb-TFT | n | 2 | 2 | 0.75 |

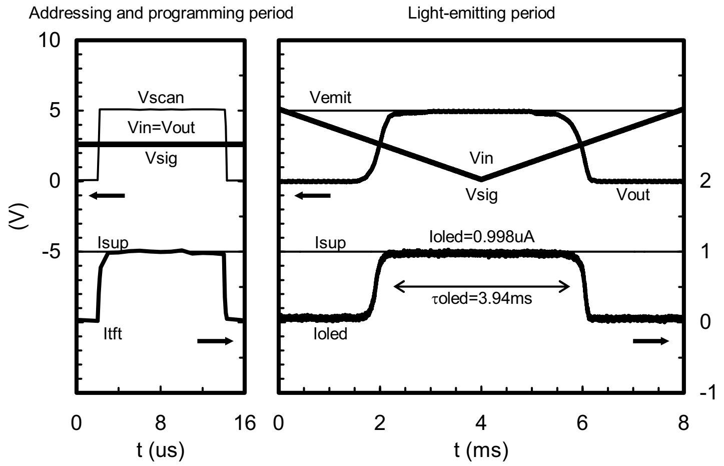
| | C (pF) |
|---|---|
| Csig | 0.1 |

**Cu-part**

| | Type | W (μm) | L (μm) | LDD (μm) |
|---|---|---|---|---|
| Dr-TFT | p | 5 | 2 | S/A |
| Prg-TFT | n | 2 | 2 | 0.75 |
| Sup-TFT | n | 10 | 2 | 0.75 |
| Pwm-TFT | n | 10 | 2 | 0.75 |

| | C (pF) |
|---|---|
| Cst | 2 |

(a) Design parameters

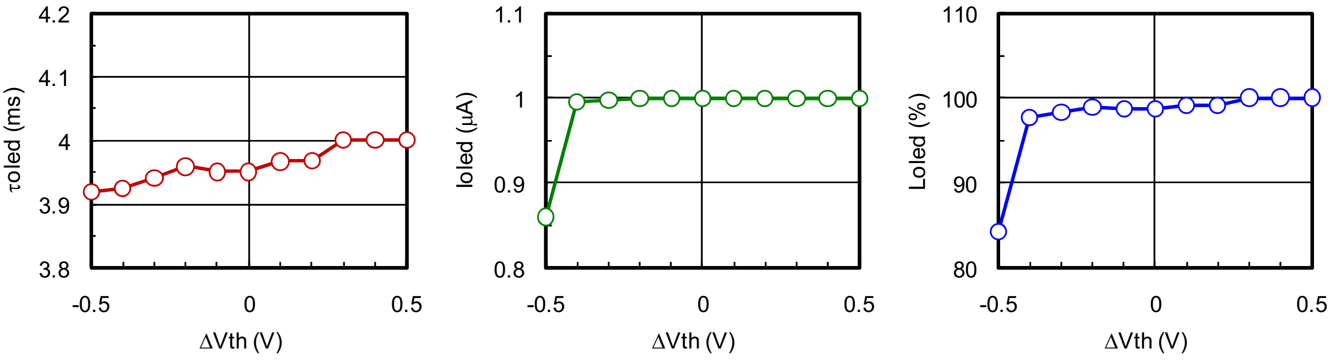


(b) Voltage and current waveforms

Fig. 2
Working confirmation of the driving method using circuit simulation.

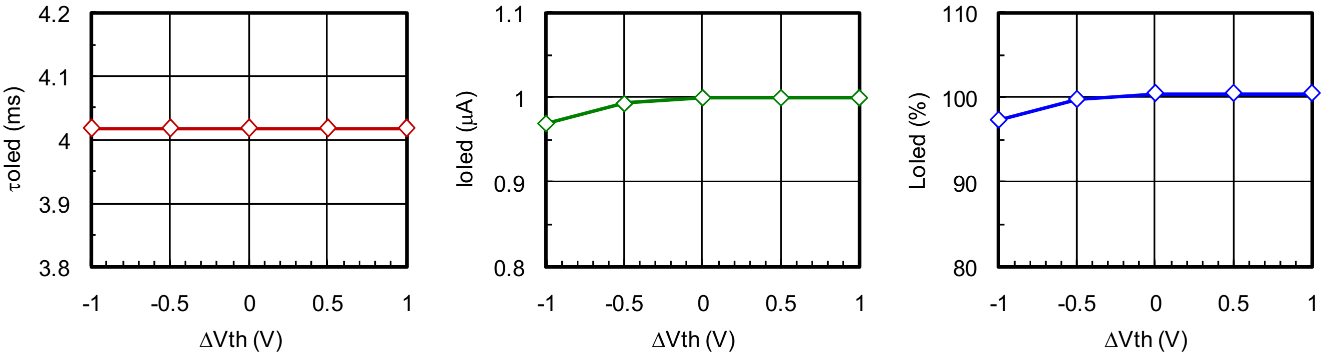
value is estimated by multiplying τoled by Ioled, are evaluated.

It is found in Fig. 3(a) that the average value of τoled is almost similar to the required value and the variation of τoled is sufficiently small against ΔVth of TFTs. Moreover, the average value of Ioled is also almost similar to the required value, and the variations of Ioled is also sufficiently small except for ΔVth of TFTs is -0.5 V. Consequently, so is Loled. It is also found in Fig. 3(b) that the average value of τoled is almost similar to the required value and the variation of τoled is sufficiently small against ΔVth of OLEDs. Moreover, the average value of Ioled is also almost similar to the required value, and the variations of Ioled is also sufficiently small except for ΔVth of OLEDs is -1 V. Consequently, so is Loled. Since ΔVth of TFTs of -0.5 V and ΔVth of OLEDs of -1 V are considerably large values and those in mass-fabrication technologies is probably small, it is verified that the pulse-width modulation with current uniformization using reduced pixel circuit can simultaneously achieve precise grayscale and exceedingly improve luminance uniformity.



τoled Ioled Loled

(a) ΔVth of TFTs



τoled Ioled Loled

(b) ΔVth of OLEDs

Fig. 3
Tolerance confirmation against characteristic deviations of TFTs and OLEDs.

## Conclusion

We have proposed a novel driving concept for TFT-OLEDs, pulse-width modulation with current uniformization. This driving method can simultaneously achieve precise grayscale and exceedingly improve luminance uniformity. Lately, we succeeded to reduce the number of TFTs in a pixel circuit from nine to seven. Especially in this paper, its working and tolerance against characteristic deviations of TFTs and OLEDs were confirmed using circuit simulation. We will confirm its working and tolerance against characteristic deviations of TFTs and OLEDs using actual pixel equivalent circuits in the near future.

## Acknowledgments

The authors wish to thank Drs. Hiroyuki Hara, Satoshi Inoue, Hitoshi Fukushima, Tomoyuki Kamakura, Simon W. B. Tam, some members of Seiko Epson, Prof. Tatsuya Shimoda of Japan Advanced Institute of Science and Technology, Silvaco International, Silvaco Japan, Cadence Design Systems, Cadence Design Systems Japan, Dr. Yoshiki Katsuyama of Cybernet Systems, and Dr. Tsuneo Munakata of Jedat.

This research is partially supported by a collaborative research with Seiko Epson Corporation, a research project of the Joint Research Center for Science and Technology of Ryukoku University, a grant for research facility equipment for private universities from the Ministry of Education, Culture, Sports, Science and Technology, and a grant for special research facilities from the Faculty of Science and Technology of Ryukoku University.

## References

[1] M. Kimura, I. Yudasaka, S. Kanbe, H. Kobayashi, H. Kiguchi, S. Seki, S. Miyashita, T. Shimoda, T. Ozawa, K. Kitawada, T. Nakazawa, W. Miyazawa and H. Ohshima, IEEE Trans. Electron Devices 46, 2282 (1999).
[2] M. Kimura, H. Maeda, Y. Matsueda, H. Kobayashi, S. Miyashita and T. Shimoda, J. SID 8, 93 (2000).
[3] M. Kimura, Y. Matsueda, T. Ozawa and M. J. Quinn, Jpn. Patent Application, H10-69147 (1998) (in Japanese).
[4] R. M. A. Dawson, Z. Shen, D. A. Furst, S. Connor, J. Hsu, M. G. Kane, R. G. Stewart, A. Ipri, C. N. King, P. J. Green, R. T. Flegal, S. Pearson, W. A. Barrow, E. Dickey, K. Ping, S. Robinson, C. W. Tang, S. V. Slyke, C. H. Chen, J. Shi, M. H. Lu, M. Moskewicz and J. C. Strum, SID '99, 438.
[5] http://www.sony.co.jp/SonyInfo/News/Press/200102/01-007/ (in Japanese).
[6] S. W. B. Tam, M. Kimura, R. Friend, T. Shimoda and P. Migliorato, IDW '02, 243.
[7] H. Kageyama, H. Akimoto, T. Ouchi. N. Kasai, H. Awakura, N. Tokuda and T. Sato, SID ’03, 96.
[8] R. M. A. Dawson, Z. Shen, D. A. Furst, S. Connor, J. Hsu, M. G. Kane, R. G. Stewart, A. Ipri, C. N. King, P. J. Green, R. T. Flegal, S. Pearson, W. A. Barrow, E. Dickey, K. Ping, S. Robinson, C. W. Tang, S. V. Slyke, C. H. Chen, J. Shi, M. H. Lu and J. C. Strum, IEDM '98, 875.
[9] M. Ohta, H. Tsutsu, H. Takahara, I. Kobayashi, T. Uemura and Y. Takubo, SID '03, 108.
[10] Y. Matsueda, D.-Y. Shin, K.-N. Kim, D.-H. Ryu, B.-Y. Chung, H.-K. Kim, H.-K. Chung and O.-K. Kwon, IDW '04, 263.
[11] M. Kimura, Y. Hara, M. Kato, H. Hara, T. Okuyama, S. Inoue and Tatsuya Shimoda, Jpn.

J. Appl. Phys. 45, 4407 (2006).
[12] M. Kimura, D. Suzuki, Y. Hara, S. Sawamura and M. Kato, SID '08, 1173 (2008).
[13] D. Suzuki, M. Koike, S. Sawamura, M. Kato and M. Kimura, AM-FPD '09, 177.
[14] D. Suzuki, M. Koike, S. Sawamura, M. Kato and M. Kimura, The 6th Thin Film Materials and Devices Meeting, 129 (2009) (in Japanese).
[15] M. Kimura, S. Inoue and Tatsuya Shimoda, IEEE Trans. Computer-Aided Design of ICAS 21, 1101 (2002).