Frequency Dependence of OLED Voltage Shift Degradation

***Hyunjong Kim*[1]*, Suhwan Kim*[1]*, Seung Wook Chang*[2]*, Dongkyu Lee*[2]*, Dong Seob Jeong*[2]*, Ho Kyoon Chung*[2]* and Yongtaek Hong*[1]**
[1]Dept. of EECS, Seoul National University, Seoul 151-744, KOREA
TEL:82-2-880-9567, e-mail: yongtaek@snu.ac.kr.
[2]Corporate R&D Center, Display Lab, Samsung SDI Co., Ltd.,
428-5 Gongse-Dong, Kiheung-Gu, Yongin-Si, Gyeonggi-do 449-577, KOREA

Keywords : OLED, degradation, frequency, active-matrix, digital driving

Abstract

OLED driving voltage shift can reduce the OLED display lifetime, especially for digitally driven AMOLED. By operating OLED at high frequency, we were able to suppress OLED voltage shift degradation, expecting improved AMOLED lifetime. We describe frequency dependence of voltage shift obtained from bias stress test of OLED.

1. Introduction

Active-matrix organic light-emitting display (AMOLED) technology is now much matured and the actual mass production of AMOLED panel occurs this year. Most of the AMOLEDs are based on an analog driving method where compensation pixel circuits are implemented in the pixel structure to significantly improve the quality of thin-film transistor (TFT) backplane. TFT backplanes are typically based on either poly-crystalline (poly-Si) [1] or amorphous silicon (a-Si) [2] technology. However, it is well known that both poly- and a-Si TFTs can degrade the quality of AMOLED image due to non-uniform current flow through the pixel organic light-emitting diodes (OLEDs) that result from the non-uniformity of poly-Si TFT performance resulting from the non-uniform TFT fabrication processes and from the degradation of a-Si TFT performance as display operation time increases, respectively. Therefore, a certain level of compensation for these problems must be incorporated in AMOLED pixels for longer display lifetime. [3]

However, since the compensation circuit typically contains several TFTs in each pixel, it will definitely increase manufacturing and operation cost for AMOLED, which is one of the several critical issues for AMOLED to compete with other types of display technologies. Therefore, for simple and inexpensive manufacturing and operation purposes, a so-called digital driving method is being considered, where the driving TFT operates in the linear regime and the AMOLED pixel is digitally driven to operate each pixel in fully on or off modes. The variation of the TFT characteristics can be compensated by fully turning the AMOLED pixel on or off with a data signal high or low enough to turn the pixel fully on or off irrespective of TFT threshold voltage variation. [4] For the digital driving method, however, since the driving TFT operates in the linear regime, the AMOLED pixel is more sensitive to OLED operation stability, especially to OLED driving voltage shift. If there is OLED driving voltage shift after a certain period of display operation, its effect can directly be observed as an additional reduction of the AMOLED luminance which will further reduce the display lifetime. Thus, high-efficient, long-lifetime OLED device structures and improved digital driving method must be developed to improve the digitally driven AMOLED lifetime.

In this paper, we the dependency of the OLED driving voltage shift on OLED operation frequencies. We observed the OLED driving voltage suppression at certain high frequencies of the OLED driving signal. Frequency dependence of OLED impedance change [5] and lifetime improvement of OLED through duty ratio driving method [6] have been reported. Since semiconductor devices typically show reduced charge trapping or degradation effects when the same driving signal is applied to the device, but at higher frequencies, we combined frequency modification and duty ratio driving method to further improve the OLED operation lifetime.

2. Experimental

For the experiments of the frequency dependency of the OLED driving voltage shift, we used top-emission blue fluorescent (TBOLED), and bottom-emission blue (BBOLED) and green (BGOLED) fluorescent OLEDs, which were fabricated on glass substrates at Samsung SDI. The ITO substrates were treated with ultraviolet (UV) ozone for 15 minutes and then annealed on a hot plate for 10 minutes. The structure of BBOLED and BGOLED is ITO/HIL/HTL /EML/ETL/LiF/Al. All the OLEDs were encapsulated by glass caps with desiccant. The light emitting area was 4 mm^2.

For the OLED performance characterization and bias-stress test, a semiconductor parameter analyzer, HP 4155C, connected with a pulse generator unit, HP 41501B was used. To measure the initial absolute OLED luminance (cd/m^2), we used Minolta luminance meter LS-100. We stressed the OLEDs by applying pulsed voltage signals with 50% duty ratio at several frequencies for a certain period of time. Then, the stress pulsed voltage signal was intermittently stopped to measure current-voltage (I-V) characteristics of OLED and an OLED voltage at a given constant current level. During I-V characteristics measurement, OLED light output was measured with a photodiode to monitor the luminance change relative to its initial luminance. The photodiode produces photo-current corresponding to the OLED light output or luminance. We carefully optimized the sweep step and range of the sweeping OLED voltage for I-V characteristics measurement so that the contribution of the measurement to the total OLED stress time is minimal. All the device characterization and stress test were performed in the air at room temperature.

3. Results and discussion

Table 1 shows the peak voltage (V_{peak}) of the stress pulsed voltage signals and the corresponding peak current density (J_{peak}) and luminance (L_{peak}) at the peak voltage for TBOLED, BBOLED, and BGOLED. Since we used 50% duty ratio in this paper, the averaged luminance (L_{avg}) is the half of the peak luminance, which are 2000, 3000, 5000 cd/m^2 for TBOLED, BBOLED, and BGOLED, respectively. We used the relatively high initial luminance conditions to accelerate the degradation process of each OLED. Typical values of the maximum luminance required for 150 cd/m^2 maximum luminance of the commercially available hand-held phone are 800-900, 1200-1400, and 700-800 for red, green, and blue OLEDs, respectively. Although we used the luminance four to five times higher than those required for the commercial applications, our OLEDs showed little change (especially for BBOLED and BGOLED) in luminance and driving voltage after the 60000 sec stress test.

TABLE 1. OLED stress conditions

	V_{peak} (V)	J_{peak} (mA/cm^2)	L_{peak} (cd/m^2)	L_{avg} (cd/m^2)
TBOLED	7.5~7.8	50	4000	2000
BBOLED	8.2~8.3	75	6000	3000
BGOLED	7.2~7.3	50	10000	5000

We applied the stress pulsed voltage signals at several frequencies (60~240Hz) to TBOLED to investigate the OLED driving voltage degradation behavior. Figure 1 shows the TBOLED driving voltage shift ($\Delta V_{shift} = V_{stressed} - V_{initial}$) for the initial averaged luminance of about 2000 cd/m^2. $V_{initial}$ and $V_{stressed}$ are voltage values that were measured at a constant current density of 50 mA/cm^2 before and after a certain period of the stress test. In Fig. 1, the schematic description of the stress pulsed voltage signals for 60, 120, and 240 Hz operations are also included. As the frequency of the stress pulsed voltage signals increases, the OLED driving voltage shift was observed to be suppressed. There was little change in the OLED light-emission efficiency for the stress test performed at several frequencies. The OLED light emission efficiency degraded only a few percent from the initial averaged luminance for all the stress pulsed voltage signals at the several frequencies when the same averaged driving current (thus the same averaged luminance) and the same duty ratio signals were used during the stress test. Table 2 summarizes the values of the TBOLED driving voltage shift during the stress test at 60, 120, and 240 Hz.

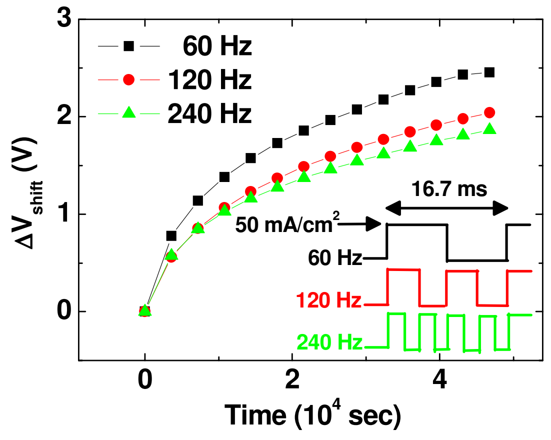


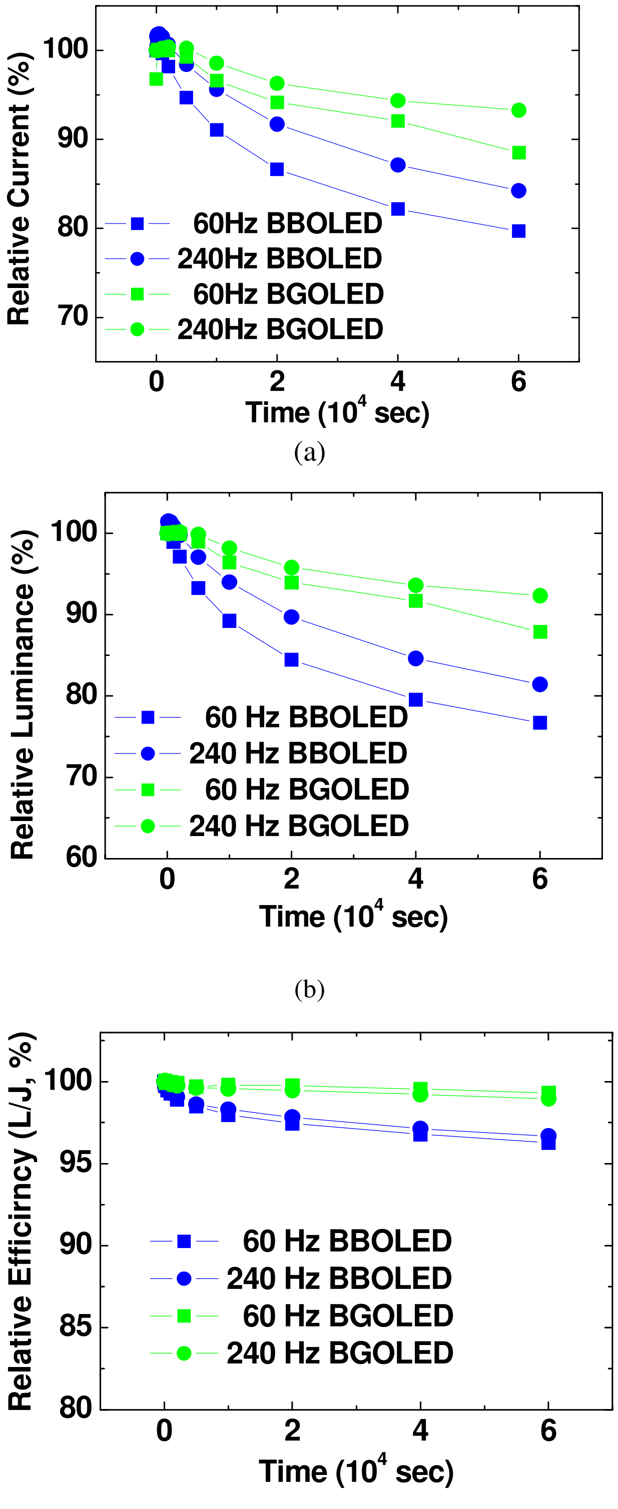
Fig. 1. TBOLED driving voltage shift and the waveforms used for the stress test

TABLE 2. TBOLED driving voltage shift during the stress test at several frequencies

Stress time (10^4 sec)	60 Hz	120 Hz	240 Hz
0	7.67	7.76	7.53
2.2	8.42	8.05	7.90
4.3	9.00	8.54	8.34
Total ΔV_{shift}	2.43	1.98	1.81

To further analyze the dependency of OLED driving voltage on the driving frequency, we used the same method for BBOLED and BGOLED. We monitored both OLED current and luminance changes at a given OLED driving voltage during the pulsed voltage stress test at frequencies of 60 and 240Hz. Figure 2 shows the change of the current flow, luminance, and calculated efficiency of OLEDs from their initial values for BBOLED and BGOLED. For the calculated efficiency, the measured luminance was divided by the measured current. All the relative values show the percent ratio of the stressed value to the initial value.

The current and luminance were measured at constant voltages of 8 and 7.2 volts for BBOLED and BGOLED, respectively. These voltage values are the same as the peak voltage that were used for the pulsed voltage stress as shown in the Table 1. It is shown in Fig. 2 that the reduction of current and luminance (thus, degradation of OLED performance) were suppressed when the 240 Hz pulsed voltage signal was used for the stress test in comparison with the result of the 60 Hz pulsed voltage signals. After 60000 sec stress time, the current flow through the BBOLED and BGOLED for the same driving voltage was reduced to 79 and 84% of the initial current flow for the pulsed voltage stress test at 60 Hz. Since OLED luminance is typically proportional to the current flow through the OLED, the luminance change follows the tendency of the current flow change. However, the absolute amount of the luminance degradation can be different from that of the current flow degradation when the OLED efficiency cd/A degradation is differently affected by the stress pulsed voltage signals with 60 and 240 Hz frequencies. From Fig. 2(c), the efficiency degradation is little affected by the frequency of the OLED driving voltage. Difference in the amount of the efficiency reduction for 60 and 240 Hz is only less than 0.4% for both devices after 60000 sec stress time. The change of current flow, luminance, and calculated efficiency is summarized in Table 3. If we define the lifetime of OLED (95% lifetime) at the time when the luminance drops to 95% of the initial luminance, the lifetime of BBOLED and BGOLED is



(a)

(b)

(c)

Fig. 2. Change of (a) current, (b) luminance, and (c) calculated efficiency for BBOLED and BGOLED. Current and luminance were measured at a constant voltage that is the peak voltage value of the stress pulsed voltage signals for each device.

3600 and 15700 second, respectively, for the 60 Hz stress conditions. The lifetime has been increased to 8300 and 27300 seconds for BBOLED and BGOLED, respectively, for the 240 Hz stress conditions. If we compare the driving voltage shift at the end of the about 40000 sec stress time of TBOLED and BBOLD, the BBOLED showed the better device stability with less than 5% increase ($\Delta V_{shift}/V_{peak}$ = 0.4/8.2~8.3) from the initial driving voltage value while the TBOLED showed about 25% ($\Delta V_{shift}/V_{peak}$ = 2.43/7.5~7.8) increase. It is noted that the more accelerated initial stress conditions were used for BBOLED (Table 1). Therefore, for blue OLEDs, bottom-emission type OLED showed the much better device stability in comparison with the top-emission counterpart.

TABLE 3. BBOLED and BGOLED current, luminance, calculated efficiency reduction after 60000 sec stress time

	BBOLED		BGOLED	
	60 Hz	240 Hz	60 Hz	240 Hz
Current	79 %	84 %	88 %	93 %
Luminance	76 %	81 %	88 %	92 %
Efficiency	96.3 %	96.7 %	99 %	99.3 %

4. Summary

We observed that the OLED driving voltage shift can be suppressed with little change in the device efficiency by operating the OLED at high frequency. Based on our result, 240 Hz operation of OLED showed smaller OLED driving voltage shift in comparison with 60 Hz operation for TBOLED, BBOLED and BGOLED, after the same amount of the pulsed voltage stress time. Thus, the 95% lifetime of BBOLED and BGOLED has been increased by almost two times when 240 Hz stress conditions were used. We are currently further investigating this frequency dependence of OLED driving voltage shift at other frequencies for several OLED devices. Based on our preliminary result, it may not be expected that the suppression effect monotonously increases as the operation frequency increases. There can be an optimal frequency to produce the best suppression effect for each type of OLED. By combining the optimization of the operation frequency and the duty ratio driving method, further improvement of OLED lifetime is expected; thus, the improved lifetime of digitally driven AMOLED can be obtained. Simple digital driving method will give a big benefit to AMOLED technology, such as further reduction of fabrication and driving cost of AMOLED.

5. Acknowledgement

Authors Kim, Kim, and Hong thank Display Technology Research Center and Inter-University Semiconductor Research Center at SNU for facility support. This work was financially supported by SSDIP (SNU-Samsung SDI Display Innovation Program)

6. References

[1] Y. Matsueda et al, *IMID'06 Technical Digest*, p.393 (2006).

[2] T. Tsujimura, *Japanese Journal of Applied Physics*, **43**, 5122 (2004).

[3] W. Nam et al, *IMID'06 Technical Digest*, p.399 (2006).

[4] M. Kimura et al, *IEEE Trans. Elec. Dev.*, **46**, 2282 (1999).

[5] L.S.C. Pingree et al, *Applied Physics Letters*, **86**, 073509 (2005)

[6] Tsujioka et al, *Japanese Journal of Applied Physics*, **40**, 2523 (2001)