A 2T1C AMOLED Display with External Compensation Reducing On-Panel Current Variations to 0.079%

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Abstract

This paper presents a new compensation principle using a 2T1C pixel circuit. The implementation shows significant improvement in uniformity for all grey-levels, due to compensation for both V_T and β -factor variations. The resulting current variation after compensation in the characterized display area reaches values down to 0.079%.

Author Keywords

Flexible displays; AMOLED; compensation; calibration; uniformity; V_T -shift; variations; 2T1C pixel circuit; metal-oxide semiconductors

1. Introduction

Despite all their advantages, the thin-film transistor (TFT) backplane technologies used in AMOLED and AMLED displays, such as low temperature polysilicon (LTPS) or amorphous Indium Gallium Zinc Oxide (a-IGZO) suffer from several problems. One of the most significant challenges is the threshold voltage (V_T) variations between transistors on panel, which results in nonuniform display appearance. Several techniques have already been explored, both for in-pixel [1] and external [2,3,4] V_T compensation. In-pixel techniques require more transistors per pixel negatively impacting display resolution and pixel scaling. Therefore, external compensation methods are more desirable for high-resolution displays.

Although a previous compensation method [4] shows promising results for compensating for V_T variations with only 3 transistors per pixel, the variability of this method significantly increases for different grey-levels. Hence, this demonstrates the need for an improved compensation method, considering not only V_T variations, but also different sources of variations, such as mobility variations, variations in channel width or length due to etching non-uniformities, etc. [5]. This paper implements a new compensation method, that compensates for both V_T and β - (or K -) factor variations using a simple 2T1C pixel circuit. The implementation of this method shows a significant improvement in uniformity for all grey levels, with current variations down to 0.079%.

2. Backplane Fabrication

The displays used in this paper demonstrating the compensation method are manufactured with a self-aligned a-IGZO dual-gate TFT backplane. The layer stack, as shown in Figure 1, is similar to the technology used in [4,6]. Since the dual-gate functionality is not required for this compensation method, the backgate of every TFT is connected to its frontgate.

Figure 1. Backplane cross-section.

3. Compensation Method

The proposed compensation method is implemented using a 2T1C pixel circuit, shown in Figure 2 (a). The transistor T_1 functions as a select transistor whereby T_2 acts as drive transistor, to control the current flowing through the OLED. The capacitor (C) is used as storage element to keep the voltage on the gate of T_2 constant while the select transistor T_1 is open. Figure 2 (b) provides a microscope picture of the display with this pixel circuit, used in this work to evaluate the compensation principle.

Although different compensation methods already exist, these methods usually compensate only for V_T or one current level. The current through the drive TFT (I_{DS}), and thus through the OLED, when operating saturation regime can be calculated for a certain data voltage (V_{GS}) by using formula (1).

$$I_{DS} = \frac{\mu \cdot C_{ox}}{2} * \frac{W}{L} (V_{GS} - V_T)^2 = \beta * (V_{GS} - V_T)^2 \quad (1)$$

Compensating only for V_T or one current level can eliminate variations in current for one grey level. However, if the β -factor is different for each pixel, the current will still vary for different grey levels, even after V_T compensation. Therefore, this compensation method proposes to compensate for β -factor variations as well as for V_T variations.

Figure 2. 2T1C pixel circuit. (a) Schematic, (b) Microscope picture.

The compensation cycle starts with measuring the current through each pixel for different data voltages. Then, the measurements results are fitted to formula (1) and the corresponding β and V_T are subsequently extracted and stored for each pixel. The compensated data voltage (V_{GS}) can then be calculated using formula (2).

$$V_{GS} = \sqrt{\frac{I_{DS}}{\beta}} - V_T \quad (2)$$

This formula uses three parameters to determine the compensated data voltage, namely the desired current through the pixel (I_{DS}), and the two fitting parameters (β and V_T). The desired current indicates the grey level of the pixel in the image to be displayed, whereas the fitting parameters are stored in the external memory. Since the compensated data voltage needs to be calculated for every pixel and every frame, it is important that the computation power for this calculation is minimized. Therefore, the parameter $1/\beta$ is stored in the external memory instead of β , so the division can be replaced by a multiplication, which is a much faster implementation. The resulting calculation, schematically represented in Figure 3, only requires one multiplication, one square root, and one addition. Since these operations only require limited computation time, it is feasible to implement this for display applications, such as real-time videos. Furthermore, to limit recalibration time, it is possible to only measure one data point for recalibration, since the β -factor variations are caused by process variations, and hence should not change significantly during operation.

Figure 3. Block diagram indicating the required processing to calculate the compensated gate voltage (V_G) for a certain desired current I_{DS} (grey-level).

4. Display Characterization

The compensation method is evaluated by characterizing a 32x32 pixel area (1024 pixels). The current through each pixel is measured for different gate voltages. First, in the measurement, before calibration, shown in Figure 4 (a), the current through each pixel is measured for multiple fixed gate voltages. Thereafter, β and V_T are extracted from these measurements for each pixel. Lastly, the current through each pixel is measured at multiple fixed grey levels, using the corresponding compensated gate voltages calculated with these parameters. This last measurement, presented in Figure 4 (b), provides the current for each pixel after compensation at different grey levels. The resulting graphs of Figure 4 clearly show a significant improvement in uniformity at all grey levels after compensation by using the proposed compensation method.

Figure 4. Measured current at different grey levels for 1024 pixels. (a) before calibration, (b) after calibration.

Figure 5. Current variation at different grey levels before calibration (blue) and after calibration (purple).

Figure 5 shows the current variation at different grey levels before and after compensation. The current variation before calibration varies from 17.2% at low brightness, to 2.8% at high brightness, whereas the current variation after calibration is reduced, ranging from 1.8% at low brightness, to 0.079% at medium brightness. It should be noted that the 1.8% current variation at low brightness corresponds to a variation of only a few nA. Hence, at these grey levels, the measured current variation is limited by the measurement accuracy. At a medium brightness level ($I_{\text{mean}} = 4\mu\text{A}$), the current variation before calibration is 4.15%. Hence the uniformity is improved by a factor up to 52.5.

To further assess the compensation method, some optical measurements are performed using a ProMetric12 camera from Radiant Vision Systems. Because of some dead pixels in the characterized display area, the optical measurements are performed on 1015 pixels, which is still sufficient to get statistical data. Figure 6 shows a 2D map in false color with the measured brightness of each pixel for grey levels 5% and 25% before and after compensation. These 2D brightness maps clearly show that the compensation method also improves optical uniformity.

Figure 6. Colormap of measured brightness for each pixel. (a) at grey level 5% before compensation, (b) at grey level 5% after compensation, (c) at grey level 25% before compensation, (d) at grey level 25% after compensation.

Figure 7. Scatter plot showing the measured brightness of each pixel at different grey levels (5%, 10% and 25%) before and after compensation.

The brightness of each pixel at different grey levels, more specifically at 5%, 10% and 25%, before and after calibration is presented in Figure 7. This scatter plot shows that the variation in brightness is much lower after compensation for all these grey levels. Consequently, we can conclude that the proposed compensation principle improves the uniformity optically as well.

5. Scalability

The characterization of this compensation method was performed on a small display area with large pixels. Nevertheless, the compensation principle can be implemented as well on larger display sizes with higher resolutions. The large pixels were chosen for this implementation to facilitate the optical characterization, but the actual pixel circuit is much smaller than the pixel pitch, as can be seen in Figure 2 (b). Furthermore, the compensation method can be implemented on a full display for very large display sizes due to the simple driving scheme. Figure 8 shows a picture of a fully compensated display.

Figure 8. Picture of a compensated image on a full display.

6. Conclusion

This work demonstrates the effectiveness of a new external compensation method for AMOLED displays. In this method not only V_T variations are compensated, but also other sources of variations are taken into account by using the β -factor. The

implementation of this compensation method shows an improvement in uniformity with more than a factor 50, reducing the current variation to 0.079%. Since the proposed compensation principle uses a simple driving scheme and a 2T1C pixel circuit, it can be implemented to realize large high-resolution uniform displays.

7. Acknowledgements

We would like to express our gratitude to the processing team of Holst Centre's R&D TFT Pilot Line for fabrication of the display backplanes. Furthermore, we want to gratefully thank the OLED team from imec for the OLED depositions. This work was financed by the Flexlines project within the Interreg V-program Flanders-The Netherlands, a cross-border cooperation program with financial support from the European Regional Development Fund, and co-financed by the Province of Noord-Brabant, The Netherlands.

8. References

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