Going Towards High-Resolution, Uniform AMOLED Displays with a High Brightness Range

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Abstract

Going towards high-resolution, uniform displays with a high-brightness range requires optimizations on different topics. This work presents an overview on this subject. To achieve a good uniformity, a compensation method is proposed using a 2T1C pixel circuit, compatible with high-resolution requirements, improving uniformity by a factor 52.5. In order to further increase the achievable resolution, a new technology stack, using a planar and a vertical TFT is introduced. For increasing the brightness range, a global dimming method, compatible with the 2T1C pixel circuit, is demonstrated.

Author Keywords

AMOLED; IGZO; high-resolution; variation; uniformity; compensation; global brightness dimming.

1. Introduction

The industry imposes ever increasing demands on resolution. Especially for mobile applications and when going towards augmented reality (AR) or virtual reality (VR), higher resolutions are vital. Nevertheless, this cannot come at the cost of uniformity. In-pixel compensation techniques usually require additional transistors in the pixel, yielding e.g., 6 [1,2] or 8 [3] transistors per subpixel. Since the additional transistors reduce the achievable resolution, these compensation methods are not desirable for high-resolution applications. Hence, an external compensation method, using a minimal 2T1C pixel circuit [4,5] is preferred. The compensation method presented in this work, shows significant improvement in uniformity at all gray levels.

Although reducing the number of transistors in a pixel can significantly increase the resolution, this approach is limited by technology. Therefore, in this work, we propose a new technology stack, enabling higher resolutions. The proposed technology stack consists of 2 different thin-film transistors (TFTs), a planar and a vertical TFT [6]. The design study for this new stack shows an increased resolution from 1129 ppi to 1752 ppi by going from a known self-aligned stack [4,5] to the proposed stack, while using the same critical dimension.

Another important factor for displays, more specifically in mobile applications, is the brightness range. When a display is used in a very bright environment, the display needs to be able to emit at a high brightness. On the other hand, when the display is used in a very dark environment, good gray level control is required at much lower brightness. To tackle this issue, we propose a global dimming method to set the average (global) brightness separately from the gray level control [7]. Since the global dimming needs to be compatible with the high-resolution requirement, our method uses the backgate of the drive transistor in a 2T1C pixel circuit to implement the global dimming (Figure 7).

2. Compensation Methods for High-Resolution AMOLED Displays

The proposed compensation method uses a minimal 2T1C pixel circuit, as shown in Figure 1. The OLED brightness is determined by the current flowing through the OLED and the drive TFT, i.e., the TFT in series with the OLED. This current is set by a voltage written from the data line, through the select TFT, to the gate of the drive TFT. Since the data is set by the gate voltage of the drive TFT, and the brightness is determined by the current through the drive TFT, any variations in TFT characteristics, such as threshold voltage (V_T) and mobility, result in nonuniformities. Therefore, the compensation method measures the pixel currents at different data voltages, and extracts V_T and β from these measurements, during a calibration cycle. Thereafter, during normal operation, the compensated data voltage is calculated for each pixel based on the desired gray level (I_{DS}) and the fitting parameters (V_T and β), following the TFT equation for operation is saturation regime [8]. This calculation is illustrated in following equation.

$$\boldsymbol{V_{GS}} = \sqrt{\frac{\boldsymbol{I_{DS}}}{\boldsymbol{\beta}}} - \boldsymbol{V_T}$$

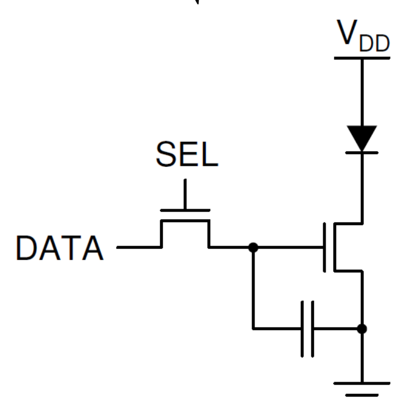

Figure 1. 2T1C pixel circuit.

The compensation method is evaluated by both electrical measurements on 1024 pixels and optical measurements on 1015 pixels. Figure 2 plots the variation in measured current of these 1024 pixels at different gray levels before and after compensation. This plot clearly shows a strong improvement in current variation. At a medium gray level (I_{avg} = 4 µA), the current variation is reduced by a factor 52.5, from 4.15% to 0.079%, by implementing this compensation method. The results of the optical measurements are provided in Figure 3. By plotting the histograms of the 1015 pixels measured at 2 different gray levels, both before and after compensation, on top of each other, it is evident that the proposed method also reduces optical variation.

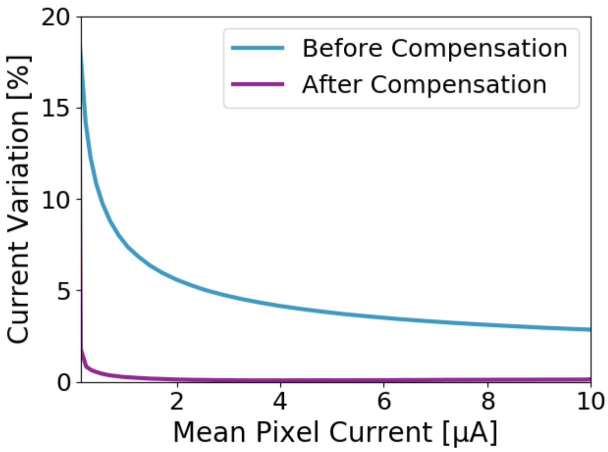

Figure 2. Variation in the measured current of 1024 pixels at different gray levels before and after compensation. [4]

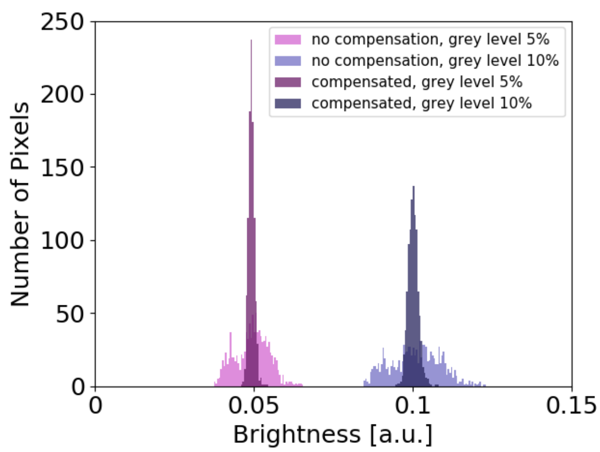

Figure 3. Histogram of the measured brightness of 1015 pixels before and after compensation at 2 different gray levels. [5]

3. Technology for High-Resolution Displays

To further enhance the achievable resolution, technology optimizations are desirable. Therefore, a new technology stack, schematically presented in Figure 4, is proposed. This stack combines 2 different TFTs in one stack, namely a vertical TFT and a planar TFT. In this stack, the gate metal of the planar TFT is the same layer as a SD layer of the vertical TFT. This is ideal to make a connection between the gate of one TFT and the source or drain of another TFT, such as in the 2T1C pixel circuit, without requiring a VIA, and thus saving area. Another area saving aspect in this stack is the 2 TFTs stacked on top of each other, allowing overlapping the footprint of both TFTs.

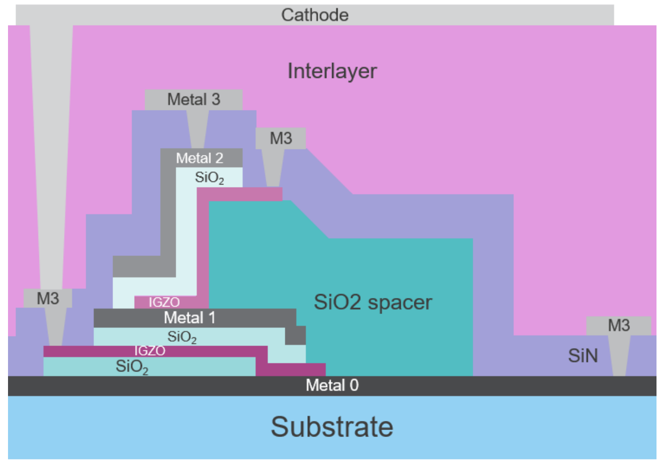

Figure 4. Cross-section of the proposed new technology stack, using a vertical TFT and a planar TFT in one flow.

To determine the area gain for this new stack, a layout was designed for the 2T1C pixel circuit, using predetermined design rules, more specifically, a critical dimension (CD) of 1.5 µm and an overlay of 0.5 µm, both for the proposed vertical TFT stack and the reference self-aligned stack [4,5]. Both layouts are shown in Figure 5, yielding a resolution of 1129 ppi for the reference self-aligned stack, and 1752 ppi for the proposed vertical TFT stack, respectively.

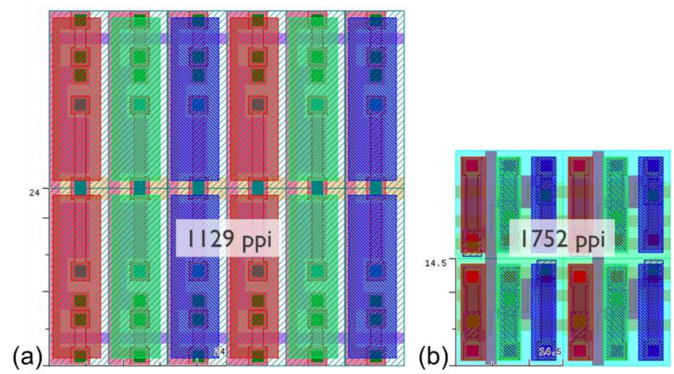

Figure 5. Layout designed with critical dimension (CD) 1.5 µm and overlay 0.5 µm for (a) a known self-aligned stack [4,5] and (b) the proposed new vertical TFT stack.

Figure 6 illustrates the increase in resolution for different critical dimensions by implementing the proposed features. From this graph, it is evident that going from an 8T1C pixel circuit [3] to a compensation method using a 2T1C can significantly improve the resolution. Moreover, implementing the proposed VTFT stack enables even higher resolutions.

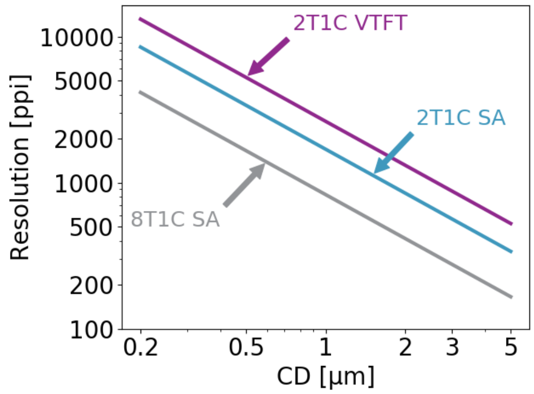

Figure 6. Maximum achievable resolution as a function of critical dimension (CD) for an 8T1C pixel circuit [3] using the reference self-aligned (SA) stack, the proposed 2T1C pixel circuit using the reference SA stack, and the proposed 2T1C pixel circuit using the proposed vertical TFT (VTFT) stack.

4. Implementing Global Dimming to Increase Brightness Range

To increase the brightness range of the display, a global dimming method is proposed. This method applies a global dimming pulse-width modulation (PWM) signal to the pixel, that is independent from the gray level control. Consequently, good gray level control is expected at all different global (average) brightness settings, yielding good image quality in both bright and dark environments. For high-resolution displays, it is not desirable to add any elements, such as transistors, in the pixel circuit. Therefore, the global dimming PWM signal is applied to the backgate of the drive transistor, as shown in Figure 7.

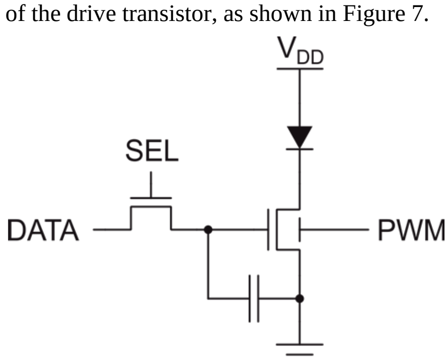

Figure 7. 2T1C pixel circuit with a global PWM signal connected to the backgate of all drive transistors to implement the global dimming method.

The method works by relying on the fact that varying the voltage on the backgate of a TFT, shifts the threshold voltage of that TFT [9]. This effect is illustrated in Figure 8. When the PWM signal, i.e., the backgate voltage is high, the current through the OLED is controlled by the gate voltage, i.e., the data voltage. On the other hand, when the PWM signal, i.e., the backgate voltage is low, the threshold voltage of the drive transistor is shifted more positive, inducing no current through the OLED, regardless of the data voltage, and thus turning the pixel off. By varying the duty cycle of the PWM signal, the average brightness is altered, resulting in different global brightness levels, without interfering with the gray level control.

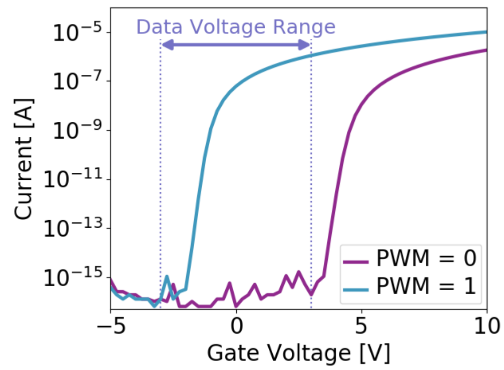

Figure 8. Effect of the backgate voltage on the transistor characteristics.

Figure 9 shows a picture of Lena on the test display at different brightness settings. In Figure 9 (a), the PWM duty cycle is 100%, i.e., the display is emitting light all the time, whereas in Figure 9 (b), the PWM duty cycle is set at 50%, i.e., the display is emitting light during half of the frame, and the other half of the frame, the display is turned off. Since this switching occurs at high frequencies, the eye averages the image content, resulting in an image that appears much dimmer, while still displaying the image with good gray level control.

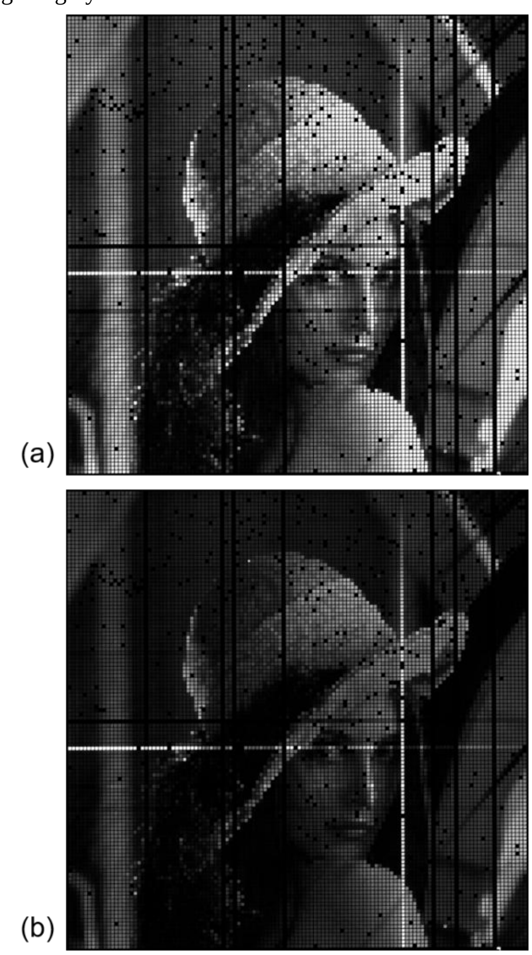

Figure 9. Picture on the test display at a global brightness setting of (a) 100%, and (b) 50%.

5. Conclusion

Good uniformity can be obtained for high resolution AMOLED displays by implementing the proposed external compensation method using a 2T1C pixel circuit, decreasing variations down to 0.079%. A further increase in resolution is enabled by introducing a new technology stack, containing 2 different TFTs, stacked on top of each other. Lastly, we have demonstrated a method to increase the brightness range by implementing a global dimming PWM signal. Accordingly, this work offers an approach on how to go towards high-resolution, uniform displays with a high brightness range.

6. Acknowledgements

7. References

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