# High Performance 2.2 inch Full-Color AMOLED Display for Mobile Phone

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## Abstract

*We developed a high performance 2.2" active matrix OLED display for IMT-2000 mobile phone. Scan and Data driver circuits were integrated on the glass substrate, using low temperature poly-Si(LTPS) TFT CMOS technology. High efficiency EL materials were employed to the panel for low power consumption. Peak luminescence of the panel was higher than 250cd/㎡ with power consumption of 200㎽.*

## 1. Introduction

Active Matrix Organic Light Emitting Diode (AMOLED) displays have attracted much interest in recent years due to the outstanding advantages such as high-speed response, low-driving voltage, high brightness, wide viewing angle and low power consumption. Samsung SDI has succeeded to develop several kinds of AMOLED displays such as 3.6, 8.4[1], and 15.1inch panels since 2000. More recently, we developed 2.2 inch AMOLED display for IMT-2000 mobile phone using LTPS TFT CMOS technology. The number of pixels in the panel is 176 x RGB x 220. We integrated scan and data driver for compact design and also used high efficiency EL materials for low power consumption. In this paper, we report the simulation results and the performance of the panel in detail.

## 2. TFT & OLED model

We extracted SPICE model parameters using RPI poly-Si model[2] for TFT and junction diode model for OLED. Table I shows the characteristics of our TFT. We employed lightly doped drain structure in n-type TFTs to reduce leakage current and improve reliability.

**Table 1. Characteristics of TFTs (Vth:Vg@ Id=10nA)**

| | $U_{eff}$(㎠/Vs) | $V_{th}$(V) | S slope(V/dec) | $I_{leak}$(A) |
|---|---|---|---|---|
| ptft | 88 | -1.4 | 0.42 | 2.9E-13 |
| ntft | 70 | 2.0 | 0.49 | 2.3E-12 |

In the case of OLED, it was difficult to obtain model parameters that could cover a wide driving range. Thus we focused on fitting parameters in the range of pixel current. Fig.1 shows the measurement data & spice fitting curves of fluorescent OLEDs.

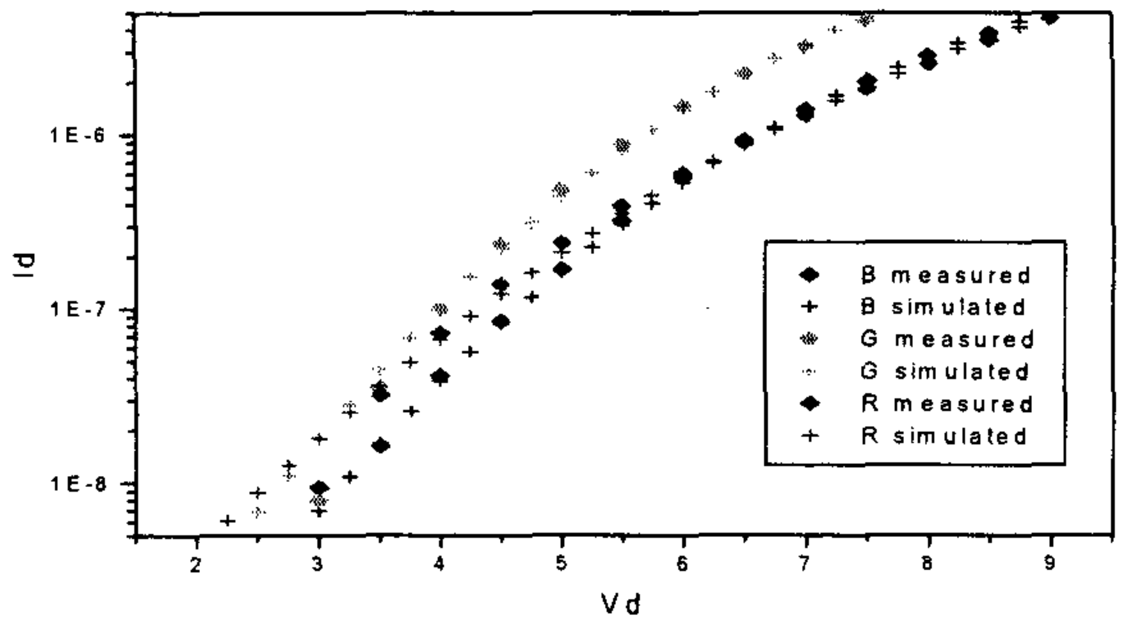

**Fig 1. Measurement vs. Simulation data of fluorescent OLEDs(Area:0.012㎟)**

## 3. Circuit Simulation & Low power consumption

Our 2.2 inch AMOLED display was developed for IMT-2000 mobile phone. Table 2 shows design specifications of 2.2 inch AMOLED panel. According to outdoor readability test, we need at least 100cd/㎡ luminescence to identify characters easily.

**Table 2. Design specifications of 2.2inch AMOLED panel**

| | |
|---|---|
| Effective Display Area | 2.2inch(34.848㎜ x 43.56㎜) |
| Number of pixels(H x V) | 176 x RGB x 220 |
| Pixel pitch(H x V) | 66㎛ x 198㎛ |
| Peak luminescence | 100cd/㎡(on polarizer film) |
| White Color coordinate | (x, y) = (0.3101, 0.3162) |
| Frame frequency | 60Hz |

To be adopted to mobile phone, display should be simple and have a low power consumption characteristics. For these purposes, we integrated scan and data driver circuits on the glass substrate using

LTPS TFT CMOS technology. Fig.2 shows the block diagram of the 2.2 inch AMOLED display. In the case of data driver, we employed DEMUX structure to minimize driving frequency of shift register. When we used this structure to integrated driver circuits, we could accomplish low power consumption under 2㎽ in the integrated circuits parts.(supply voltage:12V)

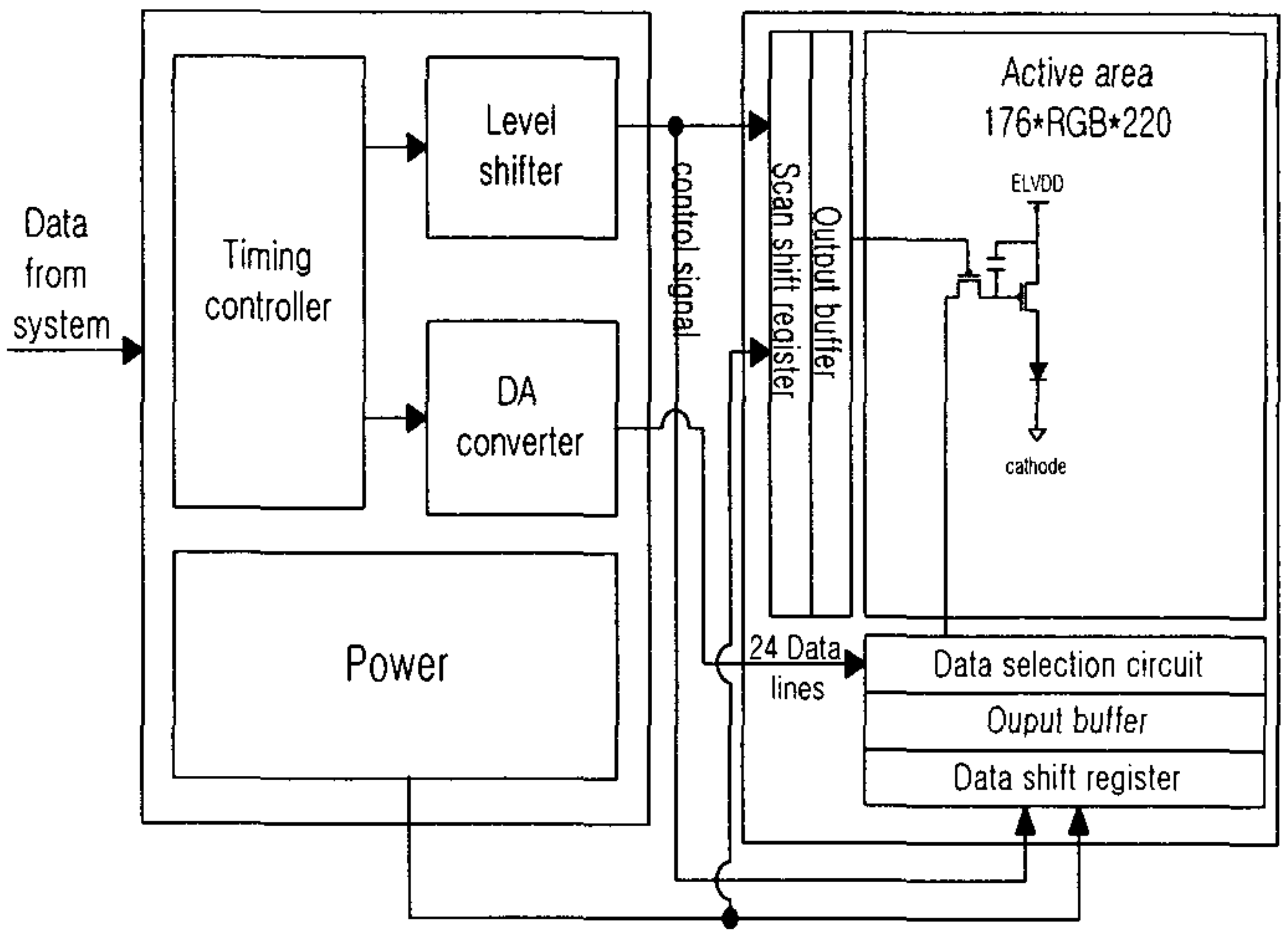

**Fig.2 Block diagram of 2.2inch AMOLED display**

RGB luminescence ratio to meet white balance is determined by each color's CIE coordinates. Table 3 shows the characteristics of our EL materials. Assuming that transmission ratio of polarizer film is 40%, the power consumption for individual color was estimated.(Table 3) Red and green materials listed under high efficiency materials in Table3 are phosphorescent materials which have been developed by UDC(Universal Display Corp.). These materials are capable of producing an internal quantum efficiency close to 100%, since prior to emission, singlet excitons created in EL devices are converted into triplet excitons. Losses in the internal quantum efficiency of EL devices using phosphorescent materials can be explained in terms of non-radiative processes.

**Table3. The characteristics & power consumption of high efficiency materials**

| | fluorescent EL materials | | | | High efficiency materials | | | |
|---|---|---|---|---|---|---|---|---|
| | x | y | cd/A | Power | X | y | cd/A | Power |
| **Red** | 0.60 | 0.38 | 5.1 | **0.38W** | 0.65 | 0.35 | 5.6 | **0.25W** |
| **Green** | 0.30 | 0.65 | 13 | **0.15W** | 0.27 | 0.65 | 22 | **0.09W** |
| **Blue** | 0.14 | 0.16 | 4.7 | **0.29W** | 0.14 | 0.16 | 5.7 | **0.20W** |
| **White** | 0.310 | 0.316 | | **0.829W** | 0.310 | 0.316 | | **0.54W** |

The phosphorescent devices used in the 2.2 inch panel were designed to reduce these non-radiative losses while maintaining other desired performance characteristics such as life time and ease of manufacture. Fig.3 shows I-V curves of EL materials in Table 3. Driving voltage and resistance of red phosphorescent EL materials are smaller than those of red fluorescent EL materials. Thus we could reduce the driving voltage to about 2V. For the green EL material, driving voltage of phosphorescent EL material is higher than that of fluorescent EL material. As shown in Fig.4, the efficiency of green phosphorescent EL material was so high that current density under 5㎃/㎠ was sufficient to meet our panel specification. The resulting driving voltage for green phosphorescent EL was in the range of the driving voltage for red phosphorescent EL. When we used high efficiency materials with the characteristics as shown in Table 3, the power consumption for the panel was reduced by 30% compared to that of fluorescent EL materials.

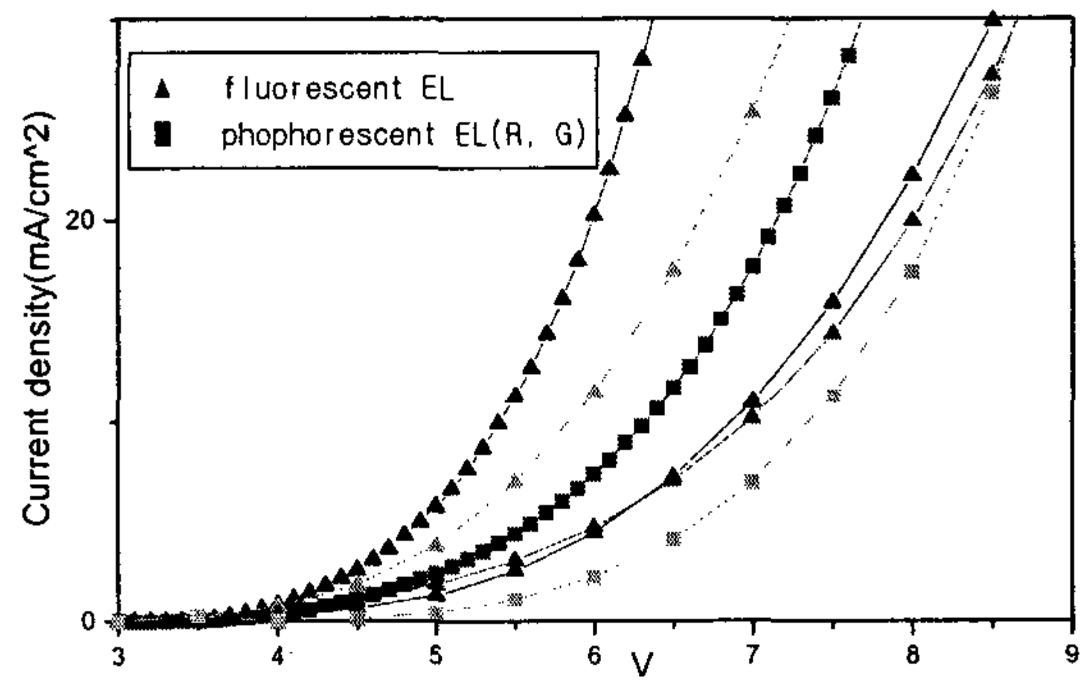

**Fig. 3 I-V curves of EL materials**

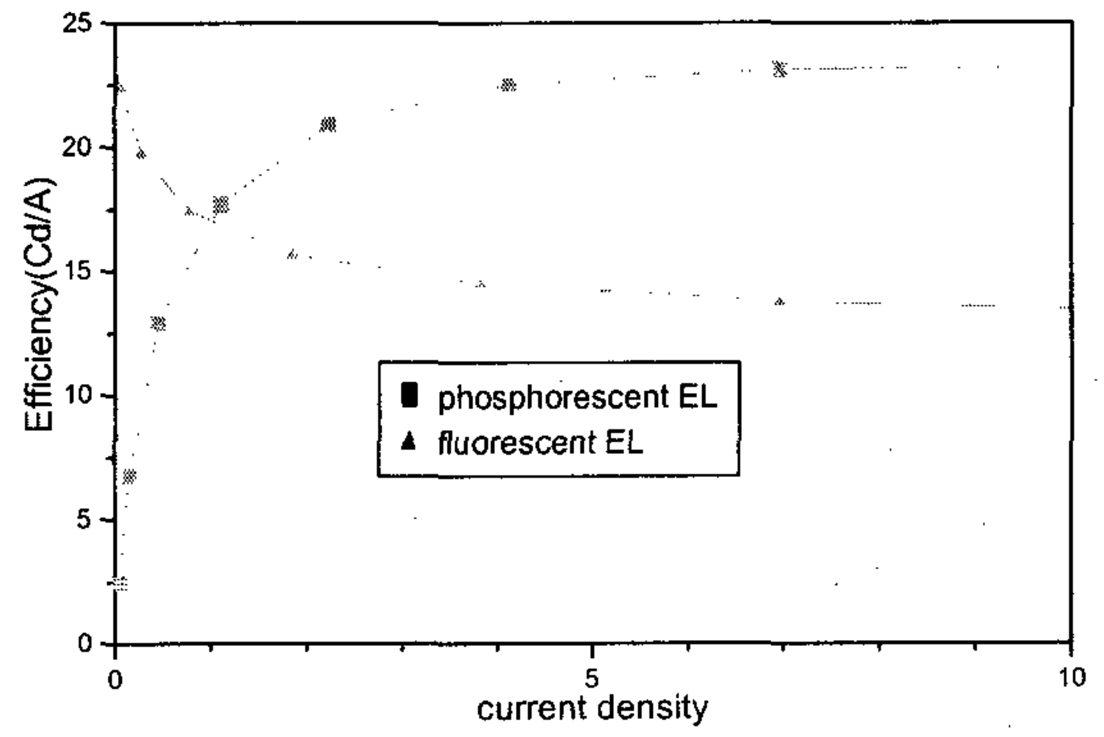

**Fig. 4 Efficiency curves of Green EL materials**

As shown in Fig. 4, the efficiency of Green EL varied widely as a function of current density. Thus we used different data voltage ranges to R, G and B pixels to obtain the white balance. To determine operating conditions, we performed simulations on $V_{data}$, $V_{cathode}$ – $I_{EL}$, using spice models of TFT & OLED. According to the simulation results, our panel required 2.5~3.5V data ranges for driving TFTs and at least 10V for voltage difference between anode and cathode. In actual operation, we need to consider the variation of OLED's resistance due to aging and temperature. Thus we need to consider at least 2V for additional margin. The power consumption shown in Table 3 was estimated under the above conditions.

In AMOLED display, the voltage drop on current supply line is inevitable due to finite resistivity of the line material. To minimize IR drop we used wide power lines, yielding IR drop lower than 100㎷ in full white case. Fig. 5 shows the simulation results on the voltage drop of current line which supplies the current to active area. Applying this result, we could also reduce dead space to achieve in the aperture ratio up to 32%.

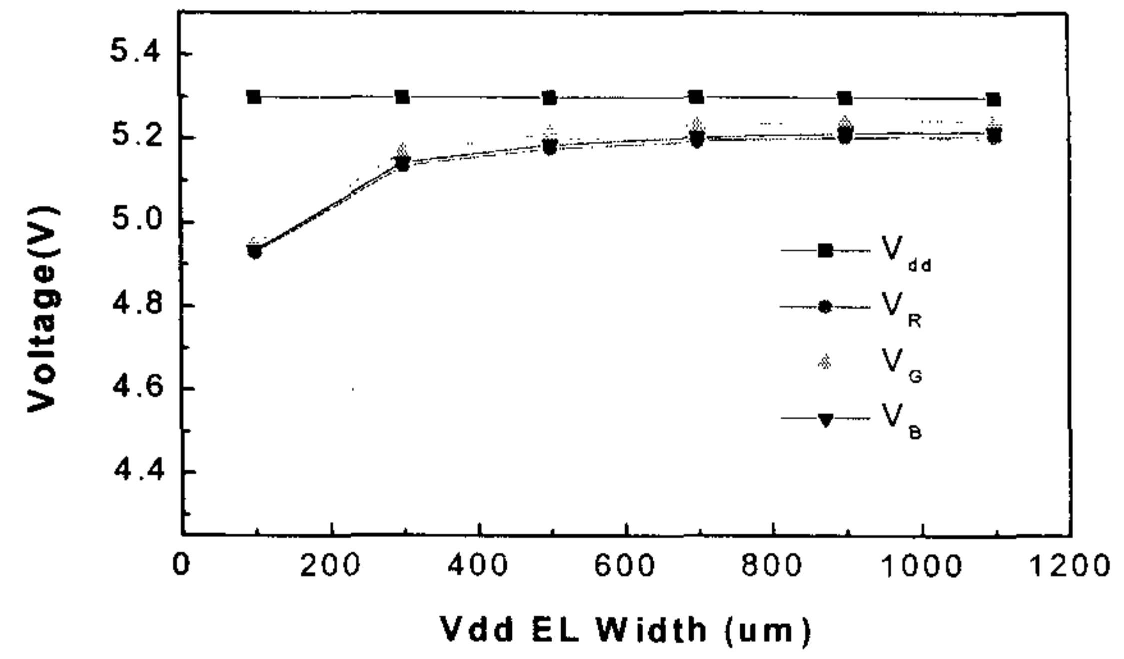

**Fig. 5 The simulation results of voltage drop on power line(250Cd/㎡ without polarizer)**

## 4. Fabrication & Results

The pixel circuit used in the panels for this study is composed of 2 p-channel TFTs and 1 storage capacitor. This structure is well known as a basic pixel circuit for AMOLED and has some difficulty in realizing a good uniform image. But the basic pixel circuit has the strong advantages of achieving high aperture ratio and high yield, which are essential for mass production. To achieve uniform performance, we used a dual-channel driving TFT having a long channel over 30㎛ and we put the channels into a line.

We proceeded evaporation process & glass encapsulation with 370 x 400 glass. We have also optimized conditions for fine metal mask such as material, thickness, tension force, shape and dummy pixel design. Previously Samsung SDI had already made a large size fine metal mask successfully using CAE technology in the case of 15.1 inch AMOLED panel.

The characteristics of the 2.2inch AMOLED panel are summarized in Table 4. The white CIE coordinates are x=0.31 and y=0.32. The peak luminescence of this panel is over 250Cd/㎡ and contrast ratio is 100:1 under the light of 500Lx. When we tested moving picture, the power consumption of this panel was under 200㎽. The 2.2inch AMOLED display images are shown in Fig.6. For the actual displays, the extensive L-I-V characterization exhibited fast response, excellent CIE coordinates, and wide viewing angle. Full color displays were demonstrated with uniform images with 64 gray scales.

**Table 4. The characteristics of 2.2inch full color AMOLED**

| | |
|---|---|
| Display size & resolution | 2.2inch QCIF (176 x RGB x 220) |
| Aperture Ratio | 32% |
| Gray scale | 64 |
| Color coordinates | R(0.65, 0.34) |
| | G(0.27, 0.65) |
| | B(0.14, 0.16) |
| | White(0.31, 0.32) |
| Peak Luminescence | >250cd/㎡ |
| Power consumption* | <200㎽ |

***when 30% of the pixels are on(250Cd/㎡ without polarizer)**

**Fig.6 Images of 2.2inch AMOLED Display**

## 5. Conclusion

We have successfully developed 2.2inch full color AMOLED display with LTPS TFT CMOS technology and high efficiency EL materials. The power consumption of the panel was under 200㎽ on moving picture. This is attractive result, compared to the values reported in the literature for a comparable fluorescent EL display, which was about 350~400㎽[3]. It can be suitable for the mobile phone. The total thickness of this panel is less than 2㎜ and it weighs about 9.8g, which will make the mobile phone ultra thin and light.

## 6. Acknowledgements

We appreciate UDC for supporting phosphorescent EL materials and our process engineers for supporting this work.

## 7. References

[1] H. K. Chung, IMID 2001, 325.

[2] M. D. Jacunski and Michael Hack, IEEE Transactions on electron device, Vol. 43, No. 9. September 1996.

[3] G. Rajeswaran et al., SID proceedings 31 974(2000)