P-1434: Invited Paper: Recent Advances In Small Molecule OLED Microdisplays

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Abstract

eMagin's unique OLED-on-silicon microdisplay technology is unique and is based on small molecule white OLED with color filters using a top emitter structure. This paper will present results of recent improvements in the technology including improved lifetimes and uniformity and will feature an SVGA resolution full color microdisplay that is 0.44 inches diagonal.

1. Introduction

Small molecule OLED technology [1-5] has significantly matured over the last few years. OLED microdisplays, in particular, have significantly evolved during this period resulting in many viable products. OLED microdisplays have certain unique features and requirements compared to large area direct view displays. However, most of the technology developed for near-to-the-eye microdisplays is applicable to large area displays. This paper presents results of some recent advancement made not only in the OLED device [6] but also in the underlying silicon active matrix circuitry [7].

2. Experimental

OLED devices were fabricated on 200 mm diameter silicon wafers, wherein, the active drive circuitry was fabricated in a semiconductor foundry using CMOS technology. Post processing of the wafers was carried out at eMagin including anode patterning, OLED deposition, thin film encapsulation, color filter patterning, cover glass attachment, dicing, wire bonding and sealing.

SVGA resolution white OLED displays were fabricated using top emitter architecture. Figure 1 shows a cross-sectional schematic of a full color display using color filters to generate the primary R,G,B colors. In the case of a 0.72 inch diagonal display (SVGA-3D) the sub-pixel dimensions are 13.5 µm x 3.5 µm with a 1.5 µm spacing to make up a 15 µm color pixel pitch. In the case of a 0.44 inch diagonal display (SVGA-3DS) the color pixel pitch is 11.1 µm, as shown in Figure 2. The white dots in the picture are via studs that connect the anode to the underlying circuitry. The sub-pixels are spaced at 1 µm compared to 1.5 µm for the SVGA-3D product, resulting in an aperture ratio of 66% for SVGA-3DS compared to 63% in the SVGA-3D.

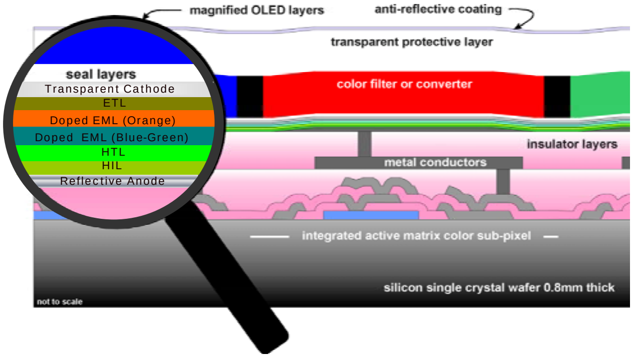


Figure 1: Schematic of top emitting full color OLED-on-silicon device.

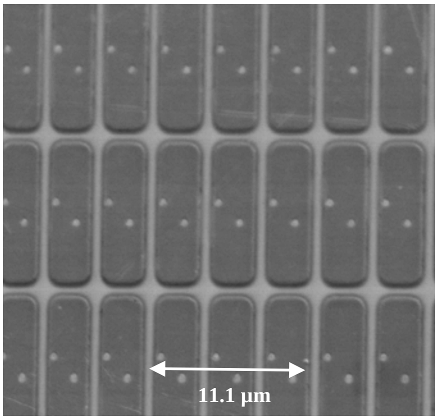


Figure 2: SEM picture of anode pattern for 0.44 inch diagonal display. Pixel pitch is 11.1 µm.

It is well known that the reflectivity of the electrodes plays an important role in the light output. As such, the anode structure was modified to accommodate the maximum reflectivity without compromising hole injection efficiency. Figure 3 shows the reflectance spectrum of the improved anode structure. OLED devices were fabricated using such high reflective anodes. In order to achieve efficient hole injection the surface of the anode was plasma treated prior to organic deposition.

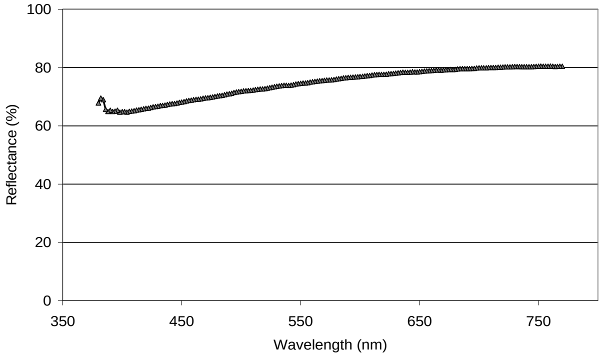
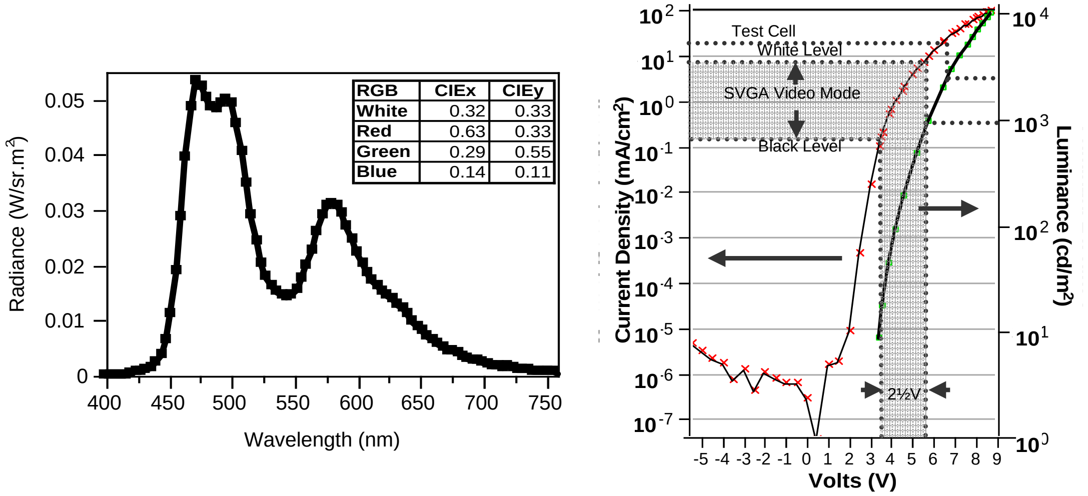


Figure 2: Multi-layer anode reflectance spectrum.

The organic stack consisted of high Tg (~130ºC) materials, deposited at 2-4 Å/sec using high vacuum ($<5x10^{-7}$ Torr) techniques. The hole injection layer (HIL) thickness was in the range of 150-200 Å and the hole transport layer (HTL) thickness was in the range of 250-350 Å. The dual emission layer (EML) consisted of a blue-green region and an orange region, resulting in white light emission. The host material in the blue-green region was doped with a blue-green dopant while the orange region was doped with an orange dopant. Typical dopant concentrations were in the molar ratios of 1.5% to 2.5% of the host, respectively. A 250-350 Å layer of undoped Alq3 was used as electron transport layer (ETL). A multi-layer semi-transparent cathode structure was deposited over the Alq3. Following the cathode a transparent passivation layer was deposited. The devices were subsequently encapsulated using thin film techniques. R,G,B color filters were photolithographically patterned over the thin film seal.

3. Results

Figure 3(a) and 3(b) show the white OLED spectrum and the I-V characteristics of the displays. Typical luminance for a full color microdisplay is about 200 cd/m^2. The CIE coordinates for these displays, using color filters, is shown in the inset of Figure 3(a). The shaded region in Figure 3(b) shows typical operating current and voltage ranges in video mode for an active matrix microdisplay. The efficiency for these devices is in excess of 10 cd/A. Figure 4 shows the chromaticity of the displays as a function of grey level. It is apparent from the figure that the CIE coordinates do not vary significantly over the entire grey level range. This is important for many applications where a wide grey level range is highly desired without losing color purity. The initial portion of these curves are noisy due to low luminance levels and instrumental sensitivity issues.



RGB	CIEx	CIEy
White	0.32	0.33
Red	0.63	0.33
Green	0.29	0.55
Blue	0.14	0.11

(a) (b)

Figure 3: (a) Spectral radiance (b) Brightness-current density-voltage characteristics

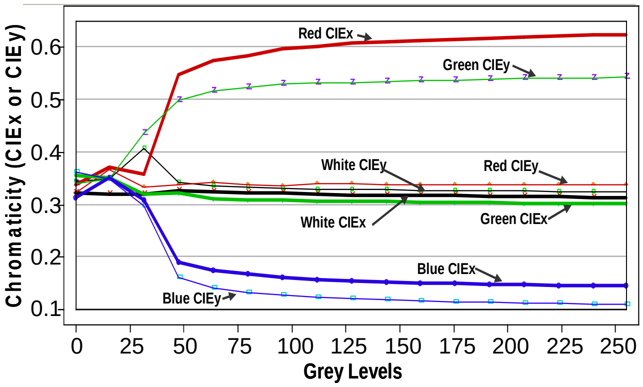


Figure 4: Chromaticity versus grey level

Figure 5 shows the degradation of relative luminance as a function of time. The measurements were done at constant current using 20 mA/cm^2 and 10 mA/ cm^2. The operating half-life at 20 mA/cm^2, with a typical luminance of 200 cd/m^2, was measured to be in excess of 6000 hours which corresponds to 25,000 hours when driven in video mode with a duty cycle of 25%. When driven at 10 mA/cm^2 the projected half life was in excess of 15,000 hours, corresponding to approximately 60,000 hours in video mode. For an initial luminance of 60 cd/m^2 the operating half-life is about 75,000 hours in video mode.

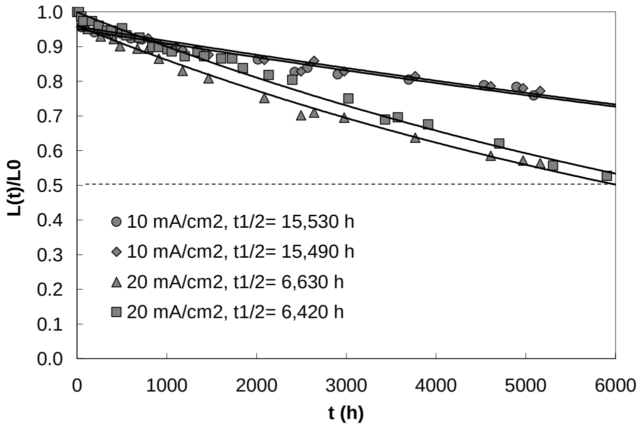


Figure 5: Relative luminance versus time. Half life is extrapolated using an exponential fit.

Table 1 shows life time measurements [8] at two different starting luminances on displays with and without improvements in OLED architecture and materials. The displays with the improvements are denoted as XL and those without improvements are denoted as Standard. It is clear from the table that the percentage improvement in the life-time of the displays was significant. The percentage improvement in life-time of the displays with lower starting luminance shows significantly higher improvement (705%) relative to those with higher starting luminance (398%). The percentage improvements are also higher during the initial phase of the operation of the displays.

Display Type	**Starting Lum. (cd/m^2)**	**90% Life**	**75% Life**	**50% Life**
Color XL	68	13000 h	33000 h	66000 h
Color Standard	68	1000 h	3700 h	8200 h
% Improvement		**1200%**	**792%**	**705%**
Color XL	170	2400 h	6200 h	12450 h
Color Standard	170	440 h	1230	2500 h
% Improvement		**445%**	**404%**	**398%**

Table 1: Life-time comparison between improved OLED architecture and materials (XL) and standard.

Figure 6 shows the results of the new circuit design that leads to better pixel-to-pixel uniformity. The results shown in Figure 6(a) are for the 0.44 inch diagonal SVGA-3DS display using improved OLED stack and architecture while Figure 6(b) shows a typical SVGA-3D display prior to improvement in circuitry.

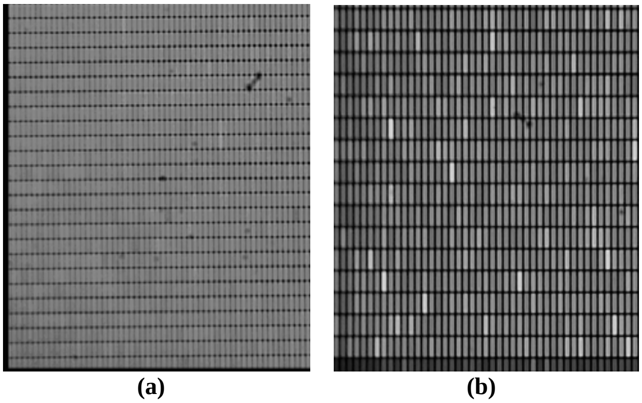

(a) (b)

Figure 6: Pixel-to-pixel uniformity improvement (a) New improved circuitry (b) Prior circuitry

Figure 7 shows a plot of luminance versus ambient temperature for SVGA-3D and SVGA-3DS displays. It is clear from the figure that the improved built-in circuitry for temperature compensation markedly improved the OLED device performance over the prior uncompensated devices. Clearly a temperature range of -55ºC to +80 ºC can be achieved without significant change in luminance. Additionally, contrast, power consumption and CIE coordinates were shown to be minimally affected by ambient temperature (-55ºC to +80 ºC range) using the built-in temperature compensation circuitry, as reported in Ref. [9].

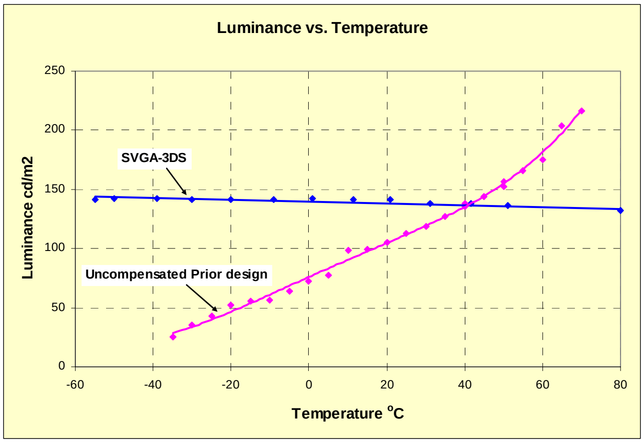


Figure 7: Luminance versus ambient temperature

Figure 8 shows a picture of eMagin's SVGA-3DS display incorporating all the improvements discussed above. As can be seen from the figure the uniformity, contrast and clarity of the image is excellent. This near-to-the-eye microdisplay is being introduced as a product.

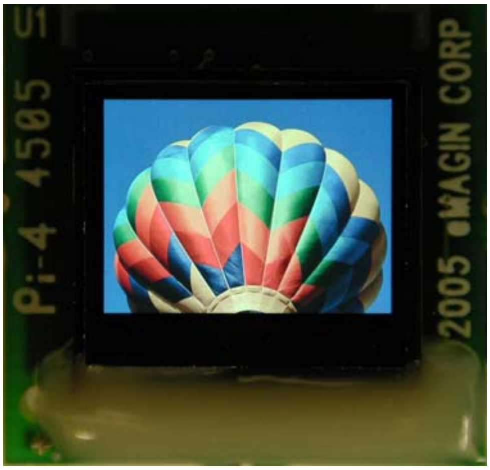


Figure 8: eMagin's SVGA-3DS display incorporating all the improvements

4. Conclusion

Several significant improvements were made to the existing OLED-on-silicon microdisplay. The improvements were across the board including the OLED device architecture, materials, chip design and features embedded in the chip. The resulting display was more efficient, longer operating half-life, marked improved pixel-to-pixel uniformity, wide temperature tolerance without significant performance degradation and vivid color and contrast. Further improvements are underway on a continuing basis.

5. Acknowledgements

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