WUXGA Resolution 3D Stereoscopic Head Mounted Full Color AMOLED Microdisplay

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Abstract

We report a WUXGA (1920×1200) resolution head mounted OLED microdisplay with luminance of 2000cd/m^2 in monochrome and 240cd/m^2 in full color. We believe this is the highest resolution OLED microdisplay based headset ever reported. The sub-pixel size for this 0.86-inch diagonal microdisplay is 2.45μm×8.5μm.

Author Keywords

WUXGA; OLED; AMOLED; Microdisplay; 3D Display; Head Mounted Display; Near-to-eye application.

1. Introduction

eMagin's active matrix organic light emitting diode (AMOLED) microdisplays are ideal for the near-to-the-eye applications because of their light weight, compactness, ruggedness, and power efficiency. In the past, eMagin developed and commercialized SVGA, SVGA+ [1] and SXGA [2-4] resolution OLED microdisplays. The need for wider field-of-view head mounted display (HMD) continues to drive the development of even higher resolution microdisplays. To this end, in 2011, eMagin introduced a WUXGA (1920×1200) resolution AMOLED microdisplay [5]. In addition to the increased resolution, this device also exhibits numerous performance improvements including high brightness, longer lifetime, high efficiency and increased data rates. The overall power consumption in the WUXGA microdisplay remains low in order to maintain acceptable battery life in portable systems. In this paper, we report on the fabrication and technical characteristics of a WUXGA resolution 3D stereoscopic OLED microdisplay for use in a near-to-the-eye headset.

2. Design and Fabrication

The lightweight headset, as shown in Figure 1, consists of ergonomically designed optics and the WUXGA resolution OLED microdiplays. These headsets may include white, full color and high brightness monochrome green and yellow. The headset is capable of showing true 3D video in HD format with a large virtual screen effect. The OLED microdisplay was fabricated using high glass transition temperature (Tg) small molecule materials sandwiched between a reflective anode and a transparent cathode. Combining the higher reflectivity anode with the optimized organic stack resulted in the high performance devices. Fluorescent materials were used for white and color displays whereas phosphorescent materials were used for high brightness green and yellow devices.

The anode pixilation is performed using standard high-resolution photolithography processes. A schematic of a typical white OLED device architecture is shown in Figure 2, where the anode is a high reflectivity metal composite, followed by hole injection layer (HIL), hole transport layer (HTL), emitter layer (EML), hole blocking layer (HBL), electron transport layer (ETL), transparent cathode and passivation layers. These layers were deposited via thermal evaporation in <5×10^{-7} Torr vacuum.

Figure 1. Binocular 3D stereoscopic HMD using full color WUXGA resolution AMOLED microdisplay (inset).

Green emission is obtained using a single dopant and single host [6]. Yellow emission is generated using several approaches as described in [7]. White emission is generated using two emitter layers with blue and red dopants respectively.

A full color microdisplay uses red, green and blue (RGB) band pass color filters on top of the white OLED emitter (Fig. 2). The advantage of such a structure is that it can be formed directly on active matrix silicon devices, which may contain active addressing and drive circuitry. The combination of the higher reflectivity anode with the optimized organic stack resulted in a high performance OLED devices reported herein.

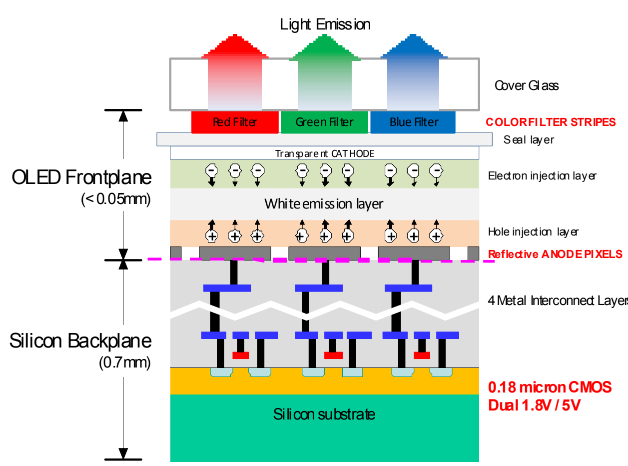

Figure 2. Schematic of eMagin full color OLED micro-display.

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Table 1. HMD Optical Parameters

Parameter	Value
Field of View (diagonal)	65 degrees
Virtual Image Focus Distance	4 m
Exit Pupil Size	10 mm
Eye Relief	25 mm
Distortion	<5%
Inter-Pupilary Distance (IPD)	62mm fixed
Total Weight	143.5g

3. Microdisplay and HMD Characteristics

Binocular 3D stereoscopic viewing has a number of advantages. One advantage is the absence of "ghosting" or inter-ocular crosstalk. A second advantage is the nonexistence of brightness reduction compared to the device where 3D content is delivered through two duplicate sets of pixels on a same microdisplay, and thus reducing the luminance twofold due to less number of subpixels contributing to the image.

Delivering 3D video content through two separate microdisplays also allows to maintain high resolution, which otherwise would be considerably reduced. Important as well, the binocular stereoscopic design eliminates the 3D "sweet" spot, which is a viewing angle for effective 3D performance. When furnished with head-tracking feature, a binocular device may also allow motion cues. Our binocular 3D stereoscopic HMD supports various video formats including WUXGA (1920×1200), HD1080 (1920×1080) and UXGA (1600×1200). The HMD has horizontal and vertical scan direction control, electronic image centering capability, horizontal and vertical shift up to 24 pixels.

The use of OLED technology allows instant start of the device and operation in wide temperature range, from -45 to +65ºC. A built-in low voltage differential signaling (LVDS) video interface offers the convenience of integrating the display in various imaging systems. An LVDS interface allows for efficient transport of the high video data rates and enables the microdisplay to be located at a remote distance from the drive electronics. The display requires only standard 24-bit digital RGB data as input to its video port in addition to power and a 2-wire serial control signal. A reference output signal is provided for use in optimizing the display gamma settings over various operating conditions. The display is equipped with on-the-fly gamma correction feature for stable color rendering over a wide brightness range. The HMD optical parameters are listed in Table 1. The total weight of about 140gm makes the binocular display an attractive choice for HMD systems.

Table 3. WUXGA Typical Parameters

Parameter	Value
Total Pixel Array*	1944 x RGB x 1224
Extra Pixels for Optical Alignment	24 columns and 24 rows
Diagonal Viewing Area	21.7 mm (0.86")
Package Envelope	26.4 x 17.5 x 4.7 mm
Weight	<3 gm
Connector	40-pin Hirose DF12D(3.0)-40DP-0.5V
White Luminance	>150 cd/m2 (color display)
CIE-x White	0.310 to 0.350
CIE-y White	0.330 to 0.370
Color Gamut	>75% of NTSC
Gray Levels	256 per primary color
Contrast Ratio	>100,000:1
Uniformity	>85% end-to-end
Analog Dimming Ratio	200:1
PWM Dimming Ratio	500:1
Video Interface	Serialized LVDS, 24-bit RGB
Refresh Rate	30 to 85 Hz
Video Source Clock	220 MHz max
LVDS Clock	442 MHz max
LVDS Data Rate	883 Mbps
Power Consumption	<250mW (video content @ 150cd/m^2)

*Total pixel count includes 24 extra columns and rows

The WUXGA resolution microdisplay, implemented in eMagin's latest full-color AMOLED technology, has a viewing area of 0.86-inch diagonal and a power consumption of only 250mW for typical video content. Table 2 compares the key parameters for the WUXGA display, with two other platforms in production at eMagin. Each increase in resolution has been accompanied by a reduction in the pixel size in order to maintain the viewing diagonal at less than one inch. This is essential in order to minimize the size and weight of the corresponding near-to-eye optic as well as to minimize production costs for the microdisplay. The fill factor, on the other hand, has steadily improved due to ongoing developments in the OLED technology, resulting in a smoother image despite the shrinking pixel dimensions. For example, the WUXGA design provides a 13% improvement in fill factor compared to the SVGA+ despite having a 60% smaller pixel. The WUXGA microdisplay characteristics are listed in Table 3. This microdisplay features 7 million total pixel elements delivering 24-bit color depth images (16.7 million colors) at ultra-high contrast ratio of more than 100,000:1. An impulse drive allows full HD+ resolution 3D imaging without flicker, motion blur or image latency.

Table 2. Comparison of SVGA+, SXGA and WUXGA designs

Parameter	SVGA+	SXGA	WUXGA
Format (pixels)	852(x3) x 600	1280(x3) x 1024	1920(x3) x 1200
Color Pixel Aspect Ratio	15μm sq. RGB color group	12μm sq. RGB color group	9.6μm sq. RGB color group
Color Pixel Arrangement	R, G, B vertical stripe	R, G, B vertical stripe	R, G, B vertical stripe
Display Size	0.61" diagonal	0.77" diagonal	0.86" diagonal
Gray Levels	256 per primary color	256 per primary color	256 per primary color
Operating Ambient Temp.	-35ºC to +65ºC	-45ºC to +70ºC	-45ºC to +70ºC
Storage Temp.	-55ºC to +90ºC	-55ºC to +90ºC	-55ºC to +90ºC
Sub-pixel Width x Height	3.5 μm x 13.5 μm	4 μm x 11 μm	2.45 μm x 8.5 μm
Fill Factor	63%	69%	71%

The WUXGA design includes on-chip look-up-tables for adjusting gamma and a digital-to-analog converter for driving the core array, dispensing with the need for any external ASIC functionality and greatly simplifying the task of the system integrator.

A combination of analog and novel pulse width modulation (PWM) dimming techniques provide the WUXGA with a versatile capability for setting the luminance output level in wide range of 0.05cd/m^2 to 2000cd/m^2 in the monochrome version and of 0.02cd/m^2 to 450cd/m^2 in the color version.

Figure 3 shows normalized luminance vs. PWM duty rate. An inset in the figure shows a close-up of the low percentage region.

The analog dimming function allows regulation of the peak current of the OLED array corresponding to an input gray level of 255. It provides linear adjustment over a dimming range of about 200:1 using a register setting.

Figure 4 shows good linear trend in the luminance changing with the grey level in the temperatures range of -40ºC to 70ºC. As can be seen from Figure 5, variation of normalized luminance at fixed grey level is no more than 15% in this temperature range.

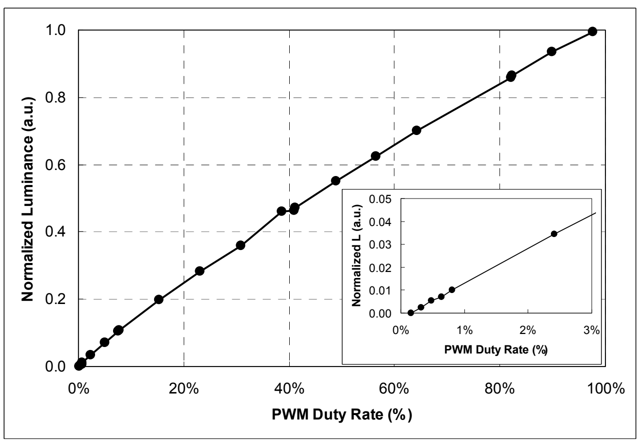

Figure 3. WUXGA white AMOLED microdisplay normalized luminance vs. PWM duty rate. The inset is a close-up of the low percentage region.

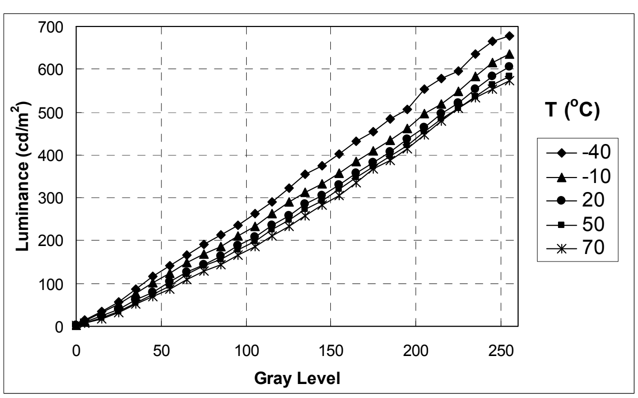

Figure 4. Luminance vs. gray level at various temperatures.

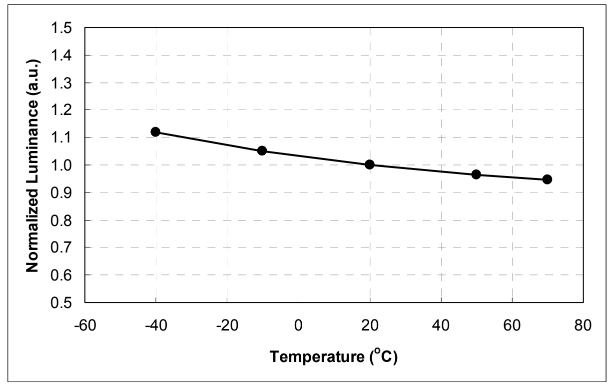

Figure 5. Normalized luminance at fixed grey level vs. temperature.

The PWM dimming capitalizes on the very fast response time of the OLED diode. Since an OLED diode will switch in less than a microsecond, over a thousand times faster than an LCD device, its output can be modulated at the horizontal line rate. A drive-to-black scheme is implemented, whereby a row of pixels is switched off in the WUXGA at any time during a frame period, to allow programmable control of the pixel duty rate (Fig.6). A total dimming range of 240:1 was measured for color device for luminance between 2.2cd/m2 and 540cd/m2 (Fig. 7).

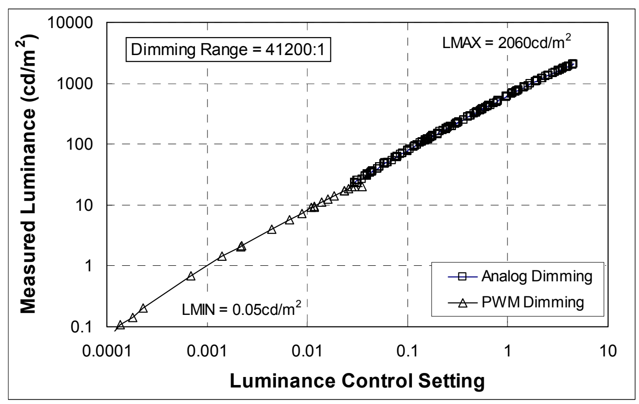

Figure 6. WUXGA white AMOLED microdisplay luminance control.

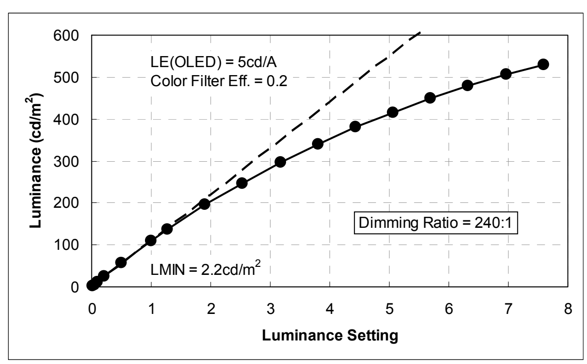

Figure 7. Luminance control in WUXGA color AMOLED microdisplay with maximum luminance reaching level of >500cd/m^2.

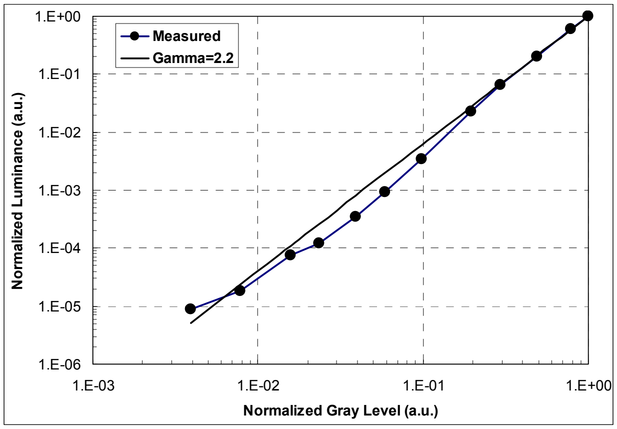

Figure 8. Luminance vs. gray level in WUXGA color AMOLED microdisplay with built-in gamma correction.

In addition to PWM, a built-in gamma correction feature helps in maintaining practically linear variation of luminance with the gray level as shown in Figure 8.

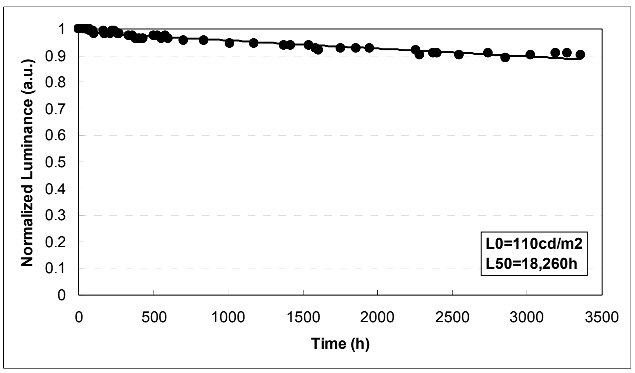

Figure 9. Life test at starting luminance 110cd/m^2 comparable a typical usage level.

The operational lifetime of WUXGA color microdisplays were measured with an initial luminance of 110cd/m^2. This luminance is in the range of typical usage level for HMD. The relative luminance data collected over 3,000 hours of actual test time at room temperature are shown in Figure 9. The operating lifetime was measured to be in excess of 18,200 hrs with flat field, all pixels on condition. This corresponds to about 73,000 hrs when driven in video mode, which has a typical duty cycle of 25%.

The overall power consumption for the WUXGA microdisplay as a function of its output luminance is given in Figure 10. The measurements were taken for three cases: 1) uniform flat field with all pixels on, 2) typical video content, and 3) all pixels off. The luminance levels are shown for the monochrome white device. A color device would generate about 20-25% of the luminance for the same power level. The power consumption for an emissive display is very much dependent on the video content it displays, so the middle curve (typical video) is the most relevant metric of the AMOLED display performance. It most closely represents average power consumption for the WUXGA under typical conditions. The measurements indicate an average power consumption of less than 250mW at a luminance of 150cd/m^2 for the color WUXGA. Portable applications, in particular, will find this level of performance in a high-resolution display to be especially compelling.

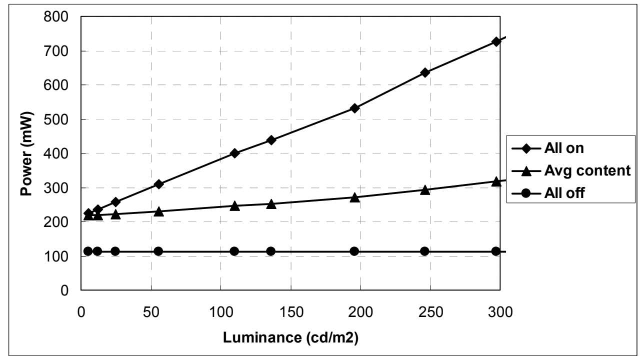

Figure 10. Monochrome WUXGA power consumption vs. luminance. In a typical video mode, the power consumption is about 250mW at 150cd/m^2.

4. Conclusions

eMagin Corporation has successfully developed an ultra-high resolution AMOLED technology that was used to produce an HDTV+ microdisplay for near-to-eye applications. The full-color WUXGA resolution microdisplay contains over 7 megadots in a 0.86” diagonal area and consumes about 250mW under typical operating conditions. It is also the first microdisplay to integrate a low-power LVDS interface directly on chip. Summarizing, our AMOLED WUXGA microdisplay is ideally suited for commercial, industrial, medical and military applications that require a wide field-of-view, low-power near-to-eye display, such as simulation and training, night vision, virtual and augmented reality, gaming and others.

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