

Ultra-High Resolution and High-Brightness AMOLED

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ABSTRACT

As part of its continuing effort to improve both the resolution and optical performance of AMOLED microdisplays, eMagin has recently developed an SXGA (1280x3x1024) microdisplay under a US Army RDECOM CERDEC NVESD contract that combines the world's smallest OLED pixel pitch with an ultra-high brightness green OLED emitter. This development is aimed at next-generation HMD systems with "see-through" and daylight imaging requirements. The OLED pixel array is built on a 0.18-micron CMOS backplane and contains over 4 million individually addressable pixels with a pixel pitch of 2.7 x 8.1 microns, resulting in an active area of 0.52 inches diagonal. Using both spatial and temporal enhancement, the display can provide over 10-bits of gray-level control for high dynamic range applications. The new pixel design also enables the future implementation of a full-color QSXGA (2560 x RGB x 2048) microdisplay in an active area of only 1.05 inch diagonal. A low-power serialized low-voltage-differential-signaling (LVDS) interface is integrated into the display for use as a remote video link for tethered systems. The new SXGA backplane has been combined with the high-brightness green OLED device developed by eMagin under an NVESD contract. This OLED device has produced an output brightness of more than 8000fL with all pixels on; lifetime measurements are currently underway and will be presented at the meeting. This paper will describe the operational features and first optical and electrical test results of the new SXGA demonstrator microdisplay.

Keywords: OLED, AMOLED, microdisplay, SXGA, QSXGA, high-brightness, virtual imaging, daylight viewing, see-through imaging, augmented reality

1. INTRODUCTION

As part of its ongoing effort to improve both the resolution and optical performance of AMOLED microdisplays, eMagin has recently developed a 1280x3x1024 resolution microdisplay (SXGA-2) under an NVESD contract that combines the world's smallest OLED pixel pitch with an ultra-high brightness green OLED emitter. The OLED pixel array is built on a 0.18-micron CMOS backplane and contains over 4 million individually addressable pixels with a pixel pitch of 2.7 x 8.1 microns, resulting in an active area of 0.52 inches diagonal. The new pixel design enables the future implementation of a full-color QSXGA (2560 x RGB x 2048) microdisplay in an active area of only 1.05 inch diagonal. The new SXGA-2 backplane has been combined with the high-brightness green OLED device developed by eMagin under an NVESD contract and reported on last year [1]. This OLED material has produced an output brightness of more than 8000fL in the prototype microdisplay with all pixels on, firmly in the range deemed necessary for HMD systems with "see-through" and daylight imaging capability. This paper presents the operational features and first optical and electrical test results for the new SXGA prototype microdisplay. Lifetime measurements for brightness levels of up to 5000fL are reported and usable life models will be discussed.

AMOLED microdisplays have achieved wide acceptance in a range of military and commercial applications in the past few years as a result of their compelling advantages in size, weight, and power consumption over competing solutions. Products are now offered with formats ranging from VGA to WUXGA [2] resolution and a typical output luminance of 70fL for color, 350fL for monochrome white, and 1500fL for monochrome green. Future applications are already demanding even greater levels of performance. In particular, AMOLED microdisplays are being challenged to meet the

needs of augmented reality, avionics, digitally fused systems, and training and simulation applications for daylight and see-through head mounted displays.

High performance microdisplays are required to support next generation integrated HMDs. These new HMDs will need to display higher resolution sensor/synthetic video and symbology over a wide field of view (FOV) to the Warfighter in either see-through or non-see-through modes. The display that is required must have the following attributes to meet the system level requirements that have been proposed.

- High resolution; needed to support high resolution sensors (>2MP)
- High luminance; needed for see-through applications (visor type HMDs)
- High contrast; needed for discerning detail in both NIR, FLIR and SWIR imagery
- Large viewing angle; to support large exit pupil systems, off-axis optics with no change in contrast over angle
- Light weight; to reduce head supported weight and center of gravity
- Low power; to reduce heat and increase operating time when on batteries
- Growth to color; color is needed for sensor fusion and symbology discrimination

A microdisplay that can satisfy all or most of the requirements above is critical to the success in fielding this next generation integrated HMD. Many integrators are seriously developing prototype systems integrating high performance near infrared (NIR) technology into their HMDs or stand-alone digital fused goggles to support night navigation without conventional ANVIS goggles. These HMDs will also be required to display distributed aperture system (DAS) video for situational awareness. Active matrix organic light emitting diode (AMOLED) microdisplays of the type produced by eMagin already meet many of the key performance parameters described above and are progressing rapidly in others.

DAS and NIR sensors will exceed 4MP and therefore a display is required to meet this native resolution along with the attributes noted above. The ISIE4000 EBAPS low light sensor, for example, has a video frame of 2000 columns x 2000 rows. eMagin has been reporting on pixel density improvement efforts over the past several years aimed at increasing the resolution of its AMOLED microdisplays to meet the expected requirements as shown in Figure 1.

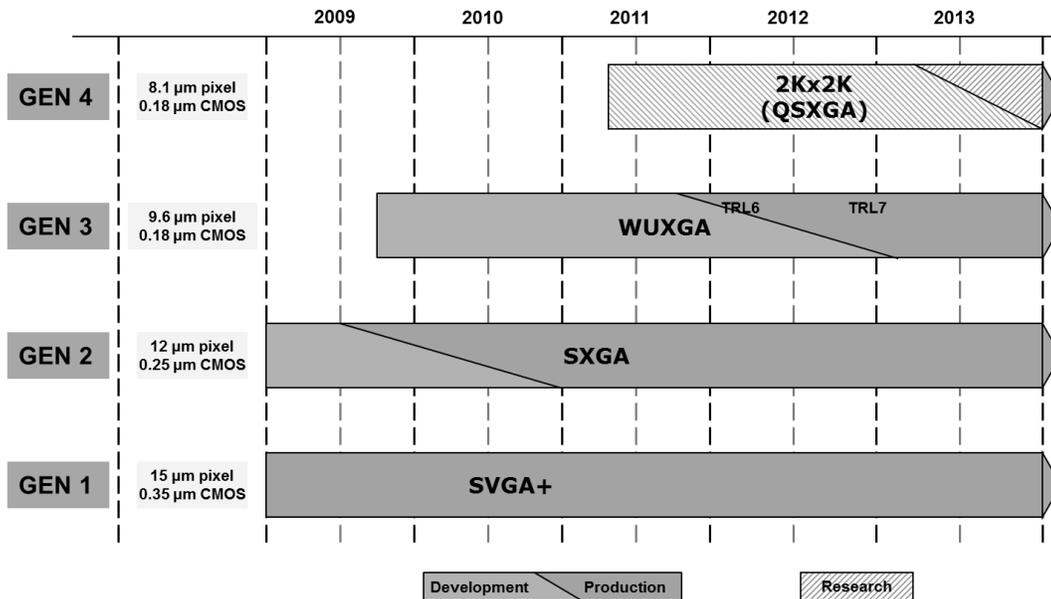


Figure 1: AMOLED Technology Roadmap

In 2009 eMagin demonstrated an SXGA display using a 4x12 micron pixel. In 2011 eMagin introduced the WUXGA microdisplay built with a 3.2x9.6 micron pixel. Most recently, under a contract funded by NVESD, a prototype

1280xRGBx1024 microdisplay with a pixel size of only 2.7x8.1 micron (SXGA-2) has been developed. A pixel of this size can be used in the near future to build a full color microdisplay with resolution of 2KxRGBx2K in a 0.92" diagonal area, and a full color QSXGA display with a diagonal of only 1.05".

In 2008, 2009, 2010, and 2011, via research contracts managed by NVESD, eMagin developed further lifetime improvements in their displays, utilizing different materials and modifying different processes for long-life monochrome and color displays. The performance of the high brightness green OLED-XLT reported in 2011 [1] showed excellent characteristics and consequently was combined with the new 8.1-micron test display in this work to demonstrate the feasibility of and evaluate its performance in an ultra-high resolution see-through application. In addition to serving the military market for advanced HMDs, these next generation displays will also meet the needs of commercial applications such as see-through goggles for industrial, medical, and augmented reality.

2. HIGH BRIGHTNESS GREEN OLED

A comparison of the material characteristics of monochrome green OLED currently used in eMagin's displays is given in Figure 2. The OLED-XL material is based on fluorescent material, while the new high brightness green OLED-XLT is based on phosphorescent material¹. It has been introduced into production starting this year. Phosphorescent materials are increasingly used in OLED products as a result of their significantly higher efficiency and higher luminance output.

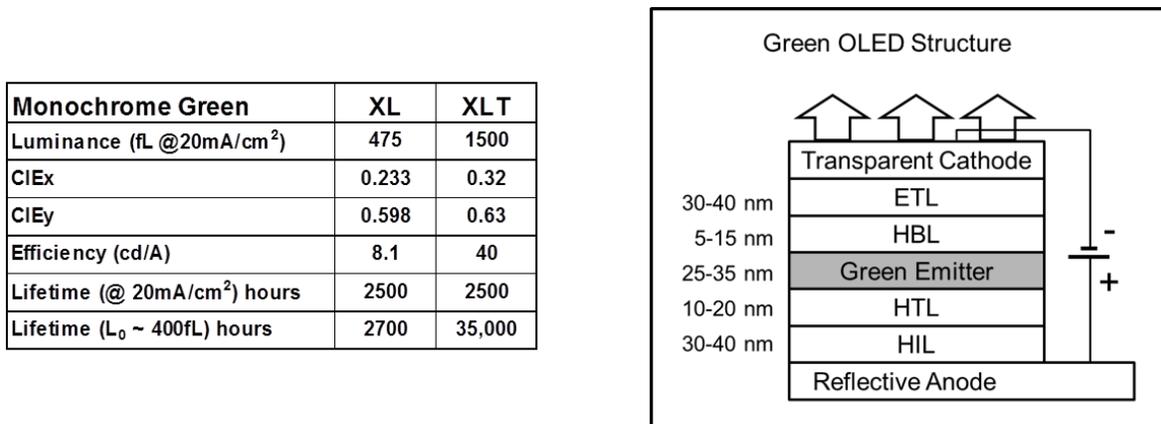


Figure 2: Comparison of monochrome green OLED characteristics and structure

The organic stack used in eMagin displays is a top emitter structure that is sandwiched between a reflective anode and a transparent cathode, and is fabricated on standard 200mm silicon wafers. Combining a high reflectivity anode with the optimized organic stack has enabled high performance devices to be achieved. The pixelated anode layer is defined using standard high resolution photolithography processes. A schematic of a typical green 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), green emitter layer (EML), hole blocking layer (HBL), electron transport layer (ETL), transparent cathode and passivation layers. These layers were deposited via thermal evaporation in $<5 \times 10^{-7}$ Torr vacuum. The organic layers in this stack are high glass transition temperature (T_g) materials, which allows for better environmental stability and ease of processing. Green emission is produced using a single dopant and single host system [3].

For color displays available today a white OLED is used in combination with red, green, and blue (RGB) band pass color filters defined in a striped pattern, and formed on top of the cathode. White emission is generated by using two emitters consisting of blue and red layers. Such a structure is less suitable for a high-brightness application because the

¹ Some materials from Universal Display Corporation were used

color filters reduce overall luminance by a factor of 4. Alternate approaches such as direct patterning of OLED emitters are under active development for future high-brightness and long-life color displays.

3. SXGA-2 ARCHITECTURE

3.1 SXGA-2 Backplane Architecture

A new SXGA backplane, denoted as SXGA-2, was recently developed under an NVESD contract and two versions of the display were built with different objectives in mind – one, to serve as a prototype for a future SXGA product having a reduced viewing diagonal compared to the current SXGA product (0.62” vs. 0.87” respectively) and two, to provide a test-bed for the next generation of pixel design. The key features and performance attributes of the new SXGA-2 display are given in Table 1. In the prototype version the pixel array consists of the GEN-3 pixel design which has a pitch of 9.6 microns for the color group, while the test version uses the latest GEN-4 pixel design which has a pitch of 8.1 micron for the color group. Other than the size of the pixel used to implement the array, the drive architecture and overall layout is identical. The parameters shown in Table 1 apply to both versions of the SXGA-2 display except where noted.

Table 1: SXGA-2 features and performance summary

Parameter	Value	Parameter	Value
Total Pixel Array	1292 x RGB x 1036	Uniformity	>85% end-to-end
Extra Pixels for Optical Alignment	12 columns and 12 rows	Analog Dimming Ratio	200:1
Pixel Size	9.6 micron RGB color group 8.1 micron color group in test-chip	PWM Dimming Ratio	500:1
Fill Factor	71% (66% in test-chip)	Video Interface	Serialized LVDS, 24-bit RGB
Diagonal Viewing Area	15.7 mm (0.62") 13.3mm (0.52") in test-chip	Refresh Rate	30 to 120 Hz
Weight	<3 gm	Video Source Clock	220 MHz max
Connector	50-pin Hirose DF12D(3.0)-50DP-0.5V	LVDS Clock	442 MHz max
White Luminance	>250 cd/m2 (color display)	LVDS Data Rate	883 Mbps max
CIE-x, CIE-y	0.270 to 0.370, 0.320 to 0.380	Power Consumption (color)	<200mW (video content @ 150cd/m2)
HBG Luminance	>8000 cd/m2 (mono-green display)	Power Consumption (HBG)	<200mW (video content @ 6000cd/m2)
CIE-x, CIE-y	0.355, 0.617 (typical)	Operating Temperature	-45 to 70°C
Gray Levels	256 per primary color	Storage Temperature	-55 to 90°C
Contrast Ratio	>10,000:1	Humidity	85% RH non-condensing

A high degree of integration was a primary goal for the SXGA-2 architecture so that head mounted display (HMD) developers could build very compact eyepiece assemblies. This is illustrated in the block diagram of the SXGA system shown in Figure 3. The SXGA backplane design consists of a display core with column and row sequencer logic, digital-to-analog converters, seven 256 x 10-bit look-up-tables, LVDS receiver, I²C serial interface and register memory, timing control, analog sensor functions, dc-to-dc converter, and test circuitry. All voltage references and bias currents are generated on chip. Power-on-reset and temperature monitoring functions are included for power management.

The core block is comprised of a 1296 x 1036 array of color pixels, each of which is arranged in a spatial triad of primary color sub-pixels, for a total of 4.03 megapixels on chip. An extra 12 columns and 12 rows have been added to enable shifting the viewing area in either direction in increments of one pixel for optical alignment. The column and row sequencer logic is designed to support a variety of active area formats by setting a number of 8-bit registers. A novel drive-to-black function, which was added to the row sequencer logic, is used to control the on-time of the pixels during a frame period. This feature provides a simple and power-efficient method for dimming the array using a pulse-width-modulation (PWM) approach. In combination with the analog dimming control that is also built-in, this technique allows an extended dimming range of over 25,000:1 to be readily achieved.

The pixel drive circuit employed in the SXGA array functions as a voltage to current converter for setting the OLED luminance, which is proportional to the current flowing through the OLED. A voltage is used to program the pixel cell in order to maximize switching response and to reduce spatial noise. A 10-bit digital-to-analog converter based on the sampled-ramp method is implemented with an on-chip digital ramp generator. Incoming 8-bit digital video data is

converted into an analog voltage signal that is sampled and stored in a pixel cell during each refresh period. Internal 10-bit precision ensures that 256 levels of grayscale accuracy will be maintained over a wide range of operating conditions. Separate buffer amplifiers feed the ramp signal into the even and odd columns from opposite sides of the pixel array.

A set of user programmable look-up-tables (LUTs) is provided on-chip to accommodate an arbitrary setting for the display gamma. Three 256 x 10b LUTs support the even columns and three additional ones support the odd columns. An additional buffer LUT is included to enable asynchronous programming via the serial port. Updated LUT data is transferred to the data path LUTs during a vertical blanking interval so as to prevent any noticeable image disturbance. The color point of the display can be modified by the user by setting different LUT values for each primary color. A reference output signal is provided by the microdisplay that can be used to externally generate the LUT values required for a precise linear grayscale reproduction.

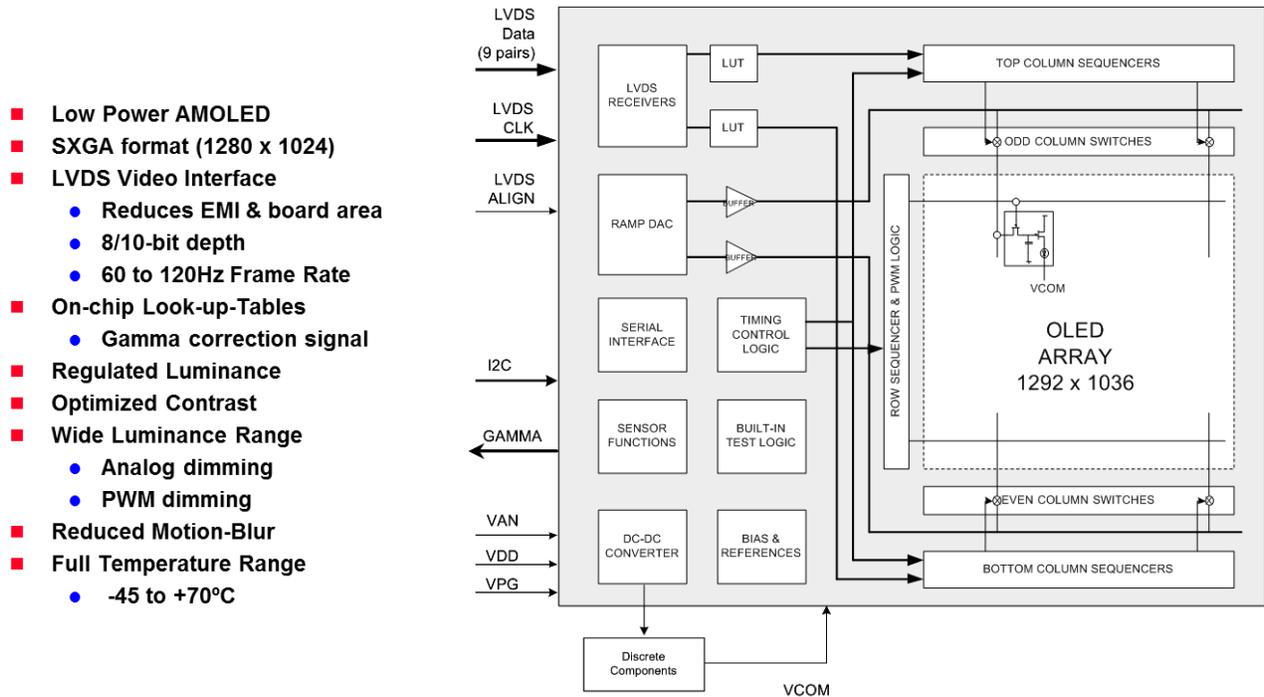


Figure 3: SXGA-2 Block Diagram

The on-chip timing generator is designed to accommodate a variety of video formats including HD720 and SXGA, and to accept flexible timing conditions ranging from VESA to reduced blanking formats. Standard horizontal synchronization, vertical synchronization and data enable signals are required as inputs from the video source. Minimum timing requirements consist of a 1% vertical blanking time and a 6% horizontal blanking time for operation in SXGA format at refresh rates ranging from 30Hz to 120Hz. The timing generator also supports progressive and interlaced scan modes as well as Stereo Vision based on the VESA standard.

An LVDS receiver is provided on-chip to support efficient transport of the high video data rates and enables the microdisplay to be located at a remote distance from the drive electronics while minimizing electromagnetic interference (EMI) and reducing board area. A lightweight and flexible cable can be readily implemented to serve as the link between video source and display. The LVDS receiver contains a new programmable capability that supports up to 30-bit digital RGB input data, a 120Hz frame rate, and full SXGA VESA format while reducing the number of data lines required for lower performance applications. The number of data input channels can be adjusted between four and nine line-pairs depending on system requirements.

All display attributes and setup options are adjusted using a 2-wire I²C serial control signal.

3.2 Physical Design

A view of the physical design for both versions of the SXGA-2 microdisplay showing the arrangement of its major functional blocks is given in Figure 4. All input pads are located along the wide bottom-end side of the chip. The row and column matrix drivers were laid out to match the 9.6 micron pitch of the prototype product version, resulting in a seamless pixel array as shown in the left-side image. In the case of the test chip shown in the right side of the figure, the pixel array is divided into four equal segments for simplified routing between the array and the drivers. The pixels are wired to the matrix drivers via signal lines that fan-out from the array at 8.1 micron pitch to match the 9.6 micron pitch of the column and row drivers. This layout configuration avoided the need to redesign the entire display and resulted in savings of both time and cost in developing the test chip. The overall die dimension for both displays is 14.8 x 13.0 mm.

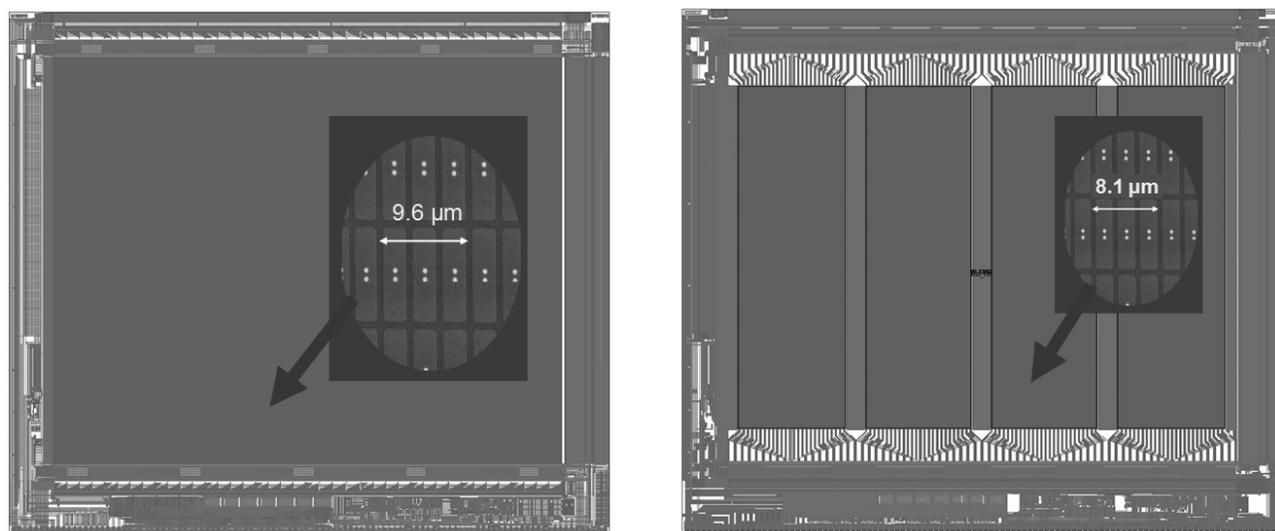


Figure 4: Layout of SXGA-2 main chip (left) and test chip (right)

4. EXPERIMENTAL RESULTS

4.1 Grayscale Video Results

The SXGA-2 displays were glued and wire-bonded to a custom printed circuit board (pcb) using eMagin standard packaging procedures. Finished assemblies for both the main chip and test chip are shown in Figure 5 where the segmented nature of the 8.1 micron pixel array is clearly visible in the test chip. The carrier board pcb was designed to be slightly oversized and contains an exposed gold-plated top metal layer to which the silicon die is bonded using a thermally conductive adhesive. An effective means of passive heat removal was achieved by attaching a small heatsink to the exposed metal surface. This was particularly useful in avoiding degradation of the OLED life due to self-heating at the very high brightness levels that were used for some of the lifetime measurements.

The prototype SXGA-2 displays were produced in both color and HBG monochrome versions in order to validate the color capability of the GEN-4 pixel design as well as its high brightness performance. Color images produced by both the 9.6 micron prototype and the 8.1 micron test chip are compared in Figure 6 for an output luminance of 45fL. As noted earlier, the smaller pixel array was physically separated into four equal segments to mate with the larger matrix

drivers. If the four segments were to be placed side-by-side the resulting image would be seamless and would have a real viewing diagonal of 0.52". The color displays were fabricated by using the standard white emitting OLED material with an advanced patterning process for the RGB color filter overlay. Full 8-bit depth per color was achieved for both displays with comparable grayscale performance as demonstrated in the figure. Good color rendering was achieved for both versions of the pixel array with the main difference being a reduction in fill factor to 66% for the smaller pixel compared the 71% obtained in the 9.6 micron array.

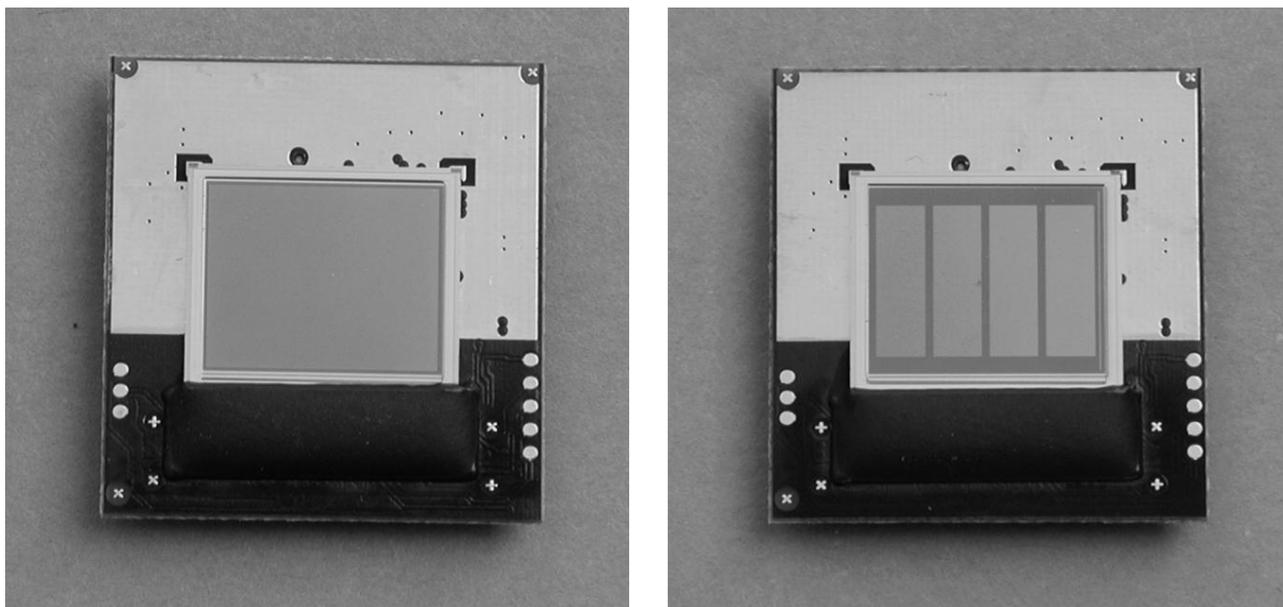


Figure 5: SXGA-2 main (left) and test-chip (right) packaged assemblies



Figure 6: Color images produced by the SXGA-2 main and test microdisplays at 45fL

Images obtained for the main and test versions of the high brightness green monochrome display are shown in Figure 7 for an output luminance of 6900 and 6200fL, respectively. As before, the 8-bit color depth and the on-chip gamma correction provide for excellent grayscale response with virtually no discernible difference in image quality between the two displays.



Figure 7: High brightness monochrome green images (Yosemite National Park) for the SXGA-2 displays

4.2 HBG Luminance and Chromaticity

The full-on luminance is used to determine the visibility of display symbology in see-through vision systems. A minimum value of 1000fL is derived from the see-through contrast requirement of 1.2:1 for the display against a 10,000fL background. Assumed system optical parameters are 50% see-through optical combiner, a 20% transmissive visor or tinted optic between the combiner and the outside world. A minimum value of 5000fL is similarly determined, but with a clear visor between the user and the outside world. Consequently, the SXGA-2 prototype microdisplay was tested for a maximum output luminance of more than 8000fL to verify these requirements could be met.

The controllable output luminance as a function of the OLED current density range that was achieved with the SXGA-2 display is shown in the left-side chart of Figure 8. High brightness lifetime measurements and operational characterization was generally limited to no more than 5000fL, or about the middle of the display's output capability. For night vision applications, the same display would have to be dimmed to a peak luminance at the eye of about 1fL. Below this level the human eye resolution performance is a limiting factor on the overall system performance. Again, assuming the combiner optics are 50% transmissive, the full-on luminance at the eye should be adjustable from 2500fL down to 1fL or 2500:1. This objective is exceeded in the SXGA-2 display by a combination of analog and pulse-width-modulation (PWM) dimming techniques that are provided on-chip. Measurements have confirmed that a total full-on luminance range of greater than 25,000:1 could be readily achieved.

The current efficiency of the green OLED-XLT emitter is given in the chart on the right side of Figure 8. It peaks at about 43cd/A at low luminance and declines gradually as the luminance level is increased. The efficiency of this phosphorescent-based emitter is about 5 times greater than that of the fluorescent-based material used in previous eMagin displays.

The output spectrum for the single emitter OLED used in the green display is shown in the left-side chart of Figure 9 with the P53 green phosphor emission line shown for reference. Although the OLED material produces a relatively broad spectrum, it has good NVIS compatibility which can be optimized with additional filtering if needed. Moreover, the CIE coordinates of the green emitter are essentially constant over the entire operating luminance range of the microdisplay as demonstrated by chart on the right-side of Figure 9.

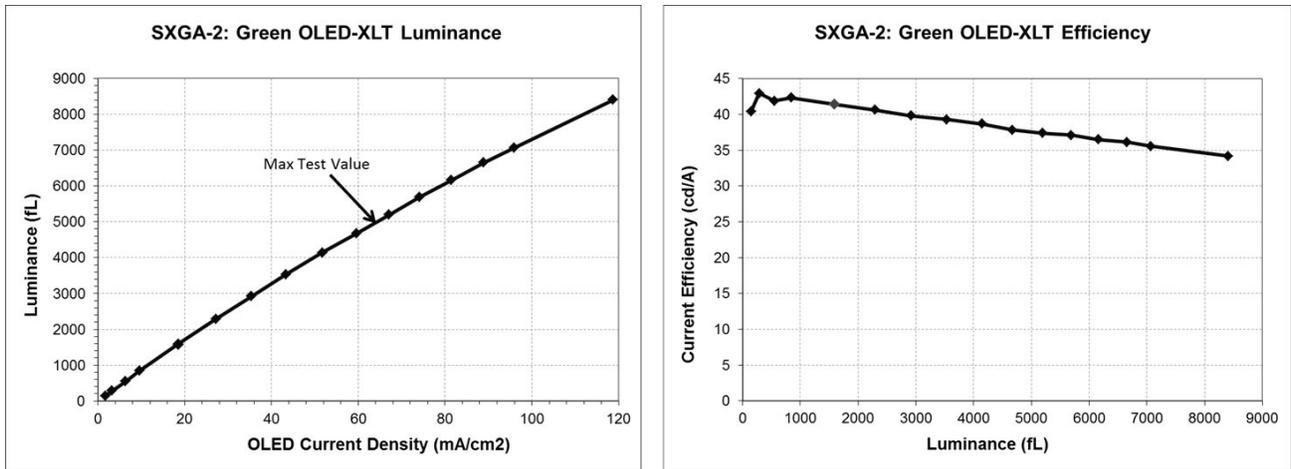


Figure 8: Luminance (left) and current efficiency (right)

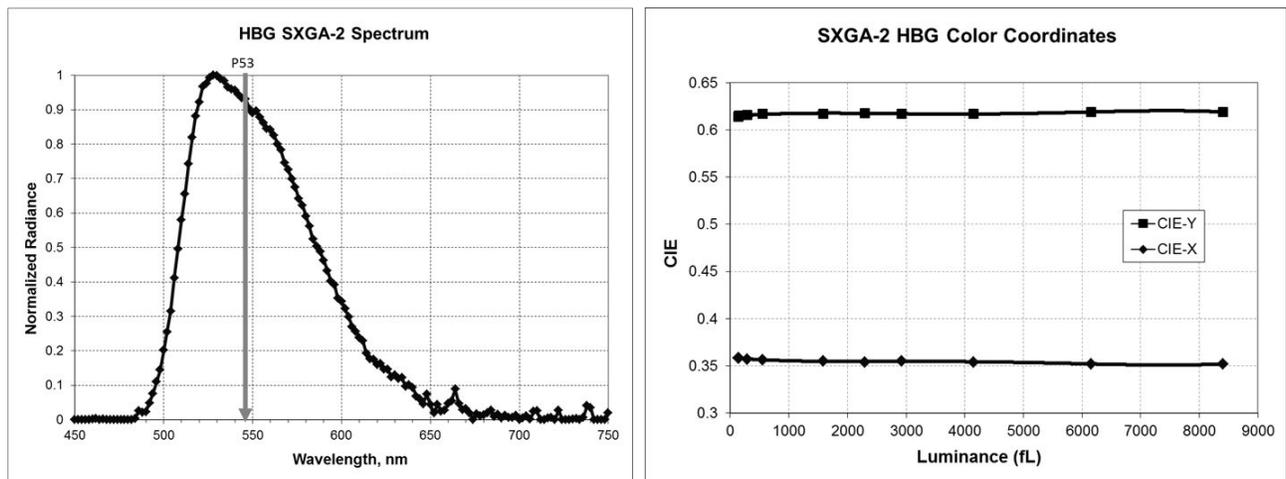


Figure 9: Spectrum and chromaticity for Green SXGA-2 display

4.3 Contrast Performance

The on-off contrast affects the impact and interference of the display background (pixels set to the lowest drive level) when viewed as part of a see-through system. This parameter also can be used to determine the useful dynamic range and number of visible gray shades for video images. A minimum value of 200:1 is desired based on an eye noise threshold luminance of 0.005fL and about 8 bits of gray level addressability. The display background should not detract or conflict with the external world in a see-through system when the display is dimmed to a full-on luminance of 1fL. A contrast of 1000:1 meets the above requirement and also permits the display to be used with greater than 8 bits of gray level addressability. An OLED display is inherently capable of delivering this contrast performance and higher because of its emissive nature. To ensure optimum results, the SXGA-2 display includes a pixel drive architecture that is designed to provide maximum contrast across its full luminance and temperature operating ranges, thus enabling more than 8 bits of gray level addressability to be easily achieved in the see-through system described above.

A SMPTE test image was used to evaluate the ability of the SXGA-2 design with the 8.1 micron pixel to resolve fine detail at high contrast. A photograph of the actual display image with a close-up of a region containing single-pixel lines and spaces is shown in Figure 10. The image demonstrated sharp definition and high contrast, even at the high full-on luminance of 6200fL that was used in the test. A measurement of the MTF at the limiting pixel resolution of 62 line pairs per mm resulted in a value of 0.9 for the vertical lines and 0.7 for the horizontal lines. The stability of the image and the absence of any pixel cross-talk provided confirmation that the backplane circuits were operating successfully at the full required bandwidth.

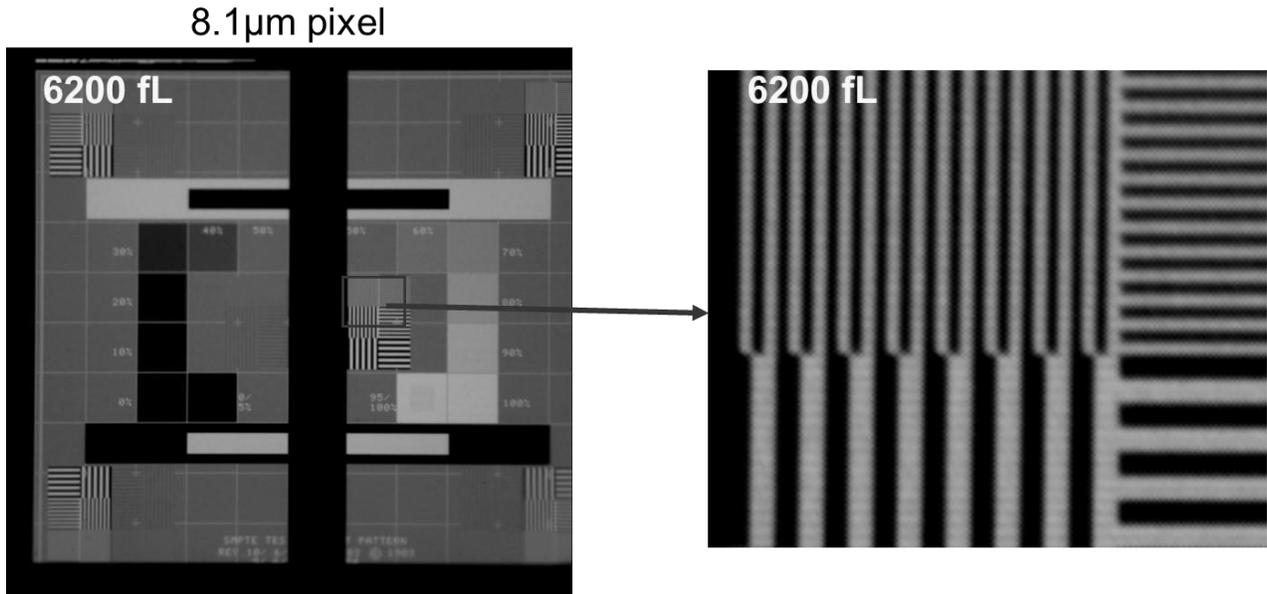


Figure 10: Close-up of line-on/line-off pattern in 8.1 micron test chip

The results of full on-off contrast measurements taken for the entire range of luminance are shown in the chart on the left side of Figure 11. At low luminance levels the contrast level is very high and the reading tends to be limited more by instrument capability and background light leakage rather than the display performance. At the higher luminance levels on the other hand, the contrast value is limited by the dynamic range of the pixel driver circuit which is constrained to operate within the voltage limits of the CMOS backplane technology. In all modes of operation the maximum contrast is achieved automatically as a result of the contrast optimization function that is designed into the pixel driver circuits.

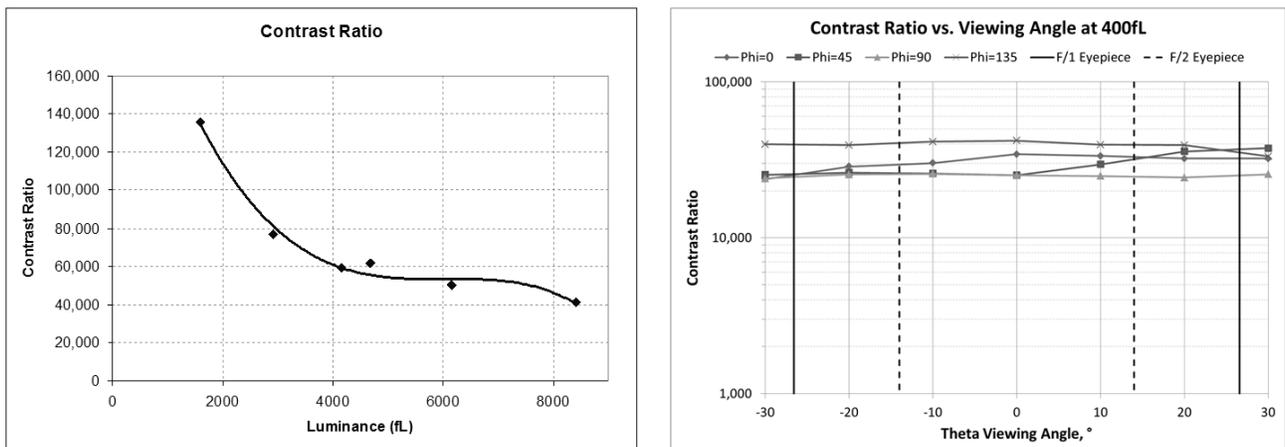


Figure 11: Contrast dependency on luminance (left) and viewing angle (right)

Unlike and LCD display with polarizers, the OLED display provides a very stable contrast ratio over a large range of viewing angles as demonstrated by the chart on the right side of Figure 11. The contrast is plotted as a function of the angle, Theta, between the viewing direction and the normal to the plane of the display. Four sets of curves were taken at 45 degree increments about the normal to the plane of the display. The two pairs of vertical markers on the chart represent the collection angles for an F/1 and F/2 eyepiece. Because this is a monochrome display, there is essentially no angular dependence of the contrast about the normal to the plane of the display. A consistently high contrast over a very large viewing angle range is particularly important for the design of HMDs with a wide field of view.

4.4 Power Consumption

Power consumption data for the SXGA-2 microdisplay taken at ambient temperatures is shown in the chart on the left-side of Figure 12. Three curves are plotted corresponding to the cases of all pixels full-on, average video content, and all pixels full-off. An average pixel luminance of 30% is assumed for the video content mode, which generally represents a good approximation for the long term average power consumption of an OLED display used for viewing typical video imagery in an occluded HMD.

A slightly different representation of the power consumption is given in the chart on the right-side of Figure 12, which better represents the situation when viewing symbology in a see-through HMD. The chart shows the dependence of power on the percentage of pixels that are turned on for three different levels of full-on luminance. The density of symbols and lines in a see-through application such as avionics is usually limited to low values in order to avoid overwhelming the foreground image, and is highlighted by the area on the left side of the chart. Unlike an LCD display which draws a constant power to the backlight under all conditions, the OLED display draws less power as fewer pixels are active and consequently can be very efficient even at very high luminance levels. As shown in the chart, even at a full-on luminance of 5000fL the SXGA-2 display consumes less than 200mW of power in symbology mode.

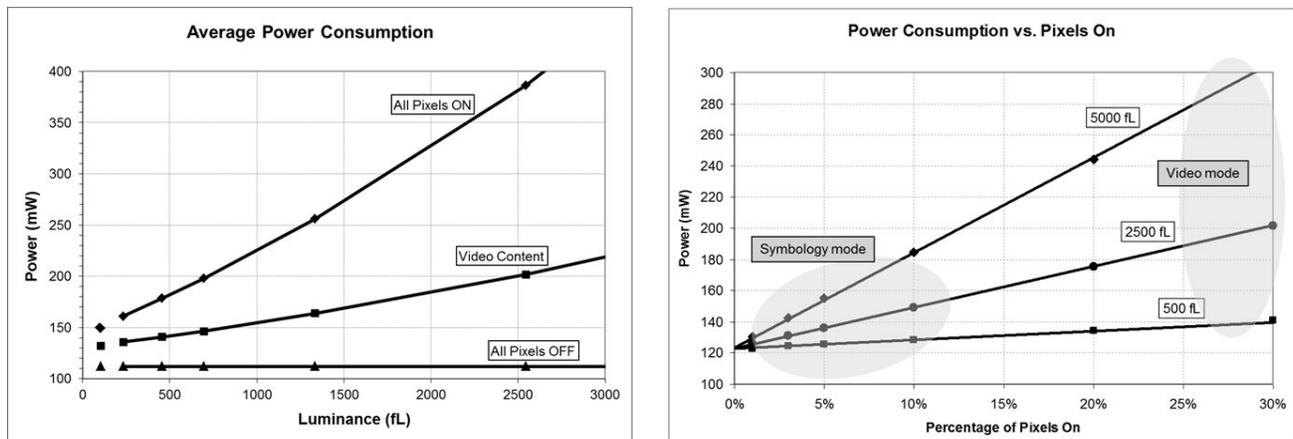


Figure 12: Power consumption measurement results for SXGA-2 OLED-XLT

4.5 Lifetime

Lifetime evaluations have been performed on various eMagin devices by US Army RDECOM CERDEC NVESD under a Cooperative Research and Development Agreement (CRADA) and published jointly on a yearly basis. In this work the measurements have been extended to the high brightness levels required in a see-through and daylight application and were carried out on SXGA-2 displays fabricated with the latest Green OLED-XLT material. These results have been combined with a usage model based on the pixel duty rate so that a prediction could be made for the usable life of the

display in a typical see-through HMD, working mostly with symbology content. Additional characterization results for the SXGA-2 display are discussed by David Fellowes et al. in “Active matrix organic light emitting diode (AMOLED) performance and life test results” (Paper 8383A-11) which is being published concurrently with this paper.

The setup used for carrying out the lifetime tests is shown on the left-side of Figure 13, where an SXGA-2 display with the green OLED-XLT material is shown under test. A small heat sink has been attached to the exposed gold-plated copper layer on the display carrier board for improved heat removal under high luminance operation, especially for the case of all pixels full-on. The tests were all carried out at room temperature ambient and only passive cooling was utilized. The OLED display was operated at constant current using an on-chip test capability, thus requiring only the connection of external power and a serial port to set the current level. Total array current was monitored during the test to ensure that the internal current generator did not change over time. It was confirmed that over the length of the test the array current changed by no more than 2%.

A plot of the output luminance for three different starting luminance conditions is given in the chart on the right-side of Figure 13. The data for all initial luminance cases was fitted using a stretched exponential decay (SED) [4] function which provided an excellent match as demonstrated in the chart. Coefficients for the SED function used for all three curves as well as for other estimated starting luminance values are given in Table 2.

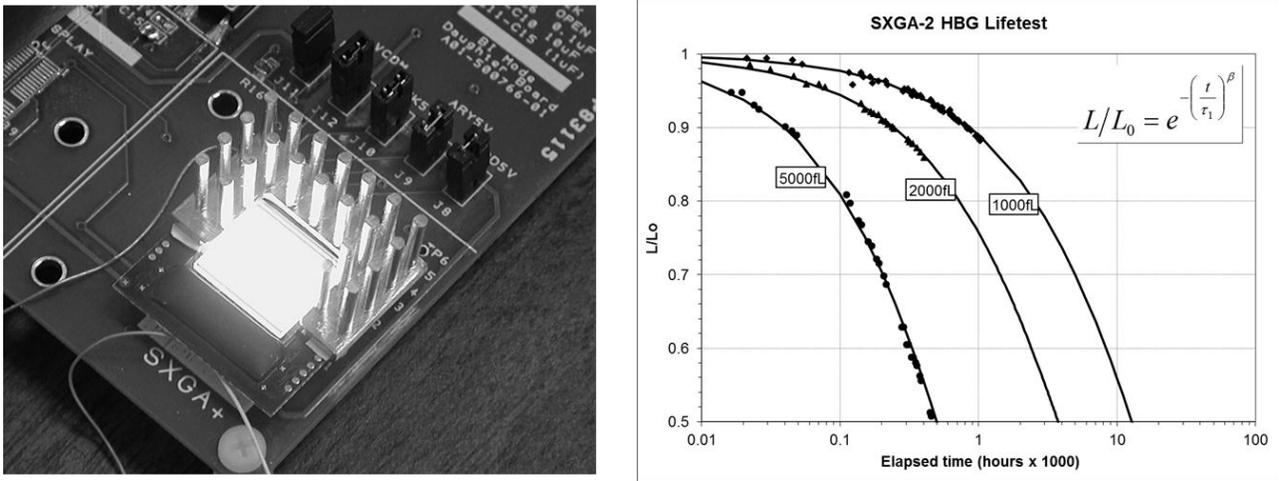


Figure 13: HBG life-test setup and measurement results

Table 2: Coefficients for SED function

Starting Luminance (fL)	T50 (hours)	SED Coefficients		Note
		τ	β	
400	80000	130	0.7	estimated
1000	12850	21.7	0.7	
2000	3750	6.4	0.69	
5000	500	0.82	0.74	

Using the measured data and the well-known relation, $L_0^n * t_{1/2} = const$, where n is an acceleration constant, L_0 is the starting luminance, and $t_{1/2}$ is the half-life, the curve shown in Figure 14 was generated for use in predicting the life to 50% luminance (T50) from any starting luminance. A curve for the life to 90% luminance (T90) was also generated and is shown in the figure as well. The T90 curve is of particular usefulness in estimating the time to noticeable burn-in when using fixed patterns such as computer icons and crosshairs. For those items there are measures that can be taken to

mitigate the problem and extend life. The T50 curve however provides a good estimate for the usable life of the display for the case of video and moving symbology content of the kind that would be used in a see-through HMD application.

The predicted life shown in Figure 14 is for a display in which all the pixels are operating full-on at maximum luminance for the duration of the test. This is rarely the case in a real display application where the average luminance of a pixel is normally much less than its full-on value. As mentioned earlier, in a see-through application with mostly moving symbology for content, the average pixel luminance or duty rate will be quite low, in the range of less than 10% of the full-on luminance. The chart given in Figure 15 shows the predicted life to 50% luminance (T50) as a function of average pixel duty rate. Curves are provided for the cases of 1000, 2000, and 5000fL full-on operating luminance. For a full-on luminance of 5000fL a usable life of about 10,000 hours is predicted for the SXGA-2 microdisplay fabricated with the Green OLED-XLT material.

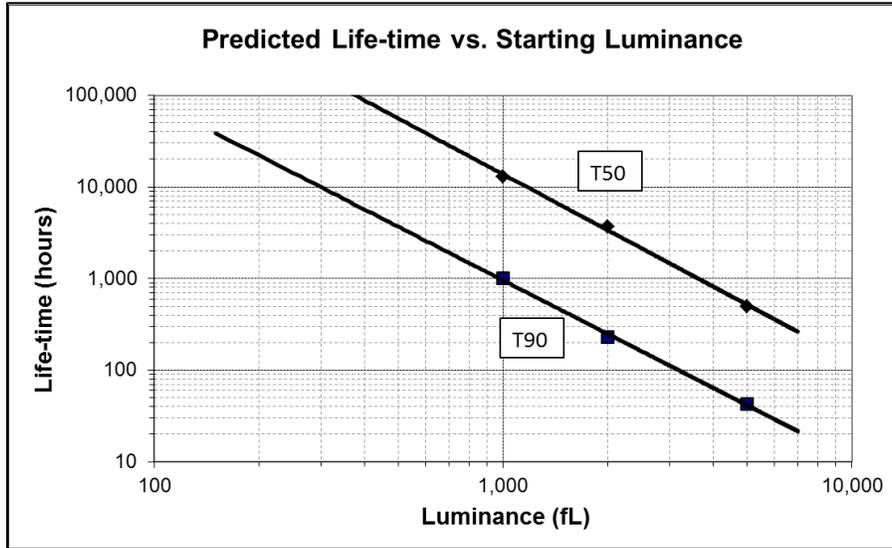


Figure 14: Lifetime vs. Starting Luminance curves

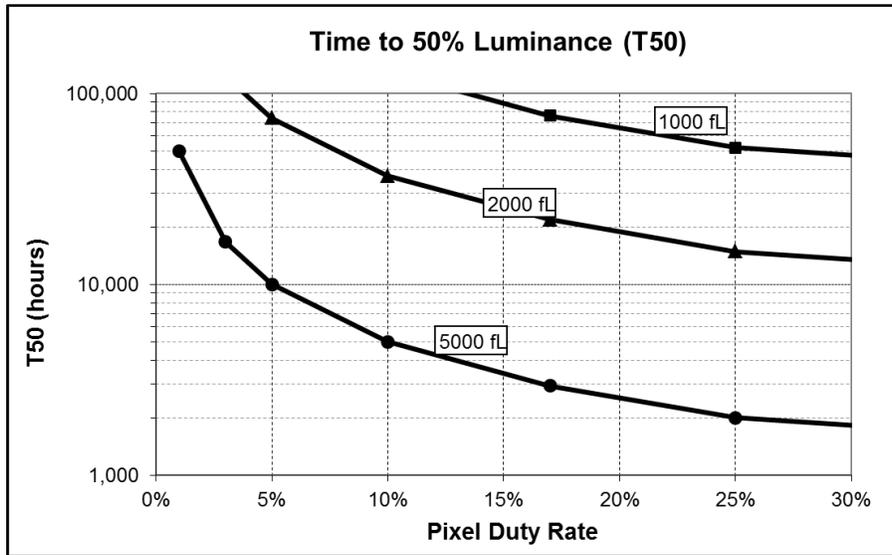


Figure 15: Usage based lifetime

5. CONCLUSIONS

eMagin Corporation has successfully demonstrated a fully functional prototype microdisplay in SXGA format built with the world's smallest full-color OLED pixel. The 8.1-micron pixel technology will enable future AMOLED microdisplays with resolutions up to QSXGA to be implemented. The prototype SXGA display was fabricated in both color and a monochrome green version that used the latest phosphorescent OLED-XLT material. Characterization of the monochrome green display performance and usable life was carried out at a full-on luminance of up to 5000fL. Based on a usage model for display operation employing mostly symbology content, it was demonstrated that the combination of high resolution provided by the 8.1-micron pixel technology and high luminance using the green OLED-XLT, upcoming AMOLED microdisplay will meet the requirements of next generation see-through HMDs. Future developments promise to extend the OLED high-brightness and high-resolution capability to full-color performance as well.

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