Active Matrix Full Color OLED Microdisplays

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Outline

- Introduction
- Technology
- Process Overview
- Performance & results
- Summary
- Acknowledgement
eMagin

- Located in Hopewell Junction, New York
- OLED development started in 1997
- First Active Matrix OLED Microdisplay shipped in 2002
- Currently the only company in full production of Active Matrix OLED microdisplays
Introduction

eMagin microdisplays:

- Typically need a lens to view
- Are primarily for near-to-the-eye applications

Virtual image ~ 105 inches diagonal at 12 feet
Applications

Consumer

Medical

Industrial

Military
eMagin’s Technology

- 200 mm single crystal silicon wafers
- CMOS drive circuitry from foundry
- High Tg fluorescent materials
- Post processing at eMagin

Top Emitter
White OLED
Thin Film Seal
Color Filters
eMagin’s Display Platforms

**SVGA+ 852 x 600**
- 0.61 inch diagonal
- 15.0 µm pixel pitch
- 5.0 µm sub-pixel pitch

**SXGA 1280 x 1024**
- 0.77 inch diagonal
- 12.0 µm pixel pitch
- 4.0 µm sub-pixel pitch

**WUXGA 1920 x 1200**
- 0.87 inch diagonal
- 9.6 µm pixel pitch
- 3.2 µm sub-pixel pitch

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Active Area

**SVGA**

Active Area

**SXGA**

Active Area

**WUXGA**

Active Area

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Encapsulant
Cover Glass
Silicon Die
Carrier PCB
Connector

4.72 mm

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China FPD 03-17-2011

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Back Plane Layout

SXGA 1280 x1024
0.77” diagonal

WUXGA 1920 x1200
0.86” diagonal

- Peripheral drive circuitry is on the silicon
- Self contained and highly integrated display

Sub-pixel dimensions: 4 µm x 11 µm

Sub-pixel dimensions: 2.45 µm x 8.5µm
Highlights of Drive Circuit

- **Current driven architecture: SVGA+**
  - Simpler gamma control but limited to ≥ 15x15um square pixel

- **Voltage driven architecture (SXGA & WUXGA)**
  - Allows for a smaller pixel size
  - Provides a better storage capacitor to pixel size ratio
  - Improved pixel-to-pixel uniformity
  - RGB digital interface – feature for our latest architecture
  - On board low power DAC
  - Built in features
    - Gamma correction
    - Luminance regulation over wide temp range
    - Row and column addressing circuitry

*eMagin’s OLED Microdisplays have very low power consumption – 75% less than a comparable LCD microdisplay*
# Microdisplay Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SVGA+</th>
<th>SXGA</th>
<th>WUXGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Format (pixels)</td>
<td>852(x3) x 600</td>
<td>1280(x3) x 1024</td>
<td>1920(x3) x 1200</td>
</tr>
<tr>
<td>Color Pixel Aspect Ratio</td>
<td>15µm sq. color group</td>
<td>12µm sq. color group</td>
<td>9.6µm sq. color group</td>
</tr>
<tr>
<td>Display Size</td>
<td>0.61” diagonal</td>
<td>0.77” diagonal</td>
<td>0.86” diagonal</td>
</tr>
<tr>
<td>Gray Levels</td>
<td>256 per primary color</td>
<td>256 per primary color</td>
<td>256 per primary color</td>
</tr>
<tr>
<td>Operating Ambient Temp.</td>
<td>-45°C to +70°C</td>
<td>-45°C to +70°C</td>
<td>-45°C to +70°C</td>
</tr>
<tr>
<td>Storage Temp.</td>
<td>-55°C to +90°C</td>
<td>-55°C to +90°C</td>
<td>-55°C to +90°C</td>
</tr>
<tr>
<td>Sub-pixel Width x Height (active area)</td>
<td>3.5 µm x 13.5 µm</td>
<td>4 µm x 11 µm</td>
<td>2.45 µm x 8.5 µm</td>
</tr>
<tr>
<td>Fill Factor</td>
<td>63 %</td>
<td>69 %</td>
<td>71 %</td>
</tr>
</tbody>
</table>
Device Structure of OLED on Silicon

- Reflective Anode
- ETL
- Doped EML (Orange)
- Doped EML (Blue-Green)
- HTL
- HIL
- Transparent Cathode
- color filter or converter
- insulator layers
- metal conductors
- integrated active matrix color sub-pixel
- silicon single crystal wafer 0.8mm thick
Schematic of Color OLED Microdisplay

- High Tg materials
- Two layer white structure
- High reflective metal anode
- Thin film seal
- Color filters directly on top of seal
eMagin’s Microcavity Modeling Software

Features:
- Monte Carlo simulation up to 30 layer stack OLED
- Simultaneous independent thickness variation for two individual layers – 2D Mapping of any given parameter vs. two thicknesses
- Viewing angle variation
- Multi-dopant capability in individual emission layers
- Exciton diffusion length variation
- Dopant concentration variation

Output:
- Spectra
- 1931 CIEx and CIEy
- 1976 CIEu’ and CIEv’
- Luminance
- Out-coupling efficiency
Example of Modeling

- Experiment
- Simulation

Normalized Intensity (a.u.) vs. Wavelength (nm)
OLED Micro-display Fabrication

Si wafer from foundry → Deposit and pattern anode → OLED deposition

Thin film seal → Color filter processing → Cover glass attach

Microdisplay singulation → Die attach to board → Wire bond, test & inspect
Typical LIV for SXGA

![Graph showing the eMagin OLED LIV Characteristic at 25°C](chart.png)

- Current Density (mA/cm²) vs. Vbias
- Luminance (cd/m²) vs. Vbias

Key Points:
- **Video Mode**: Indicates the current density range for video signal levels.
- **Black Level**: Luminance value at the lowest current density.
- **White Level**: Luminance value at the highest current density.
- **3V**: Voltage point indicating a specific luminance level.

This graph illustrates the relationship between voltage bias (Vbias) and current density, as well as luminance for typical SXGA applications, highlighting the operational range and efficiency of the OLED display technology.
Typical CIE Color Coordinates for SXGA

<table>
<thead>
<tr>
<th>Color</th>
<th>CIEx</th>
<th>CIEy</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>0.30</td>
<td>0.37</td>
</tr>
<tr>
<td>Red</td>
<td>0.63</td>
<td>0.35</td>
</tr>
<tr>
<td>Green</td>
<td>0.26</td>
<td>0.53</td>
</tr>
<tr>
<td>Blue</td>
<td>0.15</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Temperature Compensation

Luminance vs. Temperature

Temperature (°C)

Normalized Luminance

SXGA

SVGA
OLED I-V Compensation with Temperature

- Many applications require a wide temperature range
- Back plane is designed to provide the voltages for this wide operating temperature range

![Graph showing current density vs. bias voltage at different temperatures.](image-url)
Temperature Dependence of Contrast

SXGA Contrast vs. Temperature (100 cd/m²)
CIE Coordinates versus Gray Level

SXGA: CIE vs. Gray Level (L_{max} = 310 \text{ cd/m}^2)
Angular Dependence of Luminance

SXGA - Rotation About Axis (R3BLP) - Color display

Angle (Degree)

Normalized Luminance

AXIS
- HOR
- VER
Angular Dependence of CIE Coordinates

SXGA Rotation About Horizontal Axis (R3BLP)

SXGA Rotation About Vertical Axis (R3BLP)
Lifetime of SXGA

Constant Current Full Color SXGA Life Test Raw Data

Color OLED XL™ SXGA Accelerated Lifetime
(Constant Current Mode; All Pixels On; Initial Lum. 170 cd/m²)

<table>
<thead>
<tr>
<th>Serial #</th>
<th>90% Life (h)</th>
<th>75% Life (h)</th>
<th>50% Life (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R3BN0</td>
<td>5,200</td>
<td>11,500</td>
<td>23,000</td>
</tr>
<tr>
<td>R39JL</td>
<td>4,700</td>
<td>10,700</td>
<td>21,500</td>
</tr>
<tr>
<td>R3BNJ</td>
<td>5,200</td>
<td>11,500</td>
<td>23,000</td>
</tr>
</tbody>
</table>

Independent Lab measurements
Multichannel Automated Life Test System
Operating SXGA Microdisplays
Features

- 7 Million Total Pixel Elements
- Low Voltage Differential Signaling (LVDS) Video Interface
- 24-bit Color Depth (16.7 Million Colors)
- Supported Video Formats
  - WUXGA (1920 x 1200)
  - HD1080 (1920 x 1080)
  - UXGA (1600 x 1200)
- Stereovision for Binocular Application
- Ultra-high Dynamic Range (>100,000:1)
- Horizontal/Vertical Scan Direction Control
- Electronic Image Centering
  - Horizontal/Vertical Shift up to 24 pixels
- Low Power Operation (<300mW @ 100 cd/m²)
Summary

• OLED on Silicon microdisplay technology is maturing

• SVGA and SXGA resolution microdisplays with new and improved features are already products

• WUXGA microdisplays demonstrated - qualification is the next step

• Further improvements in OLED performance are under way

• Even higher resolution microdisplays are under development
Acknowledgements

The authors wish to thank the staff of eMagin Corporation for their help in fabricating and testing of the OLED Displays and U.S. Army for their support.
Thank You!!