An Overview of OLED Display Technology

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Outline

- OLED device structure and operation
- OLED materials (polymers and small molecules)
- Evolution of OLED performance
- OLED process and fabrication technologies
- White emitting OLEDs
- Color capabilities
- Products and demonstrators
Human hair is 200X the thickness of the OLED layers
OLED Device Operation Principles

OLEDs rely on organic materials (polymers or small molecules) that give off light when tweaked with an electrical current:

- Electrons injected from cathode
- Holes injected from anode
- Transport and radiative recombination of electron hole pairs at the emissive polymer
LUMINANCE is the luminous intensity per unit area projected in a given direction.

The SI unit is the candela per square meter ($cd/m^2$), which is still sometimes called a nit.

The footlambert (fL) is also in common use: 1 fL = 3.426 cd/m$^2$

http://www.resuba.com/wa3dsp/light/lumin.html
Evolution of LED performance

- GaP:Zn,O
- GaAs
- AlGaAs/GaAs
- AlInGaP/GaAs
- InGaN
- SM OLED
- Polymer OLED

Time (years)

Performance (Lumens/Watt)


Unfiltered Incandescent Lamp

Thomas Edison's first bulb

GaAs, P, Q, 0.4, 0.6

Red, Yellow, Green

Molecular Solids

Polymers

Nitrides

SiC, PPV

Courtesy of Agilent Technologies
Electroluminescent Conjugated Polymers

Conducting polymers

- Polyaniline (PANI:PSS)
- Polyethylenedioxythiophene (PDOT:PSS)

Emissive polymers

- Polyphenylenevinylene (R-PPV)
- Polyfluorene (PF)

Processed by:
Spin casting, Printing, Roll-to-roll web coating

IP owned by Cambridge Display Technology
Multiple emission colors achieved by Covion

Different emission colors can be obtained with a variety of chemical structures

PPP
PPV
PT or CN-PPV
Multiple emission colors achieved by Dow Chemical

\[
\left( \begin{array}{c}
R_1 \\
R_1
\end{array} \right)_n
\]

PF

CIE 1931 2^* CHROMATICITY DIAGRAM

Opto Semiconductors
Polymer OLED display fabrication steps

Deposit and pattern anode (ITO)

Pattern polymer layers (first conducting then emissive)
- Spin coating
- Ink Jet printing
- Screen printing
- Web coating

Vacuum deposit and pattern cathode (Ba,Ca/Al)
Ink Jet Printing to Pattern Polymers
(Full Color Applications)

Ink Jet Head

Red emitter

Green emitter

Blue emitter

Substrate

Ink Jet printing to define and pattern R, G, B emitting subpixels
The Holy Grail: Flexible OLEDs

Sheila Kennedy, Harvard Univ., 1999
Polymer and Small Molecule Device Structures

Small molecule

- Cathode - Li/Al
- ETL - Alq₃
- EML - doped Alq₃
- HTL - NPB
- HIL - CuPc
- Anode - ITO
- Substrate - glass

Polymer

- Cathode – Ba, Ca/Al
- ETL - PPV, PF
- HIL - PDOT, Pani
- Anode - ITO
- Substrate - glass

Multi-layer structure made all in vacuum

Bilayer structure made from solution
Electroluminescent Small Molecules

Hole transport small molecules
- Metal-phthalocyanines
- Arylamines, starburst amines

Emissive small molecules
- Metal chelates, distyrylbenzenes
- Fluorescent dyes

Processed and deposited by:
thermal evaporation in vacuum

IP owned by Eastman Kodak
Full color patterning with small molecules

Small molecules are thermally evaporated in vacuum

R, G, B patterning is defined by shadow masking in vacuum
White emitting small molecule OLEDs

Initial Luminance 1000nits

Relative Luminance vs. Operational Time (Hours)

- T = 25 C
- T = 40 C
- T = 60 C
- T = 85 C
Phosphorescent small molecule OLED (both singlets and triplets are harvested)

Phosphorescence enhanced by mixing the singlet and triplet excited states by spin orbit coupling via heavy metal atom (Pt or Ir)

$\eta_{\text{ext}} = 19\%$ and $\eta_{\text{int}} = 87\%$
Full-color/Multi-color Approaches

RGB- polymer emitters

Advantages:
- power efficient
- lower production cost
- mature ITO technology

Disadvantages:
- emitters have to be optimized separately (common cathode?)
- differential aging of emitters
- patterning of emitters necessary

Color filters

White emitter

Advantages:
- well-established technology (LCD)
- no patterning of emitter necessary
- homogeneous aging of emitter (?)

Disadvantages:
- power inefficient
- ITO sputtering on filters
- efficient white emitter necessary

Color Changing Media (CCMs)

Advantages:
- homogeneous aging of emitter (?)
- more efficient than filters
- no patterning of emitter necessary

Disadvantages:
- ITO Sputtering on CCMs
- stable blue emitter necessary
- aging of CCMs
Obtaining a Full Color OLED Display

**Ink Jet printing of R,G,B emissive polymers defines the R,G,B subpixels**

\[(x_R, y_R) \quad (x_G, y_G) \quad (x_B, y_B)\]
# Device Color, Efficiency and Lifetime

<table>
<thead>
<tr>
<th>Color</th>
<th>Polymers</th>
<th>Small Molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Efficiency (cd/A)</td>
<td>Half-Life* (hrs) @150 nits, RT</td>
</tr>
<tr>
<td><strong>Red</strong></td>
<td>1-2</td>
<td>&gt;20,000</td>
</tr>
<tr>
<td><strong>Green</strong></td>
<td>8-10</td>
<td>15,000</td>
</tr>
<tr>
<td><strong>Blue</strong></td>
<td>4</td>
<td>3,000</td>
</tr>
<tr>
<td><strong>Yellow</strong></td>
<td>8-10</td>
<td>&gt;30,000</td>
</tr>
<tr>
<td><strong>White</strong></td>
<td>2-4</td>
<td>5,000</td>
</tr>
</tbody>
</table>

*Extrapolated Lifetime under constant current conditions*
Small Molecule Passive Matrix Display Products

Motorola (by Appeal)

Samsung Electronics
Kodak Licensed SNMD to Manufacture PM OLED Displays

Lucky Goldstar (LG)

Motorola (by Appeal)

96x64 Full Color PM Display
Small Molecule Active Matrix Display Products

**Eastman Kodak:** Digital camera

**Sanyo:** Cell Phone with Digital camera
Top Emission Adaptive Current Drive technology, allows OLEDs to be larger and higher in brightness and resolution. A 13-inch full-color AMOLED using poly-Si TFT was made where the light emits through the transparent cathode and thus, the filling factor does not depend on the TFT structure.

The schematic vertical structure of the device is substrate/TFT/metal anode/organic layers/transparent cathode/passivation layer/transparent sealing.

Display format: 800 x 600 (SVGA); pixel pitch 0.33x0.33mm²
Polymer Passive Matrix Display Products

**Philips**: Electrical Shaver

**Delta Electronics**: Display for MP3 player
San Jose, CA – May 15, 2003 -- Osram Opto Semiconductors, a global leader of solid-state lighting devices, today announced its Pictiva™ Evaluation Kit. Announced earlier this week, the Pictiva brand is Osram’s suite of organic light emitting diode (OLED) technologies. Pictiva displays offer a high level of brightness and contrast, video capabilities, wide viewing angles and a thin-profile, enabling developers and engineers to have greater design flexibility when developing the next-generation state-of-the-art electronics products.