Overview of OLED Display Technology

Homer Antoniadis, Ph.D.
Product Development Group Manager
phone: (408) 456-4004
cell: (408) 314-6460
e-mail: homer.antoniadis@osram-os.com
Outline

- OLED device structure and operation
- OLED materials (polymers and small molecules)
- Evolution of OLED performance
- OLED process and fabrication technologies
- Color capabilities
- White emitting OLEDs
- Passive and active matrix driving schemes
- OLED market potential
- Products and demonstrators
OLED Display and Pixel Structure

Display

Pixel

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
Optoelectronic Device Characteristics

LUMINANCE is the luminous intensity per unit area projected in a given direction.

The SI unit is the candela per square meter (cd/m²), which is still sometimes called a nit.

The footlambert (fL) is also in common use:

1 fL = 3.426 cd/m²

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

Time (years)

Performance (Lumens/Watt)


GaP:Zn,O
GaAs:0.6P:0.4
GaAsP:N
AlGaAs/GaAs
AlGaAs/GaAs
InGaN
AlInGaP/GaP
InGaP/GaAs
SM OLED
Polymer OLED

Courtesy of Agilent Technologies
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

\[(\text{PF})_n\]
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

Homer Antoniadis | OLED Product Development | Opto Semiconductors
page:12
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
Polymer and Small Molecule Device Structures

Small molecule

- Cathode - LiF/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
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

White OLED EL Spectra - Operational Stability
1000 hrs 20 mA/cm² Initial Lum ~ 980 cd/m²

- Before Operation
- After 1000 hrs
Phosphorescent small molecule OLEDs

PHOLED technology offers significant room for further performance advances
The Head-Start of Small Molecule OLEDs

- **Manufacturing started**
  - Pioneer 1997
  - TDK (Alpine, 2001)
  - RiTdisplay (2003)
  - Sanyo-Kodak (2003)

- **R, G, B colors available**
  - limited lifetimes for blue

- **Shadow masking allows easy patterning for area color**
  - presents challenges with scalability and high volume manufacturing

- **Shadow masking challenging for full color**
  - high throughput and scalability is a challenge
Advantages of Solution Processing (Polymer) OLEDs

- **Lower fabrication cost**
  - fewer vacuum deposition steps - lower capital cost
  - advantageous materials usage and scalability (l/j printing)

- **Solution processing techniques**
  - compatible with printing techniques
    - lower cost for full color
  - scalable to very large substrates (high volume manufacturing)
  - better mechanical integrity
  - compatible with roll process for flex manufacturing
**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
Ink Jet printing of R,G,B emissive polymers defines the R,G,B subpixels

\[(x_R, y_R) \quad (x_G, y_G) \quad (x_B, y_B)\]
Passive Matrix Addressing

- Line by line multiplex scanning
- Duration of addressing is 1/mux rate
- Pixel pulsed luminance = mux rate times average luminance
  - if 64 rows then pixel L=6400 nits for an average of 100 nits
- Limited addressed lines

Courtesy of Philips Electronics
Passive Matrix Addressing

- Line by line multiplex scanning
- Duration of addressing is 1/mux rate
- Pixel pulsed luminance = mux rate times average luminance
  - if 64 rows then pixel L=6400 nits for an average of 100 nits
- Limited addressed lines

Courtesy of Philips Electronics
Active Matrix Addressing

- Place a switching TFT at each pixel
- Selected pixel stays on until next refresh cycle (pixels are switched and shine continuously)
- Common cathode
- Unlimited addressed lines
OLED Market will show strong growth

Worldwide OLED Market, 2000-2006

Flat panel market 2006 $57B

Value (Mio $)

Thsd. units

250,000

200,000

150,000

100,000

50,000

0

2001
2002
2003
2004
2005
2006
2007
2008

TFT LCD
75%

PDP
12%

PM LCD
6%

OLED
4%

Other
3%

VFD: vacuum fluorescent display
EL: electroluminescence
DLP: Digital Light Processing

Small Molecule Area Color Passive Matrix Displays

Examples of Wireless Products With Kodak Display Technology

Motorola (by Appeal)

Samsung Electronics

Lucky Goldstar (LG)
Small Molecule Full Color Passive Matrix Displays

Caller ID Subdisplays

Samsung Electronics
96x64 Full Color PM Display
Kodak Licensed SNMD to Manufacture PM OLED Displays

Fujitsu F505i GPS
With Pioneer Full Color (4,096 colors) PHOLED 1.1-inch 96x72 pixels display. Phosphorescent material developed by Universal Display Corp.
Small Molecule Active Matrix Display Products

**Eastman Kodak**: Digital camera

**Sanyo**: Cell Phone with Digital camera
Kodak-Sanyo 15-in flat panel display (based on white)

15-inch HDTV format (1280x720) AM a-Si OLED display by Sanyo-Kodak. Full Color based on white OLED with Integrated Color Filters. The two companies showed the prototype at the CEATEC JAPAN trade show (Sep 2002).
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: 800x600 (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.