Organic Light Emitting Diodes (OLED)

Karlheinz Blankenbach

Pforzheim University, Germany

Prof. Dr. Karlheinz Blankenbach
Pforzheim University
Tiefenbronner Str. 65
D-75175 Pforzheim, Germany

Phone : +49 7231 - 28 - 6658
Fax : +49 7231 - 28 - 6060
Email : kb@displaylabor.de
Web : www.displaylabor.de
Organic Light Emitting Diode

• Basic function like semiconductor LED
• Emissive display technology
• Cheaper than semiconductor LEDs of same area
• Two technologies of OLEDs:
  - SM: Small Molecules (KODAK, mainstream)
  - LEP: Light Emitting Polymers (CDT)
• 3V to 5V forward voltage
• Luminance ~ Current (LCD: voltage)
• Direct, Passive Matrix (PMOLED)
  and Active Matrix (AMOLED) like LCD
• Current driven pixel needs 2 or more
  TFTs per subpixel (AM LCD: 1)
OLEDs in Mass Production

Passive Matrix since about 2005, mainly MP3 players

Limit in resolution etc. similar to PM LCDs.

Active Matrix since about 2010, mainly mobile phones

Issues: High resolution (ppi) and uniformity of TFTs.

Most professional OLED projects failed.
OLED TV Prototypes: 55” CES/SID 2012

LG

SAMSUNG

Low volume MP since 4Q2013
First Commercial Curved OLED TV’s late 2013

LG       SAMSUNG

Radius of bezel or table larger than that of the OLEDs

→ Impression of larger curvature
OLED Market Forecast

Source: IHS OLED Market Tracker
Overview

1. Small Molecules vs. Polymers
2. OLED Characteristics
3. Direct Drive & PM OLEDs
4. AM OLEDs
5. Summary & Comparison
OLED History

Discovery of Anthracen


First display application
SM : Alq3

Kodak

Cambridge DT Polymer (PPV)

Industrialization Passive Matrix

Prototype 20“ Active Matrix

First product (SM) Passive Matrix

Product : 2” Active Matrix

SM

SM
# Technologies

<table>
<thead>
<tr>
<th></th>
<th>Small Molecules (SM OLED)</th>
<th>Polymers (PLED)</th>
<th>Small Molecules + Phosphor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inventor &amp; Patents</strong></td>
<td>KODAK</td>
<td>CDT</td>
<td>UDC</td>
</tr>
<tr>
<td><strong>Chemical structure</strong></td>
<td><img src="image1" alt="Small Molecule Structure" /></td>
<td><img src="image2" alt="Polymers Structure" /></td>
<td>High efficiency</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>Mass production</td>
<td>Some products</td>
<td>Some products</td>
</tr>
<tr>
<td><strong>Production</strong></td>
<td>Vacuum &amp; masks</td>
<td>Printing (ink jet, screen) or Spin Coating</td>
<td>Vacuum &amp; masks</td>
</tr>
<tr>
<td><strong>Tasks</strong></td>
<td>Vacuum is costly, masks degrade, large area is challenging</td>
<td>Printing is potentially cheap but uniformity and tact time issues. PLEDs are some years “behind” Small Molecules</td>
<td></td>
</tr>
</tbody>
</table>

**OLED problem:** Scalability from samples to mass production
OLED History: 1st SM OLED by Tang, KODAK

- High efficiency: 1 % quantum efficiency (electron/photon), 1.5 lm/W luminous efficiency
- Low driving voltage: more than 1000 cd/m² below 10 V

OLED History: 1st PLED Cambridge Display Technology

Synthetic route of PPV

CH2C—CH2Cl

MeOH, 50 °C

Cl2

S

Cl

-Pt

H

Dialysis

PPV precursor

250°C Vacuum

PPV

Glass Substrate

Small Molecule Stack

First idea of OLED was to have only 1 layer!

Germany is leader in OLED materials! NOVALED, MERCK, BASF, … and major supplier of production equipment like AIXTRON, M.BRAUN

Cathode 150 nm
Electron Injection Layer (EIL) 200 nm
Electron Transport Layer (ETL) 35 nm
Emitted Layer (EML)
Hole Transport Layer (HTL) 50 nm
Hole Injection Layer (HIL) 20 nm
Anode 100 nm
Substrate

Thinner as LCD as no backlight needed

Light
Small Molecule Stack

…first idea of OLED was to have only 1 layer!
But all great things consist of more than one layer!
Polymer and Small Molecule Device Structures

Small Molecules
(Kodak)

- **Anode**: ITO
- **Substrate**: glass
- **EML**: doped Alq$_3$
- **HTL**: NPB
- **HIL**: CuPc

Polymer
(CDT)

- **Anode**: ITO
- **Substrate**: glass
- **EML**: PPV, PF
- **HIL**: PDOT, Pani
- **Cathode**: Ba, Ca/Al

**ETL**: Electron transport layer, **EML**: Emission layer
**HTL**: Hole transport layer, **HIL**: Hole injection layer
OLED Display and Device Structure

Single Pixel

Human hair is 200x the thickness of the OLED layers
**OLED Module**

- Emissive display technology (ambient light performance, Burn-In)
- Advantages: “unlimited” viewing angle, superfast response time
- Thin (thinner as AM LCD as no backlight required)
- Current driven (basic function similar to LEDs)
- Panel electronics and interface similar/same as for LCDs
- OLED display modules similar/same as for LCD: Direct, MUX, PM, AM
Summary OLED Fundamentals

- OLEDs have a short history

- 2 major types (small molecules & polymers) exist

- SM seems to be easier for display manufacturing. PLED based displays may be cheaper in production by printing in some years, e.g., demonstrated by FRAUNHOFER IAP, Potsdam

- All OLED base on multiple ultrathin layers of different materials. This is required for high efficiency.

- OLED material stack is thinner than LC layer thus requiring less material.

- Digital OLED interfaces (RGB, LVDS) are same/similar as for LCDs.
Overview

1. Small Molecules vs. Polymers
2. OLED Characteristics
3. Direct Drive & PM OLEDs
4. AM OLEDs
5. Summary & Comparison
Organic LEDs Overview

- Small Molecules
- Polymers
- Phosphorescent Small Molecules

Direct

- Monochrome
- Area colour
- Full colour

Multiplex, Passive Matrix

< 100 lines

Active Matrix

- 3 Terminal Silicon
- Amorphous Si
- poly Si
- Bulk (MOS)

Material class

Driving

Mainstream
Electro-optical Characteristic

- Linear $L - I$ characteristics
- Wide dynamic range
- Gray scale by current control
OLED Efficiency

Efficiency lowers for high voltage (luminance), which is needed for PM drive:
→ Power consumption increases
→ Lifetime lowered
→ High resolution requires AM OLED
OLED Viewing Angle

→ OLEDs have 'unlimited' viewing angle
OLED - Ageing of a Pixel

Reduction of active area (aperture) by moisture, ...

Shorts / dark spots

After 190h @ 1200 cd/m²

Pre-coat
Post-coat
Post-lifetest
Shelf
Driven

UDC, SID 2003
Reduction of OLED Lifetime By High T and Luminance

Temperature

- 25°C
- 85°C
- 120°C

Relative luminance vs. time (hours)

Luminance

- 2 mA
- 4 mA
- 8 mA
- 12 mA

Relative luminance vs. time (hours)

25°C: 20,000 h ⇒ 500 h

25°C: \( y = 1E+07x^{-1.44} \)

50°C: \( y = 5E+06x^{-1.43} \)

75°C: \( y = 27740x^{-1.18} \)

OLED

Initial Luminance in cd/m²

Automotive displays require high luminance during day ⇒ Lifetime!

„Double trouble“:
High T occur at high ambient illuminance ⇒ increase L ...
Reduction in ‘Useful Lifetime’

- Lifetime given in spec: 50,000 h @ 25°C
- $\Delta E^*_{LUV} = 10$ is clearly visible for neighboring pixel (100% ON vs. OFF)
- This results in 20,000 h ‘useful lifetime’ @ 25°C
- Operating at 75°C lowers lifetime by e.g. a factor of 4 down to 5,000 h which is only 10% of spec!

Further reduction by differential ageing.

High temperature reduces ‘useful lifetime’ significantly. Evaluate at operating temp!
OLED - Simulation of Burn-In and Differential Ageing

A. Donath, K. Blankenbach
SID ME, 3/2004, Frankfurt

- Simulated image

Color difference is the only method for judging Burn-in and Differential Aging

- False color acc.

$\Delta E$ (CIELUV)

Suitable for evaluation of necessary lifetime and optimization of GUI
Differential Ageing

- Caused by different lifetime of RGB subpixel used by SAMSUNG (can be avoided by white emitter and color filter like LCD but low efficiency, LG)
- Results in colour shift
- Irreversible!

- Lifetime, burn-in and differential ageing limit currently the application of OLEDs for, e.g., industrial and automotive applications!
Summary OLED Characteristics

• OLEDs displays have the same categories as LCDs:
  Direct drive (every segment connected to driver), Passive and Active Matrix

• OLED are current driven opposite to voltage driven LCDs.
  This makes driver ICs more costly.

• Light emission of OLEDs is proportional to current

• Innovations in light outcoupling (total reflection) improves efficiency and
  and reduces viewing angle degradations.

• OLED materials degrade by high temperature and luminance.
  This limits the use in professional applications like automotive and medical
  with a large portion of fixed content. Neighboring pixel can differ largely in
  luminance and color when their ON time differs largely. This makes the
  evaluation for professional applications more complex for OLEDs.
Overview

1. Small Molecules vs. Polymers
2. OLED Characteristics
3. Direct Drive & PM OLEDs
4. AM OLEDs
5. Summary & Comparison
Examples of Direct Drive and PM - Module

Direct Drive

- From electronics point of view very similar to LCD: Several manufacturers of character and low res graphics OLED modules exist.
- Practical limits of PM OLEDs: < 2”, < 128 rows

Sources: Display Lab
Direct Drive of OLEDs

Only few applications, e.g. solar calculator with OLEDs is not possible due to high power consumption.

Typical current drive equivalent circuit (like for LEDs, also for PM drive):

- $R_{\text{col}}$
- $C_{\text{col}}$
- $R_{\text{typ.}} = 1\,\text{K}\,\Omega \max$
- $C_{\text{typ.}} = 30\,\text{pF}$

- Many voltage-drive IC’s available
- Current-drive required
- Variable output current available
- ‘Programmable’ driver-IC required
OLED : PM - Driving

• Similar to other PM - technologies
• Pre-charging is necessary due to parasitic capacitors
• Power consumption ~ 25 mW for 96x64 pixel (25% ON)
Passive Matrix OLED

Principle: Like PM LCD but current driven

![Passive Matrix OLED Diagram]

High luminance of pixel due to duty ratio required: \( L_{\text{Display}} = \frac{L_{\text{maxPixel}}}{N_{\text{Row}}} \)

Example:
\[
L_{\text{Display}} = 100 \text{ cd/m}^2; \quad N = 100 \text{ rows} \quad \rightarrow \quad L_{\text{maxPixel}} = 10,000 \text{ cd/m}^2
\]

With losses: 30,000 cd/m²
Passive Matrix Luminance

Maximum luminance of Alq3

1530 nit (corresponds to 300 nit white raster)

Passive Matrix is only achievable below QVGA
PM - Module with LCD - Compatible Interface

HD 44780 Character Display
Limits of Passive Matrix OLEDs

- High resolution requires extreme high peak luminance (life time ↓)

- Ghosting (like PM LCDs)

- High power consumption due to capacitive and resistive losses

→ Active Matrix OLEDs

(> 200 rows, lines)
Summary PM OLEDs

• Direct driving of OLEDs is only rarely used as price significantly higher as for an direct driven LCD.

• Passive Matrix OLEDs show flash like emission of high peak luminance as rows are subsequentially activated and OLEDs have ultra low switching time. High luminance reduces both efficiency and lifetime.

• A potential application of PM OLEDs is flexible displays are they are easier to manufacture than AM OLEDs with TFTs (see § Summary)

• PM OLEDs were used in MP3 players, but these devices disappeared with the rise of smartphones.
Overview

1. Small Molecules vs. Polymers
2. OLED Characteristics
3. Direct Drive & PM OLEDs
4. AM OLEDs
5. Summary & Comparison
# AM OLED Products & Prototypes

## Products

- SAMSUNG mobile
- Photo frames and TV sets at low volume

## Prototypes

- Transparent AMOLED Samsung

Only Small Molecules
Active Matrix Colour OLED

Only few companies have mature LTPS process!
AM OLED Monitor Block Diagram

- Data
- Vsync
- R
- G
- B
- Comp
- Sync Separator
- Hsync
- PLL
- PI
- Bias
- Ref
- I^2C
- Digital Control
- Column Driver
- Sample & Hold
- MUX & Buffers
- Row Driver
- V-to-I & Pre-distortion
- Gain & Offset DACs
- 852x600x3 Pixel Array
- Sample & Hold
- Column Driver

TTL digital
RGB IF like LCD

Electronic Displays

Blankenbach / Pforzheim Univ. / www.displaylabor.de / OLEDs / WS 2014
Active Matrix OLEDs: Driving Principle

... is more complex as current drive compared to voltage drive of LCDs

Data Storage Capacitor (keeps Vg constant during frame time)

Additional line for current supply (compared to AM LCD)

Write Transistor (acts as switch to allow data to be written to power transistor)

Power Transistor
Vg level controls gray scale

Common Cathode (unpatterned cathode film common to all pixels)

Data Line (applies voltage to power transistor gate)
## Active Matrix for High Resolution and/or Image Quality

### Non-Emissive (LCD, E Ink)
- **Voltage drive** (low TFT requ.)
- **1 TFT pP** (6 Mio for HDTV)
- **Aperture** $\approx 70\%$

### Self-Emissive (OLED)
- **Current drive** (high TFT requ.)
- $\geq 2$ TFTs pP (uniformity)
- **Aperture** $\approx 30\%$ higher for top emission (inverted stack)

### Comparison
- AM LCD simpler than AM OLED
Active Matrix OLEDs: Driving - # of TFTs

<table>
<thead>
<tr>
<th>Voltage Drive</th>
<th>Current Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td><strong>Data</strong></td>
</tr>
<tr>
<td><strong>Storage Capacitor</strong></td>
<td><strong>Address TFT</strong></td>
</tr>
<tr>
<td><strong>Drive TFT</strong></td>
<td><strong>Scan</strong></td>
</tr>
<tr>
<td><strong>OLED</strong></td>
<td><strong>Scan</strong></td>
</tr>
</tbody>
</table>

More TFTs = better quality
Active Matrix OLEDs: Driving - Uniformity

Voltage Drive

2 TFTs per pixel

→ Better uniformity with more TFTs per pixel → aperture ↓, cost ↑

Current Drive

4 TFTs per pixel
Active Matrix Structures

Conventional Structure

- Metal cathode
- Transparent anode (ITO)
- Aperture \( \approx 30\% \)

Driving Circuit

OLED

Top Emitting Structure

- Semi-transparent cathode
- Seal plate
- Resin
- Metal anode
- Aperture \( \approx 80\% \)

Light

OLED on top of Circuit
Active Matrix OLED Cross Section

Producing AM OLEDs is more complex because of many OLED layers where thickness is critical and underlaying TFT array. This is however „manageable“ as mass production of SAMSUNG and LG proves.
The Importance of Aperture Ratio (AR)

To achieve the same pixel luminance:

- Higher current density results as AR decreases
  - Higher current density leads to decreased lifetime

- AR for each color adjusted to prevent white-balance shift over display lifetime

- Top emission format useful to maintain high aperture ratio as TFT complexity increases
  (see above)
Active Matrix TFT Requirements

- OLED is current driven - circuit must supply high current:
  - HIGH MOBILITY TRANSISTORS

- OLED displays must be stable in time:
  - HIGH STABILITY TRANSISTORS

- OLED displays must have a uniform brightness:
  - HIGH UNIFORMITY TRANSISTORS
## Active Matrix Addressing by TFTs

<table>
<thead>
<tr>
<th>Amorphous silicon (a-Si)</th>
<th>Low Temperature Polysilicon (LTPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- low electron mobility ~ 1 cm²/Vs</td>
<td>- high electron mobility ~ 100 cm²/Vs</td>
</tr>
<tr>
<td>- good uniformity</td>
<td>- bad uniformity</td>
</tr>
<tr>
<td>- max. 35 % aperture ratio</td>
<td>- up to 50 % fill factor</td>
</tr>
<tr>
<td>- top emitting structures preferred</td>
<td>- bottom emitters will work as well</td>
</tr>
<tr>
<td>- low array cost (5 masks)</td>
<td>- higher array costs (10 masks)</td>
</tr>
<tr>
<td>- drivers cannot be integrated</td>
<td>- drivers may be integrated</td>
</tr>
<tr>
<td>- lower system cost for large panel</td>
<td>- lower system cost for small panel</td>
</tr>
<tr>
<td>- low current stability</td>
<td>- high current stability</td>
</tr>
<tr>
<td>- more sensitive to OLED degradation</td>
<td>- less OLED degradation</td>
</tr>
<tr>
<td>- lower equipment costs</td>
<td>- Only &lt; GEN 4 production</td>
</tr>
<tr>
<td>- high yield</td>
<td>- high investment</td>
</tr>
<tr>
<td></td>
<td>- bad yield / immature process</td>
</tr>
</tbody>
</table>
## Active Matrix TFT Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Mobility cm²/Vs</th>
<th>Uniformity</th>
<th>Stability</th>
<th>Suitable for OLED?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic electronics</td>
<td>&lt;&lt;1</td>
<td>poor</td>
<td>poor</td>
<td>x</td>
</tr>
<tr>
<td>Amorphous Silicon TFT</td>
<td>1</td>
<td>reasonable</td>
<td>reasonable</td>
<td>Prototypes</td>
</tr>
<tr>
<td>Polycrystal Si (LTPS)</td>
<td>100</td>
<td>reasonable</td>
<td>excellent</td>
<td>Yes</td>
</tr>
<tr>
<td>Monocrystal Si (Alien/eMagin)</td>
<td>1000</td>
<td>excellent</td>
<td>excellent</td>
<td>Yes but... price, yield...</td>
</tr>
</tbody>
</table>
## OLED Approaches to Full Colour

<table>
<thead>
<tr>
<th>Method</th>
<th>RGB Emitters</th>
<th>Colour Filters + White Emitter</th>
<th>Colour Changing Media</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Power efficient</td>
<td>+ Colour filter like LCD</td>
<td>+ Colour filter like LCD</td>
<td>+ Homogeneous aging of emitter</td>
</tr>
<tr>
<td></td>
<td>+ No patterning of emitter</td>
<td>+ No patterning of emitter</td>
<td>+ More efficient than filters</td>
</tr>
<tr>
<td></td>
<td>+ Homogeneous aging of emitter</td>
<td>+ Homogeneous aging of emitter</td>
<td>+ No patterning of emitter</td>
</tr>
<tr>
<td>- Differential aging of emitters</td>
<td></td>
<td></td>
<td>- Stable blue emitter necessary</td>
</tr>
<tr>
<td>- Complex patterning mask and process</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SAMSUNG** | **LG**
Summary AM OLED

• AM OLED modules have same digital IF like AM LCDs

• AM OLEDs are more expensive (2013) than AM LCDs because of more complex AM backplane (more TFTs, higher requirements for TFTs, …).

• Many TFTs per pixel reduce yield in production thus rising cost.

• TFT improvements may decide on long time success of AM OLEDs

• Color for OLEDs can be achieved by RGB emitters (suffer of differential aging, SAMSUNG) or color by white similar to AM LCDs (reduces luminance, LG). Color by white may “win” on the long run as white OLEDs are used for lighting.

• AM OLEDs are in mass production for mobile phones (2013) mainly produced by SAMSUNG.
Overview

1. Small Molecules vs. Polymers
2. OLED Characteristics
3. Direct Drive & PM OLEDs
4. AM OLEDs
5. Summary & Comparison
Flexible OLED Prototypes

Sources = names

AM OLEDs

LG, UDC

PM OLED

by FUTABA, easier to manufacture than AM OLEDs
### Flexible OLEDs Approaches

<table>
<thead>
<tr>
<th></th>
<th>SDI</th>
<th>Sony</th>
<th>LGE</th>
<th>LGD/UDC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Substrate</strong></td>
<td>Metal foil, Thin glass</td>
<td>Plastic</td>
<td>Metal foil</td>
<td>Metal foil</td>
</tr>
<tr>
<td><strong>TFT</strong></td>
<td>LTPS TFT</td>
<td>Organic TFT</td>
<td>Oxide TFT</td>
<td>a-Si TFT</td>
</tr>
<tr>
<td><strong>OLED</strong></td>
<td>Top emission</td>
<td>Top emission</td>
<td>Top emission</td>
<td>Top emission</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>• Glass bonding</td>
<td>• All organic display</td>
<td>• Oxide TFT</td>
<td>• Glass bonding</td>
</tr>
</tbody>
</table>

**Demo**

- **SDI**:
  - 5.6” F-AMOLED (2006, STS)
  - 4” Curved AMOLED (2007, thin glass)

- **Sony**:
  - 2.5” F-AMOLED (2007, plastic)
  - 3.5”, 176XRGBX220 F-AMOLED (2007, STS)

- **LGE**:
  - 4”, 320XRGBX240 F-AMOLED (2007, STS)

Source: V&V
Curved TVs

First curved OLED TV @ CES 2013. **Benefits:** Life-like viewing experience for panorama landscapes (feeling surrounded). **Selling** of curved OLED TVs may start before 2014.

Real benefits? Gamers? OLED TVs were announced for hanging on the wall.

Sources = names
OLEDs vs. LCDs: Power Consumption

Small Size ( ~ 5“)

Large Size ( ~ 55“)

<table>
<thead>
<tr>
<th>55” TV</th>
<th>OLED</th>
<th>LCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>L / cd/m²</td>
<td>150 – 600</td>
<td>&gt; 500</td>
</tr>
<tr>
<td>Power /W</td>
<td>170 – 250</td>
<td>100 - 150</td>
</tr>
</tbody>
</table>

Power consumption:
- Small size: $P_{OLED} \approx P_{LCD}$
- Large size: $P_{OLED} \approx 2 \times P_{LCD}$

⇒ Advantages of OLED?
## OLEDs vs. LCDs: Power Consumption @ 55”

### 55” curved OLED

<table>
<thead>
<tr>
<th>Display and Mode</th>
<th>$L_W$ (cd/m²)</th>
<th>$L_K$ (cd/m²)</th>
<th>Full-Screen K or W Power, $P$ (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Samsung OLED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic</td>
<td>489</td>
<td>0</td>
<td>$P_K = 115$</td>
</tr>
<tr>
<td>Standard</td>
<td>398</td>
<td>0</td>
<td>$P_W = 219$</td>
</tr>
<tr>
<td>Movie</td>
<td>221</td>
<td>0</td>
<td>$P_W = 188$</td>
</tr>
<tr>
<td><strong>LG OLED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vivid</td>
<td>373</td>
<td>0</td>
<td>$P_W = 213$</td>
</tr>
<tr>
<td>Standard</td>
<td>389</td>
<td>0</td>
<td>$P_W = 210$</td>
</tr>
<tr>
<td>Eco</td>
<td>267</td>
<td>0</td>
<td>$P_W = 171$</td>
</tr>
</tbody>
</table>

OLED power consumption depends on content.

- $P_{\text{white}}(250 \text{ cd/m}^2) \approx 180 \text{ W (55”)}$
- $P_{\text{white}}(489 \text{ cd/m}^2) \approx 252 \text{ W (55”)}$

### Compare to 55” LCD TV

- **Samsung (UE55F8090)**: $P_{\text{white}}(250 \text{ cd/m}^2) \approx 75 \text{ W (55”)}$
- **LG (55LM960V)**: $P_{\text{white}}(480 \text{ cd/m}^2) \approx 125 \text{ W (55”)}$

For 55” $P_{\text{OLED}} \approx 2 \times P_{\text{LCD}}$
OLEDs vs. LCDs for Color AM - Displays

**OLED***

- Polarizer
- Glass
- Colour filter
- OLED / LC layer
- 4 vs. 1 TFT p.P.
- Glass
- Polarizer
- Backlight

**Appr. same price**

**LCD**

- Polarizer
- Glass
- Colour filter
- OLED / LC layer
- 4 vs. 1 TFT p.P.
- Glass
- Polarizer
- Backlight

*: Top emitting, white emitter

**Same price ?**

**Lifetime, no burn in, ... !**

**Production process costs of OLED layers ?**
# OLED vs. LCD

<table>
<thead>
<tr>
<th>OLED strengths = LCD weaknesses</th>
<th>LCD improvements (done &amp; prototype status)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viewing angle</td>
<td>IPS, VA, multi-domain (all in MP)</td>
</tr>
<tr>
<td>Gamut (WLED)</td>
<td>Quantum Dot film</td>
</tr>
<tr>
<td>Response time</td>
<td>&gt; 3ms, Blue Phase LC &lt; 1 ms</td>
</tr>
<tr>
<td>Thin, light</td>
<td>Backlight needed, but slim today</td>
</tr>
<tr>
<td></td>
<td>(mobile panel &lt; 1mm, 42“ : 2,6 mm)</td>
</tr>
<tr>
<td>Efficiency (image dependent)</td>
<td>Sequential color backlight, polarizer-free</td>
</tr>
</tbody>
</table>

OLED seems to be superior in some topics over LCD but LCD has cost advantage and new approaches.

**OLED drawbacks:** complex TFT backplane, color, ... (power for TV)
OLEDs vs. LCDs by OLED - Manufacturer
OLED Summary

- OLEDs have a short history
- Electro-optical characteristic is similar to semiconductor LEDs
- Passive Matrix OLEDs have limits in terms of resolution
- AM OLED backplane is more complex as for AM LCDs which require however a backlight (increases thickness).
- Some small sized OLEDs are in professional applications like
  - Climate control in MERCEDES E-class
  - Multimeter by AGILENT
- Mass production of AM OLEDs (2013) mainly for mobile devices
- Flexible plastic (unbreakable) OLEDs may push these displays for mobile applications.
## Summary: Technologies vs. Applications

<table>
<thead>
<tr>
<th>Requirement, Application</th>
<th>Suitable?</th>
<th>Range</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viewing distance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color, video</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viewing angle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feasibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trends</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary “OLEDs”

- PM OLED is limited in resolution like LCD.
- AM OLED backplane is more complex than for AM LCD (cost!).
- Some professional PM OLEDs are available.
- AM OLEDs are in MP for mobile CE products.

- OLED lifetime in app is most important.
- Emissive display, so negative contrast is preferred.