A History of Flat Panel Displays

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Founder (Retired)
Planar Systems, Inc.
May 2009
Laying the Scientific Foundations
1960 - 1980

- Liquid Crystal Displays
- Plasma Displays
- Thin Film Electroluminescent Displays
The Birth of LCDs at the RCA Sarnoff Laboratories

- 1962 R. Williams discovers the phenomenon of “Williams Domains” in nematic liquid crystals.
- 1968 G. Heilmeir and his group develop first liquid crystal displays based on dynamic scattering effects.
Williams Domains

Domains in liquid crystals with an applied voltage of 2,500 V/cm observed by Richard Williams in 1962.
RCA demonstrating Dynamic Scattering LCD Clock (1968)
First Digital LCD Watch Optel (1970)
First LCD Calculator Rockwell (1972)
A new electro-optical effect in twisted nematic liquid crystals is described which allows variations of the rotation of linearly polarized light continuously from 0° to 90°. It requires lower voltage than other electro-optic effects.
Twisted Nematic Liquid Crystal Display (TN-LCD)

Cyanobiphenyls (1972)

G. Gray, J. Nash and K. Harrison

A - Nematic Range: 54 - 80 degrees C

B - Nematic Range: 22 - 35 degrees C

C - Nematic Range: 28 - 42 degrees C

D - Nematic Range: 130 - 239 degrees C
Invention of ac Plasma Display at the University of Illinois

- 1964 D. Bitzer, G. Slottow, & D. Wilson
- 1968 Owens-Illinois develops open cell structure
- 1971 12” diag. 512 x 512 Graphic Display product
Original University of Illinois Plasma Display Patent
Open Cell Structure Developed by Owens Illinois (1968)
First ac Plasma Product
Owens Illinois (1971)
Thin Film EL Breakthrough by Sharp Laboratories

- 1974 T. Inoguchi and his group report a stable and high brightness TFEL Display
- 1975 Sharp demonstrates a 320x240 QVGA display
- 1983 Sharp introduces first commercial TFEL display product
Thin Film Electroluminescent (TFEL) Display Technology

**Advantages**
- High contrast
- Wide operating temperature range
- Emissive - excellent viewing angle
- Fast response time

**Disadvantages**
- High voltage drivers
1980s: The Quest for High Information Content

• The birth of the personal computer created a desire for a portable computer with a flat panel screen
• This market opportunity led to fierce competition between emissive and non-emissive display technologies
TFEL Prototype built at Tektronix
## Calculated Power Consumption for a TFEL 10.4” VGA with No Power Reduction Circuitry

<table>
<thead>
<tr>
<th>Power Component</th>
<th>Typical Power $m = 0.1 , M$</th>
<th>Maximum Power $m = 0.5 , M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Light</td>
<td>0.125</td>
<td>0.625</td>
</tr>
<tr>
<td>P Row Charge</td>
<td>2.59</td>
<td>2.59</td>
</tr>
<tr>
<td>P Column Charge</td>
<td>4.93</td>
<td>12.32</td>
</tr>
<tr>
<td>P Total</td>
<td>7.645</td>
<td>15.54</td>
</tr>
</tbody>
</table>
CAPACITOR CHARGING POWER CONSUMPTION

\[ W_C = W_R = \frac{1}{2} CV^2 \]

\[ P = f \times C \times V^2 \]
POWER REQUIRED TO DRIVE THE COLUMNS
10" Diagonal, VGA TFEL Panel

% of ON Pixels per Row

Power (Watts)
TFEL Computer Displays in the 1980’s

- Grid 1983
- HP 1985
- Data General 1986
- DEC 1989
Progression of EL Display Information

- 320 x 240
- 512 x 256
- 640 x 200
- 640 x 400
- 640 x 480
- 640 x 800
- 1024 x 864
TWO STEP ENERGY SAVINGS

\[ W_{\text{2STEP}} = \frac{1}{2} C (V/2)^2 + \frac{1}{2} C (V/2)^2 = \frac{1}{4} CV^2 \]
IBM Plasma Display
The Development of the STN LCD

• 1983 T. Scheffer and Jürgen Nehring at Brown Broveri Co. discover the Super Twisted-Nematic effect

• 1985 Brown Broveri Co. demonstrates a 10.7 inch diag. 540 x 270 STN panel

• By the end of the 1980s the STN-LCD becomes the dominant flat panel display technology for portable computers
The 1990s: The Quest for Color

• All of the three major flat panel technologies needed to make significant changes to their device structures and materials to achieve color in the 1990s.

• Successful color development positioned flat panels to compete directly with the CRT.
Active Matrix LCDs

• Although passive matrix addressed LCDs dominated the market for low power displays, emissive displays had superior performance in terms of brightness, contrast, viewing angle and response time.

• Active matrix addressed LCD with a-Si TFTs solved the basic materials limitations of liquid crystals and the addition of a mosaic color filter enabled color.
Color Reproduction

- Transmissive TN Mode
- RGB Color Mosaic Filter + Backlight
- Pixel Pitch and Viewing Distance
Early TFT Development

• 1968 P. Brody’s group at Westinghouse builds TFT addressed EL display
• 1974 P. Brody builds first AMLCD using CdSe TFTs.
• 1979 P. Le Comber and W. Spear at the Univ. of Dundee demonstrate a-Si TFT
• 1983 S. Morozumi and his colleagues at Seiko Epson build first commercial hand held color LCD TV
Seiko Epson Hand Held TV
Cost Competitive AMLCD

• The manufacture of small AMLCDs for the hand held TV market allowed Japanese companies to go down the manufacturing cost learning curve.

• In 1991 IBM and Toshiba formed a joint venture to manufacture color AMLCDs for portable computers.

• The IBM Think Pad portable PC was introduced in 1992.
**TFT Color LCD Power Consumption**

- Initial 10.4” VGA consumed > 10W
- Power Reduction Actions
  - Improve Back Light and power supply efficiencies
  - Match Back Light spectrum to color filter transmission curves
  - Brightness Enhancement Films
  - Increase the TFT aperture ratio
APERTURE RATIO ENHANCEMENT

Conventional ~ 55 %

Super High Aperture up to 80 %
# Power Reduction for 10.4” VGA by IBM

<table>
<thead>
<tr>
<th>Date</th>
<th>Product</th>
<th>Display Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/1991</td>
<td>PS/55</td>
<td>15</td>
</tr>
<tr>
<td>10/1992</td>
<td>ThinkPad 700C</td>
<td>8.5</td>
</tr>
<tr>
<td>9/1993</td>
<td>ThinkPad 750C</td>
<td>5.6</td>
</tr>
<tr>
<td>11/1994</td>
<td>ThinkPad 755CE</td>
<td>3.6</td>
</tr>
</tbody>
</table>
LCD History

US Activity

- Si MOS
- HT Poly-Si TFT
- LT Poly-Si TFT
- MIM
- a-Si TFT


- Twilight

- Small TV

- Monitor Displays

- Portable PC

- 1st Gen
- 2nd Gen
- 3rd Gen
- 4th Gen

(in US$)

- 0
- 5B
- 10B

Color Plasma Displays

- 1990 T. Shinoda of Fujitsu invents the three-electrode panel with RGB phosphors excited by Xenon gas discharge
- 1992 Fujitsu 21 inch dia. Color PDP
- 1996 Fujitsu 42 inch dia. Color PDP
- By the end of the decade color PDP is the premium large flat panel TV screen
Color Plasma Display Structure
## 21” Diagonal Color Plasma Display

### (1992)

<table>
<thead>
<tr>
<th>Item</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display Area</td>
<td>422 x 316 mm</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>4 : 3</td>
</tr>
<tr>
<td>Number of Pixels</td>
<td>640(R,G,B) X 480</td>
</tr>
<tr>
<td>Pixel Pitch</td>
<td>0.66mm X 0.66mm</td>
</tr>
<tr>
<td>Number of Colors</td>
<td>260,000</td>
</tr>
<tr>
<td>Luminance</td>
<td>180 cd / m2</td>
</tr>
<tr>
<td>Viewing Angle</td>
<td>&gt; 160 degrees</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>100 W max</td>
</tr>
<tr>
<td>Weight</td>
<td>4.8Kg</td>
</tr>
</tbody>
</table>
42” Diagonal Color Plasma Display

(1996)
The Long Quest for Color Inorganic EL

- 1987 S. Tanaka & H. Kobayashi of Tottori University propose color by white structure
- 1993 Planar introduces Red-Yellow-Green TFEL product
- Planar demonstrates several RGB prototypes using SrS:Ce, SrS:Cu, or SrGa$_2$S$_4$:Ce for the blue phosphor
Red-Yellow-Green TFEL Products

Multi Color VGA

Multi Color QVGA
Color Prototypes

Color QVGA TFEL

Color VGA AMEL
Blue EL Phosphor Breakthrough

- 1999 N. Miura of Meiji University discovered efficient blue EL in BaAl$_2$S$_4$:Eu
- 2004 X. Wu of iFire reports on Color by Blue structure using BaAl$_2$S$_4$:Eu
- 2007 iFire demonstrates a 34 inch dia. Color EL TV panel
Achieving Full Color (Color By Blue)

Based on the Physics of Photoluminescence

- **Blue EL Phosphor** - “Blue Pump”
  - Emits blue light

- **Green Conversion**
  - Absorbs Blue
  - Emits Green

- **Red Conversion**
  - Absorbs Blue
  - Emits Red
iFire 34” Diagonal Color EL
Organic EL Technology Milestones

• 1987 C. Tang and S. Van Slyke of Kodak report the development of an efficient OLED device.
• 1995 C. Hosokawa of Idemitsu Kosan develops an efficient blue emitter material.
• 1999 S. Forrest and M. Thompson develop efficient red & green electrophosphorescent materials.
## PHOSPHORESCENT OLED PERFORMANCE

### 2009 UNIVERSAL DISPLAY CORP.

<table>
<thead>
<tr>
<th>PHOLEDS</th>
<th>CIE Color Coord.</th>
<th>Luminous Efficiency (cd/A)</th>
<th>Luminous Efficiency (Lum/Watt)</th>
<th>Lifetime to 50% Lo (hrs)</th>
<th>Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Red</td>
<td>(0.67,0.33)</td>
<td>21</td>
<td>15.3</td>
<td>80,000</td>
<td>4.3</td>
</tr>
<tr>
<td>Deep Red</td>
<td>(0.66,0.34)</td>
<td>22</td>
<td>19.6</td>
<td>200,000</td>
<td>2.8</td>
</tr>
<tr>
<td>Red</td>
<td>(0.64,0.36)</td>
<td>28</td>
<td>31.4</td>
<td>500,000</td>
<td>2.8</td>
</tr>
<tr>
<td>Green</td>
<td>(0.36,0.60)</td>
<td>58</td>
<td>65</td>
<td>100,000</td>
<td>2.8</td>
</tr>
<tr>
<td>Green</td>
<td>(0.36,0.60)</td>
<td>67</td>
<td>45</td>
<td>250,000</td>
<td>45</td>
</tr>
</tbody>
</table>
Organic EL Product Milestones

- 1996 Pioneer introduces first commercial monochrome OLED display
- 2003 Kodak and Sanyo introduce first color AMOLED product
- 2008 Sony introduces first color AMOLED TV
OLED Products and Prototypes

Pioneer Monochrome OLED display 256x64 pixels (FM radio sold only in Japan)

Pioneer Multicolor OLED display in a AM/FM CD changer sold worldwide

Sony SVGA AMOLED Prototype

Sanyo Color AMOLED display - 852x222 pixels (prototype, 2.5” diag.) A 5-inch QVGA has also been shown

Pioneer Multicolor OLED display in a Cell phone product
OLED Products - Kodak Digital Camera

KODAK EasyShare LS63 Zoom digital camera...

- Screen and camera made by Kodak
- Launched February 2003
Sony AMOLED-TV – Model XEL1

- 11" and 3mm thick
- Contrast ratio: $10^6$ to 1
- View angle: 180 degree
- Resolution: 960 x 450
- Color gamut: 101% NTSC
- Power consumption: 45W
AMOLED PMOLED Market Trend

Source: iSuppli, August 2008

US$ ~ 0.5 Billion
Coexistence of display technologies

- Market value will peak in 2008 and gradually decline due to continuous price drop

- Coexistence of display technologies, but AMLCDs lead, while PMLCDs used in low value applications
  - OLEDs struggling with manufacturing to expand volume

- OLED market will grow but will have a fairly small piece

- Low-end character and segmented MSTN displays continue in white goods:
  - Microwaves, coffee machines etc
### Flat Panel Success Requirements

**Components for Success**

<table>
<thead>
<tr>
<th></th>
<th>LCD</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. High Volume Entry Market&lt;br&gt; - Key Features</td>
<td>Watches, Calculators&lt;br&gt; - Low Power Monochrome</td>
<td>Cell Phones&lt;br&gt; Low Power Color</td>
</tr>
<tr>
<td>2. High Information Content Capability&lt;br&gt; - Market&lt;br&gt; - Display Type&lt;br&gt; - Key Technology</td>
<td>Computer Display&lt;br&gt; AMLCD&lt;br&gt; a-Si TFT</td>
<td>TV Screen&lt;br&gt; AMOLED&lt;br&gt; ? TFT</td>
</tr>
<tr>
<td>3. Full Color Capability&lt;br&gt; - Market&lt;br&gt; - Initial Competitors&lt;br&gt; - Technical Issues&lt;br&gt;   - Viewing Angel&lt;br&gt;   - Response Time&lt;br&gt;   - Color Gamut&lt;br&gt;   - Power Consumption</td>
<td>TV Screen&lt;br&gt; CRT, Plasma&lt;br&gt; MVA &amp; IPS&lt;br&gt; Materials, addressing, backlights&lt;br&gt; Backlights&lt;br&gt; Dynamic Backlights</td>
<td>TV Screen?&lt;br&gt; AMLCD&lt;br&gt; Excellent&lt;br&gt; Addressing Circuitry&lt;br&gt; Color Filters&lt;br&gt; <em>Very Efficient Materials</em></td>
</tr>
<tr>
<td>4. Costs&lt;br&gt; - Panel Process&lt;br&gt; - TFTs&lt;br&gt; - Color Filter&lt;br&gt; - Back Light&lt;br&gt; - Driver ICS</td>
<td>Low&lt;br&gt; Low&lt;br&gt; High&lt;br&gt; High&lt;br&gt; Low</td>
<td>Medium&lt;br&gt; <strong>High</strong>&lt;br&gt; High&lt;br&gt; None&lt;br&gt; Low</td>
</tr>
</tbody>
</table>

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Acknowledgements

LC History

Plasma History

EL History
Sony First OLED Color TV

XEL-1