Optical Films and Illumination Sources for LCDs

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Knebworth House
Quiz

Which are the six most profitable companies in the display business?
My Answer

- Corning Glass
- Fuji Film
- Merck
- Nitto Denko
- Philips Lighting
- 3M

Note: There are 2 companies from Asia, Europe and the U.S

So

1. Material suppliers make lots of money
2. You don’t have to be based in Asia
Structure of a transmissive LCD (cross-section)

Fuji’s Products

- CV film (on Fuji TAC)
  Anti-reflection film
- WV film (on Fuji TAC)
  Viewing Angle Enhancement film
- Tracer
  Color Filter Transferred on the glass substrate
- WV film (on Fuji TAC)
- Fuji TAC
  Protective film of Polarizer
Structure of a Transmissive LCD (cross-section)
Demands on Materials Suppliers

- **Cut Costs**
  - At least 10% a year
  - More this year
- **Help to Improve Form Factor**
  - Thinner
  - Lighter
- **Improve Performance**
  - Brightness and Contrast
  - Color control and gamut
  - Better off-axis viewing and uniformity
  - Faster response
  - Longer lifetime
Reducing Costs of LCDs

- Further gains from larger substrates will be very difficult
  - First forecasts of costs for 8\textsuperscript{th} gen seem higher than 7\textsuperscript{th} gen
  - Equipment suppliers will focus on enabling material cost reductions
  - Less waste – additive rather than subtractive patterning
  - Repair of faults is critical at all stages

- Most gains must come from materials & components
  - Localized production
  - More efficient suppliers
  - More effective materials
  - Better design
    - Improved backlights
    - Eliminate the color filter

- We need better packaging for small displays
32” WXGA LCD TV Panel Costs: 2005

<table>
<thead>
<tr>
<th>730*920</th>
<th>1100*1300</th>
<th>1300*1500</th>
<th>1500*1800</th>
<th>1870*2200</th>
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<td>Sales Profit</td>
<td>-$99.7</td>
<td>-$91.1</td>
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<td>Overhead, Sales Expense</td>
<td>$31.0</td>
<td>$31.0</td>
<td>$31.0</td>
<td>$31.0</td>
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<tr>
<td>R&amp;D</td>
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<td>Depreciation</td>
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<td>$421.0</td>
<td>$430.3</td>
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<td>730*920</td>
<td>1100*1300</td>
<td>1300*1500</td>
<td>1500*1800</td>
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<tr>
<td><strong>Sales Profit</strong></td>
<td>$-91.2</td>
<td>$-70.4</td>
<td>$13.0</td>
<td>$18.9</td>
</tr>
<tr>
<td><strong>Overhead, Sales Expense</strong></td>
<td>$21.7</td>
<td>$21.7</td>
<td>$21.7</td>
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<tr>
<td><strong>R&amp;D</strong></td>
<td>$21.7</td>
<td>$18.4</td>
<td>$14.1</td>
<td>$10.8</td>
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<tr>
<td><strong>Indirect Expense</strong></td>
<td>$36.6</td>
<td>$29.6</td>
<td>$27.7</td>
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<td><strong>Depreciation</strong></td>
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<td>$104.2</td>
<td>$64.5</td>
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<td><strong>Personnel Cost</strong></td>
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<td><strong>Yielded Components Cost</strong></td>
<td>$276.5</td>
<td>$299.7</td>
<td>$268.7</td>
<td>$272.7</td>
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</table>
32” LCD TV Component Costs

Breakdown of Material/Component Costs
32” WXGA

Glass
CF
Polarizers
Backlight
Driver ICs
Other mats

26%
19%
15%
26%
6%
8%

[Pie chart showing component costs]
Conventional CF Cost Structure

Cost dominated by glass, then depreciation

- Margin, 15%
- Yielded Glass, 33%
- Yielded Other Materials, 9%
- Depreciation, 21%
- Personnel Cost, 7%
- R&D, 4%
- Indirect Expenses, 3%
- Overhead, Sales Expense, 8%

Note: Forecast 2005 values for 17” on 5th Gen with, price of \$2,772. Assumptions for merchant CF maker.
Backlight Bill of Materials

Source: Albert Yang (Wellypower)
Lightweight & Thin & Low Power

To achieve a thinner & lighter backlight, the light guide plate must be reduced in thickness and the number of optical sheets must be decreased.

Increased Transmittance is the most efficient way to reduce the backlight power. "LTPS" has a higher aperture ratio than a-Si.
Energy Flow in Liquid Crystal Display

Backlight efficiency is ~15% (60 lm/W)

Transmission factor is ~ 4%

Overall efficiency is ~ 0.6% at ~2.4 lumen/Watt
Light Efficiency Breakdown of LCD module

Light emitted to the LCD surface is only 0.6% of the input power.
40% loss: At the light inlet of the light guide plate
20% loss: In the light guide plate

The light efficiency of the light guide plate must be increased.
Prism Light Guide

1.2X higher efficiency. Achieves a "Thin" & "Lightweight" lightguide.

Normal Back Light

Prism Light Guide

DBEF

Prism sheet

Prism sheet

Diffusing Sheet

L/G

Light usage effectiveness 1.2X
Low Power & Thin

Two optical sheets eliminated
(Thin & Lightweight)

More than 1.2X improvement is estimated

Diffusing Sheet

Prism sheet

Prism L/G

Prism effect is built into the Light Guide
Backlight Issues

Big concern for LCD TVs due to number of lamps, cost, performance, availability, etc.

Mercury content a growing concern in certain regions

New technologies likely to be introduced

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Diameter φ</th>
<th>2005</th>
<th>% Total</th>
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<tbody>
<tr>
<td>CCFL</td>
<td>4.9</td>
<td></td>
<td>NA</td>
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<tr>
<td></td>
<td>20</td>
<td></td>
<td>NA</td>
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<tr>
<td>Lamp</td>
<td>Unit Price</td>
<td>$2.17</td>
<td>2%</td>
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<tr>
<td></td>
<td>Total Price</td>
<td>$43.35</td>
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<tr>
<td>Diffusion board</td>
<td>for direct type</td>
<td>$19.29</td>
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<td>Diffusion sheet</td>
<td>Normal</td>
<td>$6.91</td>
<td>5%</td>
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<td>Printing (+)</td>
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<td>0%</td>
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<td>Reflective sheet</td>
<td>Normal</td>
<td>$0.94</td>
<td>1%</td>
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<tr>
<td></td>
<td>Printing (+)</td>
<td>$0.45</td>
<td>0%</td>
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<tr>
<td>BEF</td>
<td>BEF3</td>
<td>$4.08</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>DBEF</td>
<td>$12.73</td>
<td>9%</td>
</tr>
<tr>
<td>Others</td>
<td>Labor, Deprec, etc.</td>
<td>$47.4</td>
<td>35%</td>
</tr>
<tr>
<td>Unit Price</td>
<td></td>
<td>$135.5</td>
<td>100%</td>
</tr>
</tbody>
</table>

Note: 40” BLU Costs, fall 2003 forecast
Backlight Technologies for LCD

- LCD TV Backlight
  - Fluorescent Lamp
    - Tube
      - HCFL
      - CCFL
      - EEFL
      - Non-Hg FL
    - Flat Lamp
      - Flat Lamp (Hg)
      - Planon (Non-Hg)
  - LED
  - OLED Flat Lamp
  - Field Emission Lamp
    - CNT FE Flat Lamp
Improvements in Conventional CCFL Backlights

- New production equipment to make lamps with lengths over 1m
- Rotating coaters to improve chromaticity uniformity
- New glass tube and coating to reduce UV emissions
- Lower temperature operation through new electrode material (Ni -> Mo), sealing part (Kovar -> W) and thicker lead wires
- Longer life through the new electrode material and a phosphor protection coating; without this coating the luminance diminishes by 14% in 4000 hours, with the coating the loss is reduced to 10%
- New phosphors that increase the color gamut from 68% NTSC to 85% NTSC
- Electrode coating to reduce time and voltage needed in start-up
- Blinking backlight with scanning to reduce motion artifacts

Source: Albert Yang (Wellypower)
U-Type CCFLs

Advantages

- No GND Return Wire, Less Current Leakage
- Higher Efficiency & Better Uniformity
- Fewer Inverters & Simplified Structure
- Currently in production up to 26”

Source: Samsung
External Electrode Fluorescent Lamps

- Developed by Harison Toshiba

- Electrodes are on the outside of the glass tube. The electric field is capacitively coupled to the phosphor and gas inside the tube.
- Advantages include longer life due to no sputtering phenomena to degrade the electrodes and less likely to feature gas leaks.
- Argon and neon can be used, instead of mercury.
- Costs can fall due to multiple lamps being driven from a single inverter and Al tape used as the electrode rather than Ni and Mo.
- Believed to use around 10% less power, greater luminous efficiency.
- Because voltage rises linearly with current, could contribute to arcing, EMI and inverter field failures.
EEFL

CCFL (Cold Cathode Fluorescent Lamp)  →  EEFL (External Electrode Fluorescent Lamp)

- W-rod
- Glass bead
- Electrode
- Metal disk
- Phosphor
- Ti-Hg alloy pellet
- Removing the internal electrodes
- External electrode
- Phosphor
- External electrode

B/L lamp structure

Features

- Low power-consumption: 20% ↓
- One inverter (Master & Slave type 1set)
  Cost ↓
- Longer life-time: > 70,000Hr
- Environment friendly
  Pb free (non soldering lamp)

Source: LPL at DisplaySearch FPD Conference Korea, Oct 04
Embossed Backlight

Source: Samsung and Samsung-Corning
Lateral Multi-Channel Flat Discharge Fluorescent Lamp

Co-developed by Samsung Corning and University of ElectroCommunications, Chofu
Multi-channel lamp with dielectric layers
- 32” prototype built
- Low ignition voltage (700V)
- Long life anticipated

Described at SID conference
- Seattle, June 2004

This appears to be a form of dielectric barrier discharge
Planon Lamp

• The Planon lamp is a dielectric barrier discharge lamp made by Osram
• The discharge occupies the gap between two planar electrodes
• The electrodes are each covered with a dielectric layer and phosphors
• The gap is filled with Xe, so no Hg
• The ignition voltage is ~2kV
• The efficacy is relatively low, around 30 lm/W
• The lifetime is extremely long, >100,000 hours
• The lamp operates over a wide range of temperature

• A short description can be found at http://www.tridentdisplays.co.uk/home.shtml/?/articles/tft_backlight.shtml
Operation of the Planon Lamp

- PLANON® generates light using pulsed dielectric barrier discharge
- A suitable voltage is applied to the electric system of the lamp from the outside. It excites xenon atoms in the gas chamber and enables the formation of excited Xe₂⁺ molecules
- UV-radiation is transformed into visible light by phosphors

Almost a white PDP!
More Planon System Advantages

- Extremely long lamp life, up to 100,000 h (based on 50% of initial luminance)
  - no internal heater electrodes to burn-out
  - no darkening caused by loss of emitter material or mercury effects
- Colour coordinates stable over lifetime
- Lambertian characteristics
- Heat dissipation with extremely low $R_{th}$
- Inverter/ECG QT PLANON® designed for optimising lamp performance:
  Including PFC + lamp driver, lamp driver only

But the efficacy is relatively low (~30 lm/W)
Carbon Nanotube Backlights

- The Electronics Research & Service Organization (ERSO) of Taiwan’s Industrial Technology Research Institute (ITRI) announced successful development of a 20” carbon nanotube field-emission backlight (CNT-BLU)
- Japan based Nikkiso announced development of a CNT based backlight
  - FED that uses carbon nanotube emitters to accelerate electrons at a phosphor and produce light
  - Achieved illumination with an electric field of 0.74V/µm, compared to similar devices that usually operate between 1 – 2 V/µm
  - Currently a 3” prototype has 10,000 cd/m² of brightness,
  - By 2006 hope to raise to 30,000 cd/m² for a 32” LCD TV backlight that only consumes 60W of power and has a lifetime to 50,000 hours
  - Have applied for a patent on its unique CNT manufacturing process which they claim will help to simplify mass production
  - Plan to commercialize the in 2006 and target the LCD TV market
  - Also foresees multiple other illumination applications, such as wall lighting
LED Backlights

Efficiencies continue to improve, now at 30-37 lumens per watt

Claimed benefits:
- Optical efficiency of 70%, >95% NTSC color gamut, low power
- >50K hours of life, no mercury
- Easy to implement blinking backlight solutions
- >10K nits (500 nits on 5% transmission), excellent uniformity, ability to set white, etc.

Concerns:
- Price premium over CCFLs
- Brightness non-uniformity from LED degradation at different rates
- Impact of humidity on open cavity design

Status – claims in production in automotive, industrial, LCD monitors and LCD TVs within 12 months
# Comparison of LED & CCFL Backlights

<table>
<thead>
<tr>
<th>Item</th>
<th>LED B/L</th>
<th>CCFL B/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Source</td>
<td>MCPCB (Metal Core PCB)</td>
<td>W-rod, Glass bead, Electrode, Ti-Hg alloy pellet</td>
</tr>
<tr>
<td></td>
<td>High power LED</td>
<td></td>
</tr>
<tr>
<td>Luminance (32&quot;)</td>
<td>500nit</td>
<td>500nit</td>
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<tr>
<td>Color Saturation</td>
<td>NTSC 95%</td>
<td>NTSC 72%</td>
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<tr>
<td>Lamps Power Consumption</td>
<td>230 W</td>
<td>100 W</td>
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<tr>
<td>Lamp No.</td>
<td>232 ea</td>
<td>16 ea</td>
</tr>
<tr>
<td>Efficiency of Lamp</td>
<td>24 lm/W</td>
<td>80 lm/W</td>
</tr>
<tr>
<td>Green Environment</td>
<td>Hg Free</td>
<td>--</td>
</tr>
</tbody>
</table>

*Source: LPL at DisplaySearch FPD Conference Korea, Oct 04*
Polarizers and Compensation Films

Manufacturers must adapt to new modes as well as improve performance
- IPS
- VA
- OCB
- Ferroelectric?

Can one make thinner and cheaper layers?
- Anti-reflective coatings
- Thin crystal films
1. Higher Brightness & Higher Contrast

High-Performance Polarizer

Neutralization of Polarizer Hue

Transmittance [%]

Polarizing Efficiency [%]

Chromaticity Diagram

Parallel
Target
Cross
2. Higher Resolution & Glare Surface

New Low Reflectance Surface Treatment

Structure

Hard Coat with
AR coating
TAC
Polarizer
TAC
Adhesive
Release film

Spectrum

Better visibility of higher resolution LCD
High-definition image
High contrast image in a bright room
2. Higher Resolution & Glare Surface

- Combination of Anti Glare Treatment & Anti Reflection Treatment

AGS1  \[ R=4\% \]

AG150  \[ R=4\% \]

ARC150T  \[ R=2\% \]

Contrast ratio measured generally

ARC with AG > AG

Contrast ratio

Surrounding luminance (lx)
2. Higher Resolution & Glare Surface

- AG Treatment Design Compatible with Higher Resolution LCD

**Optical function for visibility improvement**

**Effect by Antiglare Treatment**

**Before**

**After**

**Effect by Antireflection Treatment**

**Before**

**After**
3. Wide Aspect & Size Up

- Wide View Angle

Shift from WV film to IPS, ASV, MVA, and PVA

Wide Viewing Polarizing Film for IPS-LCD

**Conventional**

- Polarizer
- IPS-Cell
- Polarizer

**With Compensator**

- Polarizer
- Compensator
- IPS-Cell
- Polarizer

**Contrast in all directions**

**From Obliquely Upward**
Improved Black Levels in IPS

Source: Chang-Ho Oh (LG.Philips)
New Modes Bring New Opportunities

**OCB Technology**

- **Strong candidate for LCD-TVs**
  - Wide viewing angle
  - Fast electro-optical switching

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For distribution to attendees only. Content remains the property of DisplaySearch.
OCB (Optically Compensated Bend)

**TN Mode**
- Twisted Alignment
- Asymmetric LC Configuration
- Poor Viewing Angle
- Large Molecular Action
- Slow Response Time
- Response Time: 35 msec

**OCB Mode**
- Bend Alignment
- Symmetric LC Configuration
- Wide Viewing Angle
- Slight Molecular Action
- Fast Response Time
- Response Time: 5 msec

Molecular Direction: Horizontal, Vertical

Polarizer, Glass, LC Molecule

OFF: White, ON: Black

TOSHIBA AMERICA ELECTRONIC COMPONENTS, INC.
OCB: Features

- Fast response time at any gray scale level
- Extremely fast at low temperatures (-20°C)
- Wide viewing angle

<table>
<thead>
<tr>
<th>OCB</th>
<th>ASV</th>
<th>PVA</th>
<th>IPS</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="OCB Response Time" /> -20°C : 130ms</td>
<td><img src="image2.png" alt="ASV Response Time" /> -20°C : 1300ms</td>
<td><img src="image3.png" alt="PVA Response Time" /> -20°C : 1300ms</td>
<td><img src="image4.png" alt="IPS Response Time" /> -20°C : 1700ms</td>
</tr>
</tbody>
</table>

![OCB Viewing Angle](image5.png) | ![ASV Viewing Angle](image6.png) | ![PVA Viewing Angle](image7.png) | ![IPS Viewing Angle](image8.png)
Single Layer AR Wet Coating

UV-Cured Self-Assembled Nano-Particles

AFM Image

Reflectance

Provides Cost-Effective Anti-Reflection Coating

Source: Jens Thies (DSM)
Printable Thin Crystal Film (TCF)

Organic Molecules Modified Supramolecular Chemistry

Self-Assemble In Liquid Lyotropic Liquid Crystal

Self-Align During Coating

Crystallize During Drying

Source: Carl Cobb (Optiva)
Crystallization

Aligned Liquid Crystal
~ 5 μm thick

Drying process
- phase transition liquid to solid
- rate limited by %Relative Humidity

Thin Crystal Film
~ 0.5 μm thick

Source: Carl Cobb (Optiva)
Applications to LCD Manufacturing

Polarizer Films
- Main Polarizers
- Color Correction for LC-TV (correct black state)

Compensation Films
In-cell coating
- Transflective Display
- Contrast Enhancement for TFT

Multi-layer Anisotropic Stack
- Color Selective Filter or Reflector

Source: Carl Cobb (Optiva)
Thin Crystal Film™ (TCF) Coating Process

Pre-Coat Treatment
- Film cleaning
- Rubbing, Corona
- Plasma treatment

TCF Coating
- Apply shearing force
- Slot die, MG, Mayer

Crystallization (Drying)
- Room Temp Drying
- Room Temp Drying Humidity Control

Inspect & Finish
- PSA/Release Lamination
- Dry
- Rinse
- Developer
- In-Line Rinse

Environment
- Machine Zone - Class 100
- Operational Area - Class 1000
- Other – Class 10,000

Source: Carl Cobb (Optiva)
Transflective Cellular Design - Current

**Advantage:**
1. High transmission
2. Acceptable contrast ratio

**Disadvantage**
1. Complex cell design
2. Expensive retardation film
3. Require very low deviation from the cell gap size (because LC plays a role of retarder for circular polarization)
4. Higher sensitivity to the temperature (same reason)
Optiva’s Internal Film for Single Gap

Source: Carl Cobb (Optiva)
The Home Run – No Color Filter

Why?
• ~4x increase in optical efficiency
• Avoid cost of patterning CF
• Reduce cost of backlight (perhaps by 75%)

How?
• Stacked films – difficult to manufacture & control light losses
• Microlens array – as in LCD projectors
• Field sequential color – as in DLP projectors
LCD with Micro-Lens Array

Structure

Diffraction grating to separate colors

13.3” XGA prototype
From IBM and IDTech

LEDs to give narrower frequency spread

Need directed emission from light guide

Authors recommend the use of a polarized light source

Source: IBM and IDTech (SID 2003 Int Symp, paper 43.1)
Polarized Light Source

Concept

Source: Cornelissen et al (SID 2004 Int Symp, paper 38.3)
Field Sequential Color

Requirements

- Flashing backlights
  - Easier with LEDs
- Fast LCDs
  - OCB?
  - Ferroelectric?
  - Ultra-thin TN layers?
- Faster drive electronics
  - Talk nicely to TI

Small displays have been produced by Samsung SDI & LGE for phones and PDAs

Can this technology be implemented for large screens?
This response is fast enough to support the insertion of black sub-frames, but only marginal for frame-sequential color.

Source: Hui-Wen Yang (Chi Mei Optoelectronics)
**Ferroelectric FSC Prototype from Fujitsu**

Ferroelectric LCs can be switched in much less than 1 ms

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
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<tr>
<td>Pixel number</td>
<td>800 x 600 (SVGA)</td>
</tr>
<tr>
<td>Pixel pitch (mm)</td>
<td>0.1 [254ppi]</td>
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<tr>
<td>Display area (mm)</td>
<td>80 x 60 [4 inch]</td>
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<tr>
<td>TFT type</td>
<td>Amorphous Si-TFT</td>
</tr>
<tr>
<td>Frame rate (Hz)</td>
<td>60</td>
</tr>
<tr>
<td>Display colors</td>
<td>262,144</td>
</tr>
<tr>
<td>Contrast</td>
<td>400 : 1</td>
</tr>
<tr>
<td>Brightness (cd/m²)</td>
<td>225</td>
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<tr>
<td>Transmission rate (%)</td>
<td>12.7</td>
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<tr>
<td>Drive voltage (V)</td>
<td>5</td>
</tr>
<tr>
<td>Response time (ms)</td>
<td>&lt; 1 [total from start-up to ending], 0.3 [black-white]</td>
</tr>
<tr>
<td>Color reproduction range (%)</td>
<td>NTSC ratio 117%, Adobe RGB ratio 122%</td>
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<tr>
<td>Chromaticity (x, y)</td>
<td>R: (0.6903, 0.3027)</td>
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<tr>
<td></td>
<td>G: (0.1777, 0.7381)</td>
</tr>
<tr>
<td></td>
<td>B: (0.1466, 0.0436)</td>
</tr>
</tbody>
</table>

*Source: Toshiaki Yoshiara in Nikkei Devices Flat Panel Display 2005*
Conclusions

- There are lots of exciting challenges for materials suppliers
- Winners can make lots of money
- But the real winners are those without serious competition