Optical Films and Illumination Sources for LCDs

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SID-UK Meeting on Optics of Displays

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

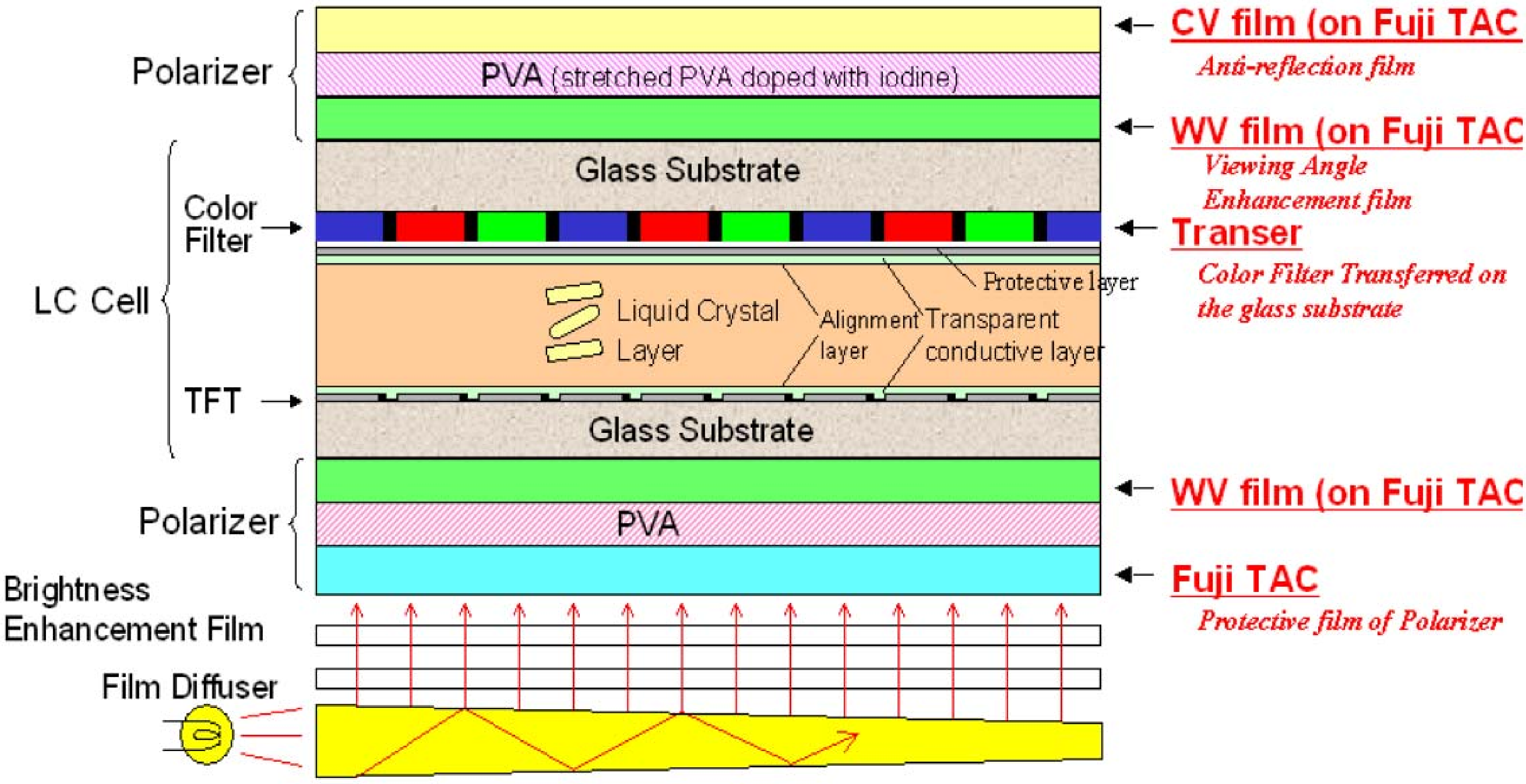
1. Material suppliers make lots of money
2. You don't have to be based in Asia

FUJIFILM
I&I – Imaging & Information

VISUAL INNOVAT
IN DISPLAY

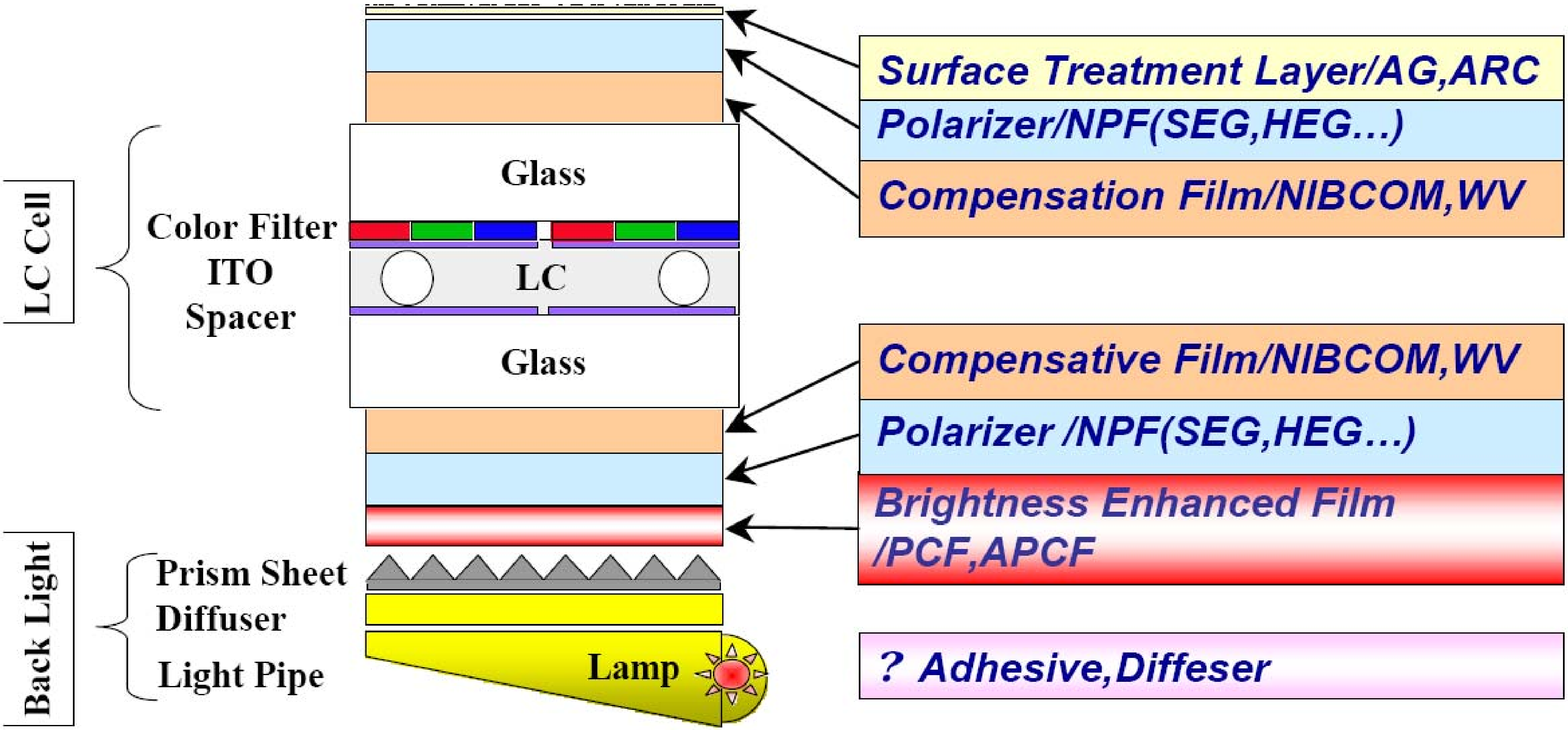
Structure of a transmissive LCD (cross-section)

Fuji's Products



Structure of a Transmissive LCD(cross-section)

Nitto's Products



Demands on Materials Suppliers

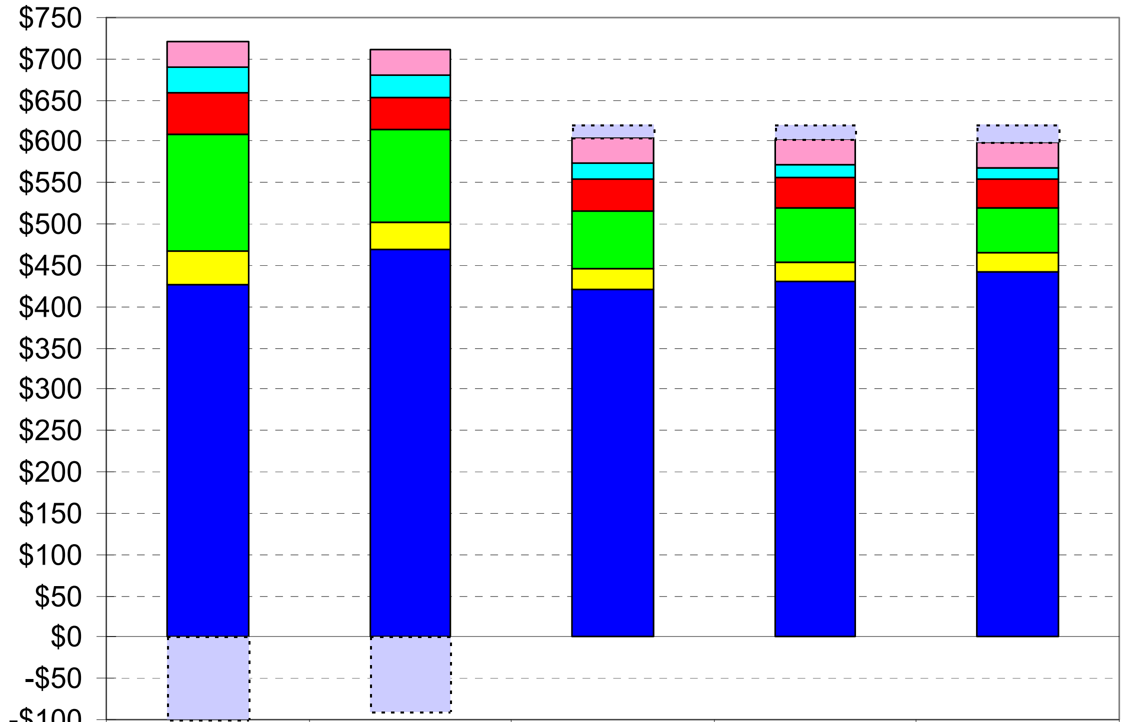
- Cut Costs
  - At least 10% a year
  - More this year
- Help to Improve Form Factor
  - Thinner
  - Lighter
- Improve Performance
  - Brightness and Contrast
  - Color control and gamut
  - Better off-axis viewing and uniformity
  - Faster response
  - Longer lifetime

Reducing Costs of LCDs

- Further gains from larger substrates will be very difficult
  - First forecasts of costs for 8th gen seem higher than 7th 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

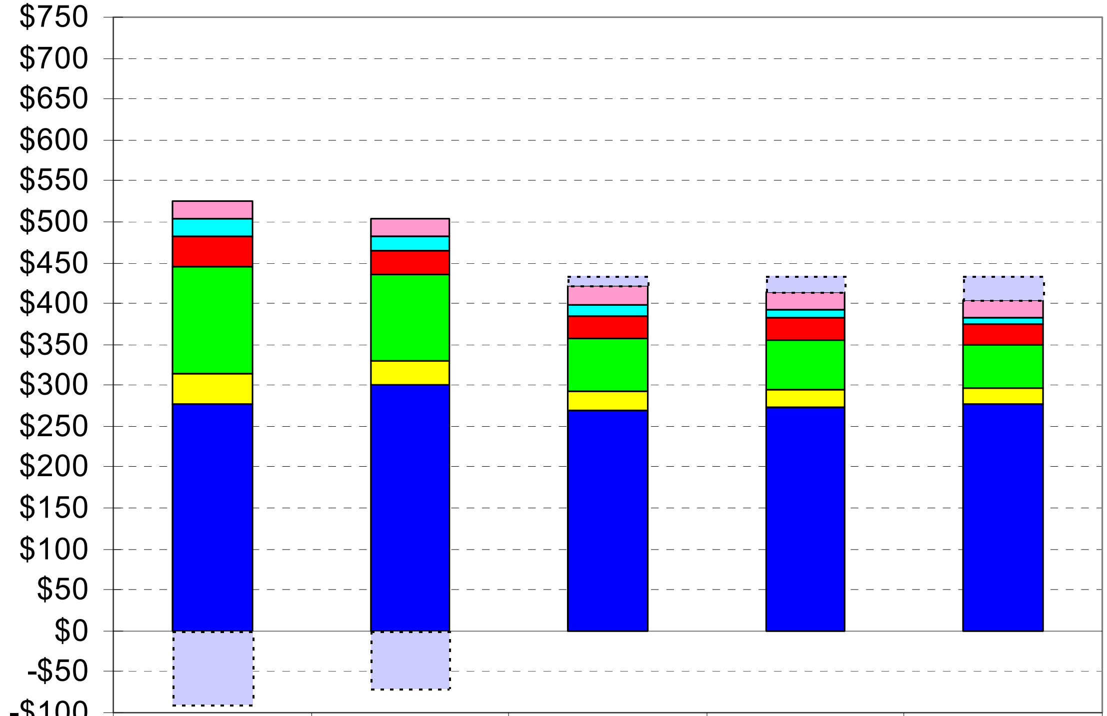
2005



	730*920	1100*1300	1300*1500	1500*1800	1870*2200
Sales Profit	-$99.7	-$91.1	$14.8	$17.8	$21.6
Overhead, Sales Expense	$31.0	$31.0	$31.0	$31.0	$31.0
R&D	$31.0	$26.4	$20.2	$15.5	$12.4
Indirect Expense	$50.2	$39.9	$38.1	$36.1	$34.8
Depreciation	$141.4	$112.1	$69.4	$65.5	$55.9 ***
Personnel Cost	$39.9	$32.9	$25.9	$24.2	$22.4
Yielded Components Cost	$426.6	$469.1	$421.0	$430.3	$442.3***

32” WXGA LCD TV Panel Costs: 2008

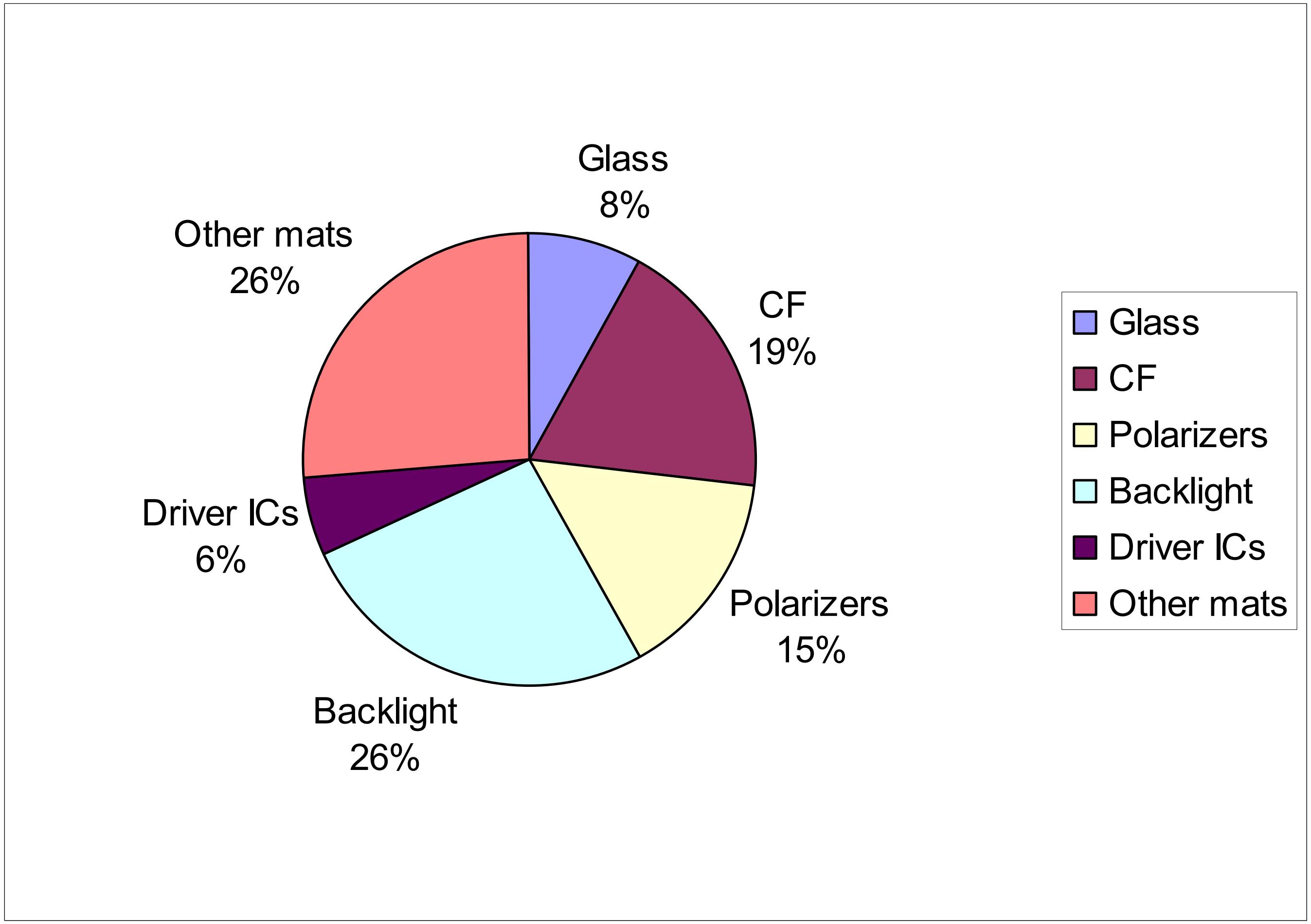
2008



	730*920	1100*1300	1300*1500	1500*1800	1870*2200
Sales Profit	-$91.2	-$70.4	$13.0	$18.9	$28.9
Overhead, Sales Expense	$21.7	$21.7	$21.7	$21.7	$21.7
R&D	$21.7	$18.4	$14.1	$10.8	$8.7
Indirect Expense	$36.6	$29.6	$27.7	$26.3	$25.4
Depreciation	$131.4	$104.2	$64.5	$60.8	$51.9 ***
Personnel Cost	$37.1	$30.6	$24.1	$22.4	$20.8
Yielded Components Cost	$276.5	$299.7	$268.7	$272.7	$276.3***

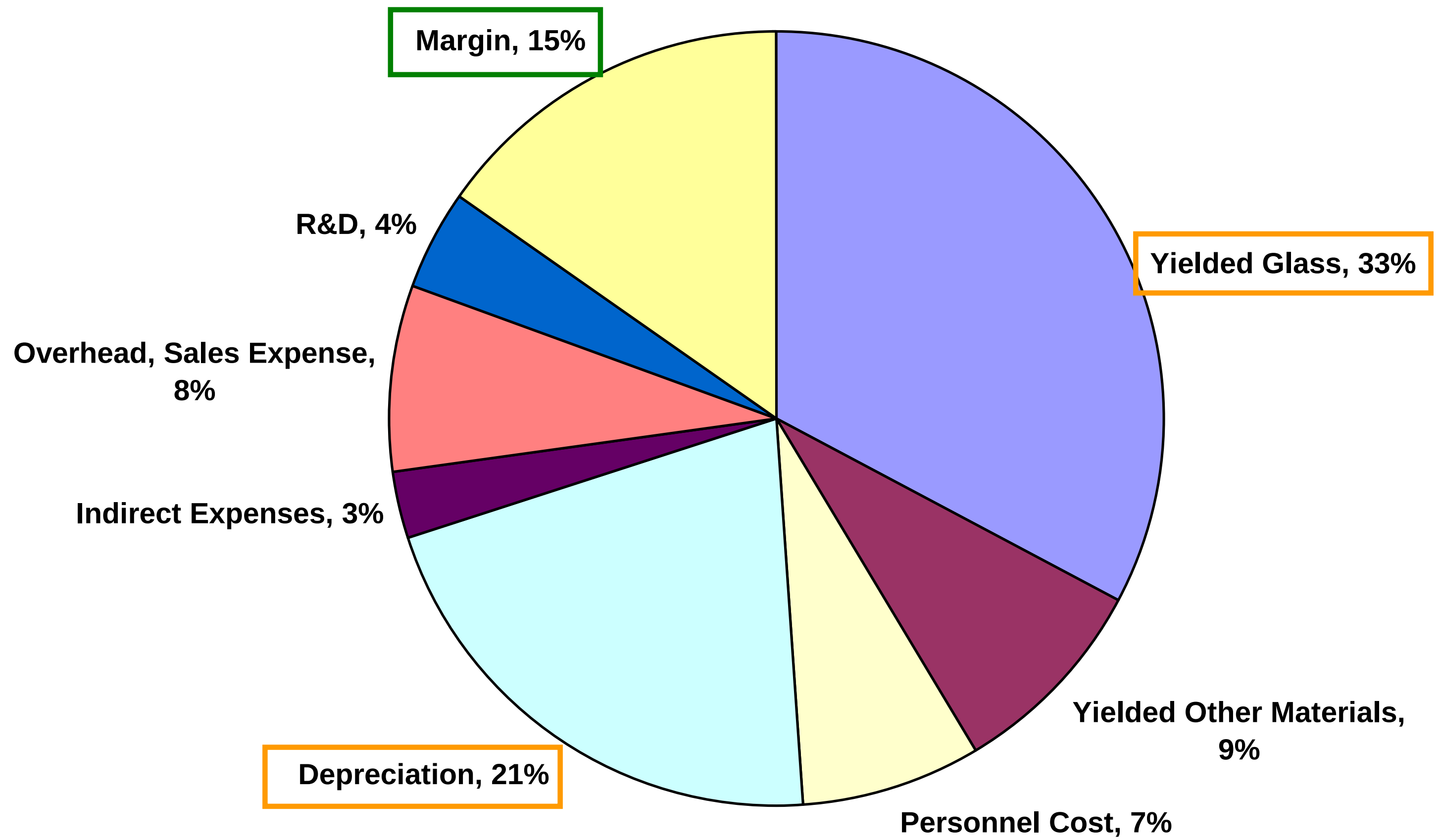
32” LCD TV Component Costs

Breakdown of Material/Component Costs
32” WXGA



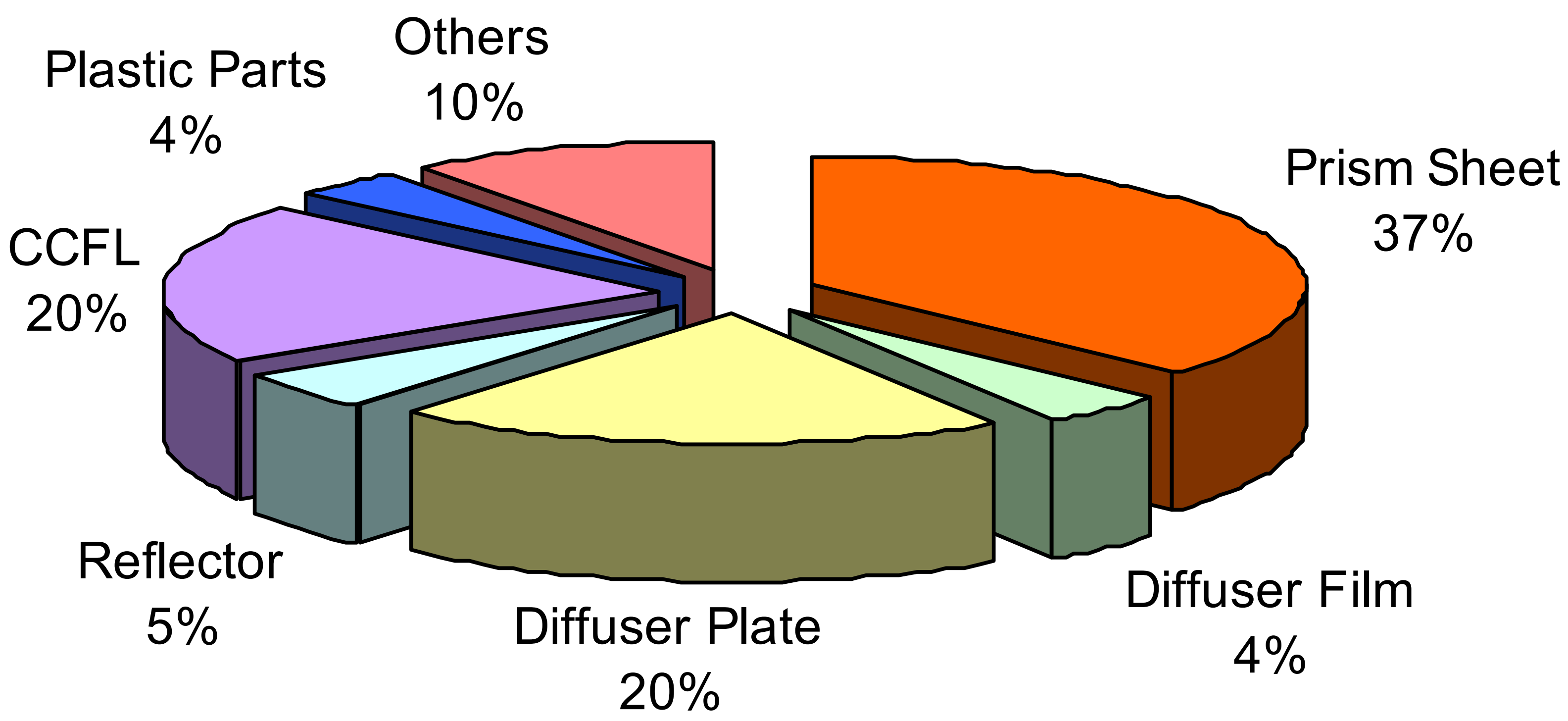
Conventional CF Cost Structure

Cost dominated by glass, then depreciation



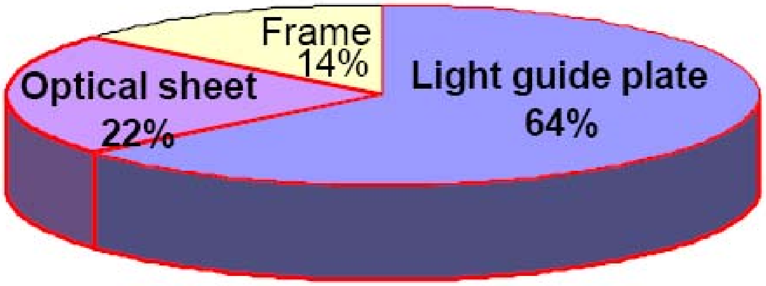
Note : Forecast 2005 values for 17" on 5th Gen with, price of \2,772. Assumptions for merchant CF maker.

Backlight Bill of Materials

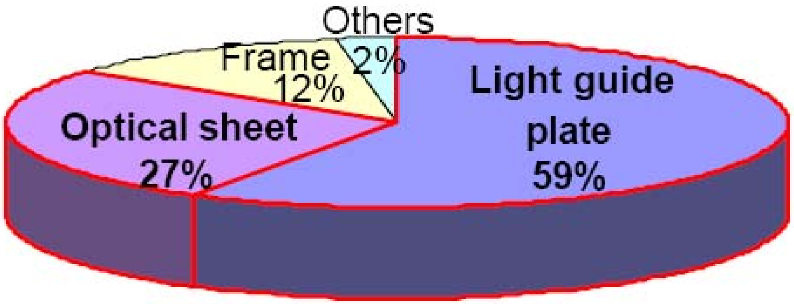


Source: Albert Yang (Wellypower)

Lightweight & Thin & Low Power



Thickness



Weight

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

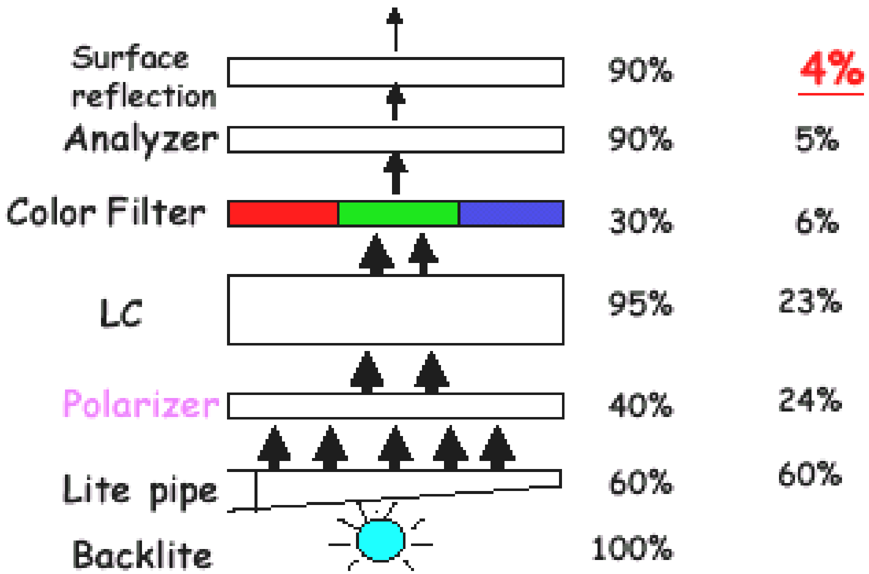
Power

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

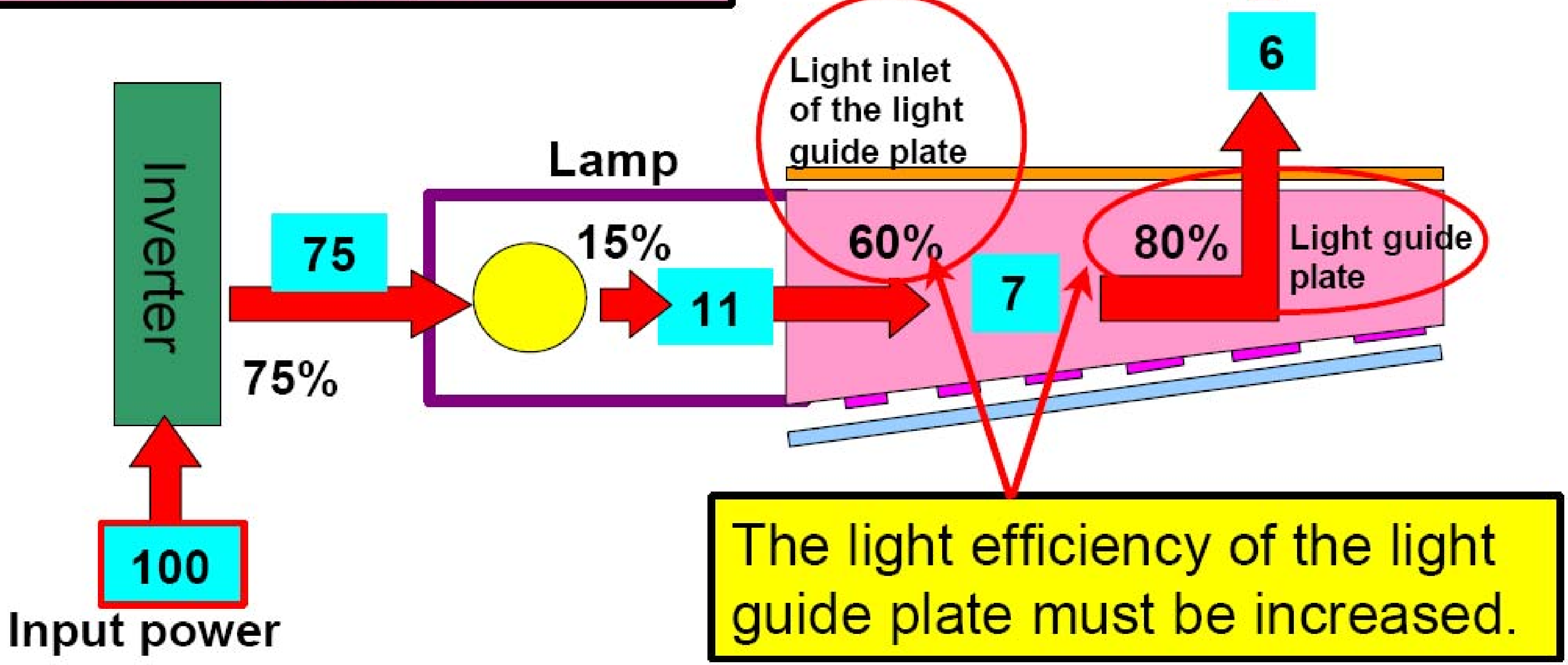
Light Efficiency Breakdown of LCD module

Light emitted to the LCD surface is only

0.6% of the input power.

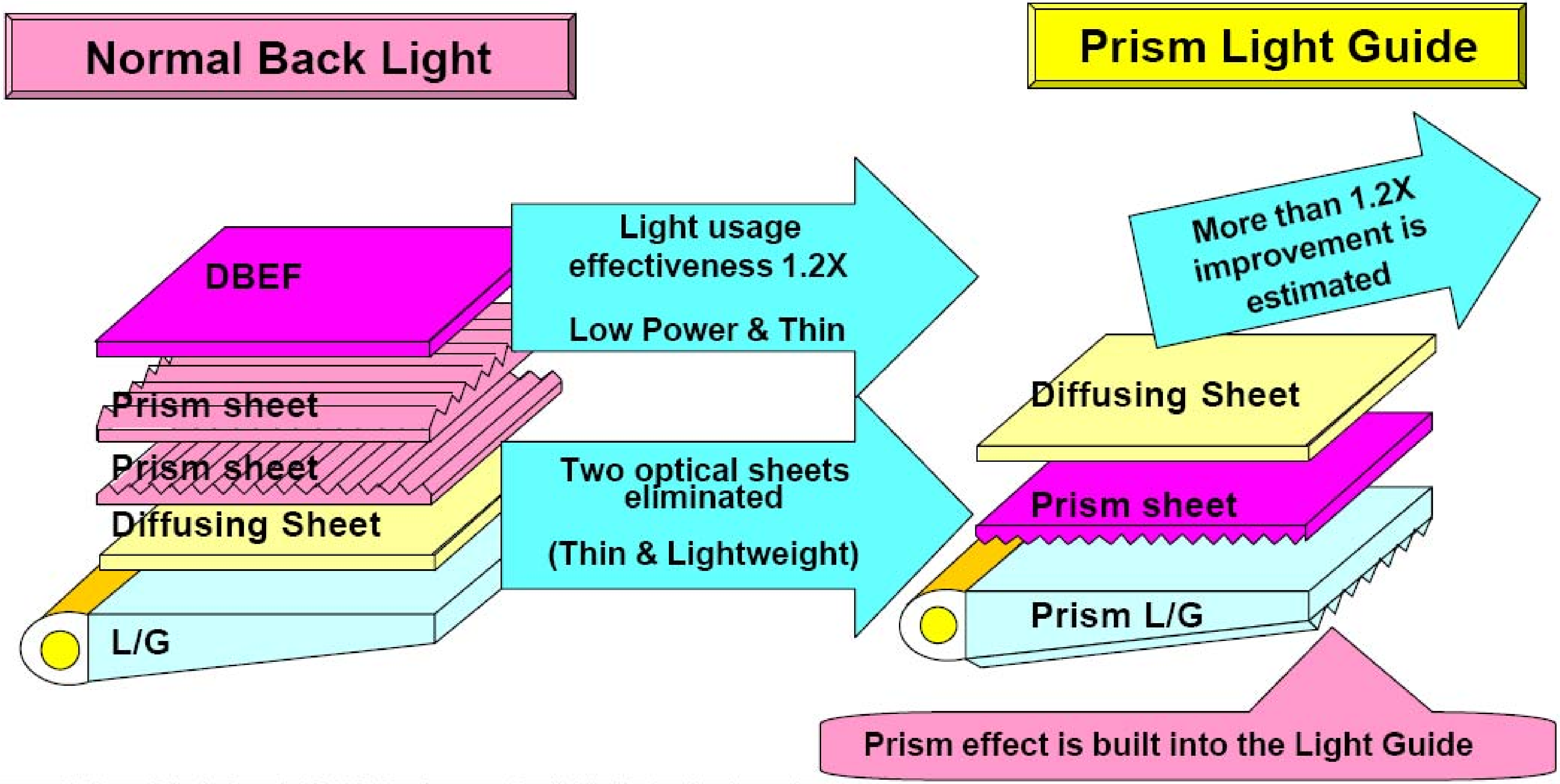
40% loss: At the light inlet of the light guide plate

20% loss: In the light guide plate



Prism Light Guide

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

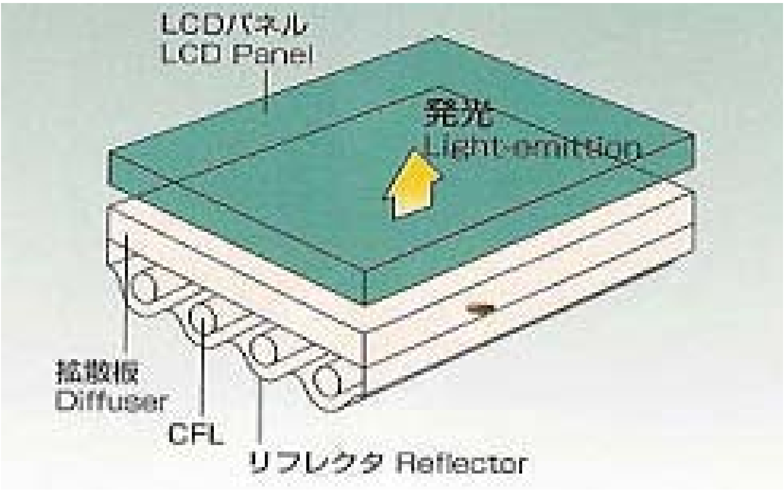


Backlight Issues

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

Mercury content a growing concern in certain regions

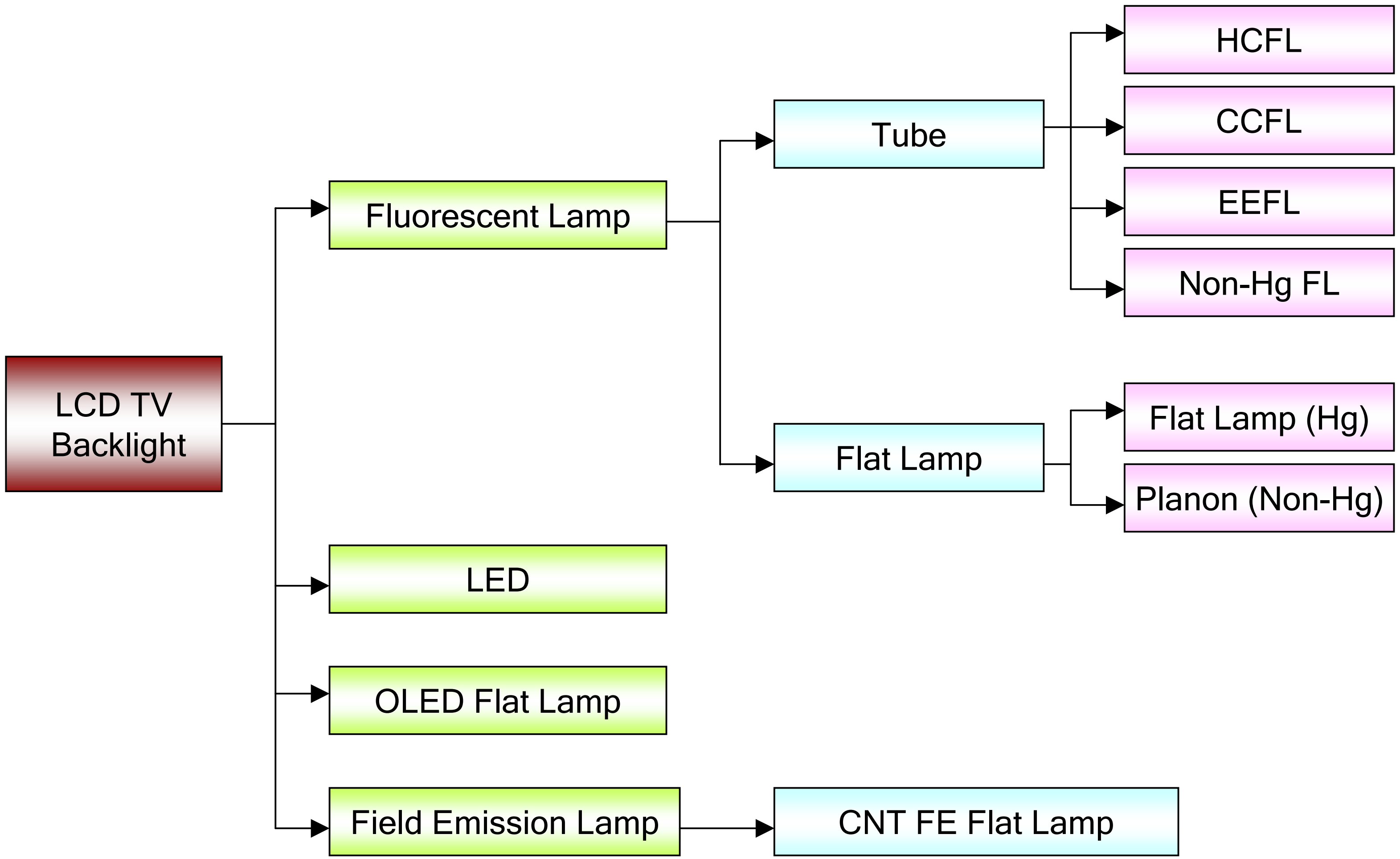
New technologies likely to be introduced



Note: 40” BLU Costs, fall 2003 forecast

		2005	% Total
Metrics	Diameter φ	4.9	NA
	CCFL	20	NA
Lamp	Unit Price	$2.17	2%
	Total Price	$43.35	**32%**
Diffusion board	for direct type	$19.29	14%
Diffusion sheet	Normal	$6.91	5%
	Priniting (+)	$0.33	0%
Reflective shee	Normal	$0.94	1%
	Priniting (+)	$0.45	0%
BEF	BEF3	$4.08	3%
	DBEF	$12.73	9%
Others	Labor, Deprec, etc.	$47.4	35%
Unit Price		$135.5	100%

Backlight Technologies for LCD



Improvements in Conventional CCFL Backlights

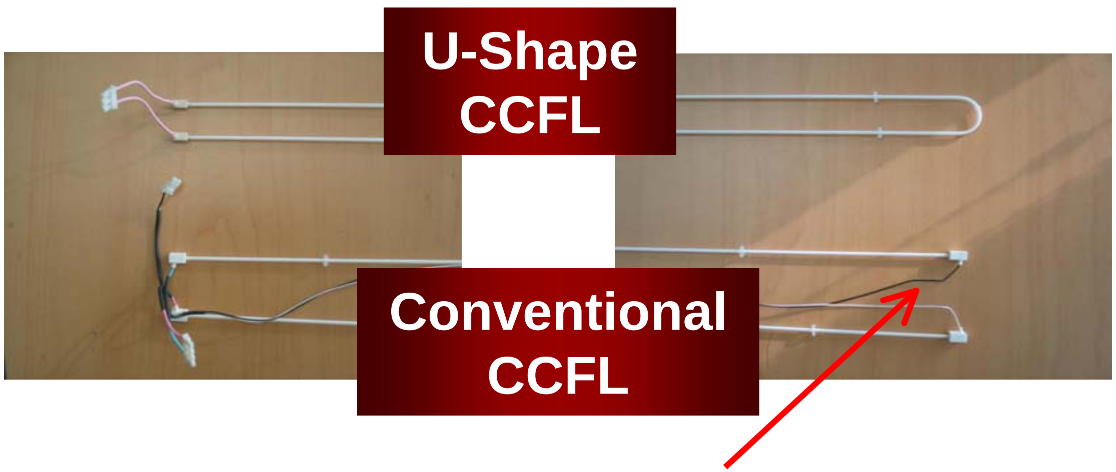
- New production equipment to make lamps with lengths over 1m
- Rotating coaters to improve chromaticity uniformity
- New glass tube and coating to reduce UV emissions
- Lower temperature operation through new electrode material (Ni -> Mo), sealing part (Kovar -> W) and thicker lead wires
- Longer life 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

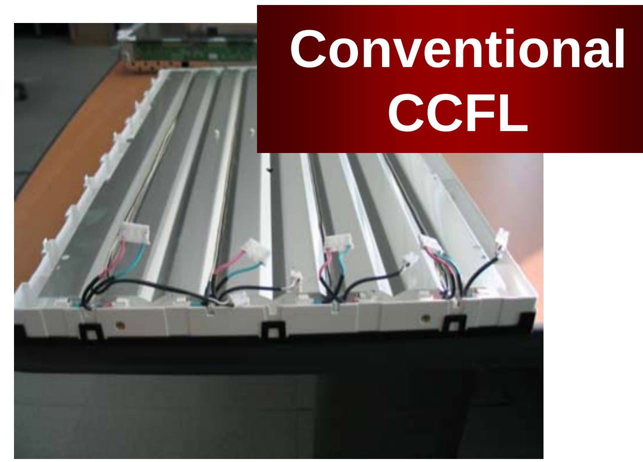
Source: Albert Yang (Wellypower)

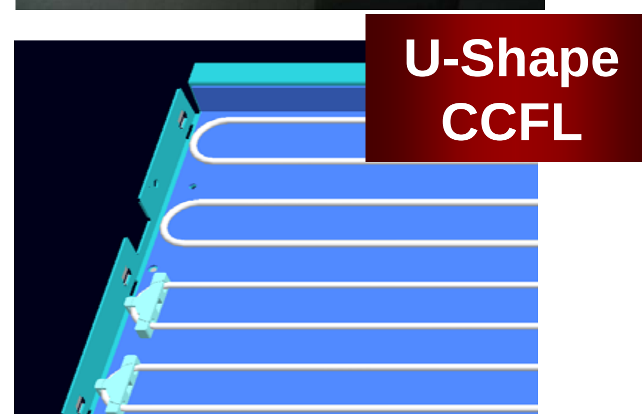
U-Type CCFLs

Advantages

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

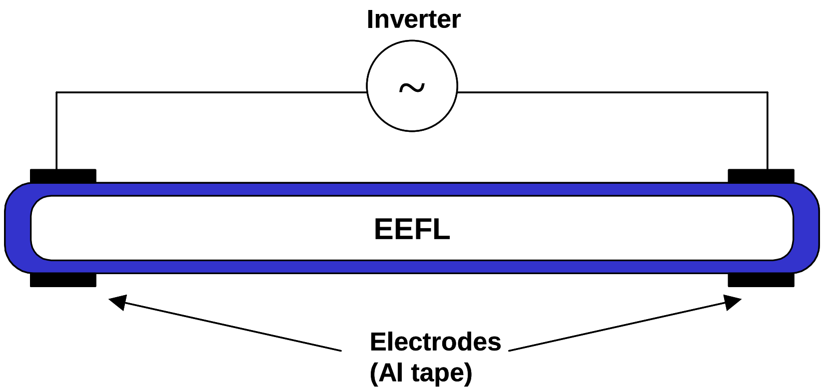






Source: Samsung

External Electrode Fluorescent Lamps

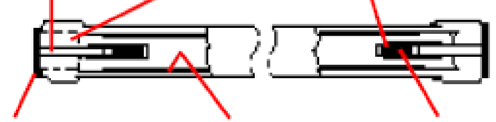


- **Developed by Harison Toshiba**

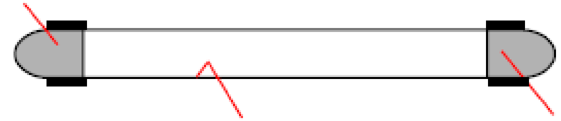
- Electrodes are on the outside of the glass tube. The electric field is capacitively coupled to the phosphor and gas inside the tube
- Advantages include longer life due to no sputtering phenomena to degrade the electrodes and less likely to feature gas leaks
- Argon and neon can be used, instead of 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

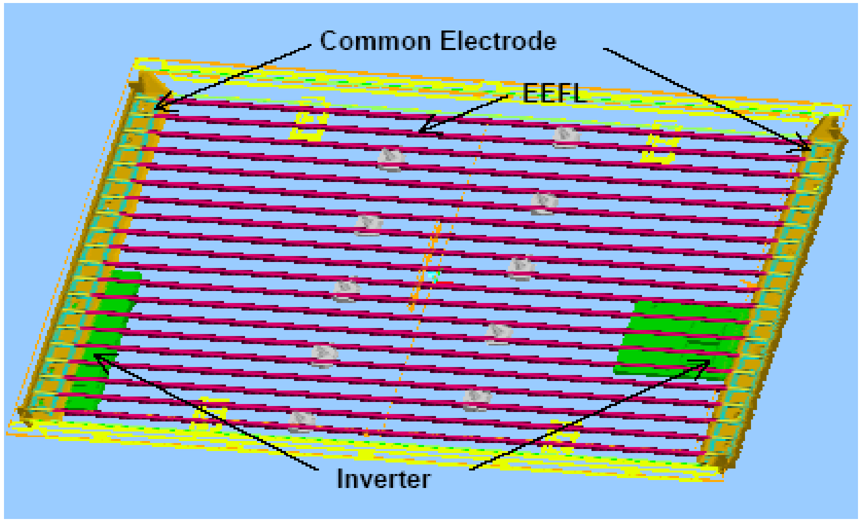
CCFL (Cold Cathode Fluorescent Lamp) → EEFL(External Electrode Fluorescent Lamp)



Removing the internal electrodes



B/L lamp structure

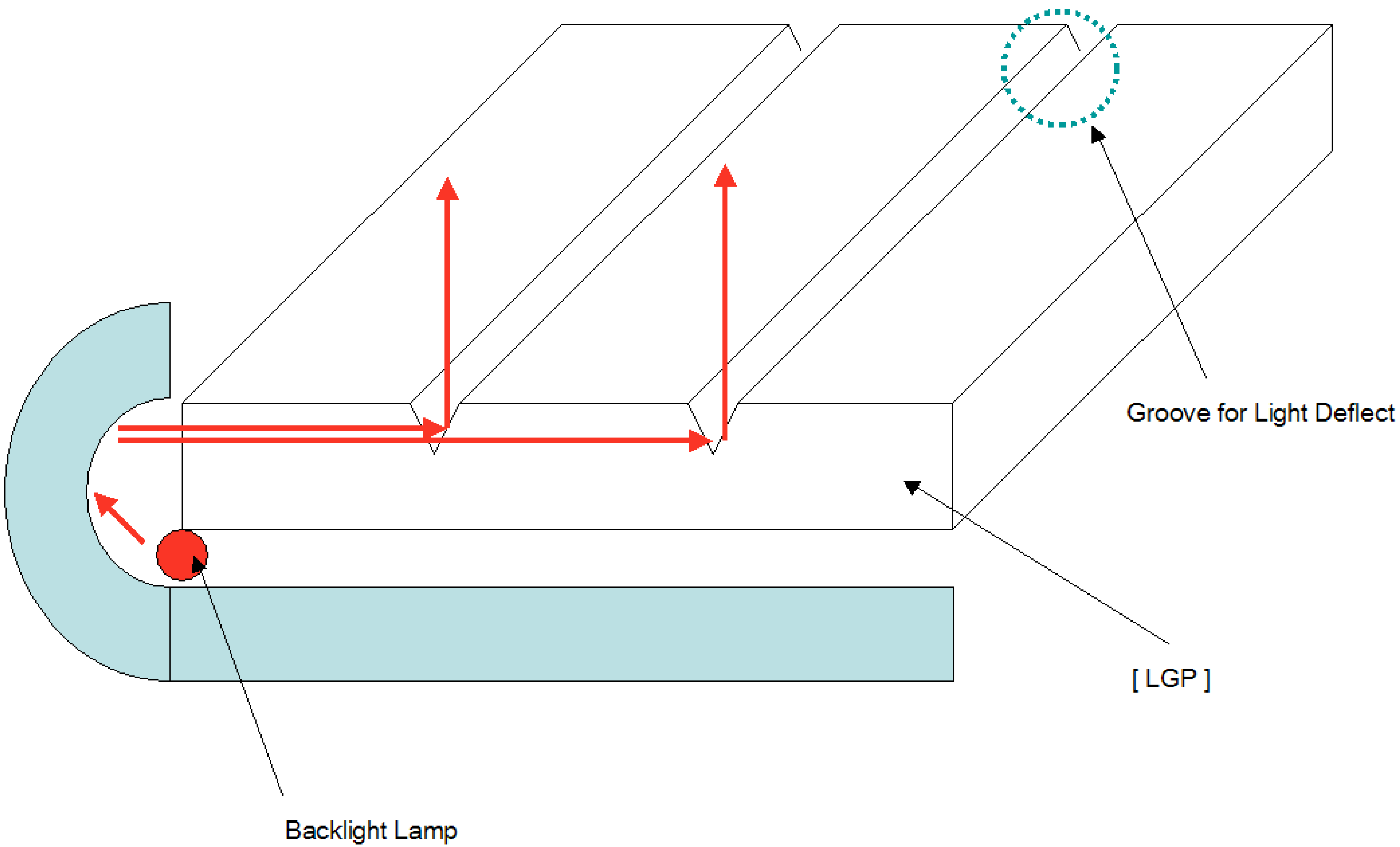


Features

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



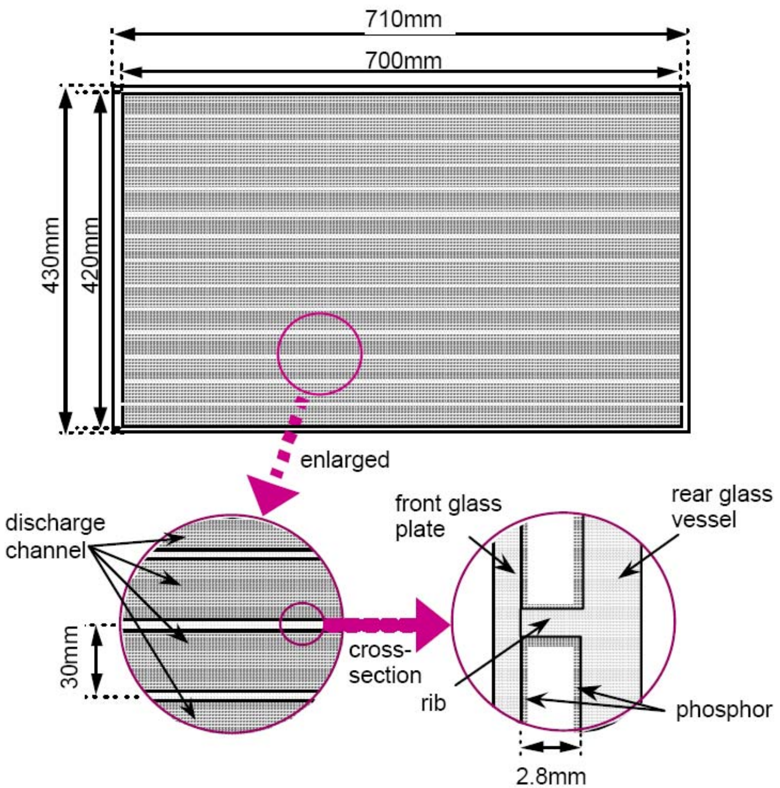
Source : Samsung and Samsung-Corning

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

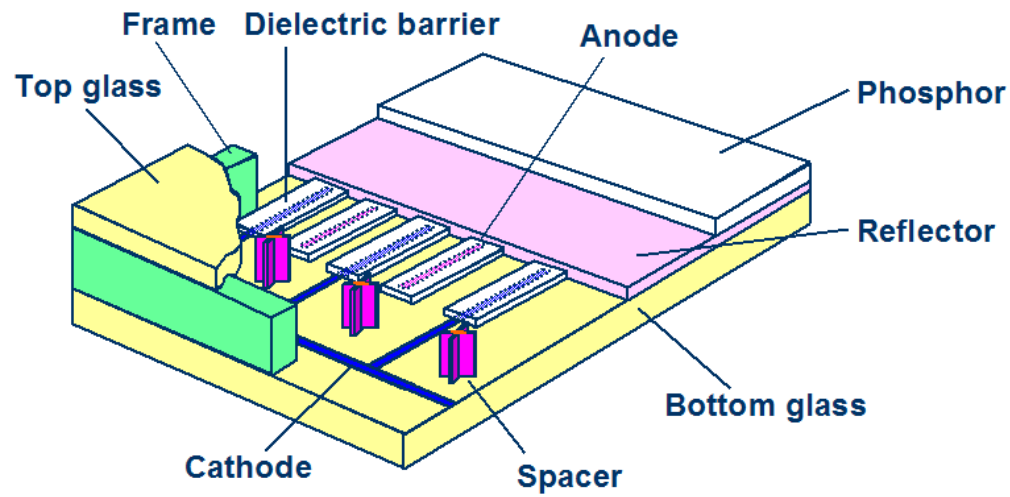
Planon Lamp

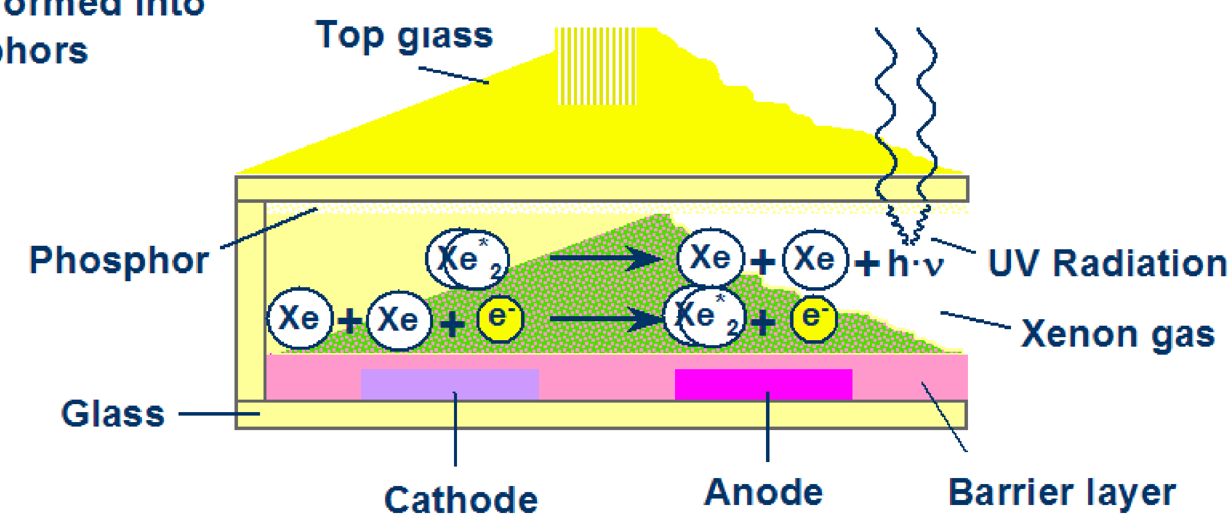
- The Planon lamp is a dielectric barrier discharge lamp made by Osram
- The discharge occupies the gap between two planar electrodes
- The electrodes are each covered with a dielectric layer and phosphors
- The gap is filled with Xe, so no Hg
- The ignition voltage is ~2kV
- The efficacy is relatively 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 electro system of the lamp from the outside. It ex xenon atoms in the gas chamber and enal the formation of excited Xe_2^* molecules
- UV-radiation is transformed into visible light by phosphors

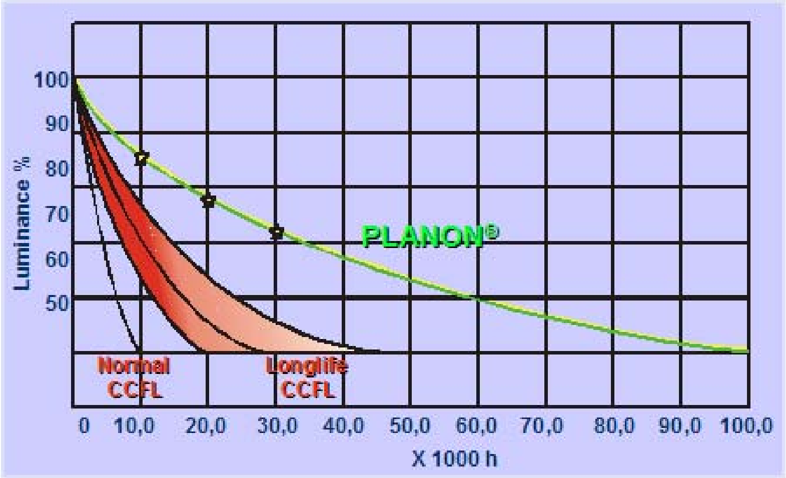




Almost a white PDP!

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/m^2 of brightness,
  - By 2006 hope to raise to 30,000 cd/m^2 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:

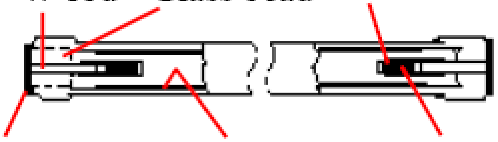
- Optical efficiency of 70%, >95% NTSC color gamut, low power
- >50K hours of life, no mercury
- Easy to implement blinking backlight solutions
- >10K nits (500 nits on 5% transmission), excellent uniformity, ability to set white, etc.

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

Item	LED B/L	CCFL B/L
Light Source		
Luminance (32”)	500nit	500nit
Color Saturation	NTSC 95%	NTSC 72%
Lamps Power Consumption	230 W	100 W
Lamp No.	232 ea	16 ea
Efficiency of Lamp	24 lm/W	80 lm/W
Green Environment	Hg Free	--

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?

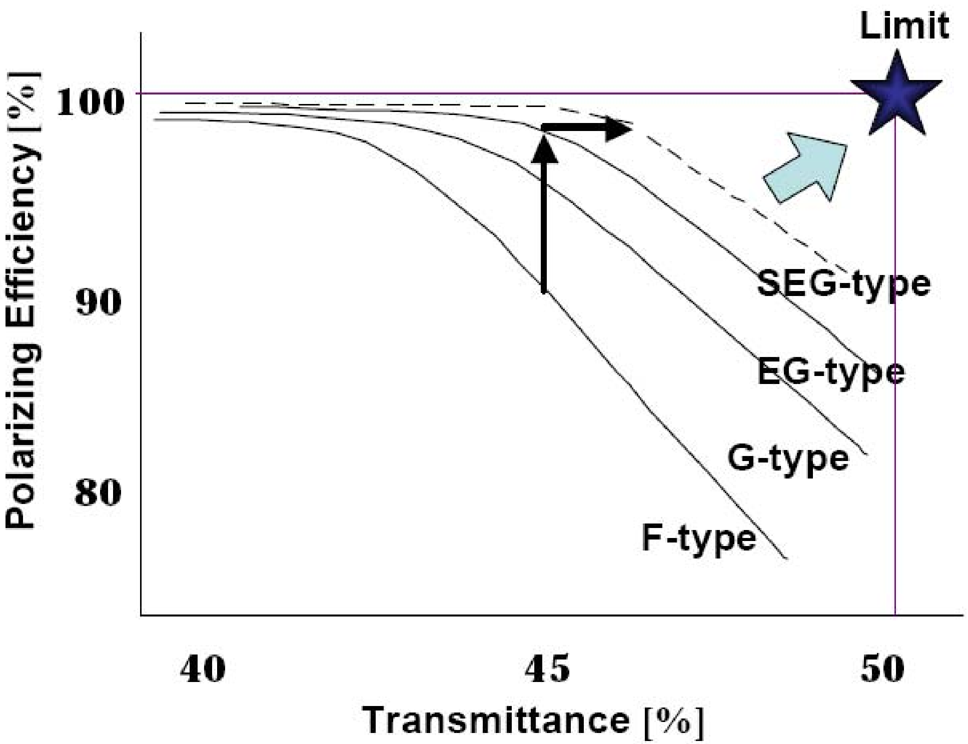
Can one make thinner and cheaper layers?

- Anti-reflective coatings
- Thin crystal films

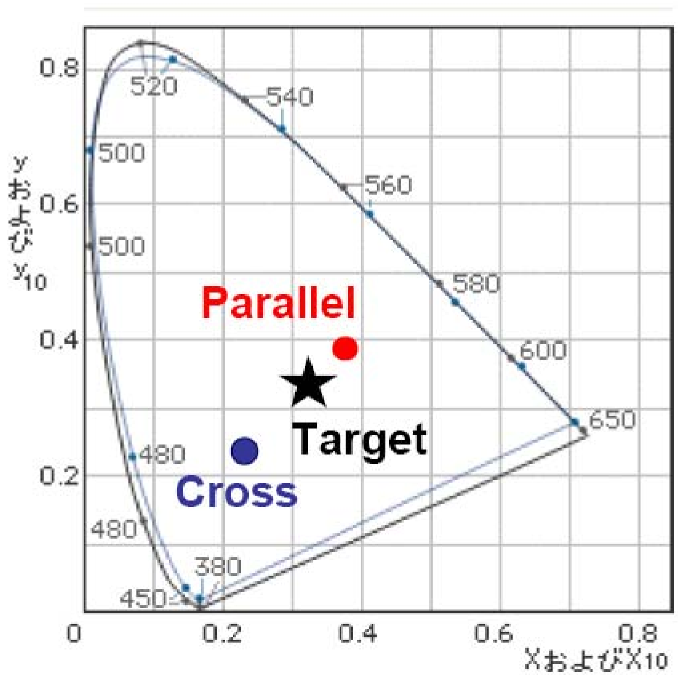
1. Higher Brightness & Higher Contrast

NITTO DENKO

High-Performance Polarizer



Neutralization of Polarizer Hue



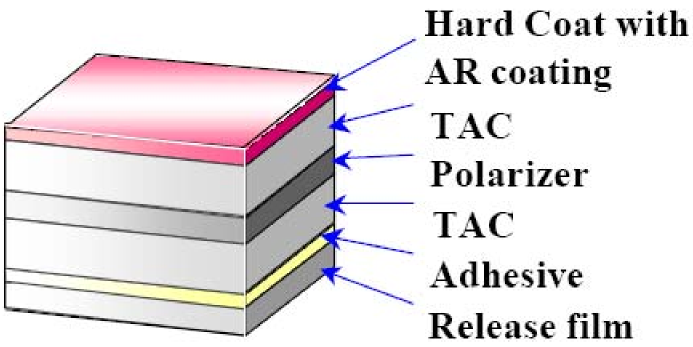
Chromaticity Diagram

2. Higher Resolution & Glare Surface

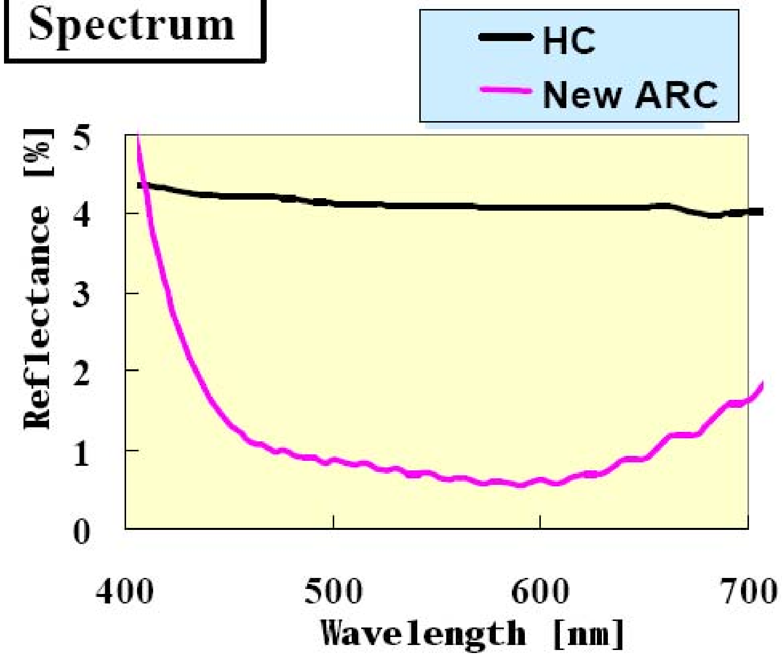
NITTO DENKO

New Low Reflectance Surface Treatment

Structure



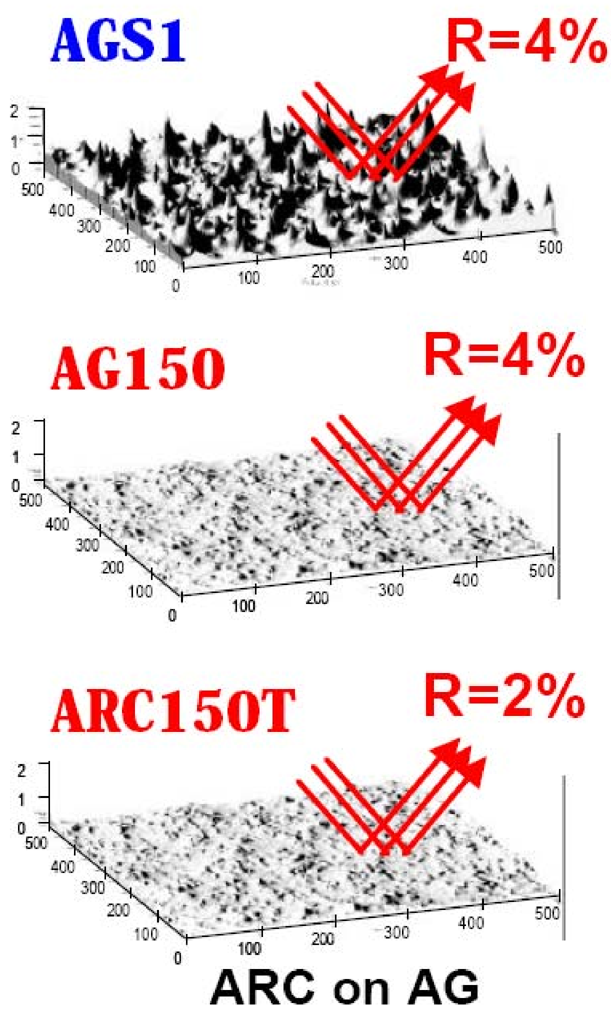
Spectrum

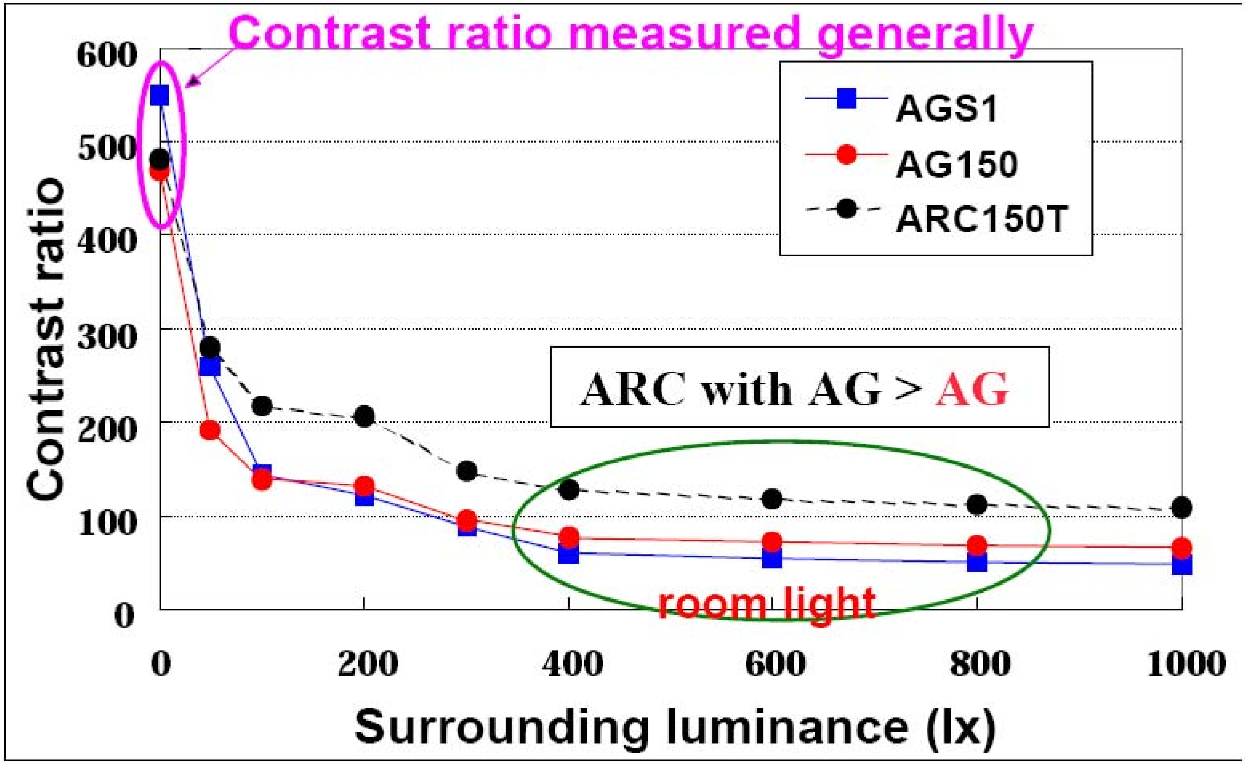


Better visibility of higher resolution LCD
- **High-definition image**
- **High contrast image in a bright room**

2. Higher Resolution & Glare Surface

- Combination of Anti Glare Treatment & Anti Reflection Treatment



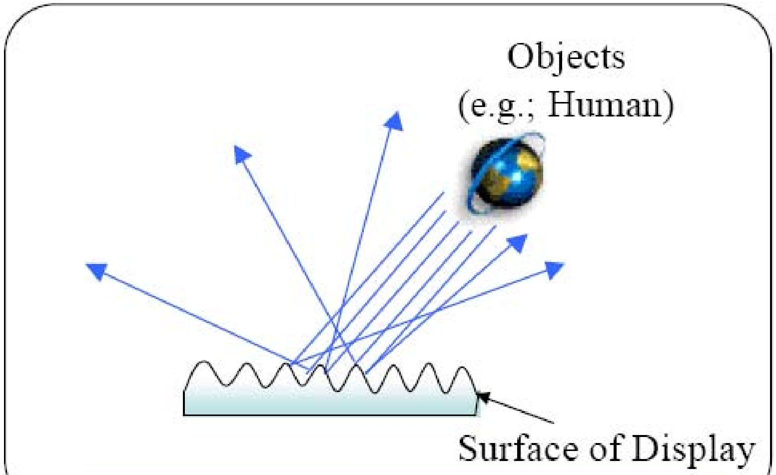


2. *Higher Resolution & Glare Surface*

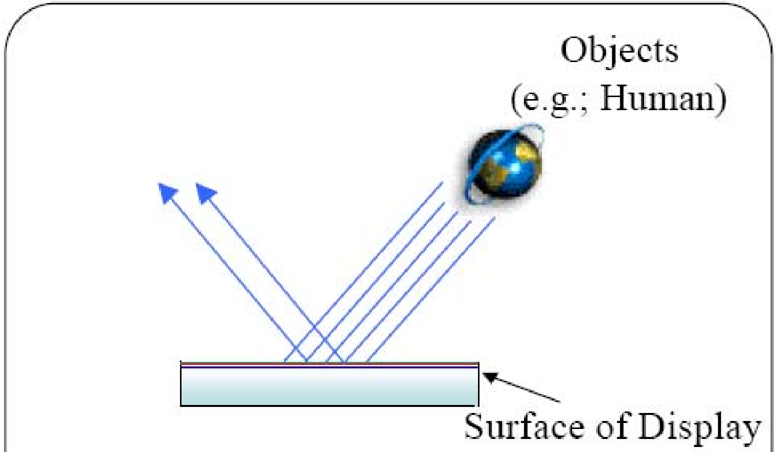
NITTO DENKO

AG Treatment Design Compatible with Higher Resolution LCD

Optical function for visibility improvement



Effect by Antiglare Treatment



Effect by Antireflection Treatment

Before **After**

Before **After**

3. Wide Aspect & Size Up

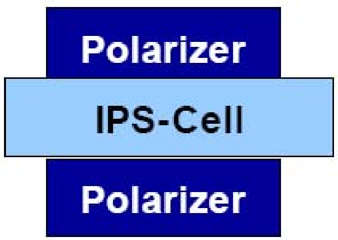
NITTO DENKO

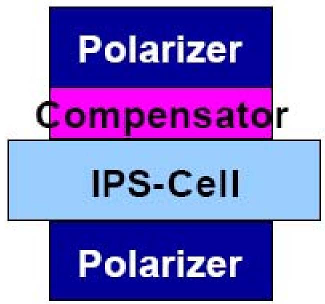
Wide View Angle

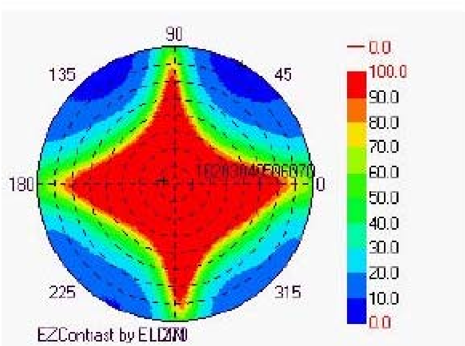
Shift from WV film to IPS, ASV, MVA, and PVA

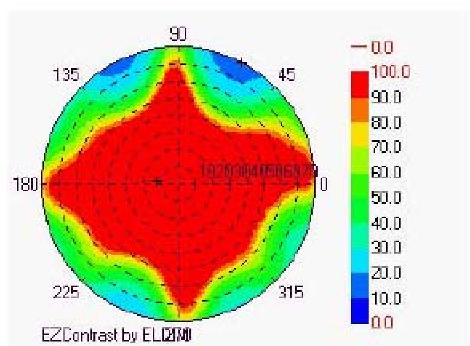
Wide Viewing Polarizing Film for IPS-LCD

Conventional | **With Compensator**



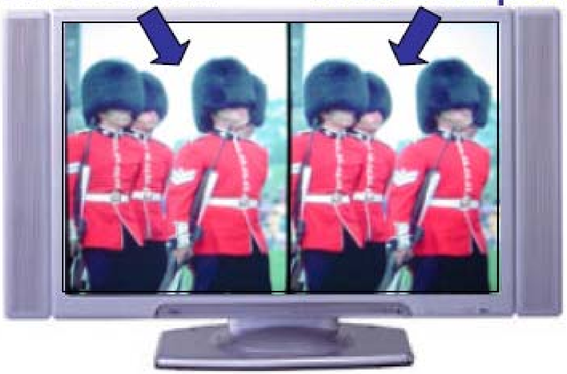






Contrast in all directions

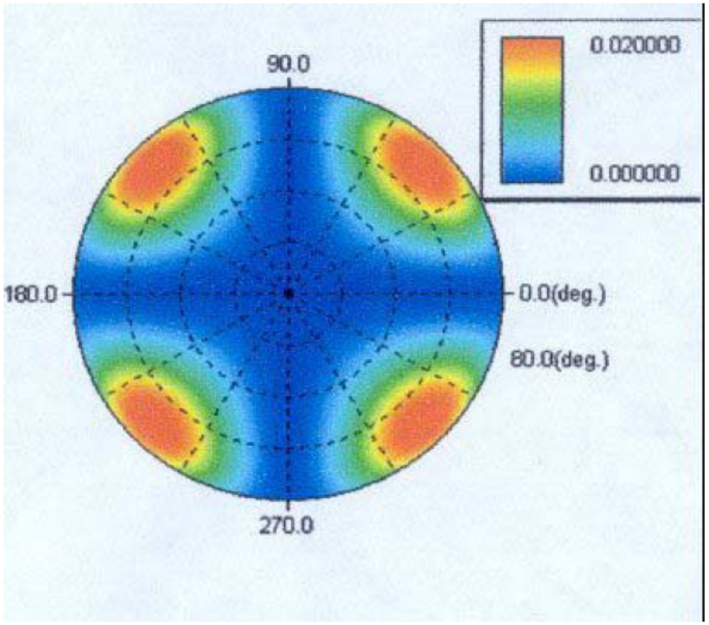
Conventional | With Compensator



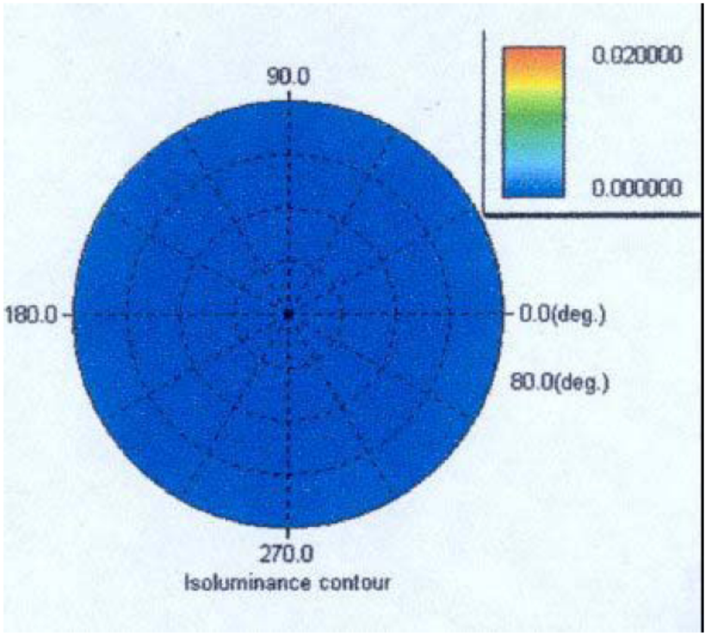
From Obliquely Upward

Improved Black Levels in IPS

Normal Polarizer

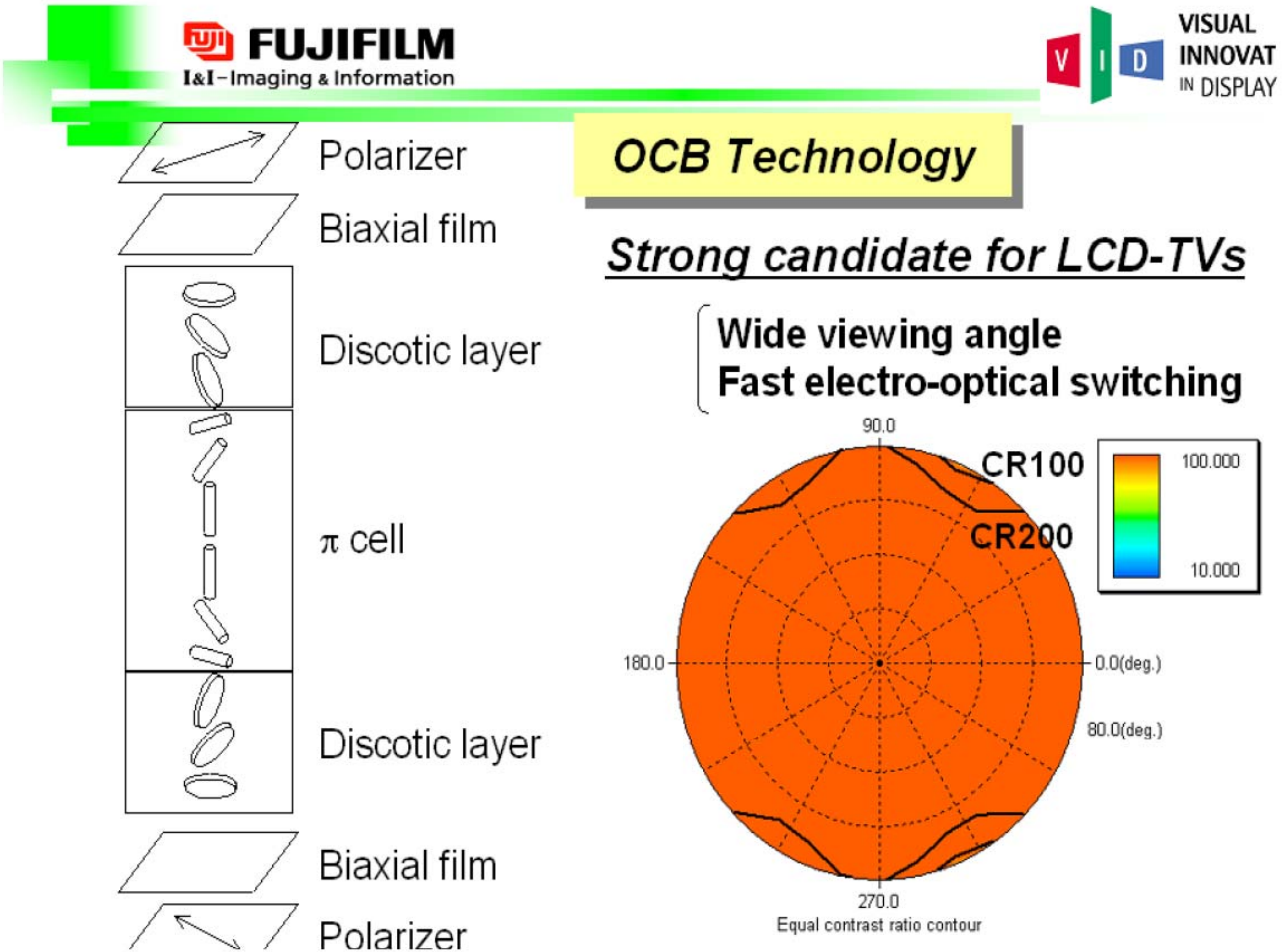


Polarizer with Optical Compensator



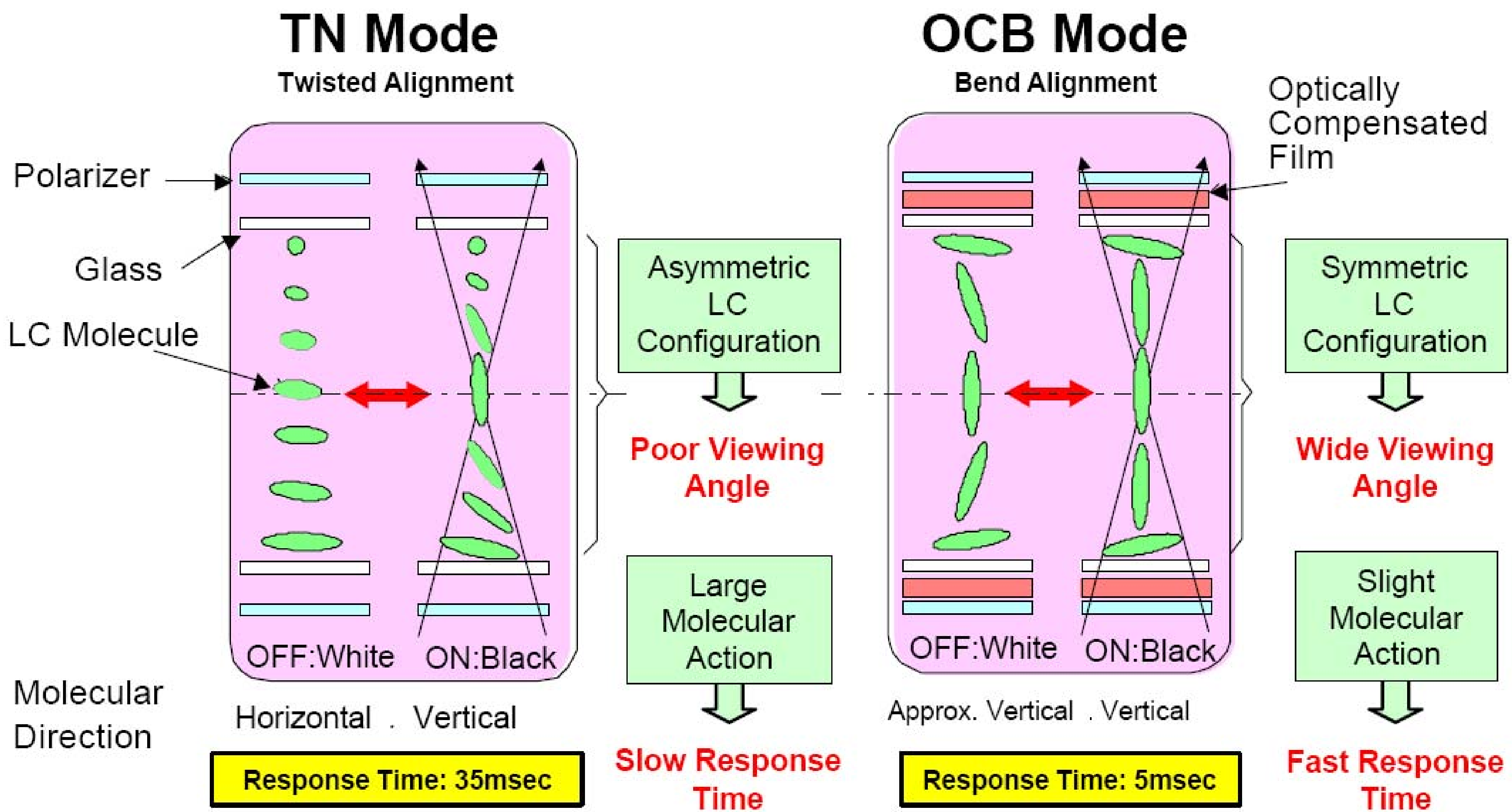
Source: Chang-Ho Oh (LG.Philips)

New Modes Bring New Opportunities



TOSHIBA

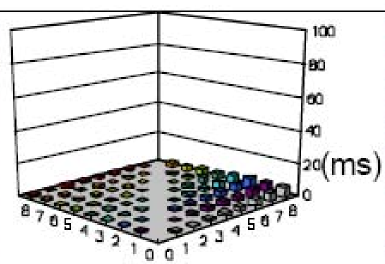
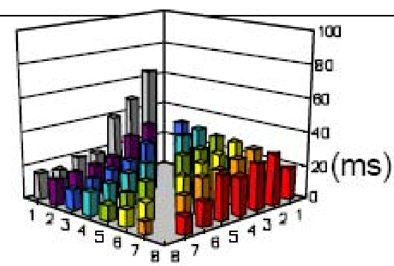
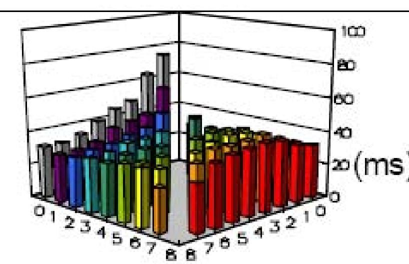
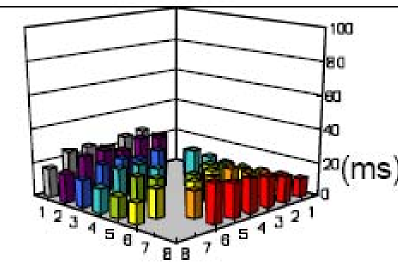
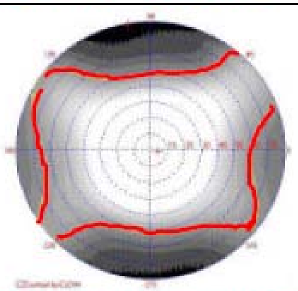
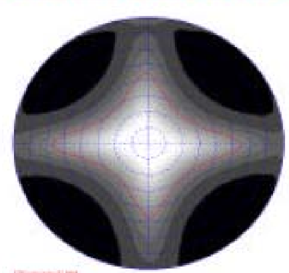
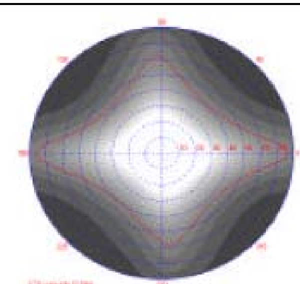
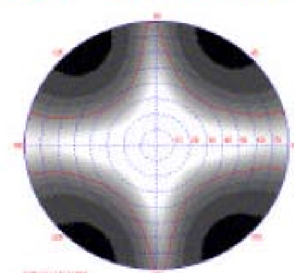
OCB (Optically Compensated Bend)



OCB: Features

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

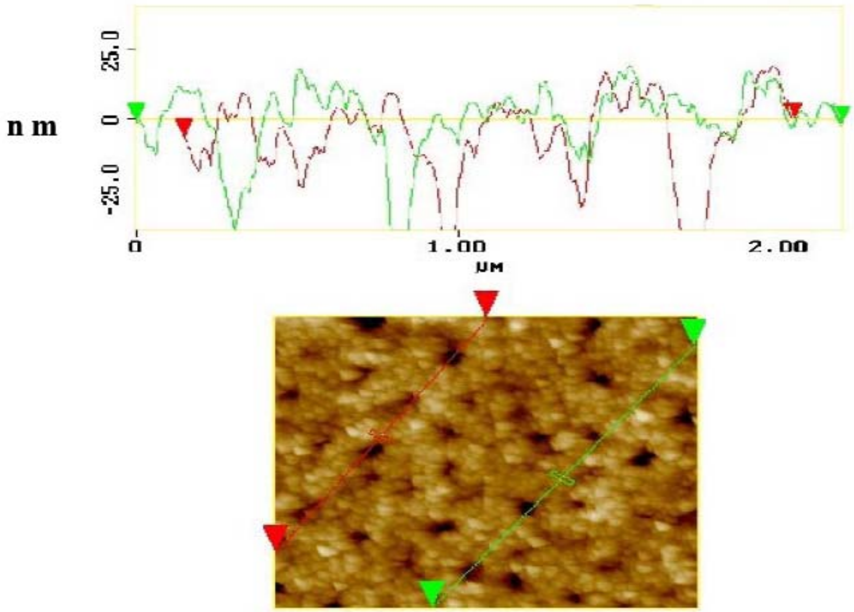
✍ **Suitable for video images !**

	OCB	ASV	PVA	IPS
Response Time (ms)	 -20? : 130ms	 -20? : 1300ms	 -20? : 1300ms	 -20? : 1700ms
Viewing Angle				

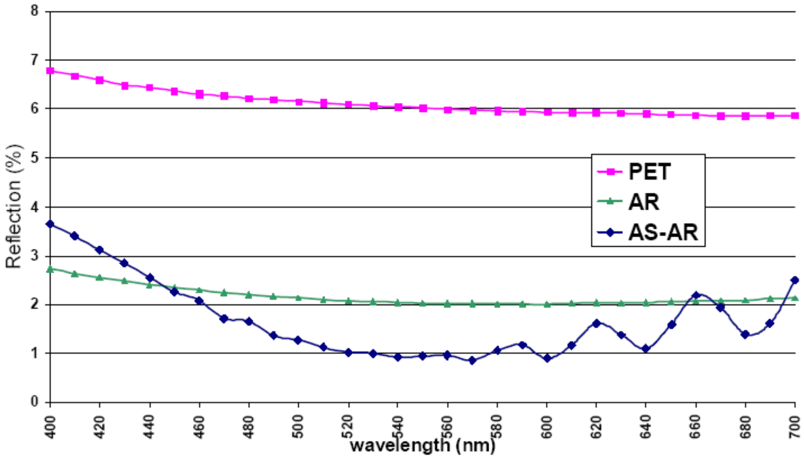
Single Layer AR Wet Coating

UV-Cured Self-Assembled Nano-Particles

AFM Image



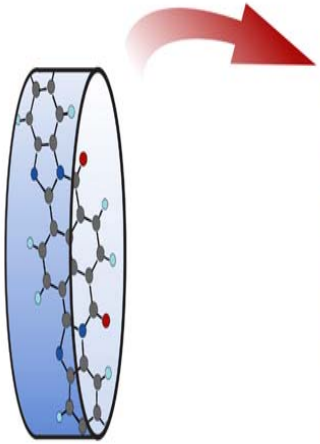
Reflectance



Provides Cost-Effective Anti-Reflection Coating

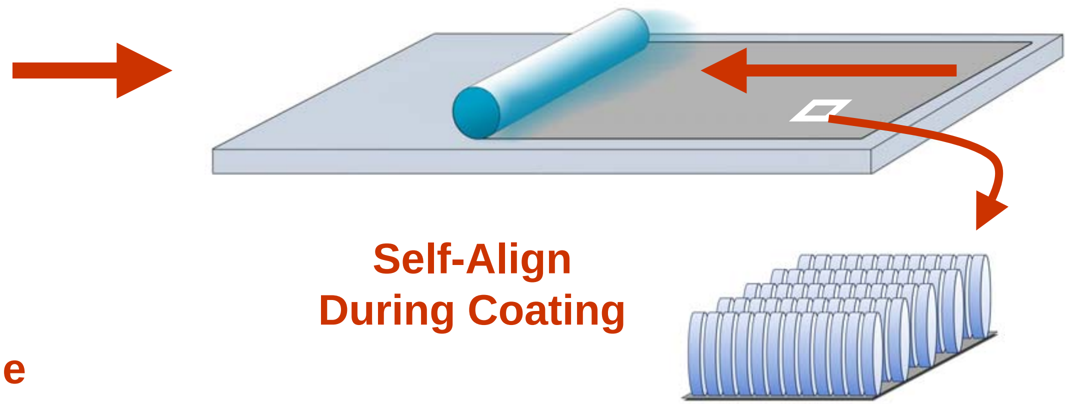
Source: Jens Thies (DSM)

Printable Thin Crystal Film (TCF)



Organic Molecules Modified
Supramolecular Chemistry

Self-Assemble In Liquid
Lyotropic Liquid Crystal



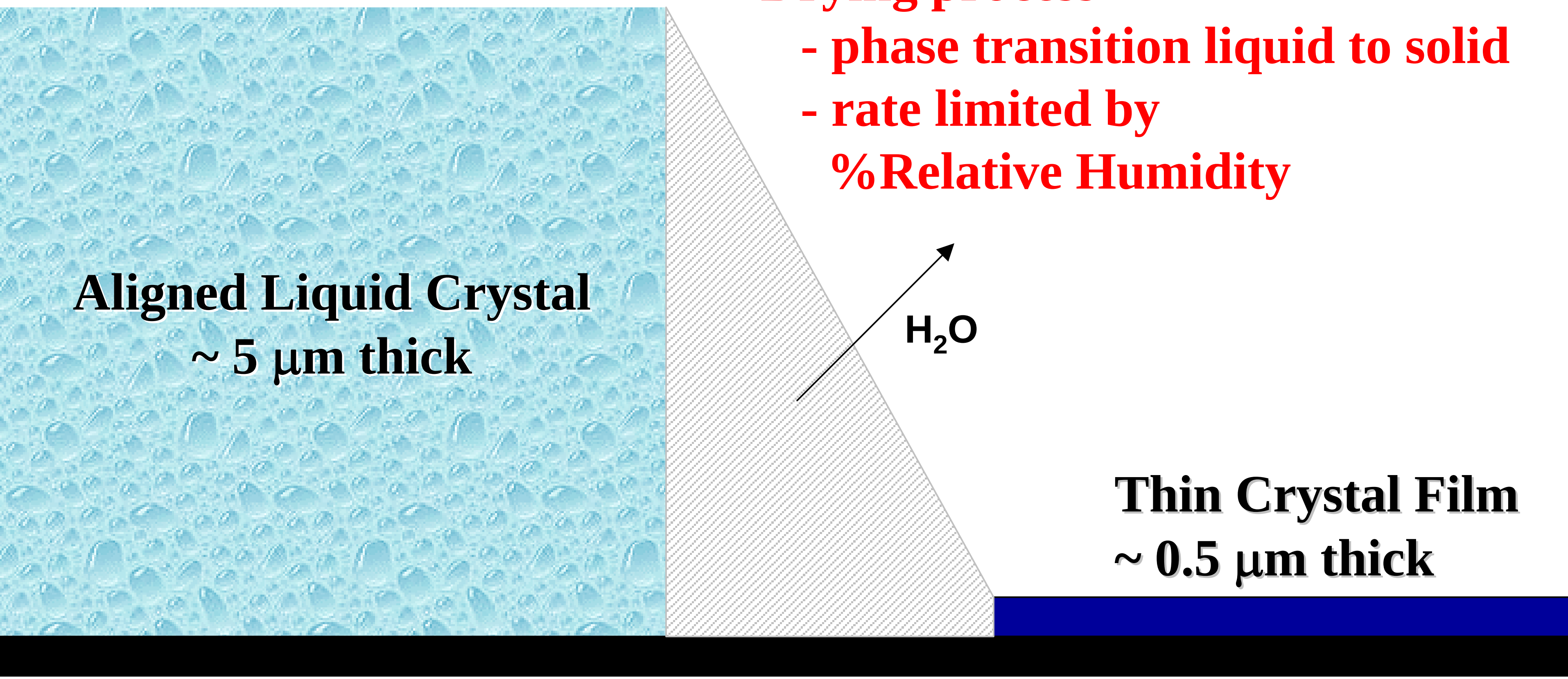
Self-Align During Coating

Crystallize During Drying

Source: Carl Cobb (Optiva)

Crystallization

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



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

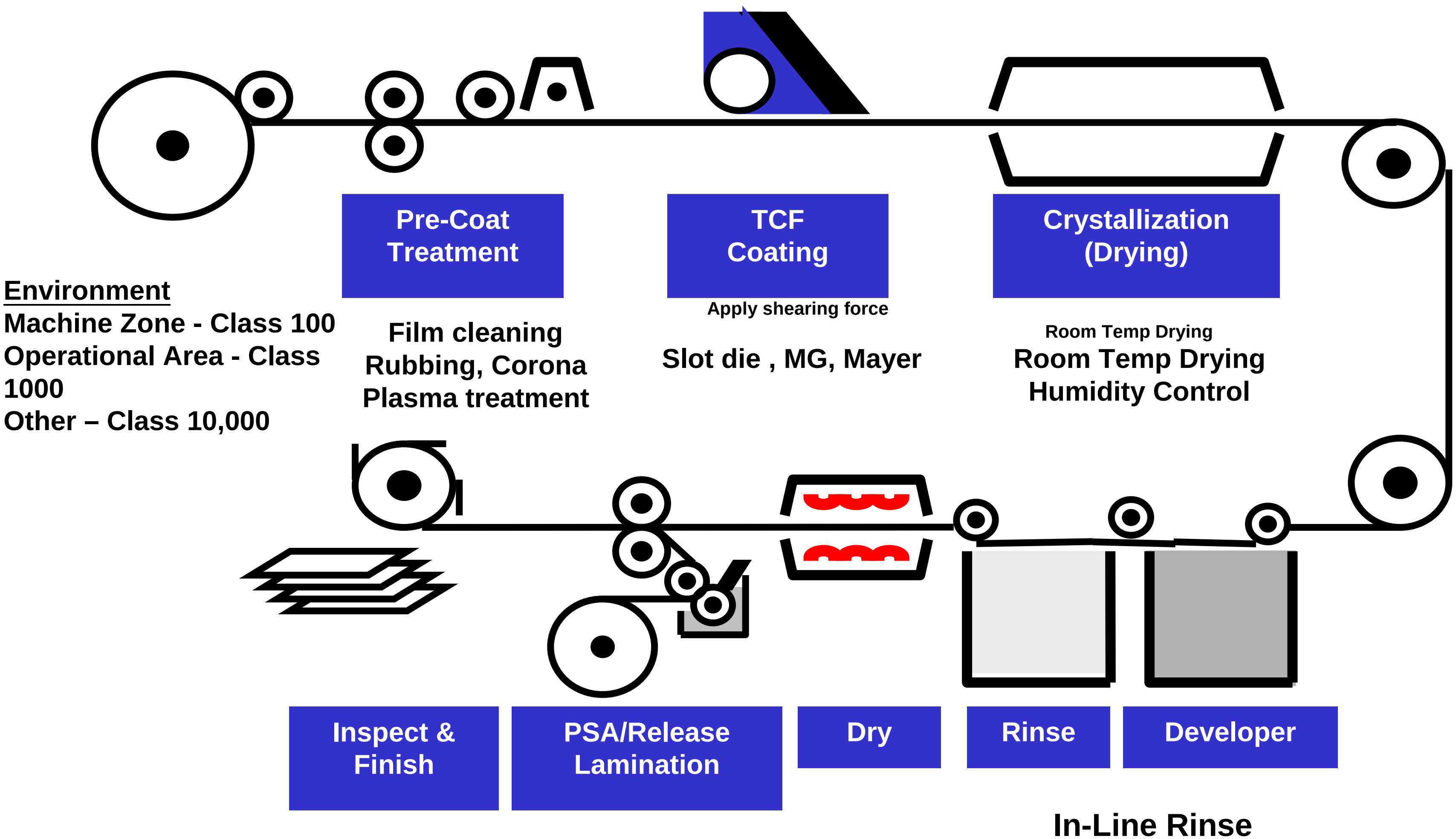
Multi-layer Anisotropic Stack

- Color Selective Filter or Reflector

Source: Carl Cobb (Optiva)

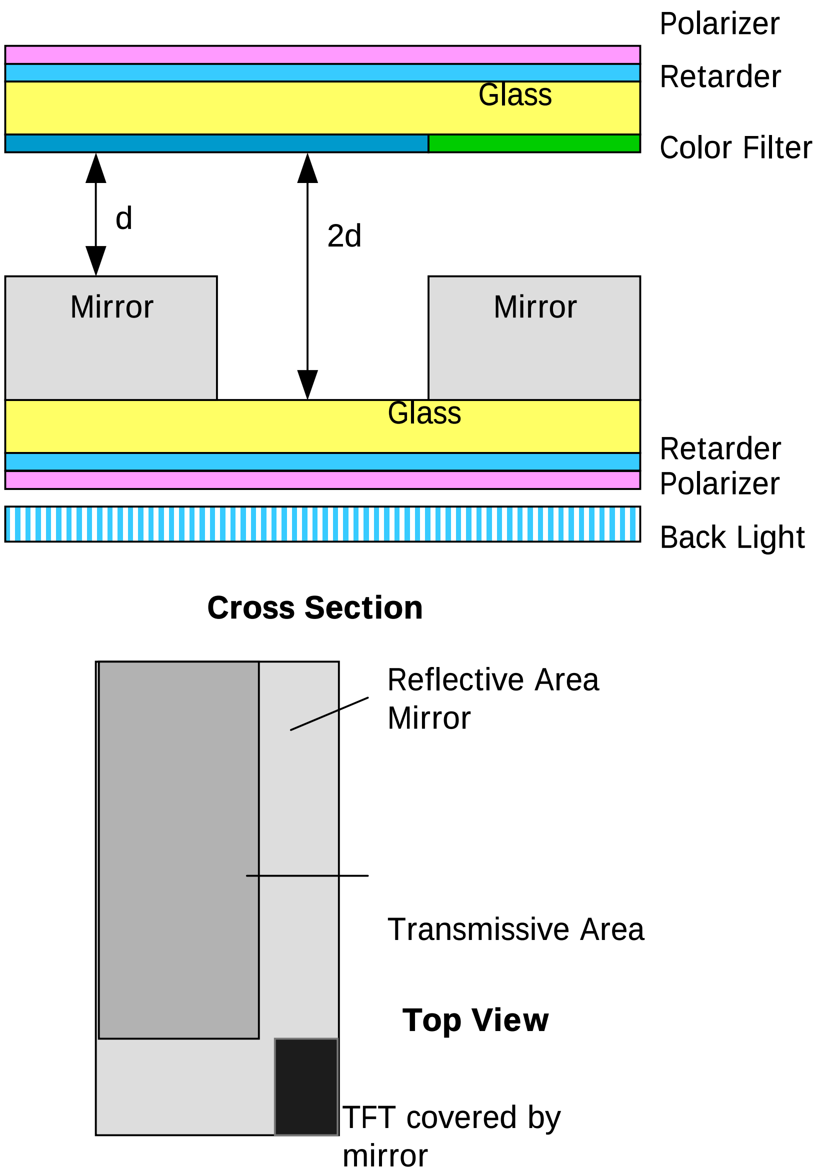
Thin Crystal Film™ (TCF) Coating Process

DisplaySearch



Source: Carl Cobb (Optiva)

Transflective Cellular Design - Current



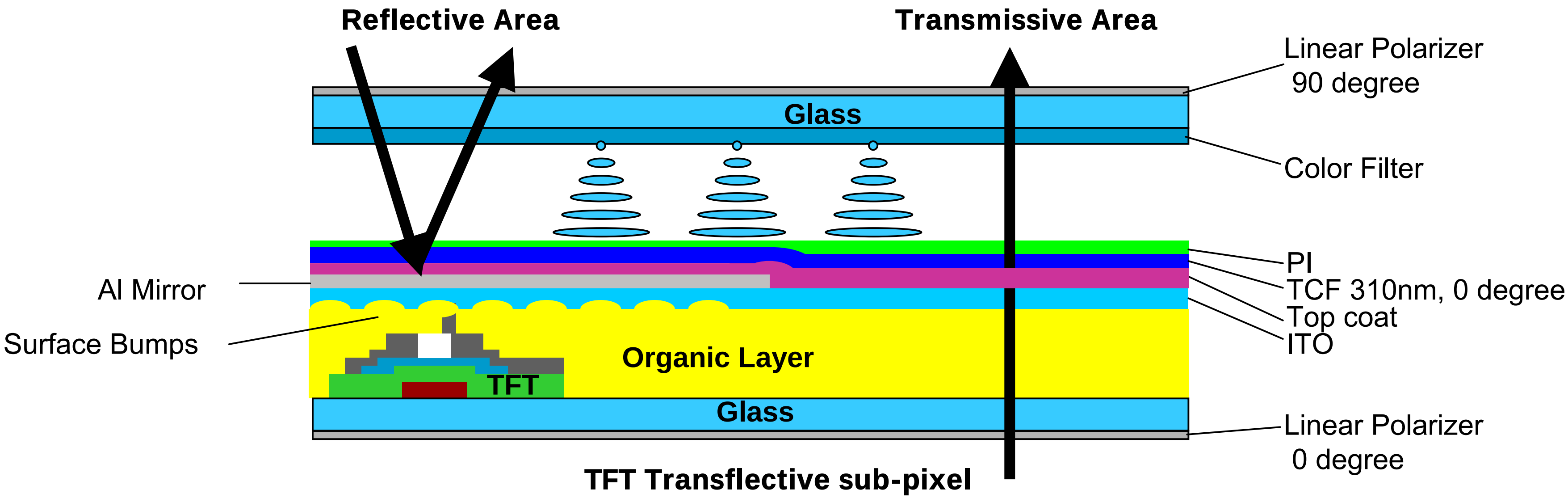
Advantage:

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?

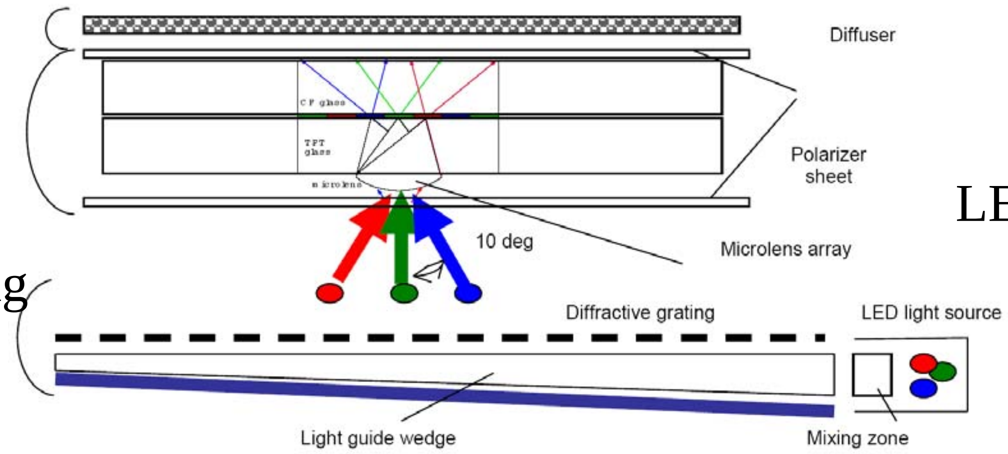
•Stacked films – difficult to manufacture & control light losses

•Microlens array – as in LCD projectors

•Field sequential color – as in DLP projectors

LCD with Micro-Lens Array

Structure

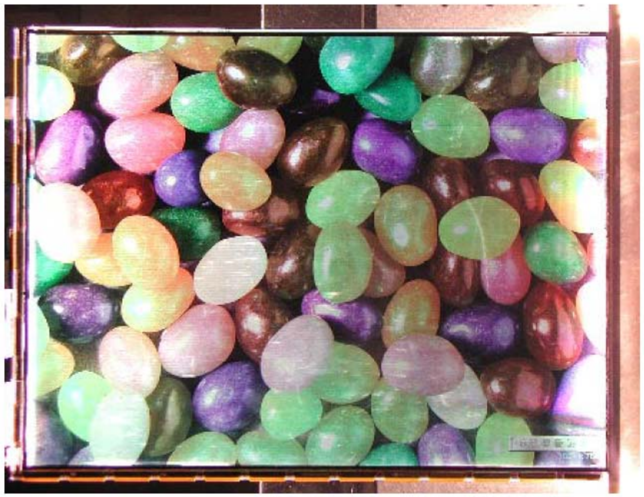


Diffraction grating to separate colors

LEDs to give narrower frequency spread

Need directed emission from light guide

13.3" XGA prototype
From IBM and IDTech

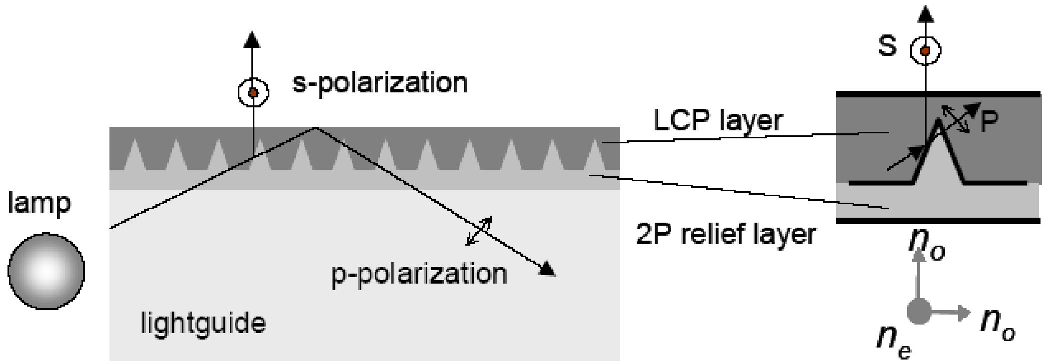


Authors recommend the use of a polarized light source

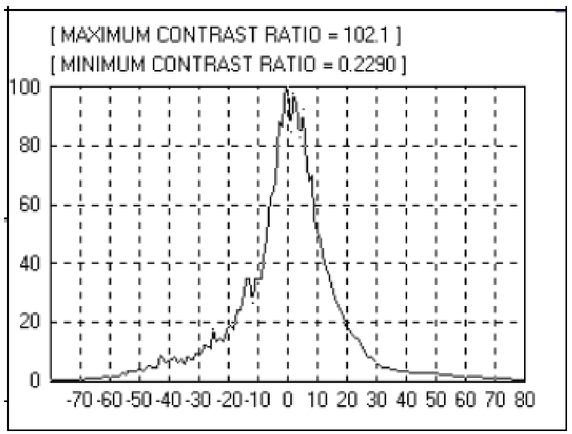
Source: IBM and IDTech (SID 2003 Int Symp, paper 43.1)

Polarized Light Source

Concept

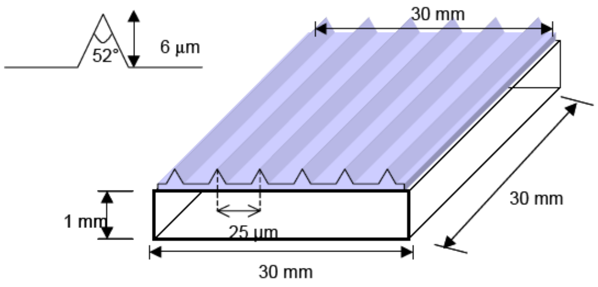


Preliminary Results

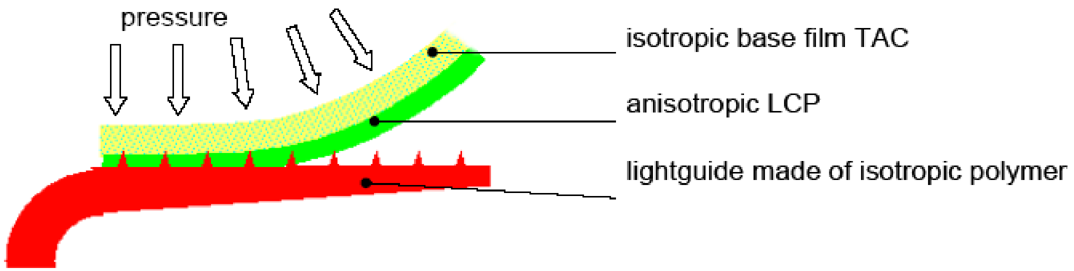


LCD side S/P ratio

Embossed Structures



Laminated LC film



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

Field Sequential Color

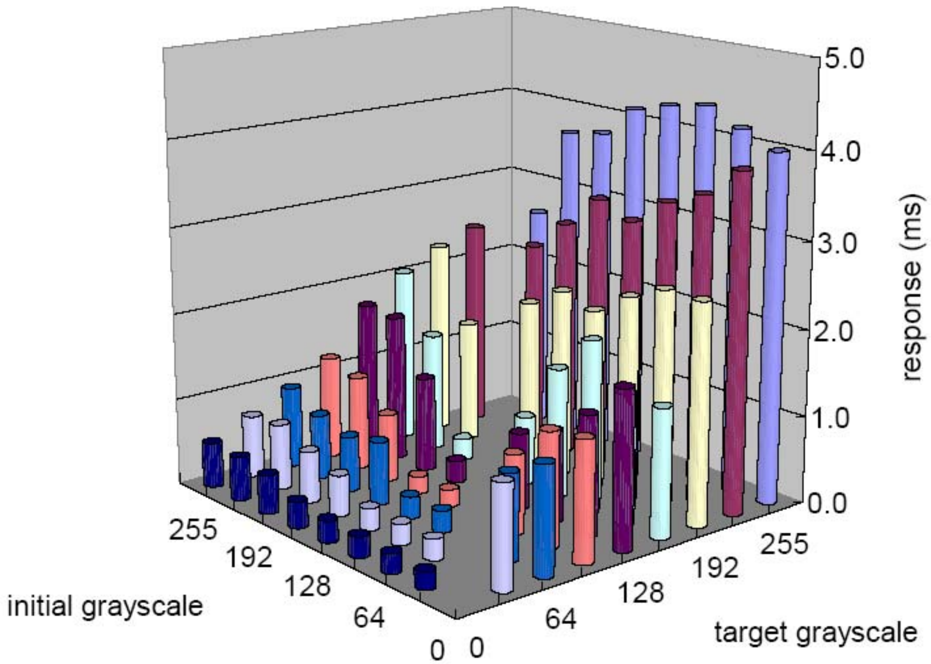
Requirements

- 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?

OCB Response Time



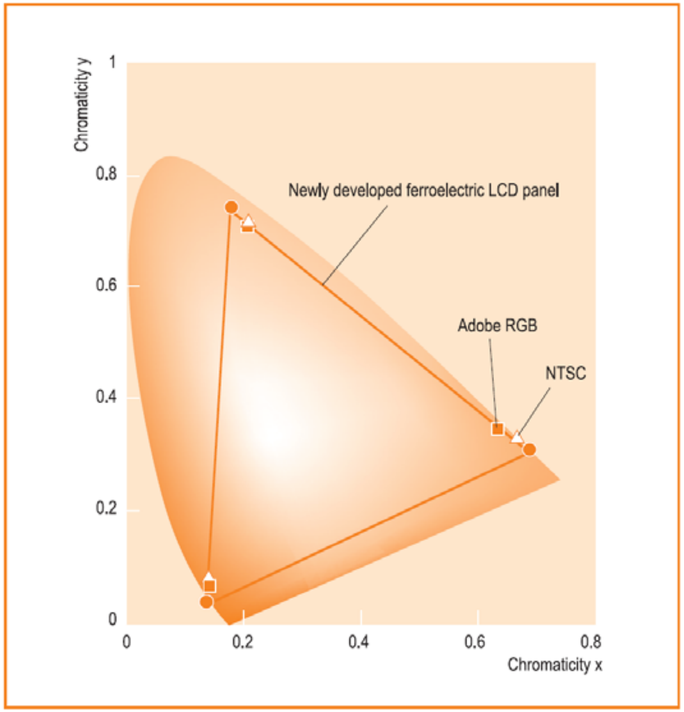
This response is fast enough to support the insertion of black sub-frames, but only marginal for frame-sequential color.

Source: Hui-Wen Yang (Chi Mei Optoelectronics)

Ferroelectric FSC Prototype from Fujitsu

Ferroelectric LCs can be switched in much less than 1 ms

Pixel number		800 x 600 (SVGA)
Pixel pitch (mm)		0.1 [254ppi]
Display area (mm)		80 x 60 [4 inch]
TFT type		Amorphous Si-TFT
Frame rate (Hz)		60
Display colors		262,144
Contrast		400 : 1
Brightness (cd/m^2)		225
Transmission rate (%)		12.7
Drive voltage (V)		5
Response time (ms)		< 1 [total from start-up to ending], 0.3 [black-white]
Color reproduction range (%)		NTSC ratio 117%, Adobe RGB ratio 122%
Chromaticity (x, y)	R	(0.6903, 0.3027)
	G	(0.1777, 0.7381)
	B	(0.1466, 0.0436)



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