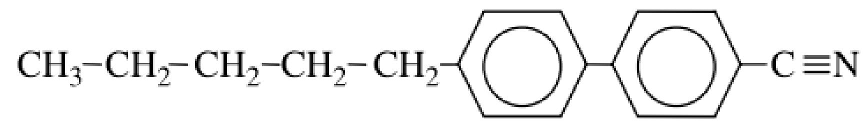
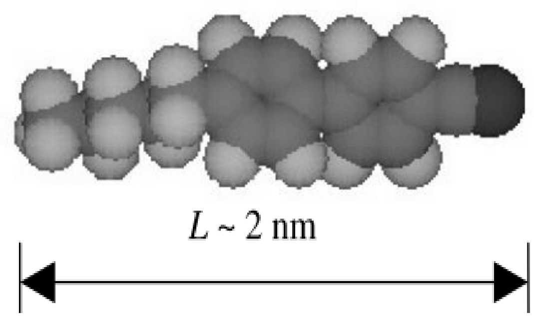
Displays: basic LCD technology

Liquid crystals are mesophases between crystalline solids and isotropic liquids. *Calamitic* (= elongated) molecules are used in LCDs

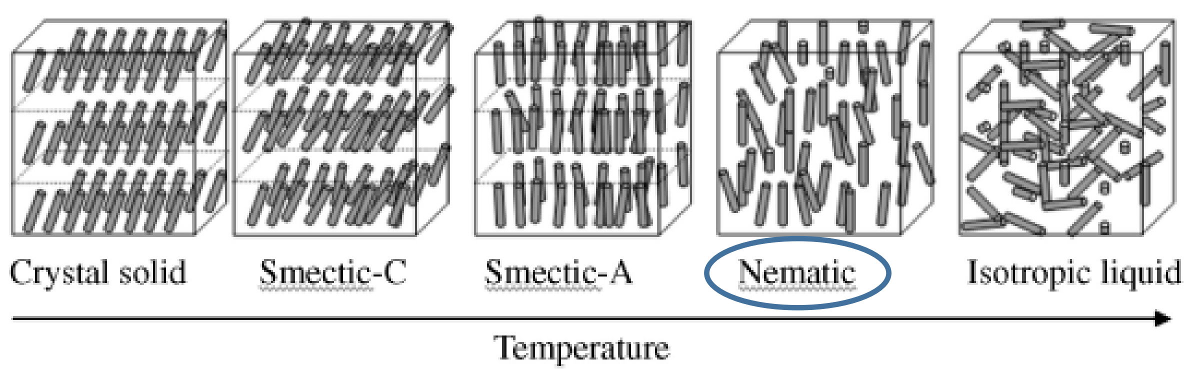
4-n-pentyl-4-cyano-biphenyl



The aromatic biphenyl $(C_6H_5)_2$ component is the rigid core, the hydrocarbon chain is the flexible tail.



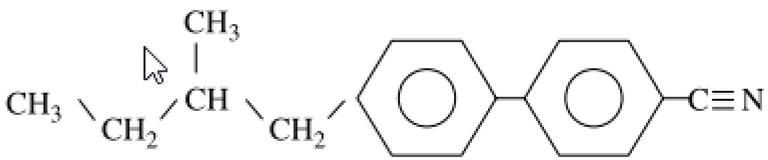
The core favors both orientational and positional order while the tail does not. With balanced rigid and flexible parts, the molecule exhibits liquid crystal phase



D.-K. Yang and S.-T. Wu, *Fundamentals of Liquid Crystal Devices, 2nd ed.*
© 2015 John Wiley & Sons

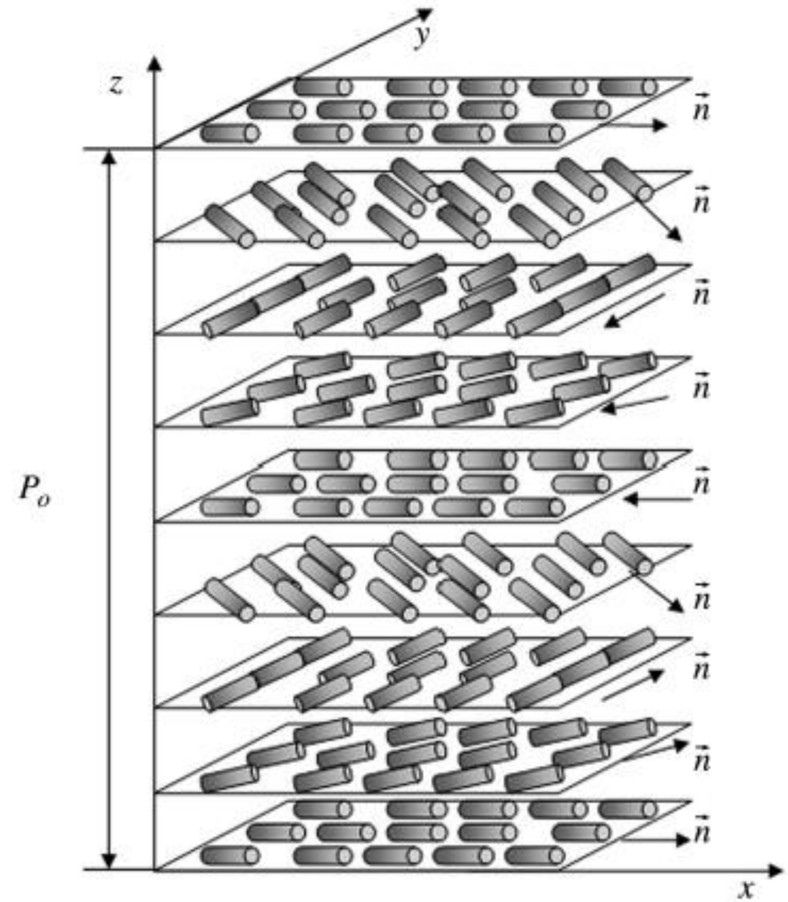
Basic LCD technology

Longitudinally asymmetric (*chyral*) molecules can be used, which organize themselves into *cholesteric* structures



LC molecules are optically anisotropic

Light propagating through the LC layers undergoes different delays in its electric field components, and accordingly modifies its polarization



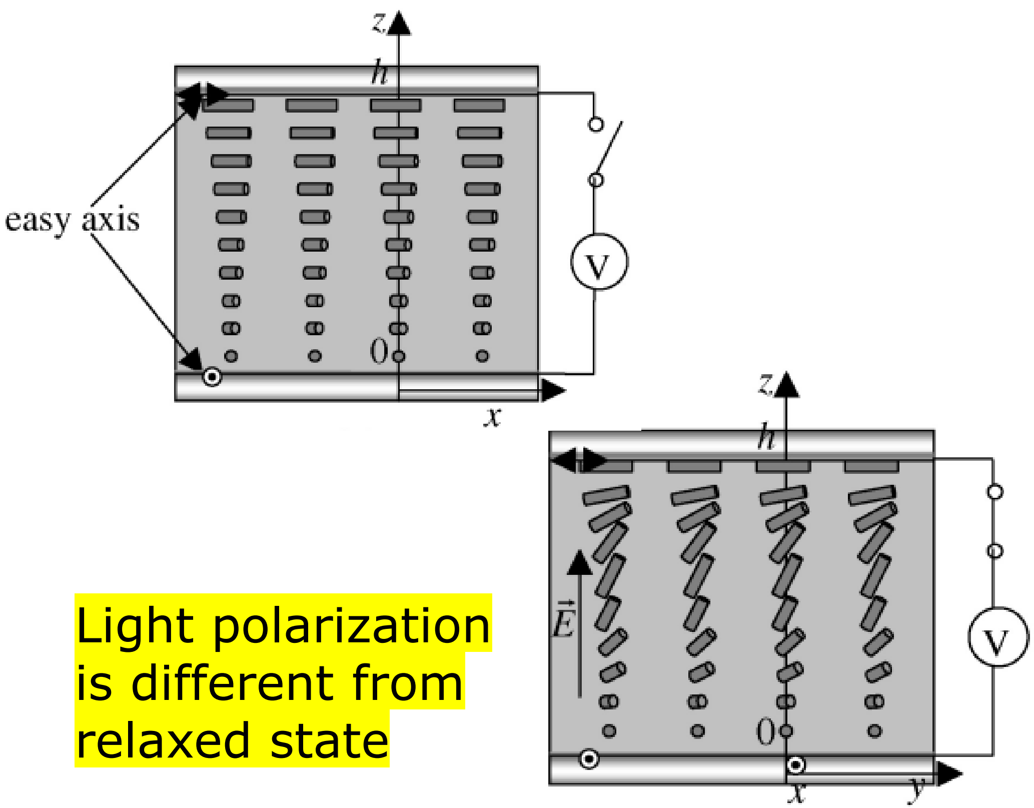
D.-K. Yang and S.-T. Wu, *Fundamentals of Liquid Crystal Devices, 2nd ed.* © 2015 John Wiley & Sons

Basic LCD technology

In a *twisted nematic* display the LC is anchored parallel to the cell surface by the alignment layers. The *total twist angle* is 90 deg here.

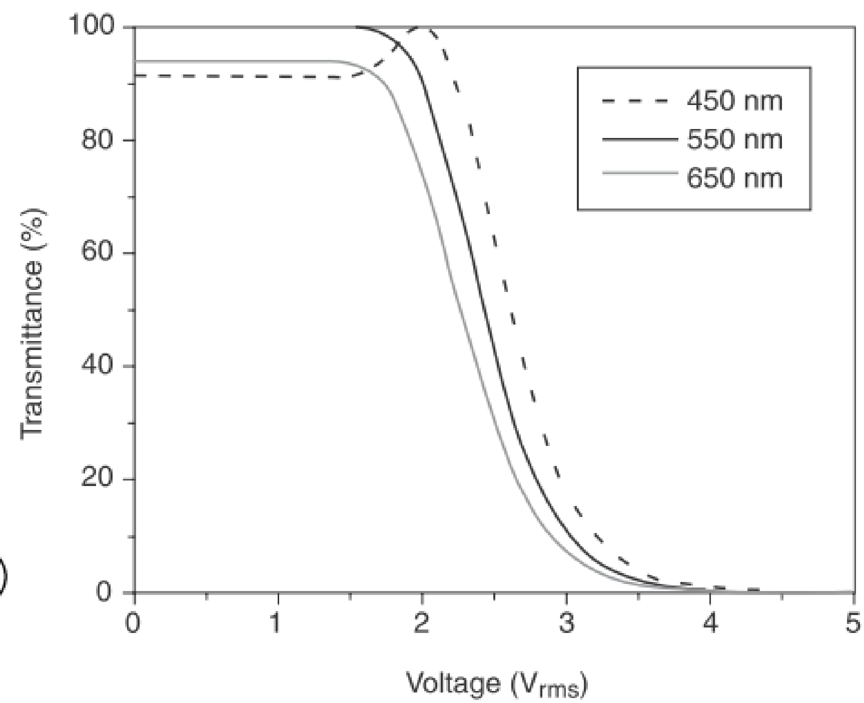
LC molecules are also electrically anisotropic

When a sufficiently high electric field is applied across the cell, the liquid crystal is tilted toward the field direction



Light polarization is different from relaxed state

Normalized transmittance



D.-K. Yang and S.-T. Wu, *Fundamentals of Liquid Crystal Devices, 2nd ed.* © 2015 John Wiley & Sons

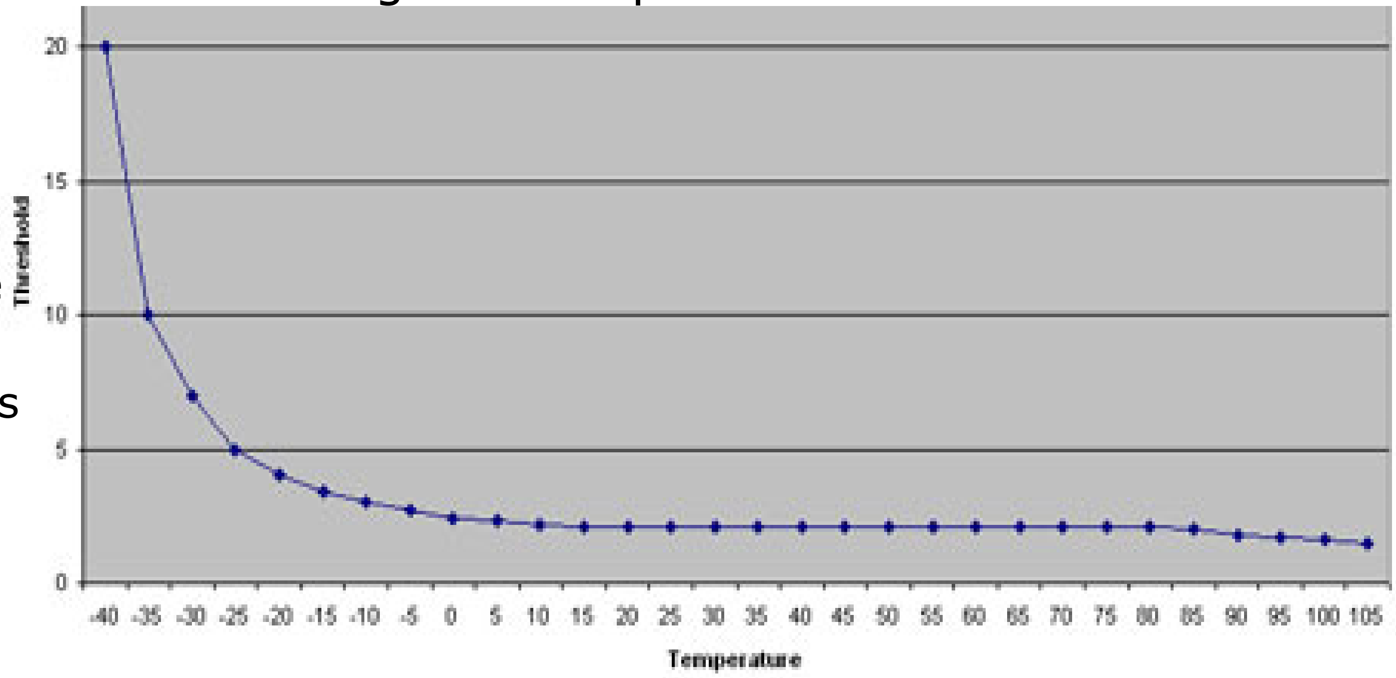
Basic LCD technology

Temperature effects

- LCD's will recover from brief exposure to *isotropic temperatures.*
- Temperatures above +100º C damage the *display's* internal coatings.
- At low temperatures the display's response time increases due to the fluid's increased viscosity.
- Change to crystalline state does not imply permanent damage.

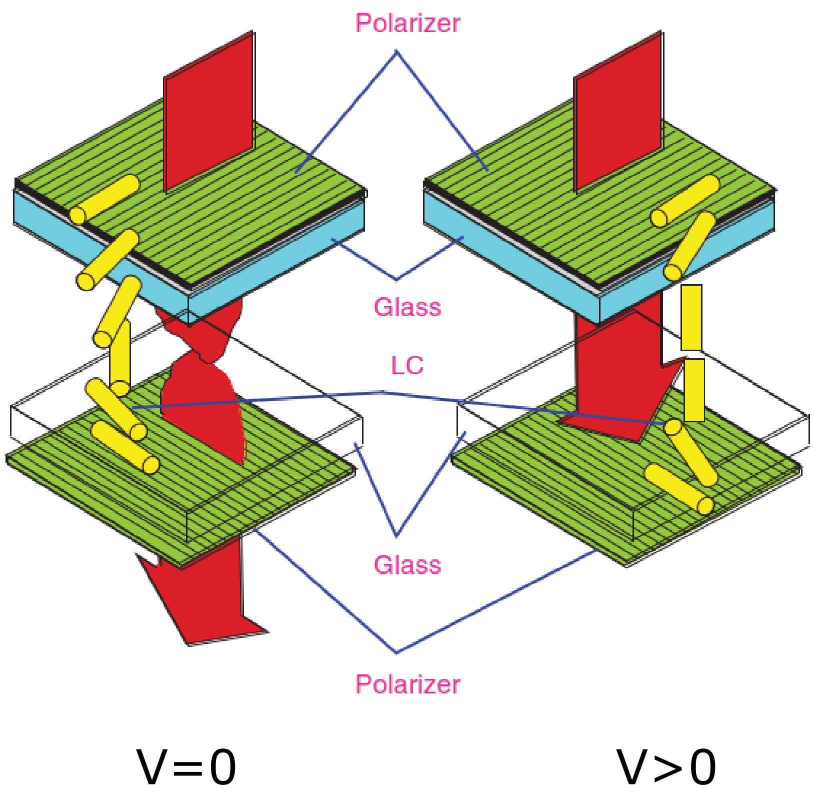
Typ. threshold voltage vs. temperature of a TN fluid

Threshold increase becomes significant below ~0 Celsius (compare to voltage values in the transmittance curves in previous slide)

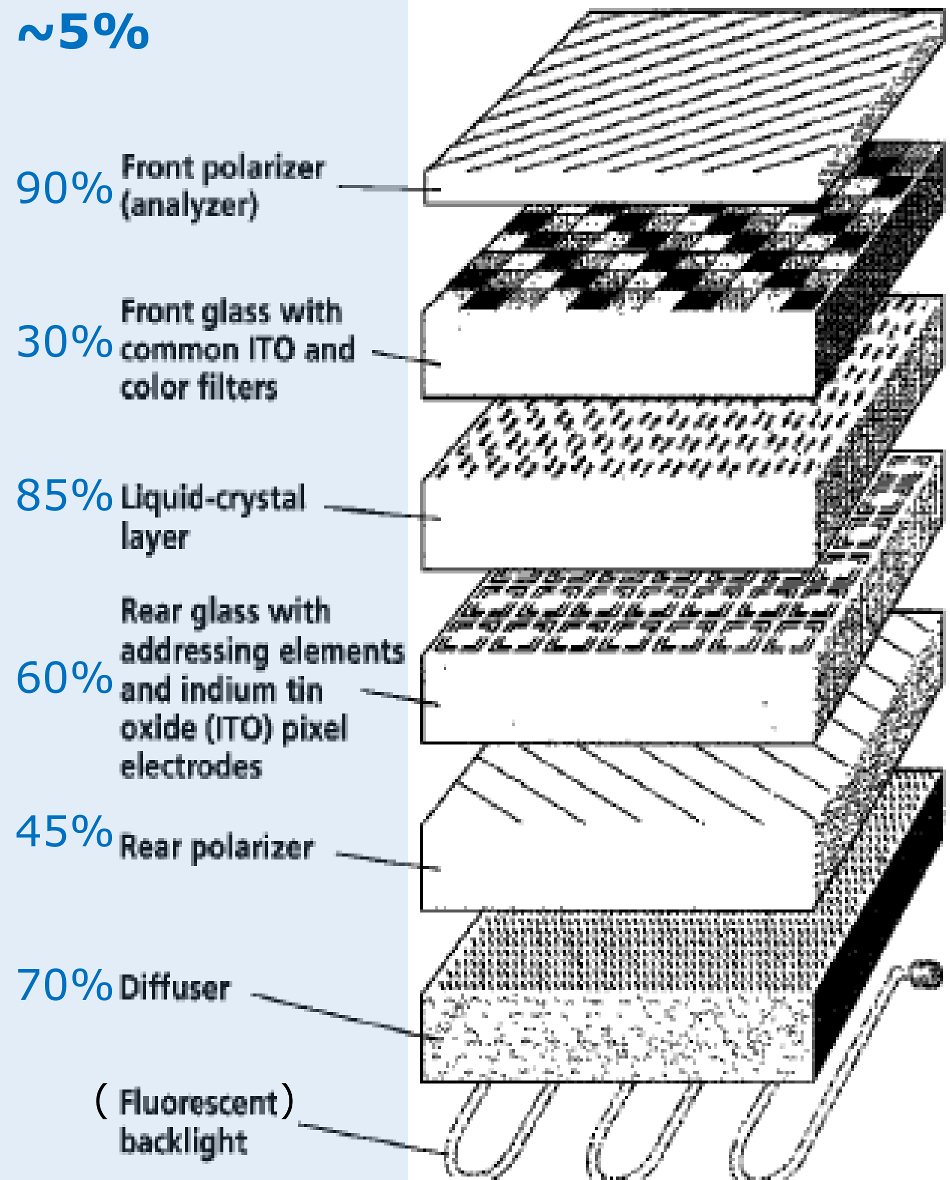


Basic LCD technology

Twisted nematic (TN), thin-film-transistor (TFT) technology



Max. overall transmittance: **~5%**



D.-K. Yang and S.-T. Wu, *Fundamentals of Liquid Crystal Devices, 2nd ed.*

Basic LCD technology

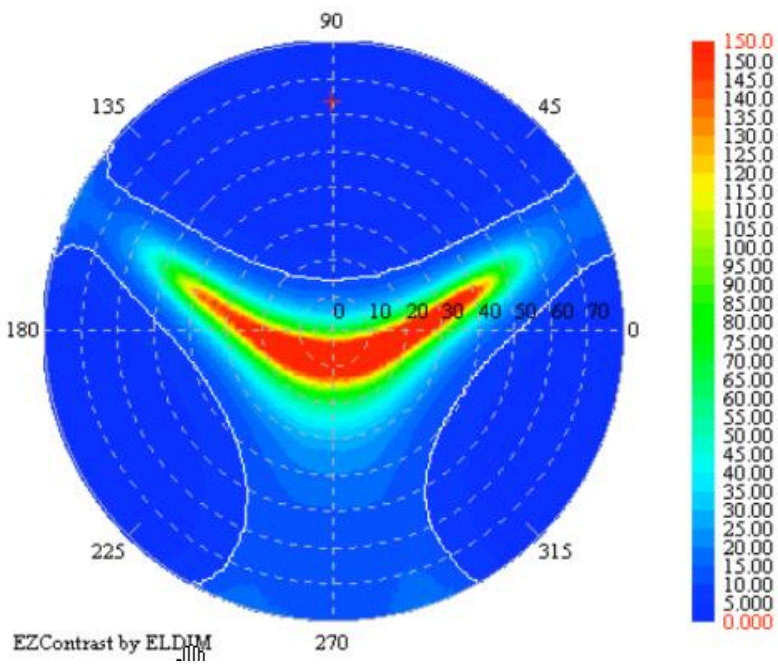
See 3M Website for more info on films and coatings

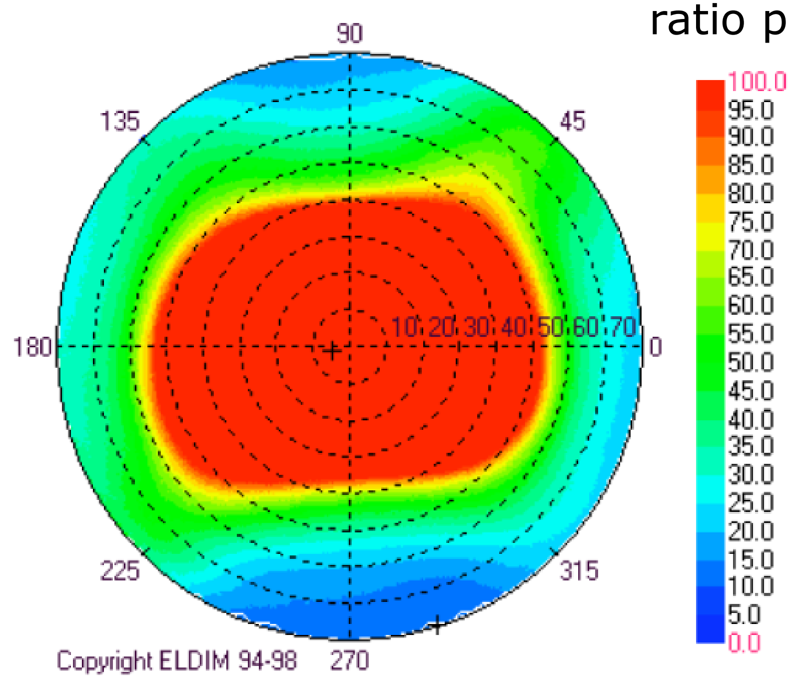
- Optical anisotropy of liquid crystals and
- Off-axis light leakage from crossed polarizers

generate rapid contrast decrease in the upper direction and in the lower diagonal directions. In the lower direction the contrast remains high, but gray-scale inversion is observed (not shown)

A pair of *wide-view* films can reduce the effect

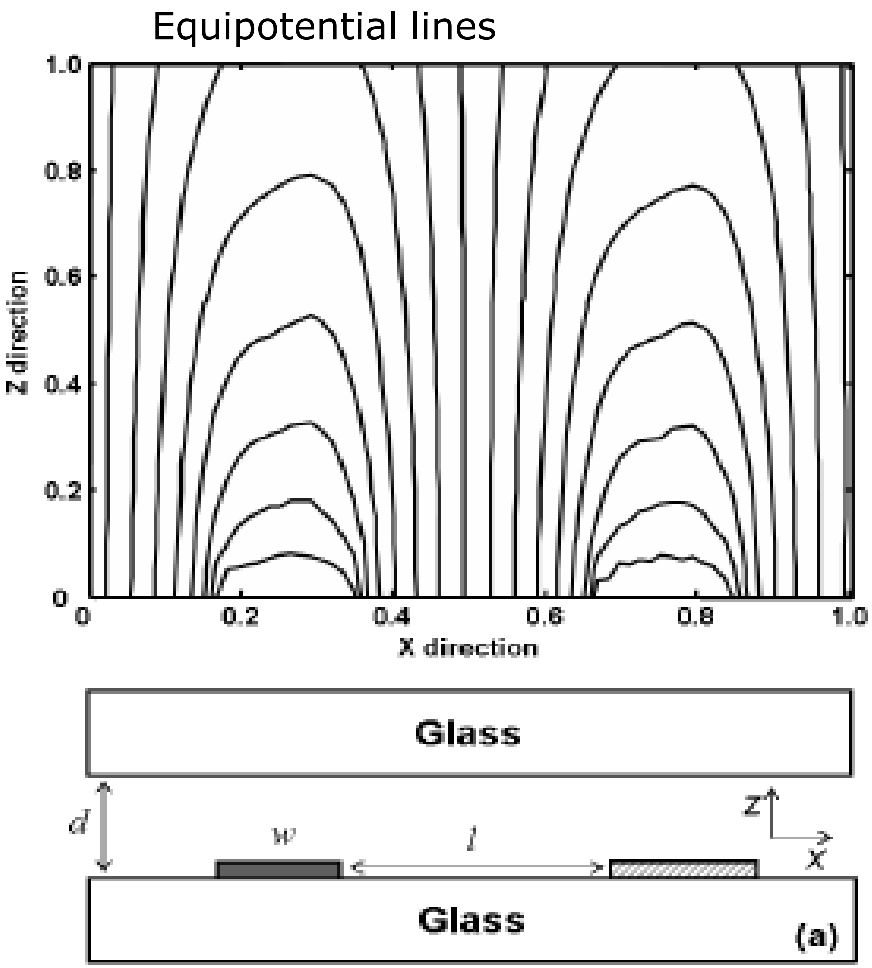
Iso-contrast-ratio plots





D.-K. Yang and S.-T. Wu, *Fundamentals of Liquid Crystal Devices, 2nd ed.* © 2015 John Wiley & Sons

IPS - LCD technology



In-Plane-Switching

(normally black)

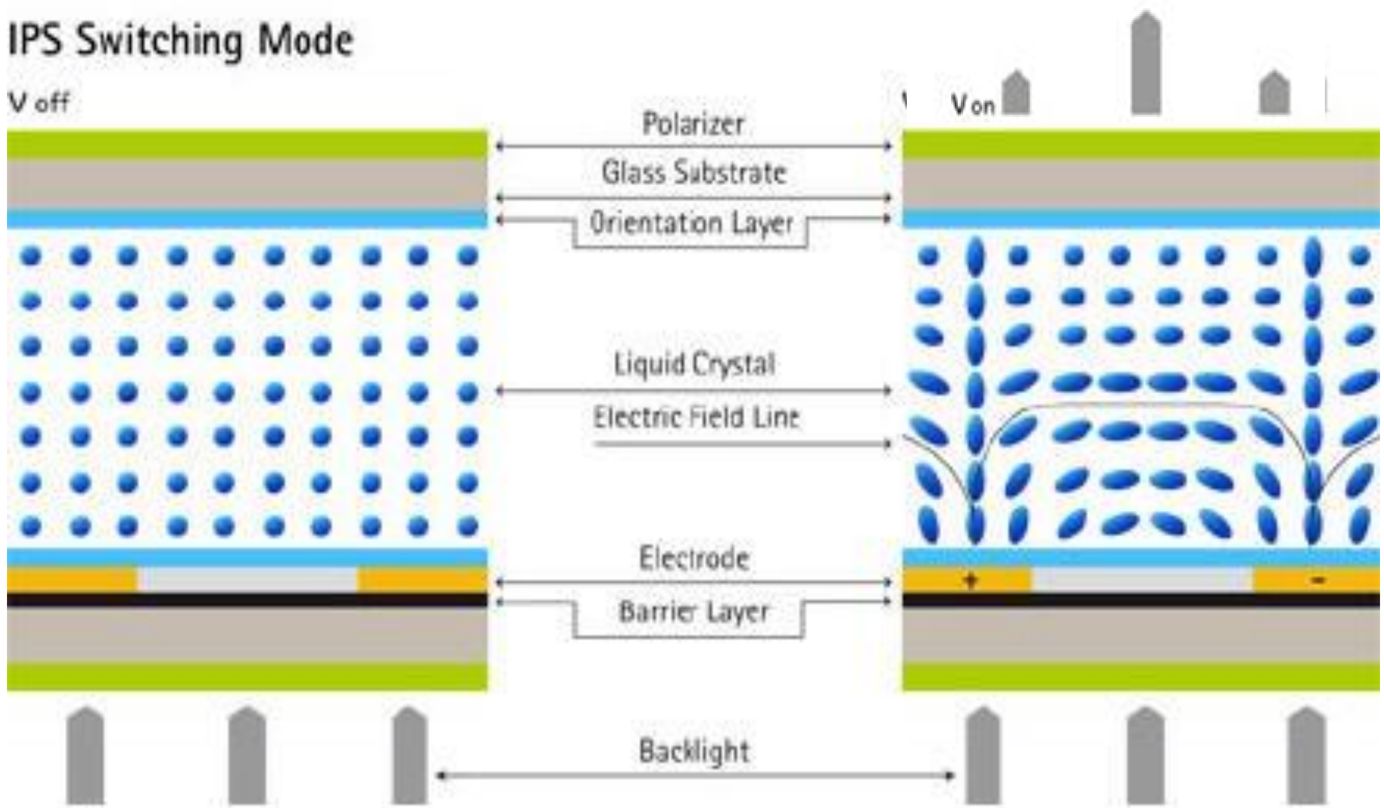
- thinner display
- reduced parallax error

IPS - LCD technology

analysis polarizer:

•

input polarizer:
→

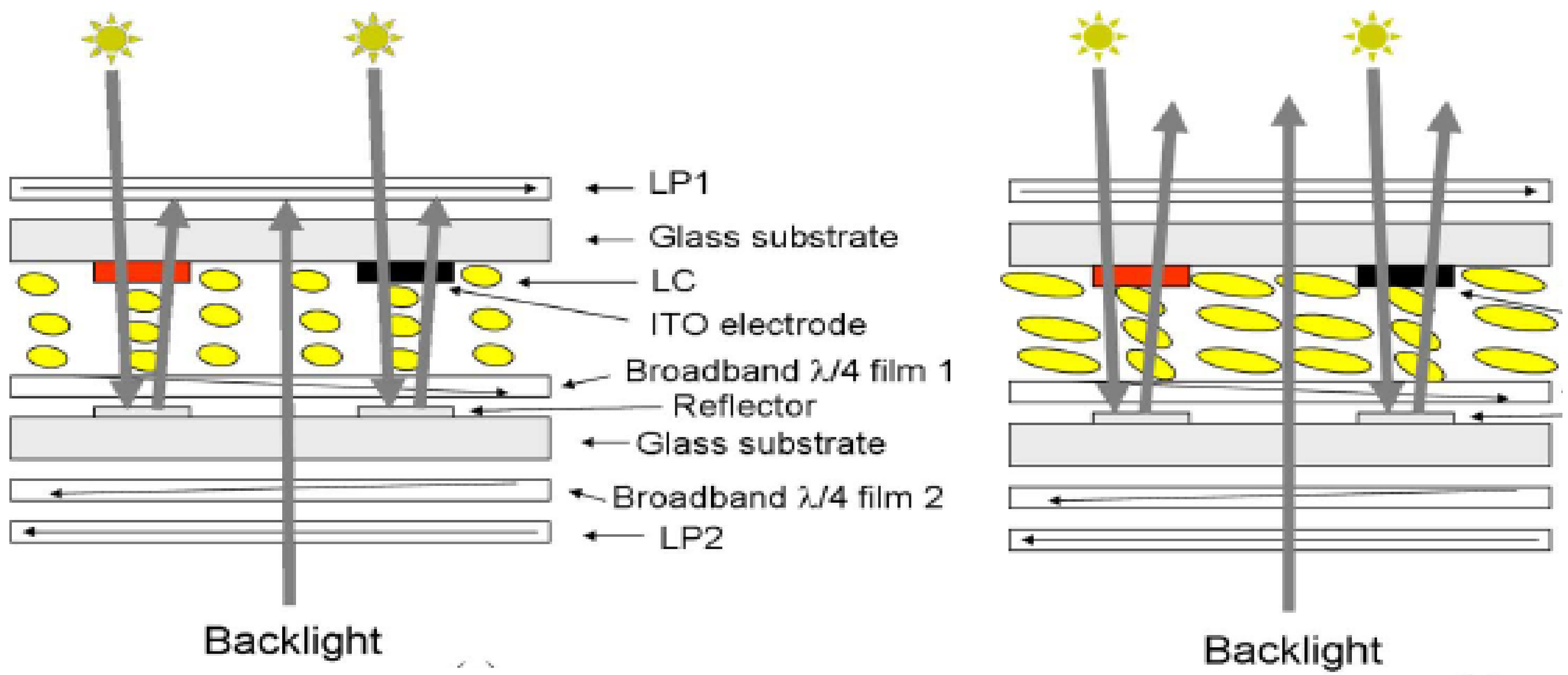


- Note light is transmitted when V = on
- A problem with IPS: above the electrodes the electric field is unable to twist the LC → the light transmittance is lower

http://www.merck-performance-materials.com/en/display/function_of_lcd_technologies/function_of_lcd_technologies.html

(Lu 2007)

Transflective IPS



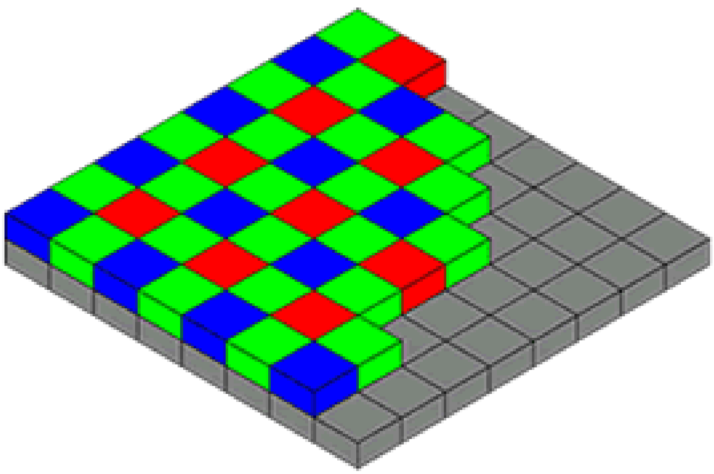
A $\lambda/4$ filter [*oriented at 45° it converts linear pol. to circular; then viceversa, at further 45°*] is traversed twice by both the back (*1x 2 filters = 90°*) and reflected light (*2x 1 filter = 90°*)

BUT two added filters absorb light → without sunlight, the display looks washed-out → needs stronger backlight → power consumption, heat

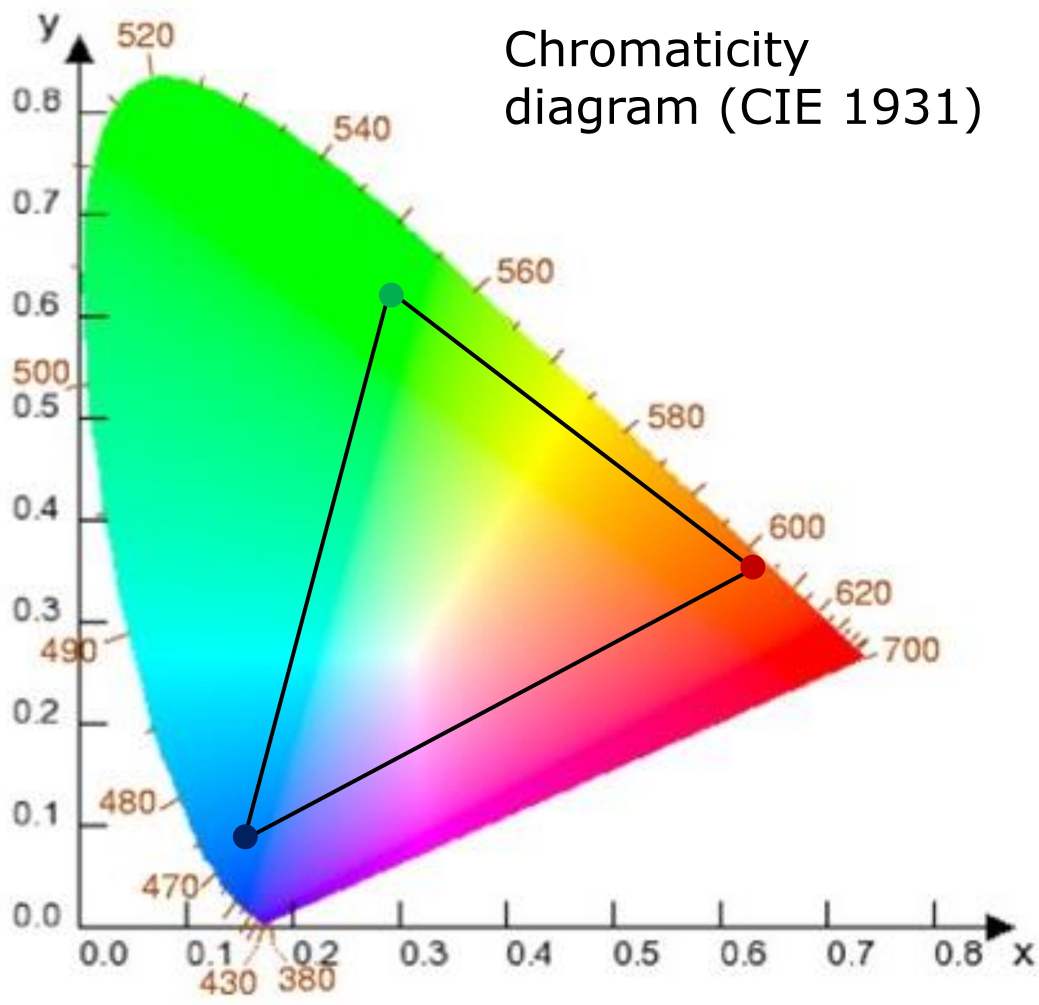
www.edmundoptics.co.uk/resources/application-notes/optics/understanding-waveplates/

Colour LCDs

Generate colour pictures using a *Bayer filter*

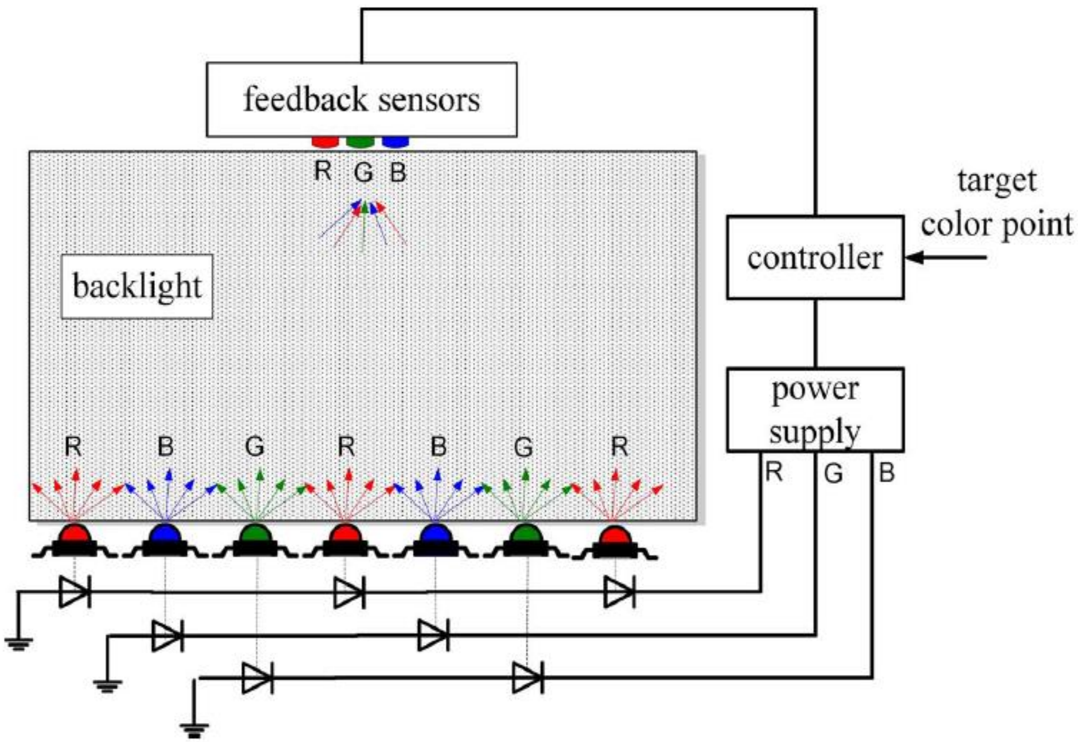


Chromaticity diagram (CIE 1931)



[See also color.m]

LED backlights



Necessity of white point control

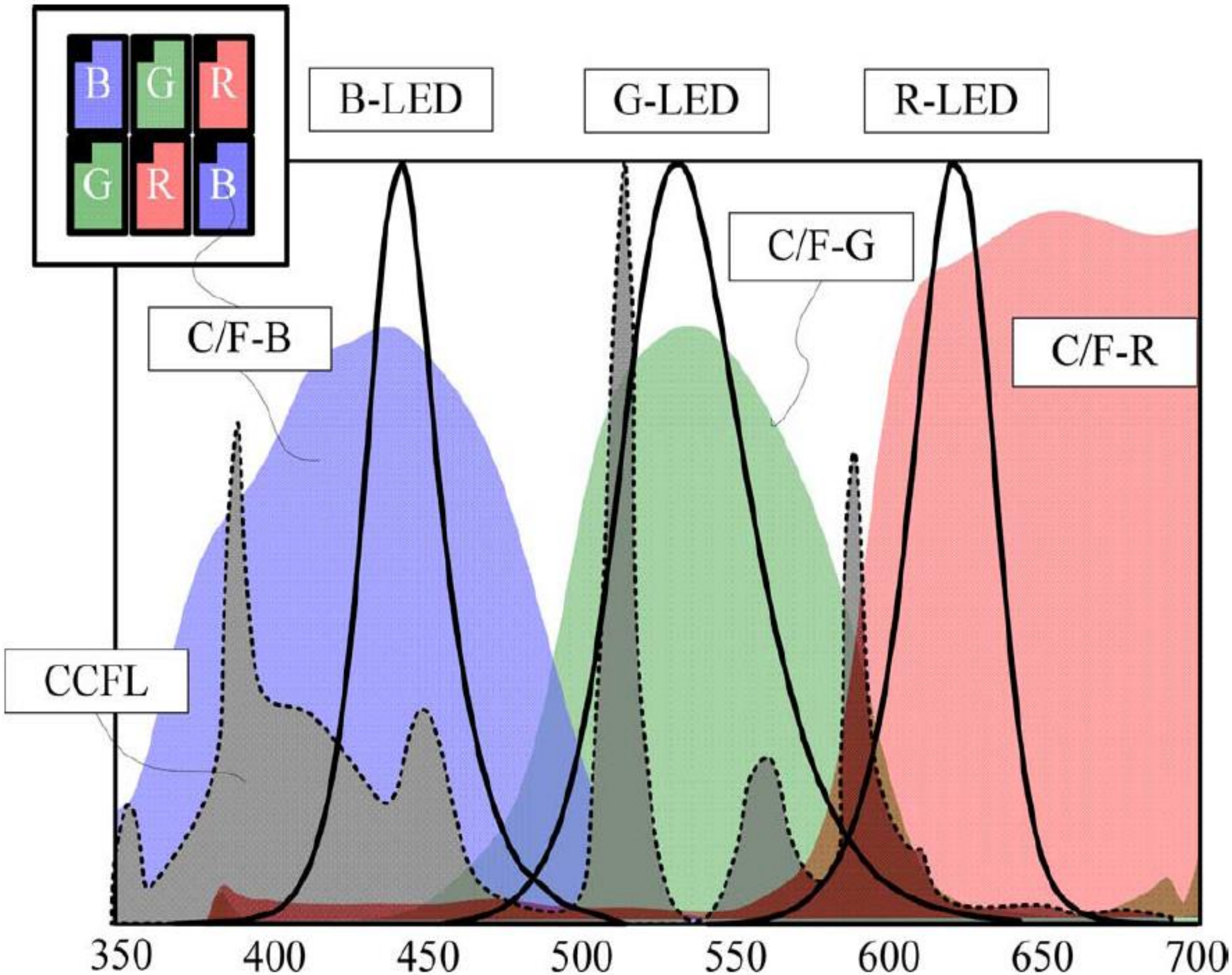
The Nobel Prize in Physics 2014

Isamu Akasaki, Hiroshi Amano
Nagoya University, Japan
Shuji Nakamura
Univ. of California, Santa Barbara, CA, USA

"for the invention [1990] of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"

LED backlights

LED spectra compared to Cold Cathode Fluorescent Lamp + colour filters



LED backlights

LEDs

- can be switched fast,
- are available in all colors,
- are small,
- are environmentally friendly (??),
- operate at low voltages

NOTE: thin and strong peaks at RGB freqs. can be obtained using **QUANTUM DOT** devices

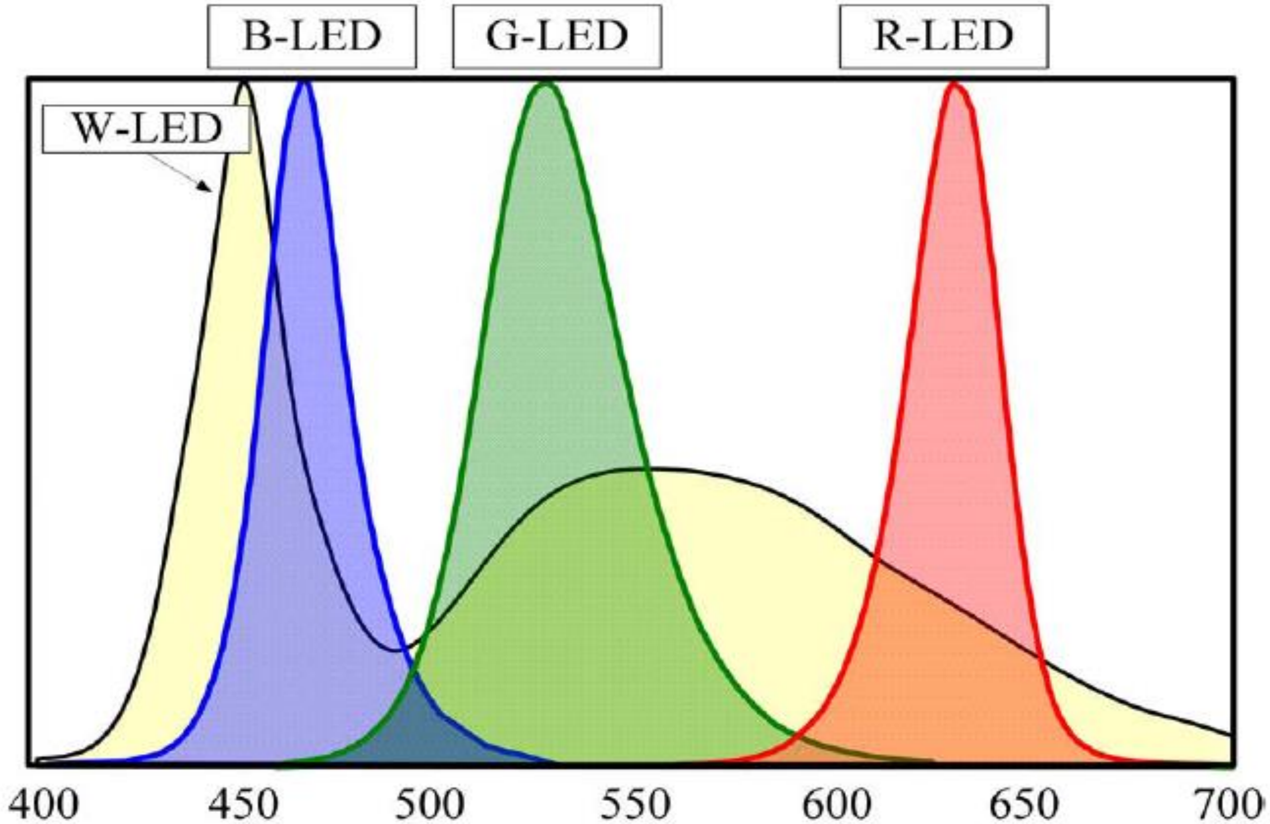


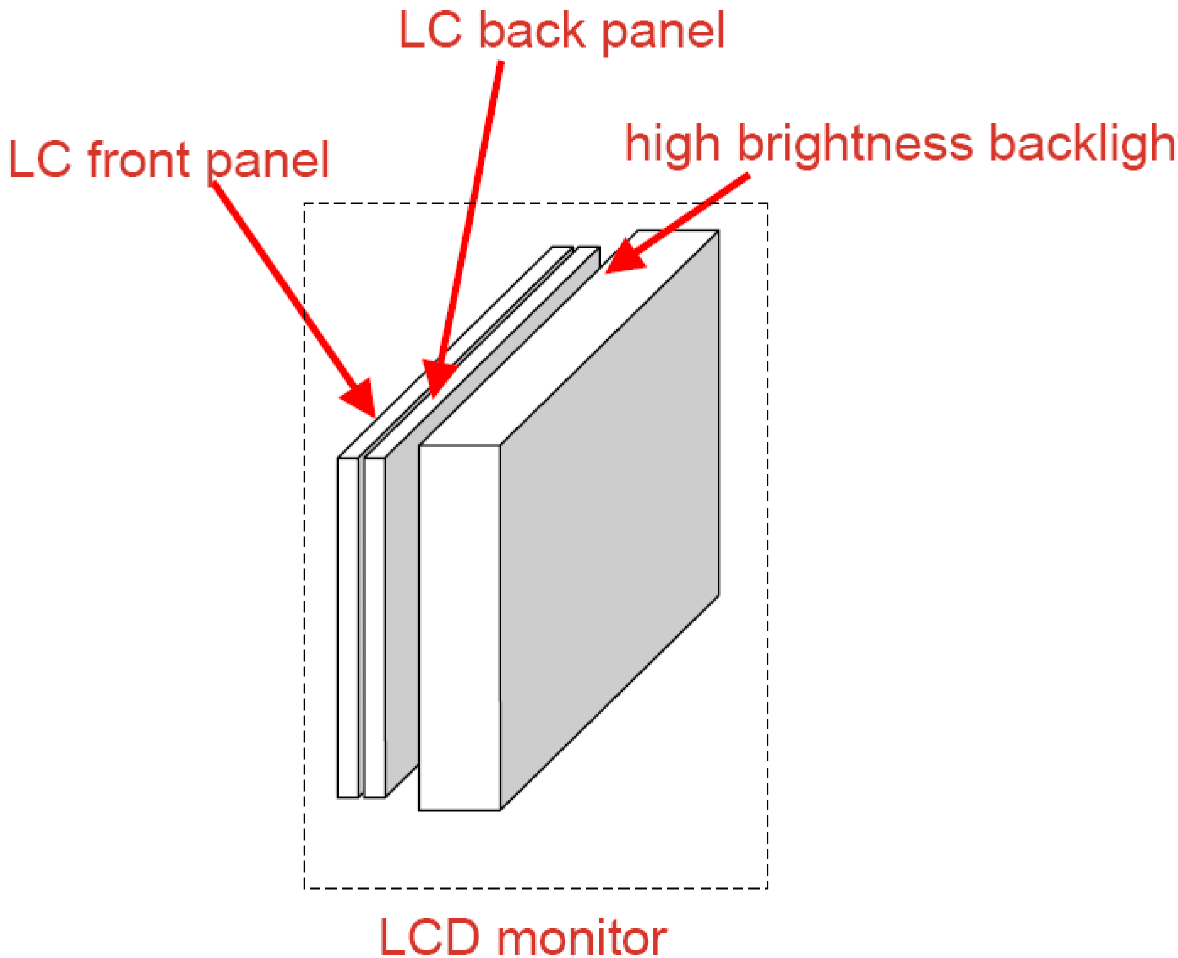
Fig. 3. Typical spectra for red, green, and blue LEDs, as used for display illumination applications. Typical wavelengths used are (dominant): 450–460 nm for blue, 520–535 nm for green, and 610–630 nm for red. Color standards often require a D65 (6500 K CCT) white point, but most displays are using higher color temperatures (9000–10000 K). The white LED consists of a blue LED, coated with a yellow (Ce-doped YAG) phosphor. Typical white points for white LEDs are in the range of 4500–9000 K.

Dual-layer LCD

The front- and rear-polarizers of the two panels must be properly oriented!

- 8+8=16 bit images
- T_{max} = 2 %
  (14%*14%)
- L_{max}/L_{min} = 90,000
  (300:1)*(300:1)
- Basic image processing: $Y = \sqrt{Y}\sqrt{Y}$

2018: studies on 4k colour display for medical applications



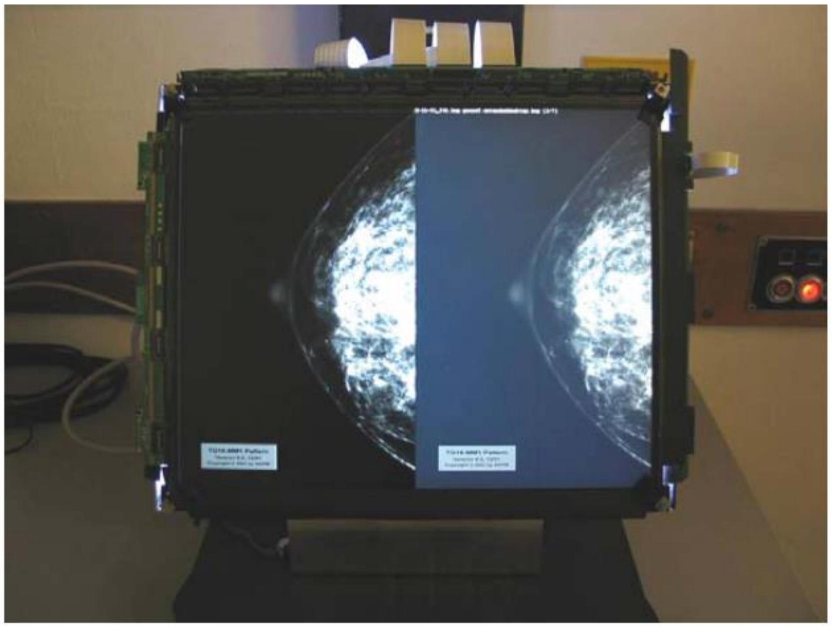
Source: Philips Research – FIMI - Barco

Dual-layer LCD

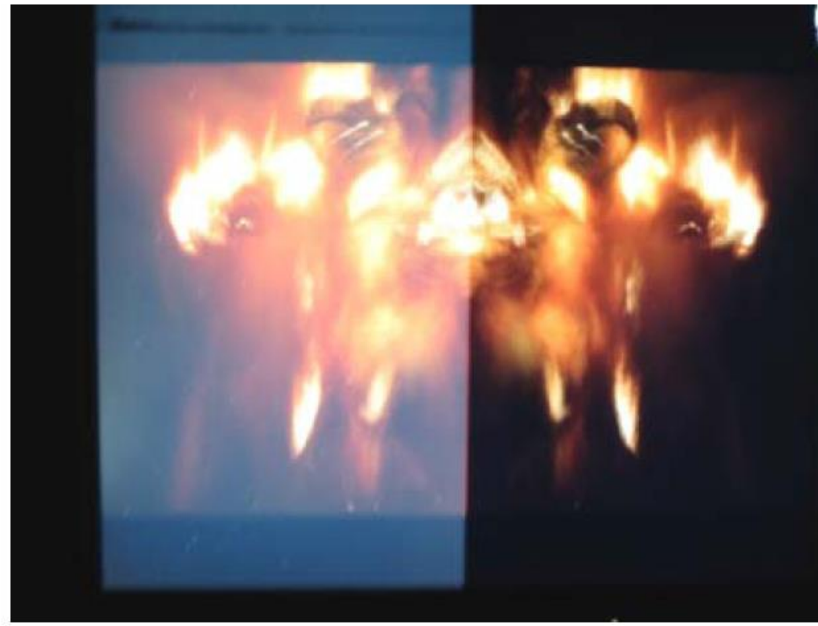
later: FIMI - Barco

PHILIPS

Dual layer LCD: pictures from the screen



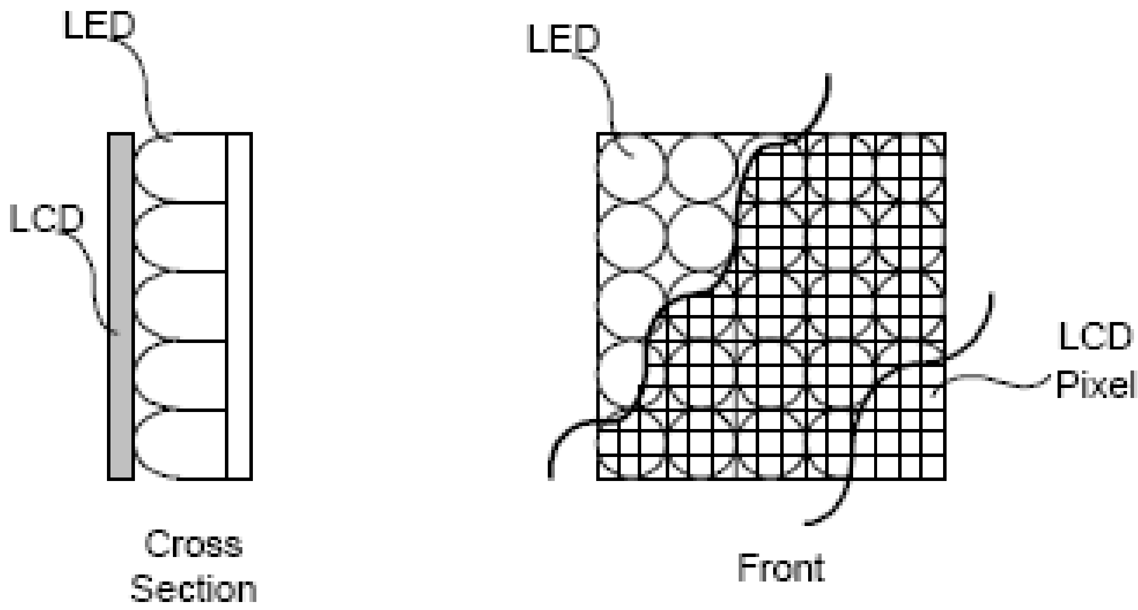
Grayscale



Color

see industrial LCD datasheet (Kyocera)

Modulated LED + LC displays



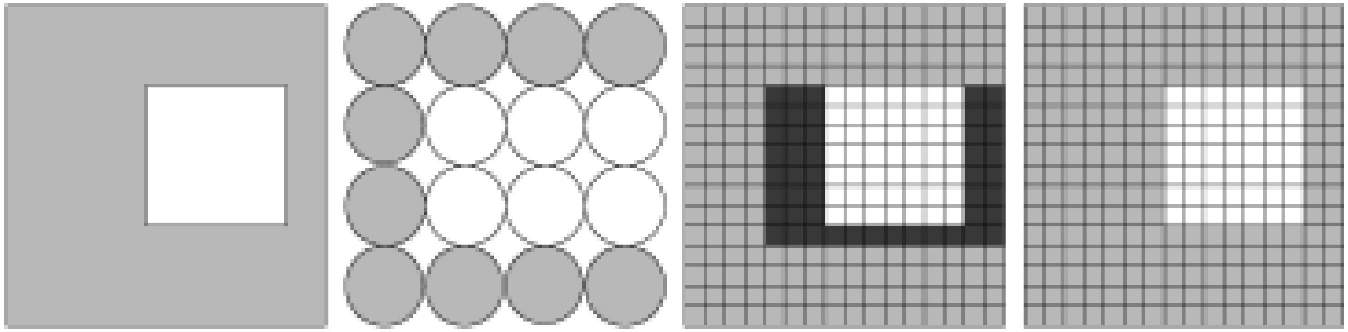
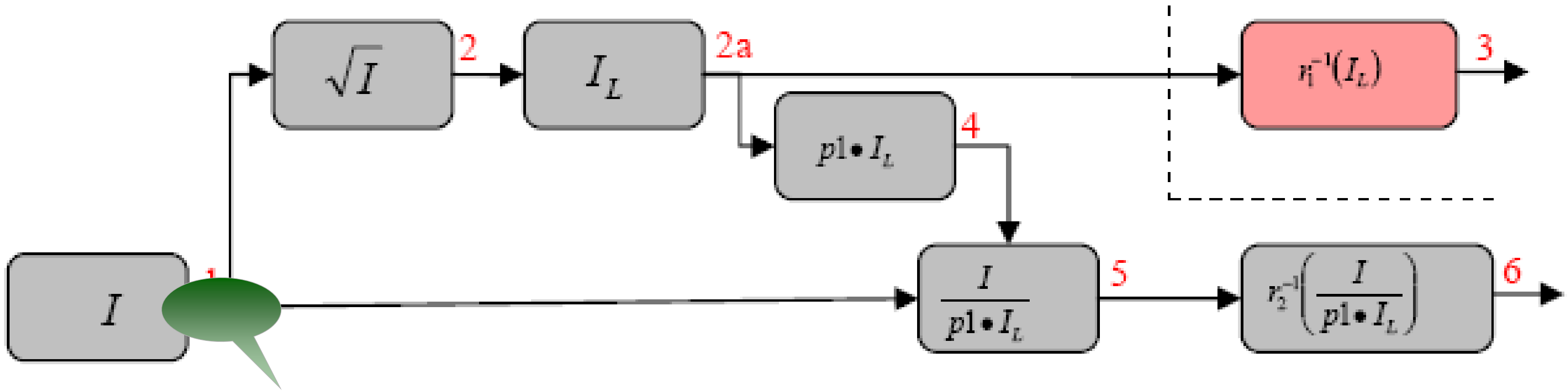
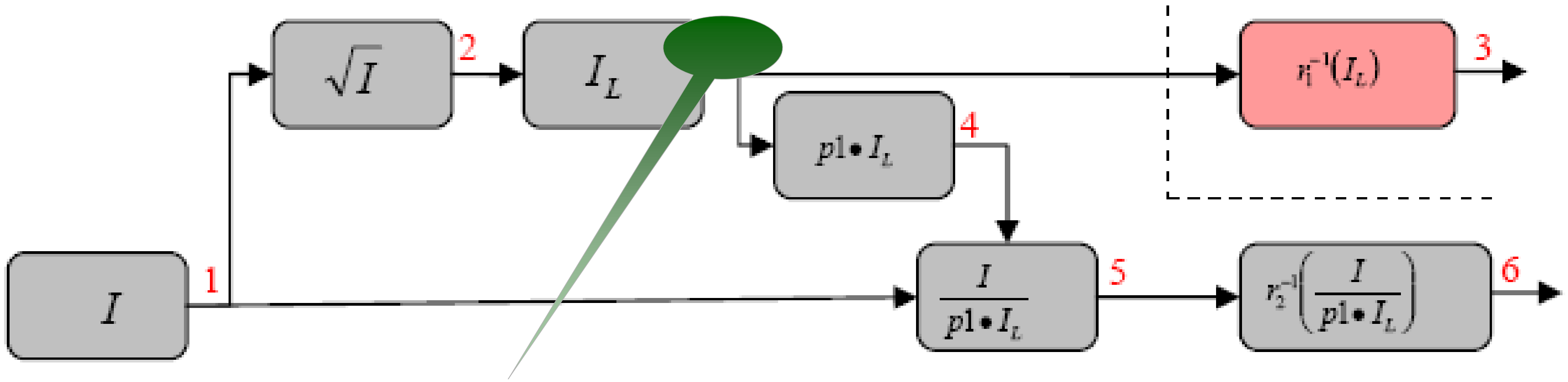


Figure 2. Composite Formation of HDR image. From left to right: Desired image, LED setting, LCD panel setting and final HDR image.

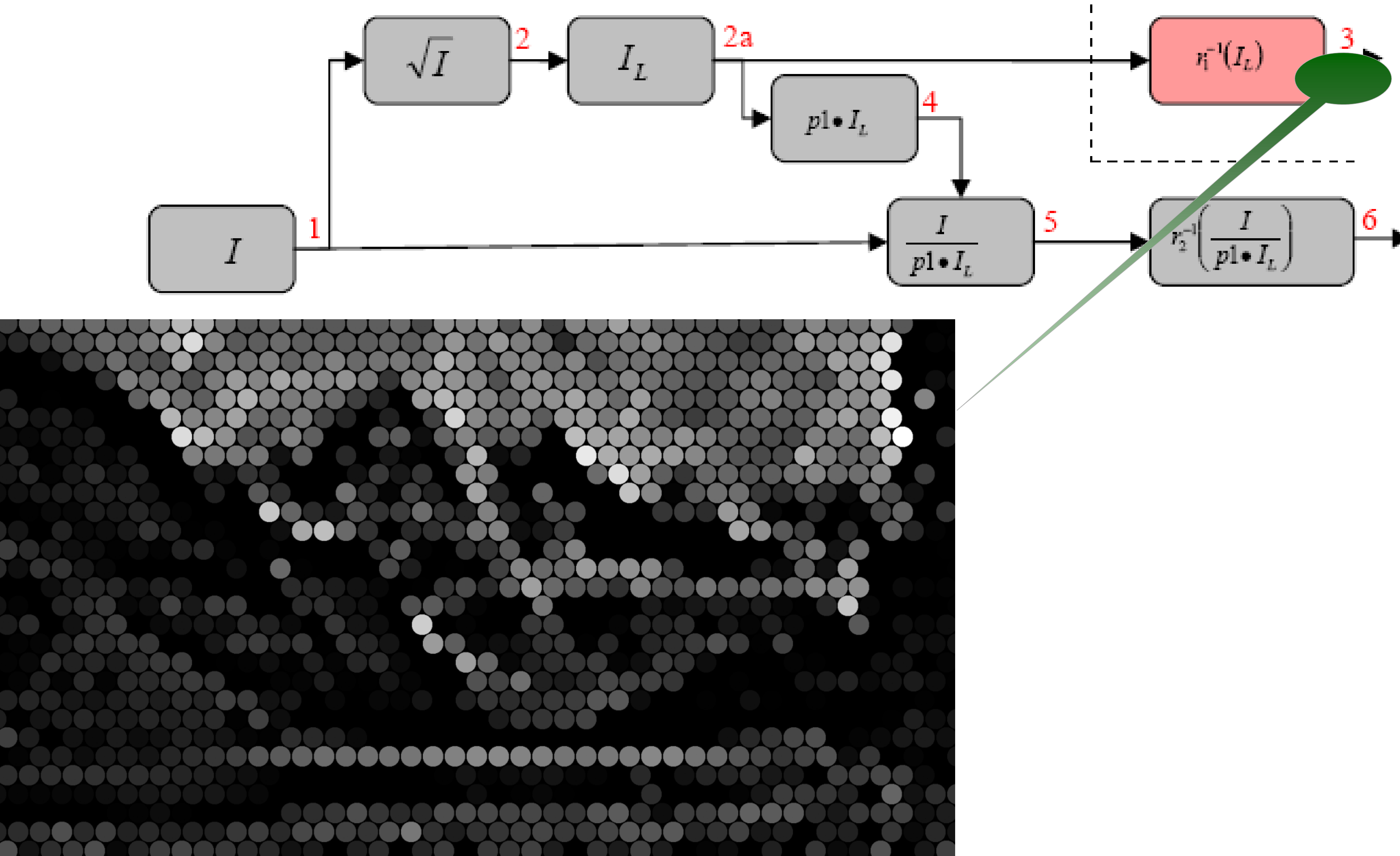
Modulated LED + LC displays



Modulated LED + LC displays

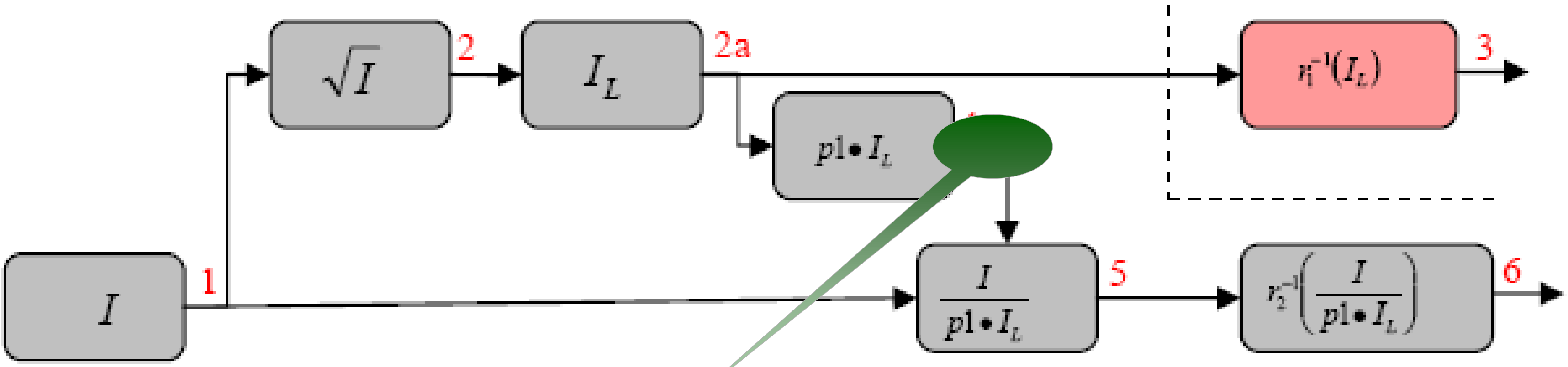


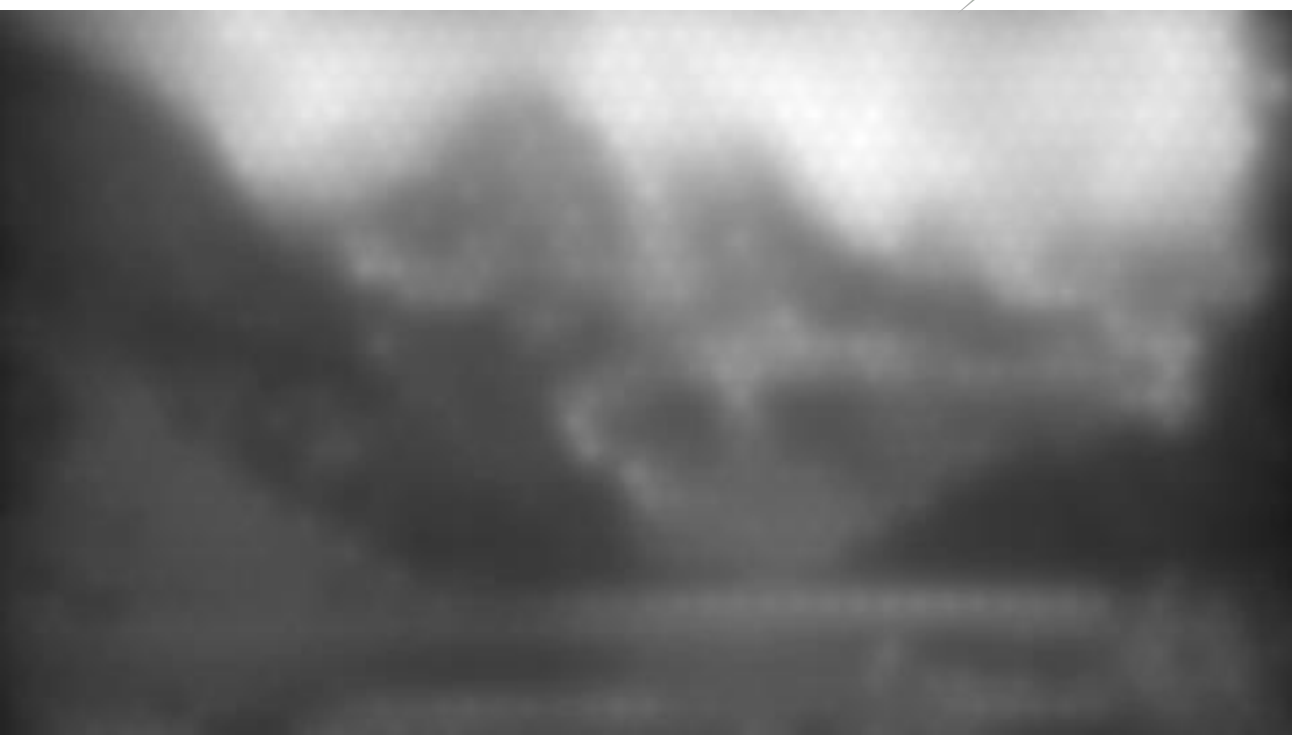
Modulated LED + LC displays



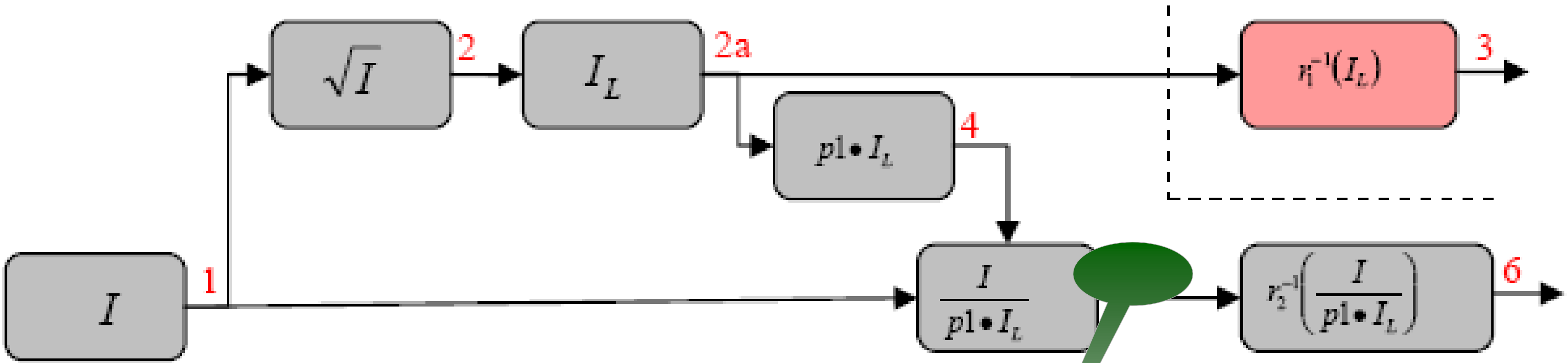
UNIVERSITÀ DEGLI STUDI DI TRIESTE

Modulated LED + LC displays





Modulated LED + LC displays



Modulated LED + LC displays

Prototypes and professional / hi-range-consumer products:

Dolby prototype 2014
- 1380 2.5Watt LEDs on hexagonal closepacking matrix, 256 lum. steps
- LCD panel: 37'', 250:1 simultaneous contrast, 1920 × 1080 resolution
- White box at center third of screen: max. measured lum. 4760 cd/m^2
- Black image: min. luminance is «zero».

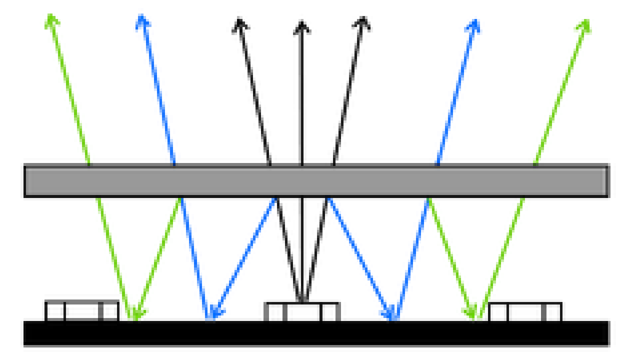


Fig. 1 Light leakage.

Mini-LED local dimming has similar technology
- 2023 Hisense 85'': 5,184 LED, max.lum. 2500 cd/m^2
- note: dimming used also in edge-lit panels

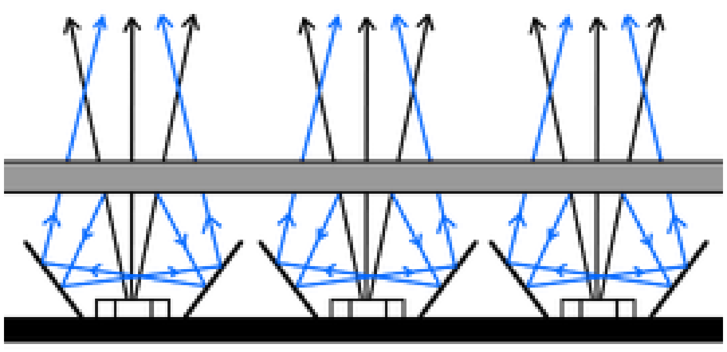


Fig. 2 LED reflectors schematic.

MicroLED displays do NOT use LC panels
→ see later

Quantum dot displays

17 JANUARY 2013 | VOL 493 | NATURE | 283

Live from your living room, in super-saturated colour: it's the quantum-dot TV! Researchers working with nanoscale fluorescent particles called quantum dots have long predicted groundbreaking achievements, such as ultra-efficient light-emitting diodes (LEDs) and solar cells, but the technology has found mainly niche applications. That could change with the announcement last week that QD Vision, based in Lexington, Massachusetts, would supply Sony Corporation of Tokyo with quantum dots for flat-screen televisions that will transmit more richly coloured images than other TVs on the market.

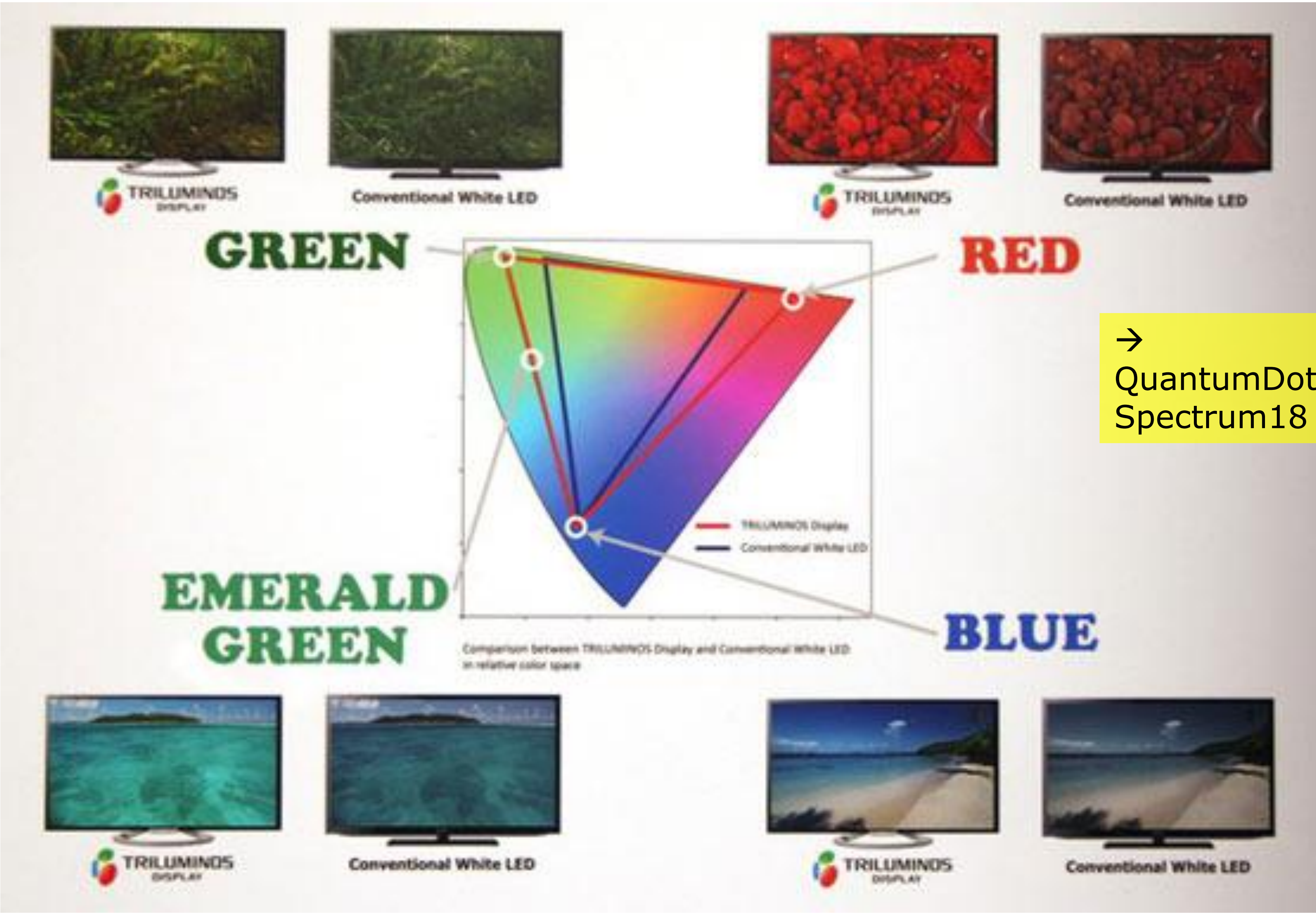
Demand for quantum-dot displays, say industry watchers, could benefit quantum-dot companies, bring down the price of these nano-materials and boost other applications that have stalled. "Displays are a potential market that could help quantum-dot companies find traction," says Jonathan Melnick, an analyst at Lux Research in Boston, Massachusetts.

Quantum dots are crystals about 10 nano-metres in diameter, made from a semiconductor material, commonly cadmium selenide. They are so tiny that their shape and size affect the quantum properties of their electrons, in particular their energy gap — the energy needed to kick electrons into a higher-energy band — which determines the colour of light that the material can emit. Whereas a bulk semiconductor is limited to emitting a single colour of light, researchers can tune the precise colour a quantum dot will absorb and re-emit by tailoring its size.

Discovered in 1981, quantum dots did not find applications until 2002. That was when the Quantum Dot Corporation of Hayward, California, began selling them to cell biologists, who prize them as fluorescent imaging labels for proteins and other biological molecules. As recently as 2010, the biomedical sector was responsible for US$48 million of $67 million in total quantum-dot revenues, according to BCC Research of Wellesley, Massachusetts.

Quantum dots have shown promise for electronics, too — for example in solar cells, in which a mix of quantum dots tuned to absorb different wavelengths of light could capture more of the energy in the solar spectrum. But one hurdle to their exploitation was their temperature sensitivity. Near the backlight of a liquid-crystal display (LCD), for example, temperatures can be around 100 °C. At this temperature, the dots lose efficiency and up to half

Quantum dot displays

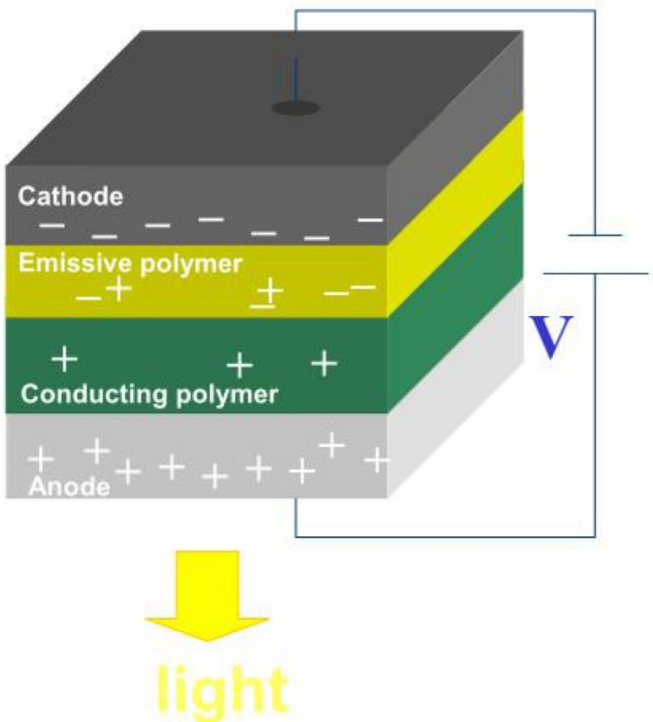


→ QuantumDot_Spectrum18

OLED Device Operation Principles

→ disp_amoled.pdf

(also about active matrix addressing and QD + OLED)



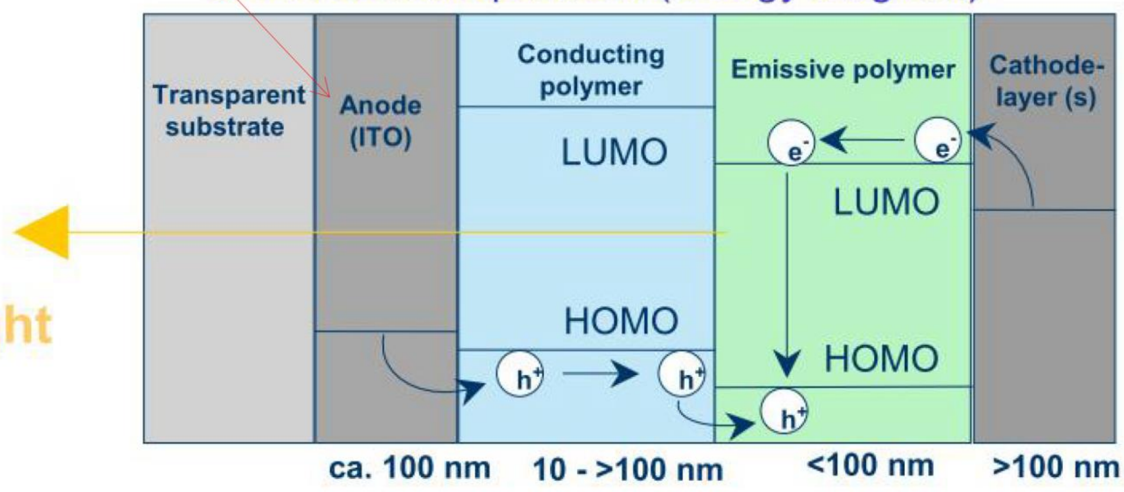
OLEDs rely on organic materials (polymers or small molecules) that give off light when tweaked with an electrical current

- Electrons injected from cathode
- Holes injected from anode
- Transport and radiative recombination of electron hole pairs at the emissive polymer

Indium Tin Oxide

HOMO: highest occupied molecular orbital
LUMO: lowest unoccupied molecular orbital

OLED device operation (energy diagram)



iat is the Retina Display. Awesome text, awesome images, and awesome video." -- *Apple CEO Steve Jobs*
'hone 4's new screen, Apple Worldwide Developers Conference, June 7 2010

iPhone 8+ (2017) [last IPS LCD]
5.5 in, 1920 x 1080 (16:9), 401 ppi
1300:1 contrast ratio
625 cd/m2 max brightness

-------- OLED displays --------

iPhone X (2017)
5.8 in, 2436 x 1125 (19.5:9), 458 ppi
1M:1 contrast *[disregarding diffuse-reflected ambient light]*

iPhone 15 Pro Max (2023)
6.7 in, 2796 x 1290 (19.5:9), 460 ppi
1600 cd/m2 peak brightness, 2000 cd/m2 (High Brightness Mode HBM),
2M:1 contrast,
120Hz, HDR10, Dolby Vision
[Back cameras:
3: main, wide, tele x5 with prisms
1: ToF (with LiDAR scanner)]

For VR headsets: (Oculus) Meta Quest 3 (**LCD**) – May23, **rem. updating Oct**
No specs about resolution or refresh rate were revealed, but we could expect a resolution of **4,128 by 2,208** pixels (2,064 by 2,208 per eye). The refresh rate will almost certainly start at 120Hz out of the box, but we'd not be surprised if the Quest 3 pushed to 144Hz
Mixed-reality with color passthrough, which means you can see the real world around you in full color through the headset, rather than in monochrome as is the case with Sony's PlayStation PSVR 2.
No eye-tracking, i.e. no PSVR 2 foveated rendering for the things you're focused on and lowering the fidelity in peripheral vision to reduce the strain on the GPU.

MicroLED displays

Strongest competitor for OLED for large displays

See z04_MicroLED xxxxx

More colour, more contrast

Dolby Vision approach https://www.dolby.com/technologies/dolby-vision/

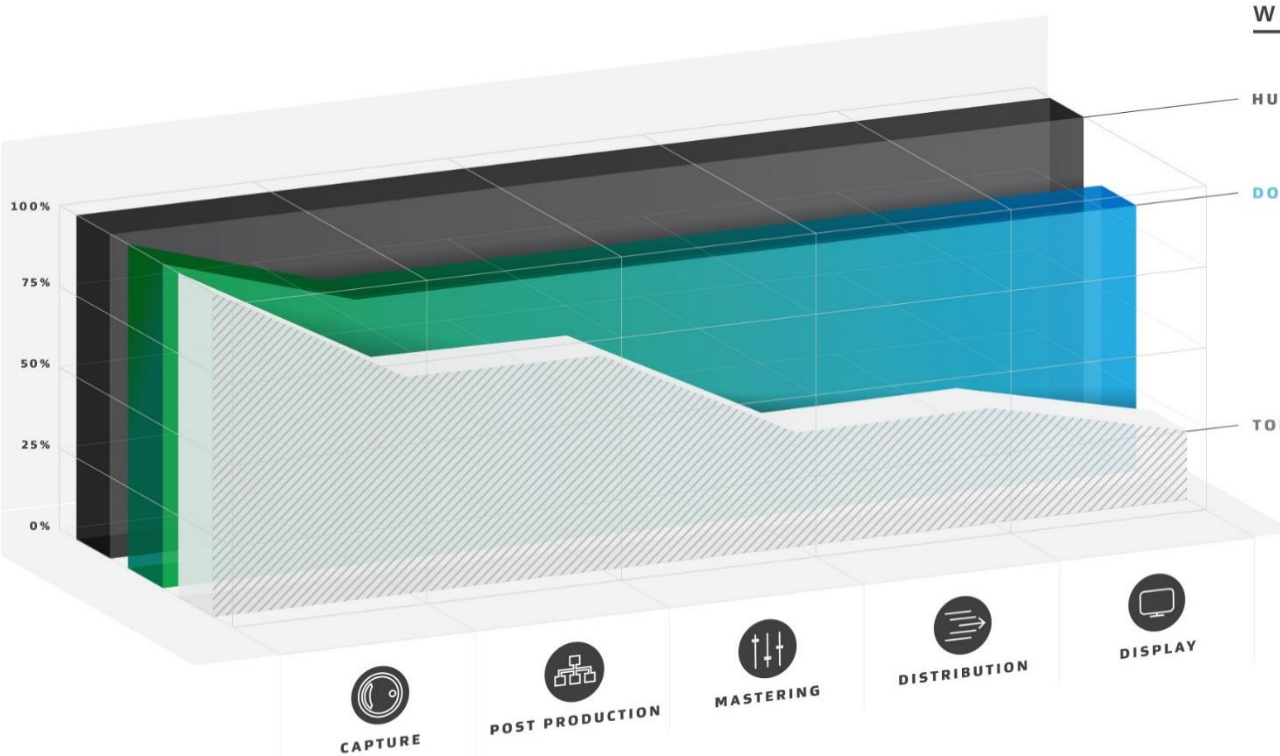
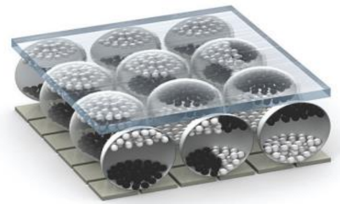


Figure 1 - Experimental HDR Display

→ Dolby16_UnifiedApproach.pdf
→ HDR10_Ecosystem.pdf

More…

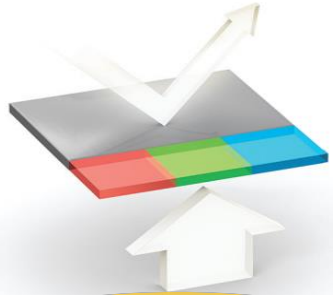
(as per predictions made in 2010)



ELECTROPHORETIC PIXEL

Black and white pigment particles with opposite charges migrate inside capsules, depending on the applied voltage.

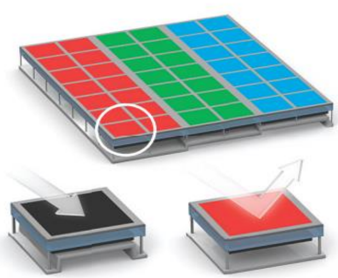
PRO Is simple to produce.
CON Slow switching limits video capability; full color is dim.
WHO E Ink
STATUS Available now



3QI MULTIMODE

This LCD variant both reflects and transmits light.

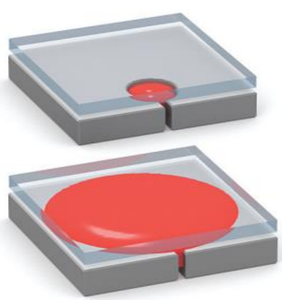
PRO Consumes minimal power and is visible indoors and out.
CON Brightness and color saturation are both compromised.
WHO Pixel Qi
STATUS Expected to ship this year



MIRASOL

A MEMS device moves a membrane to and from a stack of optical films, changing the wavelength of the light reflected.

PRO Has crisp, fast video, low power consumption, and visibility in sunlight.
CON Is expensive to produce; white is a challenge.
WHO Qualcomm
STATUS Available in small screen sizes



ELECTROFLUIDIC PIXELS

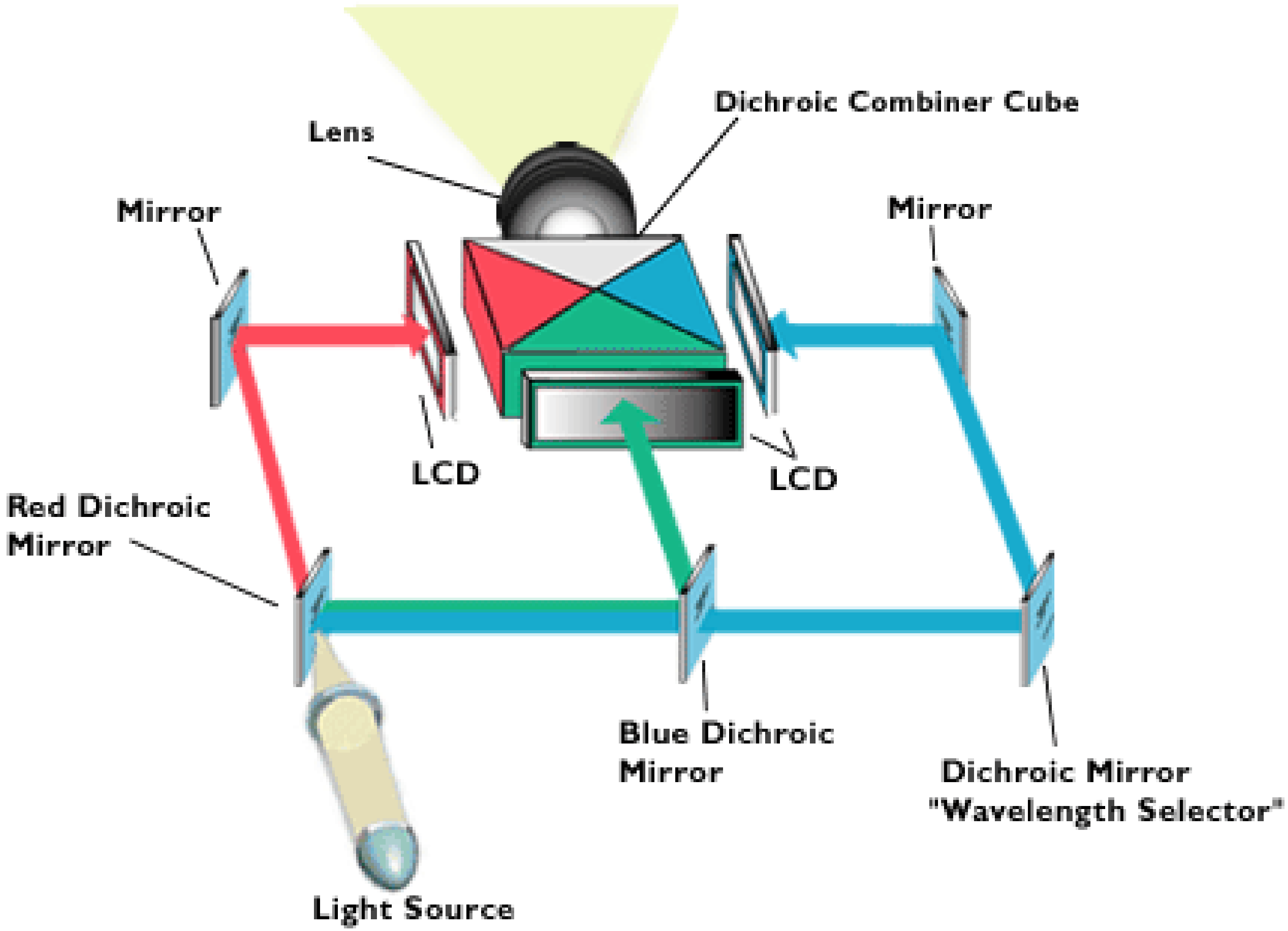
Voltage pulls an inklike fluid out of a small reservoir and into view.

PRO Materials and mechanism are similar to ink on paper; switches fast enough for video.
CON Coming late to the race.
WHO Gamma-Dynamics/University of Cincinnati
STATUS In laboratory

EMILY COOPER

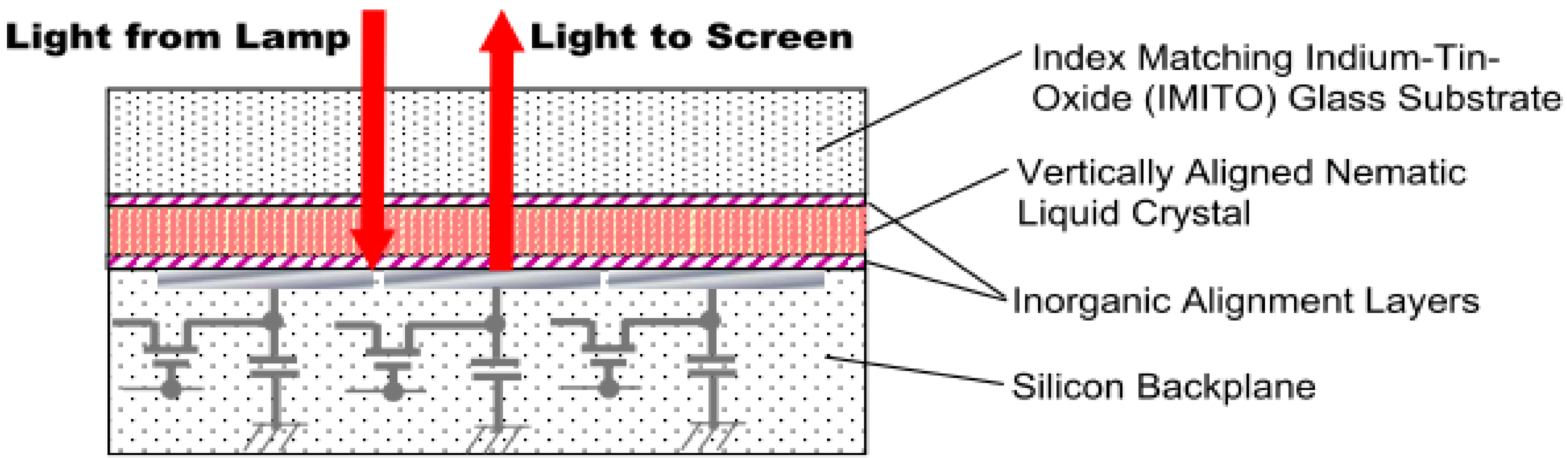
→ e-ink.pdf
→ electrowetting.pdf

Projectors: LCD



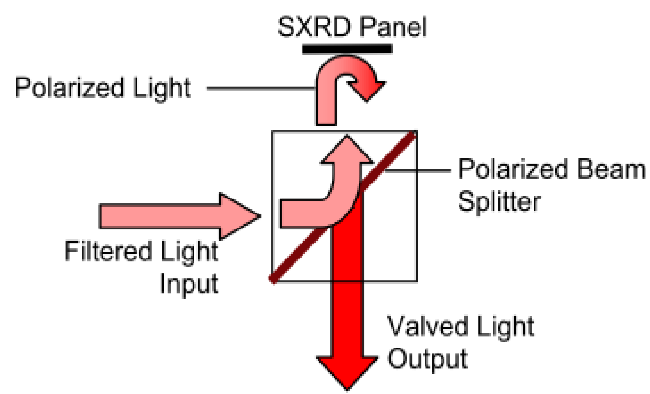
Projectors: LCoS

Liquid Crystal on Silicon
(Sony: SXRD, Silicon X-tal **Reflective** Display)

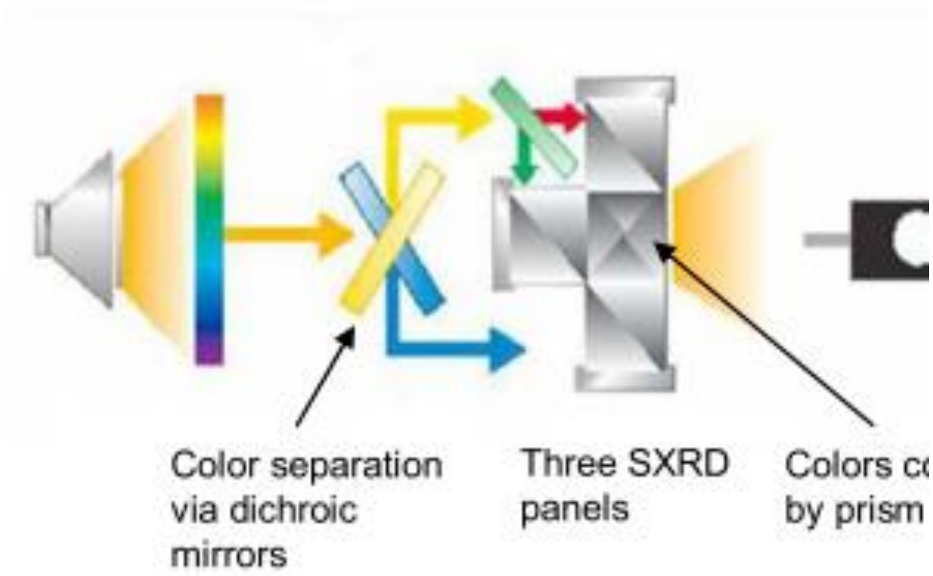


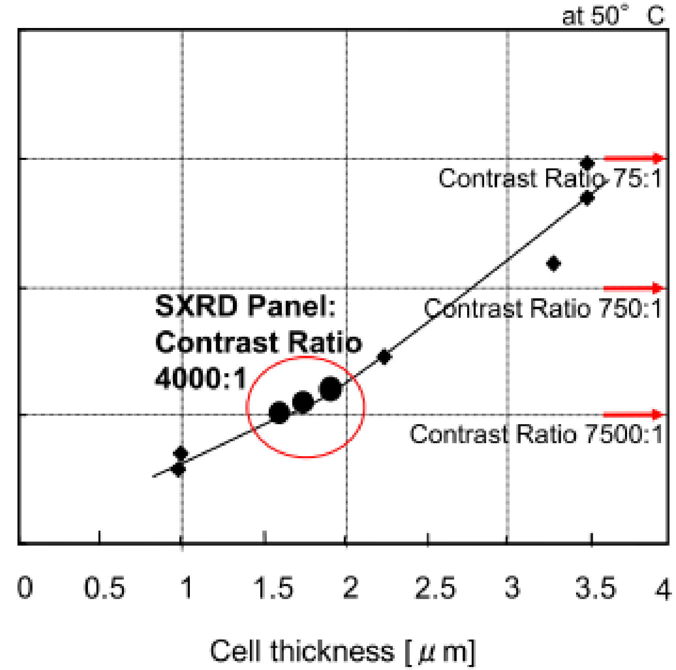
In the SXRD panel, light from the lamp enters through the glass substrate at the top, passes through the Liquid Crystal layer, reflects off the mirrored surface of the Silicon backplane, then passes out through the Liquid Crystal, toward the screen.

- Polarization is managed by splitters → no films on the LC
- LC is traversed twice by light → can be thin → fast
- High aperture ratio → efficient

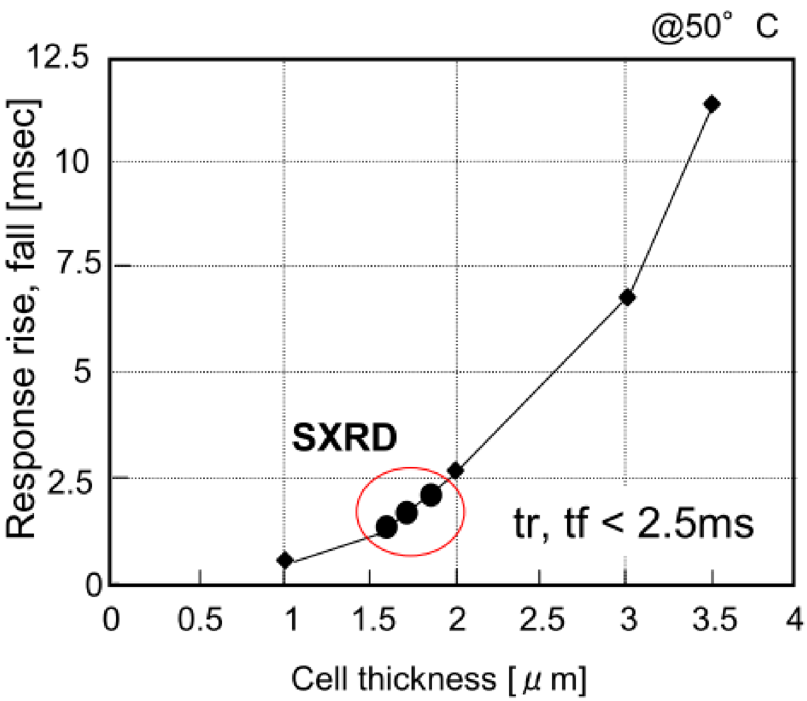


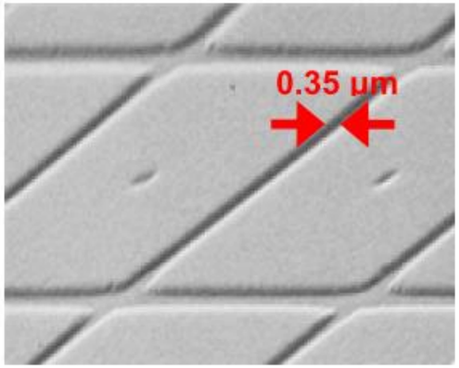
Projectors: LCoS





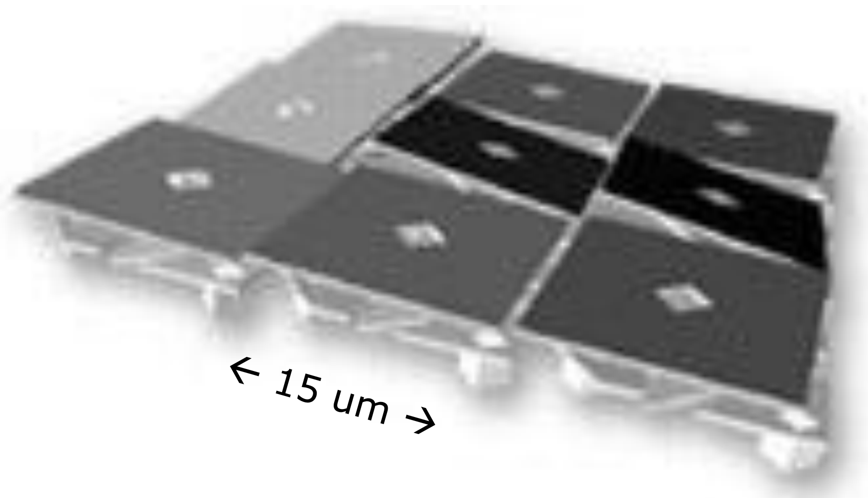
Note (like dual layer): CR forward = CR backward = 0.9/0.2=4.5; CR total = 0.81/0.04=20.

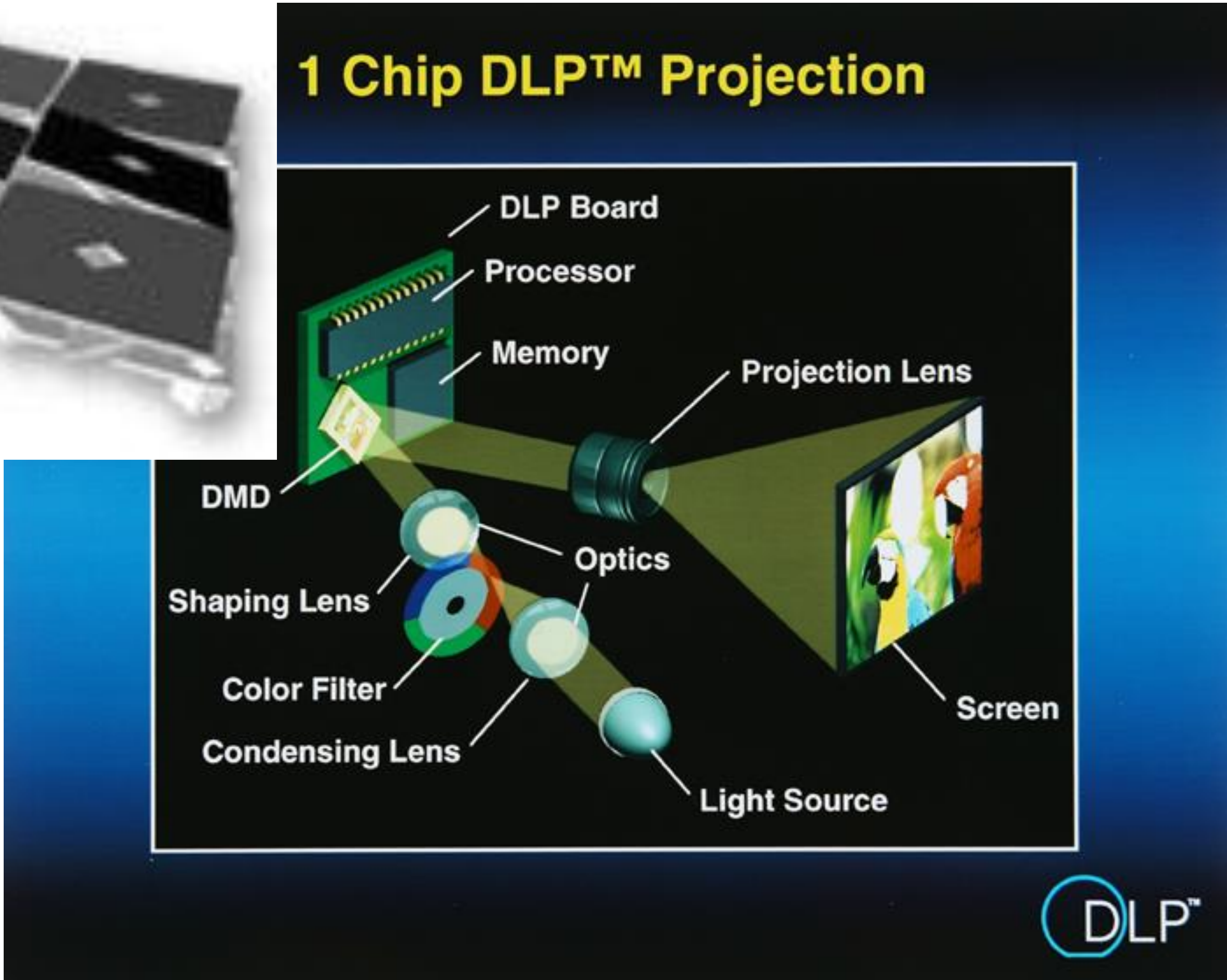




Aperture ratio 92%

Projectors: Digital Light Processing





Projectors: wobulation

→ z04_wobulation

Building a 4K projector using an HD DMD

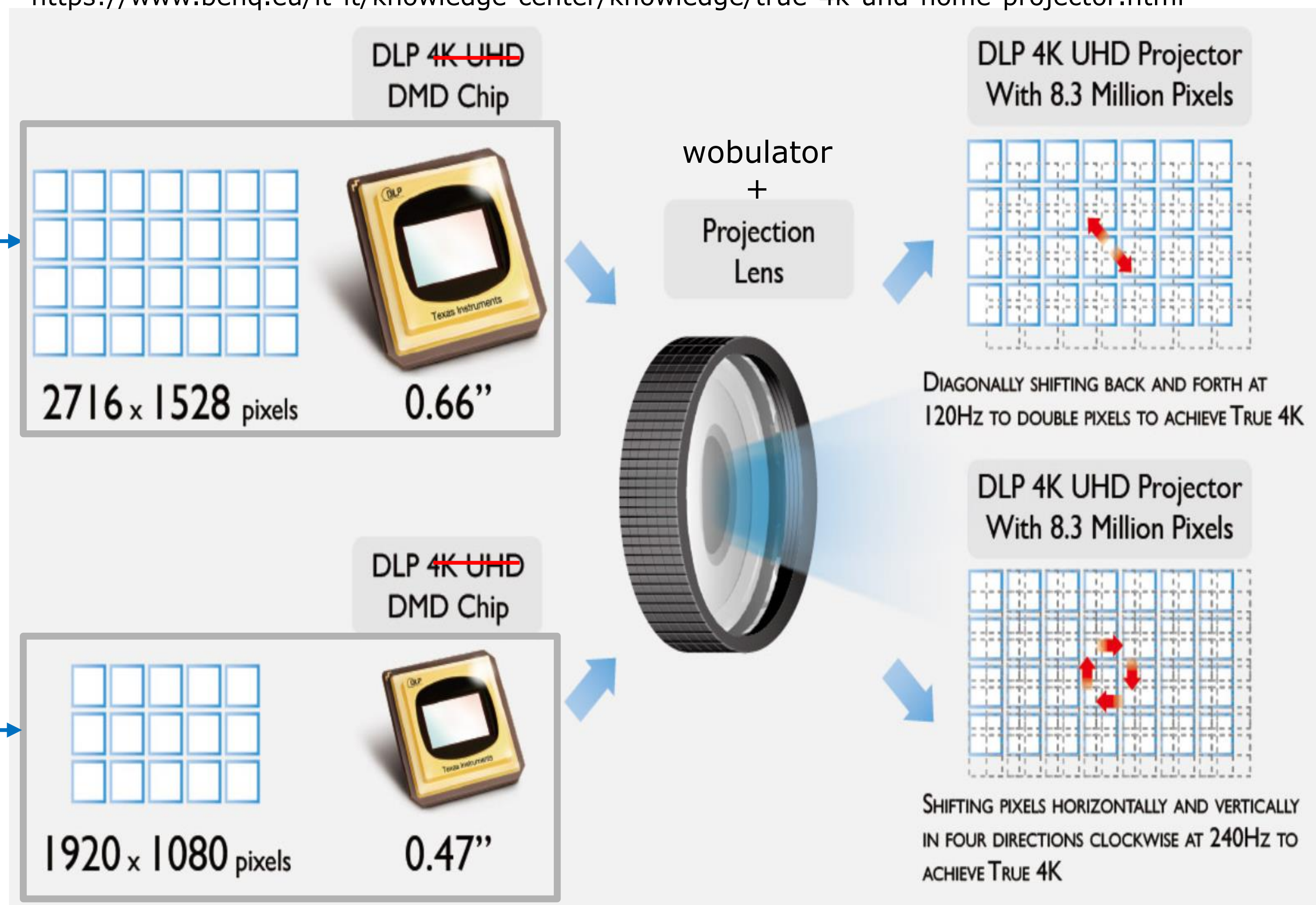
- 2022 Epson LS12000 4K PRO-UHD "Precision Shift Glass Plate Technology"
- Benq "True 4K Technology"

https://www.benq.eu/it-it/knowledge-center/knowledge/true-4k-uhd-home-projector.html

generate two 3840/√2 x 2160/√2 subframes

3840x2160 input image

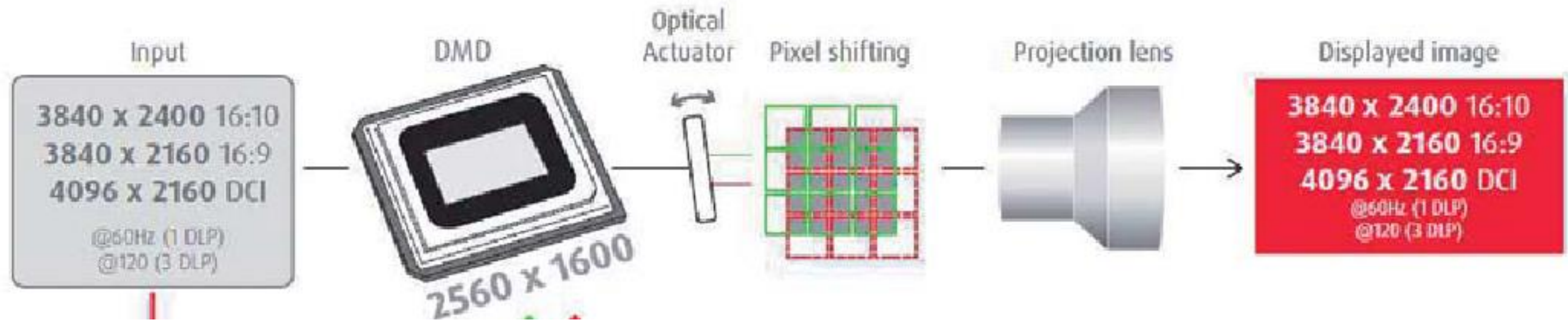
split into four 1920 x 1080 subframes



Projectors: wobulation

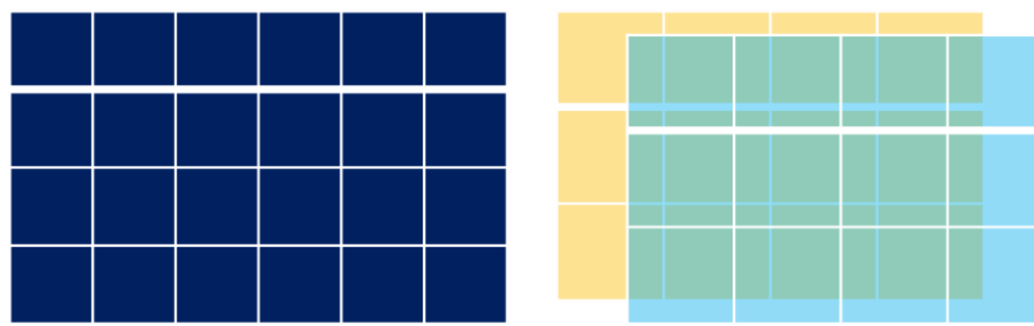
(Barco Medea series)

https://www.sistemi-integrati.net/wp-content/uploads/2019/08/Loki-DLP-UltraHD-4K.pdf



Each 4K [3840 x 2180] frame is decimated by √2 into two subframes, 3840/√2 x 2160/√2 = 2760 x 1414, with offset {0,0} and {1,1} respect.

e.g. a 10x16 block = 160 px becomes two 7x11 blocks = 154 px



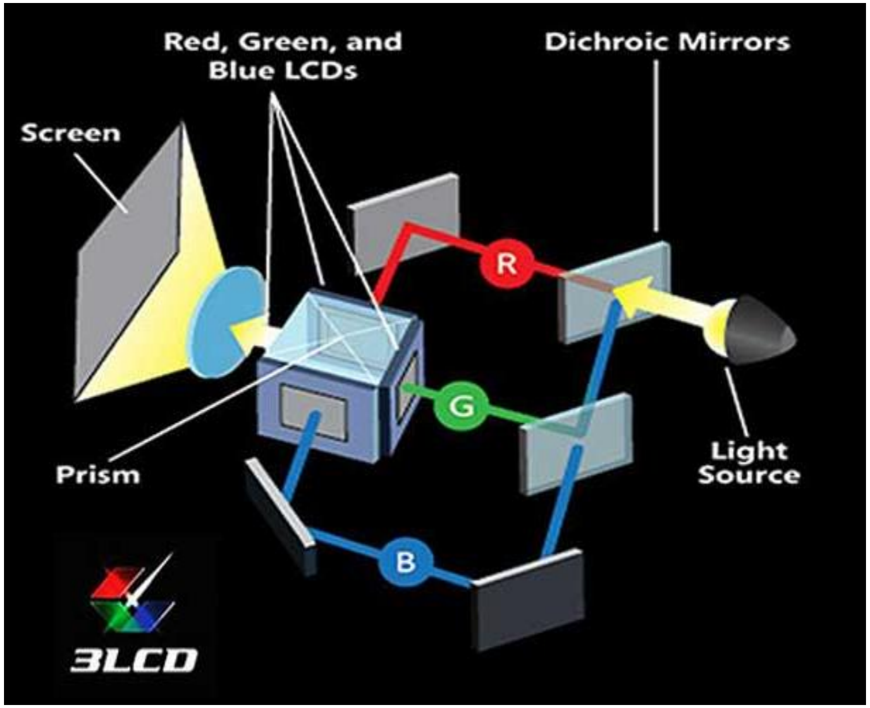
Subframes are sequentially projected to two diagonally tilted positions

Projectors: light sources

From vintage metal-halide lamps

to
LED PICO projectors

to
Discrete RGB LED light engines

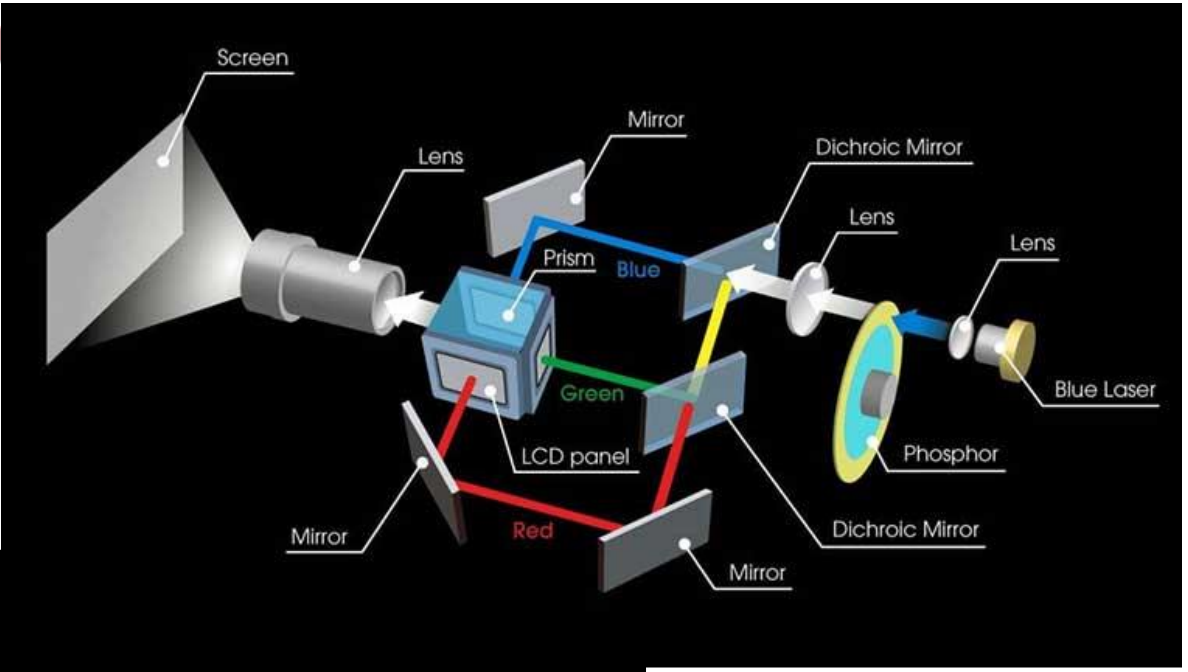


- Up to 20,000 hours
- Mercury-free
- Up to 3500 lumens of light output
- High-speed LED switching takes the place of color wheel → higher frame rate
- noise is reduced and reliability is increased

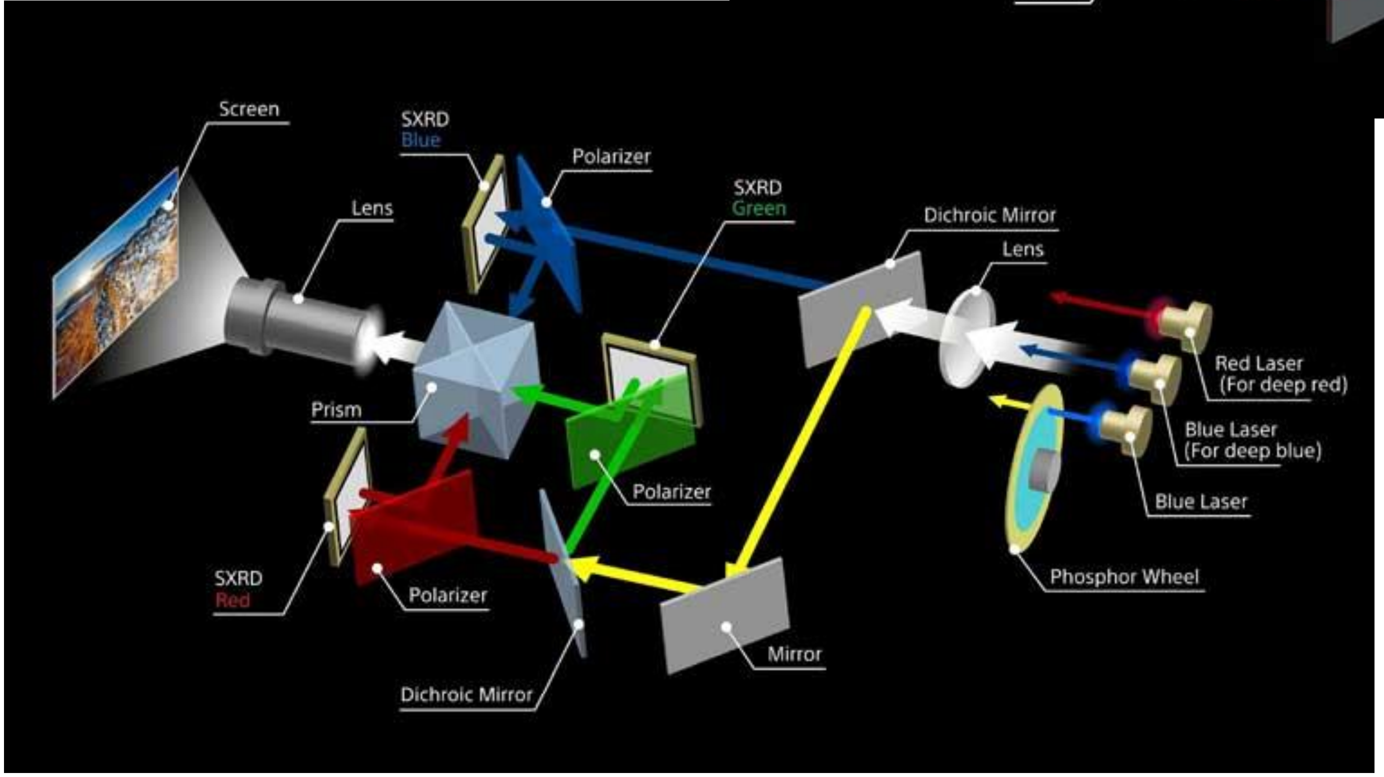
Projectors: light sou

Laser-based sources:

Laser phosphors



Hybrid laser

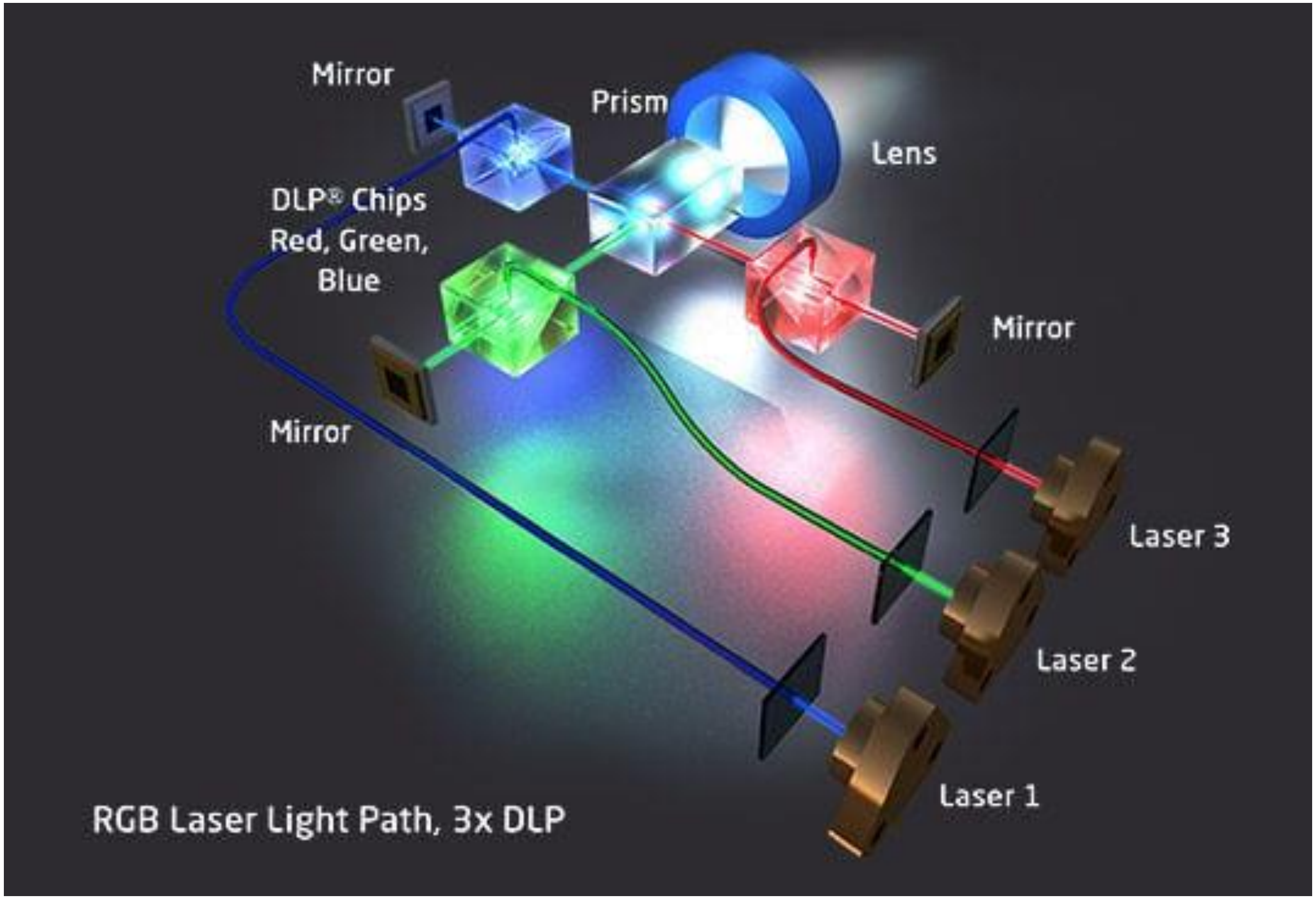


Projectors: light sources

Laser-based sources:

Discrete RGB Laser

(external lasers connected via optic fibre)



Digital Cinema Projectors

→ Barco (see specs.)

* Free-space coupled laser source (i.e. no fiber coupling)
* Semiconductor lasers:
    * blue and red are direct diodes
    * green is frequency converted IR laser diode
* Wavelengths: 460 nm for blue, 532 nm for green and 637 nm for red. Resulting colour gamut completely encompasses DCI colour gamut.
* The power of the lasers is white-balanced to standard D63 white point.
* Optical architecture: 1.38" 4K DMDs, color splitting prism.
* Low Speckle

    [Interference is always generated in light waves which hit object features (optical fibers, screen) having size close to wavelength → Light sourced by a laser is coherent → highly correlated → spatially and temporally stable interference → SPECKLE NOISE]

→ SHARP/NEC (see specs.)

Performances

Comment:
«Display manufacturers often distort the calculation of dynamic range, e.g. altering room illumination between measurements»
«... or mixing up *static* (spatial) and *dynamic* (temporal) contrast values»

Try our handheld spectrometer

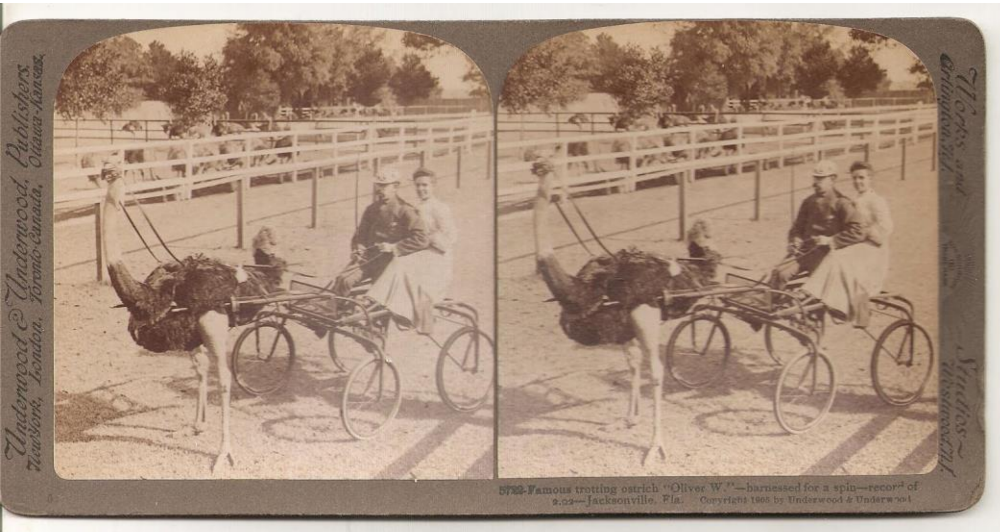
White paper, direct sunlight: 18900 *cd/m^2*
White paper, outdoor, sunny: 1630 *cd/m^2*
Dark objects, outdoor, sunny: few tens *cd/m^2*
Dark objects, indoor, natural light: few *cd/m^2*

LCD Display, indoor, white: 269 *cd/m^2*
LCD Display, indoor, black: 1.92 *cd/m^2*
LCD Display, indoor, off: 1.15 *cd/m^2*

DLP projector, dark indoor, white (100”): 57.9 *cd/m^2*
DLP projector, dark indoor, black: 0.05 *cd/m^2*
Projection screen, indoor, natural light 39.7 *cd/m^2*
-- Bad case dynamic range: (57.9+39.7) / (0.05+39.7) = 2.5

DLP projector, dark indoor, white (69”) 183 *cd/m^2*

3-D


Underwood & Underwood, Publishers,
New York, London, Toronto-Canada, Ottawa-Kansas.
Famous trotting ostrich "Oliver W."—harnessed for a spin—record of 2.02—Jacksonville, Fla.
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State of the Art in Stereoscopic and Autostereoscopic Displays

Hakan Urey, Senior Member IEEE, Kishore V. Chellappan , Erdem Erden, Student Member IEEE , and Phil Surman

Proceedings of the IEEE | Vol. 99, No. 4, April 2011

→ Displays_3D_Urey11.pdf

Looking glass light field display - see Urey

https://newsroom.accenture.com/news/accenture-invests-in-looking-glass-to-accelerate-shift-from-2d-to-3d.htm

Apple Vision Pro (not yet available)

Has *passthrough* function to see surroundings
OLED, 24 Mpix ?? I.e. e.g. 3k x 4k / eye