UNIVERSITY OF CAMBRIDGE

Solid State Devices

4B6

Lecture 13 – Projection and 3D displays: LCD, DLP and LCOS

Daping Chu

Lent 2016

Development of flat panel displays (FPDs)

Liquid crystal display (LCD) in early days

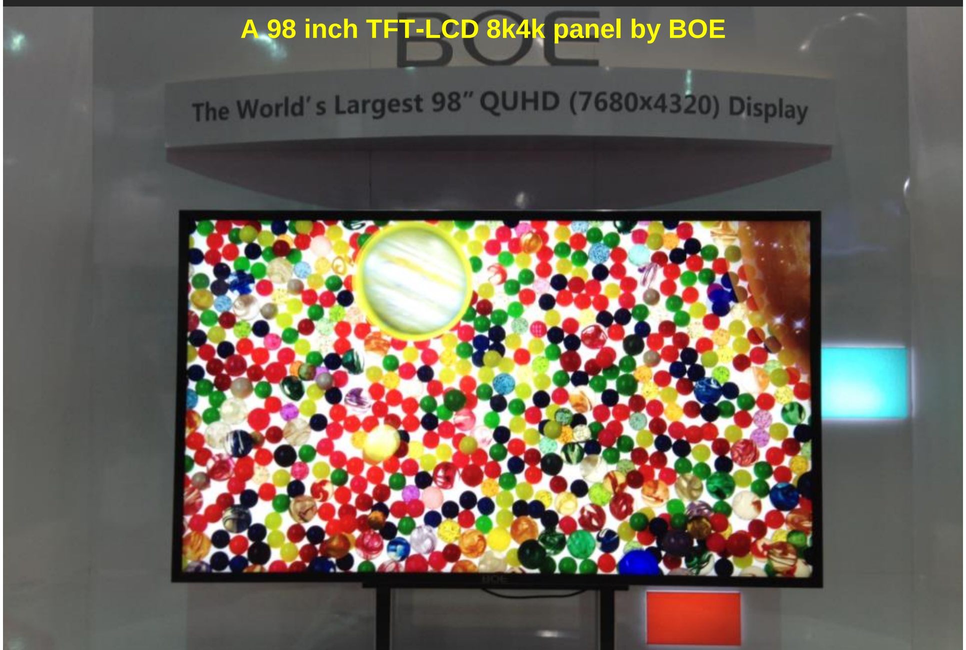
A 105 inch TFT-LCD 4k2k curved panel by Samsung

January 2014

A 105 inch OLED 3k2k curved panel by LG

January 2014

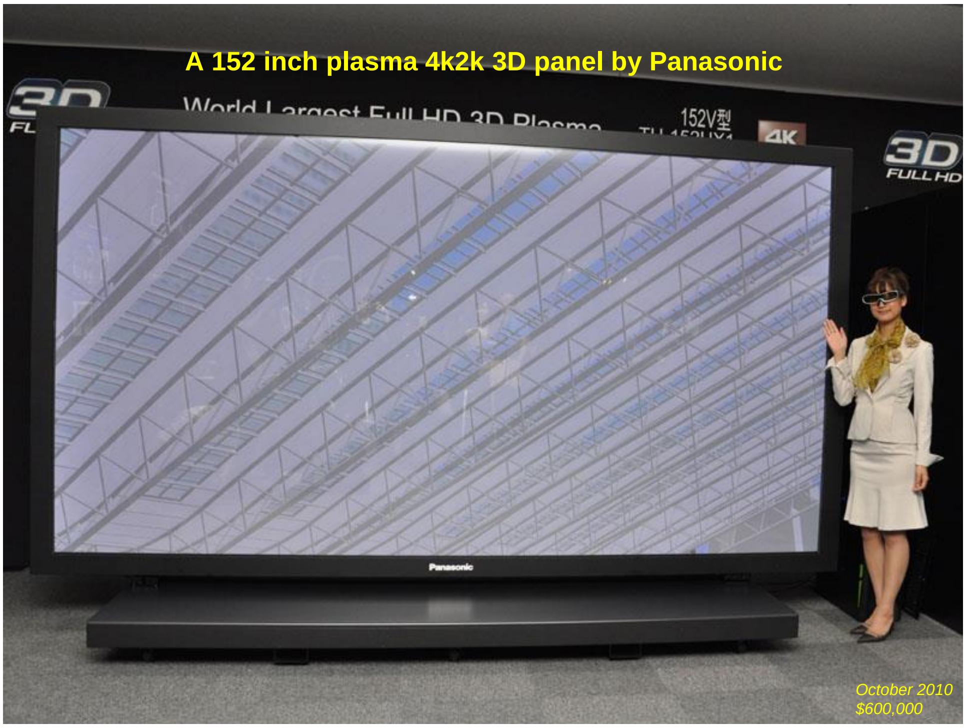
A 98 inch TFT-LCD 8k4k panel by BOE



March 2014

An 18in OLED rollable panel by LG

January 2016

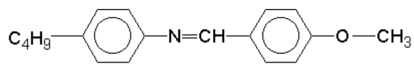

A 152 inch plasma 4k2k 3D panel by Panasonic
152V型
3D
FULL HD
Panasonic
October 2010
$600,000


How large can a FPD go – is sky the limit?

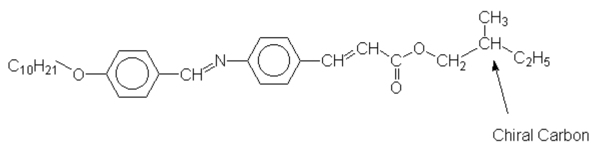
Liquid crystal display

Typical liquid crystal molecules

A Chemist's view:

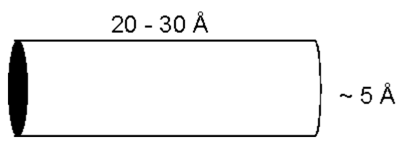


Methoxybenzilidene Butylanaline ("MBBA")



p-decyloxybenzylidene p'-amino 2-methylbutylcinnamate ("DOBAMBC")

A Physicist's view:



Liquid crystal display

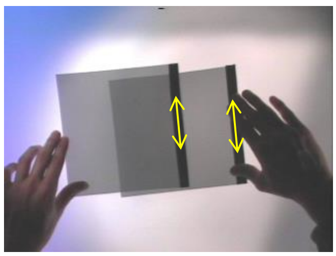
Some liquid crystal phases

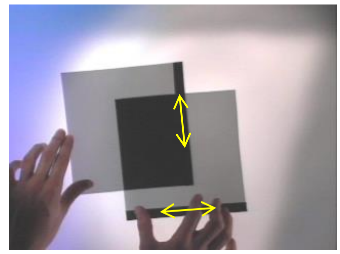
Isotropic Nematic Smectic A

External electrical field can induce dipoles in liquid crystal molecules, resulting their alignment. Some liquid crystal molecules may even have a ferroelectric phase. For example, the chiral nature of DOBAMBC permits the molecule to exhibit a "ferroelectric phase". The size of the polarization and the response of the molecule to an applied voltage depends on the chemical structure of the molecule, largely the carbonyl [C=O] group near the chiral carbon.

Liquid crystal display

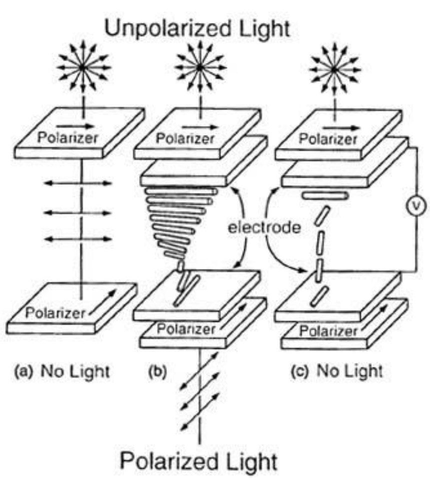
Polarising filters

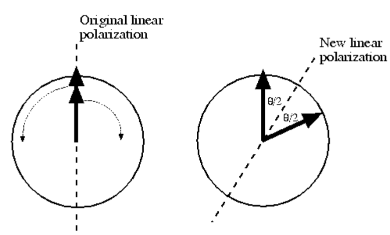




Liquid crystal display

Effect of twisted nematic liquid crystal



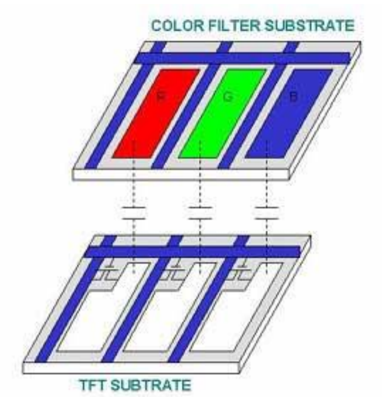


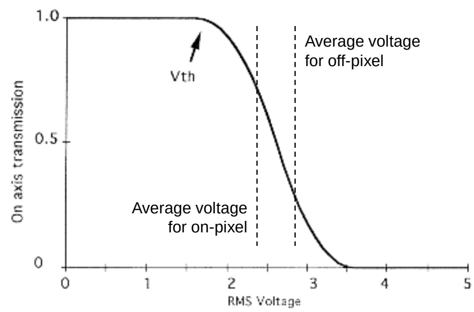
After 1st polarizer Through liquid crystal

The two arrows represent the directions of the polarisations of the components of left and right circularly polarized light at a particular point in time. After passing through the liquid crystal, the two components sum to create linear polarization in a different direction, resulting in a non-zero emission from the 2nd polarizer.

Liquid crystal display

Colour and intensity adjustment

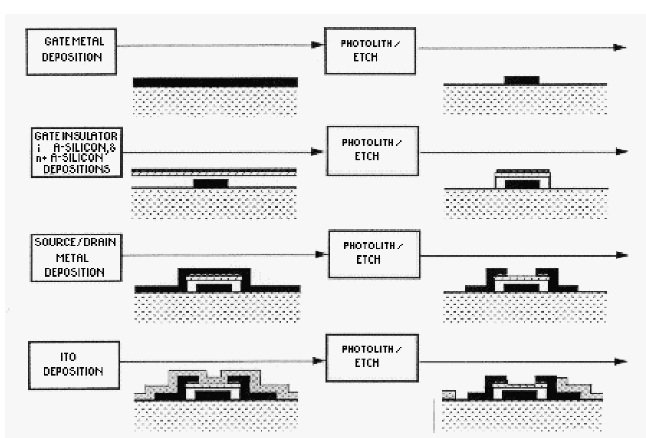




Response curve of a twisted nematic LCD cell. The range of voltage (and therefore brightness) felt by on and off pixels is much less than the full range possible.

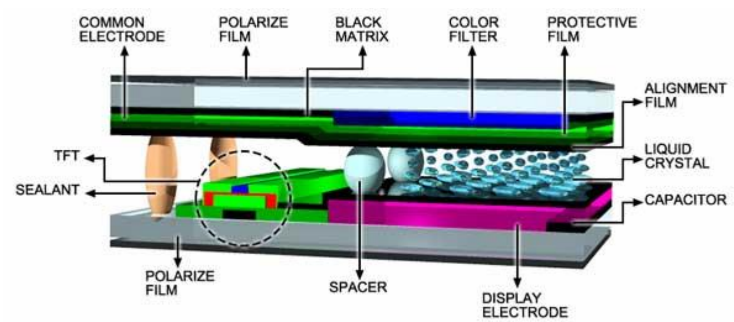
Liquid crystal display

Fabrication of amorphous Si TFT pixel transistor



Liquid crystal display

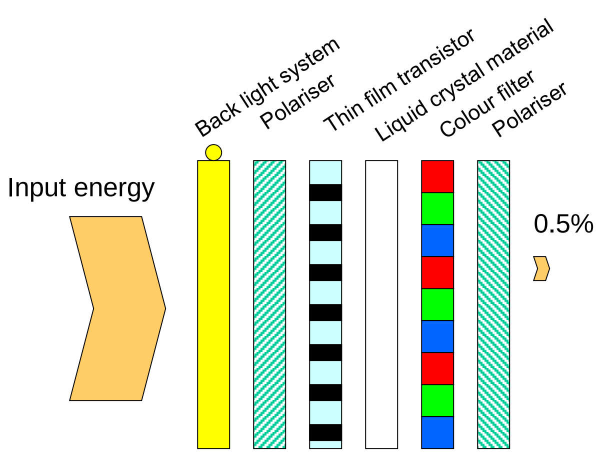
Cross section of a TFT-LCD cell



Liquid crystal is filled into the gap between bottom TFT substrate and top colour filter substrate using fast vacuum filling process.

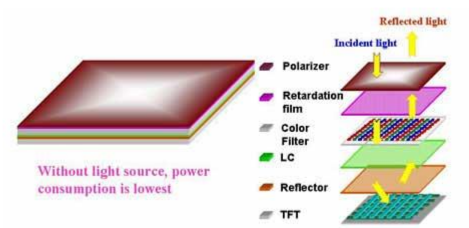
Liquid crystal display

Energy efficiency

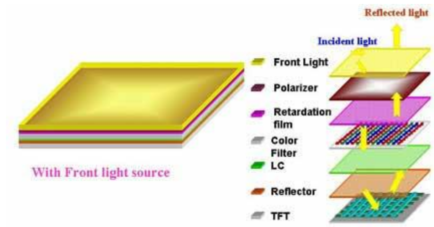


Liquid crystal display

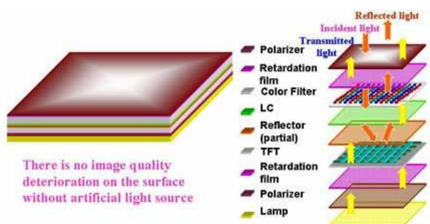
Different types of LCDs



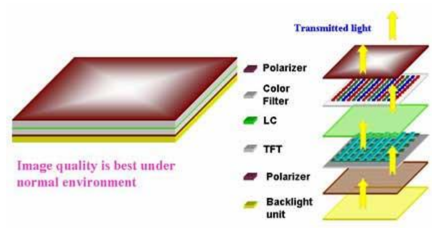
Reflective TFT-LCD with internal Diffuser



Reflective TFT-LCD with Front Light



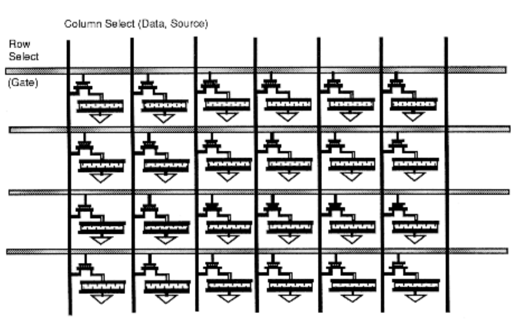
Trans-Reflective TFT-LCD



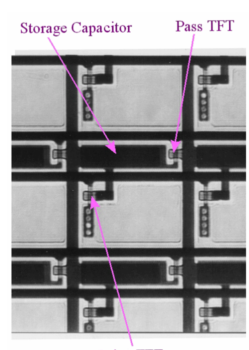
Transmissive TFT-LCD

Liquid crystal display

Active matrix TFT-LCD

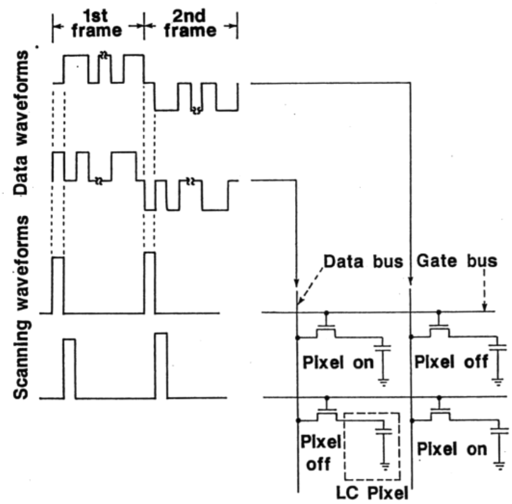


As liquid crystal material is dielectric in nature, each LCD cell has the property of a capacitor under external bias.



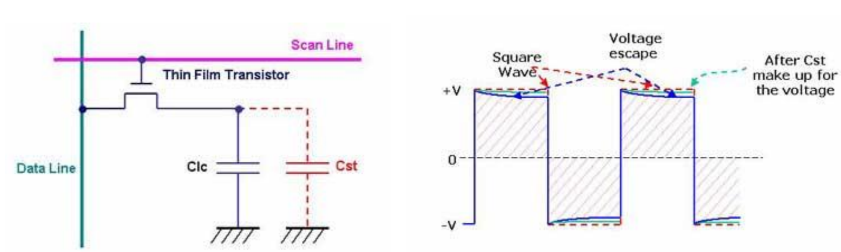
Liquid crystal display

Driving AM-LCD



Liquid crystal display

Effect of storage capacitor

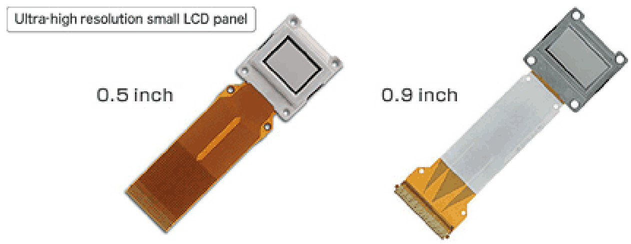


Actually liquid crystal should be driven by AC voltage. For active LCD, the voltage is only supplied in the state when switch turning on, then the switch turns off immediately. In some cases, the liquid crystal voltage will fall due to voltage leakage, stage by stage. To avoid this situation, we can use one parallel storage capacitor to make up for the leakage voltage. The larger the capacity of Cst is, the closer the voltage waveform will be to the square wave.

Liquid crystal display

HTPS LCD panels

HTPS is an abbreviation of High Temperature Poly-Silicon, an active matrix transmissive LCD. It's superior in that it is smaller in size, has higher resolution and higher contrast, and can embed drivers on panel. The main function of HTPS is as a light valve for projectors.

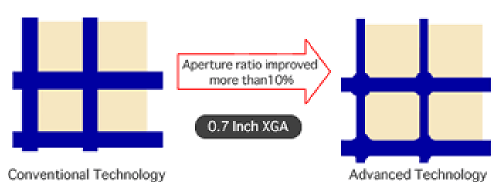


HTPS has a thin-film transistor (TFT) generated by poly-silicon in each pixel. These pixel transistors act as a conduction switch by changing the scan line's voltage. They are produced in the same way as semiconductors. They are small and highly reliable because they can easily be miniaturized (pixelation or high open area ratio) and drivers can be generated on substrates by processing at a high temperature.

Liquid crystal display

High brightness – Aperture ratio

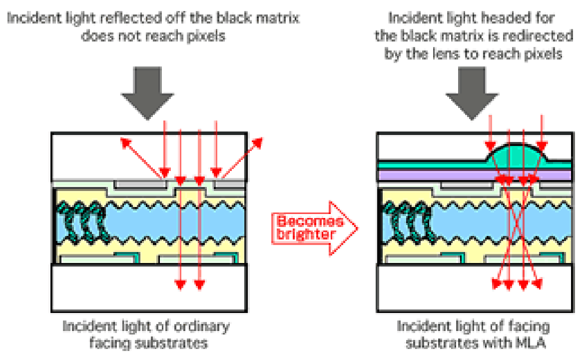
The aperture ratio is between the transparent area and the whole pixel area, excluding the pixel's wiring area and the transistor area (they are usually hidden by a black matrix). The higher the aperture ratio is, the more efficient the light penetrates the panel.



The use of micro fabrication technology in HTPS and optimisation of the wiring and element design can improve the open area ratio by reducing the black matrix area, increasing the projector's luminosity. For example, the aperture ratio is improved by more than 10% with the 0.7 inch XGA (1024 x 768 pixels).

Liquid crystal display

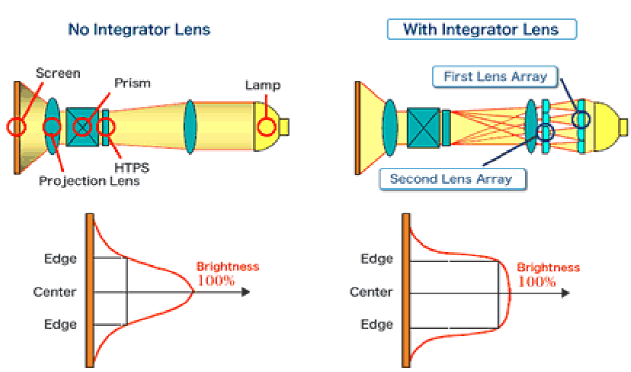
High brightness – Micro lens array (MLA)



LCD (HTPS) panels have transparent areas and lightproof areas. This technology has improved the brightness of panels between 1.5 and 1.6 times.

Liquid crystal display

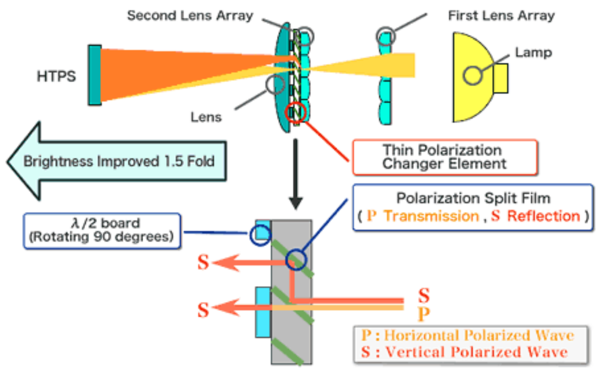
High brightness – Integrated lens



This lens technology projects the whole screen brightly by transmitting light evenly from the first lens array to the second lens array.

Liquid crystal display

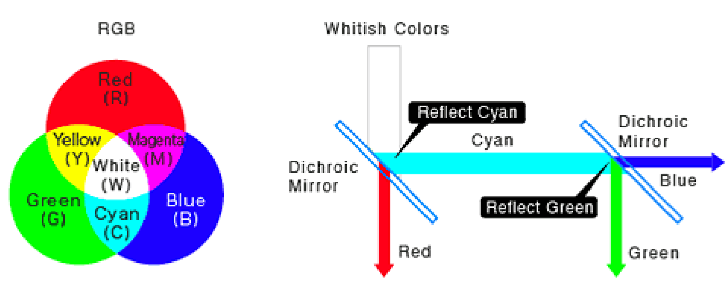
High brightness – Polarisation changer unit



Lamp emits light waves with variety of orientations, but HTPS transmits only longitudinal waves. Polarizer technology converts shear waves to longitudinal waves so that the light can penetrate through HTPS as much as possible. This technology improves brightness by about 1.5 times.

Liquid crystal display

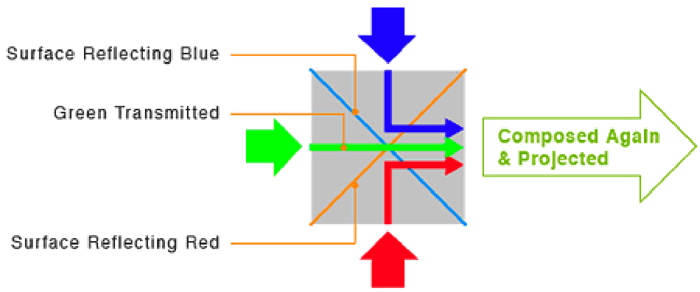
Dichroic mirrors



Two dichroic mirrors are used to divide the light from the lamp into red, green, and blue. The base glass of these two mirrors is coated with a thin film that reflects only light of a specific wavelength.

Liquid crystal display

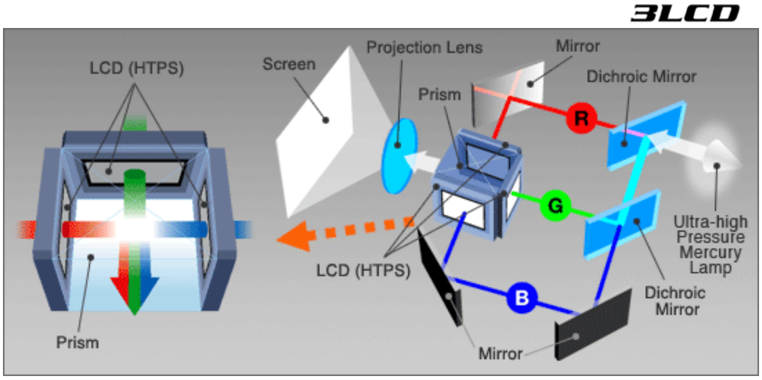
Dichroic prism



A dichroic prism is used to recompose a colour image from red, green and blue images. The prism is formed by combining four triangular poles to create one rectangular solid. High precision is required in the processing and adhesion of poles to avoid dark lines and double images.

Liquid crystal display

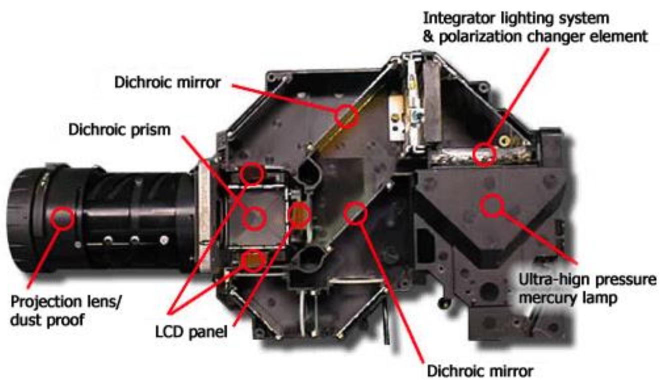
High brightness – 3LCD projector system
– using dichroic mirrors and dichroic prism



3LCD is the most widely used projection technology system in the world. 3LCD technology uses three high-temperature polysilicon liquid crystal displays (HTPS LCDs), hence the name 3LCD.

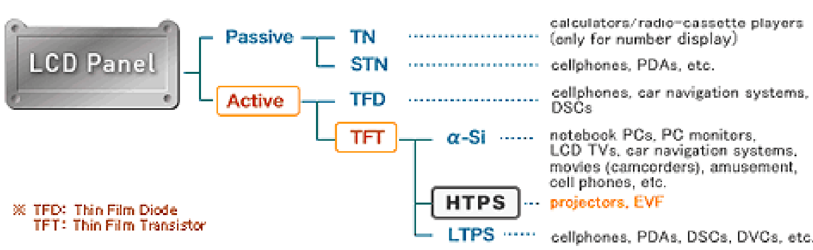
Liquid crystal display

Inside a 3LCD projector unit



Liquid crystal display

LCD panel classification



Using HTPS TFTs instead of a-Si TFTs in LCD panel for projectors is mainly because (a) n-/p-types are possible using HTPS and only n-type is possible using a-Si and the mobility of HTPS TFTs is much higher than that of a-Si TFTs (>100:1), hence, integration of drivers on panel is possible; (b) HTPS are much more stable than a-Si, particularly when operating for long time at high temperature.

Digital light processing

Digital mirror device (DMD)

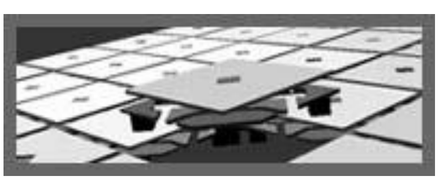
At the heart of every DLP® projection system is an optical semiconductor known as the **Digital Micromirror Device**, or DLP® chip, which was invented by Dr. Larry Hornbeck of Texas Instruments in 1987.

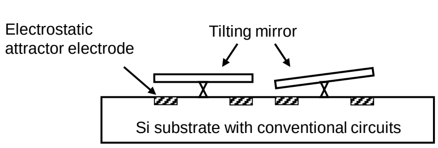
The DLP® chip is probably the world's most sophisticated light switch. It contains a rectangular array of up to 2 million hinge-mounted microscopic mirrors; each of these micro-mirrors measures less than one-fifth the width of a human hair.

When a DLP® chip is coordinated with a digital video or graphic signal, a light source, and a projection lens, its mirrors can reflect an all-digital image onto a screen or other surface. The DLP® chip and the sophisticated electronics that surround it are what is called the **Digital Light Processing™ (DLP)** technology.

Digital light processing

Digital light processing – Timer dithering for grey scales





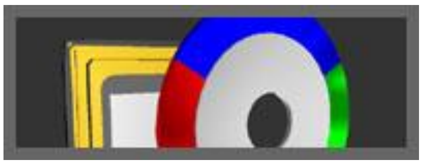
A DLP® chip's micro-mirrors are mounted on tiny hinges that enable them to tilt either toward the light source in a DLP® projection system (ON) or away from it (OFF)-creating a light or dark pixel on the projection surface.

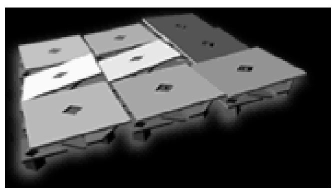
The bit-streamed image code entering the semiconductor directs each mirror to switch on and off up to several thousand times per second. When a mirror is switched on more frequently than off, it reflects a light grey pixel; a mirror that's switched off more frequently reflects a darker grey pixel.

In this way, the mirrors in a DLP® projection system can reflect pixels in up to 1,024 shades of grey to convert the video or graphic signal entering the DLP® chip into a highly detailed greyscale image.

Digital light processing

Digital light processing – Interlaced colours





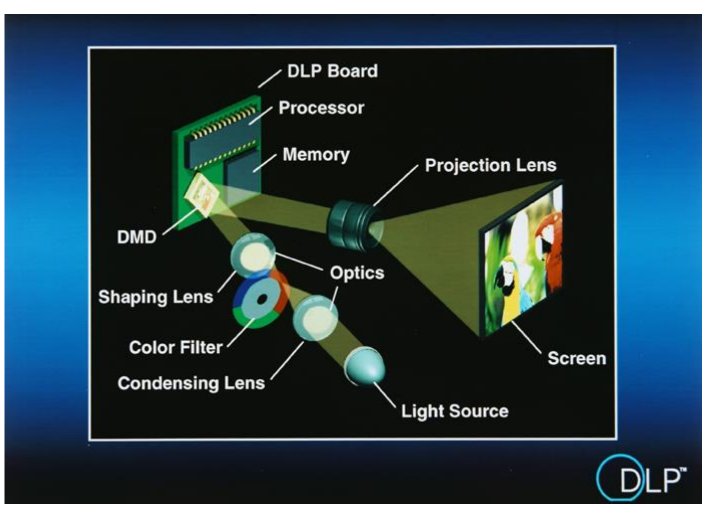
Time dithering for both colour selection (RGB) and intensity (grey scales).

The white light generated by the lamp in a DLP® projection system passes through a colour wheel as it travels to the surface of the DLP® chip. The **colour wheel** filters the light into red, green, and blue, from which a single-chip DLP® projection system can create at least **16.7 million** colours. And the 3-chip system found in DLP Cinema® projection systems is capable of producing no fewer than **35 trillion** colours.

The on and off states of each micromirror are coordinated with these three basic building blocks of colour. For example, a mirror responsible for projecting a purple pixel will only reflect red and blue light to the projection surface; our eyes then blend these rapidly alternating flashes to see the intended hue in a projected image.

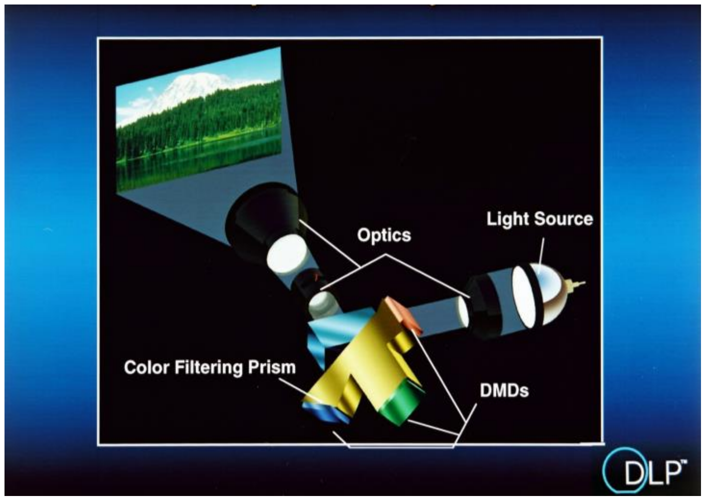
Digital light processing

1 Chip DLP projection



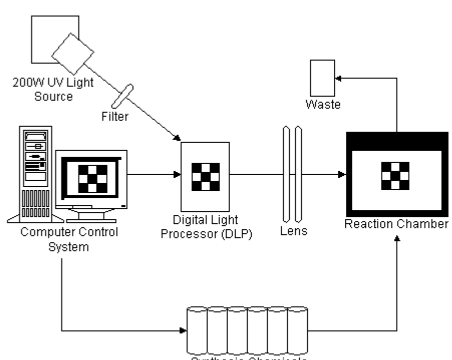
Digital light processing

3 Chip DLP projection



Digital light processing

Bio-application of DLP – Advantage of UV capability

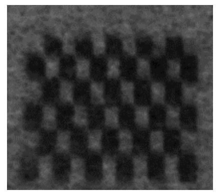


A Digital Optical Chemistry (DOC) System is a unique UV light projector that can be used to manufacture biological/chemical arrays using UV photochemistry or semiconductors using standard photoresist chemistry.

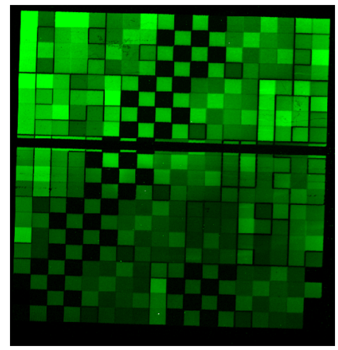
Digital light processing

Bio-application of DLP – Some examples

Generated digital mask



High resolution image



A chip that was custom made to re-sequence the cancer gene

The DOC system can manufacture high density oligo arrays for DNA re-sequencing or expression studies. These arrays can be readout using a fluorescent scanner, including the UTSW MAGNA scanner or commercial units. The advantages are: fast to make a unique mask using “digital masking”, high density array (> 2million pixels), small size machine and optical readout can be done using standard commercial equipments.

Simple comparison of LCD and DLP

AM-TFT-LCD:

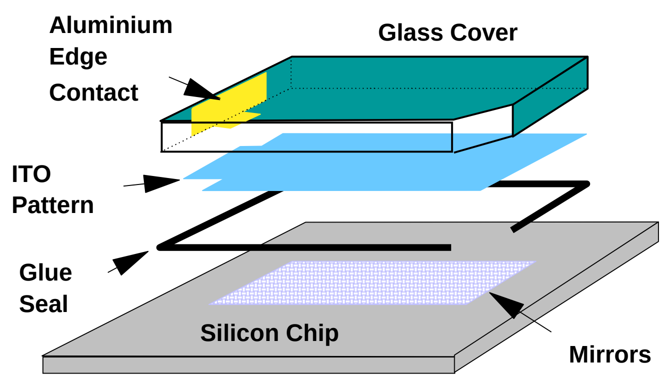
- Majority transmissive type – considerable light loss.
- Driver integration on panel.
- Direct image display possible – flat panel displays.
- Response speed limited but multi-levels.
- Back light energy efficiency problem.
- Mature technology – low cost, but low yield for large size.

DLP:

- Reflective type – less light loss.
- Separated driving circuitry.
- Image only formed through projection.
- Fast response possible but binary.
- Complicated fabrication, packaging and yield problems.
- Relatively new process – higher cost.

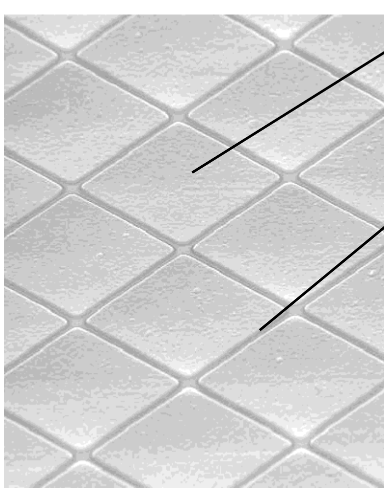
Liquid crystal on silicon

Liquid crystal on silicon (LCOS)



Liquid crystal on silicon

Merits of LCOS



Planarised (flat) surface
(CMP process, filled vias)
Highly Reflective Pixels, > 91%
(Thin top metal layer, low temperature process for small grain size and good reflectivity)

Small inter-pixel gap
(Good Fill-factor, low light-loss)
Anti-reflective coating on buried metal layer
(To give good light shielding for underlying circuits)

Small silicon feature size
(For high-speed loading and small inter-pixel gap)
Additional High Voltage Process
(To drive liquid crystal)

Liquid crystal on silicon

LCOS – Amplitude vs Phase-only

An ideal phase hologram can manipulate light beams without loss of a single photon.

Gen 1: Amplitude ➔ HDTV projection

Gen 2: Phase-only ➔ Holography

Phase-only – highest possible efficiency

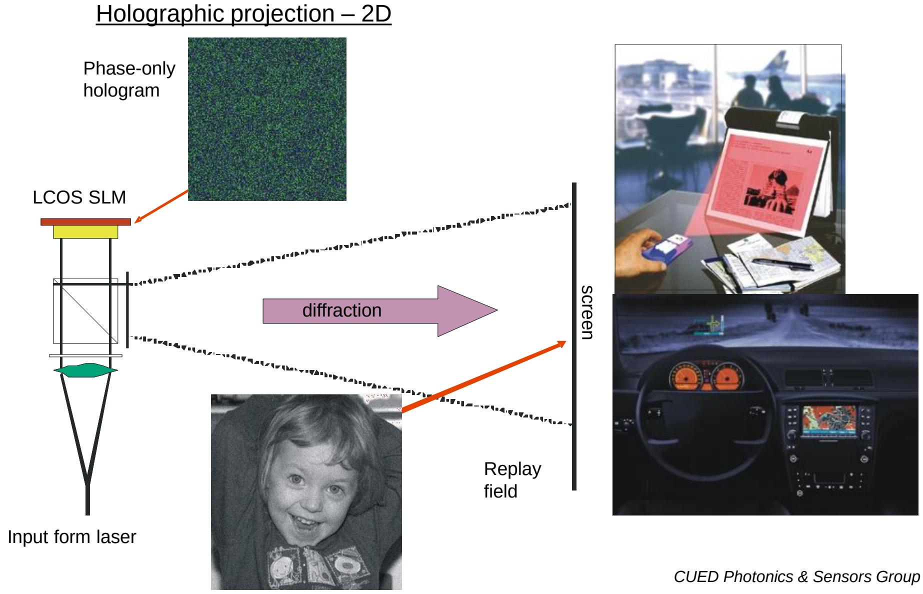
\+

Real-time holography – ultimate image manipulation

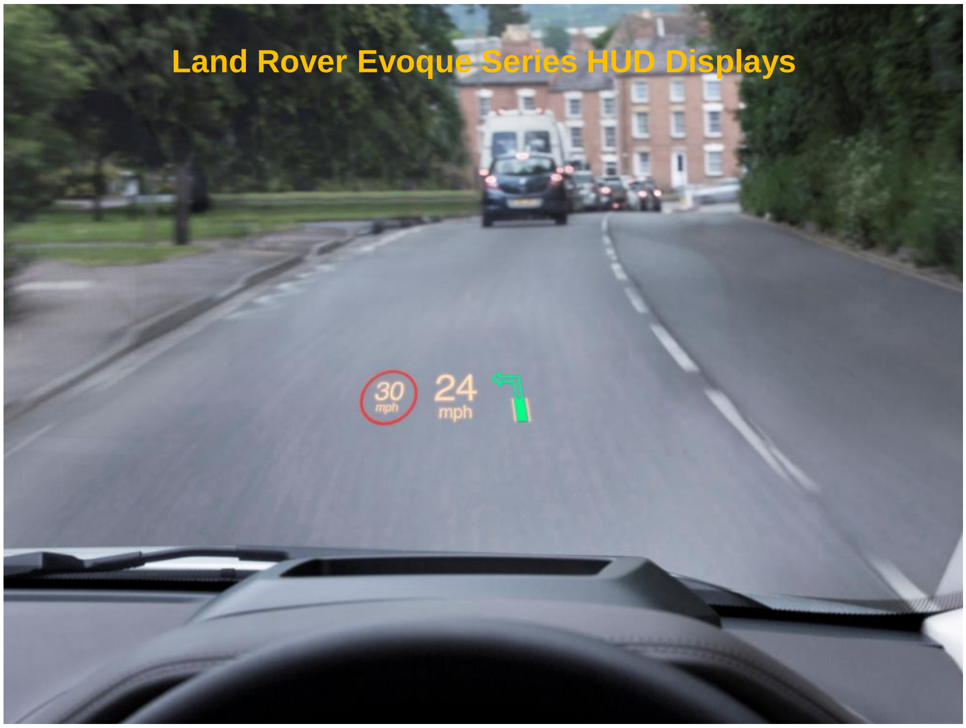
Displaying images using phase is the future.

Liquid crystal on silicon

Holographic projection – 2D

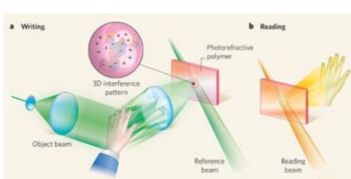


CUED Photonics & Sensors Group

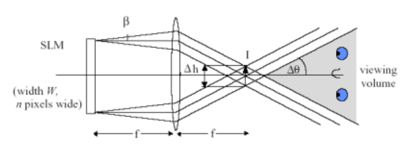


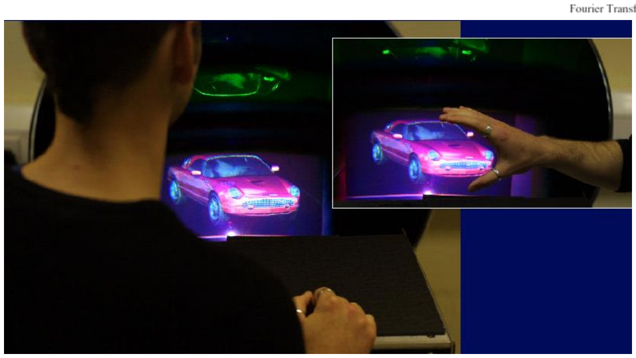
Liquid crystal on silicon

Holographic projection – 3D



"An updatable holographic three-dimensional display", Nature, 8 Feb 2008





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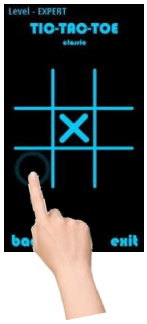
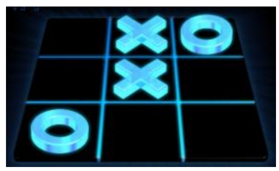
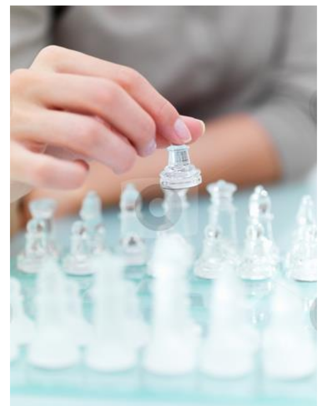
Toward interactive 3D experience



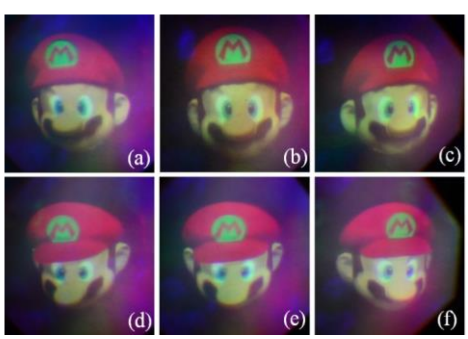


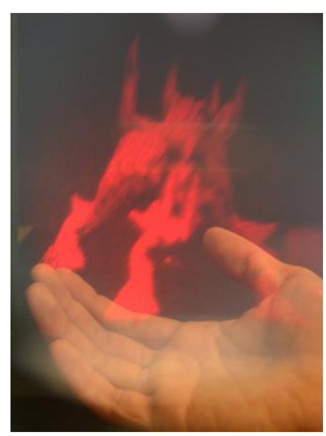


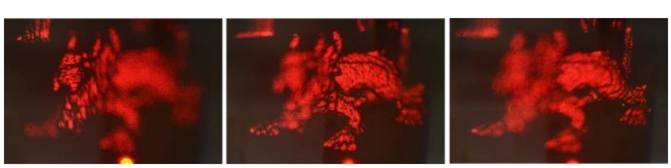
"plane to volume … touching to holding"

Toward interactive 3D experience

Large viewing angle







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