

# Introduction to Computer Graphics

## *Display Technologies*



## Image display

- a handful of technologies cover over 99% of all display devices
  - active displays
    - cathode ray tube      standard for late 20<sup>th</sup> century
    - liquid crystal display      most common today
    - plasma displays      briefly popular but power-hungry
    - digital mirror displays      increasing use in video projectors
    - OLED      expensive but increasingly used in high end TV
  - printers (passive displays)
    - laser printers      the traditional office printer
    - ink jet printers      the traditional home printer
    - commercial printers      for high volume



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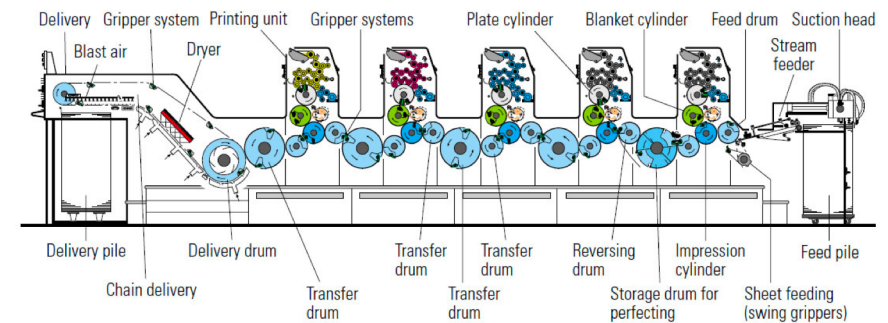
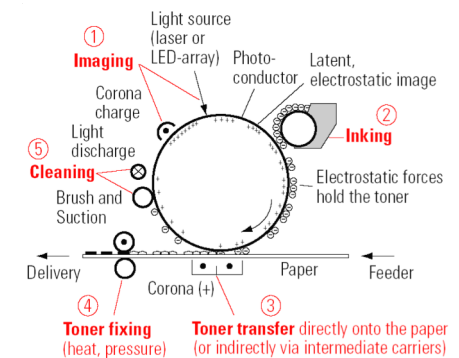
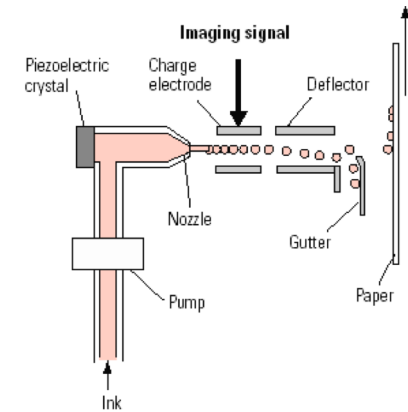
[https://en.wikipedia.org/wiki/History\\_of\\_display\\_technology](https://en.wikipedia.org/wiki/History_of_display_technology)

<http://www.samsung.com/us/explore/galaxy-s7-features-and-specs/>

The last twenty years have seen a move from bulky cathode ray tubes to a variety of flat screen devices, some incredibly thin (e.g., the mobile phone shown here), some incredibly large (e.g., the 155 inch (3.4 meters by 1.9 meters) monster OLED display prototyped by Mitsubishi in 2010).

# Printers

- many types of printer
  - ink jet
    - sprays ink onto paper
  - laser printer
    - uses a laser to lay down a pattern of charge on a drum; this picks up charged toner which is then pressed onto the paper
  - commercial offset printer
    - an image of the whole page is put on a roller
    - this is repeatedly inked and pressed against the paper to print thousands of copies of the same thing
- all make marks on paper
  - essentially binary devices: mark/no mark

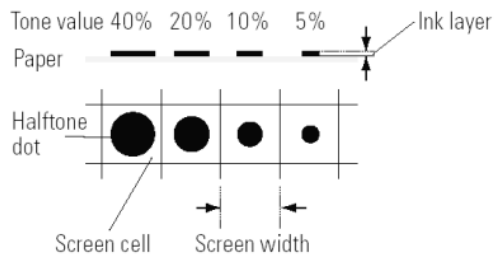


## Printer resolution

- laser printer
  - 300–1200dpi
- ink jet
  - used to be lower resolution & quality than laser printers but now have comparable resolution
- phototypesetter for commercial offset printing
  - 1200–2400 dpi
- bi-level devices: each pixel is either on or off
  - black or white (for monochrome printers)
  - *ink or no ink* (in general)

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## What about greyscale?

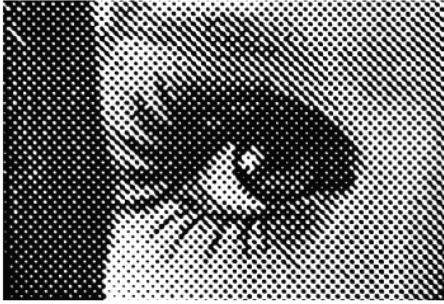


- achieved by halftoning
  - divide image into cells, in each cell draw a spot of the appropriate size for the intensity of that cell
  - on a printer each cell is  $m \times m$  pixels, allowing  $m^2+1$  different intensity levels
  - e.g. 300dpi with  $4 \times 4$  cells  $\Rightarrow$  75 cells per inch, 17 intensity levels
  - phototypesetters can make 256 intensity levels in cells so small you can only just see them
- an alternative method is dithering
  - dithering photocopies badly, halftoning photocopies well

*will discuss halftoning and dithering in Image Processing section of course*

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## Halftoning & dithering examples



Halftoning



Dithering



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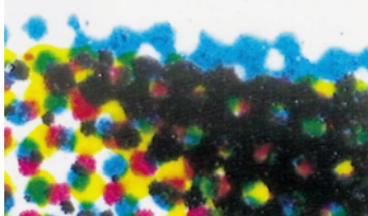
## What about colour?

- generally use cyan, magenta, yellow, and black inks (CMYK)
- inks *absorb* colour
  - c.f. lights which *emit* colour
  - CMY is the inverse of RGB
- why is black (K) necessary?
  - inks are not perfect absorbers so mixing C + M + Y gives a muddy grey, not black
  - mixing C + M + Y uses more ink than using black
  - lots of text is printed in black: trying to align C, M and Y perfectly for black text would be a nightmare

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## How do you produce halftoned colour?

- print four halftone screens, one in each colour
- carefully angle the screens to prevent interference (moiré) patterns



150 lpi × 16 dots per cell  
= 2400 dpi phototypesetter  
(16×16 dots per cell = 256  
intensity levels)

<i>Standard rulings (in lines per inch)</i>	
65 lpi	
85 lpi	newsprint
100 lpi	
120 lpi	uncoated offset paper
133 lpi	uncoated offset paper
150 lpi	matt coated offset paper or art paper publication: books, advertising leaflets
200 lpi	very smooth, expensive paper very high quality publication

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## Four colour halftone screens



- Standard angles
  - Cyan 15°
  - Black 45°
  - Magenta 75°
  - Yellow 90°
- At bottom is the moiré pattern
  - this is the best possible (minimal) moiré pattern
  - produced by this optimal set of angles
  - all four colours printed in black to highlight the effect

Magenta, Cyan & Black are at 30° relative to one another  
Yellow (least distinctive colour) is at 15° relative to Magenta and Cyan

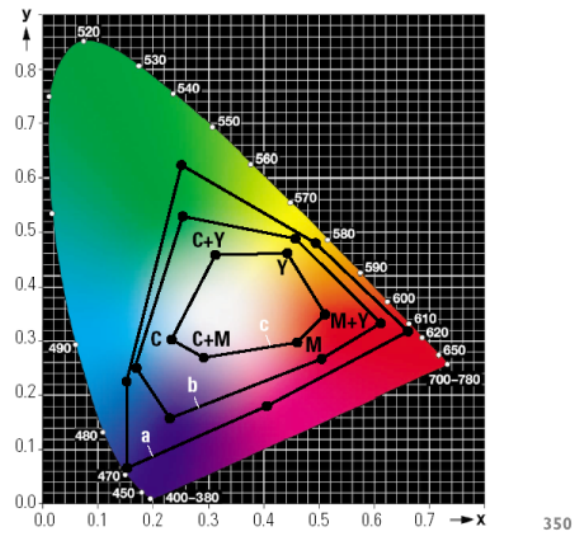
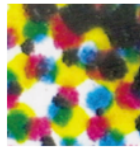
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## Range of printable colours

- a: colour photography (diapositive)
- b: high-quality offset printing
- c: newspaper printing

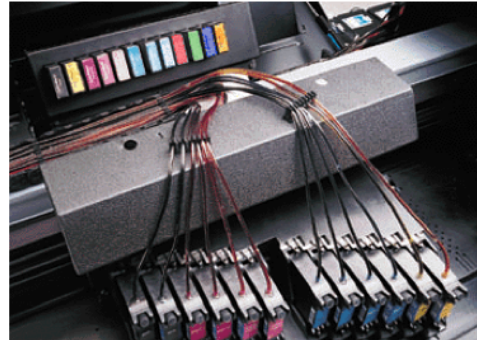
### why the hexagonal shape?

because we can print dots which only partially overlap making the situation more complex than for coloured lights



## Beyond four colour printing

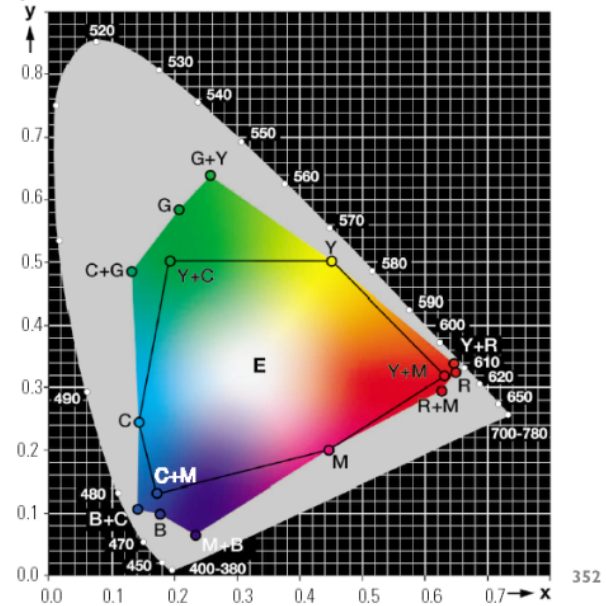
- printers can be built to do printing in more colours
  - gives a better range of printable colours
- six colour printing
  - for home photograph printing
  - dark & light cyan, dark & light magenta, yellow, black
- eight colour printing
  - 3×cyan, 3×magenta, yellow, black
  - 2×cyan, 2×magenta, yellow, 3×black
- twelve colour printing
  - 3×cyan, 3×magenta, yellow, black
  - red, green, blue, orange

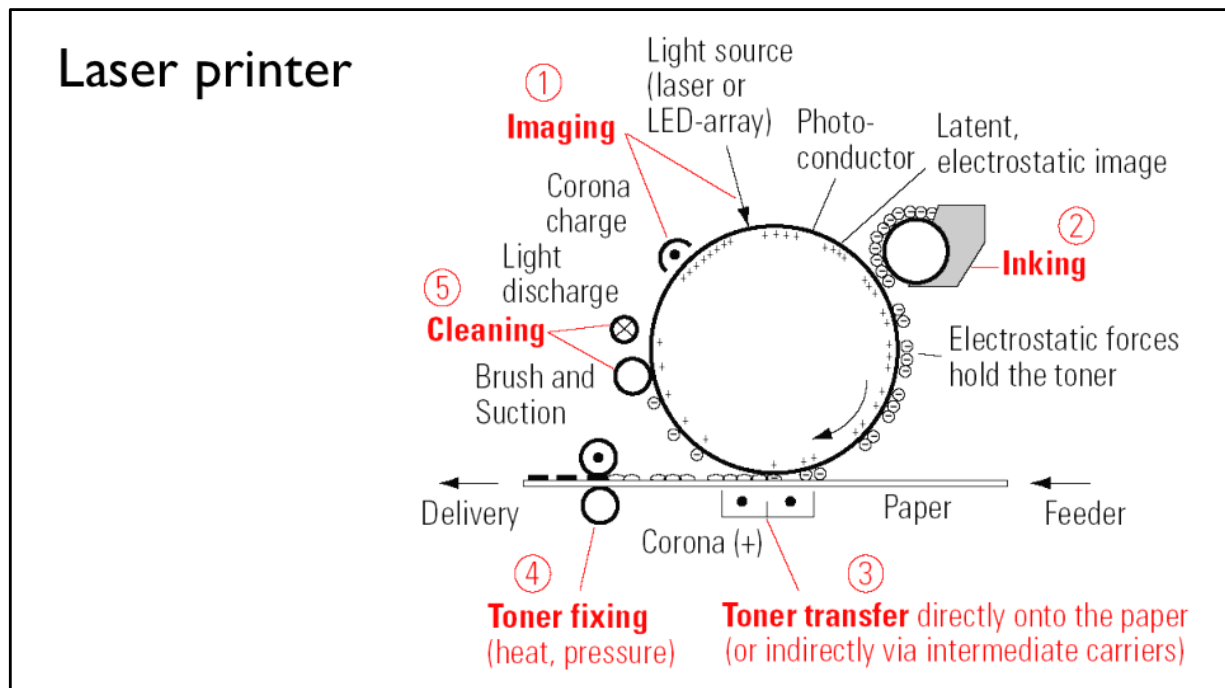


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## The extra range of colour

- this gamut is for so-called HiFi colour printing
  - uses cyan, magenta, yellow, plus red, green and blue inks





It always amazes me that laser printers work at all.

They are based on a property of selenium, which is that it is photoconductive and so, if you charge it up with positive charge, the positive charge will be lost from places on which light has shone.

Take a drum coated in selenium.

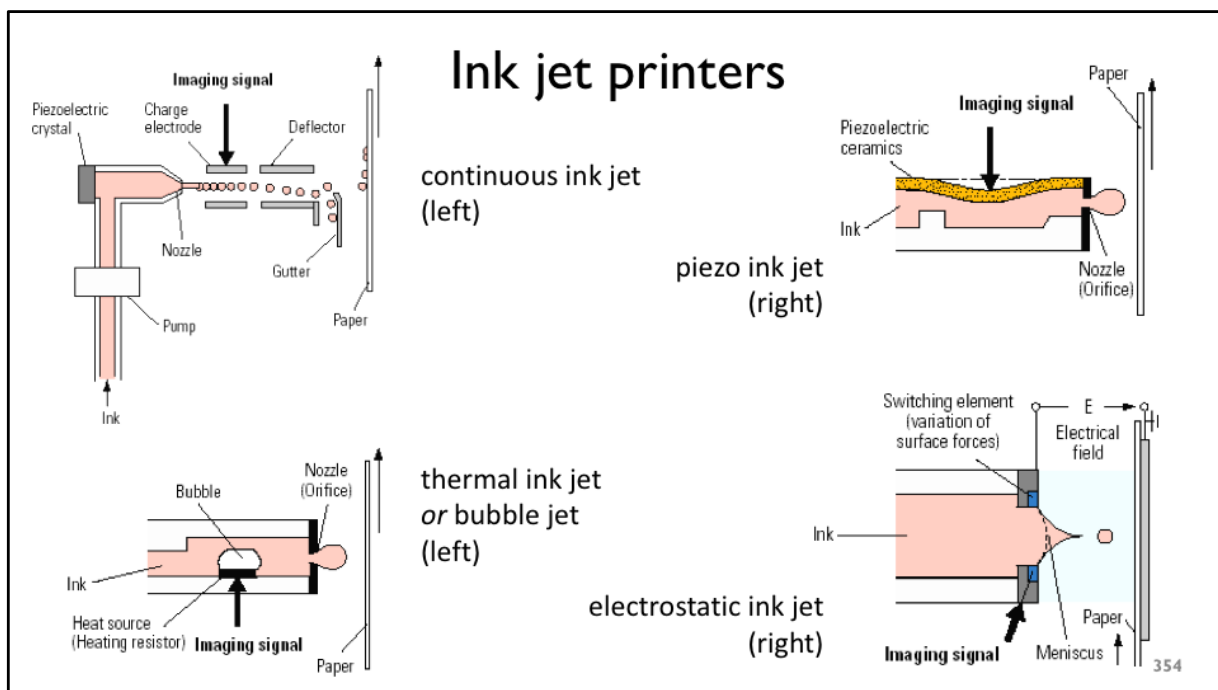
Step 1: charge the drum with positive charge and then use a laser to shine light on all parts of the paper where you do *not* want ink.

Step 2: take some negatively charged ink particles, they will be stick to the drum wherever it is positively charged.

Step 3: press the drum against paper and have a positively charged source underneath the paper that will attract the negatively charged toner onto the paper.

Step 4: use heat and pressure to melt the toner particles onto the paper so that they stick.

Step 5: there will still be some toner stuck to the drum, so clean it off and shine light on the drum to get rid of any residual positive charge.

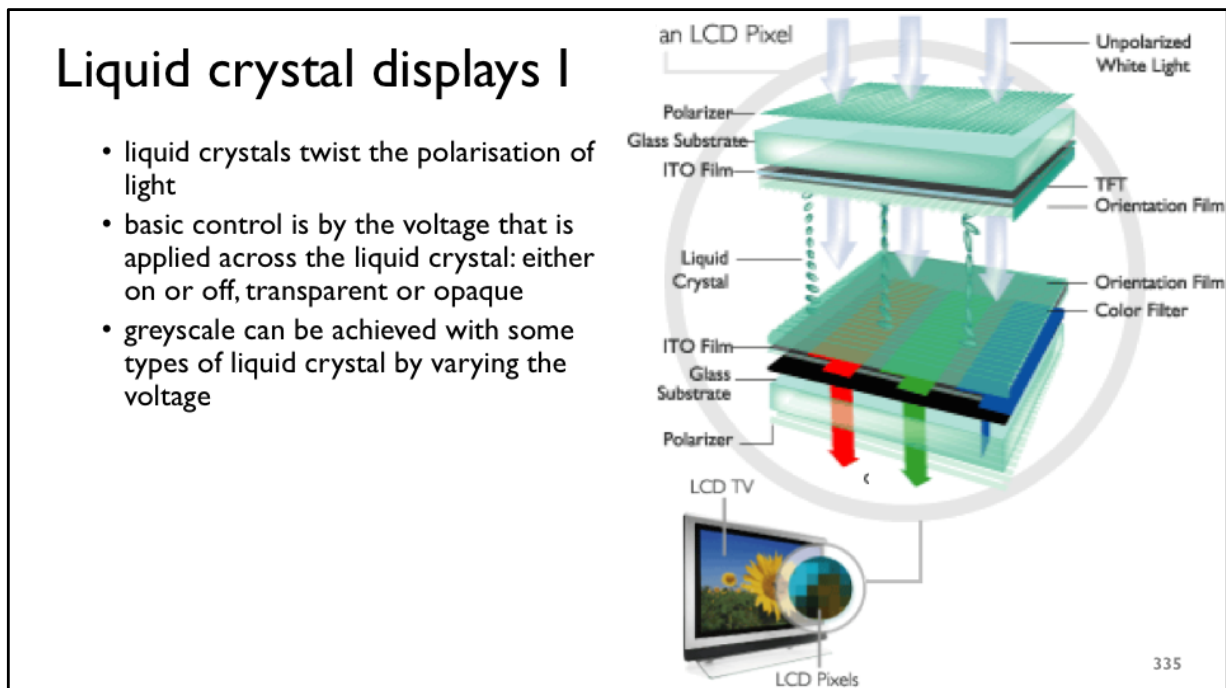


Ink jets work by squirting a jet of ink at the paper. In fact, it is not so much a jet as a sequence of bubbles of ink.

There are many ways of creating a sequence of bubbles. The continuous ink jet (top left) is one early method. It is very wasteful because most of the continuous stream of ink bubbles get deflected into a waste tray.

The other methods create bubbles only when a bubble is needed.

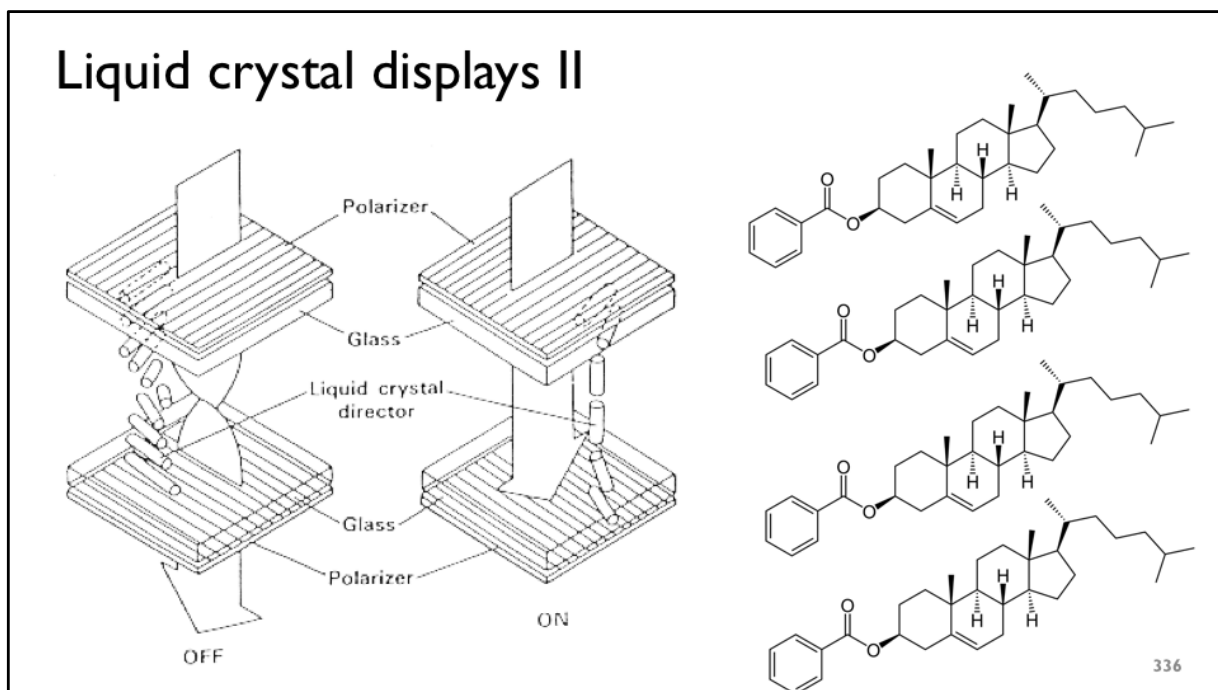
You do not need to remember how all of these methods work, but you should be mildly amazed by the ingenuity of engineers who made these work, and work reliably and cheaply.



ITO – Indium-Tin Oxide – a substance that can conduct electricity and is also transparent

TFT – Thin-Film Transistors – transistors are electronic switches

Orientation film – a thin transparent film with thousands of tiny parallel grooves in it



There are two polarizers at right angles to one another on either side of the liquid crystal: under normal circumstances these would block all light.

There are liquid crystal directors: micro-grooves which align the liquid crystal molecules next to them.

The liquid crystal molecules try to line up with one another; the micro-grooves on each side are at right angles to one another which forces the crystals' orientations to twist gently through  $90^\circ$  as you go from top to bottom, causing the polarization of the light to twist through  $90^\circ$ , making the pixel transparent.

Liquid crystal molecules are polar: they have a positive and a negative end.

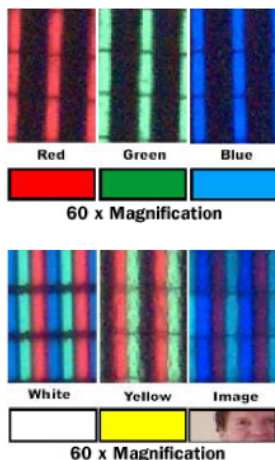
Applying a voltage across the liquid crystal causes the molecules to stand on their ends, ruining the twisting phenomenon, so light cannot get through and the pixel is opaque.

At right is the chemical cholesteryl benzoate, the first substance to be discovered to exhibit liquid crystal properties, in the late 19th century.

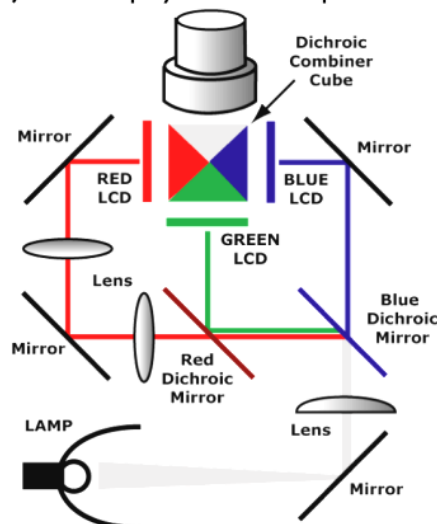


## Liquid crystal displays: RGB colour

- desktop displays have little filters over the pixels to provide the three colours: RGB



- projected displays use three panels



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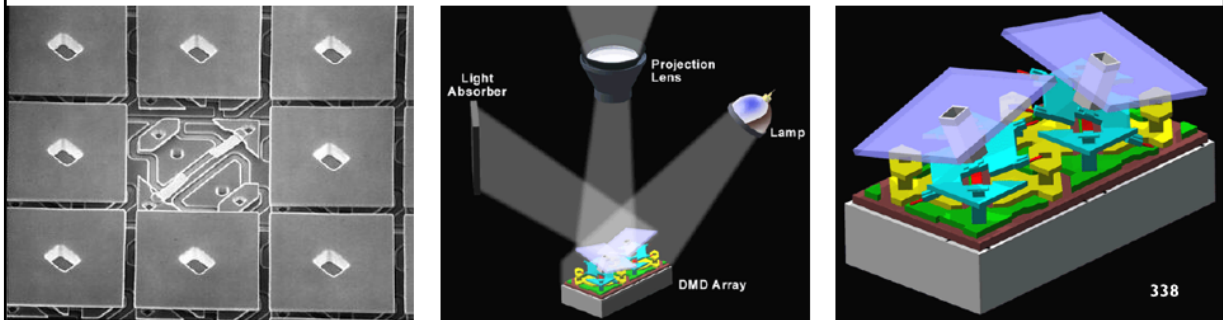
At left we see a normal LCD panel, highly magnified, with colour filters over the pixels. Notice that the display elements are thin rectangles and that three rectangles (one red, one green, one blue) make up a display unit that is roughly square: an RGB pixel.

At right we see a three LCD video projector, with colour made by devoting one LCD panel to each of red, green and blue.

The light is split using **dichroic** mirrors: these reflect some wavelengths of light and let other wavelengths straight through. For example, the blue dichroic mirror passes blue light but reflects red and green light.

## Digital micromirror devices I

- developed by Texas Instruments
  - often referred to as Digital Light Processing (DLP) technology
- invented in 1987, following ten year's work on deformable mirror devices
- manufactured like a silicon chip!
  - a standard 5 volt, 0.8 micron, CMOS process
  - micromirrors are coated with a highly reflected aluminium alloy
  - each mirror is  $16 \times 16 \mu\text{m}^2$



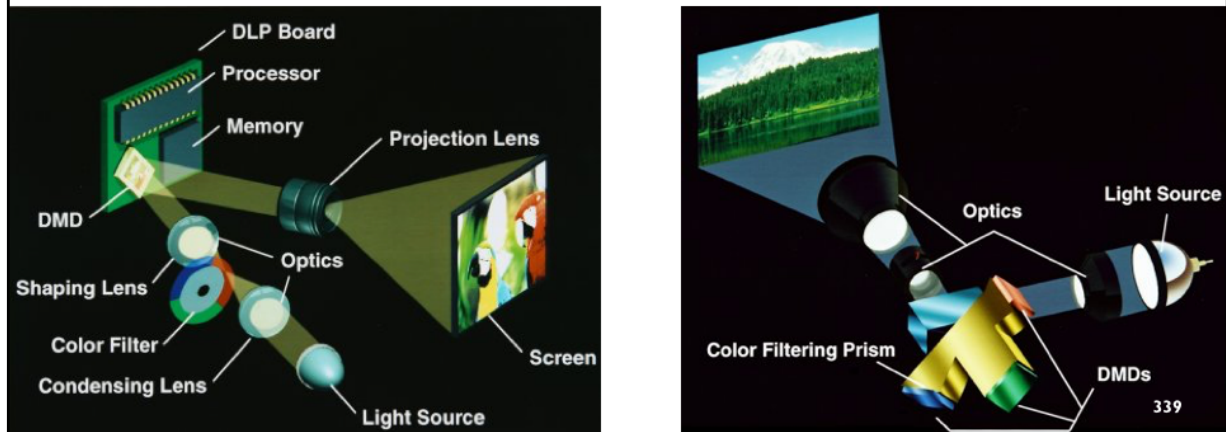
A silicon chip is manufactured in layers. Each layer is laid down using a photographic process. For example, you can lay down a photosensitive substance over the whole chip, then shine light through a photographic mask. Where the light hits the substance hardens. You then wash off the unhardened parts.

Digital micromirror devices (DMDs) have a top layer that is flat (purple in diagram at right) and coated with aluminum. They are supported by a metal pillar in the centre (grey in diagram at right), and they can rock  $10^\circ$  either side of being flat. They are mounted on a torsion spring setup (cyan in diagram at right). Underneath this are two transistors (yellow in diagram at right). Whichever one is currently “on” pulls the micromirror down towards that corner.

Making this reliably was a major challenge. A single “stuck” micromirror ruins the whole device.

## Digital micromirror devices II

- used increasingly in video projectors
- widely available from late 1990s
- colour is achieved using either three DMD chips or one chip and a rotating colour filter



The left hand version uses a rotating colour filter and therefore displays each image in three phases: red, then green, then blue. If you track rapidly moving objects on the screen, you might see the image split up between the three colours, because your eye will assume smooth movement but the display will show three separate images in one place followed by three separate images in the next place, and so on.

The right hand version uses three DMD chips, so is more expensive. The colour filtering prism is actually several prisms glued together with dichroic film in the glue to split the light correctly.

The mirrors either reflect light through the projection lens, or they do not. They are therefore binary devices: either on or off. How do you get multiple shades of colour? What you do is modulate for how long each pixel is reflecting light through the lens. The time spent projecting light through the lens is proportional to the perceived intensity at that pixel. So you flip pixels on and off very quickly. For example, if you want to show 256 levels of grey and you are displaying 60 frames a second and you have three different colours then you must be able to flip a pixel off in a time less than  $1/(256 \times 60 \times 3)$  of a second = about 20 microseconds.

## Electrophoretic displays I

- electronic paper widely used in e-books
- iRex iLiad, Sony Reader, Amazon Kindle
- 200 dpi passive display



The important thing about electrophoretic displays is that they retain their image when there is no power. That means that you only need to use power when you change the image. This means that you can have a battery life of weeks.

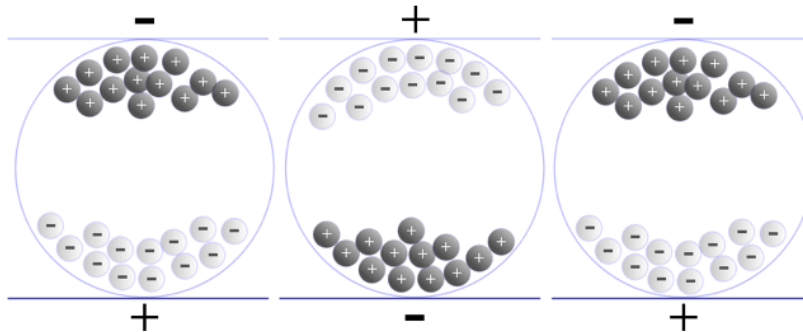
The update speed is low, so you could not display an animation, nor do many of the things expected of a modern phone, tablet, laptop or desktop display.

**Passive** means “does not need power to keep the image on the display”.

**Active** means “needs power to keep the image on the display”.

## Electrophoretic displays II

- transparent capsules about  $40\mu\text{m}$  diameter
  - filled with dark oil
  - negatively charged  $1\mu\text{m}$  titanium dioxide particles that are pure white
- electrodes in substrate attract or repel white particles
- image persists with no power consumption

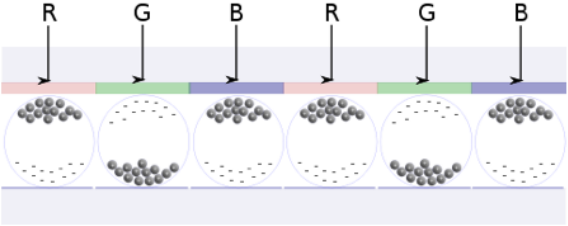


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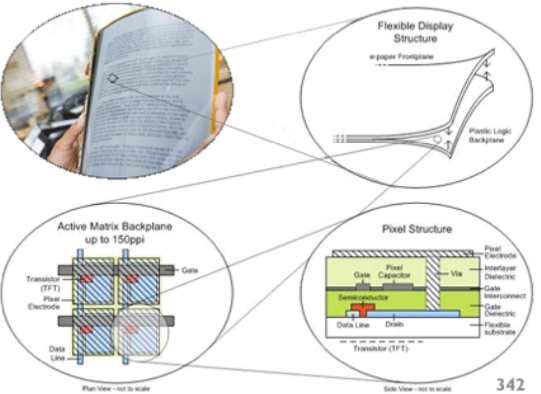
Remember that two negatives will repel each other, while a negative and a positive will attract each other. Putting a large positive voltage at the top of the capsule will pull all the negatively charged particles to the top; putting a large negative voltage at the top will push all the negatively charged particles to the bottom.

## Electrophoretic displays III

- Colour
  - Colour filters over individual pixels



- Flexible
  - flexible substrate using plastic semiconductors (Plastic Logic)



We get colour the same way that we do with LCD panels.

One fun thing about this technology is that we can make it flexible.