Display devices in computer graphics

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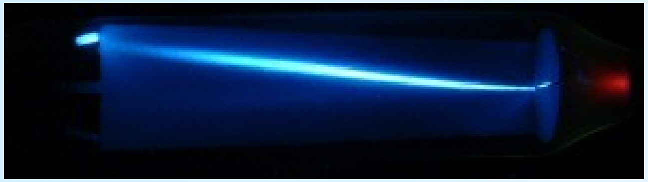
Display technology

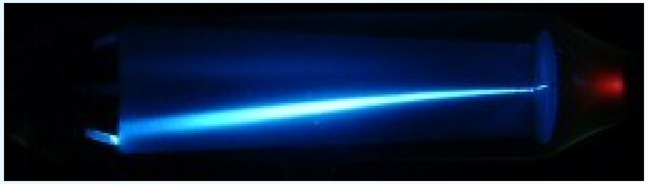
- CRT displays
- LCD displays
- Plasma displays
- Light emitting polymer displays – OLED
- Other technologies – FED, E-Ink

History of CRT

- 1855 *Geissler* – a vacuum tube filled with gas influenced by a strong electric field causes it to glow.

- 1859 *Plucker* – pointed to the existence of invisible rays between the cathode and the anode. He showed that the beam in the tube could be affected by the magnetic field.

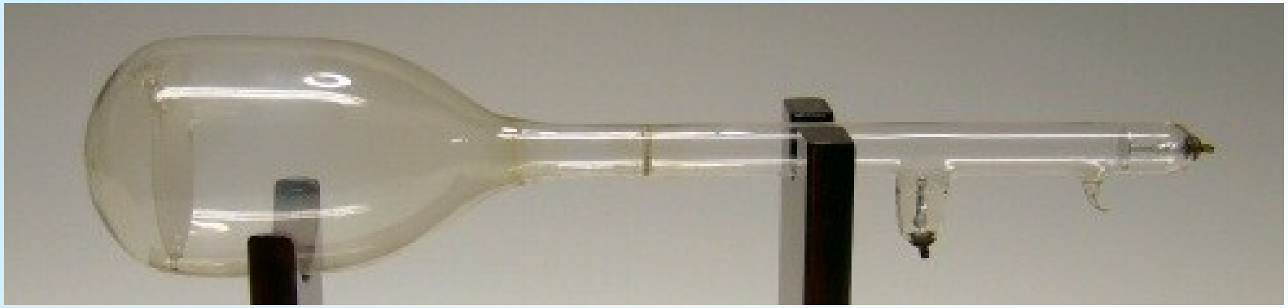




History of CRT

- 1878 *Crookes* – put a thin metal plate in the tube and showed that the electrons form a beam that can not pass through this plate.

- 1897 *Brown* – created the so-called cold CRT with electromagnetic deflection and a small screen made of mica covered with phosphorus = oscilloscope.

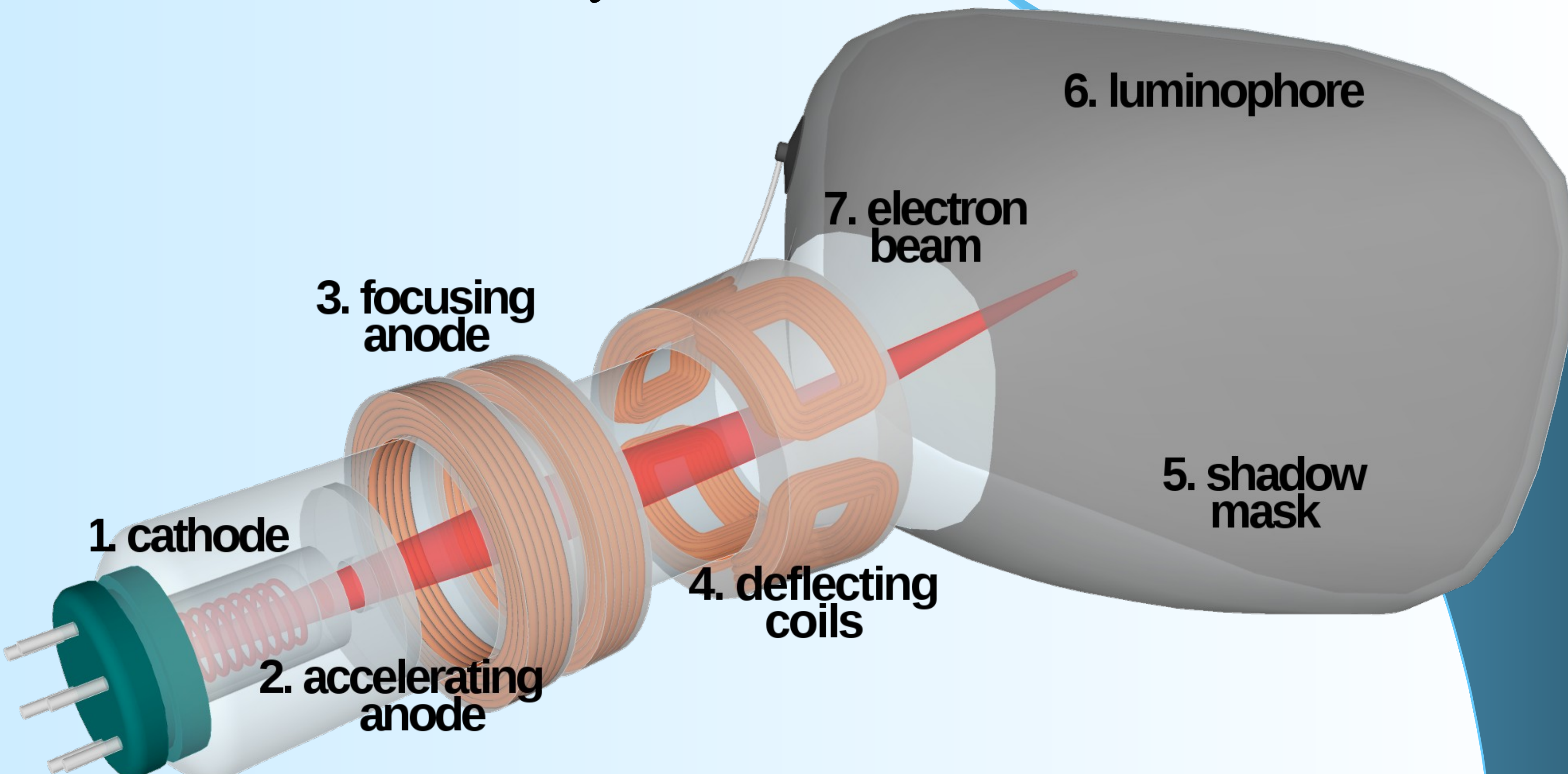


History of CRT

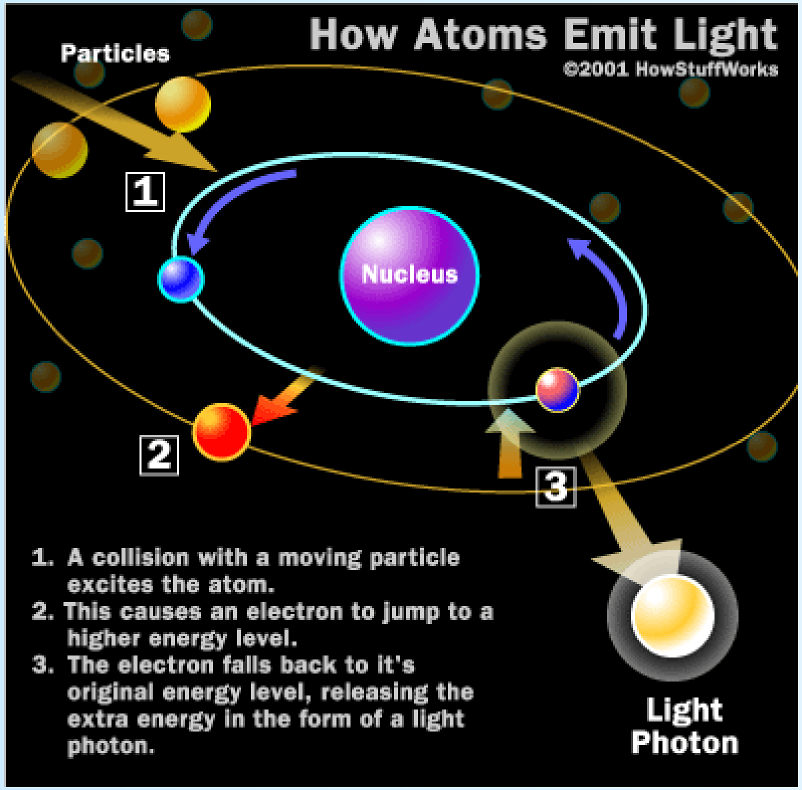
- 1923 *Zworykin* – improved the original CRT and created the first television that displayed the image.
- 1928 The first TV broadcast – AT&T „sent“ motion picture from Chicago to New York.
- 1931 *Du Mont* – The first commercial production of CRT screens.

CRT displays

- CRT = Cathode Ray Tube



Phophorus and photon emitting

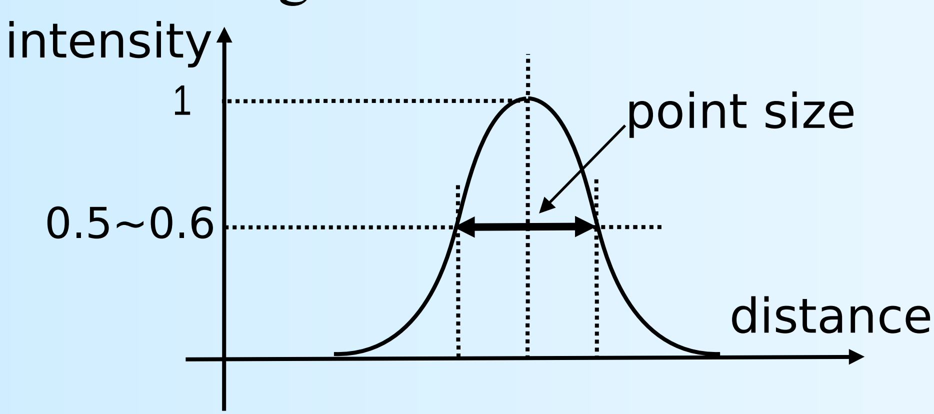


- **Fluorescence** – phosphorus electron emits a photon when it returns to its original orbit (duration: <1 ms).
- **Phosphorescence** – some molecules are further excited and emit light (duration: 15-20 ms).
- **Persistence** – is defined as the time when the emitted light drops to 1/10 of the original intensity.

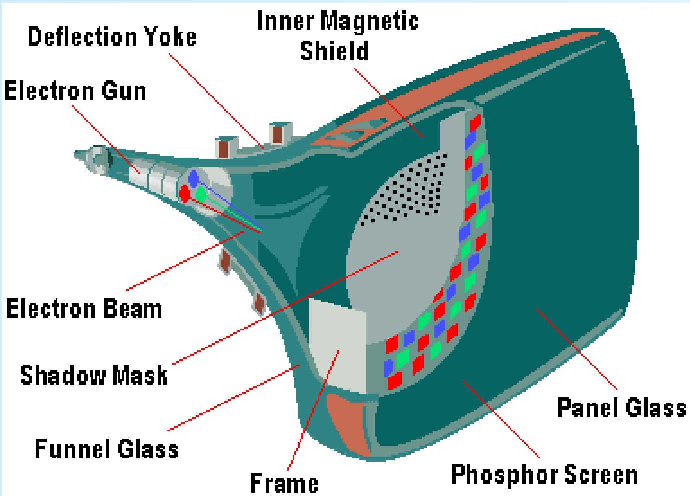
Is the shorter time of persistence better for displaying images?

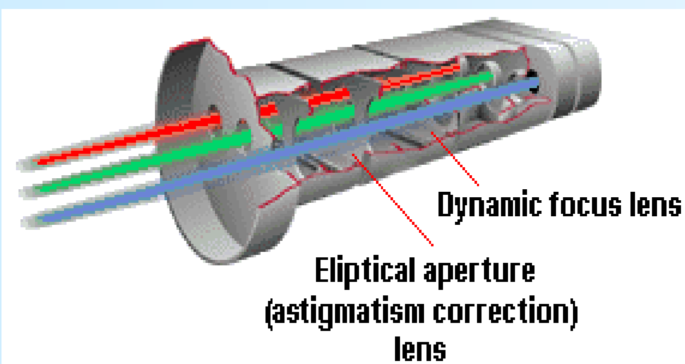
Other terms for CRT

- **Point size** – determined by 50% of the intensity value
- **Resolution** – # recognizable black lines on white background per inch
- **Band width** – # on/off switches per second
- **Vertical retrace** – # displayed rows per second
- **Refresh rate** – # displayed pictures (screens) per second
- **Critical fusion frequency** is defined as the frequency at which displayed pictures appears to be completely steady to the average human observer



Color CRT

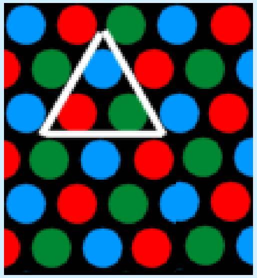




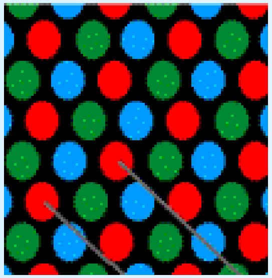
- We need 3 electron guns to create color. One ray for each *R*, *G*, *B* color component.
- Luminophore on the screen consists of many small RGB points.
- Before the phosphor layer is a **shadow mask** that filters the electrons to ensure that they hit only the desired point of phosphorus.

Shadow mask

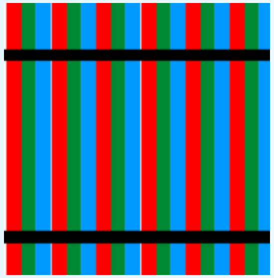
- Each point of the phosphorus forming the subpixel *R*, *G* or *B* has another chemical type of pigment.
- Color point (pixel) consists of three *R*,*G*, *B* subpixels. These subpixels are grouped into a triangle or a horizontal line.
- By combining the different intensities of these subpixels we can get any color.



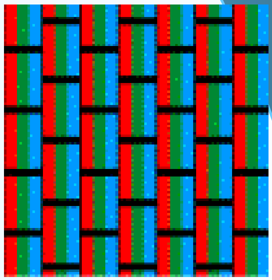
Standard Dot-trio



Hitachi Enhanced Dot Pitch

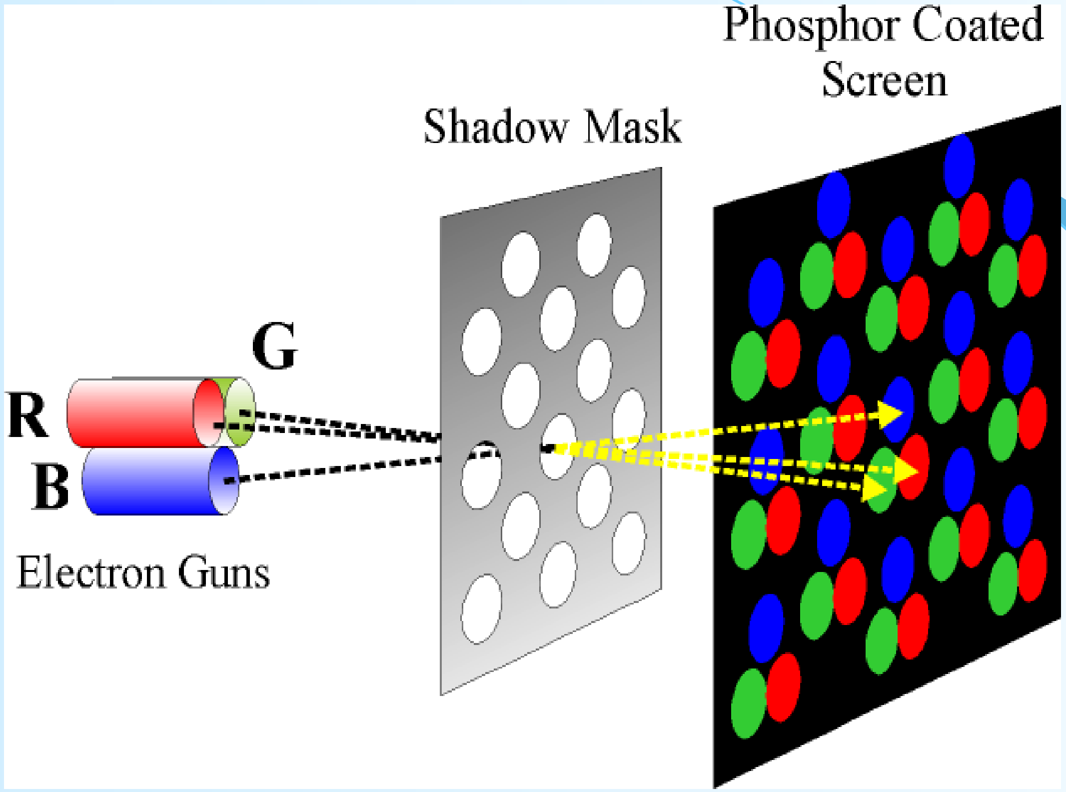


SONY Trinitron CRT



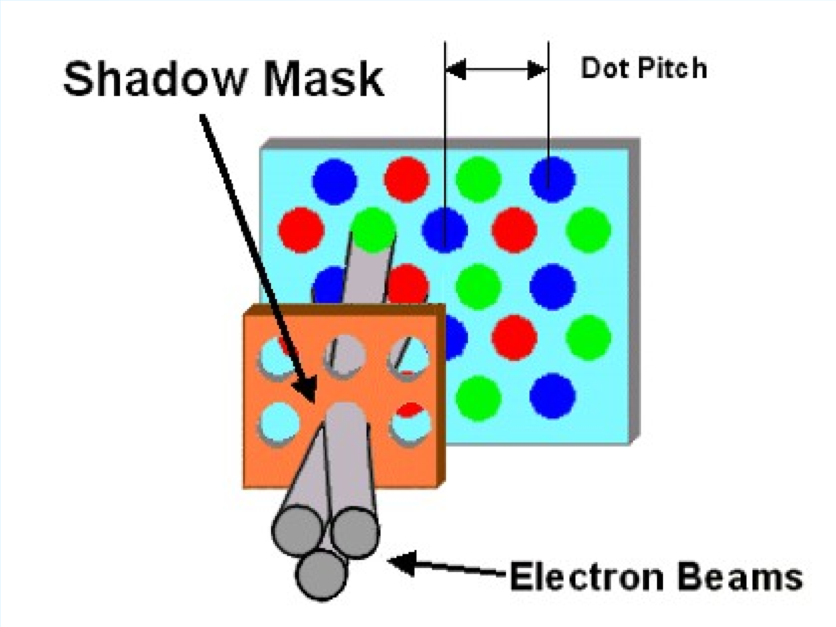
NEC Hybrid Mask

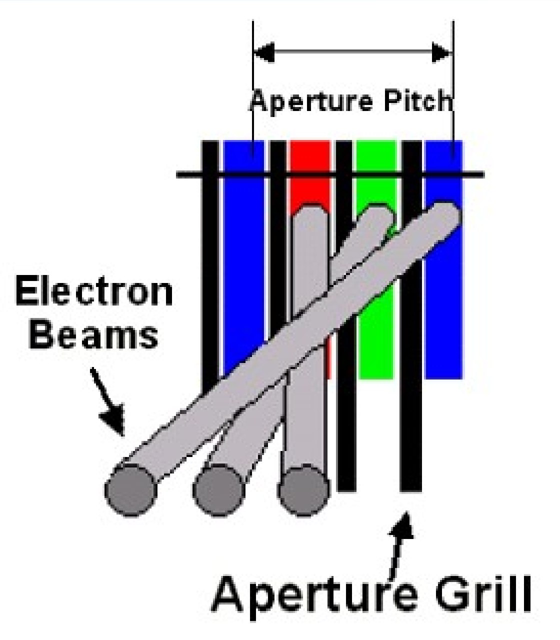
Shadow mask



- The apertures in the mask are arranged so that each beam can only affect the desired point of phosphorus.

Shadow mask...





Arrangement of electron guns and shadow masks:

- Into a triangle – **delta** technology (Invar)
- Into a line – **inline** technology (Trinitron)
- Combination of two types above – **hybrid** (CromaClear)

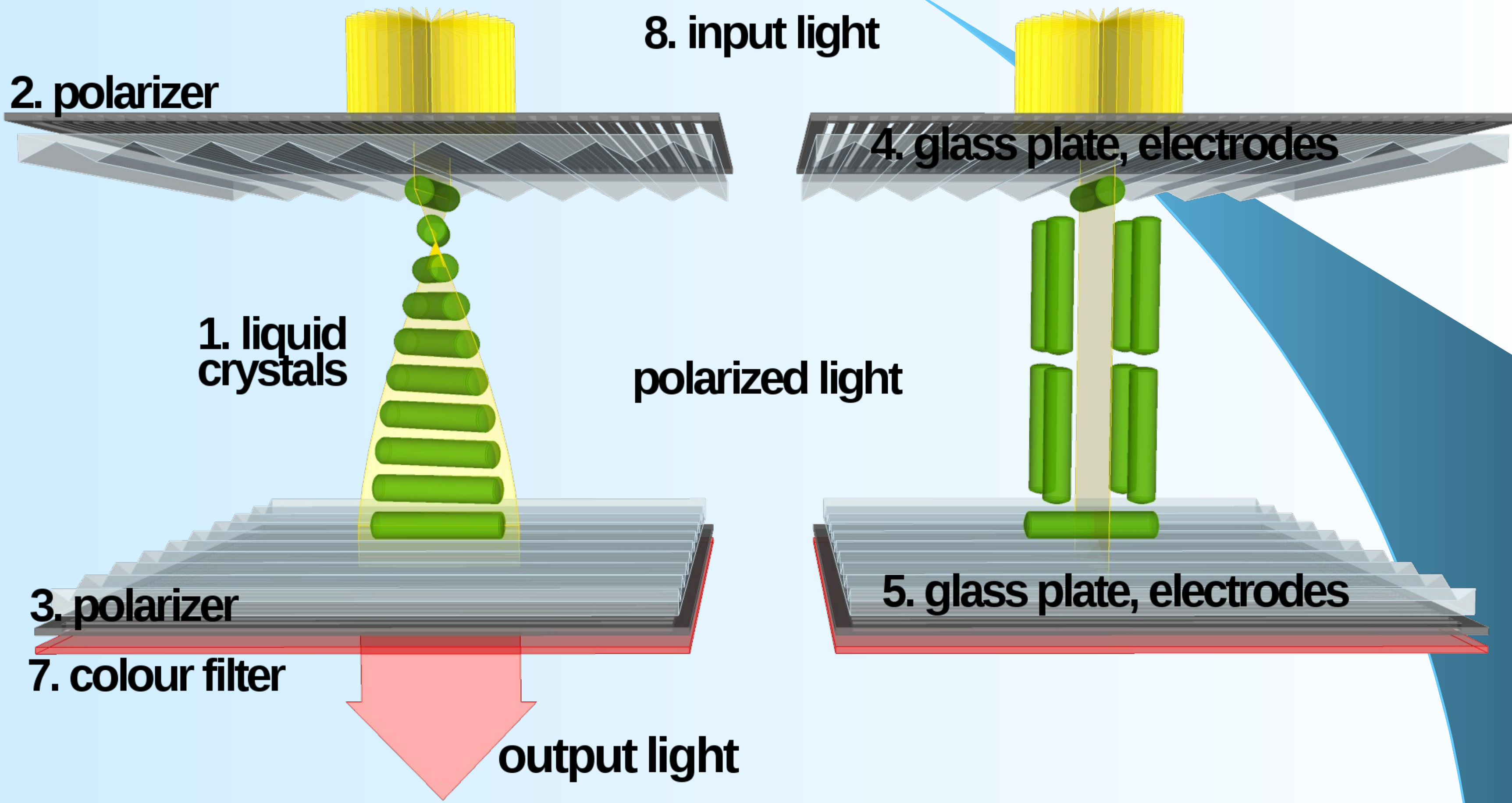
History of LCD

- 1888 *Reinitzer* – discovered a cholesterol-based substance that dissolved at 145°C to form a translucent solution. At 178°C, the solution became clear. This process was reversible.
- 1889 *Lehmann* – found that the translucent solution was made of tiny crystals = liquid crystal. He studied the effect of this substance on the polarized light.
- 1962 *Williams* – created a strip pattern on a thin layer of liquid crystal material by applying electrical voltage.
- 1964-1968 – the team led by Heilmeir worked on influencing liquid crystals by the electric field to control the light passing through it.
- Since 1970, the first LCD monitors have been produced.

LCD displays

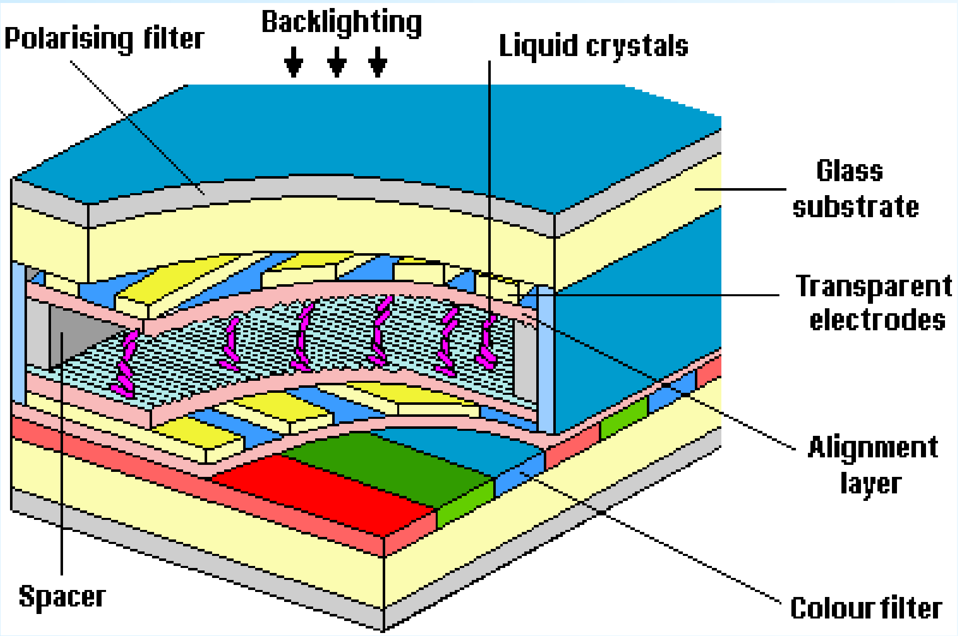
- LCD = Liquid Crystal Displays
- **Chiral nematic phase** – the liquid crystal molecules are arranged in a spiral. This spiral gradually rotates the plane of polarized light. The spiral ends are anchored to the inner planes of the glass.
- If they are affected by the electric field, the arrangement changes - they are aligned in the direction of the electric field.

LCD displays



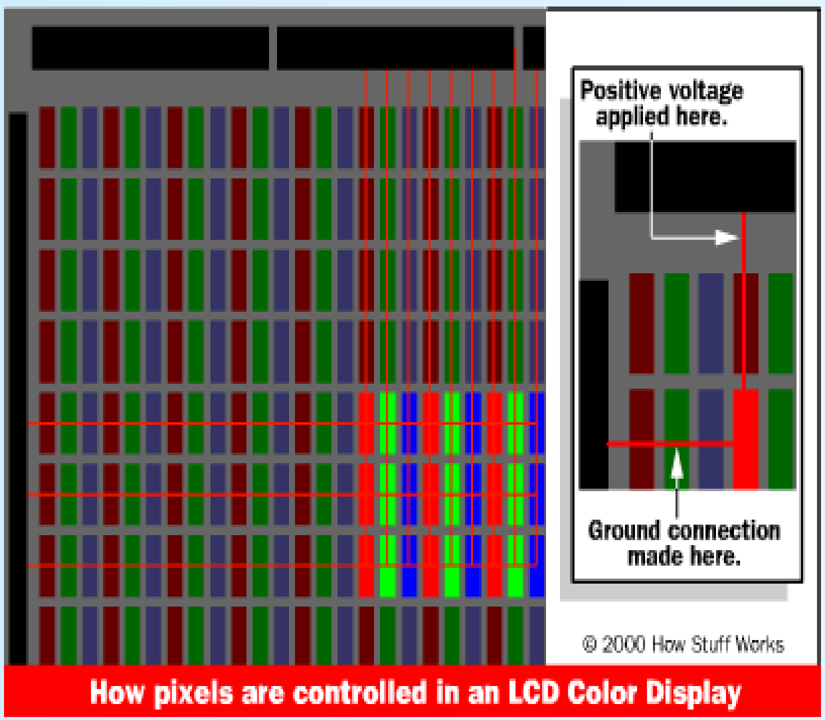
LCD enhancements

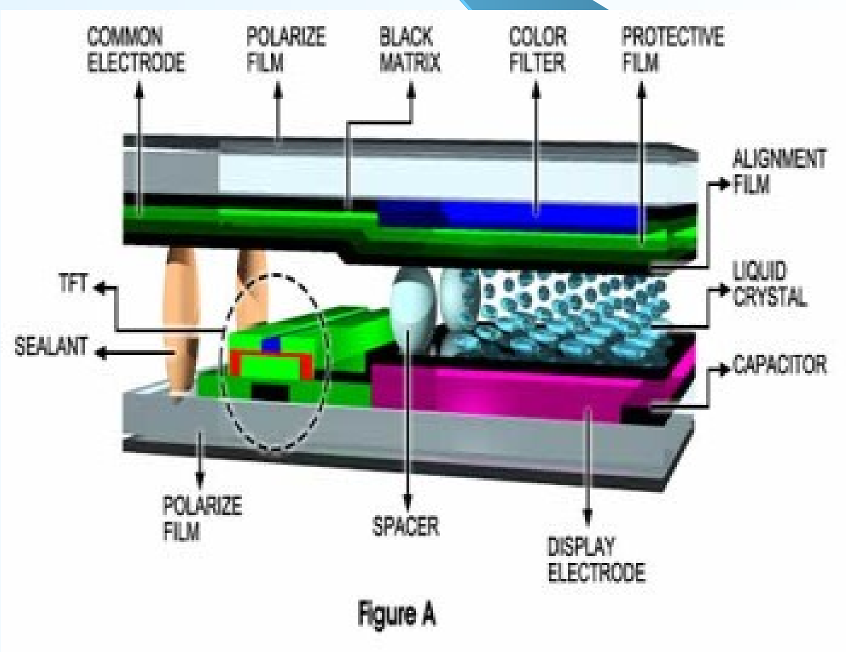
- TN = Twisted nematic
- STN = Super TN
- TFT = Thin Film Transistor
- The intensity of the light is controlled by the amount of the electrical field, which affects the "straightness" of the spiral.



LCD enhancements

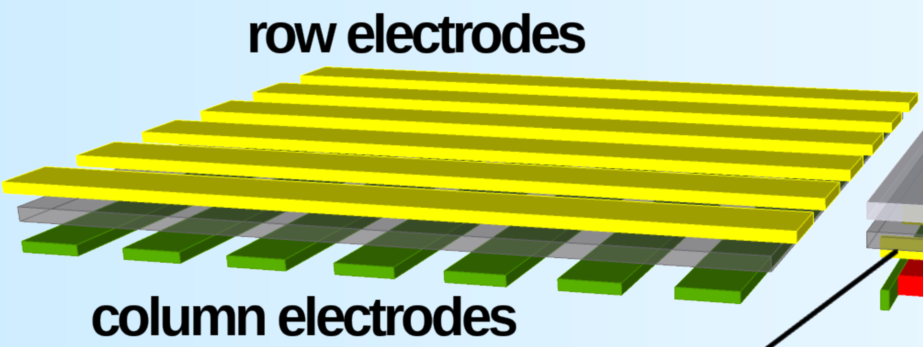
- STN uses passive matrix technology of points control
- TFT uses active matrix technology that improves rendering speed



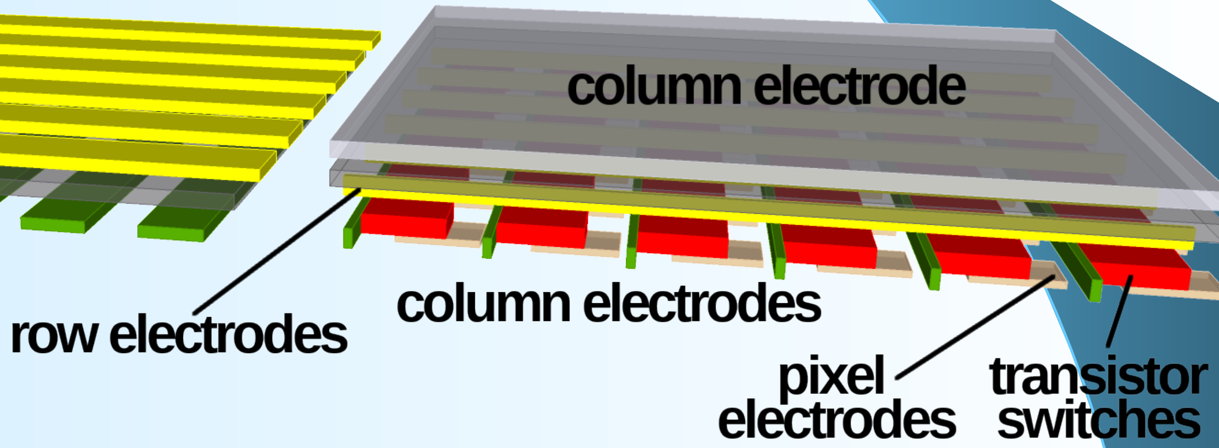


LCD enhancements

Passive matrix



Active matrix

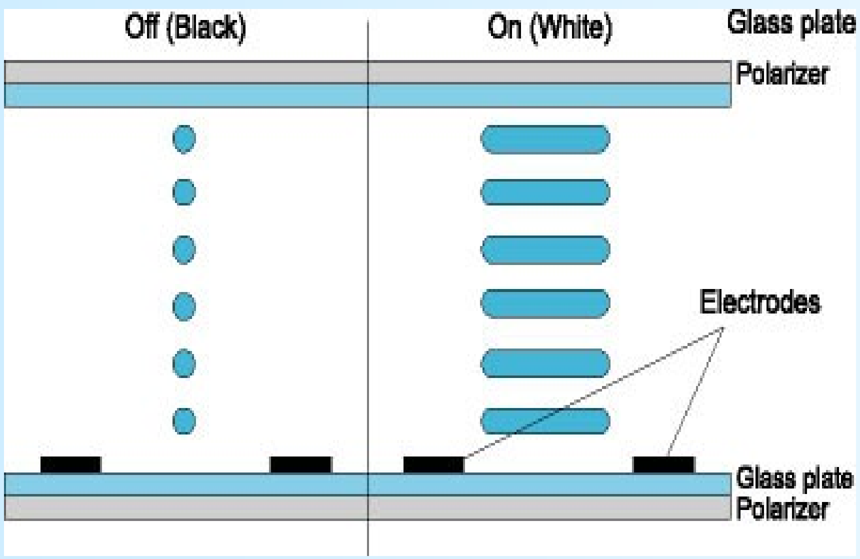


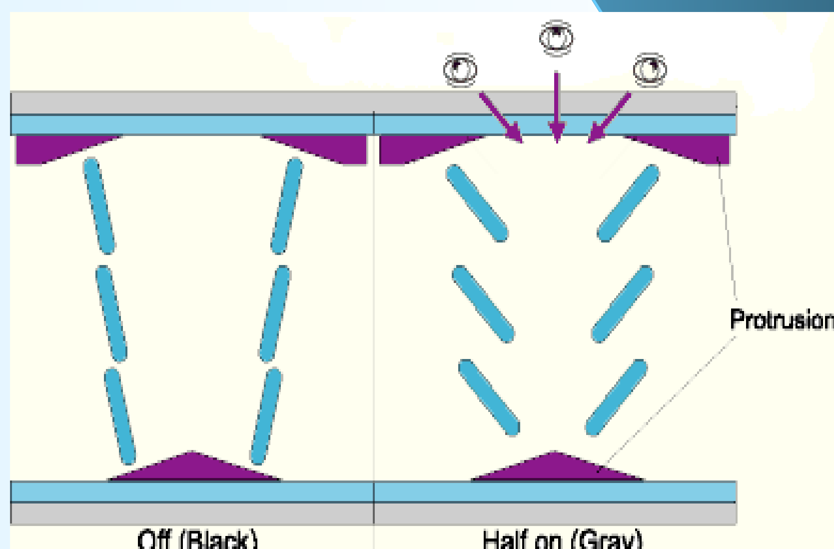
LCD enhancements

Field of view increasing:

- *In-plane switching* (1996 Hitachi) – *AS IPS, IPS Pro*
- *Multi-domain* vertical alignment (1998 Fujitsu)
- *Patterned* vertical alignment (2001 Samsung)

Bad (dead) subpixel is black.





LCD enhancements

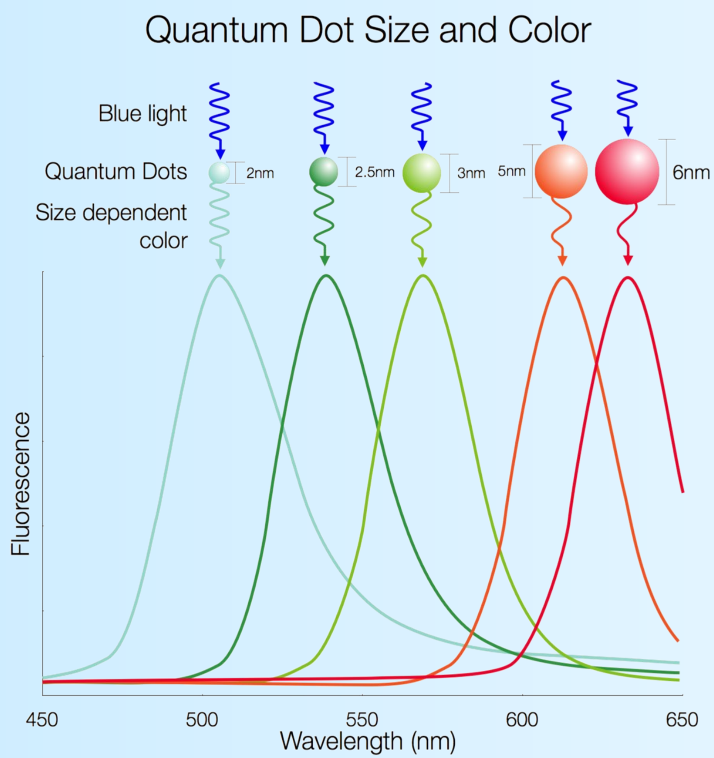
Transflective (trans-reflective) technology:

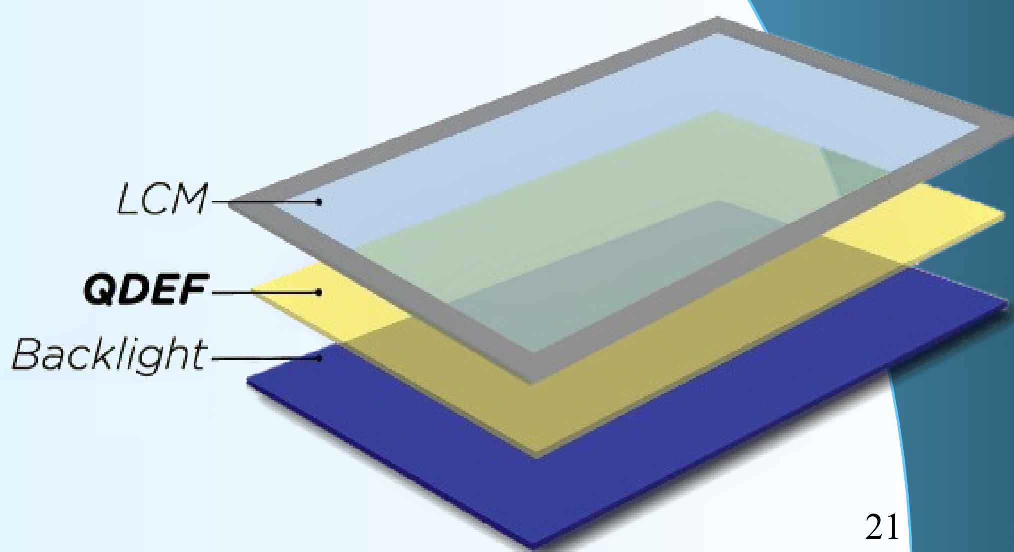
- Have transmissive and reflective characteristics.
- Contain a backlight unit and a semitransparent reflector.
- The reflector is behind the rear polarizer.
- Light from the backlight can pass the semitransparent reflector (transmissive mode) and at the same time, ambient light can be reflected.
- The display is visible in direct sunlight.

LCD enhancements

Technology of Quantum Dots:

- Very small semiconductor nanocrystal of CdSe.
- Using photoluminescence converts blue light to red and green.
- Colour depends on nanocrystalline size.





LCD enhancements

Benefits of use:

- Better colour rendering – greater colour space (gamut).
- Less power consumption.
- Greater contrast and brightness because they do not use RGB filters for subpixels.
- Longer lifetime than OLED.

Comparision – LCD vs CRT

CRT displays

Pros:

- Quick response
- Any intensity of color (great possibilty to modulate electron beam)
- Cheaper technology
- Wide field of view, high contrast and brightness

Cons:

- Heavy and big (typ. 70x70 cm = 15 kg)
- Big energy consumption (typ. 140W)
- Harmful electrical and magnetic field
- Flickering at 50-80 Hz (without memory effect)
- Convergence and geometry errors at the corners

Comparision – LCD vs CRT
LCD monitors

Pros:

- Thin and light (approx. 1/5 CRT)
- Low power consumption (typ. 1/4 CRT)
- Totally flat – no geometry errors
- No harmful radioactive radiation

Cons:

- Higher price (typ. 2x CRT)
- Smaller FOV (typ. ± 80°)
- Smaller contrast (typ. 1:700)
- Smaller brightness (typ. 300 cd/m2)
- Saturated colours
- Problem with dark colors

History of plasma displays

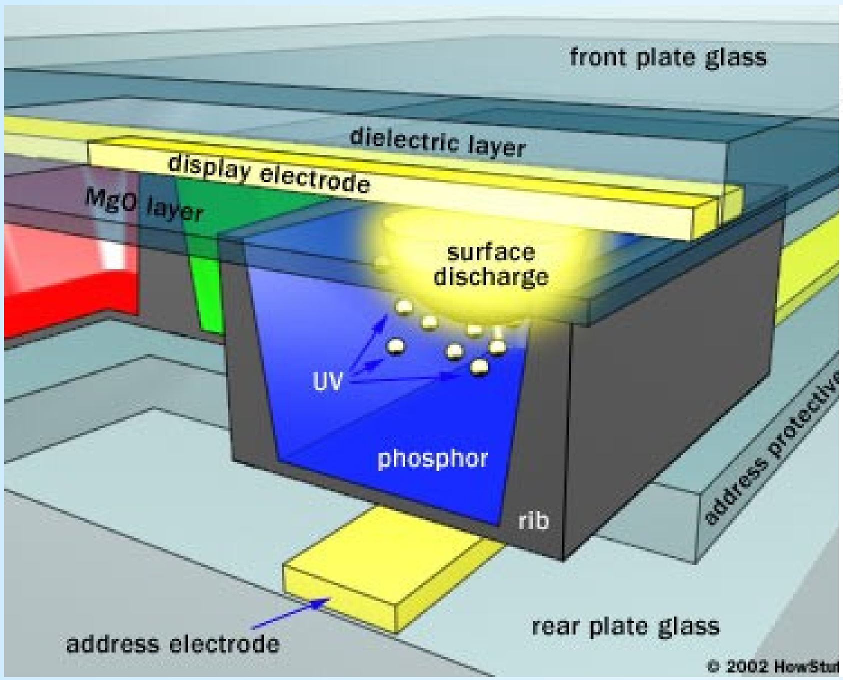
- The beginnings are the same as for CRT – 1855 *Geissler* designed a vacuum tube that glowed when it was influenced by the electric field. The color depends on the gas the tube was filled with.
- 1964 *Bitzer* et al. designed the first monochrome display.
- 1992 *Fujitsu* – made 21" color plasma display.

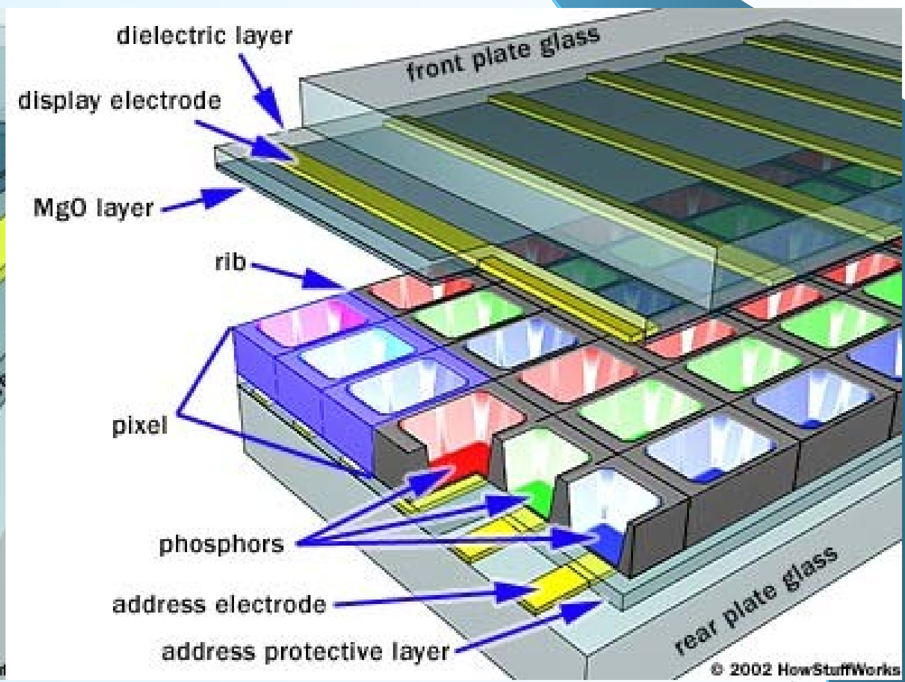
Plasma displays

- The principle is similar to a classical neon fluorescent lamp – the tube is filled with gas and its inner wall is covered with luminophore.
- When the fluorescent lamp is switched on, the electrons are released by ionizing the gas atoms and emit UV radiation (photons).
- The ultraviolet photons hit the phosphorus atoms and emit visible light – **fluorescence**.

Plasma displays

- For color displays, the colour is made up of three cells that emit either red, green or blue light depending on the luminophore.
- The intensity of the emitted light is controlled by blinking.





Comparison PD and LCD
LCD displays

Pros:

- Higher pixel density
- Greater brightness (typ. 2x plasma displays)
- Pixels do not burn in

Cons:

- Contrast (typ. 1/4 - 1/2 plasma displays)
- Blurred motion of objects
- Too saturated colors
- They are backlit, they do not emit light

Comparison PD and LCD
Plasma displays

Pros:

- Greater field of view (± 85°)
- More colours (*gamut* reaches SMPTE C)
- Darker shades of black

Cons:

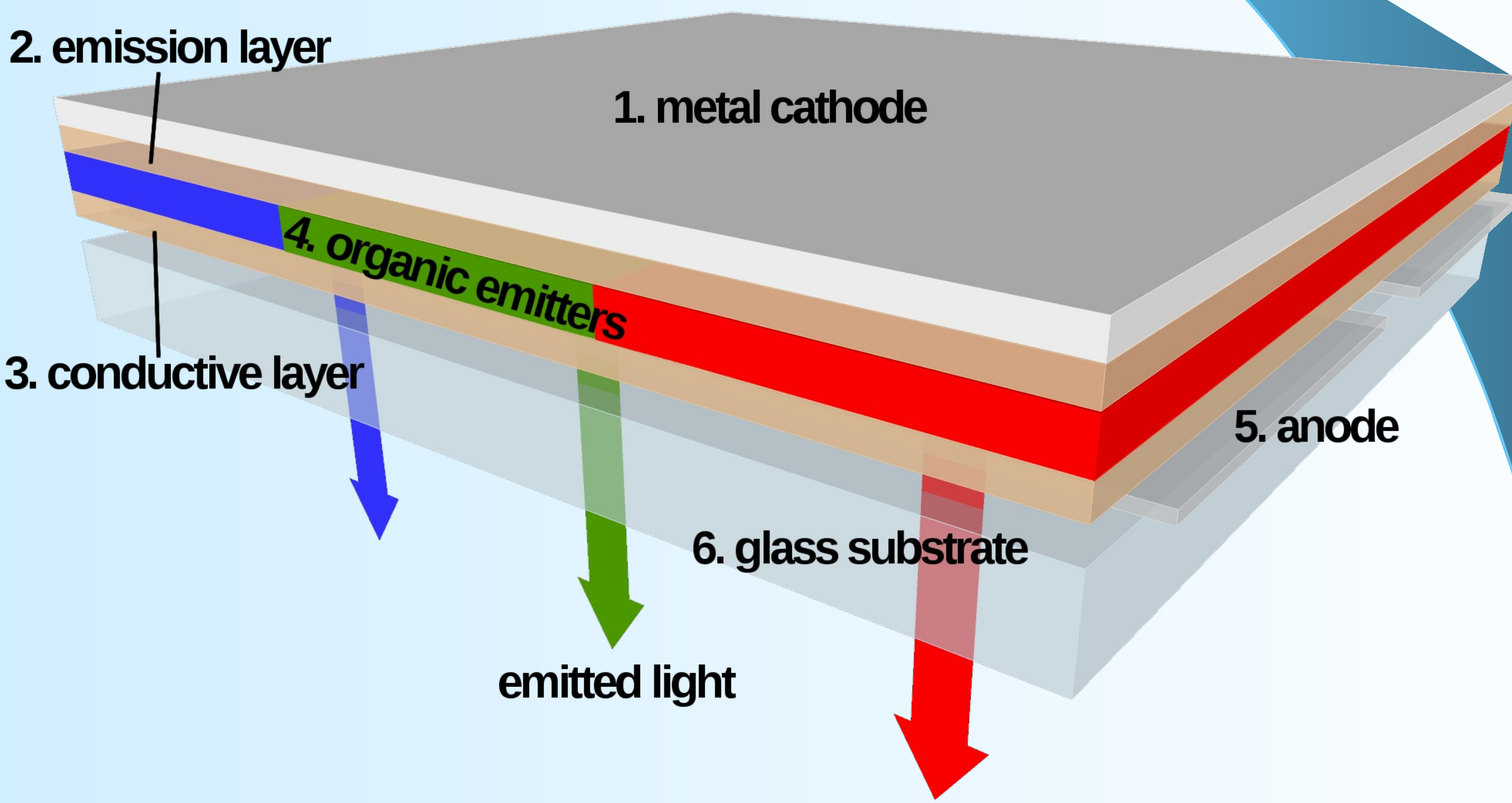
- Phosphorus burn in
- Higher power consumption
- Bigger point size (0.8 mm - 1 mm)

History of OLED

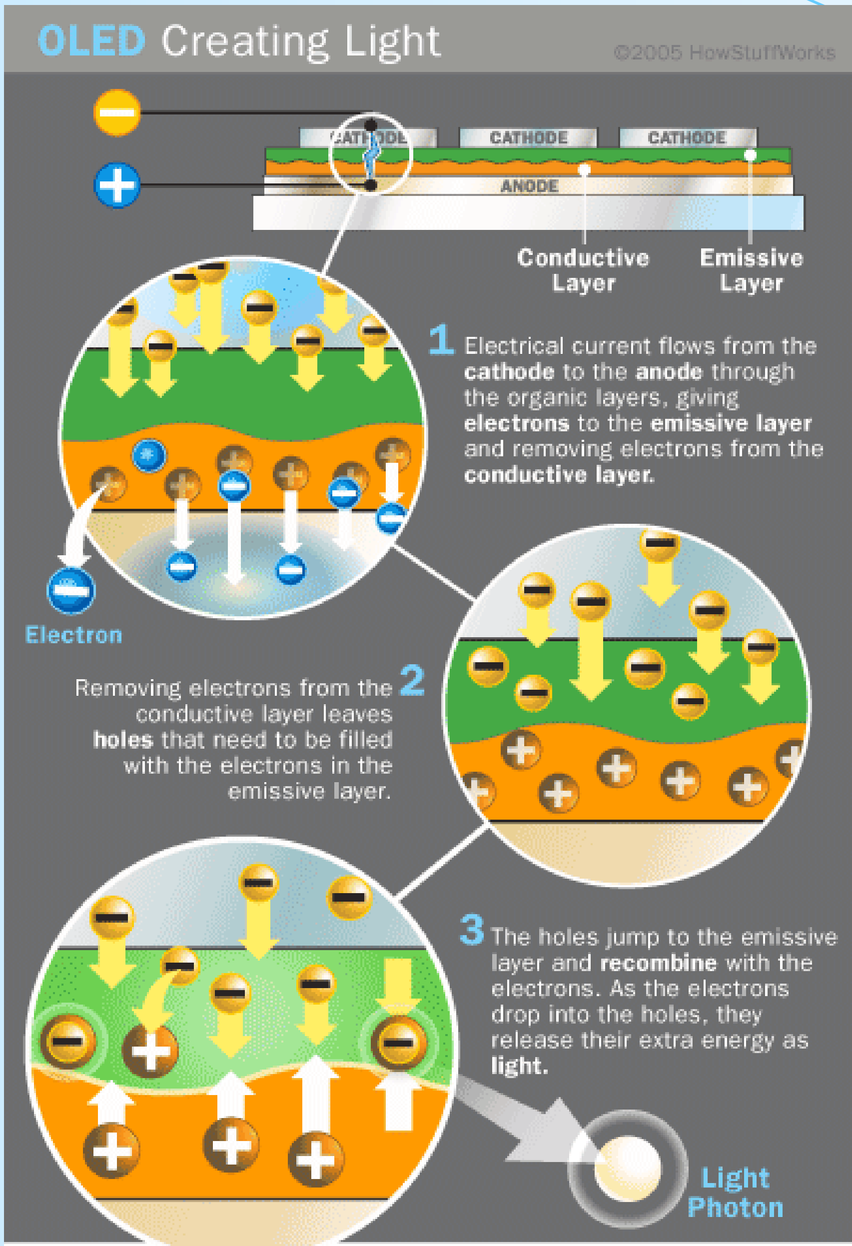
- 1950' *Bernanosov team* – created the first electroluminescent material which glowed after applying high voltage AC.
- 1960' *Dow Chemical* – developed an electroluminescent substance influenced by a DC current.
- 1977 *Shirakawa* et al. – created conductive organic polymers for which they won the Nobel Prize in 2000.
- 1980 *Eastman Kodak* (Tang & Slyke) – invented the revolutionary two-layer structure that is now the basis of OLED displays.
- 2007 *Sony XEL-1* – sold first 11" OLED TV.

OLED displays

- OLED = Organic Light Emitting Diode
- **Light emitting polymers** are special plastic materials (composed of long molecules) that convert the electric current into visible light.



OLED displays



The principle of electroluminescence

- The electron flow passes from the cathode to the anode:

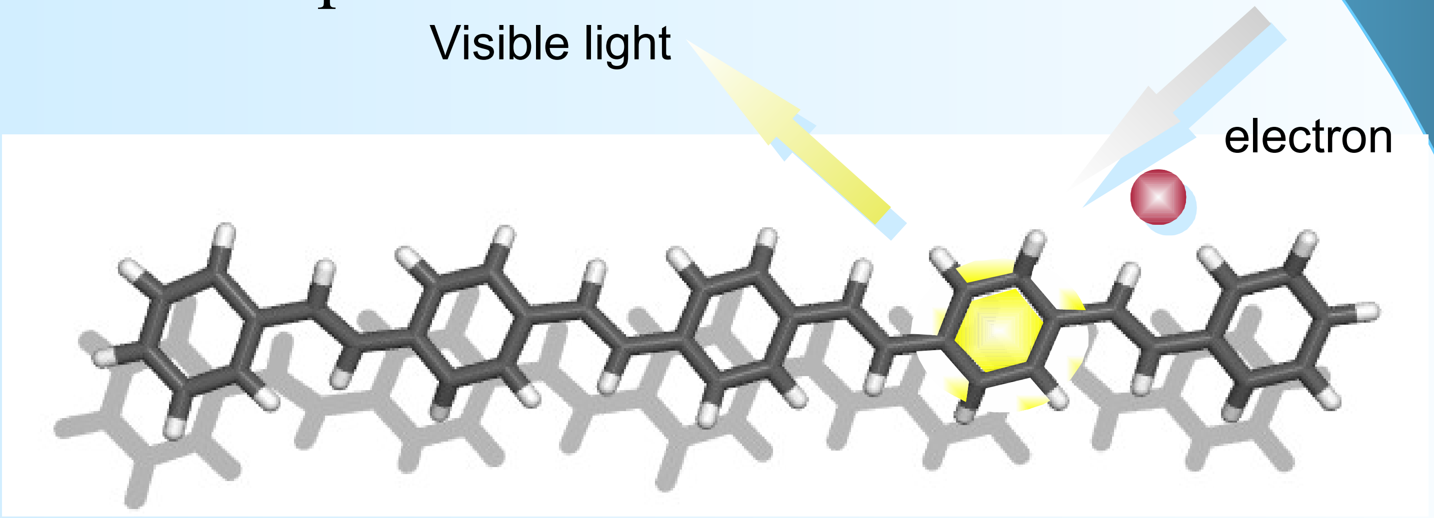
  - the cathode delivers electrons to the emission layer

  - the anode takes electrons from the conductive layer (electron holes)

- At the boundary of the E/C layer, **recombination** occurs – electrons fill holes and emit light.

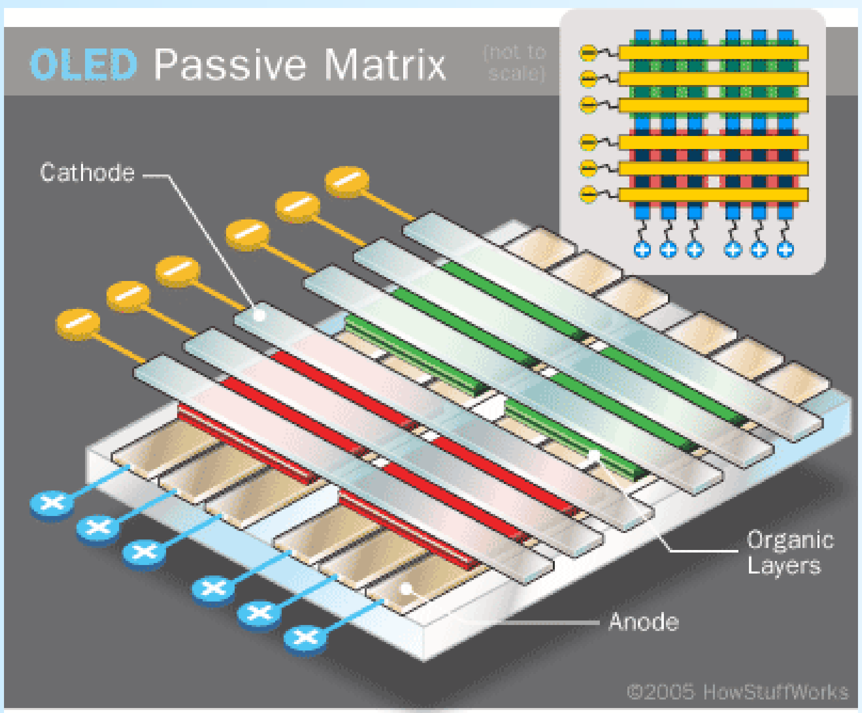
Electron-hole recombination

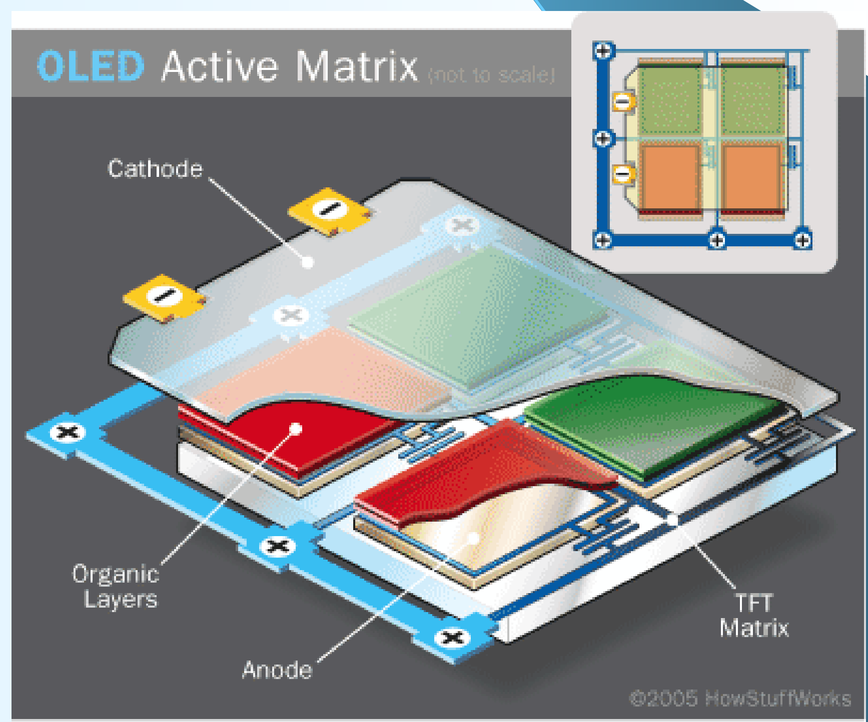
- The electrones do not remain in the conduction band and are reintegrated into the electron shell of the atom.
- The electron fills the hole and emits energy in the form of a photon.



OLED displays

- Passive Matrix OLED
- Active Matrix OLED
- Colour is created by different chemical compositions of polymers.
- The intensity of the light is controlled by changing the electrical voltage.





OLED displays

- SmOLED – Small molecule OLED. Polymers are applied in vacuum on a glass plate.
- PLED – Polymer LED. They have little energy consumption. Polymers can be applied to flexible material using *ink* technology.
- PhOLED – Phosphorescent OLED. They are very efficient.

Comparison OLED vs LCD
OLED displays

Pros:

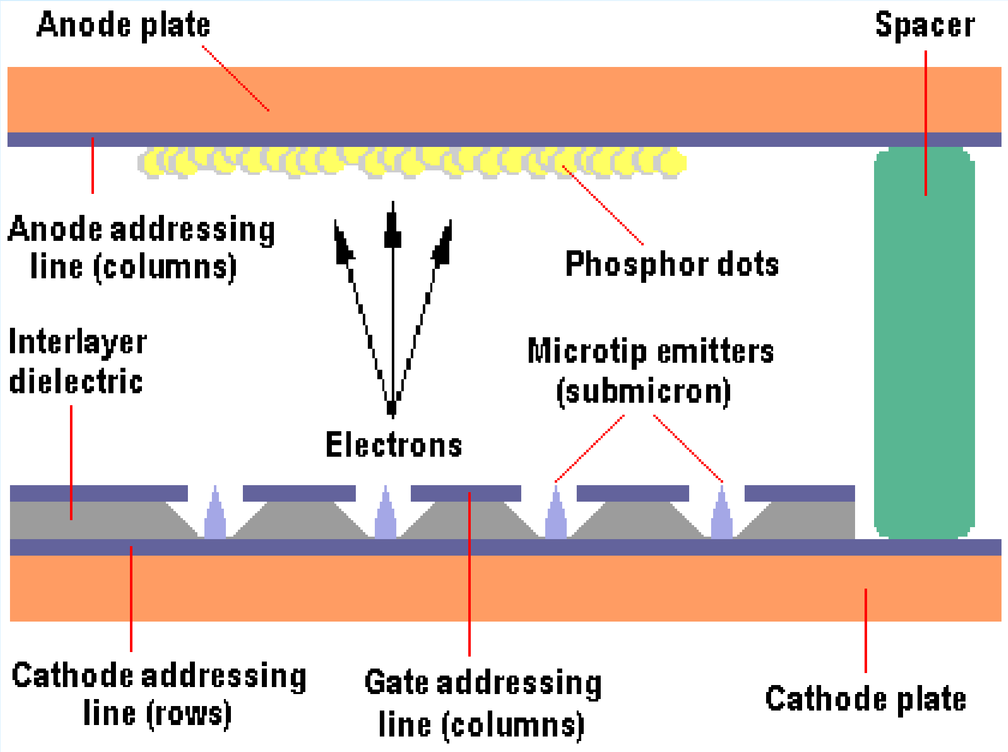
- Slimmer, lighter, flexible
- Brighter
- Do not require backlighting
- Less power consumption
- Larger field of view
- Easier to produce

Cons:

- Lifetime – red and green (≈ 60000 hours) modrá (≈ 14000 hours)
- Currently expensive production
- Water destroys OLED molecules

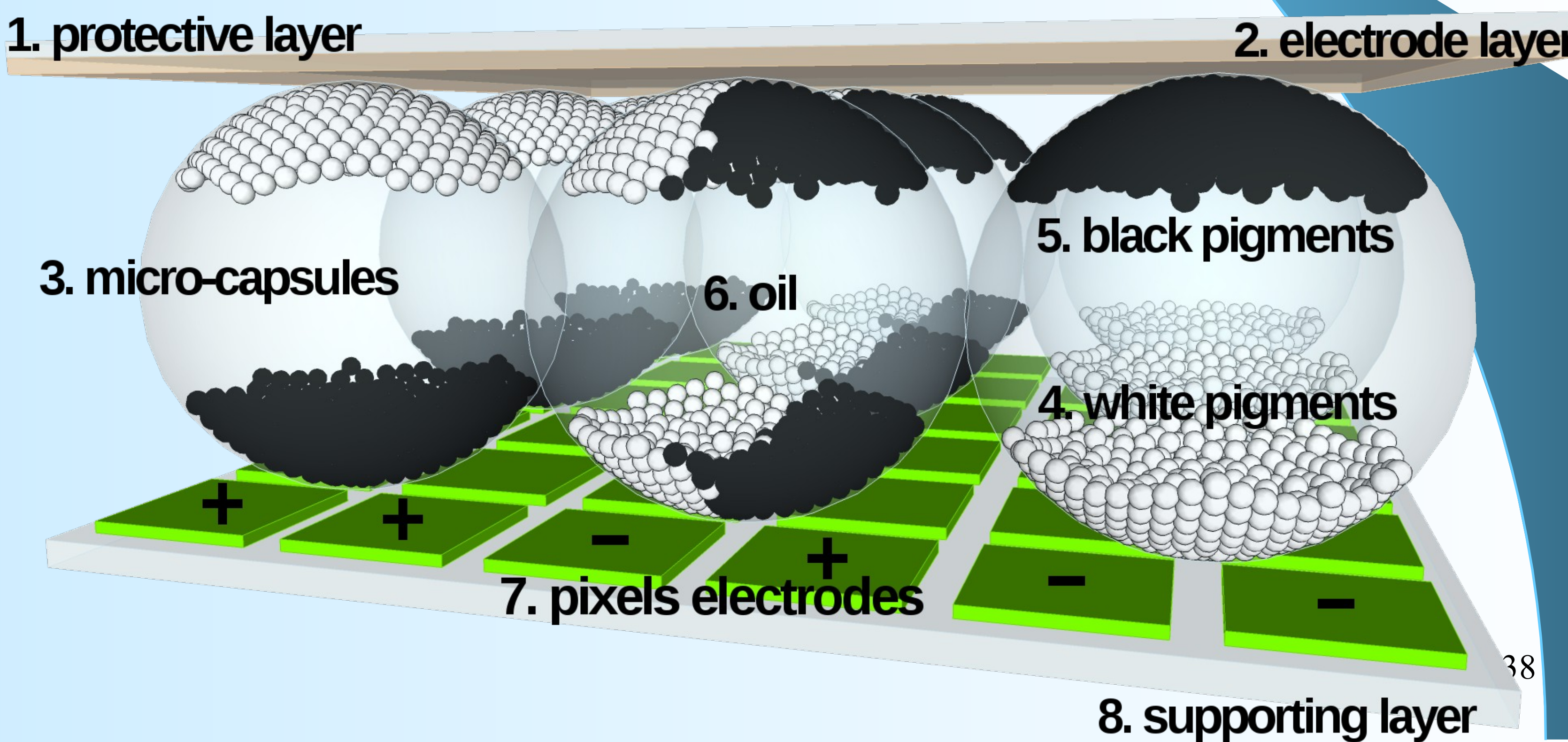
Another technologies

- FED = Field Emission Display
- Each point contains a small cell in which the electrons hit the luminophore as in the CRT.



Electronic ink

- E Ink = Electronic ink
- Positively charged particles with a white pigment are attracted by a negatively charged electrode and negatively charged ones with a black pigment are attracted to a positively charged electrode.

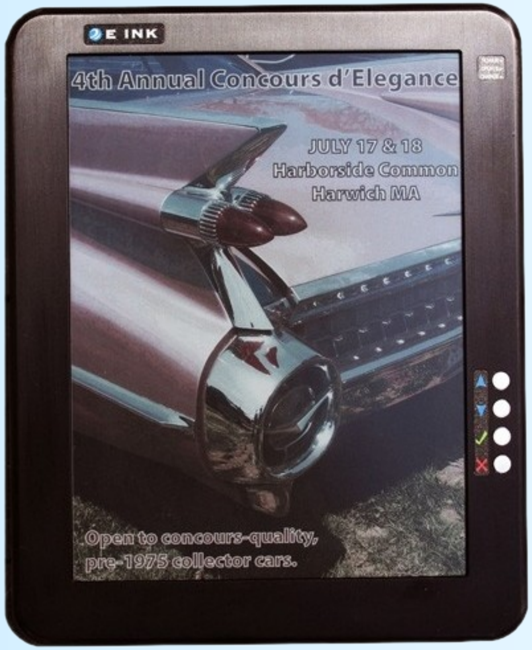


Enhancement of E Ink

- E Ink *Spectra* – uses of black, red and white pigments
- E Ink *Triton* – addition of a colour filter with R, G, B, W cells

  - bad contrast and drab colours
- *Advanced Color ePaper*

  - achieves a full color gamut using only colored pigments

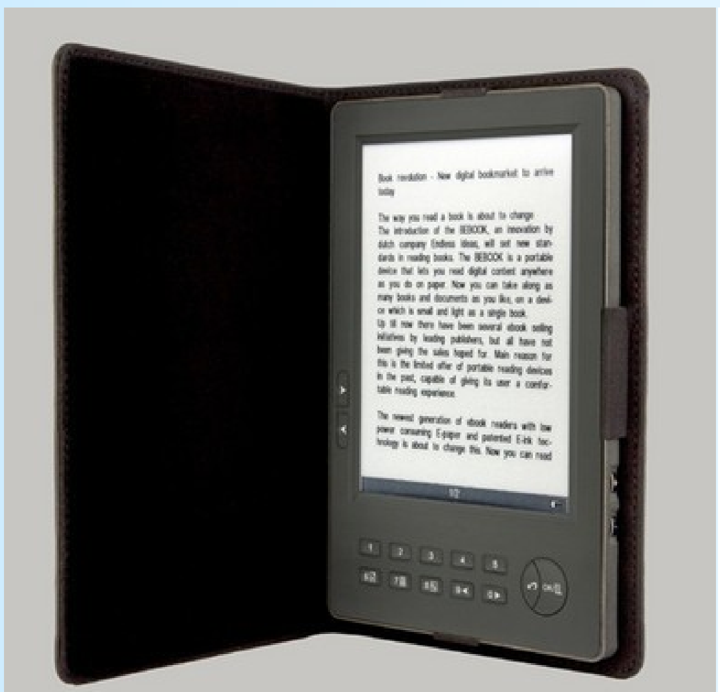


Enhancement of E Ink

- In order to eliminate the absorption of light through the touch layer and to improve the readability, backlit is used.

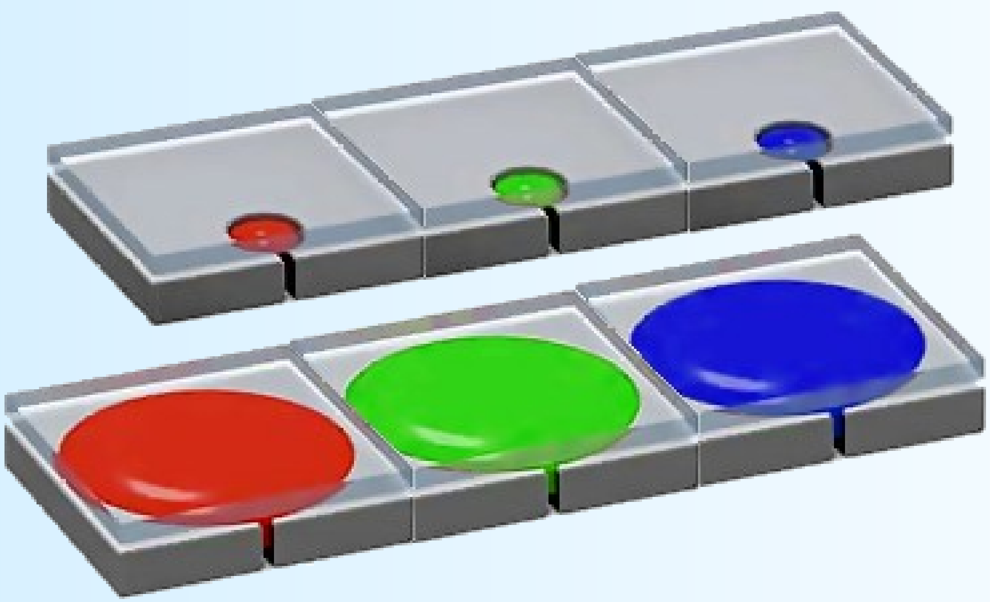
Electronic ink

- It has very low power consumption. Energy is needed only when the image is redrawn.
- Does not emit light. Uses reflected light.
- It is used in e-readers.



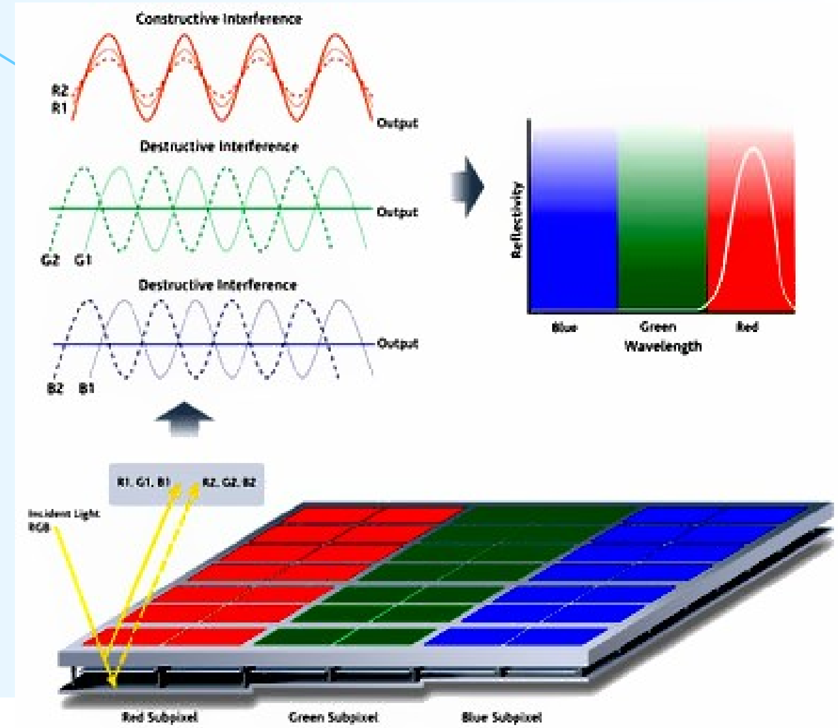
Electrofluidic

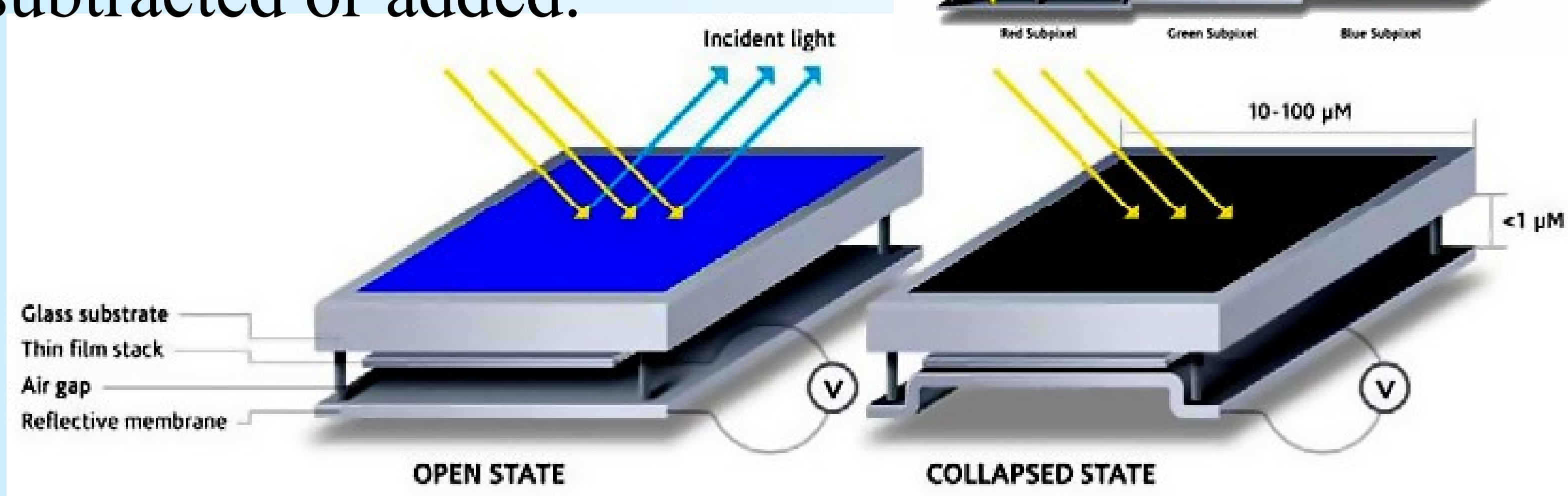
- Pixels are composed of cells containing coloured liquid.
- In the off state, the fluid is in the cell reservoir at the bottom of the cell.
- In the on state, the liquid is attracted by the electrode on the top of the cell.
- Each pixel contains three RGB cells.



Mirasol

- Uses the interference of light waves, like in the butterfly wings.
- Two waves interfere, one is reflected from the surface of the cell, the other from the reflective membrane.
- Interfering waves are subtracted or added.





Mirasol

- Compared to e ink, it has a faster response, but a worse contrast.