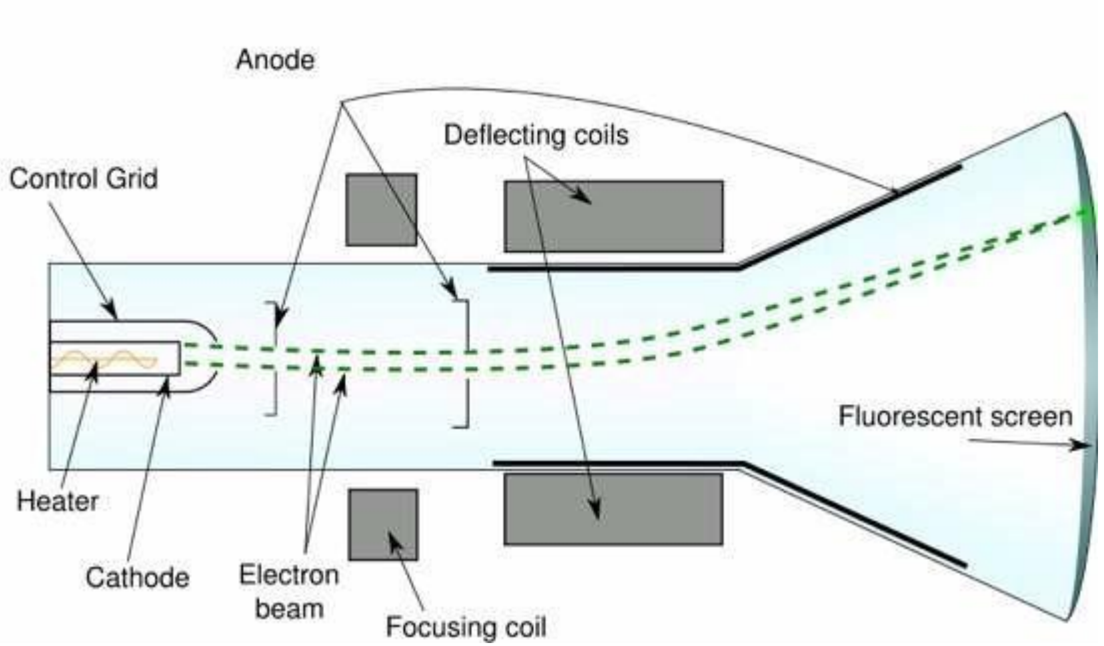
The earliest version of the CRT was known as the “Braun tube”, invented by the German physicist Ferdinand Braun in 1897

Basic CRT functional Diagram



Coca-Cola zero
'Coca-Cola', 'Coke', 'Coca-Cola Zero', the Dynamic Ribbon device and the design of the Coca-Cola Contour Bottle are registered trade marks of The Coca-Cola Company.
SAMSUNG
THE PRINCE'S RAINFORESTS PROJECT
SIGN UP AT
TDK
SANYO
THE SHOW EVERYONE
NG ABOUT

LED Display

Quantum Dots

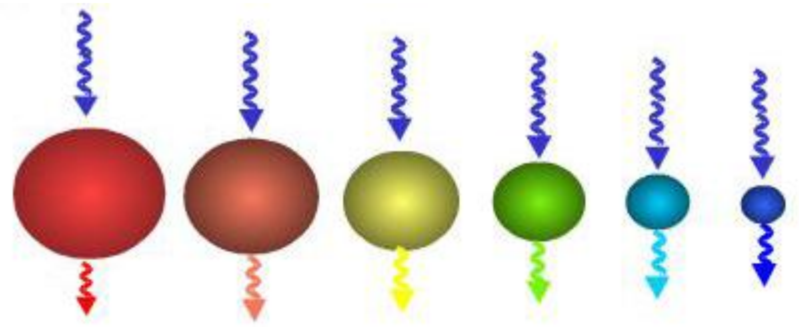
These are synthetic ‘droplets’ involving a single electron to thousands of atoms but behaving like a single huge atom

These are tiny (1-5 nm) semiconductor nanocrystals with extraordinary optical properties

Tunability in emitted light colour

Colours from blue to IR (from smallest size to bigger)

Quantum Dots



Ordinary light excites all colour QDs (any light source bluer than the QD of interest)

Quantum Dot Display Technology

Disruptive Technologies | Future Direction

Disruptive Technologies | Future Direction

Std. terminology:

▪ 720p	1280x720 resolution
▪ 1080p	1920x1080 resolution
▪ 4K	3840x2160 resolution

- UHD TV
- 4K Ultra HD TV (Vizio)
- 4K Super UHD TV (LG)
- SUHD TV (Samsumg)
- 4K HDR TV (Sony)

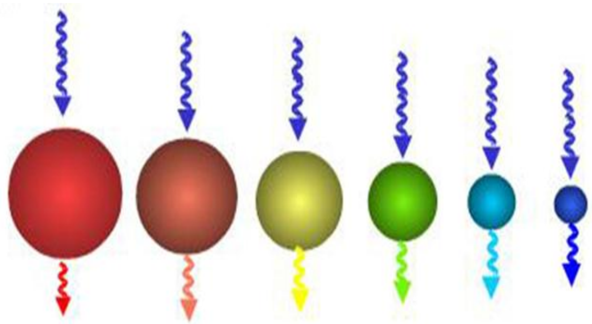
Disruptive Technologies | Future Direction

Quantum dots (QD) are tiny, nanoscale (1-5 nm) semiconductors/crystals that emit different colour light when you shine light on them.

These colours depend on the size of the QD.

Big to small QDs show a blue shift. QDs change colour with size because additional energy is required to ‘confine’ the semiconductor excitons to a smaller volume.

Disruptive Technologies | Future Direction



This gives tunability in colours.
CdSe, ZnSe, InP are the suitable materials for QDs.

Disruptive Technologies | Future Direction

R (227),
G (213),
B (29)

R (249),
G (249),
B (103)

R (49),
G (221),
B (239)

What we see on a display screen (TV, computer, mobile phone etc.) is a combination of RGB.

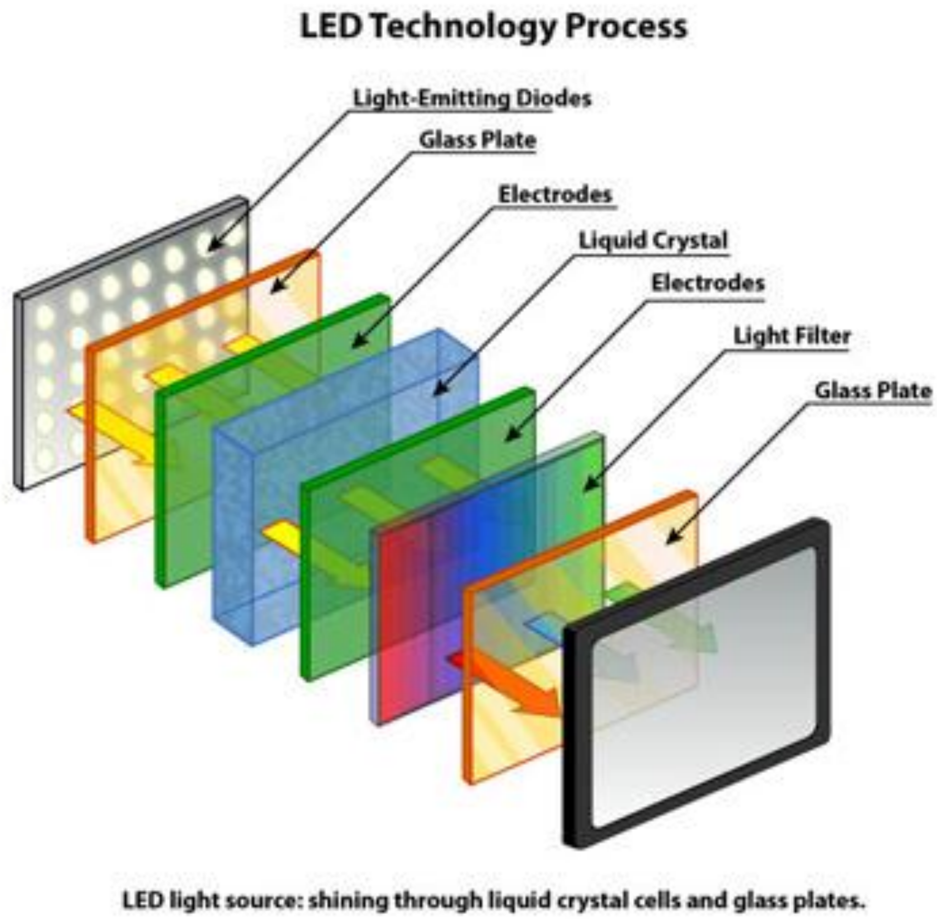
Disruptive Technologies | Future Direction

A LCD display technology has 3 parts:

- Blue backlight source
- Colour filters to divide that source into red, green and blue
- Electronics of LCD (works like a massive grid of tiny windows (pixels) emanating light of RGB (sub-pixels) that combine together to let us see what we see on the screen)

By mixing the amount of light from these sub-pixels TV creates billions of colours, to make our viewing experience as close as possible to the natural colours.

Disruptive Technologies | Future Direction



https://www.youtube.com/watch?v=Bf3547WB5qs

Disruptive Technologies | Future Direction

Old LCD display technology uses fluorescent lamps (CCFL) as backlight source.

It is replaced by an array of white light LEDs in what we call LED TVs.

The purer the light at each sub-pixel, the narrower the spectrum and the more precisely colours can be mixed at that pixel.

How to meet it?

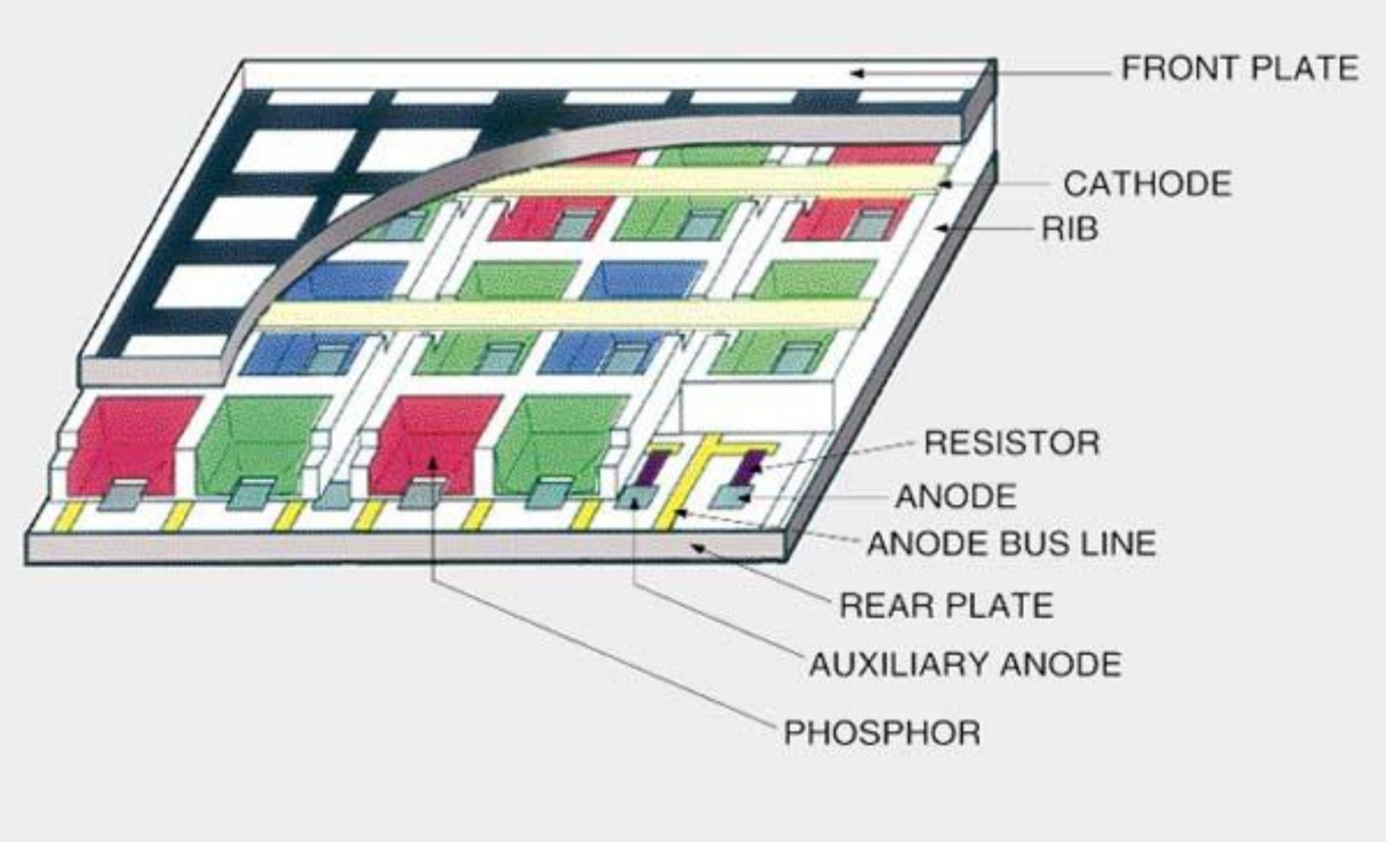
Disruptive Technologies | Future Direction

One way is to use very strict filters that allow only a sharp spectrum of R,G,B. Narrowing the filter dims the brightness and hence a big NO for TV manufacturer.

Other is to tinker the backlight itself.

What goes in white LED – a blue colour produced by GaN excites a YAG phosphor to give yellow light. Both combined together give us white light. Obviously it is rich in B & Y and poor in R & G.

Disruptive Technologies | Future Direction



Disruptive Technologies | Future Direction

To compensate on this *poorness*, filters giving out R,G,B actually allow broader spectrum in case of R & G component.

The G sub-pixel is not exactly green, but a mix of *blue* green through *yellow* green.

Obviously, these impure lights cannot give you the precise natural colour feeling while watching the TV.

Here comes the Angel called QDs.

Disruptive Technologies | Future Direction

What we do is:

- Take a blue LED (450 nm) array as backlight source
- Let it fall on a thin film of QDs
- LCD electronics remain the same

These QDs coated on this film are of two dimensions:

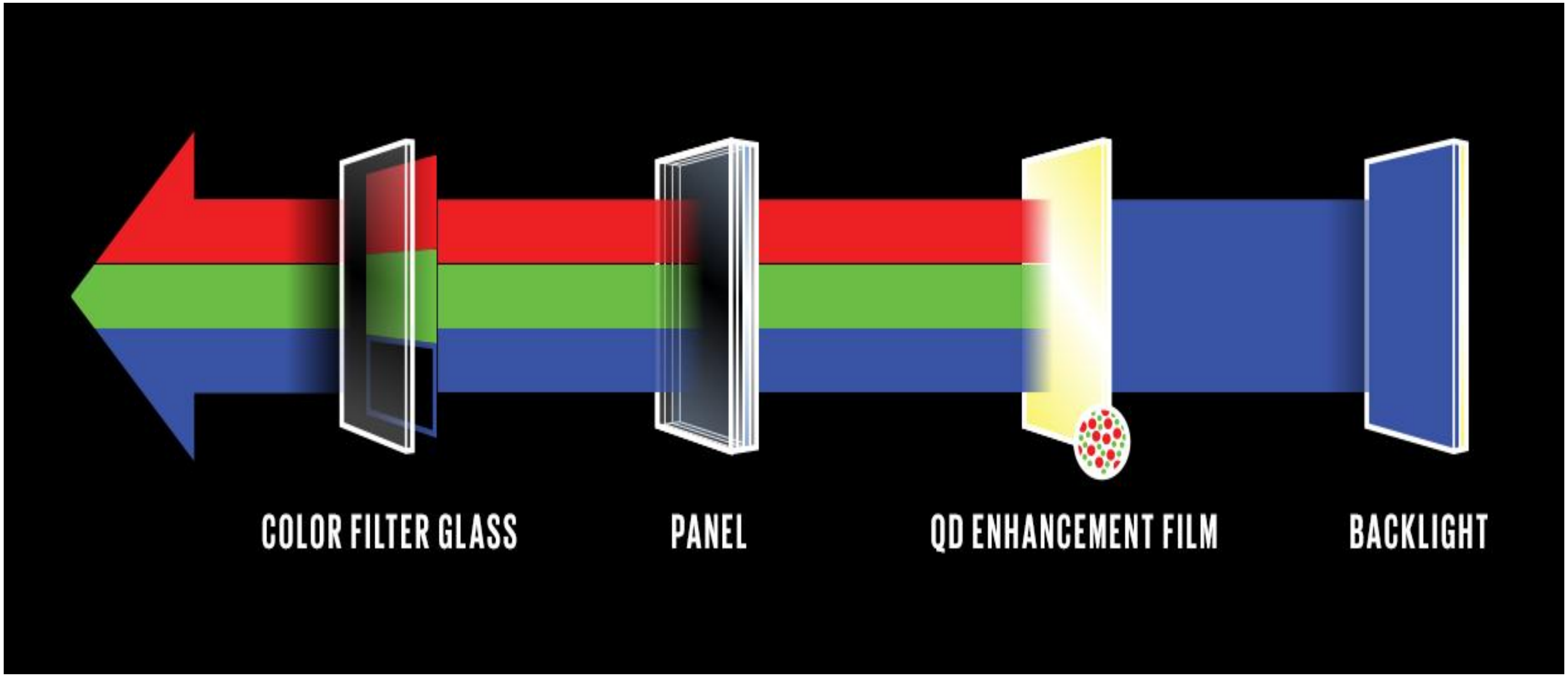
- 1.5 – 2.5 nm (giving away 527 nm green light)
- 3.0 – 5.0 nm (giving away 638 nm red light)

The tunability of QDs ensures sharp, narrow spectra of R & G. The blue we take directly from the blue LED.

Disruptive Technologies | Future Direction

Hence a QD LCD display technology guarantees

- narrowest possible R,G,B spectra at sub-pixel level and



Quantum Dots

QD absorbs light and quickly re-emits, but in a different wavelength – owing to its size.

QDs change colour with size because additional energy is required to ‘confine’ the semiconductor excitons to a smaller volume.

Quantum Dots

Recall

Atomic structure, Pauli-Exclusion principle

(not more than two electrons can occupy the same box, of opposite spins)

Energy levels

Energy bands

(too many electrons, too many levels, almost continuous life)

Quantum Dots

Recall

Bandgap (for conduction purpose)

Height of bandgap is different for different material (bulk material)

Conduction band and Valence band

Number of electrons available in conduction band is too small in comparison to those in valence band

Quantum Dots

For example: Cu (29)

10^{25} electrons in conduction band and $2x10^{26}$ is in valence band for N = 10^{25}/cc

A sufficiently strong external stimulus (thermal/irradiation) generates an electron-hole pair, known as 'exciton'

De-excitation (half life of the level)

Then recombination of e-h pair takes place

Quantum Dots

De-excitation takes place between bottom of the conduction band and top of the valence band

We get a radiation almost equal to the bandgap energy

Since bandgap is fixed in bulk material, so is the wavelength of the radiated energy

This changes at nanoscale, i.e., in QDs

Bandgap energy some typical materials

Semiconductor material	Symbol	Bandgap energy (in eV)
Germanium	Ge	0.67
Silicon	Si	1.14
Gallium arsenide	GaAs	1.43
Gallium phosphide	GaP	2.26
Gallium nitride	GaN	3.4
Diamond	C	5.5
Silicon dioxide	SiO_2	9

Quantum Dots

Exciton Bohr Radius

An average physical separation between e-h pair in an exciton

Like bandgap Exciton Bohr Radius, too, is unique for each material

In bulk material, excitons can extend up to their natural size

Nanoscale poses problems!

Quantum Dots

Ballistic Transport

For a given medium one can associate to a moving electron a mean free path as the average length that the electron can travel freely, i.e. before *hitting* against something.

The mean free path can be increased by reducing the number of impurities in a crystal.

Quantum Dots

Ballistic Transport

Ballistic transport is observed when the mean free path of the electron is (much) bigger than the size of the *box* that contains/delimits the medium through which the electron travels, such that the electron alters its motion only by hitting against the *walls*.

Hence, if the size of the box is smaller than the mean free path of the electron, it sees almost negligible electrical resistance.

Quantum Dots

Quantum Confinement

The size of a nanocrystal is comparable to the size of the material's Exciton Bohr Radius (or may be smaller)

They now have to be squeezed in several discrete levels corresponding to each pair

This situation of discrete energy levels is called quantum confinement

Quantum Dots

Under these conditions, the semiconductor material ceases to resemble a bulk, and instead can be called a quantum dot.

A few atoms added/subtracted alters the boundaries of these new emerging bandgaps.

Or even changing the geometry of the surface

Quantum Dots

The bandgap in a quantum dot (with decreasing size) will always be energetically larger; therefore, we refer to the radiation from quantum dots to be "blue shifted" reflecting the fact that electrons must fall a greater distance in terms of energy and thus produce radiation of a shorter, and therefore "bluer" wavelength.

Quantum Dots

Applications

Next-generation white LEDs

Wide ange of security and marking products including night vision pigments and inks

Photovoltaics

Medical devices

Biological probes for clinical diagnostics and in vivo diagnostics.

Quantum Dots

Behaves better than an Organic Dye

Organic Dye	Quantum Dot
Broad output spectrum	Sharper spectrum
Fades quickly ~ 100 ps	5-40 ns
unstable	Stable output over time
One dye excited at a time	Multiple excitation simultaneously possible, multicolour imaging possible