UNIT - I
Light Emitting Diodes

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Light Emitting Diode

In 1879, Edison invented the incandescent light bulb.

In the light bulb, an electric current is passed through a filament inside the bulb. When sufficient current is passed through the filament, it gets heated up and emits light.

The light emitted by the filament is the result of electrical energy converted into heat energy which in turn changes into light energy.

In Light Emitting Diodes (LEDs), electrical energy flowing through it is directly converted into light energy.

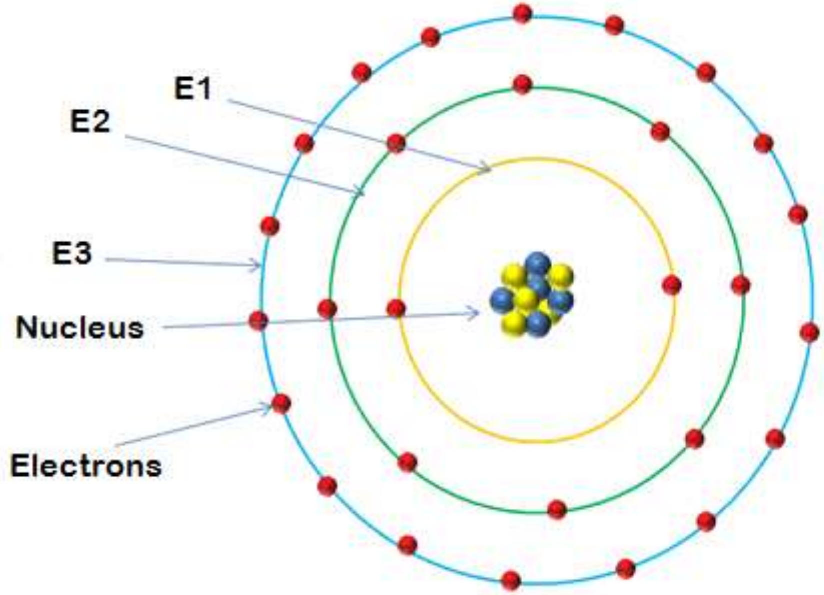
Light is a type of energy that can be released by an atom. Light is made up of many small particles called photons.

Atoms are the basic building blocks of matter.

Atoms are made up of small particles such as electrons, protons and neutrons.

Light Emitting Diode

- The attractive force between the protons and neutrons makes them stick together to form nucleus. Neutrons have no charge. Hence, the overall charge of the nucleus is positive.



- The negatively charged electrons always revolve around the positively charged nucleus because of the electrostatic force of attraction between them. Electrons revolve around the nucleus in different orbits or shells. Each orbit has different energy level.

Light Emitting Diode

- The electrons in the higher energy level will not stay for long period. After a short period, the electrons fall back to lower energy level.

- The electrons which jump from higher energy level to lower energy level will releases energy in the form of a photon or light.

- In some materials, this energy lose is released mostly in the form of heat. The electron which loses greater energy will releases a greater energy photon.

- The Light emitting diode is a two-lead semiconductor light source. In 1962, Nick Holonyak has come up with an idea of light emitting diode, and he was working for the general electric company.

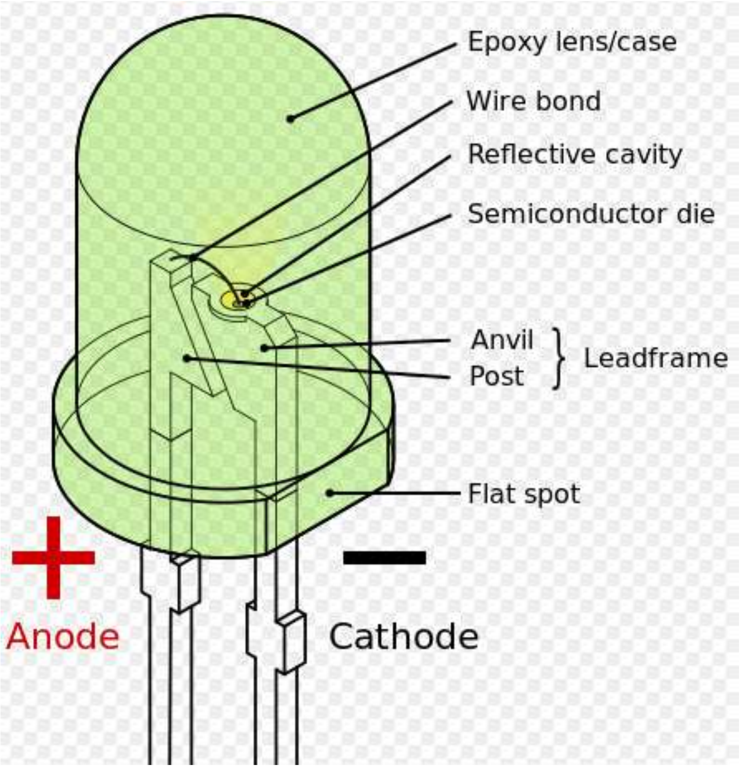
- The LED is a special type of diode and they have similar electrical characteristics of a PN junction diode. Hence the LED allows the flow of current in the forward direction and blocks the current in the reverse direction.

Light Emitting Diode

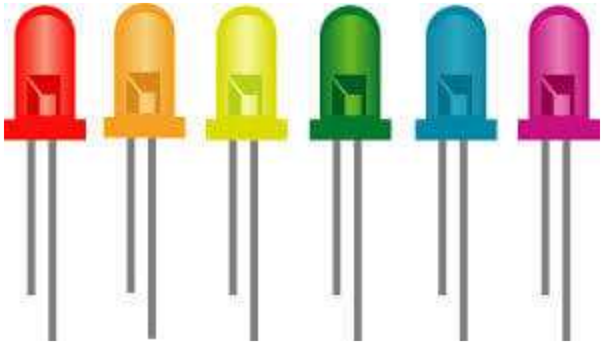
- Light Emitting Diodes (LEDs) are the most widely used semiconductor diodes among all the different types of semiconductor diodes available today.

- It emit either visible light (or) invisible infrared light when forward biased. The LEDs which emit invisible infrared light are used for remote controls.

- The LED occupies the small area which is less than the **1 mm^2**. The applications of LEDs used to make various electrical and electronic projects.



Light Emitting Diode



- When Light Emitting Diode (LED) is forward biased, free electrons in the conduction band recombines with the holes in the valence band and releases energy in the form of light.
- The process of emitting light in response to the strong electric field or flow of electric current is called electroluminescence.
- A normal p-n junction diode allows electric current only in one direction. It allows electric current when forward biased and does not allow electric current when reverse biased.
- Thus, normal p-n junction diode operates only in forward bias condition.

Light Emitting Diode

- To create an LED, the n-type material should be connected to the negative terminal of the battery and p-type material should be connected to the positive terminal of the battery.

- In other words, the n-type material should be negatively charged and the p-type material should be positively charged.

- The construction of LED is similar to the normal p-n junction diode except that gallium, phosphorus and arsenic materials are used for construction instead of silicon or germanium materials.

- In normal p-n junction diodes, silicon is most widely used because it is less sensitive to the temperature. Also, it allows electric current efficiently without any damage. In some cases, germanium is used for constructing diodes.

- However, silicon or germanium diodes do not emit energy in the form of light. Instead, they emit energy in the form of heat.

- Thus, silicon or germanium is not used for constructing LEDs.

Light Emitting Diode

Layers of LED

A Light Emitting Diode (LED) consists of three layers:
p-type semiconductor , n-type semiconductor and depletion layer. The p-type semiconductor and the n-type semiconductor are separated by a depletion region or depletion layer.

P-type semiconductor

- When trivalent impurities are added to the intrinsic or pure semiconductor, a p-type semiconductor is formed.
- In p-type semiconductor, holes are the majority charge carriers and free electrons are the minority charge carriers. Thus, holes carry most of the electric current in p-type semiconductor.

N-type semiconductor

- When pentavalent impurities are added to the intrinsic semiconductor, an n-type semiconductor is formed.
- In n-type semiconductor, free electrons are the majority charge carriers and holes are the minority charge carriers. Thus, free electrons carry most of the electric current in n-type semiconductor.

Light Emitting Diode

Depletion layer or region

Depletion region is a region present between the p-type and n-type semiconductor where no mobile charge carriers (free electrons and holes) are present.

- This region acts as barrier to the electric current. It opposes flow of electrons from n-type semiconductor and flow of holes from p-type semiconductor.

- To overcome the barrier of depletion layer, we need to apply voltage which is greater than the barrier potential of depletion layer.

How Light Emitting Diode (LED) works?

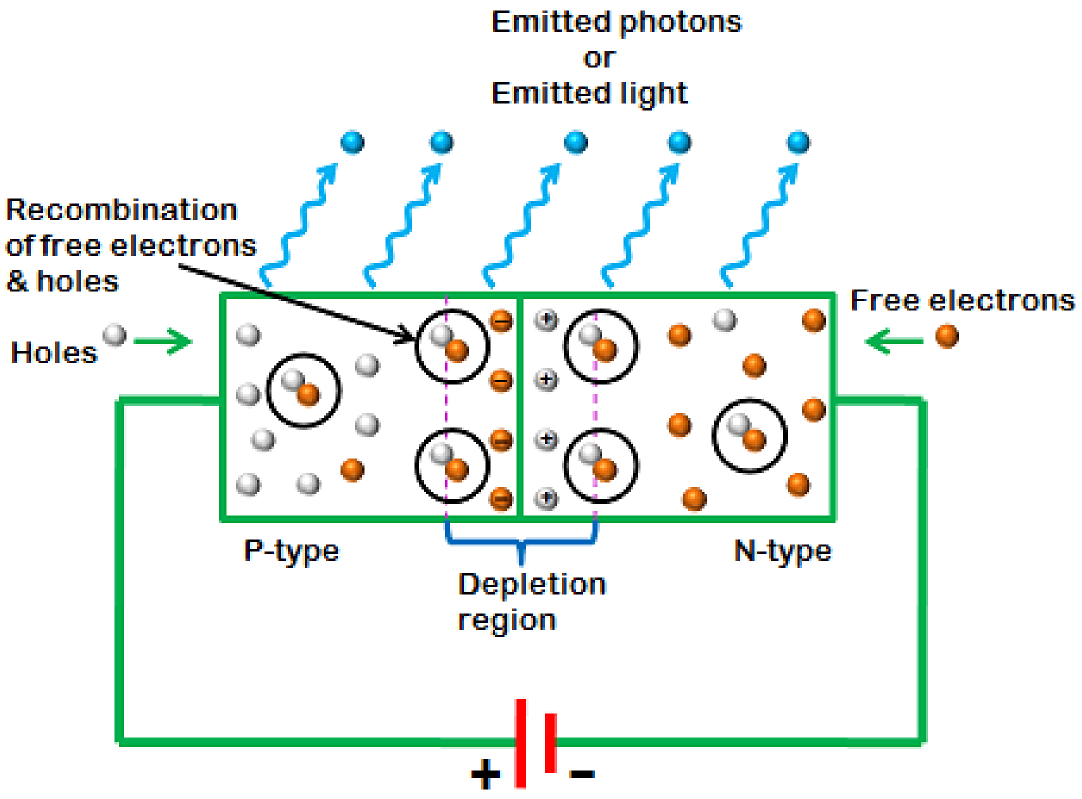
- Light Emitting Diode (LED) works only in forward bias condition. When Light Emitting Diode (LED) is forward biased, the free electrons from n-side and the holes from p-side are pushed towards the junction.

- When free electrons reach the junction or depletion region, some of the free electrons recombine with the holes in the positive ions.

- We know ,that positive ions have less number of electrons than protons.

Light Emitting Diode

- They are ready to accept electrons. Thus, free electrons recombine with holes in the depletion region. In the similar way, holes from p-side recombine with electrons in the depletion region.



Light Emitting Diode (LED)

Light Emitting Diode

- Because of the recombination of free electrons and holes in the depletion region, the width of depletion region decreases.
- As a result, more charge carriers will cross the p-n junction. Some of the charge carriers from p-side and n-side will cross the p-n junction before they recombine in the depletion region.
- For example, some free electrons from n-type semiconductor cross the p-n junction and recombines with holes in p-type semiconductor.
- In the similar way, holes from p-type semiconductor cross the p-n junction and recombines with free electrons in the n-type semiconductor. Thus, recombination takes place in depletion region as well as in p-type and n-type semiconductor.
- The free electrons in the conduction band releases energy in the form of light before they recombine with holes in the valence band.

Light Emitting Diode

- In silicon and germanium diodes, most of the energy is released in the form of heat and emitted light is too small.

- However, in materials like gallium arsenide and gallium phosphide the emitted photons have sufficient energy to produce intense visible light.

How LED emits light?

- When external voltage is applied to the valence electrons , they gain sufficient energy and breaks the bonding with the parent atom.

- The valence electrons which breaks bonding with the parent atom are called free electrons.

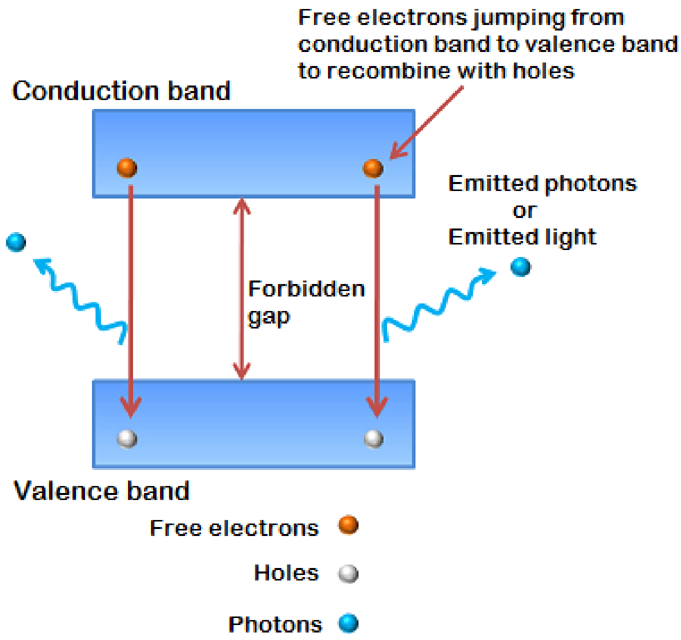
- When the valence electron left the parent atom, they leave an empty space in the valence shell at which valence electron left. This empty space in the valence shell is called a hole.

Light Emitting Diode

- The energy level of free electrons in the conduction band is high compared to the energy level of valence electrons or holes in the valence band.

- Therefore, free electrons in the conduction band need to lose energy in order to recombine with the holes in the valence band.

- The free electrons in the conduction band do not stay for long period. After a short period, the free electrons lose energy in the form of light and recombine with the holes in the valence band. Each recombination of charge carrier will emit some light energy.



Process of light emission in LED

- The energy lose of free electrons or the intensity of emitted light is depends on the forbidden gap or energy gap between conduction band and valence band.

Light Emitting Diode

- In normal silicon diodes, the energy gap between conduction band and valence band is less. Hence, the electrons fall only a short distance.
- As a result, low energy photons are released. These low energy photons have low frequency which is invisible to human eye.
- In LEDs, the energy gap between conduction band and valence band is very large so the free electrons in LEDs have greater energy than the free electrons in silicon diodes.
- Hence, the free electrons fall to a large distance. As a result, high energy photons are released. These high energy photons have high frequency which is visible to human eye.
- The efficiency of generation of light in LED increases with increase in injected current and with a decrease in temperature.
- In light emitting diodes, light is produced due to recombination process. Recombination of charge carriers takes place only under forward bias condition. Hence, LEDs operate only in forward bias condition.

Light Emitting Diode

- When light emitting diode is reverse biased, the free electrons (majority carriers) from n-side and holes (majority carriers) from p-side moves away from the junction.

- As a result, the width of depletion region increases and no recombination of charge carriers occur. Thus, no light is produced.

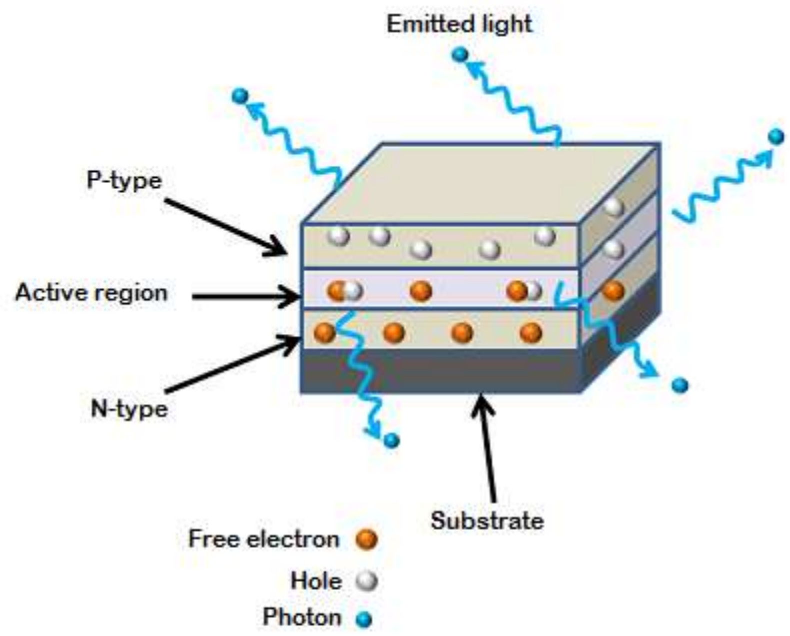
- If the reverse bias voltage applied to the LED is highly increased, the device may also be damaged.

- All diodes emit photons or light but not all diodes emit visible light. The material in an LED is selected in such a way that the wavelength of the released photons falls within the visible portion of the light spectrum.

- Light emitting diodes can be switched ON and OFF at a very fast speed of 1 ns.

Light Emitting Diode

- One of the methods used to construct LED is to deposit three semiconductor layers on the substrate. The three semiconductor layers deposited on the substrate are n-type semiconductor, p-type semiconductor and active region.
- Active region is present in between the n-type and p-type semiconductor layers.



Construction of LED

Light Emitting Diode

- When LED is forward biased, free electrons from n-type semiconductor and holes from p-type semiconductor are pushed towards the active region.
- In LED, most of the charge carriers recombine at active region. Therefore, most of the light is emitted by the active region. The active region is also called as depletion region.
- The safe forward voltage ratings of most LEDs is from 1V to 3 V and forward current ratings is from 200 mA to 100 mA.
- If the voltage applied to LED is in between 1V to 3V, LED works perfectly because the current flow for the applied voltage is in the operating range.
- However, if the voltage applied to LED is increased to a value greater than 3 volts.
- The depletion region in the LED breaks down and the electric current suddenly rises. This sudden rise in current may destroy the device.

Light Emitting Diode

I-V Characteristics of LED

- There are different types of light emitting diodes are available in the market and there are different LED characteristics which include the color light, or wavelength radiation, light intensity.

- The important characteristic of the LED is color. In the starting use of LED, there is the only red color. As the use of LED is increased with the help of the semiconductor process and doing the research on the new metals for LED, the different colors were formed.

- The amount of output light emitted by the LED is directly proportional to the amount of forward current flowing through the LED.

Visible LEDs and invisible LEDs

LEDs are mainly classified into two types: visible LEDs and invisible LEDs.

- Visible LED is a type of LED that emits visible light.

- These LEDs are mainly used for display or illumination where LEDs are used individually without photosensors.

- Invisible LED is a type of LED that emits invisible light (infrared light). These LEDs are mainly used with photosensors such as photodiodes.

Light Emitting Diode

What determines the color of an LED?

The material used for constructing LED determines its color.
In other words, the wavelength or color of the emitted light depends on the forbidden gap or energy gap of the material.

Different materials emit different colors of light.

- Gallium arsenide LEDs emit red and infrared light.
- Gallium nitride LEDs emit bright blue light.
- Yttrium aluminium garnet LEDs emit white light.
- Gallium phosphide LEDs emit red, yellow and green light.
- Aluminium gallium nitride LEDs emit ultraviolet light.
- Aluminum gallium phosphide LEDs emit green light.

Light Emitting Diode

WAVELENGTH RANGE (NM)	COLOUR	V_F @ 20MA	MATERIAL
< 400	Ultraviolet	3.1 - 4.4	Aluminium nitride (AlN) Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN)
400 - 450	Violet	2.8 - 4.0	Indium gallium nitride (InGaN)
450 - 500	Blue	2.5 - 3.7	Indium gallium nitride (InGaN) Silicon carbide (SiC)
500 - 570	Green	1.9 - 4.0	Gallium phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)
570 - 590	Yellow	2.1 - 2.2	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium phosphide (GaP)
590 - 610	Orange / amber	2.0 - 2.1	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaUInP) Gallium phosphide (GaP)
610 - 760	Red	1.6 - 2.0	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium phosphide (GaP)
> 760	Infrared	< 1.9	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)

Light Emitting Diode

Applications of Light Emitting Diodes

- There are many applications of the LED and some of them are explained below.
- LED is used as a bulb in the homes and industries
- The light emitting diodes are used in the motorcycles and cars.
- These are used in the mobile phones to display the message.
- At the traffic light signals led's are used

Advantages of LED's

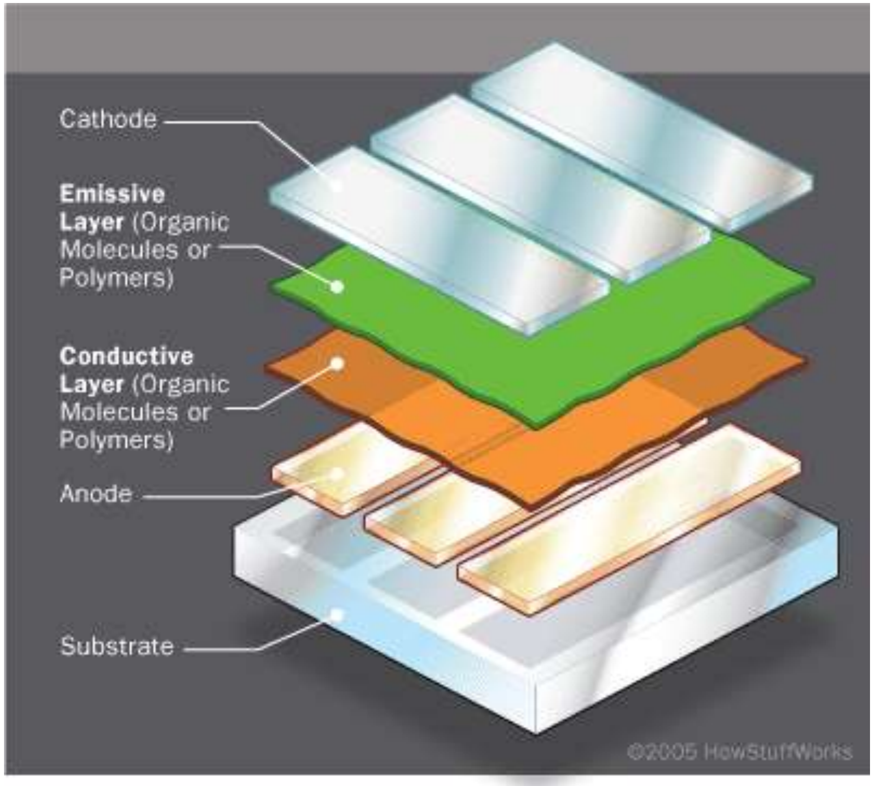
- The cost of LED's is less and they are tiny.
- By using the LED's the electricity is controlled.
- The intensity of the LED differs with the help of the microcontroller.

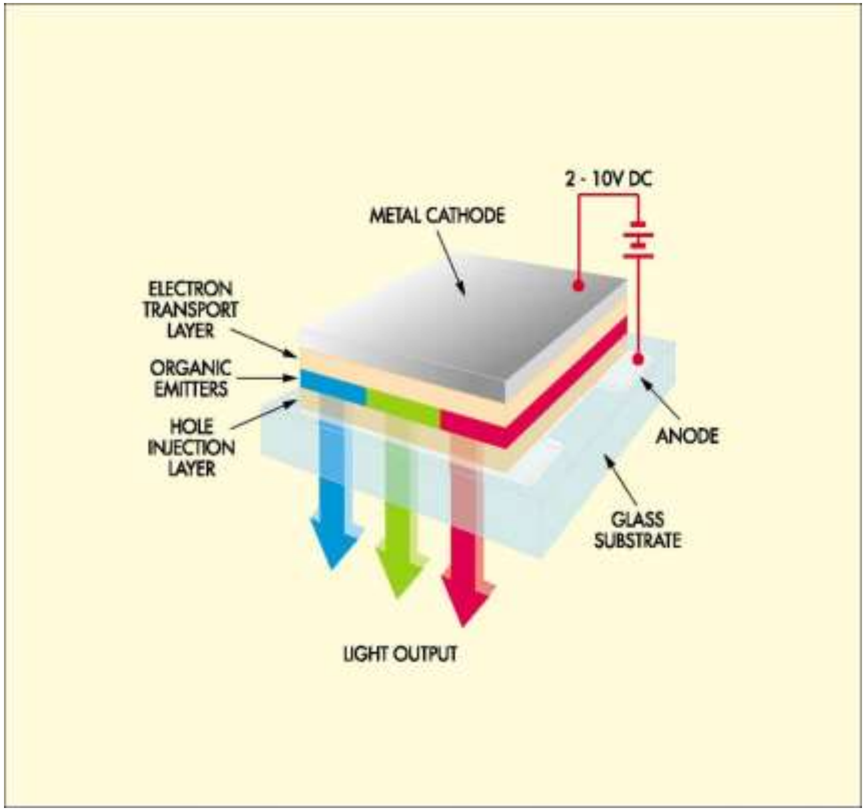
Organic - Light Emitting Diode

- What is an OLED?
- An OLED is an electronic device made by placing a series of organic thin films between two conductors.
- When electrical current is applied, a bright light is emitted.
- A device that is 100 to 500 nanometers thick or about 200 times smaller than a human hair.

Organic - Light Emitting Diode

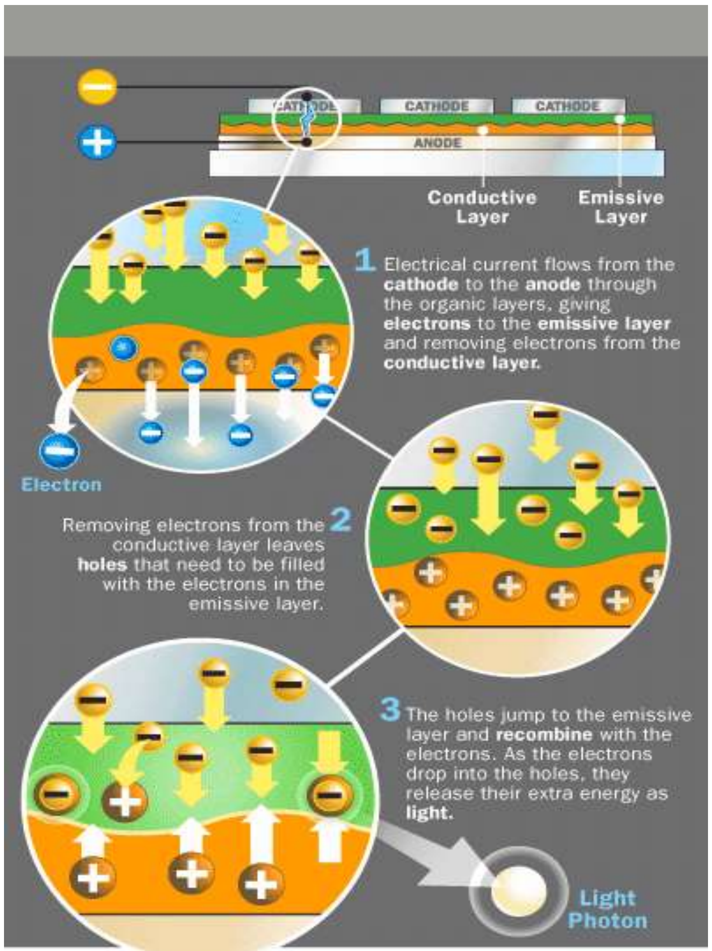
- The OLED Structure





Organic - Light Emitting Diode

- How OLEDs Emit Light



- The battery or power supply of the device containing the OLED applies a voltage across the OLED.
- An electrical current flows from the cathode to the anode through the organic layers. (an electrical current is a flow of electrons)
- At the boundary between the emissive and the conductive layers, electrons find electron holes.
- The OLED emits light.

Function and structure of an OLED and nanomaterials it contains

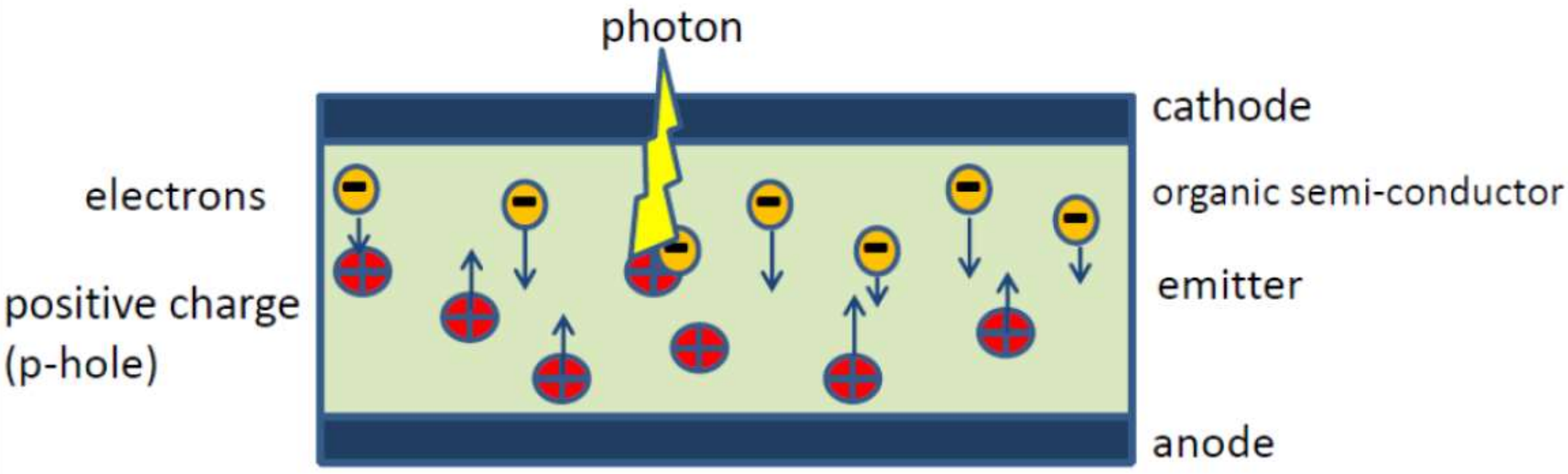
- An OLED is a thin, flat luminous component with a thickness of usually less than 1 micrometre (µm4).

- It consists of at least one light-emitting layer (emitter layer) made of organic semiconductor material, is generally built with several layers, each with a thickness of up to 100 nanometres (nm 5), which are positioned between two electrodes.

- One or both electrodes of the OLED are transparent such that light can radiate toward one or both directions and gives it a translucent appearance when switched of.

- Compared to ILEDs, OLEDs have the advantage that the colour of the light can be customised to reflect the entire visible spectrum.

Schematic representation of the structure of an OLED



- When switched on, voltage builds up between the electrodes which leads to a drift of the positive charge (p-holes) and the negative charge (electrons) in the semi-conductor layers toward each other.
- The charges accumulate in the emitter layer, creating an excited state when hitting each other: the exciton.
- Depending on the mechanism, this may be the direct excitation of a dyestuff molecule; or the dyestuff is excited by the energy released when the exciton decays.
- When the excited state of the dyestuff changes back to the basic state, a light particle (photon) with a defined wavelength is emitted.
- Two types of OLEDs are distinguished: the emitter layer consists of polymers (PLED) or of small organic molecules (small molecular organic LED = SMOLED).

Physicochemical properties of OLEDs

Photometric capacities

- Luminous flux (lumen, lm): light sources emit radiation within a defined spectrum.

- The radiant power described with the unit watt captures this emitted radiation indiscriminately across the entire light spectrum.

- However, the sensitivity of the eye varies for the different wavelengths.

- Taking into account this effect results in the luminous flux, also known as luminous power, described with the unit lumen (lm).

- Luminous intensity (candela, cd): luminous flux within a defined solid angle. The luminous intensity rates the light emitted by a light source in a defined direction.

- Illuminance E (lux, lx or lm/m^2): luminous flux cast onto a defined surface.

Physicochemical properties of OLEDs

Photometric capacities

- Luminance (candela per m², cd/m²): luminous flux emitted by a surface in a defined direction.
- Luminance is the measure that describes what the human eye perceives as brightness of a surface.
- Luminous efficacy (lamp efficacy, lumen per watt): efficiency of a light source, that is, the ratio between the benefit (emitted luminous flux) and expenditures (consumed electric power).
-
- The luminous efficacy describes how much light can be generated with the used electricity (principle of maximisation).
- However, the goal is generally to keep the required electricity as low as possible with a given luminous flux (principle of minimisation).
- Consequently, other parameters, such as e.g. the PLI number are preferable.

Organic - Light Emitting Diode

Table 1: Materials used for OLED lighting (according to Spengler et al.)

Component	Material
Organic semi-conductor/emitter layer	Polymers (e.g. poly-p-phenylene vinylene, PPV) or molecules (light emission); triarylamines, triphenylene derivatives, copper phthalocyanine (hole conductor); tris(8-oxyquinoline) aluminium complex (electron conductor); partly contained: rare earth elements (e.g. europium), precious metals (platinum, iridium)
Cathode	Metal, e.g.: aluminium, barium, magnesium, calcium, ruthenium, silver alloys, lithium fluoride
Anode	Transparent conductive oxides (TCOs), mainly Indium Tin Oxide (ITO); alternatives: doped tin oxides, silver nanowire
Other layers, including electron injection layer, hole conducting layer	Lithium fluoride, caesium fluoride or silver; PEDOT/PSS (poly(3,4-ethylene dioxythiophene/ polystyrene sulfonate, copper phthalocyanine)
Carrier material/cover	Silicon, glass (e.g. borosilicate glass or normal soda-lime glass), polymer foil, metal foil (aluminium, stainless steel), flexible plastic
Housing/holder/frame	No detailed information / many possibilities
Electronic components	No detailed information

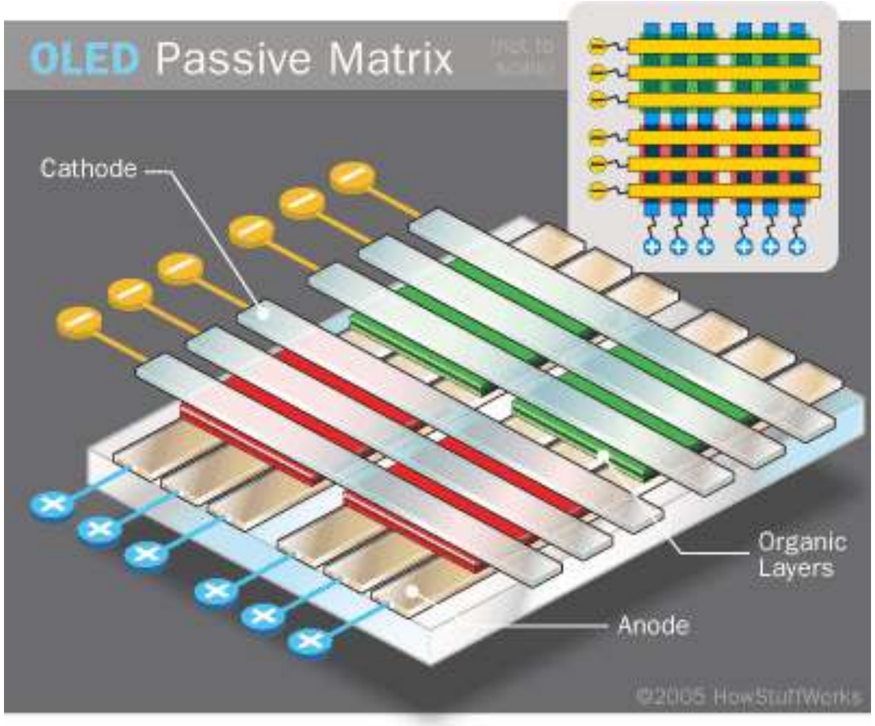
Organic - Light Emitting Diode

Types of OLEDs

- Passive-matrix
- Active-matrix
- Transparent
- Top-emitting
- Flexible
- White

Organic - Light Emitting Diode

Passive-Matrix



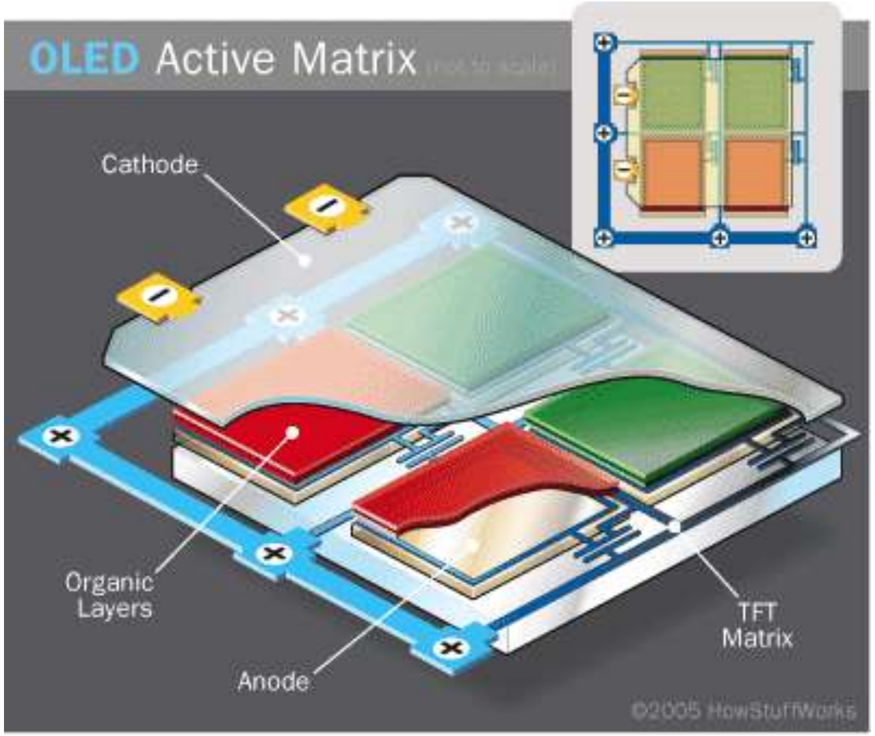
Organic - Light Emitting Diode

Passive-Matrix (PMOLED)

- PMOLEDs have strips of cathode, organic layers and strips of anode. The anode strips are arranged perpendicular to the cathode strips.
- The intersections of the cathode and anode make up the **pixels** where light is emitted.
- External circuitry applies current to selected strips of anode and cathode, determining which pixels get turned on and which pixels remain off.
- Again, the brightness of each pixel is proportional to the amount of applied current.
- PMOLEDs are easy to make, but they consume more power than other types of OLED, mainly due to the power needed for the external circuitry.
- PMOLEDs are most efficient for text and icons and are best suited for small screens (2- to 3-inch diagonal) such as those you find in cell phones, PDAs and MP3 players.
- Even with the external circuitry, passive-matrix OLEDs consume less battery power than the LCDs that currently power these devices.

Organic - Light Emitting Diode

Active-Matrix



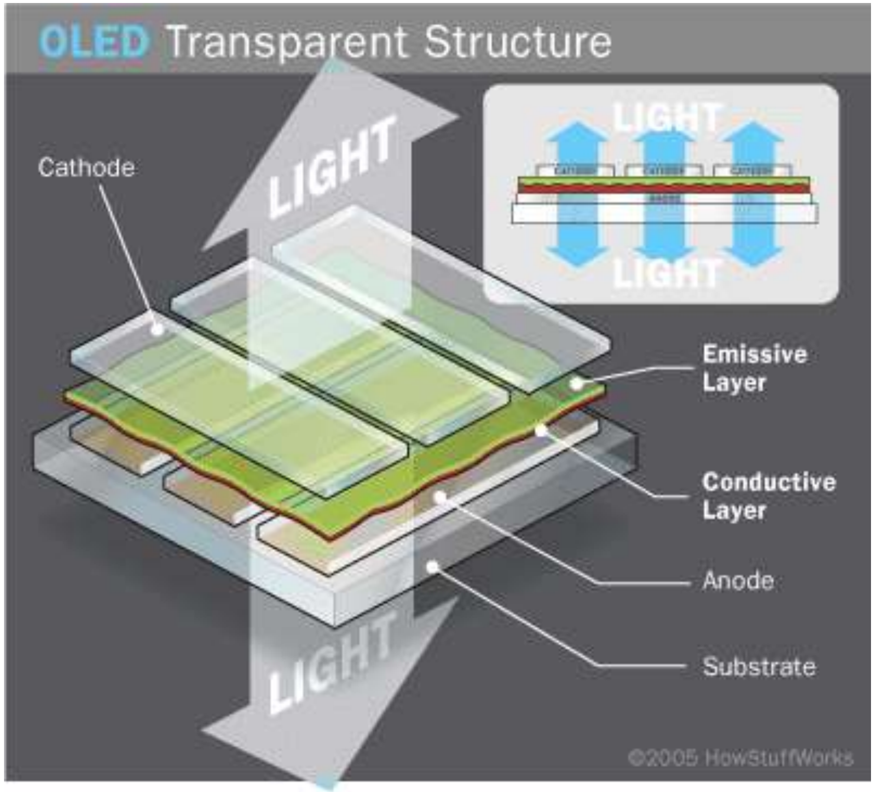
Organic - Light Emitting Diode

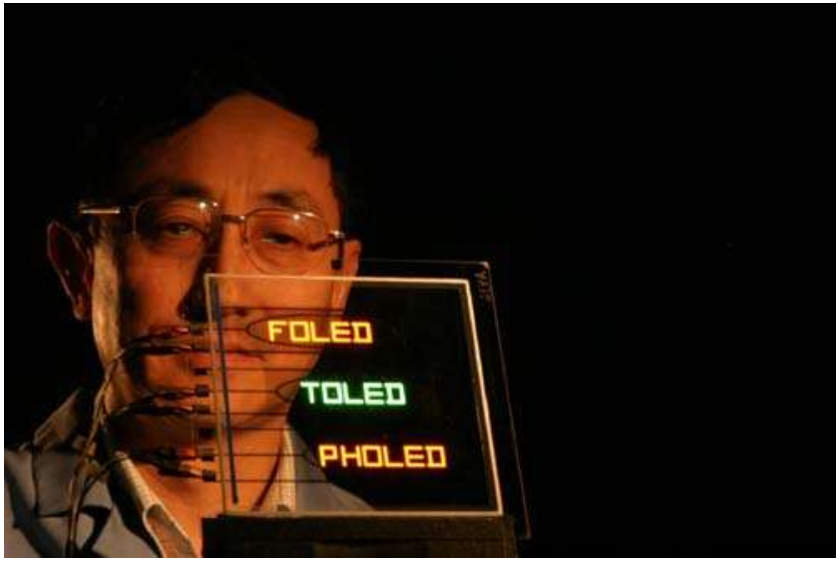
Active-Matrix (AMOLED)

- AMOLEDs have full layers of cathode, organic molecules and anode, but the anode layer overlays a thin film transistor (TFT) array that forms a matrix.
- The TFT array itself is the circuitry that determines which pixels get turned on to form an image.
- AMOLEDs consume less power than PMOLEDs because the TFT array requires less power than external circuitry, so they are efficient for large displays.
- AMOLEDs also have faster refresh rates suitable for video.
- The best uses for AMOLEDs are computer monitors, large-screen TVs and electronic signs or billboards.

Organic - Light Emitting Diode

Transparent OLED



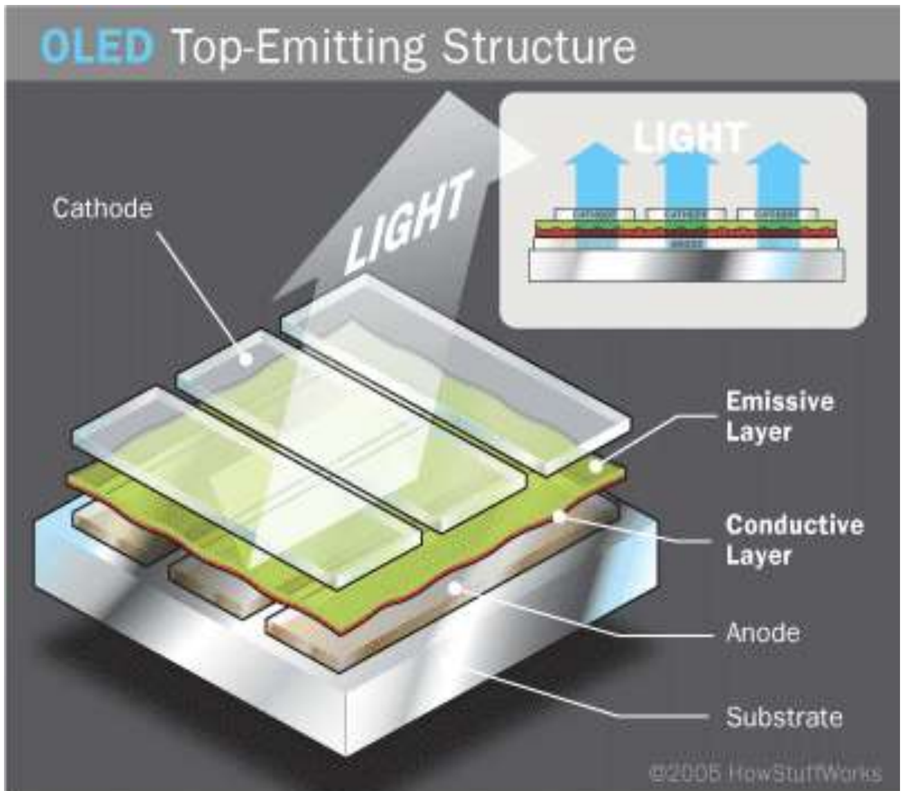


Transparent OLED

- Transparent OLEDs have only transparent components (substrate, cathode and anode) and, when turned off, are up to 85 percent as transparent as their substrate.
- When a transparent OLED display is turned on, it allows light to pass in both directions.
- A transparent OLED display can be either active- or passive-matrix.
- This technology can be used for heads-up displays

Organic - Light Emitting Diode

Top-Emitting OLED

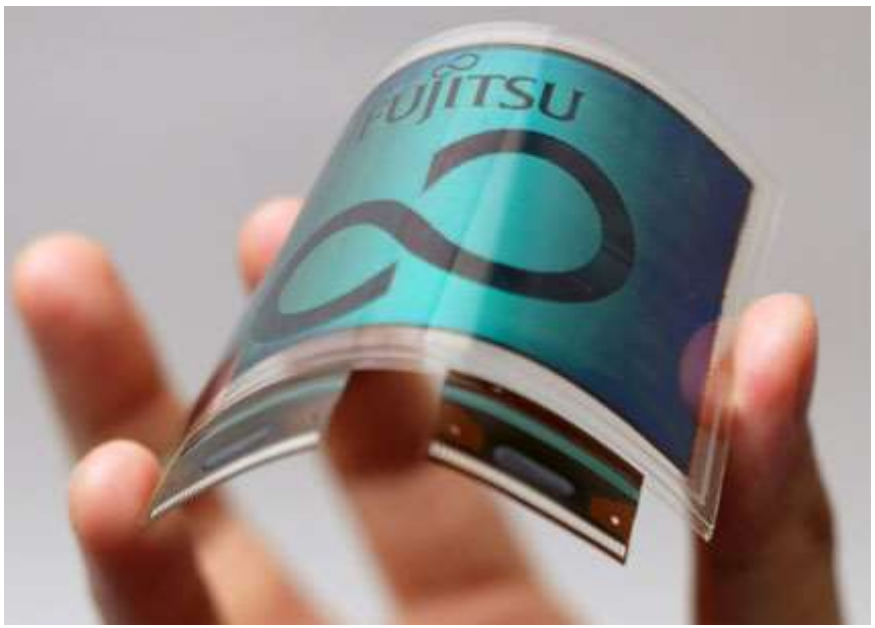


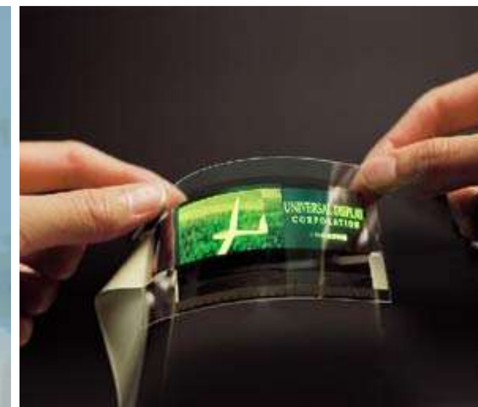
Top-Emitting OLED

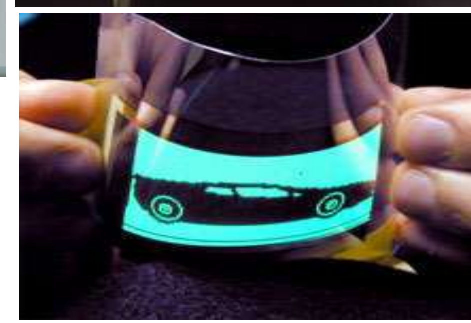
- Top-emitting OLEDs have a substrate that is either opaque or reflective.
- They are best suited to active-matrix design.
- Manufacturers may use top-emitting OLED displays in smart cards.

Organic - Light Emitting Diode

Flexible OLED





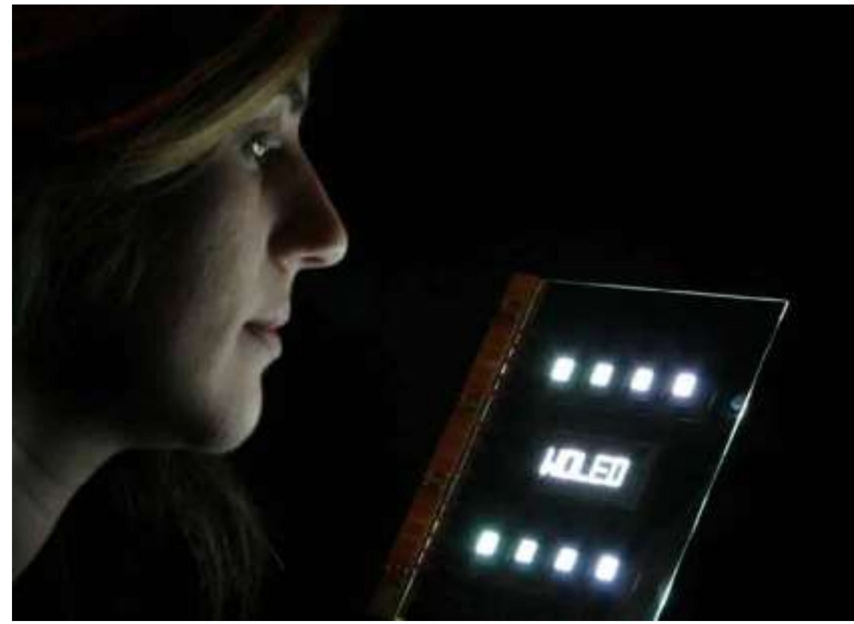


Flexible OLED

- Foldable OLEDs have substrates made of very flexible metallic foils or plastics. Foldable OLEDs are very lightweight and durable.
- Their use in devices such as cell phones and PDAs can reduce breakage, a major cause for return or repair.
- Potentially, foldable OLED displays can be attached to fabrics to create "smart" clothing, such as outdoor survival clothing with an integrated computer chip, cell phone, GPS receiver and OLED display sewn into it.

Organic - Light Emitting Diode

White OLED



White OLED

- White OLEDs emit white light that is brighter, more uniform and more energy efficient than that emitted by fluorescent lights.
- White OLEDs also have the true-color qualities of incandescent lighting.
- Because OLEDs can be made in large sheets, they can replace fluorescent lights that are currently used in homes and buildings.
- Their use could potentially reduce energy costs for lighting.

Organic - Light Emitting Diode

Advantages

- Thinner, lighter and more flexible
- Brighter
- Consume much less power
- Easier to produce and make into larger sizes
- Large field of view

Organic - Light Emitting Diode

Disadvantages

- Lifetime

- Manufacturing

- Water

Organic - Light Emitting Diode

Current OLEDs

Future of OLEDs?

OLEDs - Conclusion

- The Federal Environment Agency considers OLEDs to be an interesting factor in the future development of the lighting sector. Compared to conventional incandescent lamps, the energy requirement to generate a specific luminous efficiency is lower, while the operating life is at the same time considerably longer than the one of an incandescent lamp.

- Compared to the widely used energy-saving lamps, OLEDs do not contain mercury, which might be released in case of breakage. The quantity of included hazardous substances is extraordinarily small due to the nano-coating and no health risk is therefore expected even in case of breakage. No release of nanoparticles in connection with the technology (coating) is expected.

- Only relatively few lighting products containing OLEDs are currently on the market. Furthermore, they all have a different design. Based on the dynamic development of the innovative nanotechnology-based lighting technologies, it is difficult to predict which of these technologies will emerge to play a key role in the future.