RV College of Engineering®

UNIT-III

Chemistry of Smart Materials and Devices

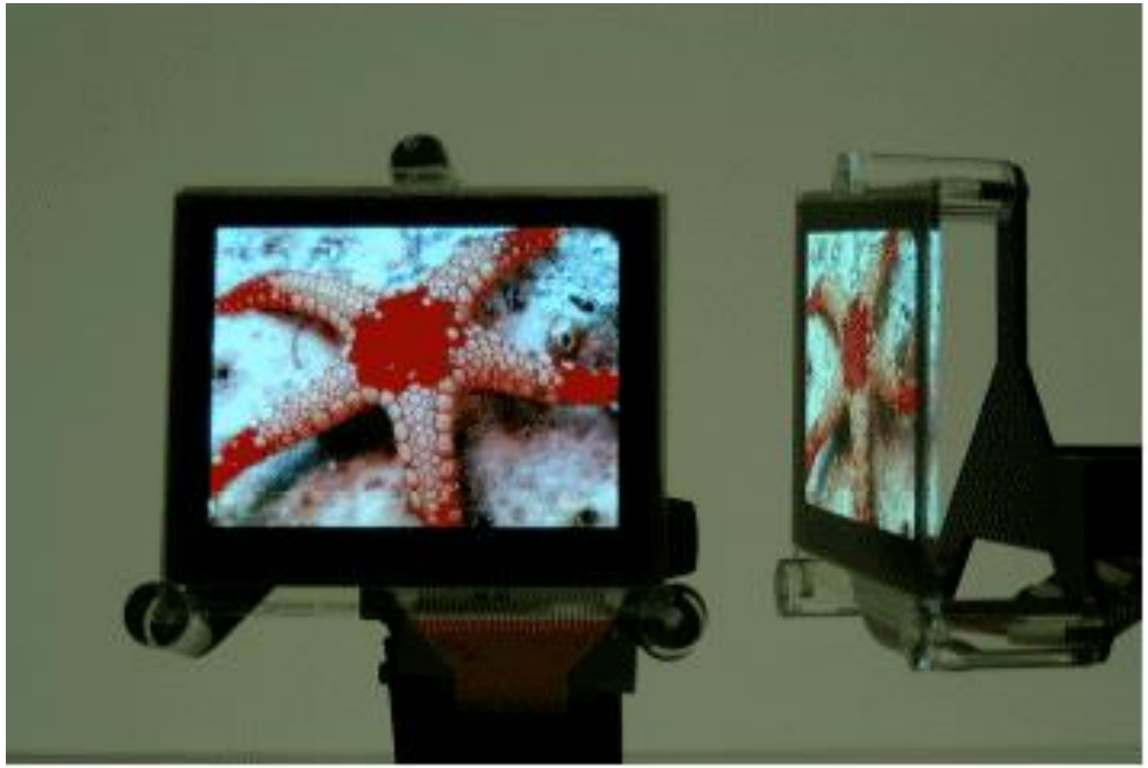
Materials for memory and display technology

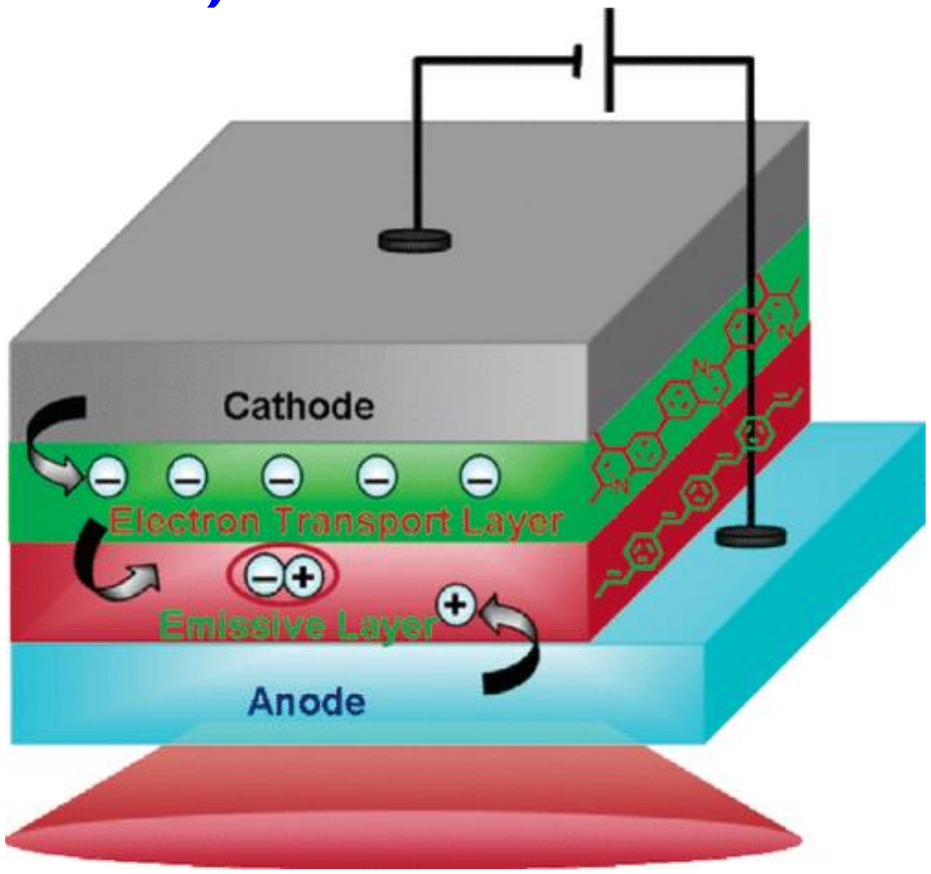
Course Contents

❖ Materials for memory and display technology:

- **Materials for memory storage:** Introduction to materials for electronic memory, classification (organic, polymeric and hybrid materials), manufacturing of semiconductor chips. Green computing: Bio-composite based memory devices.
-
- **Fabrication of smart materials and devices:** photo and electro active materials for memory devices, materials for display technology (Liquid crystals display, organic light emitting diode and light emitting electrochemical cells).

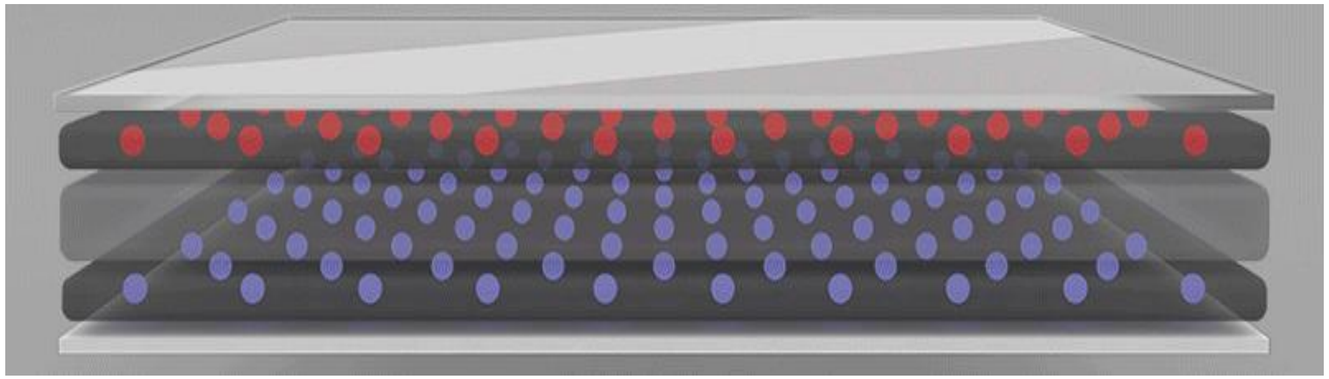
Organic Optoelectronic Devices: Organic Light-Emitting Diodes (OLED)





Organic light emitting diodes (OLEDs)

- Small molecular OLEDs (OLED)
- Polymer OLEDs (PLED)
- Applications
- Challenges

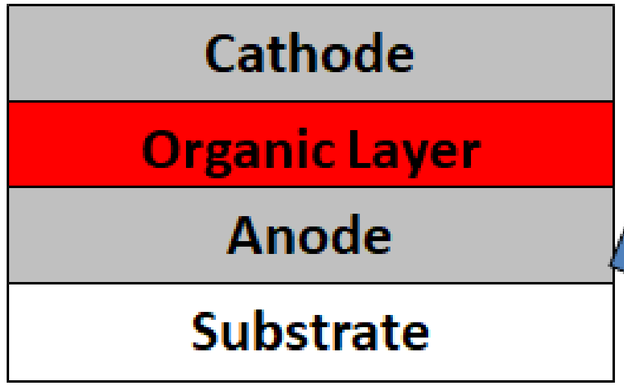


Why Organic LED?

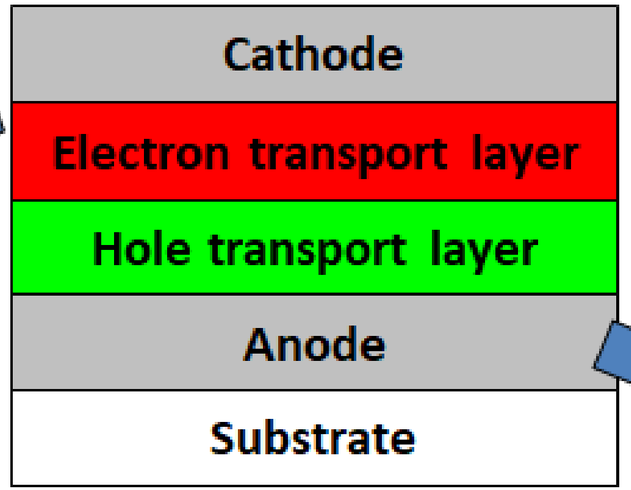
- Vibrant colors
- High contrast
- Wide viewing angles from all directions
- Low power consumption
- Low operating voltages
- Wide operating temperature range
- A thin and lightweight form factor
- Cost-effective manufacturability , etc

Small molecular OLEDs — Structure

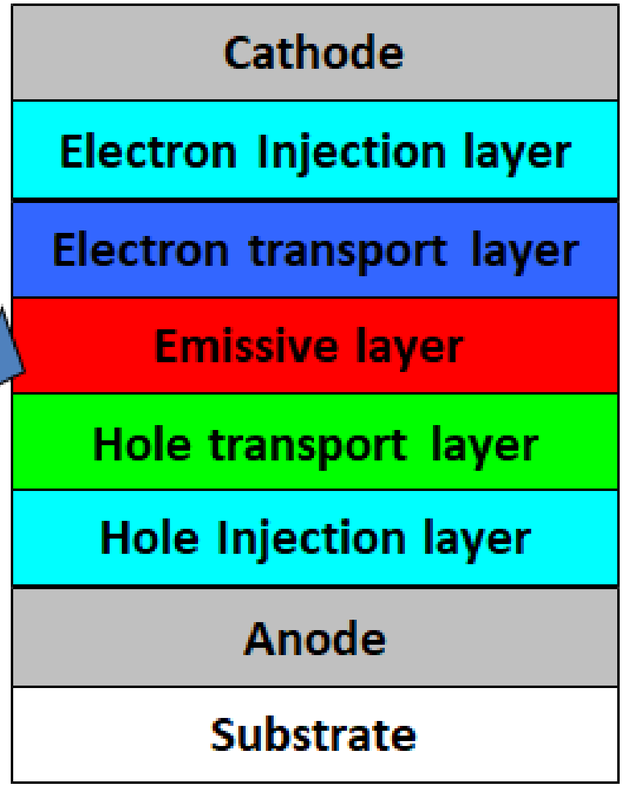
Single layer device

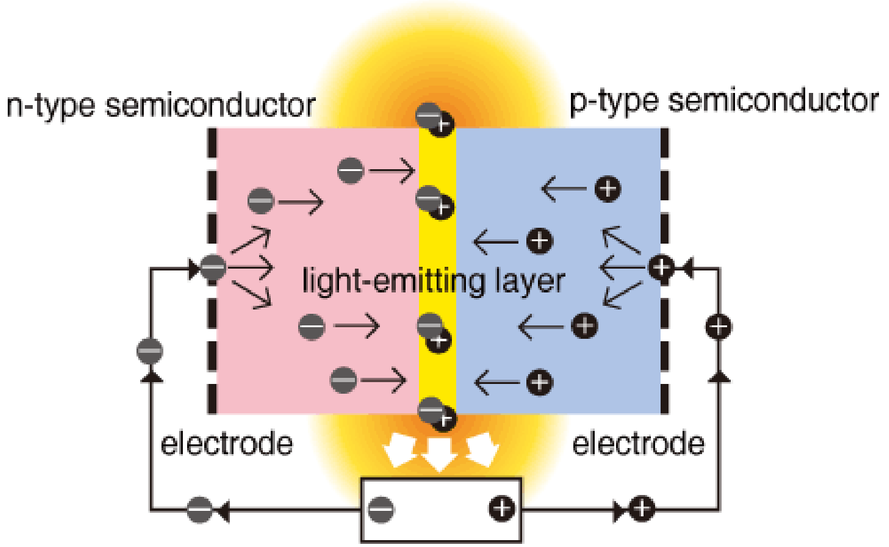


P-n junction device

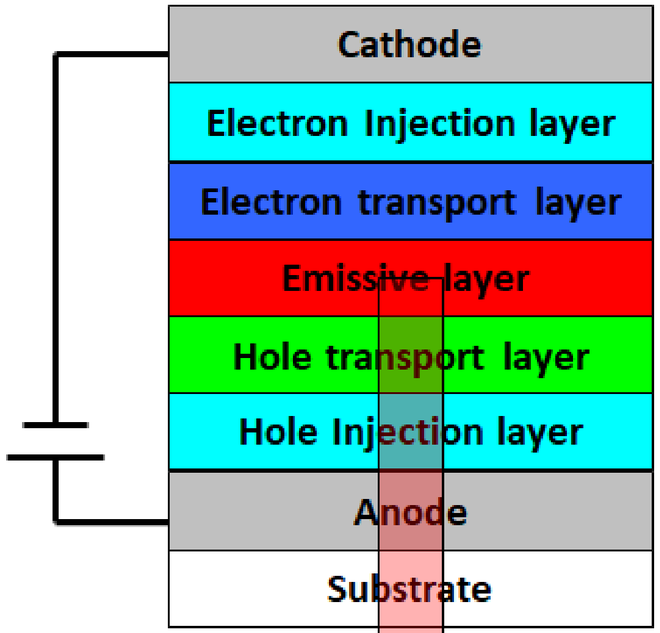


Multiple layers device

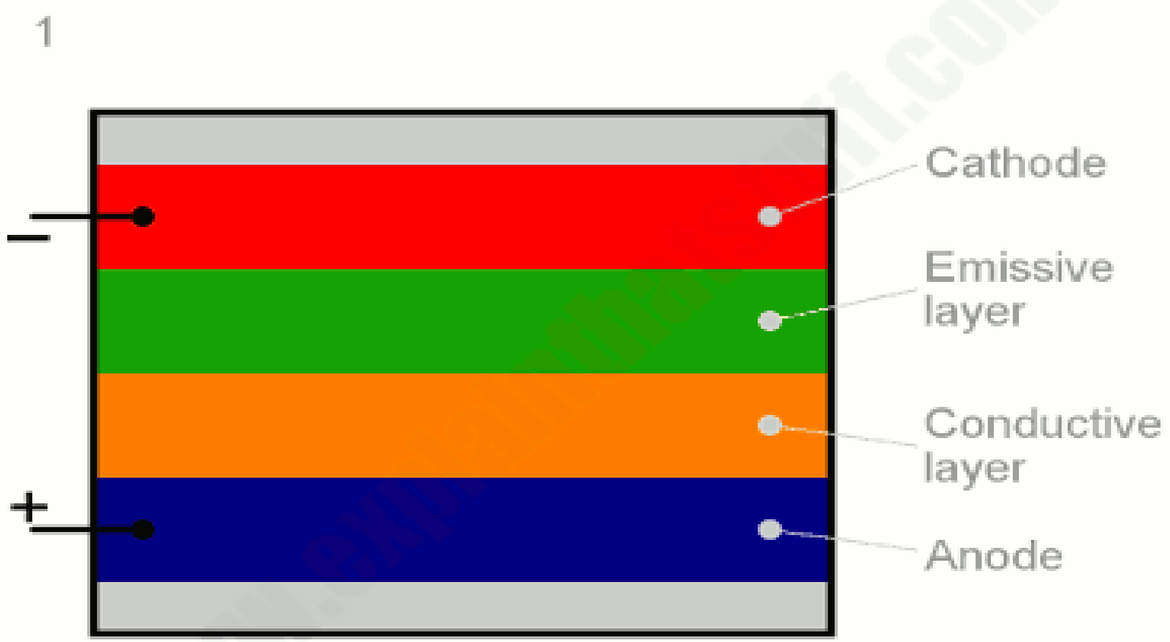


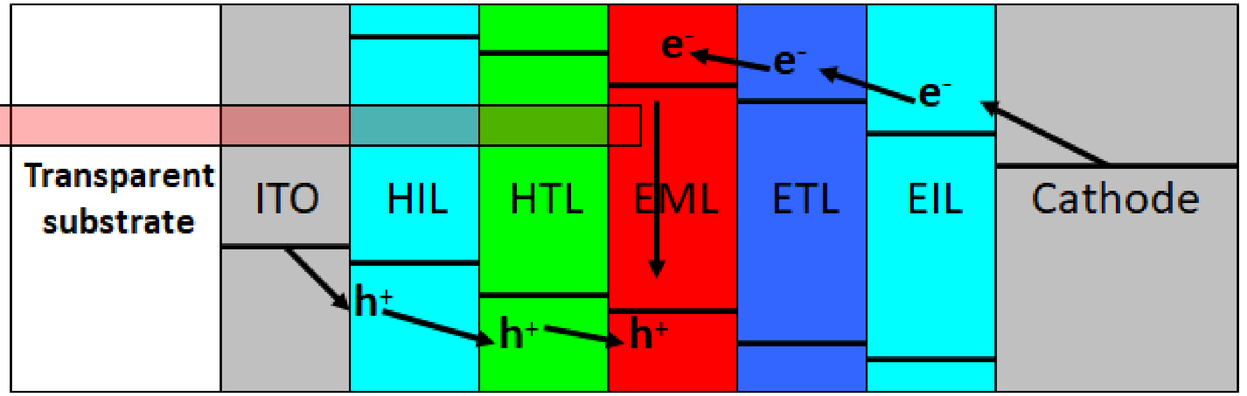


Small molecular OLEDs — Device operation principle



Light





Anode:

Indium-tin-oxide (ITO): 4.5-5.1 eV

Au: 5.1 eV

Pt: 5.7 eV

Cathode:

Ca: 2.9 eV

Mg: 3.7 eV

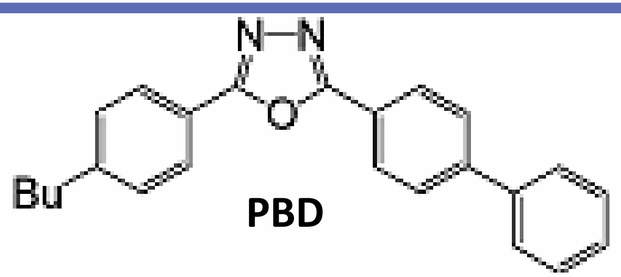
Al: 4.3 eV

Mg : Al alloys

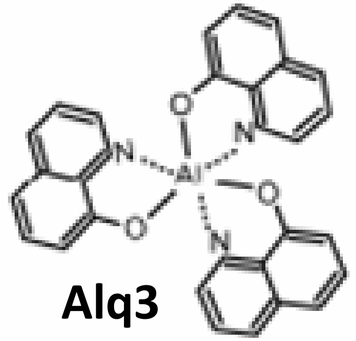
Ca : Al Alloys

Small molecular OLEDs — Materials

EIL, ETL: n-type materials: Alq3, PBD



PBD



Alq3

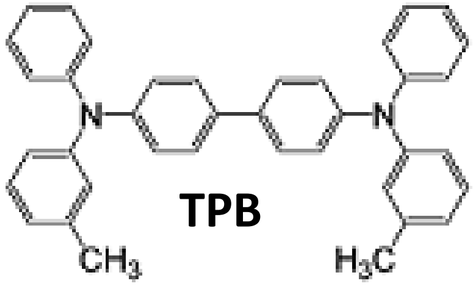
EML:

Fluorescent dye:

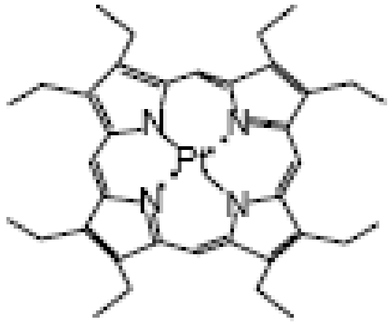
DCM2

Phosphorescent dye

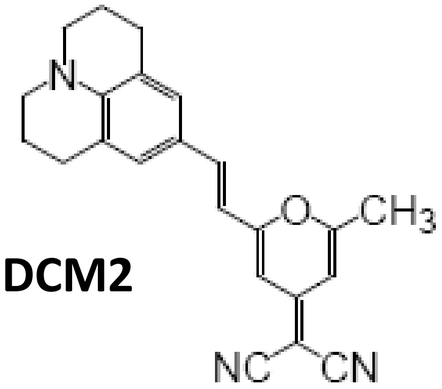
PtOEP, $Ir(ppy)_3$



TPB

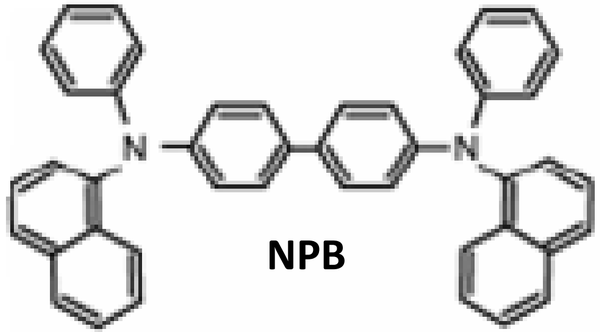


PtOEP



DCM2

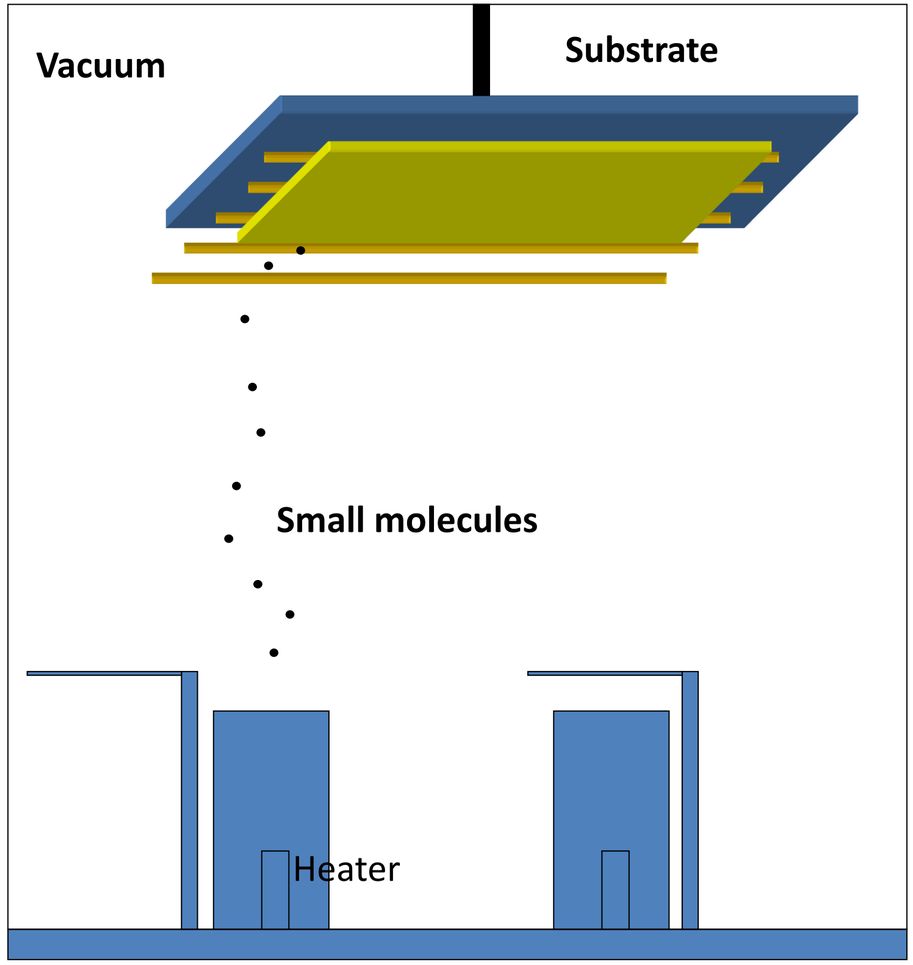
HIL, HTL: p-type materials: NPB, TPD

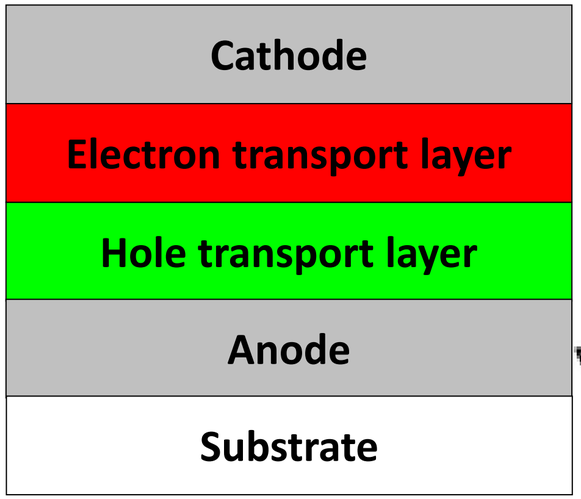


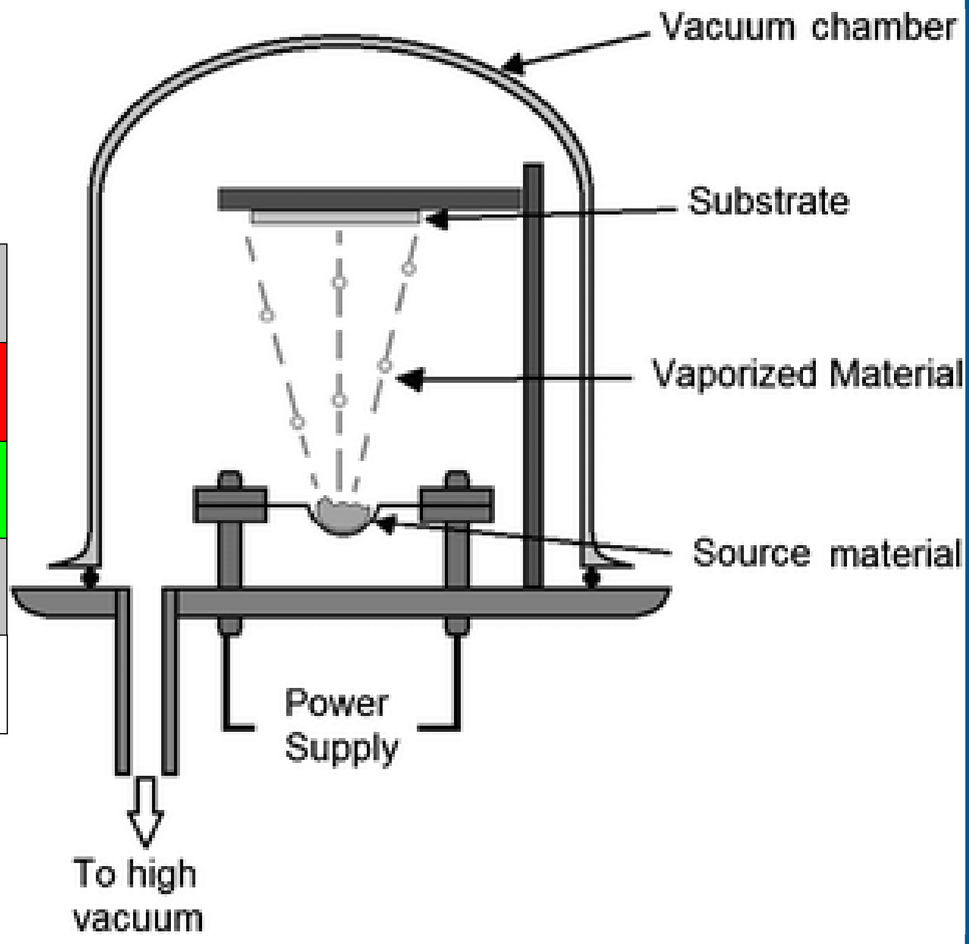
NPB

OLEDs — Device preparation

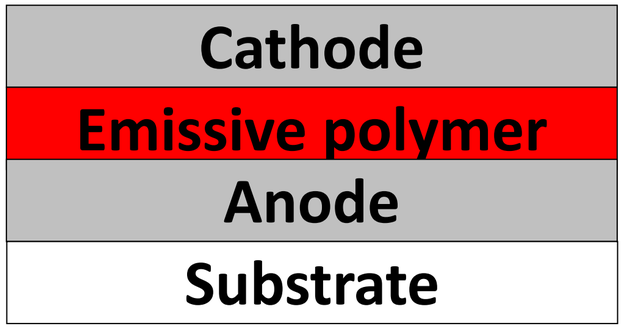
Thermal vacuum evaporation

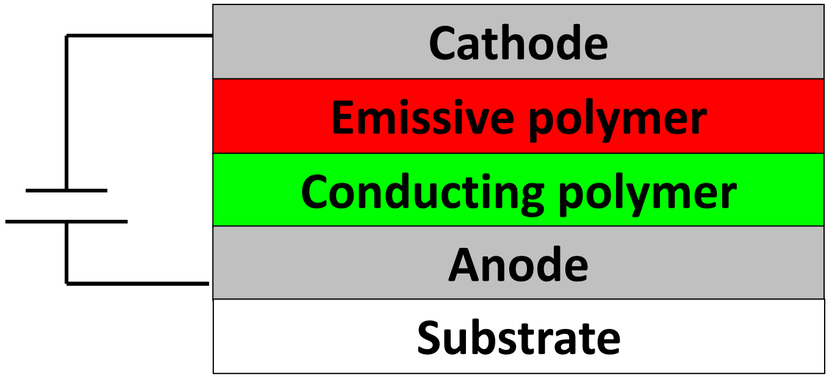


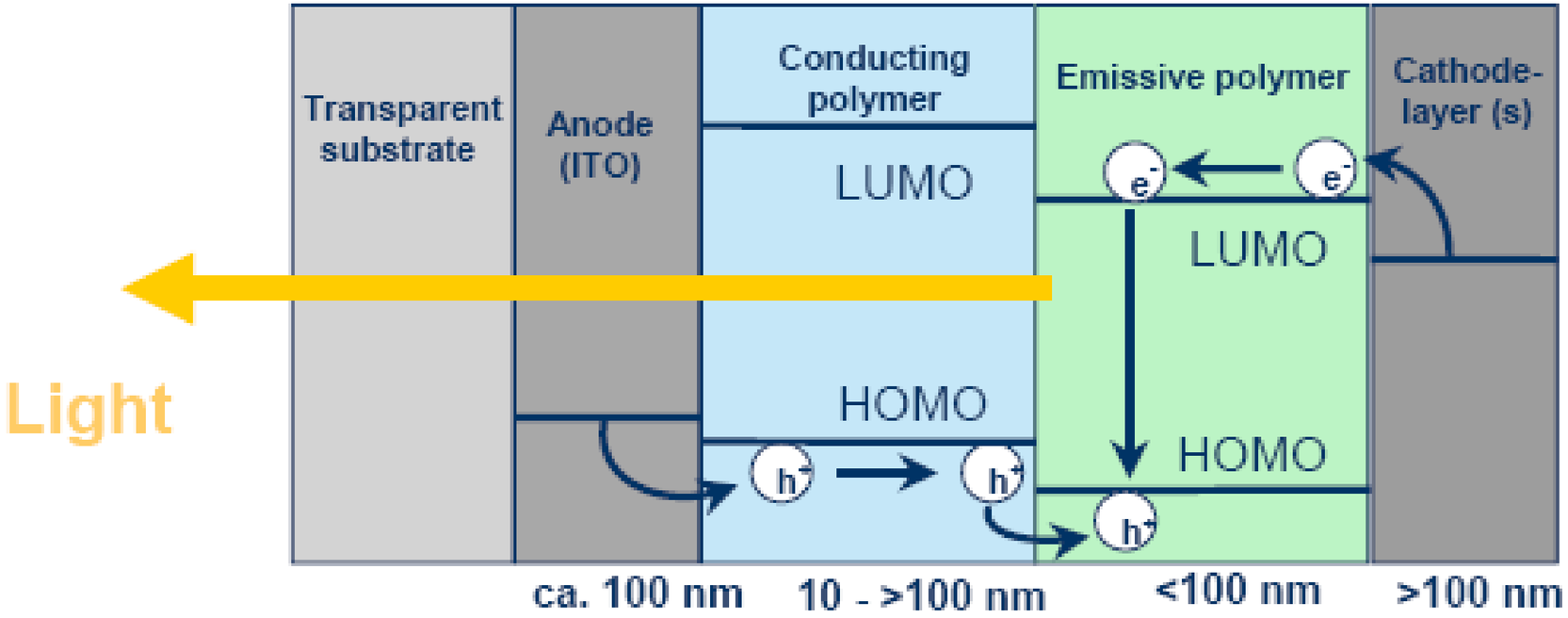




Polymer OLEDs — Structure and Operation



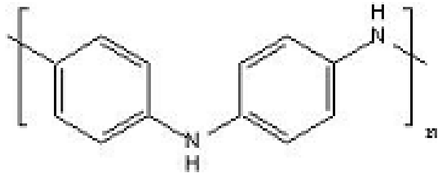




Polymer OLEDs — Materials

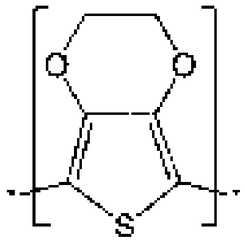
Conducting polymers:

PANI

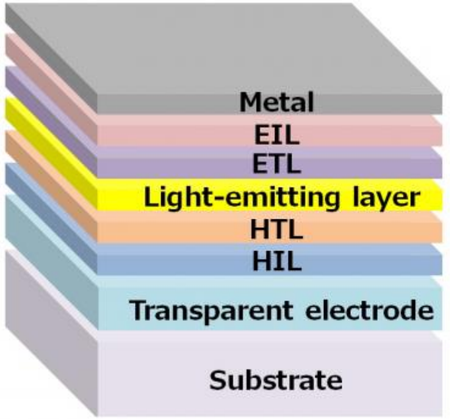


PANI

PDOT:PSS



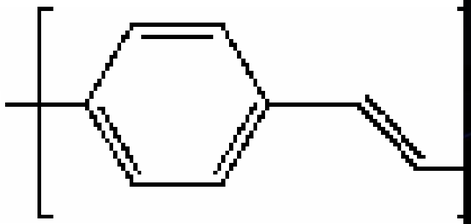
PDOT



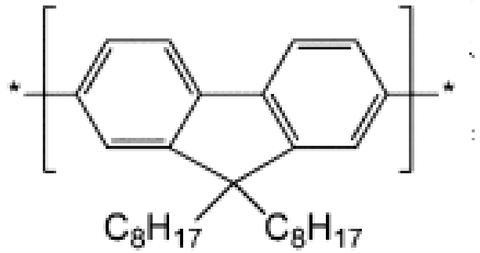
OLED

Emissive polymers:

R-PPV



PFO



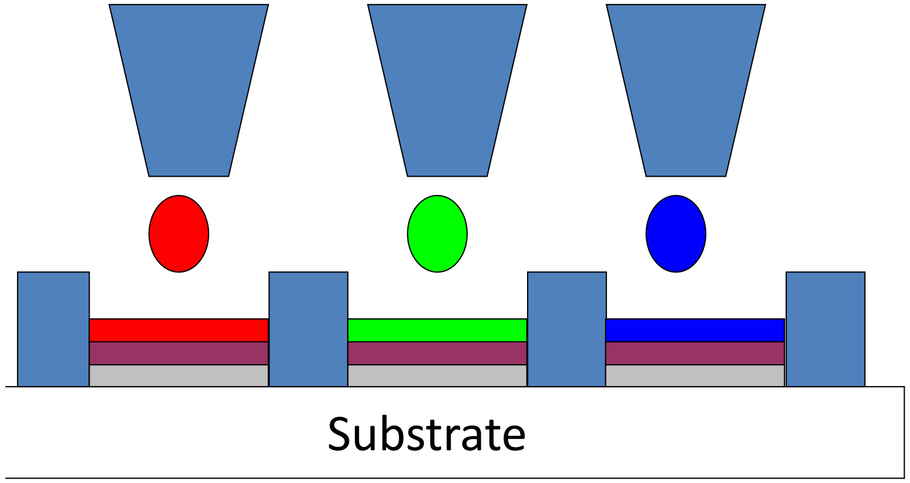
Polymer OLEDs — Fabrication

Spin coating

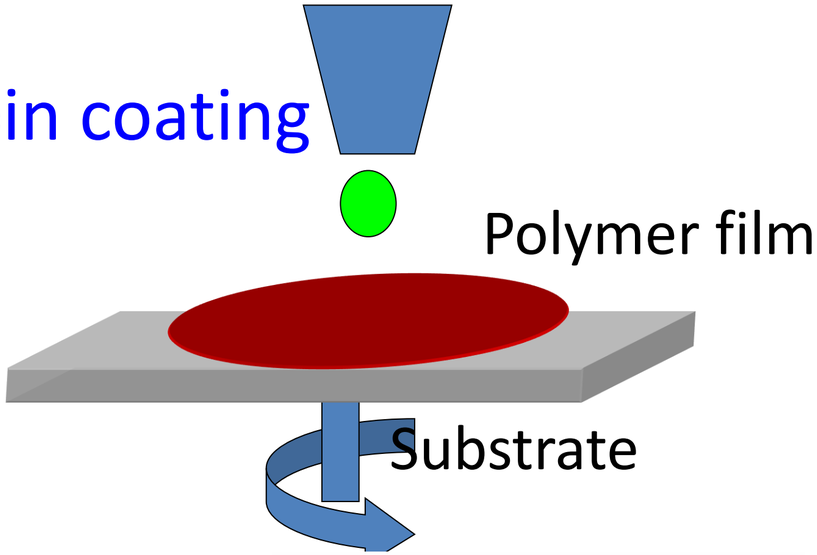
Ink jet printing

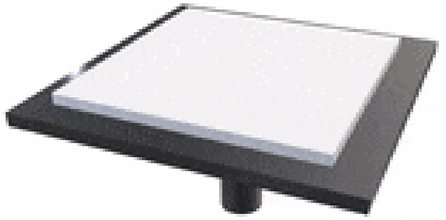
Screen printing

Ink jet printing

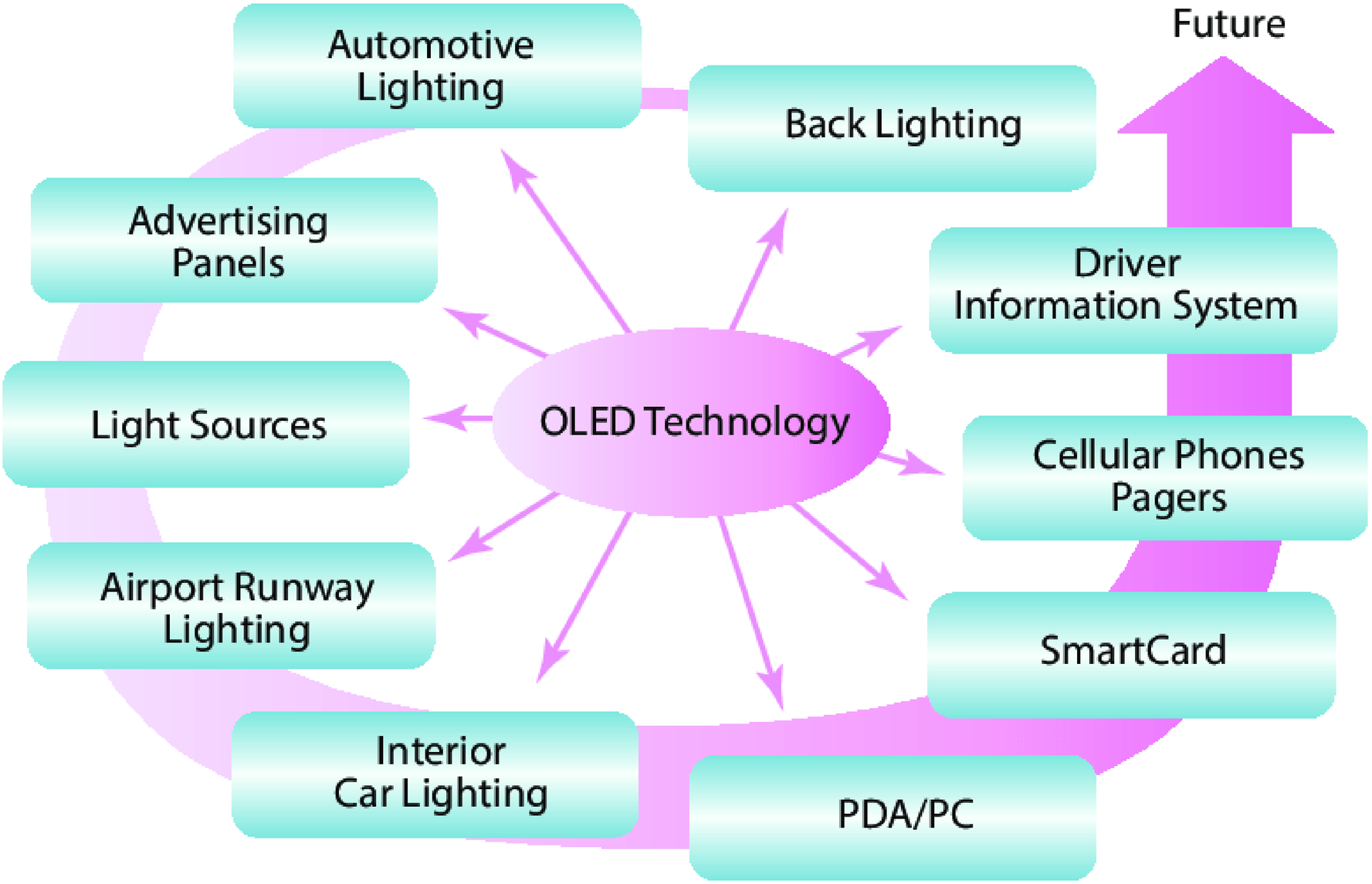


Spin coating





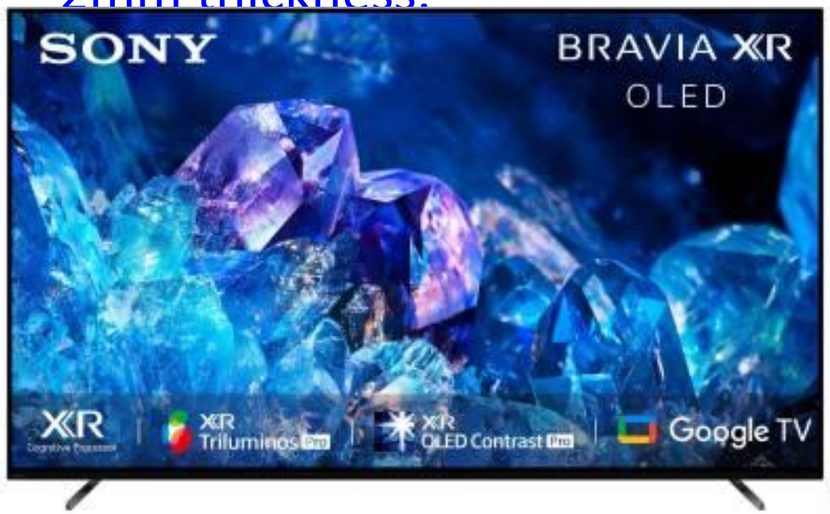
Applications — Full color OLED display



Applications — Full color OLED display

A full color, 13-inch diagonal small-molecular-weight OLED display with 2mm thickness.

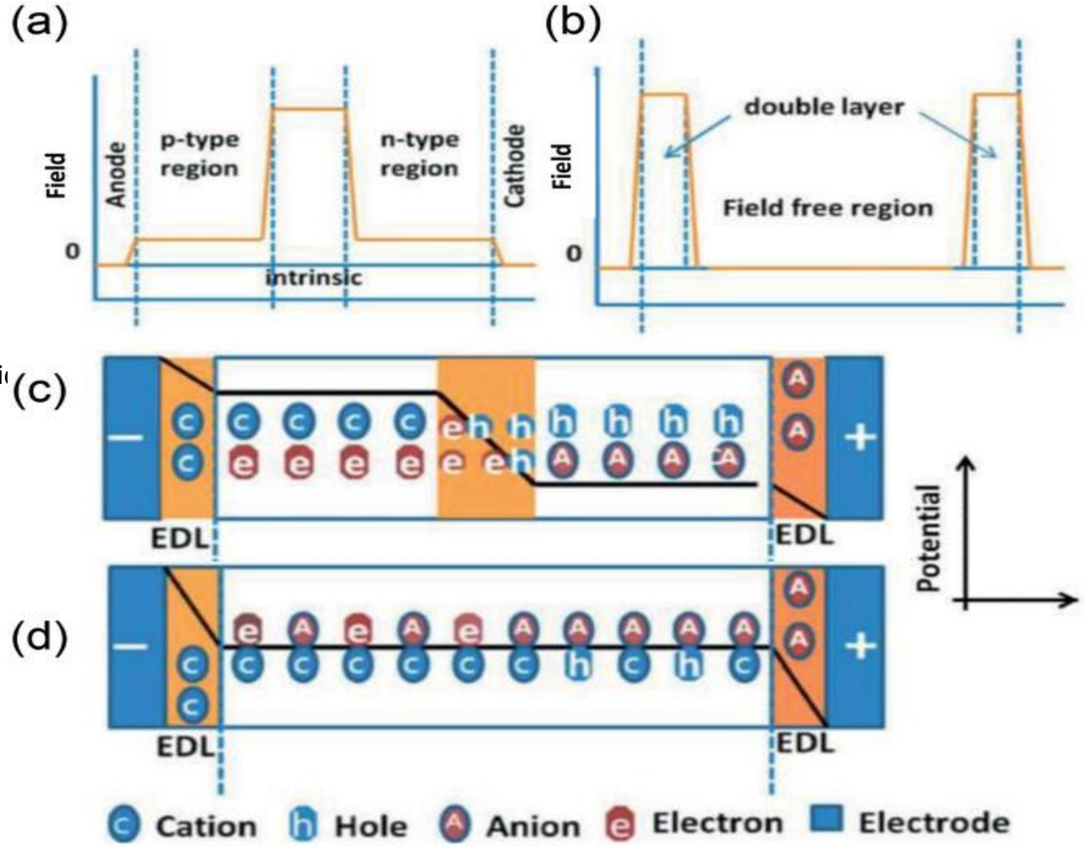
Flexible internet display screen



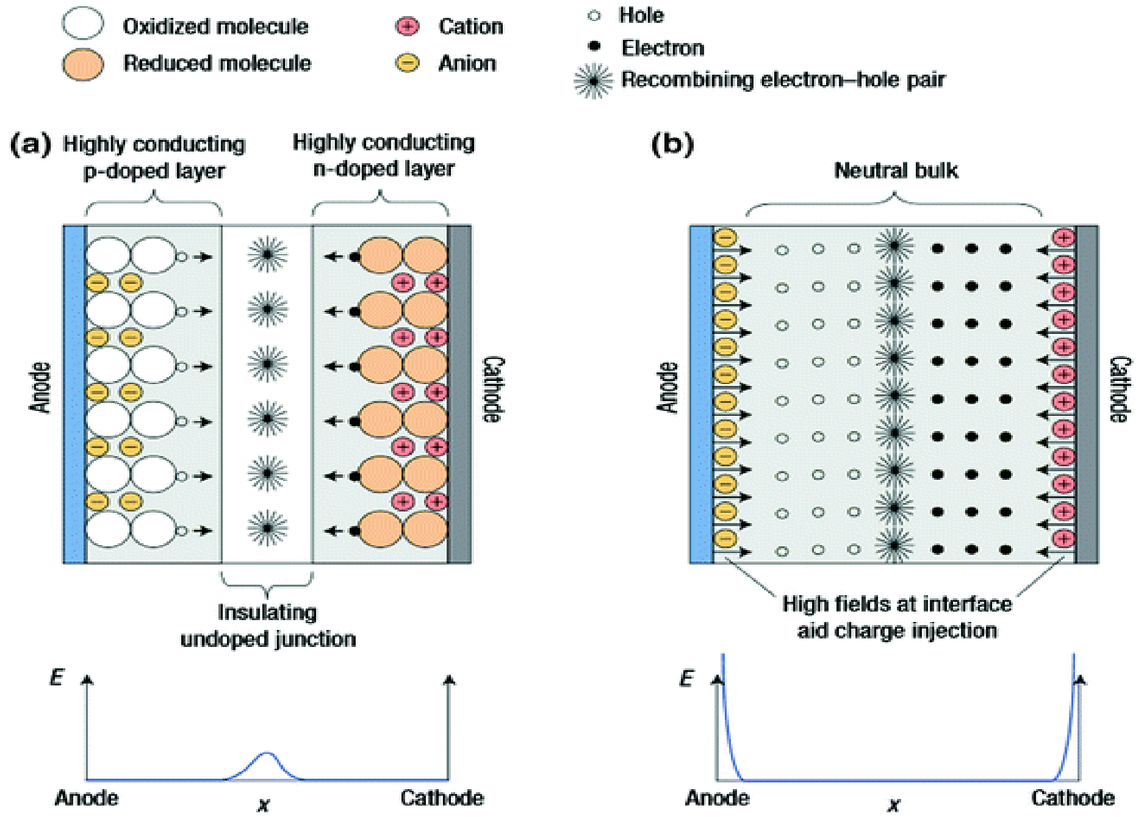
Applications — Full color OLED display

Light emitting electrochemical cells

A light-emitting electrochemical cell (LEC or LEEC) is a solid-state device that generates light from an electric current (electroluminescence). LECs are usually composed of two metal electrodes connected by (e.g. sandwiching) an organic/inorganic semiconductor containing mobile ions (from electrolyte).



P-intrinsi

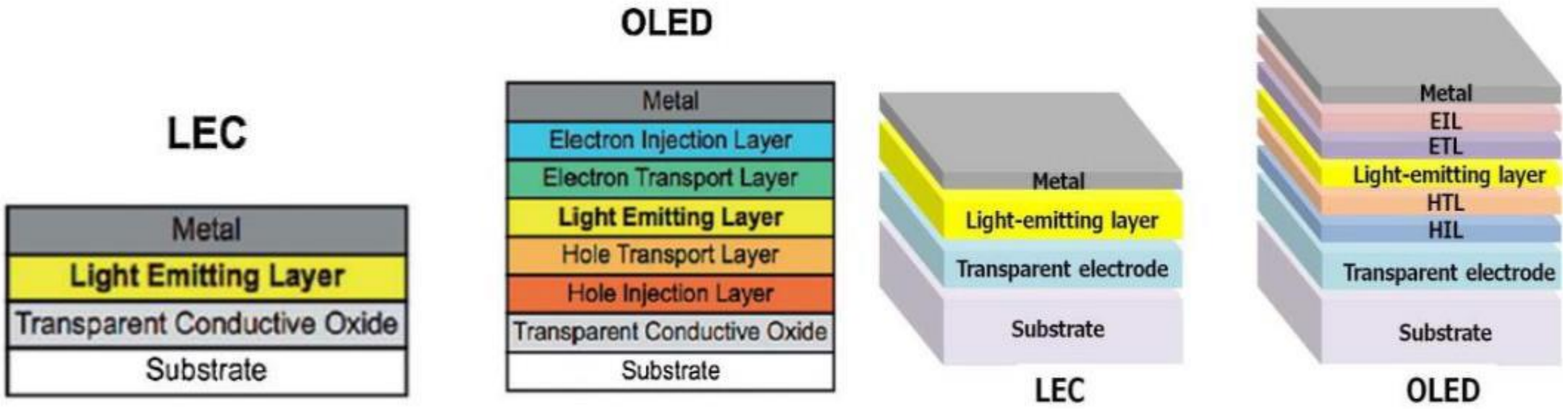


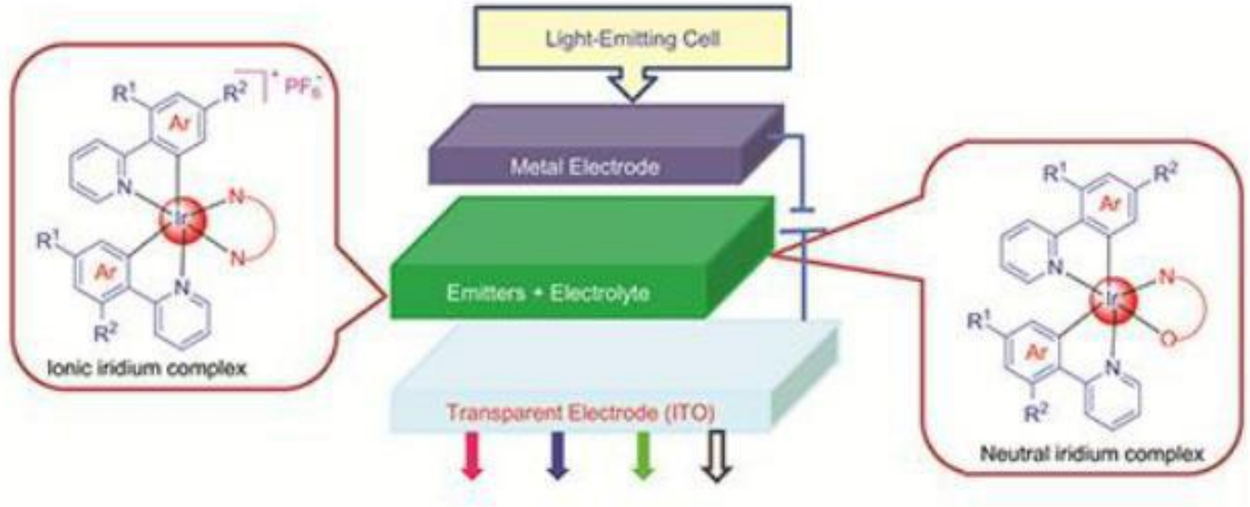
Light emitting electrochemical cells: Advantages

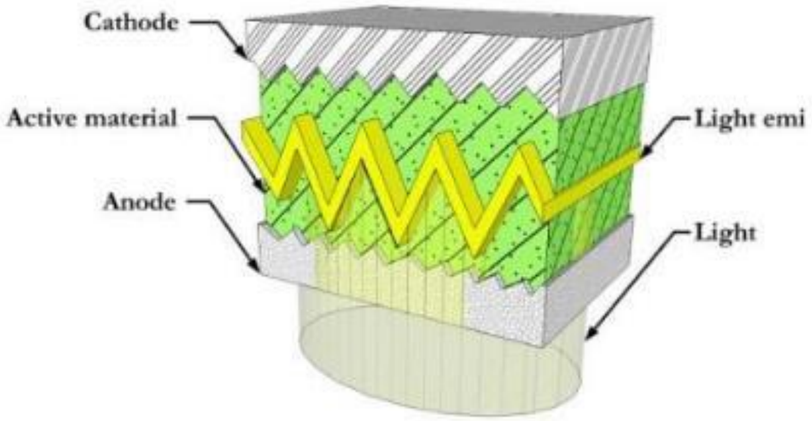
- The device is less dependent on the difference in work function of the electrodes. Consequently, the electrodes can be made of the same material (e.g. gold).
- Developed materials such as graphene or a blend of carbon nanotubes and polymers have been used as electrodes, eliminating the need for using indium tin oxide for a transparent electrode.

- The thickness of the active electroluminescent layer is not critical for the device to operate. This means that: LECs can be printed with relatively inexpensive printing processes (where control over film thicknesses can be difficult).

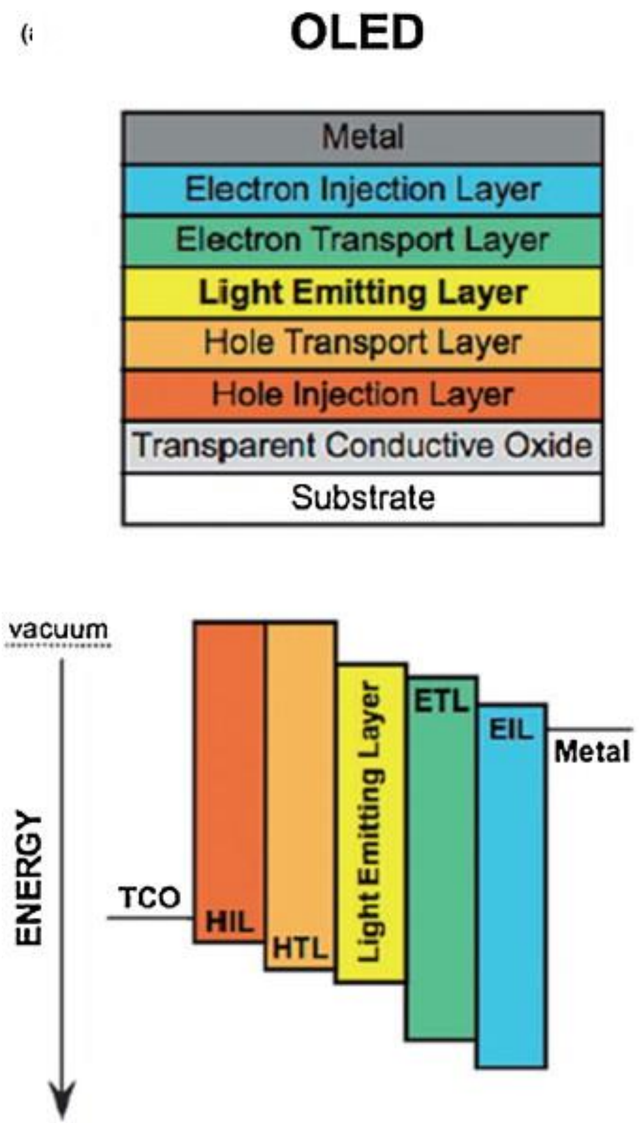
Light emitting electrochemical cells: Construction and working

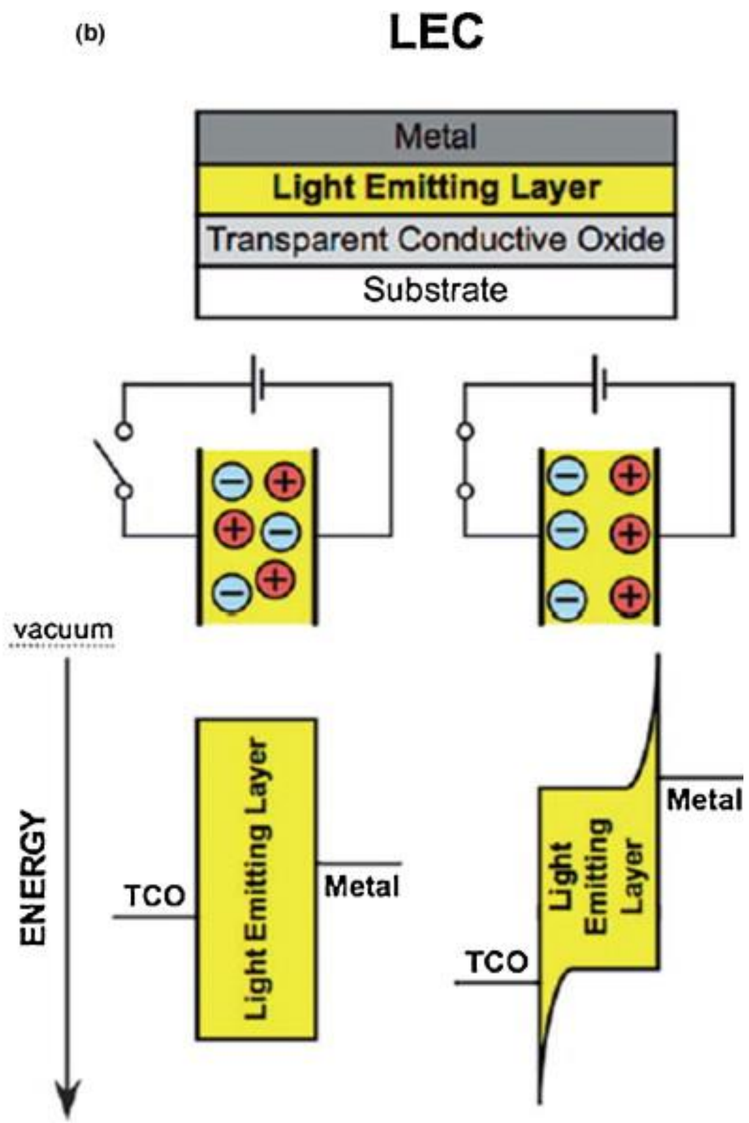


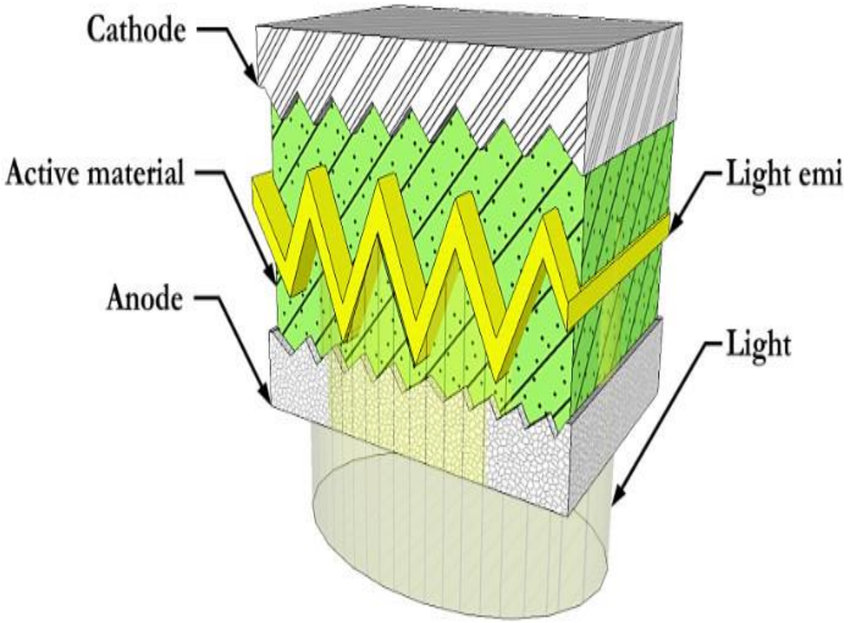




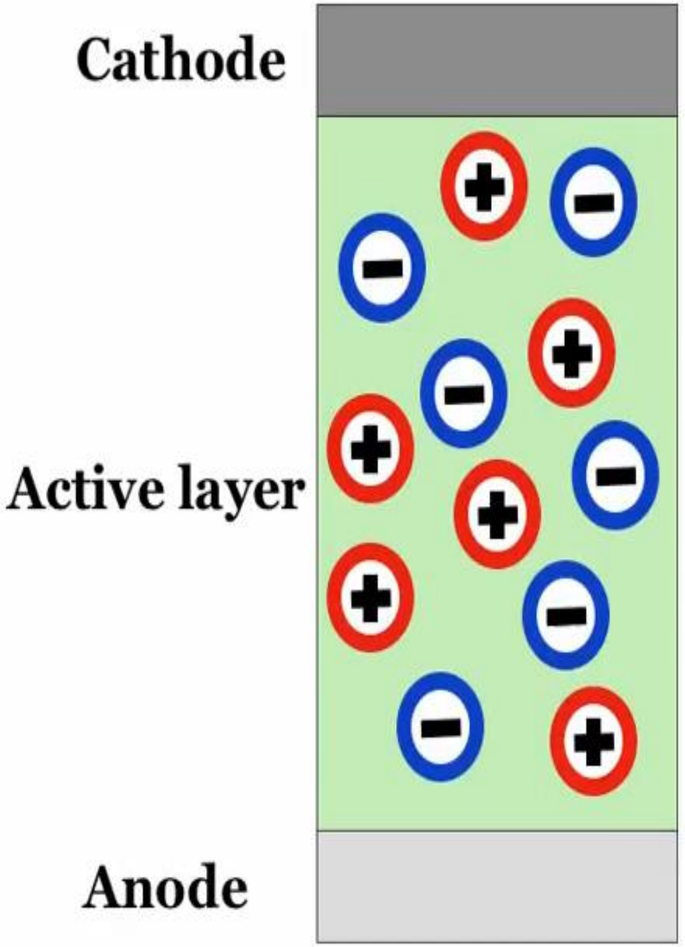
Comparison between LEC and OLED







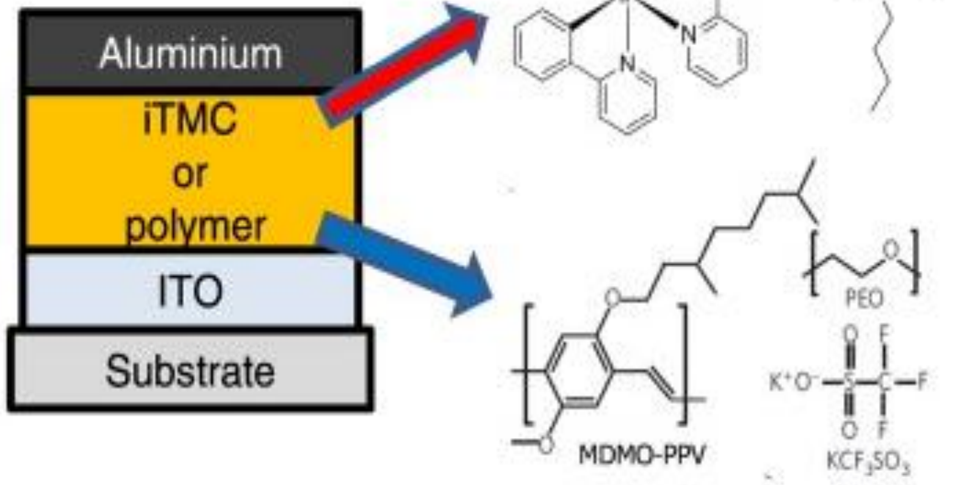
Light emitting electrochemical cells: working



Organic semiconductor

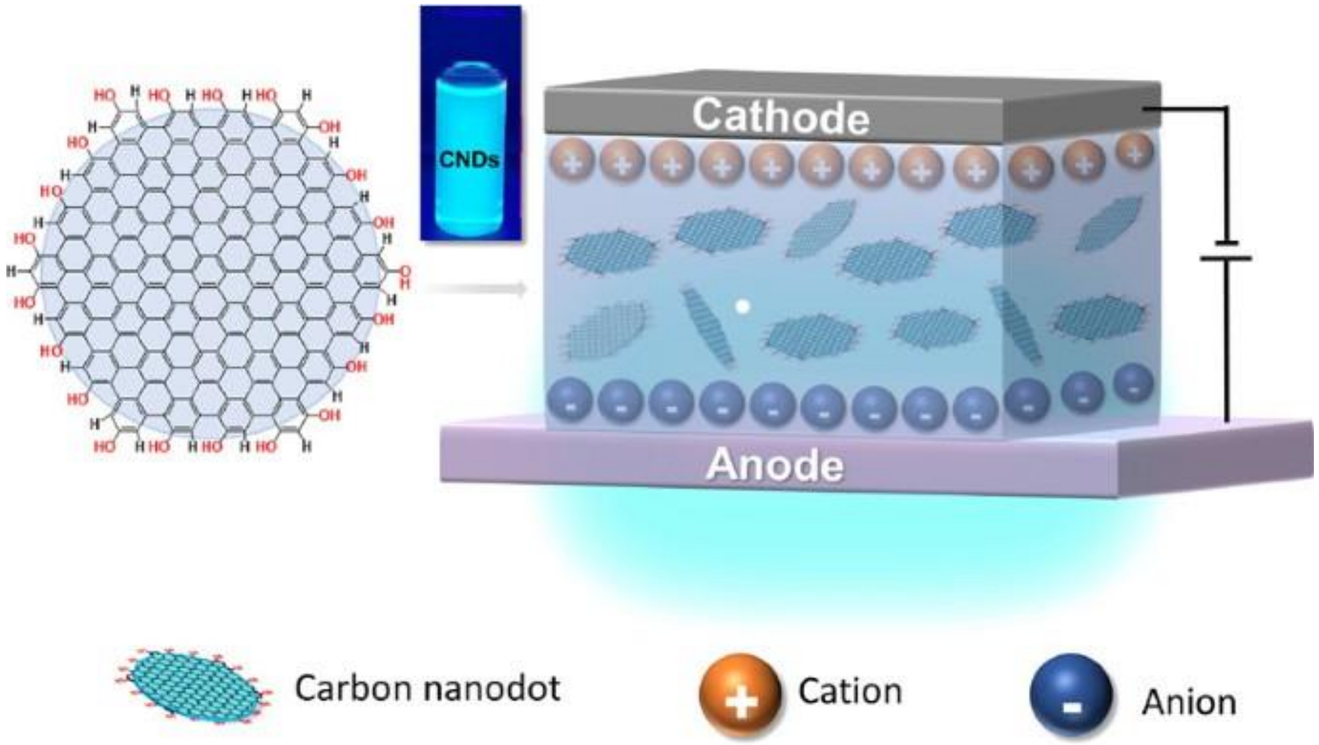
+

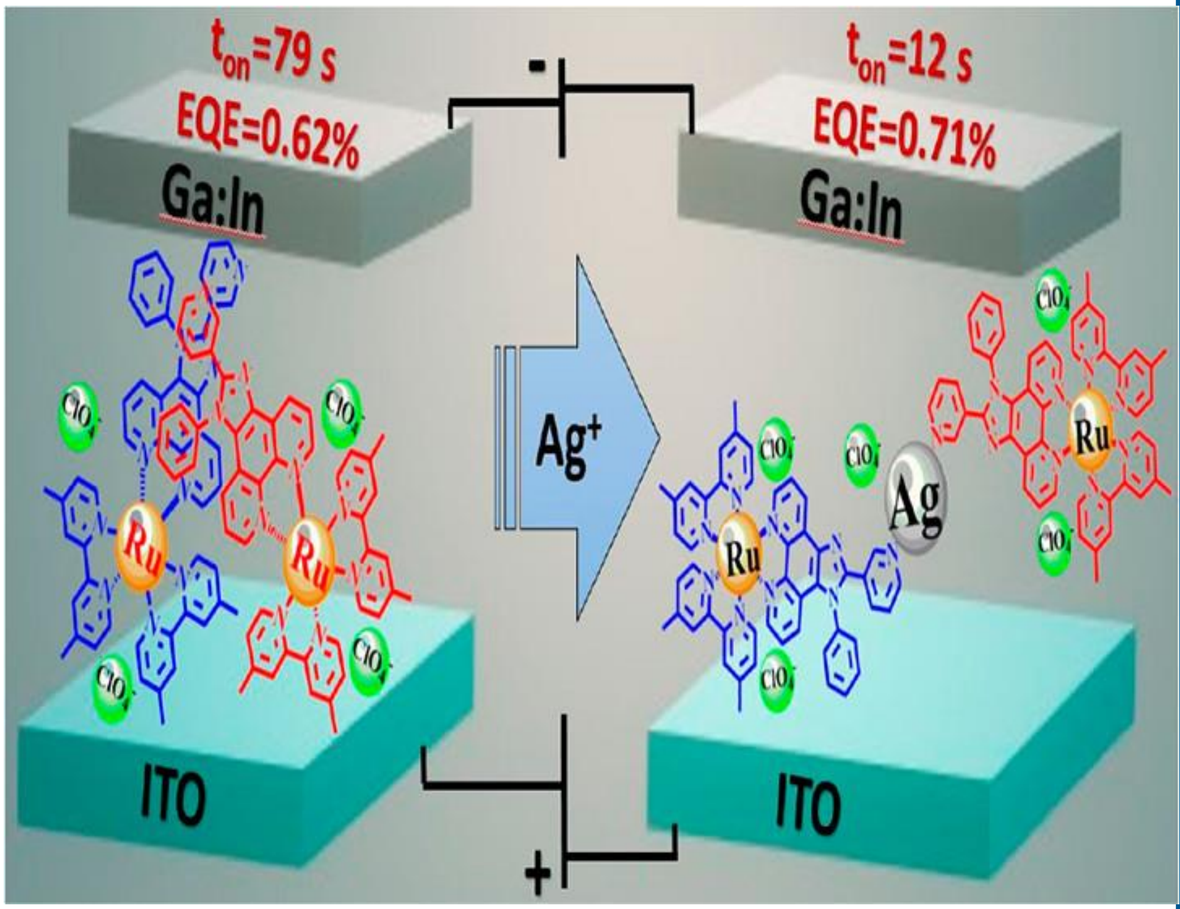
Mobile ions



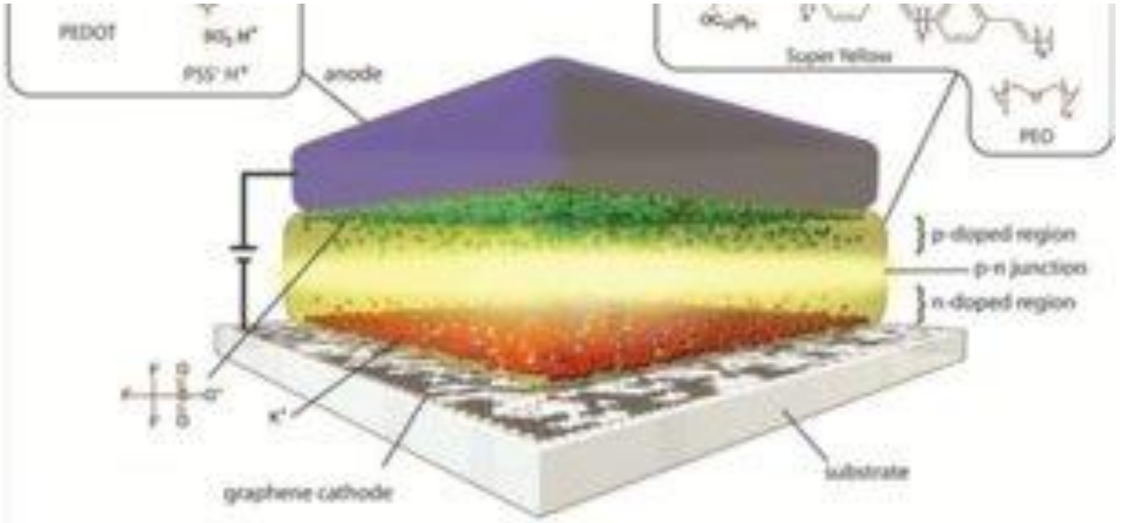
3

LEC recent advancement



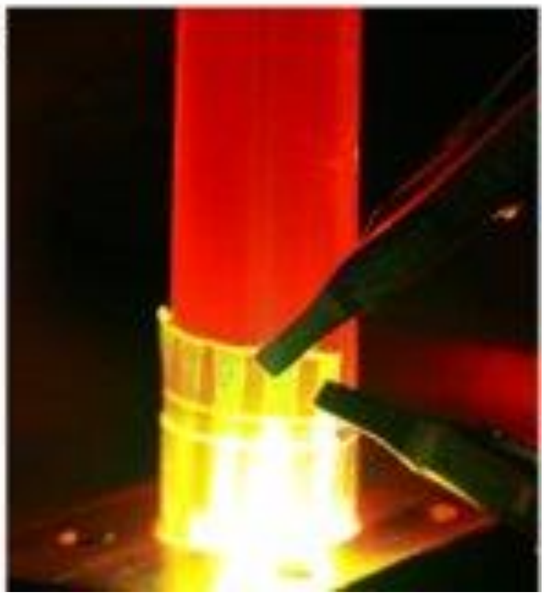


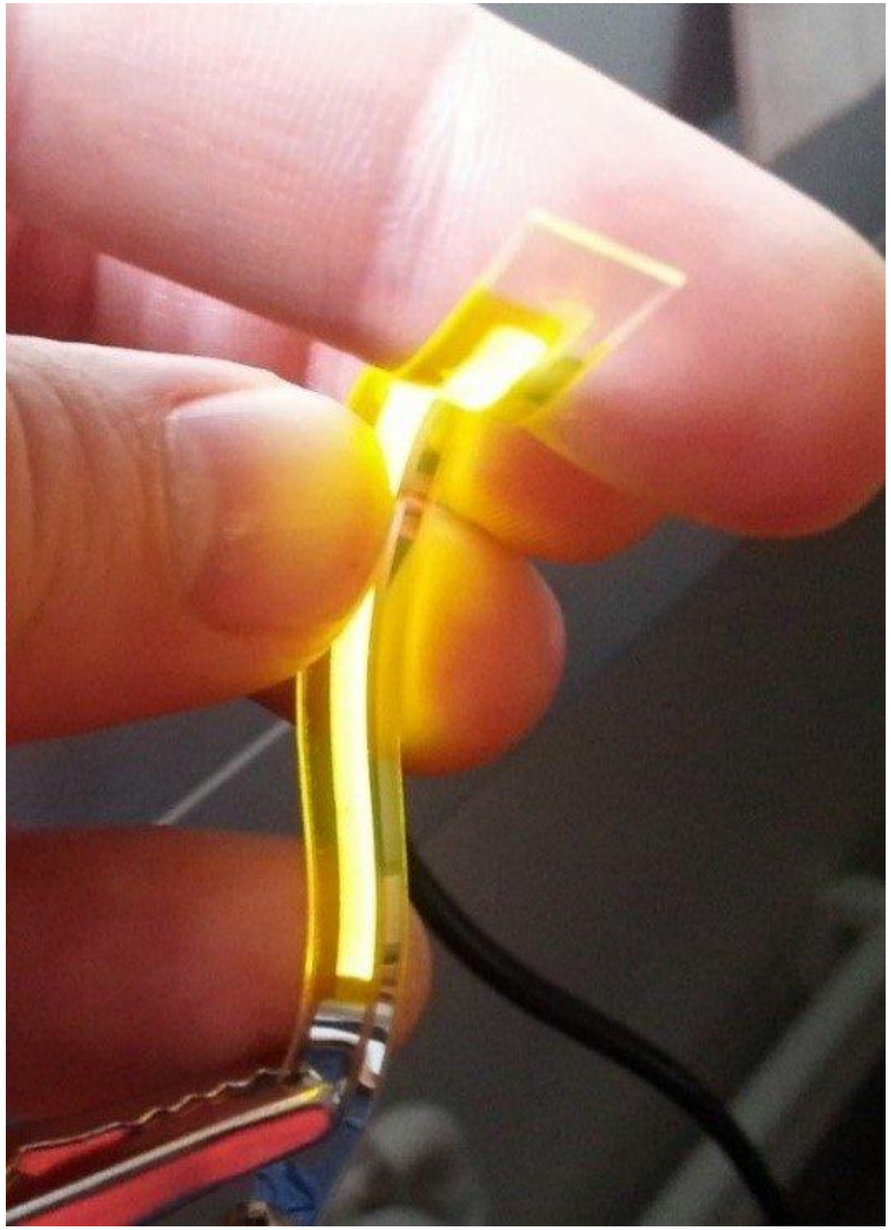
Applications of LEC



(b)

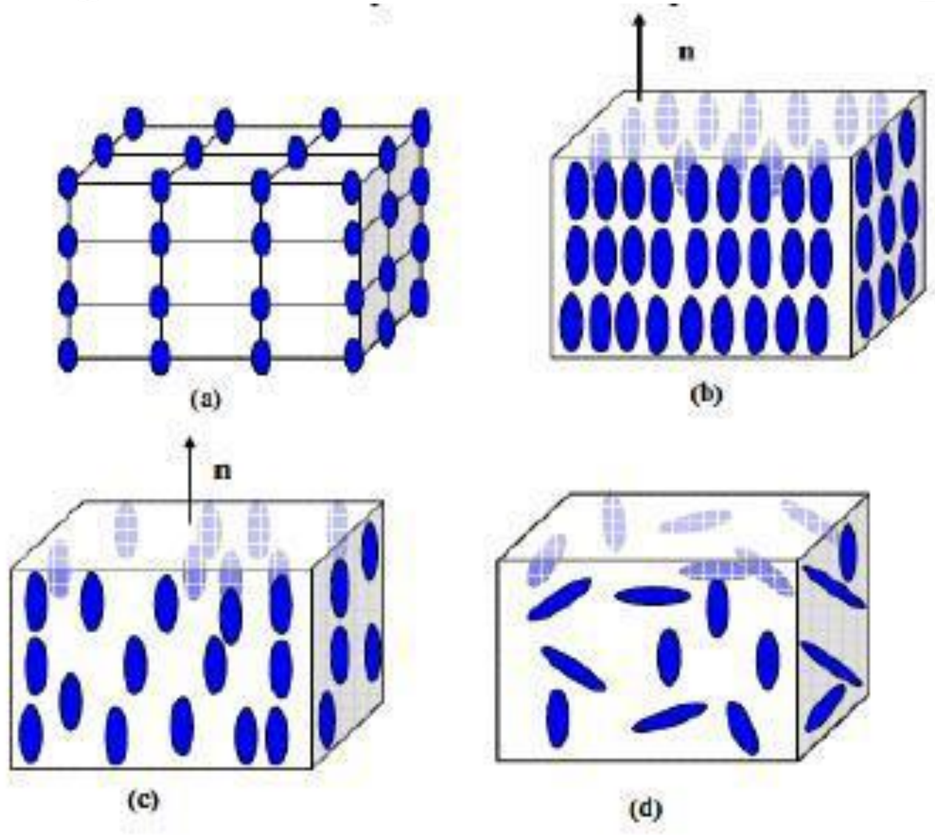
(c)

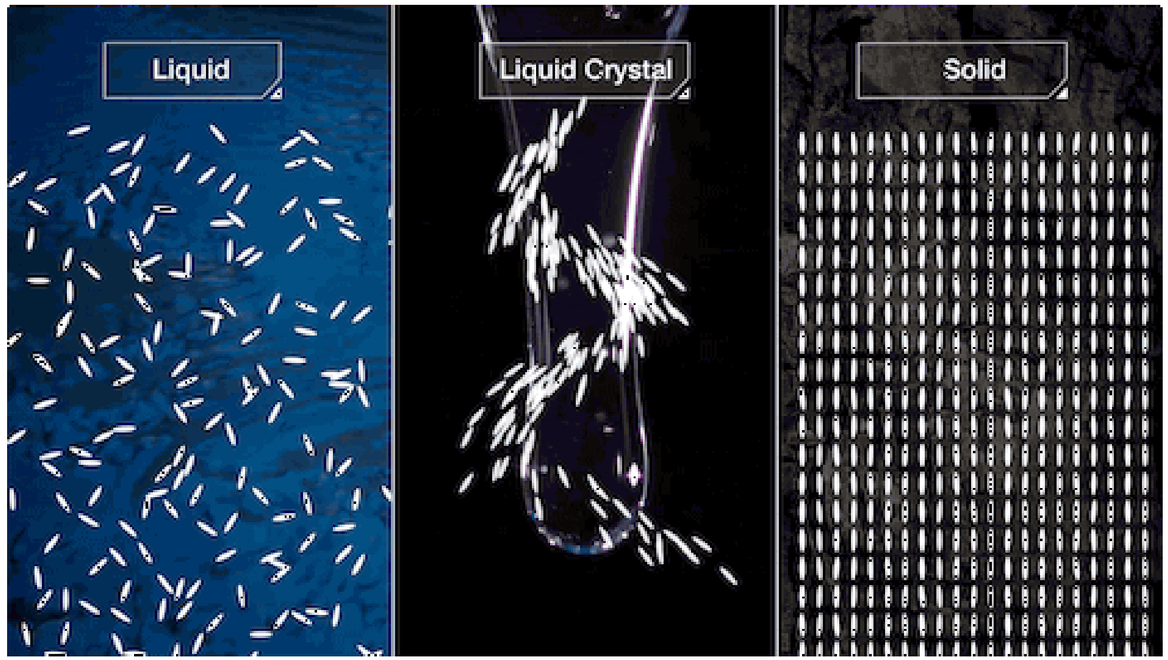




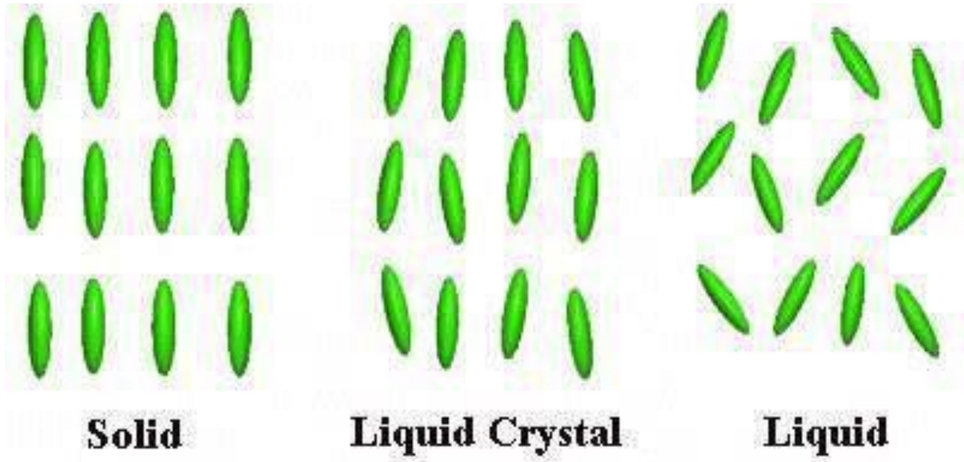
Liquid crystal display

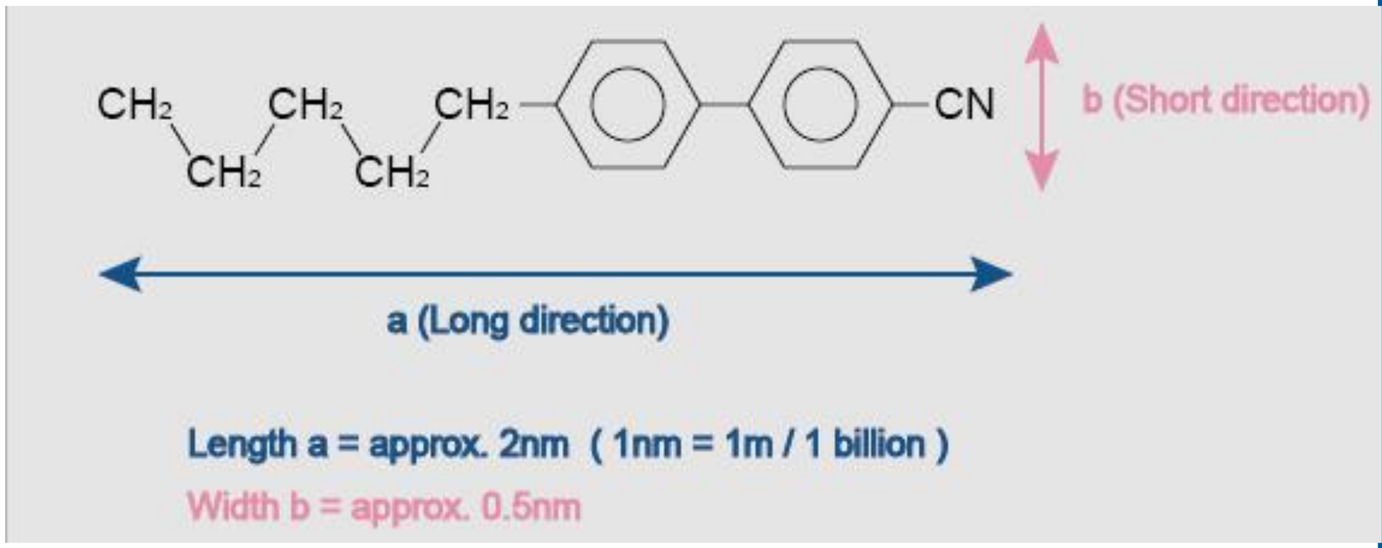
Liquid crystals are state of matter which has properties between those of conventional liquids and those of solid crystals. There are many different types of liquid –crystal phases, which can be distinguished by their different optical properties (such as textures).

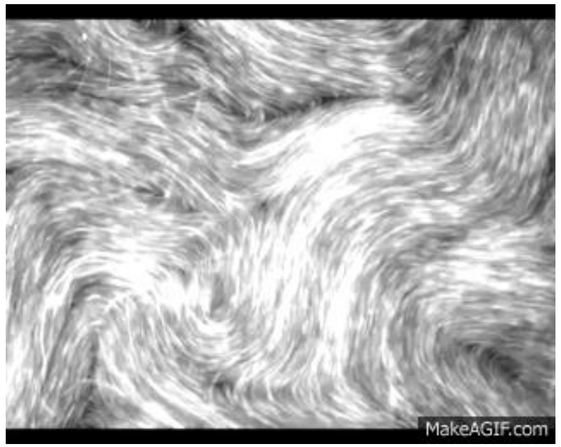


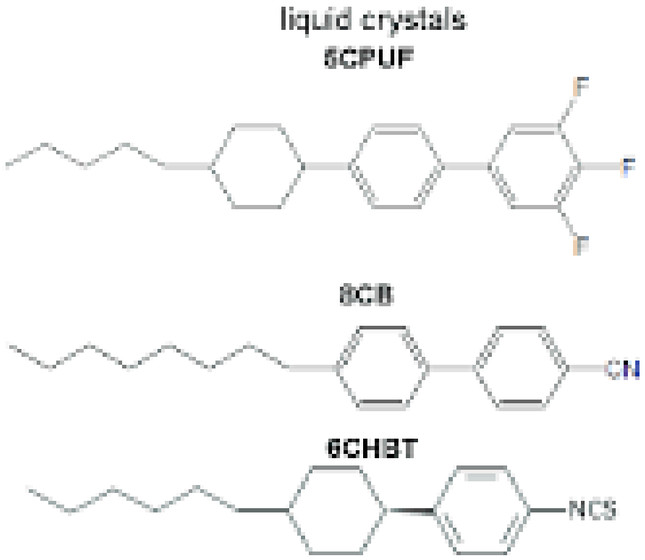


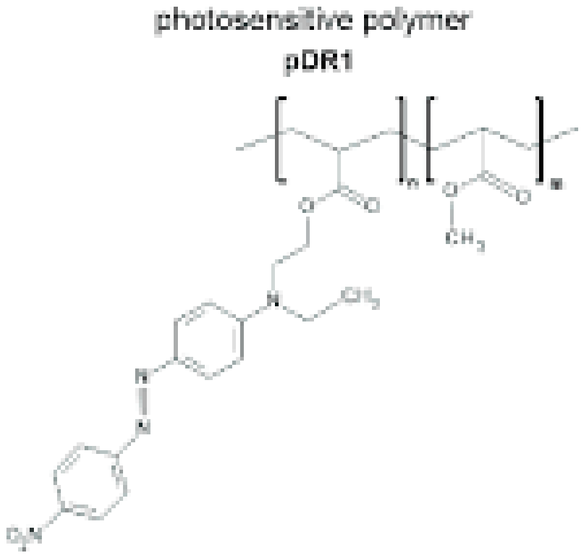
Liquid crystalline molecules











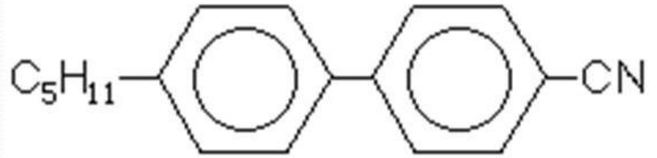
Types of Liquid crystals

1. Thermotropic consist mostly of organic molecules, although a few minerals are also known. Thermotropic LCs exhibit a phase transition into the LC phase as temperature changes.

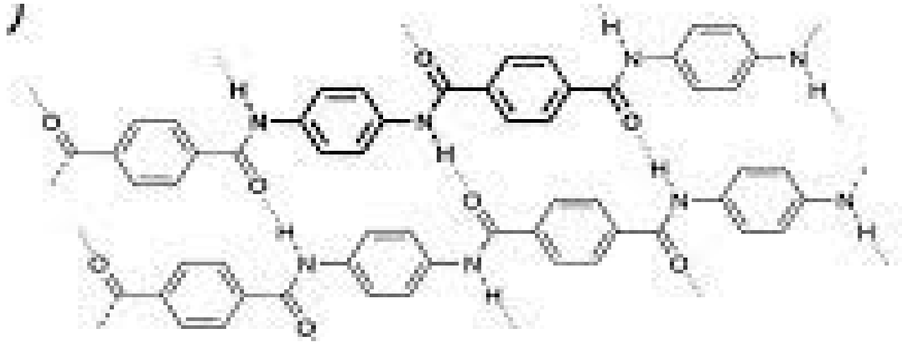
2. Lyotropic liquid crystals exhibit phase transitions as a function of both temperature and concentration of molecules in a solvent (typically water).

3. Metallotropic liquid crystals are composed of both organic and inorganic molecules; their LC transition additionally depends on the inorganic-organic composition ratio.

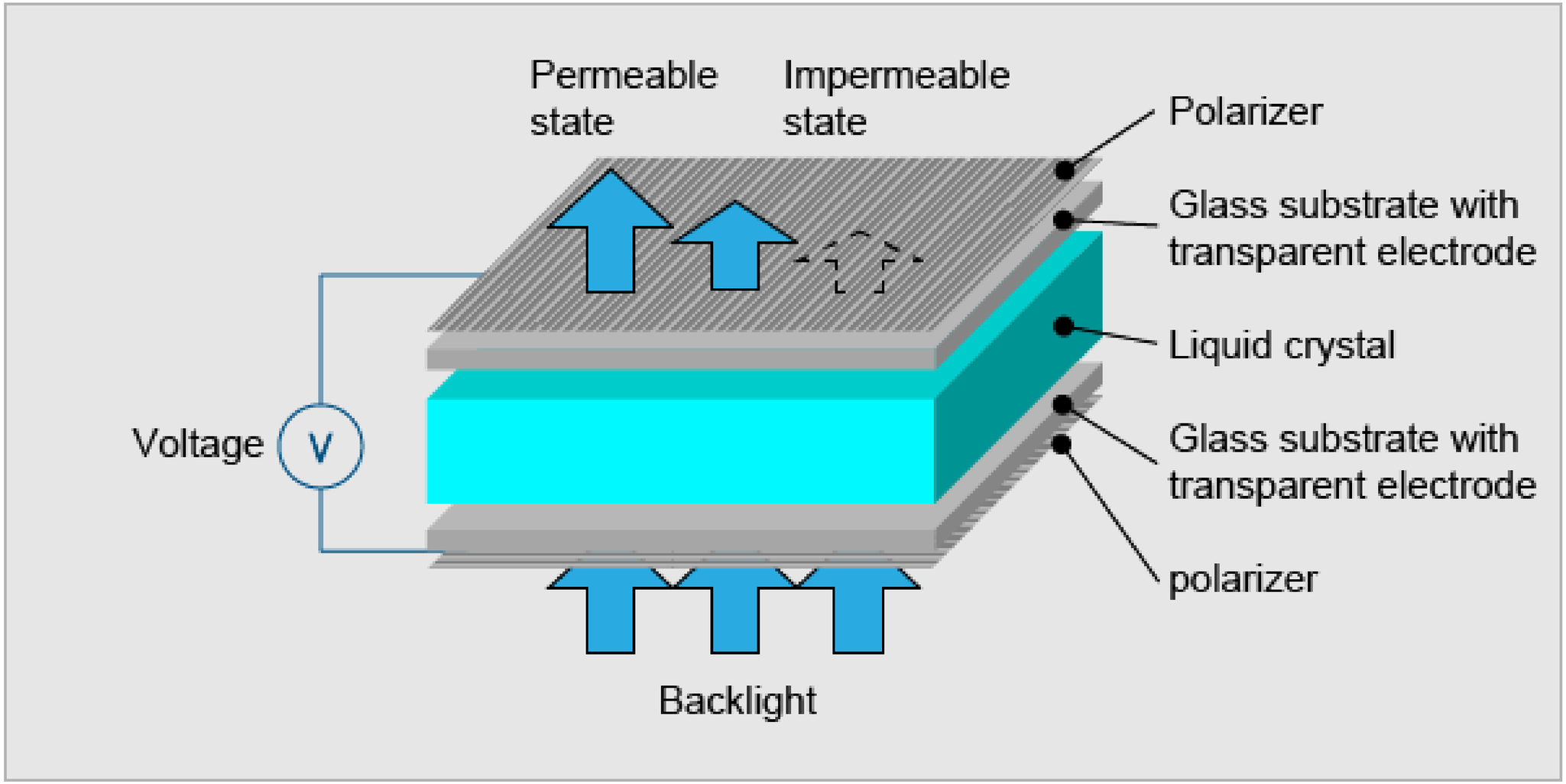
Biphenyl nitriles are commonly used as thermotropic liquid crystals.



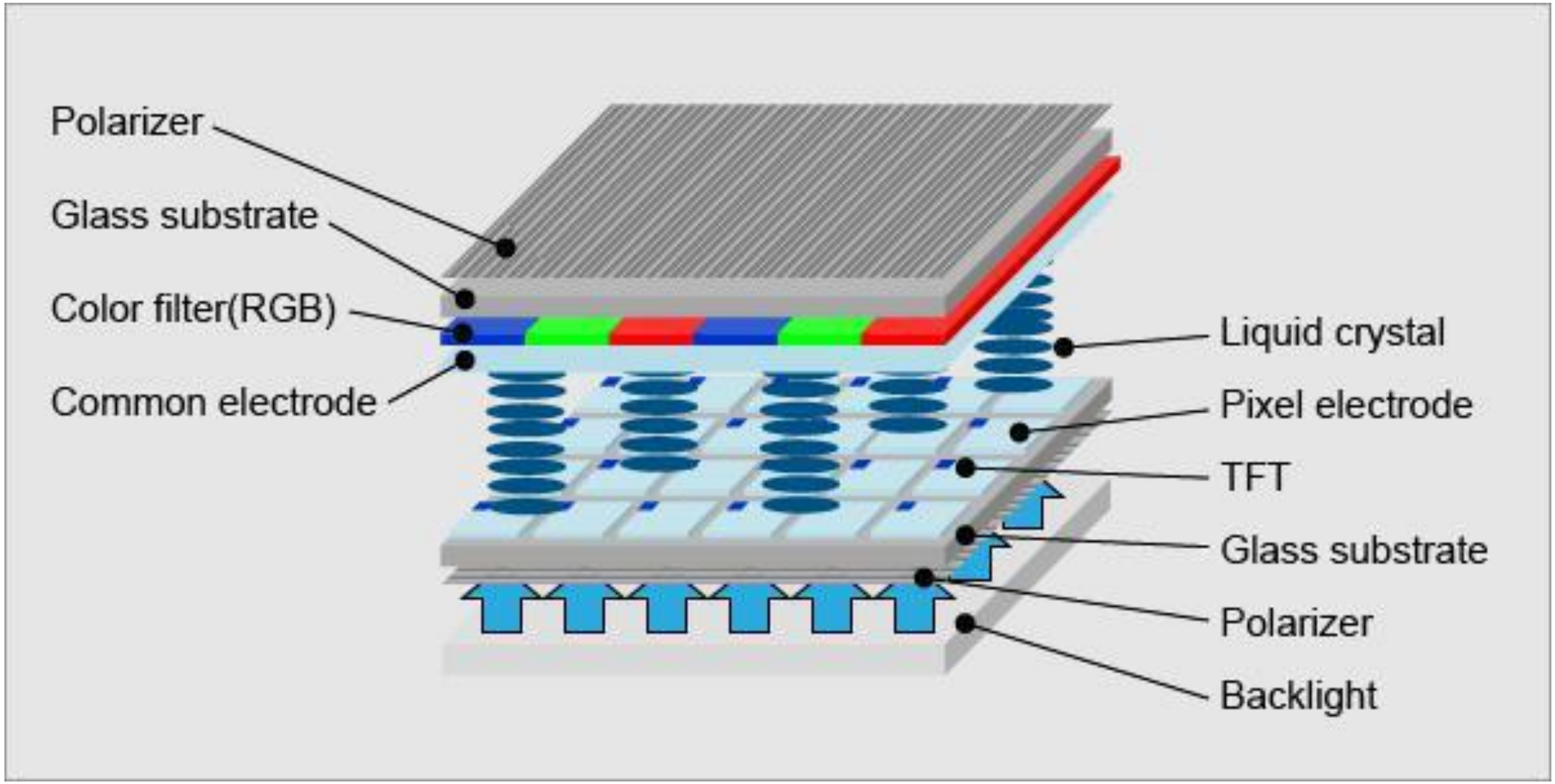
5CB *p-n* pentyl-*p'*-cyanobiphenyl (PCB)



Liquid crystal display



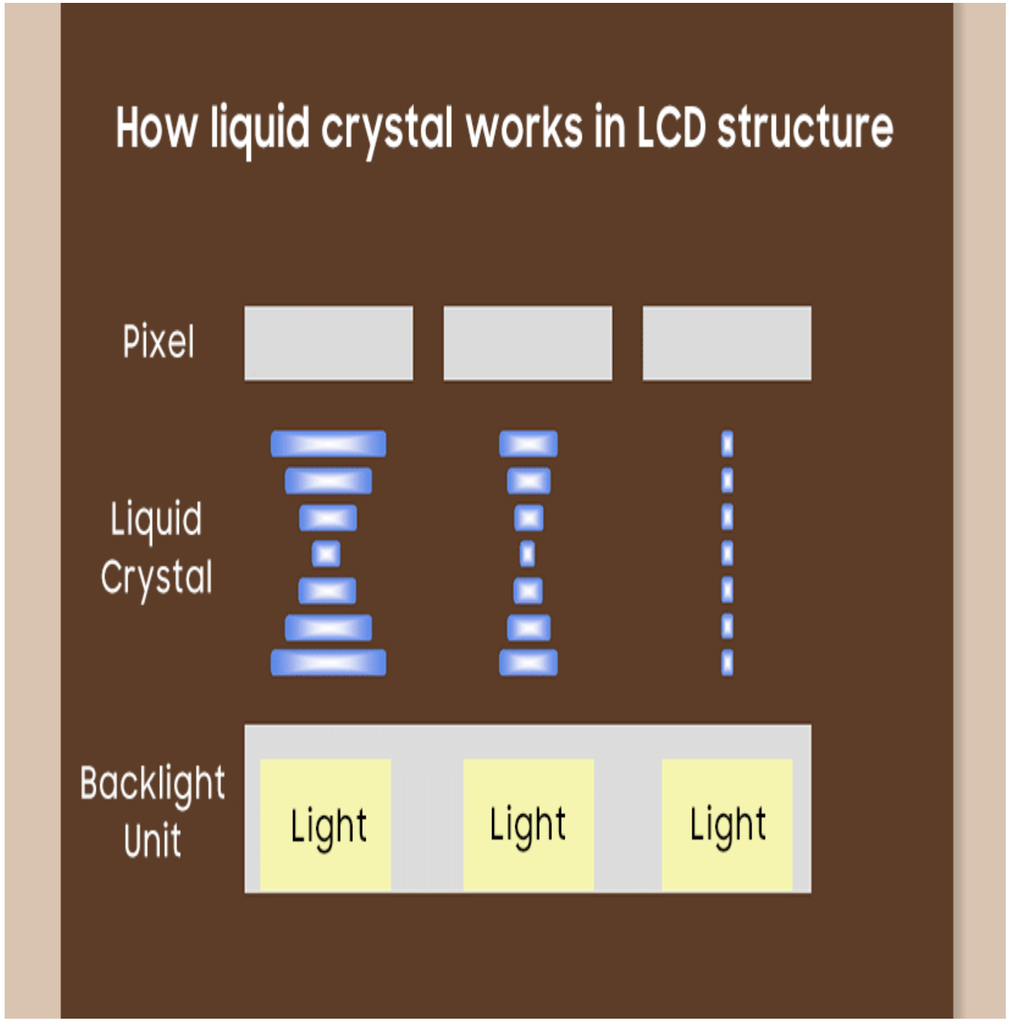
Liquid crystal display

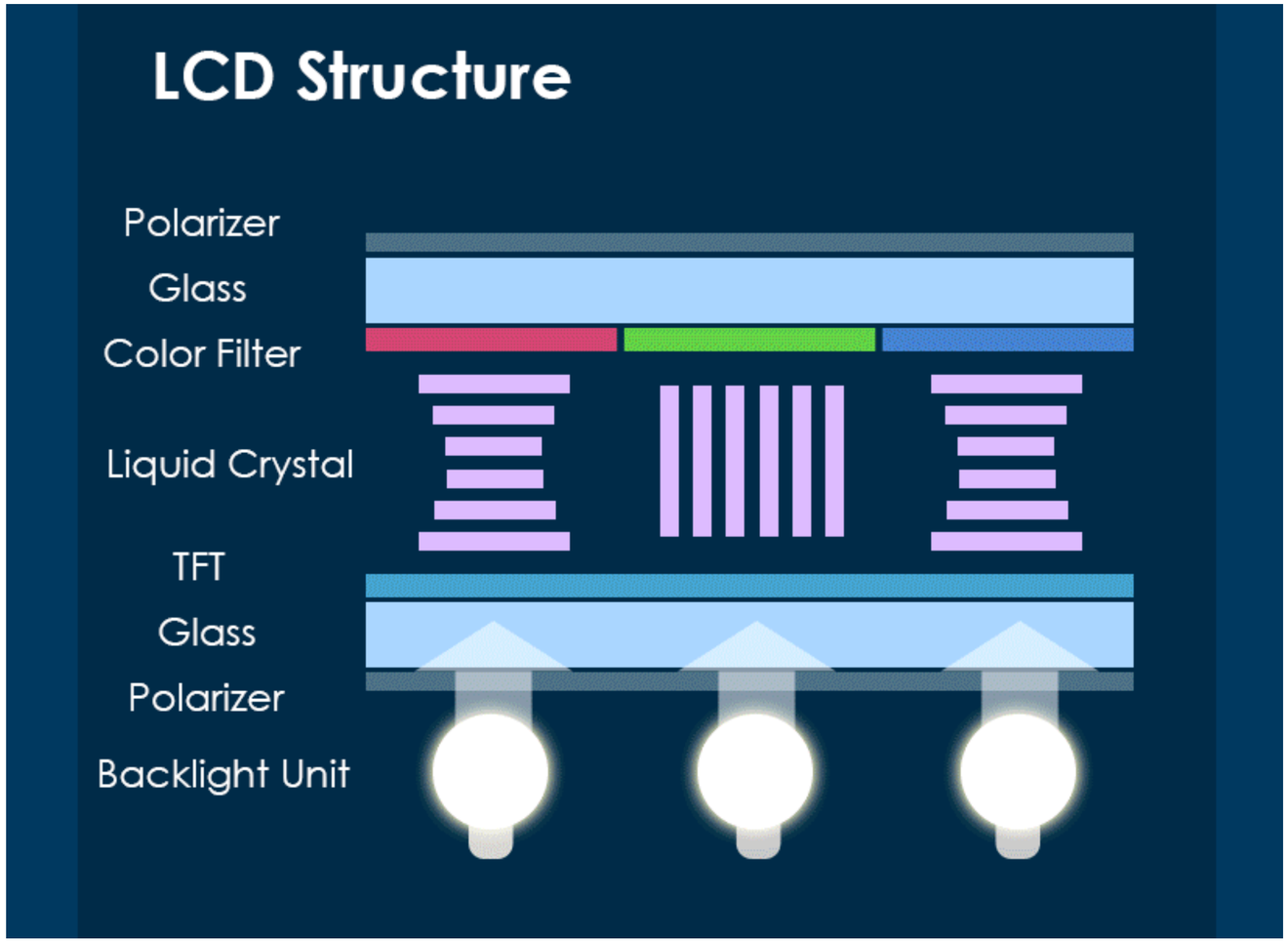


Liquid crystal display: Working

An LCD consists of many pixels. A pixel consists of three sub-pixels (Red/Green/Blue, RGB). In the case of Full-HD resolution, which is widely used for smartphones, there are more than six million (1,080 x 1,920 x 3 = 6,220,800) sub-pixels. To activate these millions of sub-pixels a TFT is required in each sub-pixel. TFT is an abbreviation for "Thin Film Transistor". A TFT is a kind of semiconductor device. It serves as a control valve to provide an appropriate voltage onto liquid crystals for individual sub-pixels. A TFT LCD has a liquid crystal layer between a glass substrate formed with TFTs and transparent pixel electrodes and another glass substrate with a color filter (RGB) and transparent counter electrodes. In addition, polarizers are placed on the outer side of each glass substrate and a backlight source on the back side. A change in voltage applied to liquid crystals changes the transmittance of the panel including the two polarizing plates, and thus changes the quantity of light that passes from the backlight to the front surface of the display. This principle allows the TFT LCD to produce full-color images.

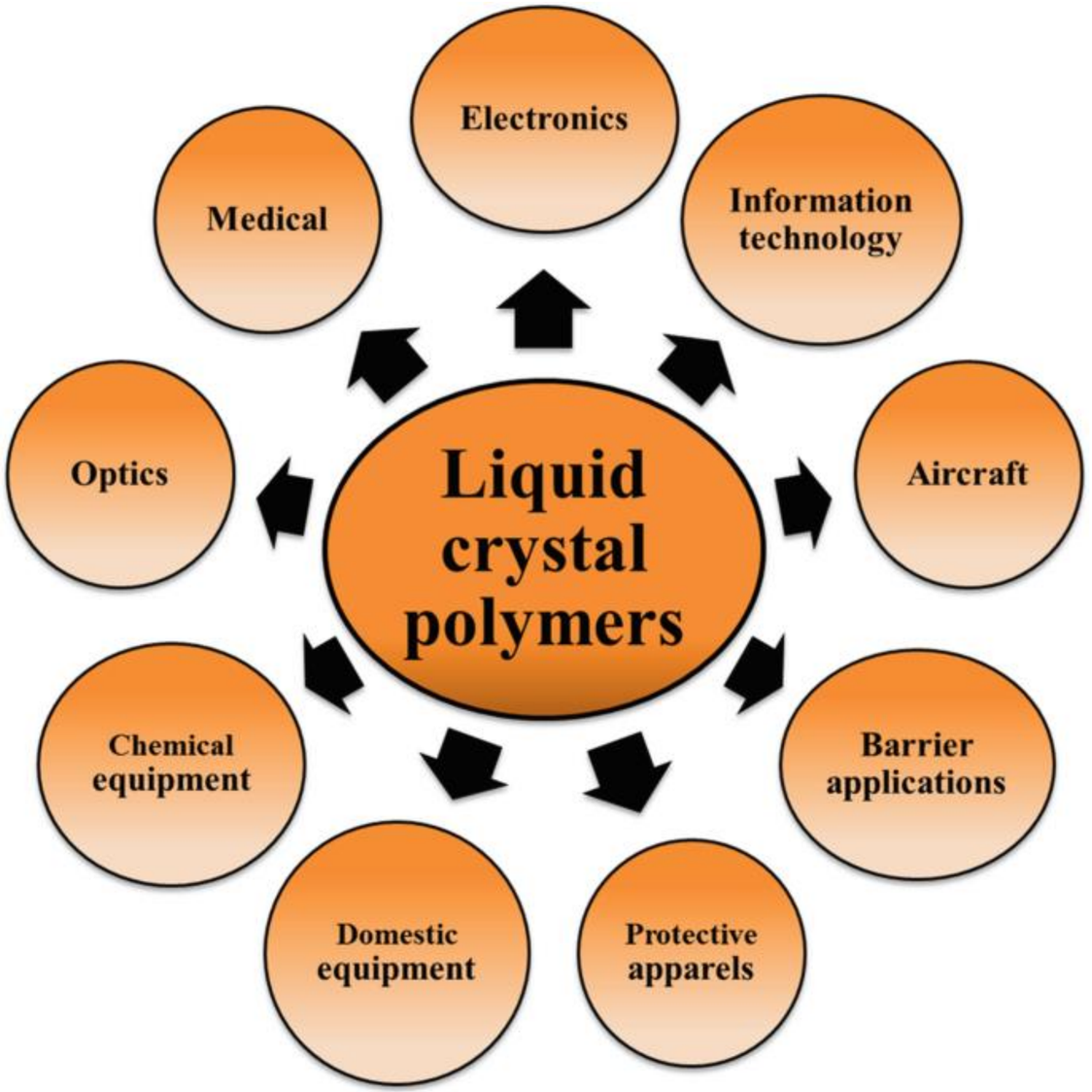
Liquid crystal display





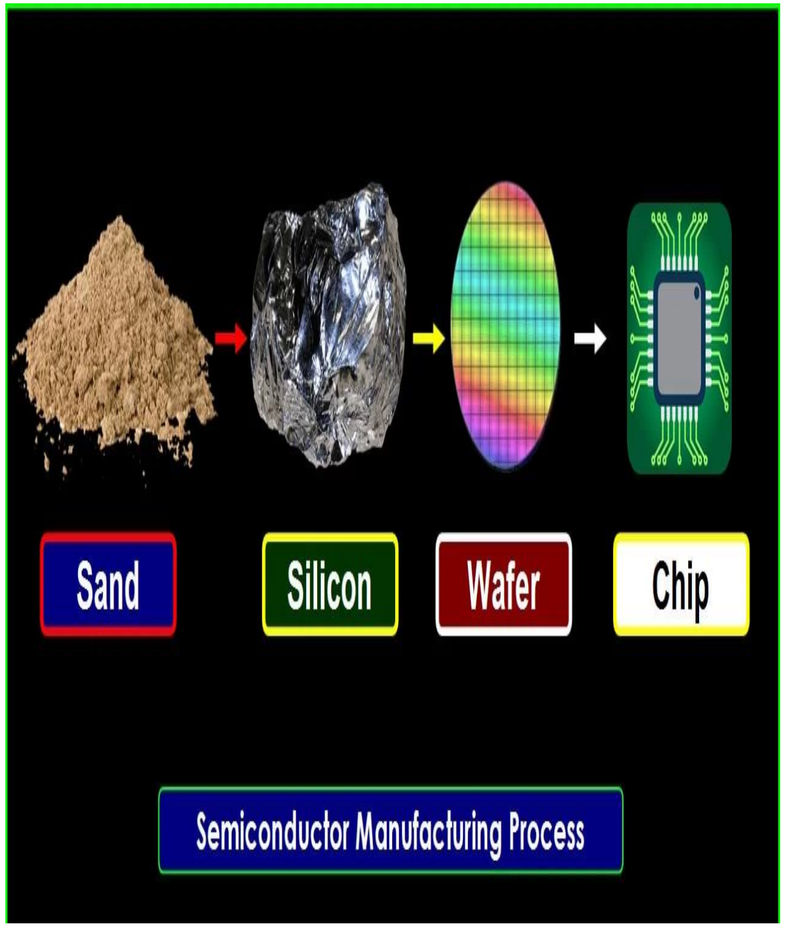
Liquid crystal display: Applications

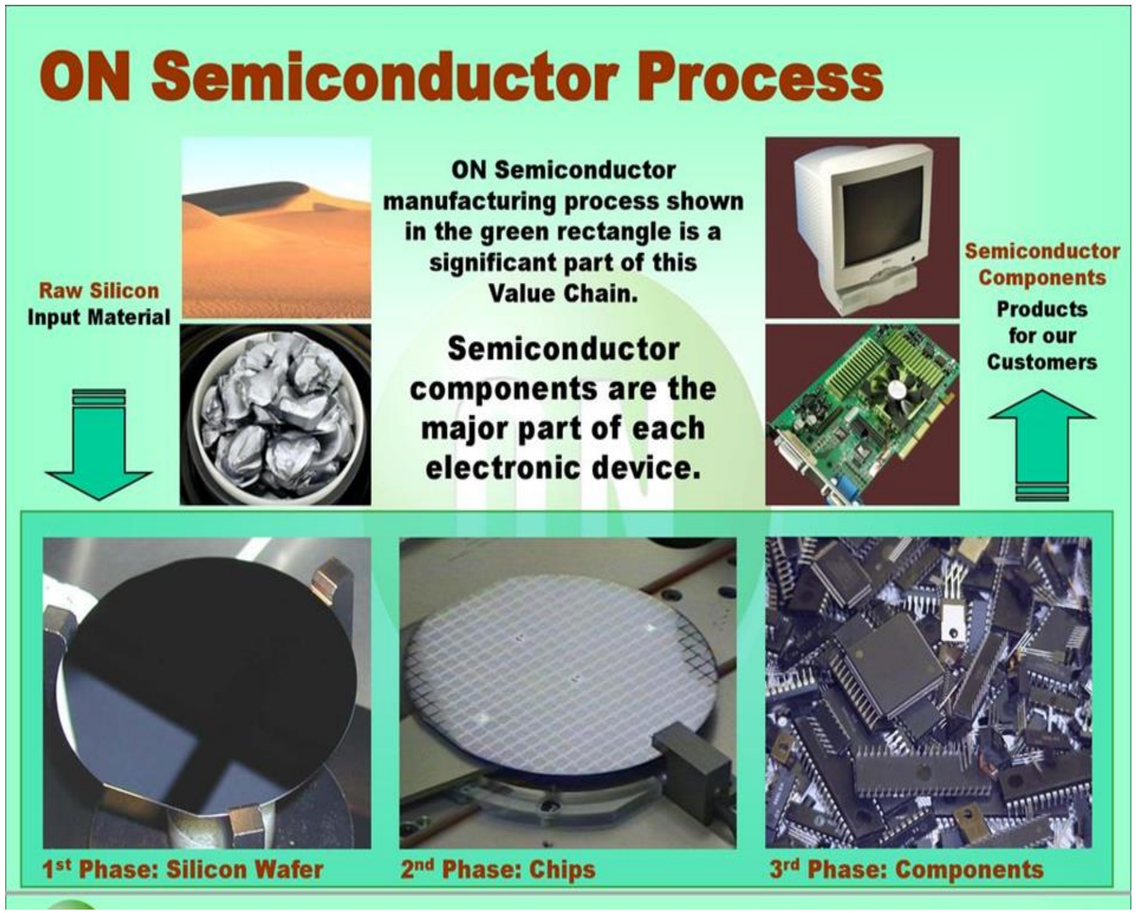
Liquid crystal display: Applications



Semiconductor chip manufacturing

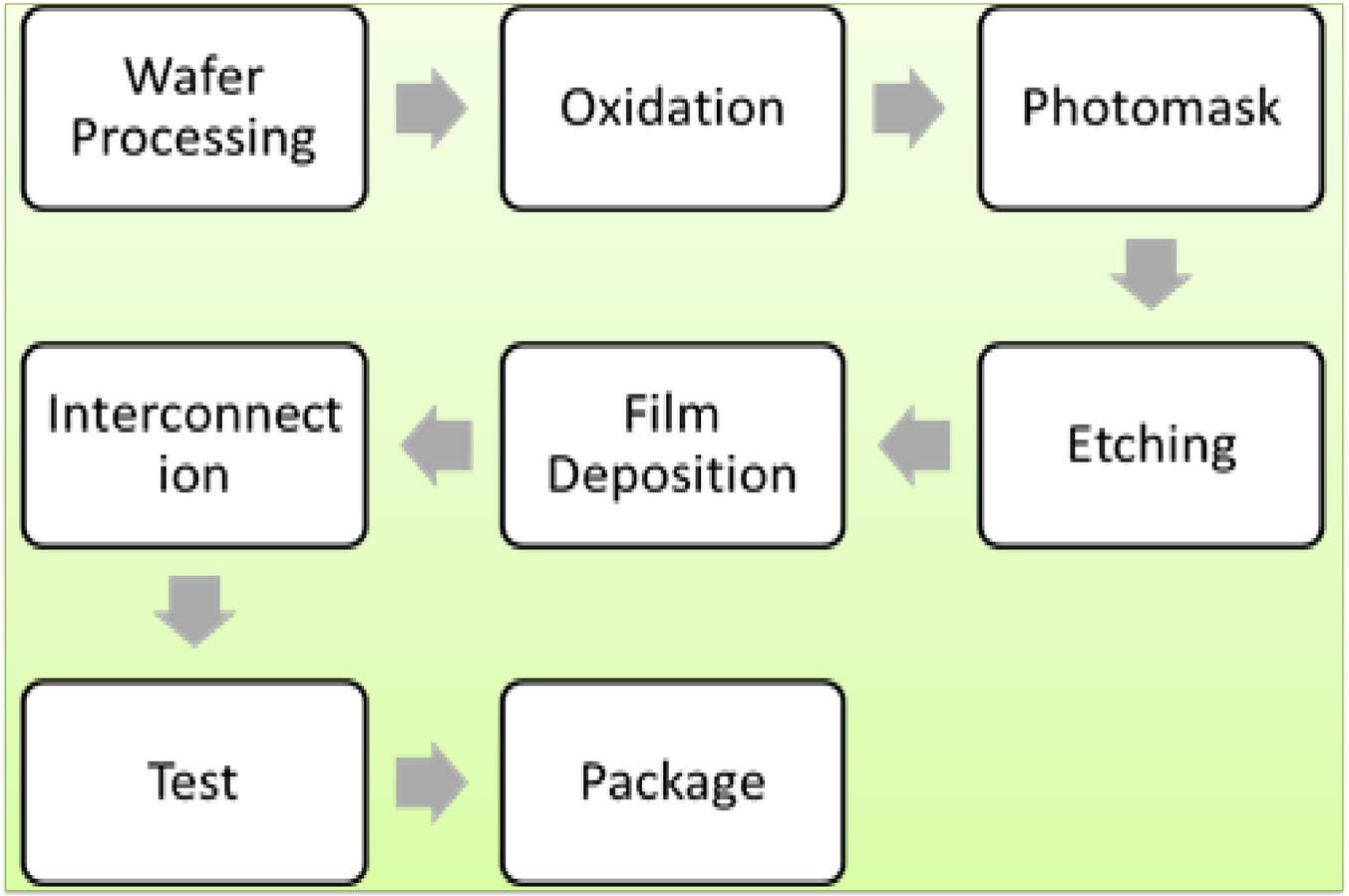
A semiconductor chip is an electric circuit constructed on a semiconductor wafer containing several components such as transistors and wiring formed on a semiconductor wafer. An electronic device comprising numerous these components is called “integrated circuit”.





Fabrication Steps:

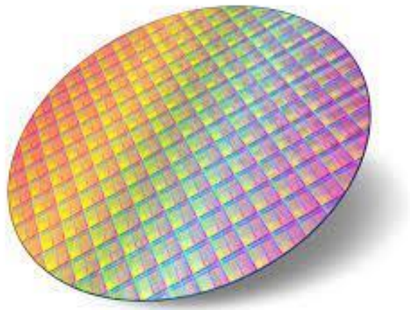
Entire manufacturing process can be divided into 8 steps.

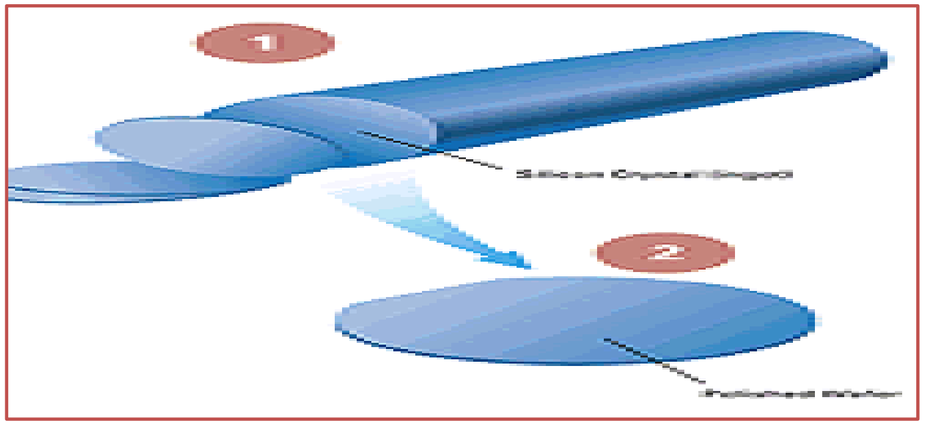


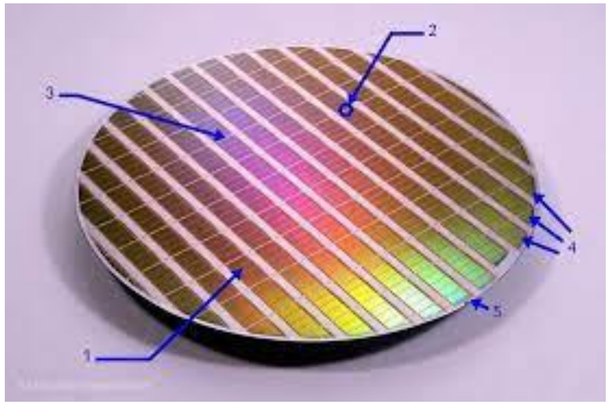
Fabrication Steps: It is a multiple-step sequence of photolithographic and chemical processing steps (such as surface passivation, thermal oxidation, planar diffusion and junction isolation) during which electronic circuits are gradually created on a wafer made of pure semiconducting material.

Steps in semiconductor manufacturing: Wafer Processing

- A wafer, also called a disc, is a thin round glossy slice of a silicon rod (or Germanium) that is cut using specific diameters for the fabrication of integrated circuits. Most wafers are made of silicon extracted from sand.
- First, it is heated until it melts into a high-purity liquid then solidified into a silicon rod, or ingot, using common growing methods like the Czochralski (chokh-RAL-skee) process or the Floating Zone process. In these process, a cylindrical ingot of high purity monocrystalline semiconductor, such as silicon or germanium, called a boule, is formed by pulling a seed crystal from a melt. These ingots are then sliced into wafers about 0.75 mm thick Then it processed.





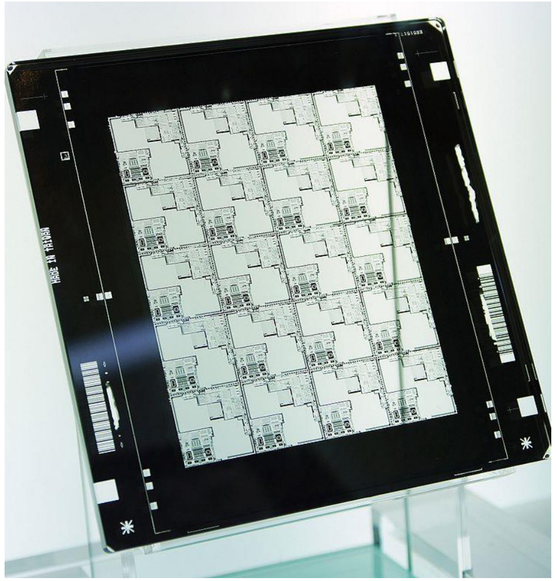


Contd.,

Steps in semiconductor manufacturing

2. Oxidation

The role of oxidation process is to form a protective film on the surface of wafer. It can protect the wafer from chemical impurities; prevent leakage current from entering circuit, diffusion during ion implantation and the wafer from slipping off during etching.



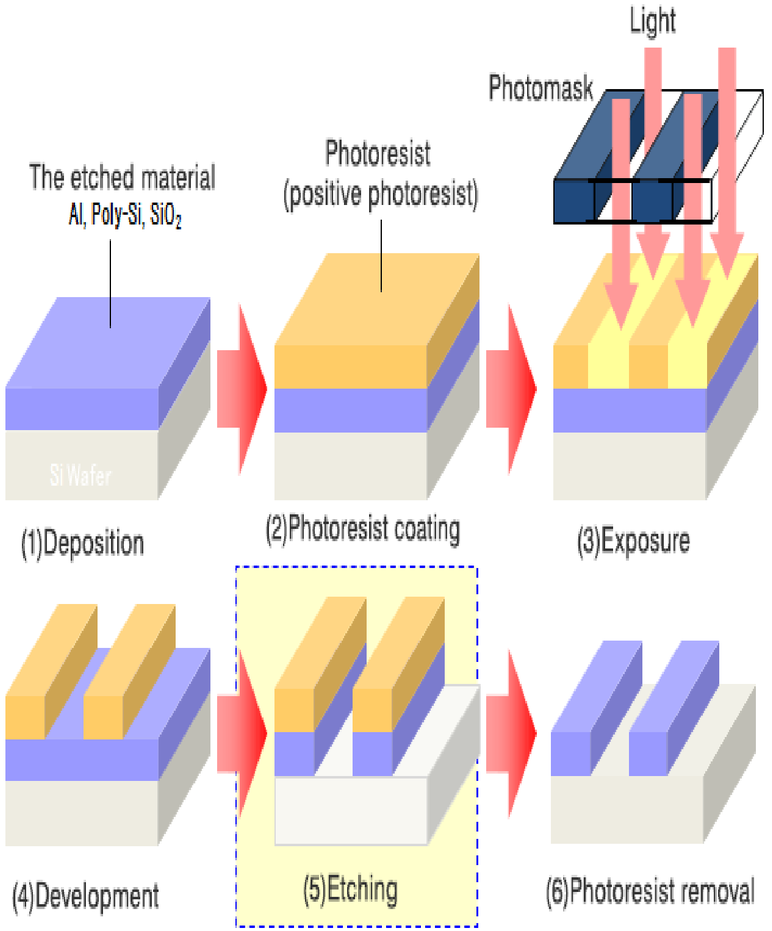
3. Photomask

A photomask is basically a “master template” of an IC design. Photomask is the use of light to print circuit patterns onto wafer. A photomask is an opaque plate with holes or transparencies that allow light to shine through in a defined pattern. (Previously, photomasks used to be produced manually by using rubylith and mylar). The wafer is then covered with a light-sensitive coating called 'photoresist'. There are two types of resist: positive and negative. The main difference between positive and negative resist is the chemical structure of the material and the way that the resist reacts with light.

Steps in semiconductor manufacturing

4. Etching

The next step is to remove the degraded resist to reveal the intended pattern. During 'etch', the wafer is baked and developed, and some of the resist is washed away to reveal a 3D pattern of open channels. Etch processes must precisely and consistently form increasingly conductive features without impacting the overall integrity and stability of the chip structure.



5. Film deposition

To create the micro devices inside the chip, deposit layers of thin films and remove excess parts by etching and add some materials to separate the different devices. Thin film layers of silicon oxide, aluminium and other metals that will become the circuit materials are formed on the wafer. Thin films of conducting, isolating or semiconducting materials – depending on the type of the structure being made are deposited on the wafer to enable the first layer to be printed on it. This important step is commonly known as 'deposition'.

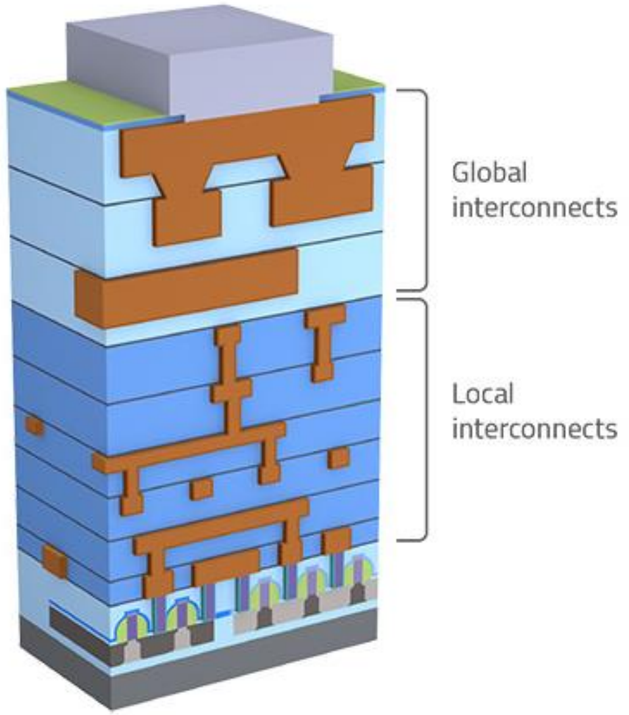
Steps in semiconductor manufacturing

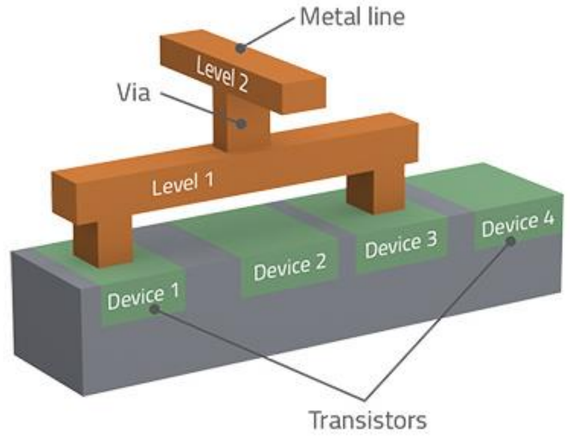
6. Interconnection

Raw silicon – the material the wafer is made of is not a perfect insulator or a perfect conductor. Silicon‟s electrical properties are somewhere in between. In order to give the silicon substrate semiconducting properties, impurities, such as phosphor or boron ions, are implanted in the wafers.

7. Test

The main goal of the test is to check whether the quality of the semiconductor chip meets a certain standard, thereby eliminating the defective products and improving the reliability of the chip. Electronic Die sorting (EDS) is a testing method for wafers. Once the front-end process has been completed, the semiconductor devices or chips are subjected to a variety of electrical tests to determine if they function properly. The percent of devices on the wafer found to perform properly is referred to as the yield.





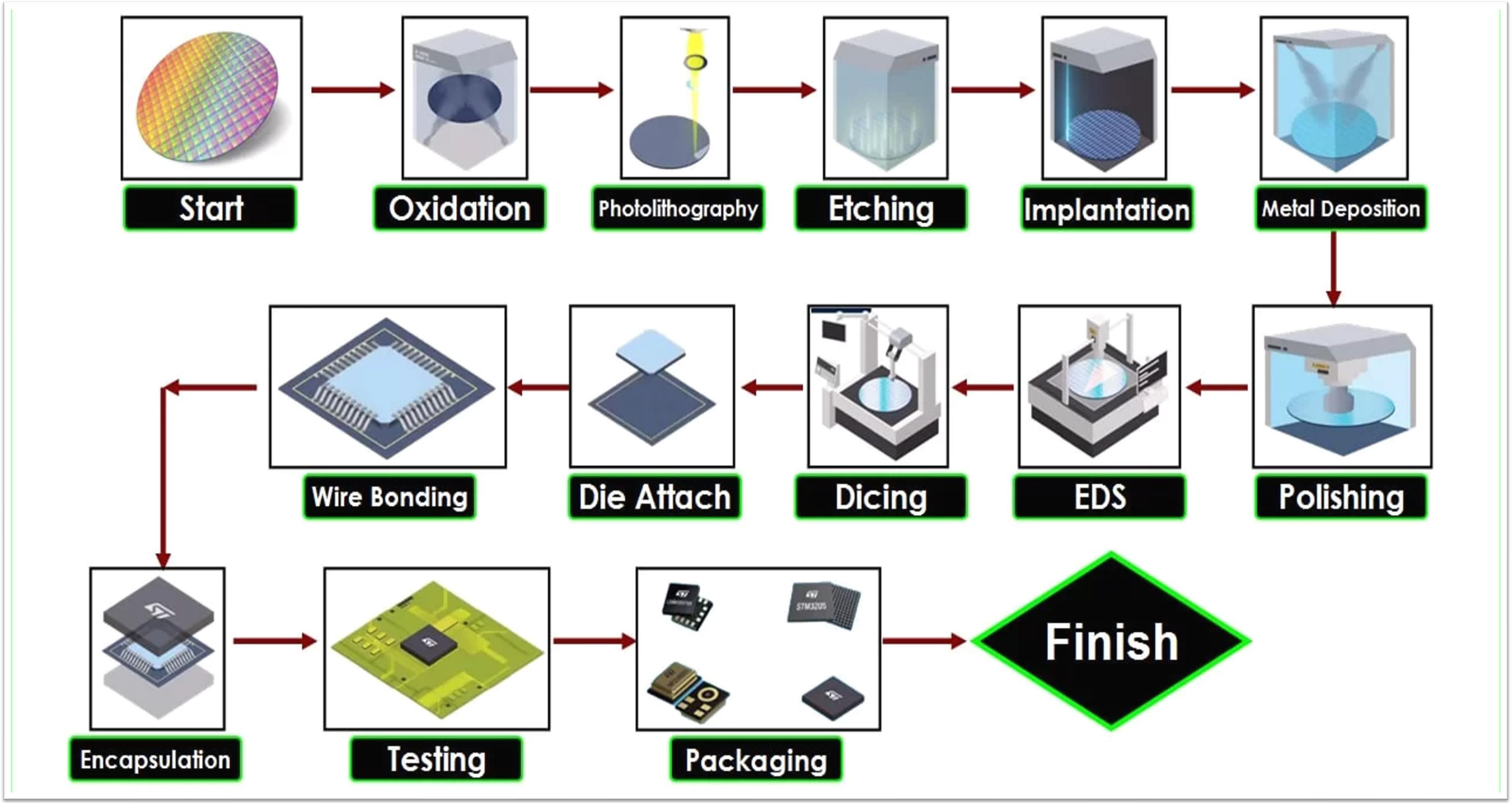
8. Package

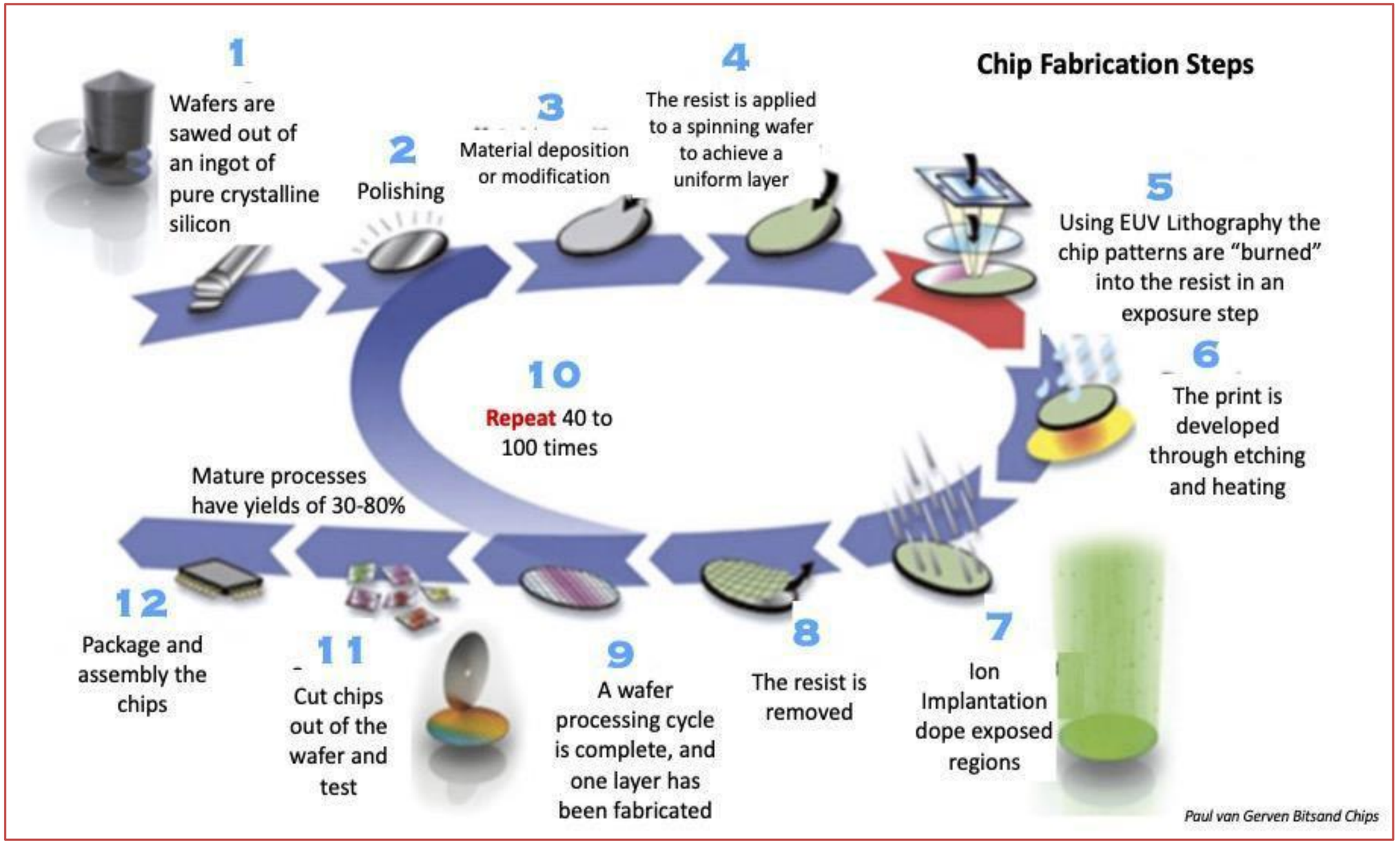
Single wafers are cut into individual chips by cutting. The entire packaging system is divided into five steps. Namely wafer sawing, single wafer attachment, interconnection, molding and packaging.

The entire process of creating a silicon wafer with working chips consists of thousands of steps and can take more than three months from design to production. To get the chips out of the wafer, it is sliced and diced with a diamond saw into individual chips. Cut from a 300- wafer, the size most often used in semiconductor manufacturing, these so-called 'dies' differ in size for various chips. Some wafers can contain thousands of chips, while others contain just a few dozen.

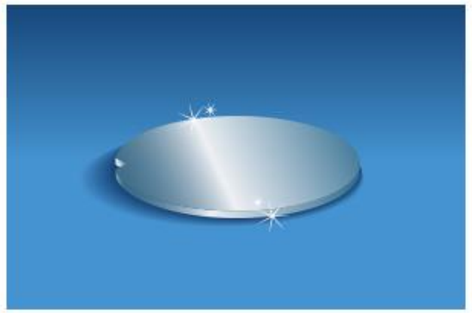
The chip die is then placed onto a 'substrate'. This is a type of baseboard for the microchip die that uses metal foils to direct the input and output signals of a chip to other parts of a system. And to close the lid, a 'heat spreader' is placed on top. This heat spreader is a small, flat metal protective container holding a cooling solution that ensures the microchip stays cool during operation.

Steps in manufacturing of semiconductor chips

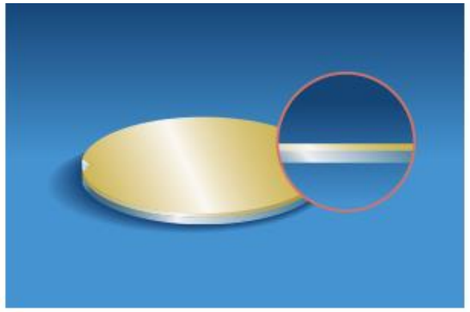



Chip Fabrication Steps
1
Wafers are sawed out of an ingot of pure crystalline silicon
2
Polishing
3
Material deposition or modification
4
The resist is applied to a spinning wafer to achieve a uniform layer
5
Using EUV Lithography the chip patterns are "burned" into the resist in an exposure step
6
The print is developed through etching and heating
7
Ion Implantation dope exposed regions
8
The resist is removed
9
A wafer processing cycle is complete, and one layer has been fabricated
10
Repeat 40 to 100 times
11
Cut chips out of the wafer and test
12
Package and assembly the chips
Mature processes have yields of 30-80%
Paul van Gerven Bitsand Chips

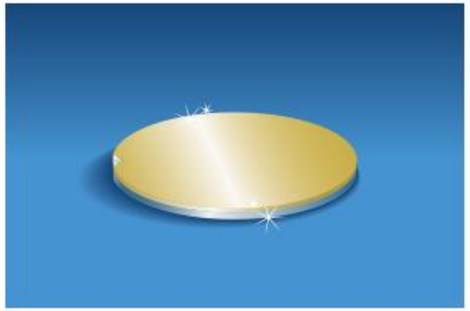
Steps in semiconductor manufacturing



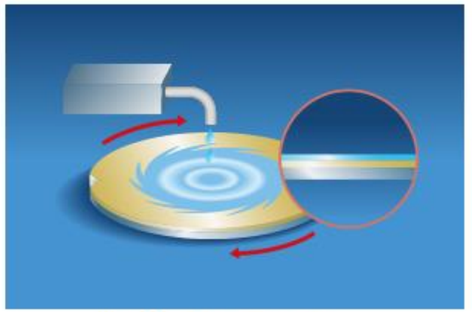
1. Cleaning



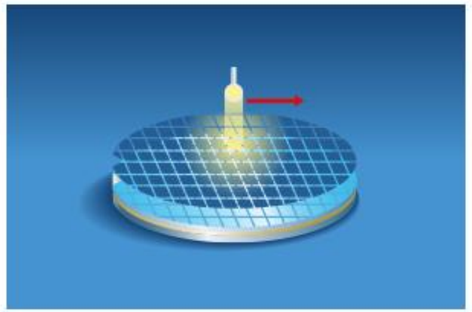
2. Film Deposition



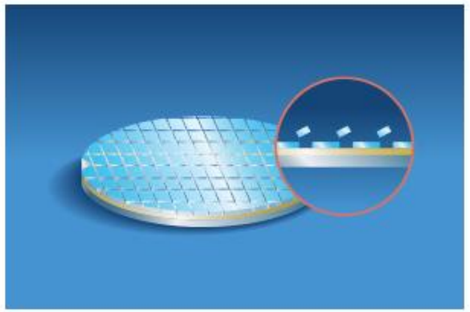
3. Post-deposition Cleaning



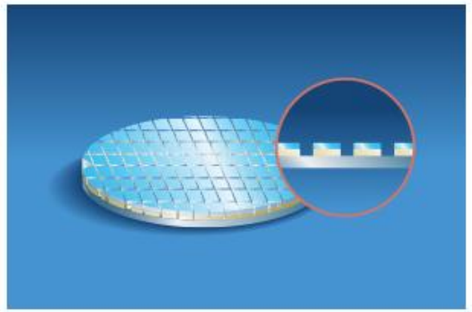
4. Resist Coating



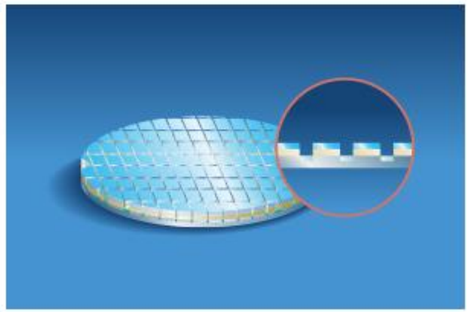
5. Exposure



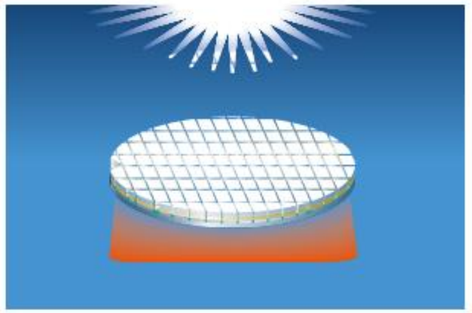
6. Development



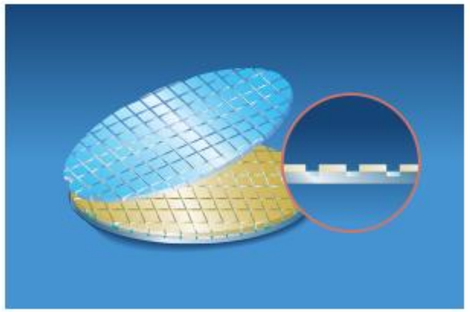
7. Etching



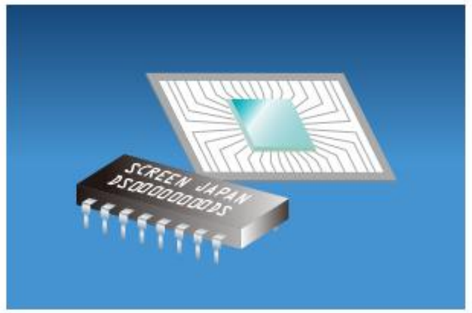
8. Implantation of Impurities



9. Activation



10. Resist Stripping



11. Assembly

Semiconductor labs(Clean Room)