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Semester: I/II						
CHEMISTRY OF SMART MATERIALS AND DEVICES (Category: Professional Core Course) Stream: CS (Theory and Practice)						
Course Code	:	22CHY12A		CIE	:	100 Marks
Credits: L:T:P	:	3:0:1		SEE	:	100 Marks
Total Hours	:	42L+ 30P		SEE Duration	:	3 Hours

Unit-III- Computational chemistry

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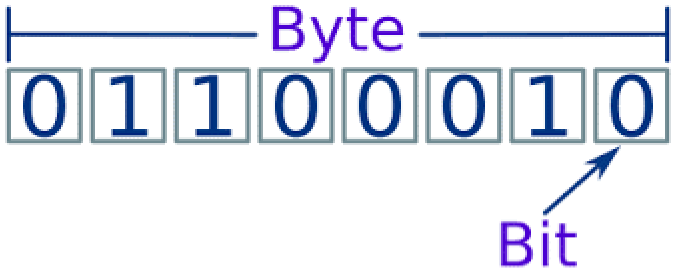
Basic Concepts of Electronic Memory

The basic goal of a memory device is to provide a means for storing and accessing binary digital data sequences of “1” and “0”, as one of the core functions (primary storage) of modern computers.

An electronic memory device is a form of semiconductor storage which is fast in response and compact in size, and can be read and written when coupled with a central processing unit (CPU, a processor).



Bit is the basic unit of memory. At a time, it can be either on or off. Generally, bits are represented using electrical voltage.

Voltage presence indicates that the bit is in ON state. Voltage absence indicates that the bit is in OFF state.

Here, OFF state is considered as 0. ON state is considered as 1.

Computer memory is the collection of several bits. Group of 8 bits are called byte.

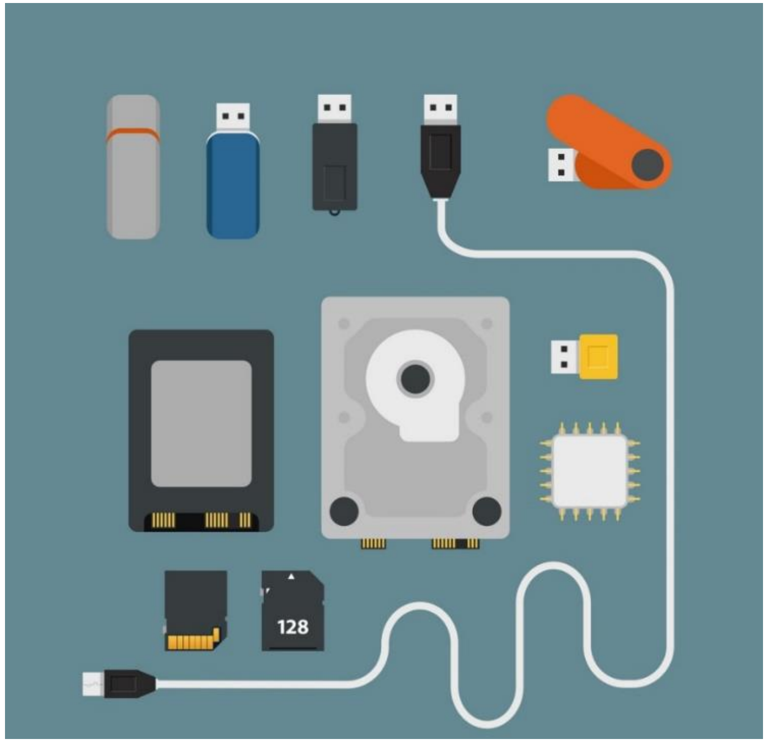
Units of Computer Memory Measurements

1 Bit = Binary Digit
8 Bits = 1 Byte
1024 Bytes = 1 KB (Kilo Byte)
1024 KB = 1 MB (Mega Byte)
1024 MB = 1 GB(Giga Byte)
1024 GB = 1 TB(Terra Byte)
1024 TB = 1 PB(Peta Byte)
1024 PB = 1 EB(Exa Byte)
1024 EB = 1 ZB(Zetta Byte)
1024 ZB = 1 YB (Yotta Byte)
1024 YB = 1 (Bronto Byte)
1024 Brontobyte = 1 (Geop Byte)
Geop Byte is The Highest Memory

I. Materials for memory storage

Memory storage devices: These are the core components of computers and electronic systems, which receive, record and store the digital information.

Computer storage or memory Devices



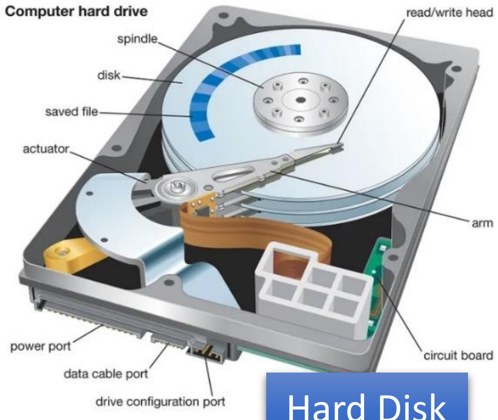
Storage devices

Internal Hard disk

External Hard disk

Magnetic tape

Floppy Disk



Hard Disk

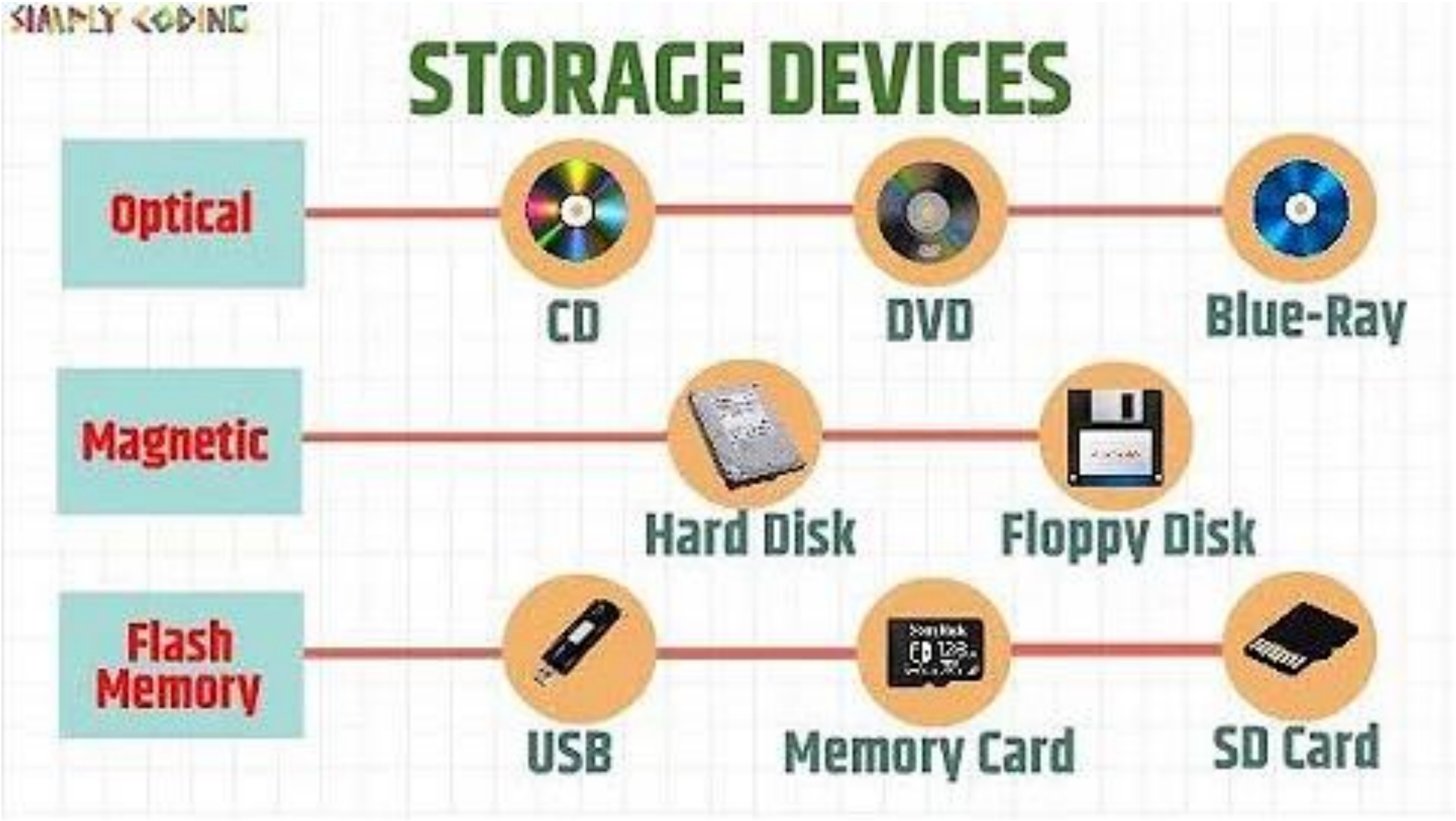
Memory Card

Online Cloud storage devices

Pen drive

https://medium.com/@navodrathnayaka123/computer-storage-devices-b1008e78f35f

Storage devices



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I. Materials for memory storage

Current Memory Technologies

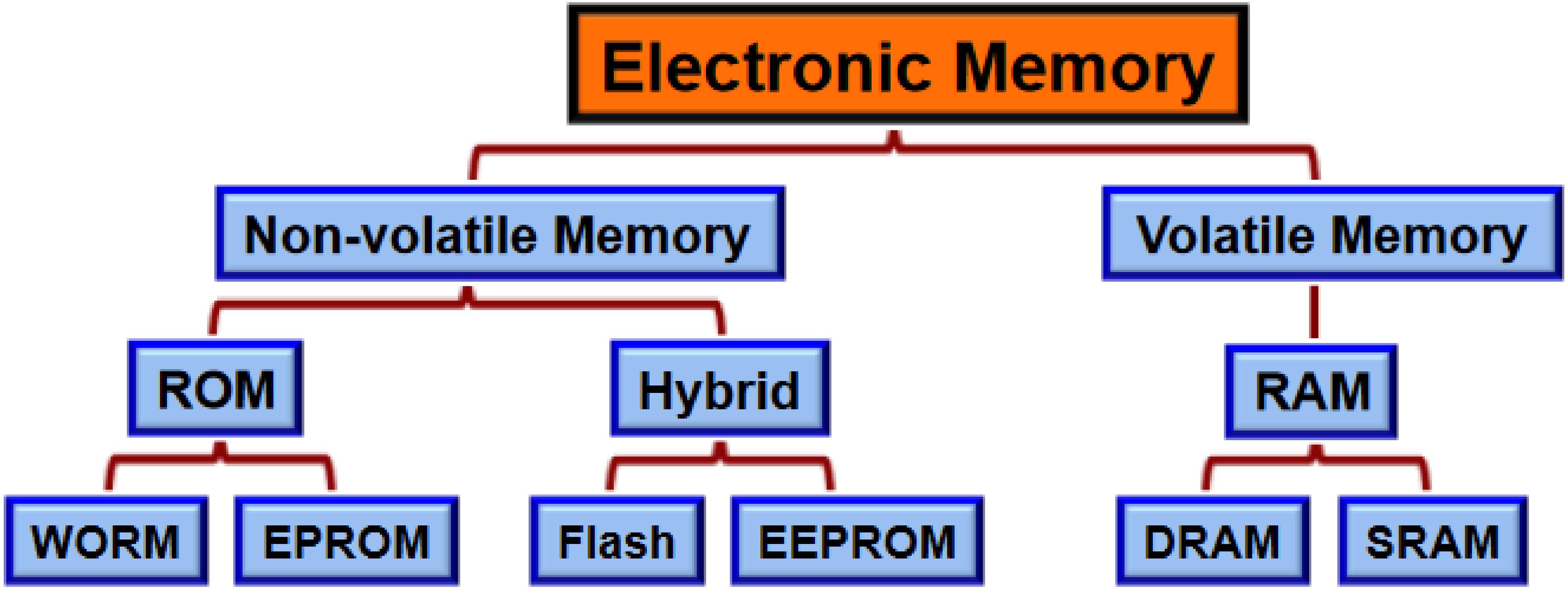
- The simplest form of a memory cell is a simple switch which can assume the state of “0” and “1”, and memorize the state.

- Electrical memory can be electrically read/write directly when connected to the central processing unit.

- Memory can be divided into two primary categories according to its volatility: **volatile and non-volatile memories**.

1. **Volatile memory** loses the stored data as soon as the system is turned off. It requires a constant power supply to retain the stored information.
2. **Non-volatile memory** can retain the stored information even when the electrical power supply has been turned off.

Classification based on power dependence

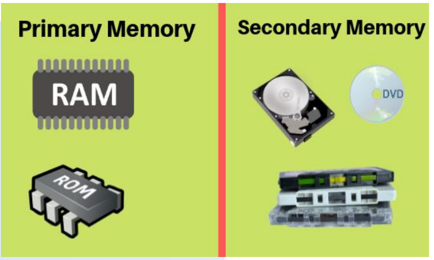


ROM: read-only memory; RAM: random-access memory; EPROM: erasable programmable read-only memory; EEPROM: electrically erasable programmable read-only memory

- Semiconductor Memory
  - Volatile Memory
    - SRAM (Static RAM)
    - DRAM (Dynamic RAM)
  - Non-Volatile Memory
    - FeRAM (Ferro electric RAM)
    - Mask ROM
    - EPROM [UV-EPROM] (Erasable Proframmable ROM)
    - EEPROM [Electrically- Erasable Programmable ROM)
    - FLASH

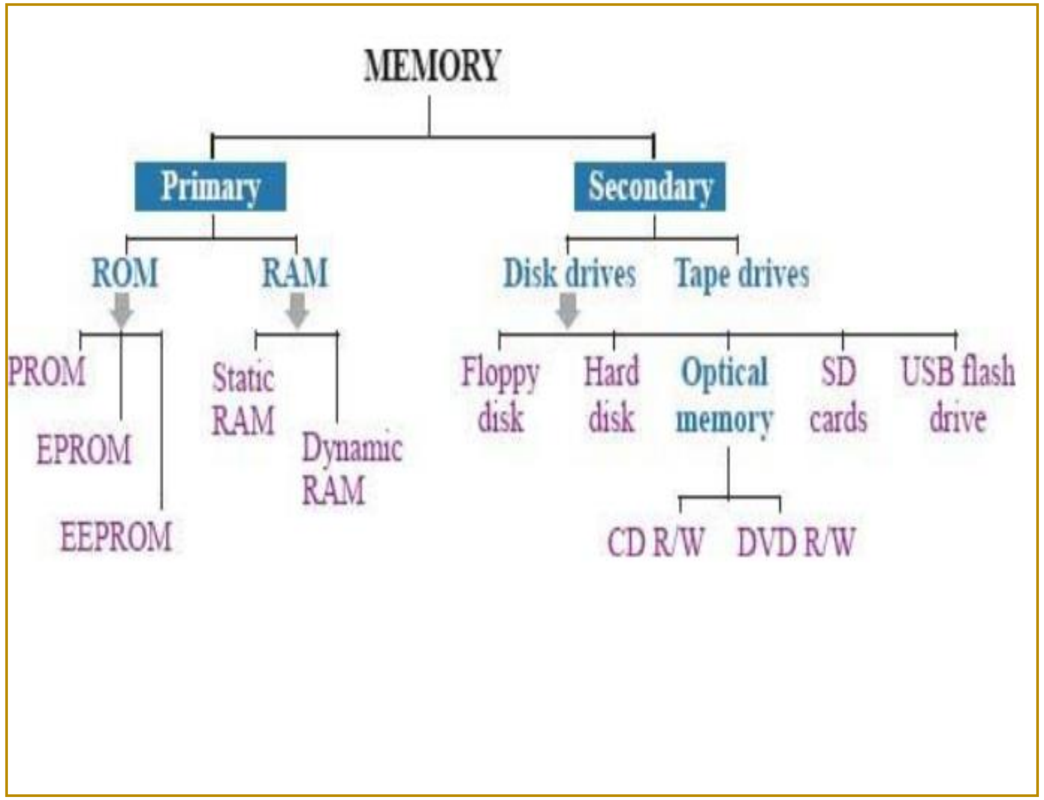
* **RAM** (Random Access Memory) : Enables Read/Write of stored contents
* **ROM** (Read Only Memory) : Allows only Read operation

Classification based on Devices type



Classification of Electrical Memory: In general, memory is of three types:

1. Primary memory or Internal memory (RAM, ROM, Cache)
2. Secondary memory or external memory (SSD, CD, Floppy disk, magnetic tape)
3. Cache memory (It is part of primary or internal memory)



Primary memory	Secondary Memory
1) Primary memory is the memory that is directly accessed by the CPU.	1) Secondary memory is a storage device that is not accessible directly by the CPU.
2) It is known as main memory. 3) A computer cannot run without primary memory	2) It is known as backup memory. 3) A computer can run without secondary memory.
4) It is faster than secondary memories.	4) It is slower than primary memories.
5) Example: ROM, RAM	5) Example: floppy disk, CD, DVD, USB flash drive

1. Primary Memory

It is also known as the main memory of the computer system. It is used to store data and programs or instructions during computer operations. It uses semiconductor technology and hence is commonly called semiconductor memory.

Primary memory is of two types:

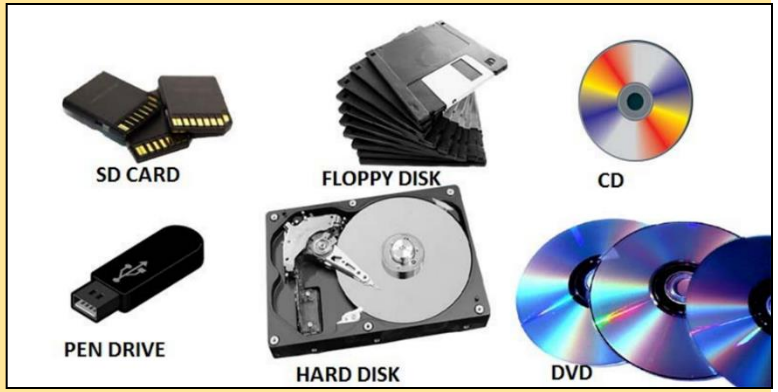
- **(i) RAM (Random Access Memory):**
  - It is a volatile memory. Volatile memory stores information based on the power supply. If the power supply fails/ interrupted/stopped, all the data & information on this memory will be lost.
  - RAM is of two types: i) SRAM (Static RAM),
    ii) DRAM (Dynamic RAM)
- **(ii) ROM (Read Only Memory):**
  - It is a non-volatile memory. Non-volatile memory stores information even when there is a power supply failed/ interrupted/stopped. ROM is used to store information that is used to operate the system. As its name refers to read-only memory, we can only read the programs and data that is stored on it.
  - ROM is of following types:
    - 1. MROM (Masked ROM),
    - 2. PROM (Programmable Read Only Memory),
    - 3. EPROM (Erasable Programmable Read Only Memory),
    - 4. EEPROM (Electrically Erasable Programmable Read Only Memory)
    - 5. ROM Flash

- https://data-flair.training/blogs/computer-storage-devices/

2. Secondary Memory

It is also known as auxiliary memory and backup memory. It is a non-volatile memory and used to store a large amount of data or information. The data or information stored in secondary memory is permanent, and it is slower than primary memory. A CPU cannot access secondary memory directly. The data/information from the auxiliary memory is first transferred to the main memory, and then the CPU can access it.

- ***Characteristics of Secondary Memory:***



  - • It is a slow memory but reusable.
  - • It is a reliable and non-volatile memory.
  - • It is cheaper than primary memory.
  - • The storage capacity of secondary memory is large.
  - • A computer system can run without secondary memory.
  - • In secondary memory, data is stored permanently even when the power is off.

3.Cache Memory

It is a type of high-speed semiconductor memory that can help the CPU run faster. Between the CPU and the main memory, it serves as a buffer. It is used to store the data and programs that the CPU uses the most frequently.

Advantages of cache memory:

- •It is faster than the main memory.
- •When compared to the main memory, it takes less time to access it.
- •It keeps the programs that can be run in a short amount of time.
- •It stores data in temporary use.

Disadvantages of cache memory:

- •Because of the semiconductors used, it is very expensive.
- •The size of the cache (amount of data it can store) is usually small.

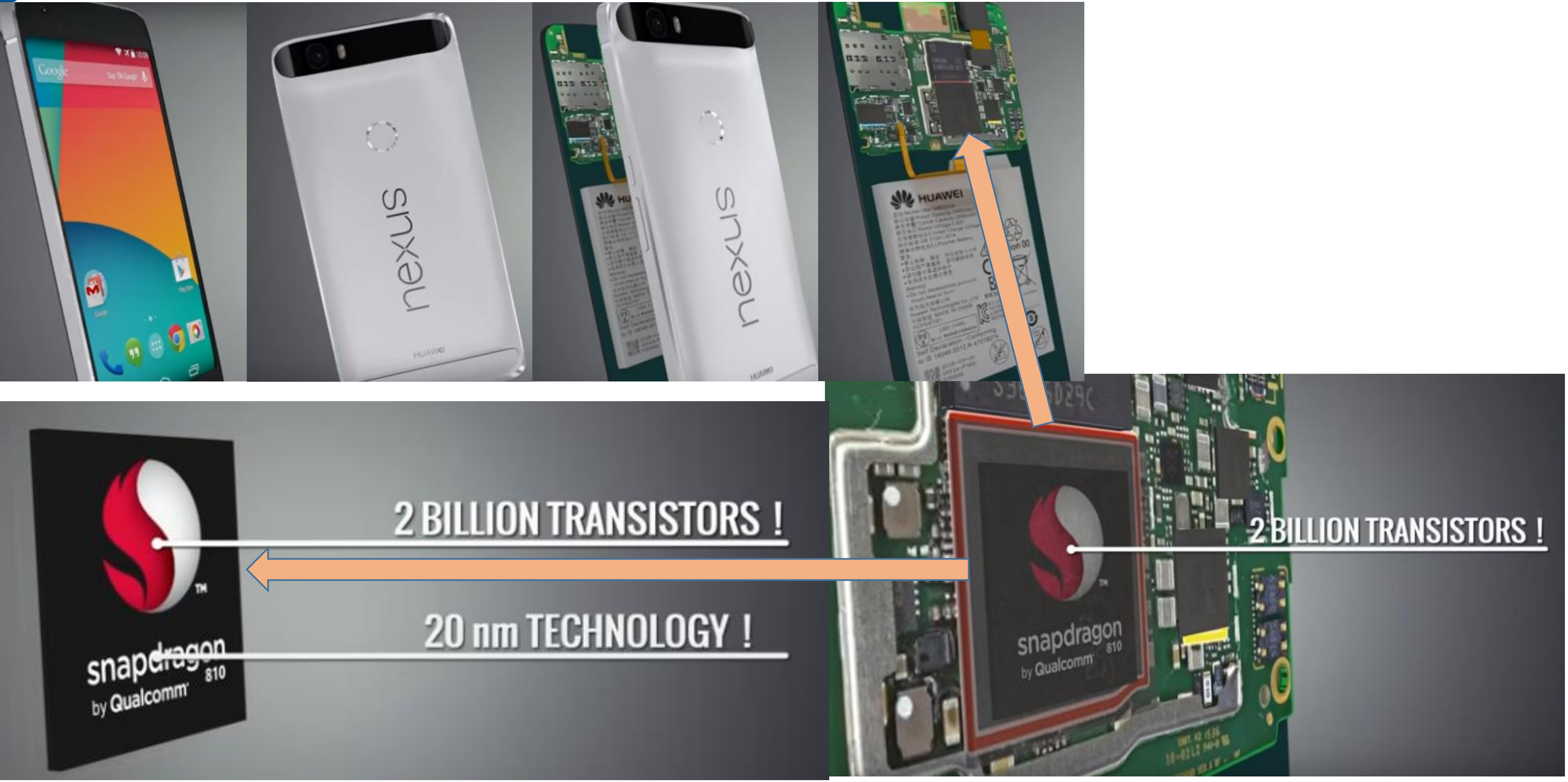
II. Classification of Electrical Memory Devices:

According to the device structure, electronic memory devices can be divided into three primary categories: transistors, capacitors and resistors.

Memory Devices: Classification of memory devices;

1. Transistor-Type Electronic Memory
2. Resistor-Type Electronic Memory
3. Capacitor-Type Electronic Memory


Transistors, How do they work?
TRANSISTOR
VACUUM TUBE COMPUTER - 1940s
TODAY'S COMPUTER
Activate Windows


nexus
nexus
HUAWEI
2 BILLION TRANSISTORS !
20 nm TECHNOLOGY !
snapdragon 810
by Qualcomm
snapdragon 810
by Qualcomm
2 BILLION TRANSISTORS !

How many transistors are in a 1GB memory?

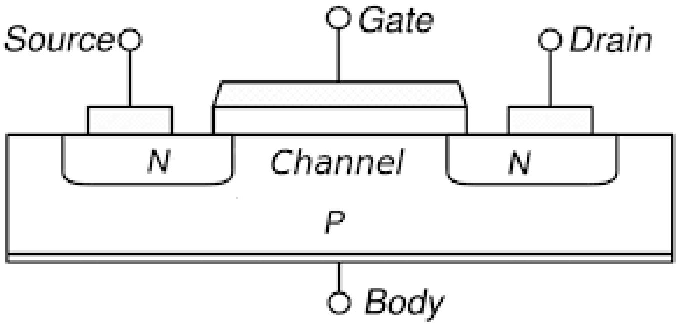
If it's a Static Random Access Memory (SRAM)
then there are
6 transistors per unit cell "bit" but
there are 8 bits in a Byte
(48 transistors/byte) so
a 1 GigaByte (GB) memory has 6*8 billion
transistors or
48 billion transistors.
A single transistor is 7-10 nm in size

1. Transistor-type memory

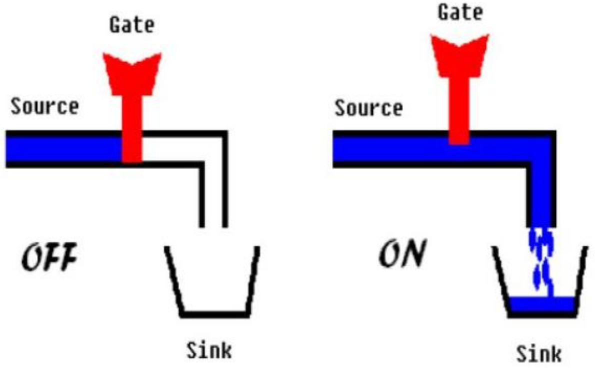
- The memory that uses one transistor and one capacitor as a basic memory.
- The NPN transistor consists of p type Si is sandwiched between n-type Si. There is a gate on the surface of p-Si and in between two n-Si, which consist of Insulating layer followed by conducting metal electrode (like capacitor).
- In NPN transistor type memory device, the ON and OFF represents the binary digit 1 and 0 respectively.
- Two n-Si acts a source and drain where electrons flows from source (n-Si) through p-Si to another n-Si (drain). Here p-Si is barrier for the e to flow from source to drain, and hence no current. This state is called OFF state (represents 0 in binary).
- In order to create the channel for e to flow from source to drain, we apply the voltage (forward bias) across the Source and Gate electrode.
- As a result, and n-channel is created below the gate electrode (in the p-Si) as shown in the figure in next slide. Then the e-flow from source to drain leads to ON state, also represents 1 in binary.
- For each binary digit, there one transistor. Like that there are billions of transistor which save the data in binary digit form.

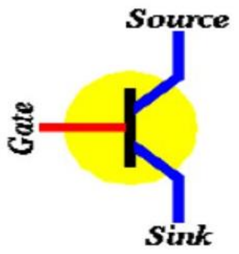
Transistor-Type Electronic Memory

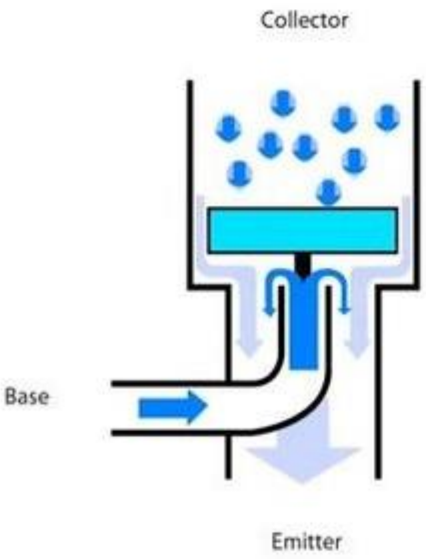
A transistor is a miniature semiconductor that act as a switch or gate for electronic signals, opening and closing an electronic gate many times per second.
It ensures the circuit is on if the current is flowing and switched off if it isn't

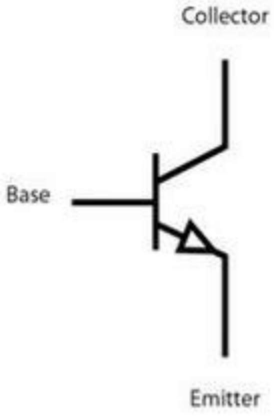


- Gate on, Water flow: 1
- Gate off, Water not flow: 0

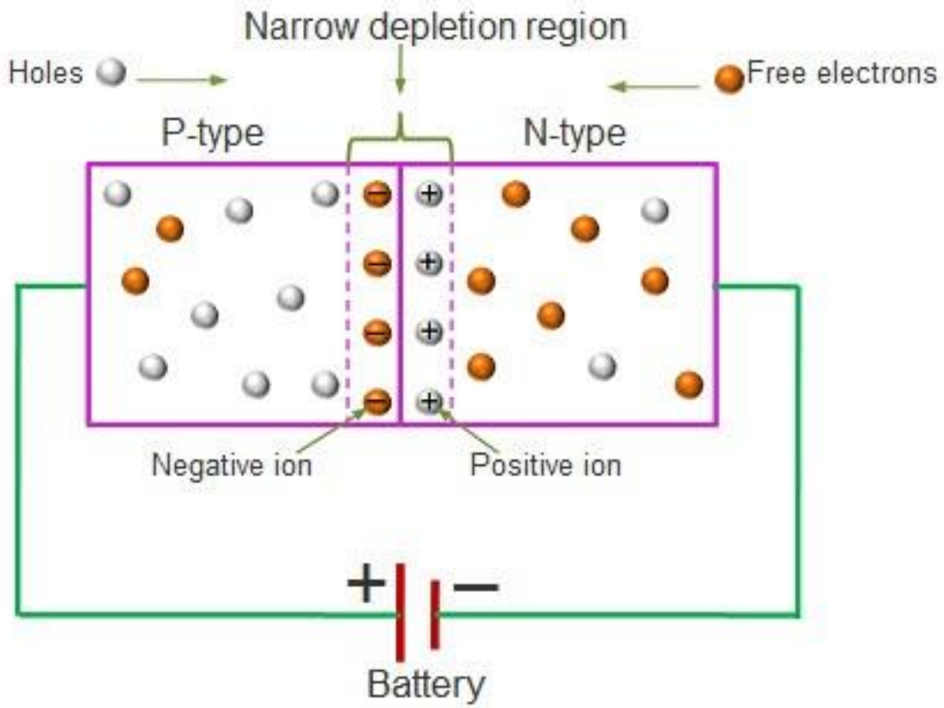


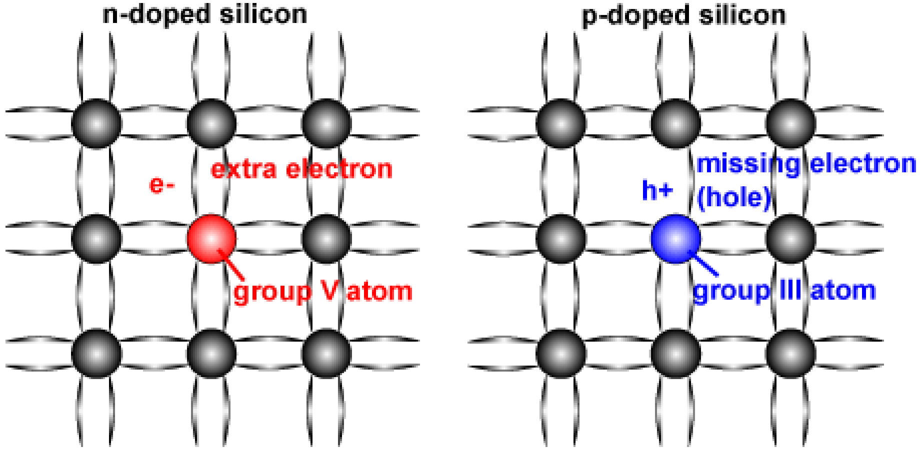


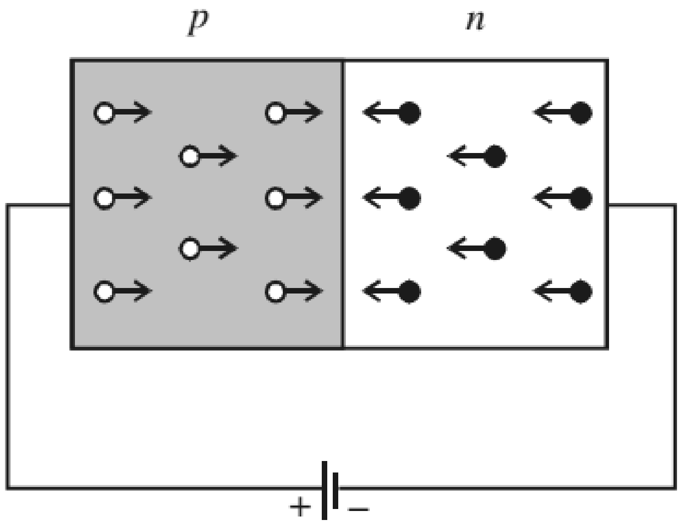


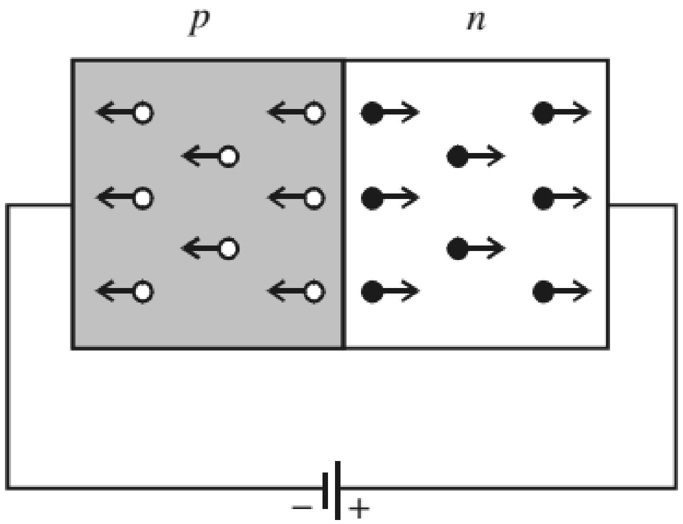


Si, Doped Si, PN diode

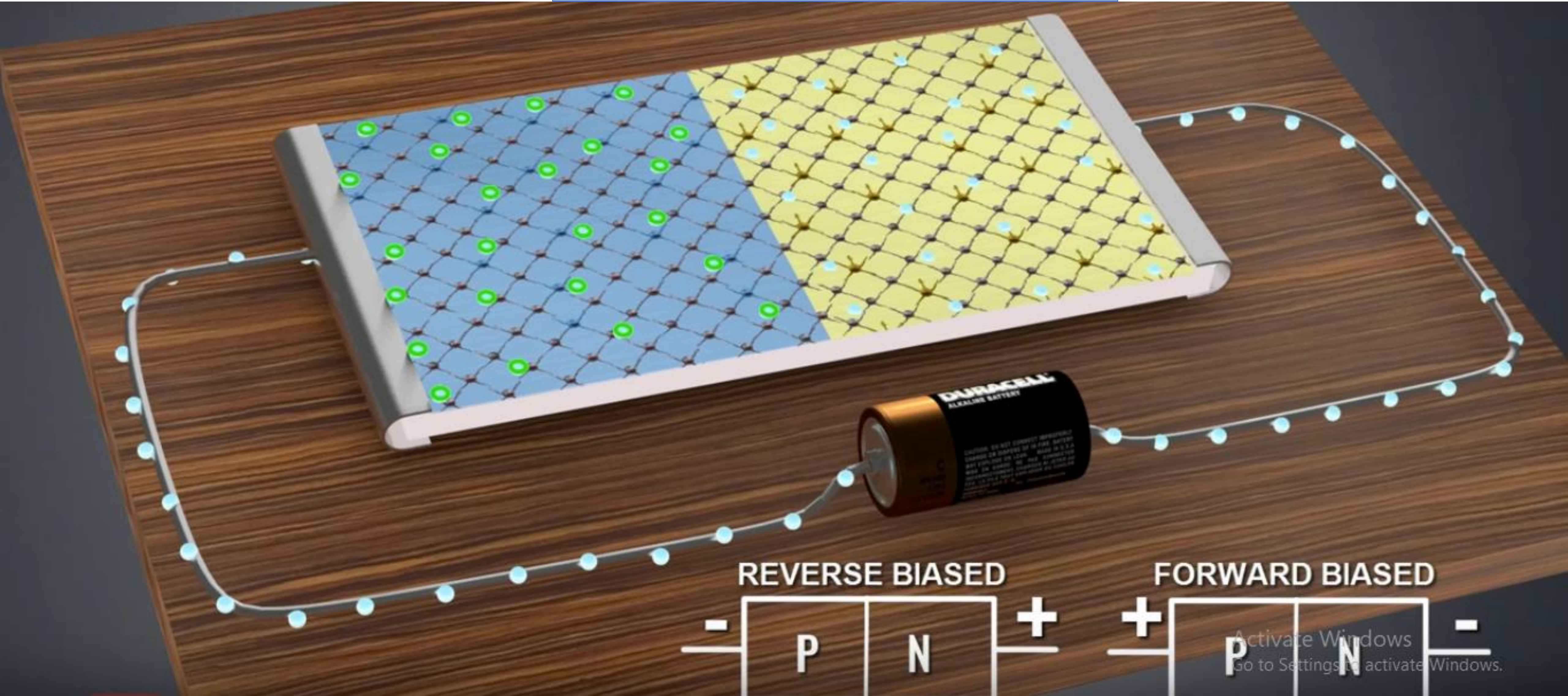


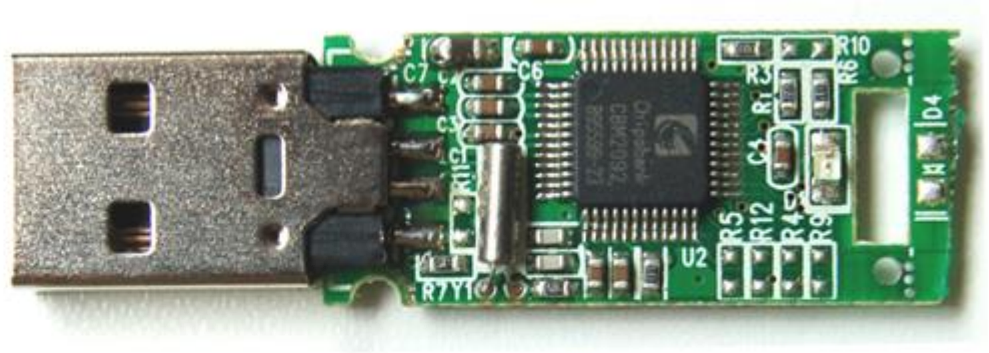


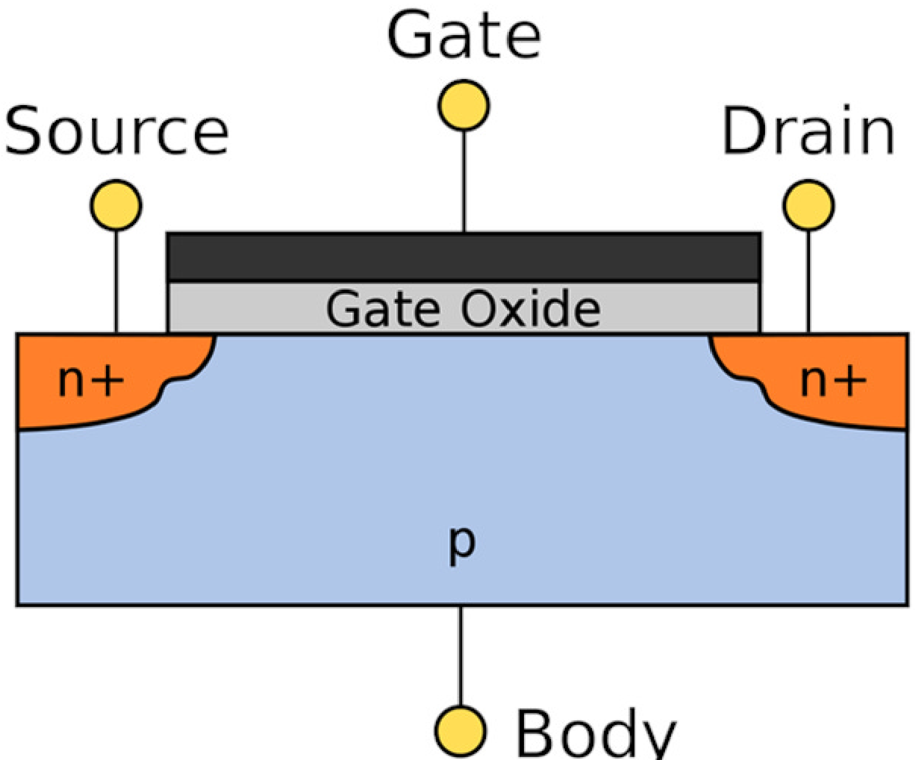


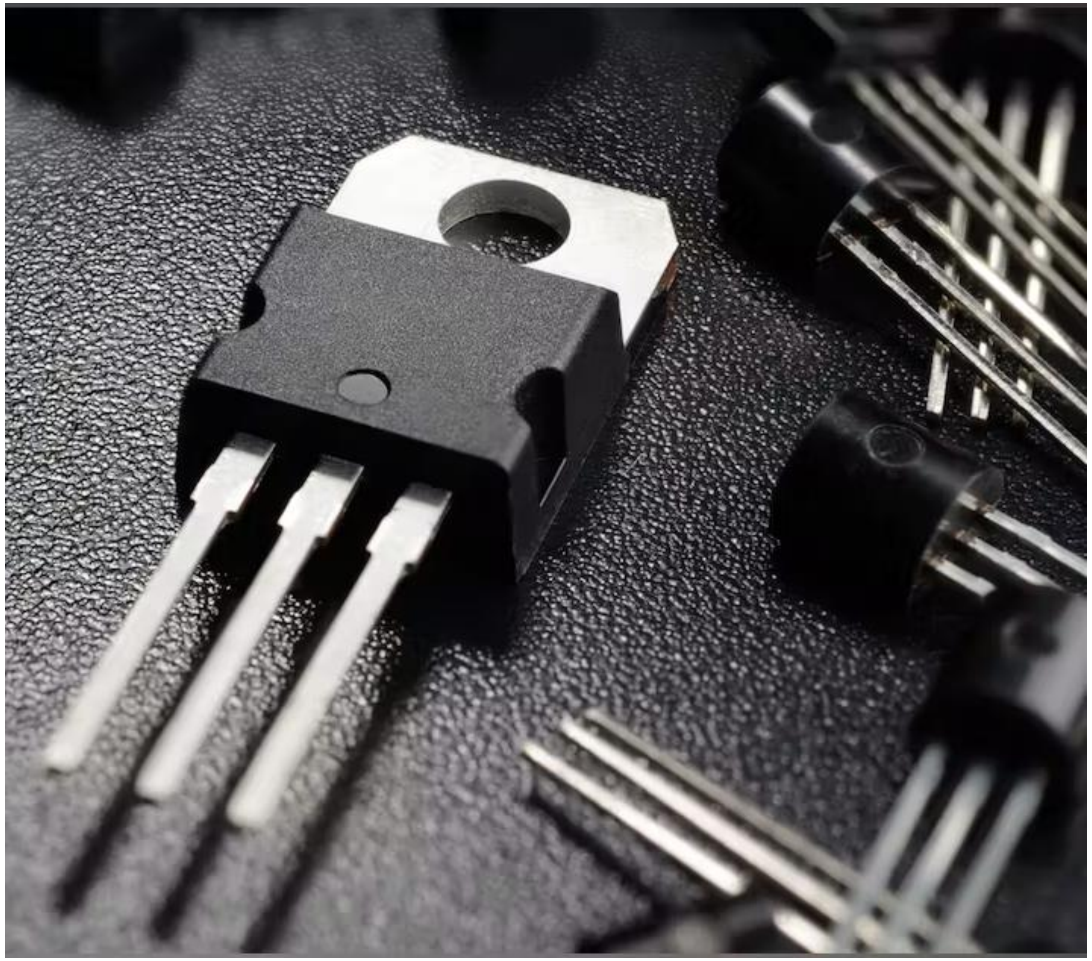


PN Diode working



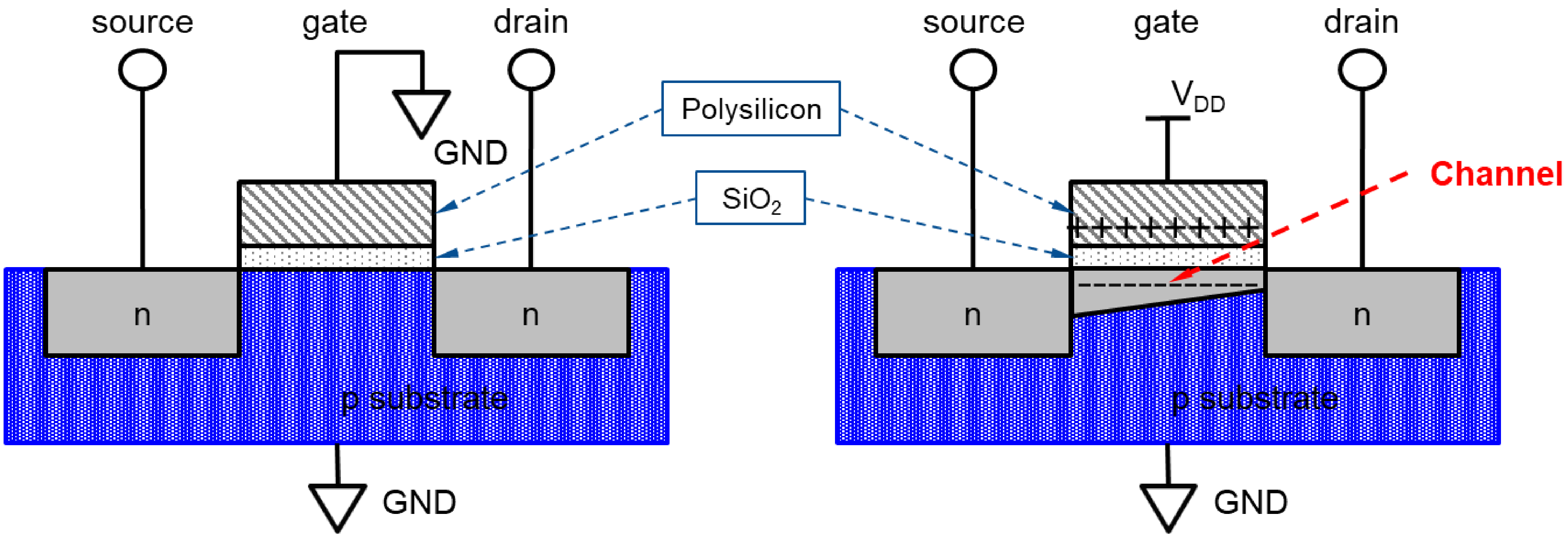


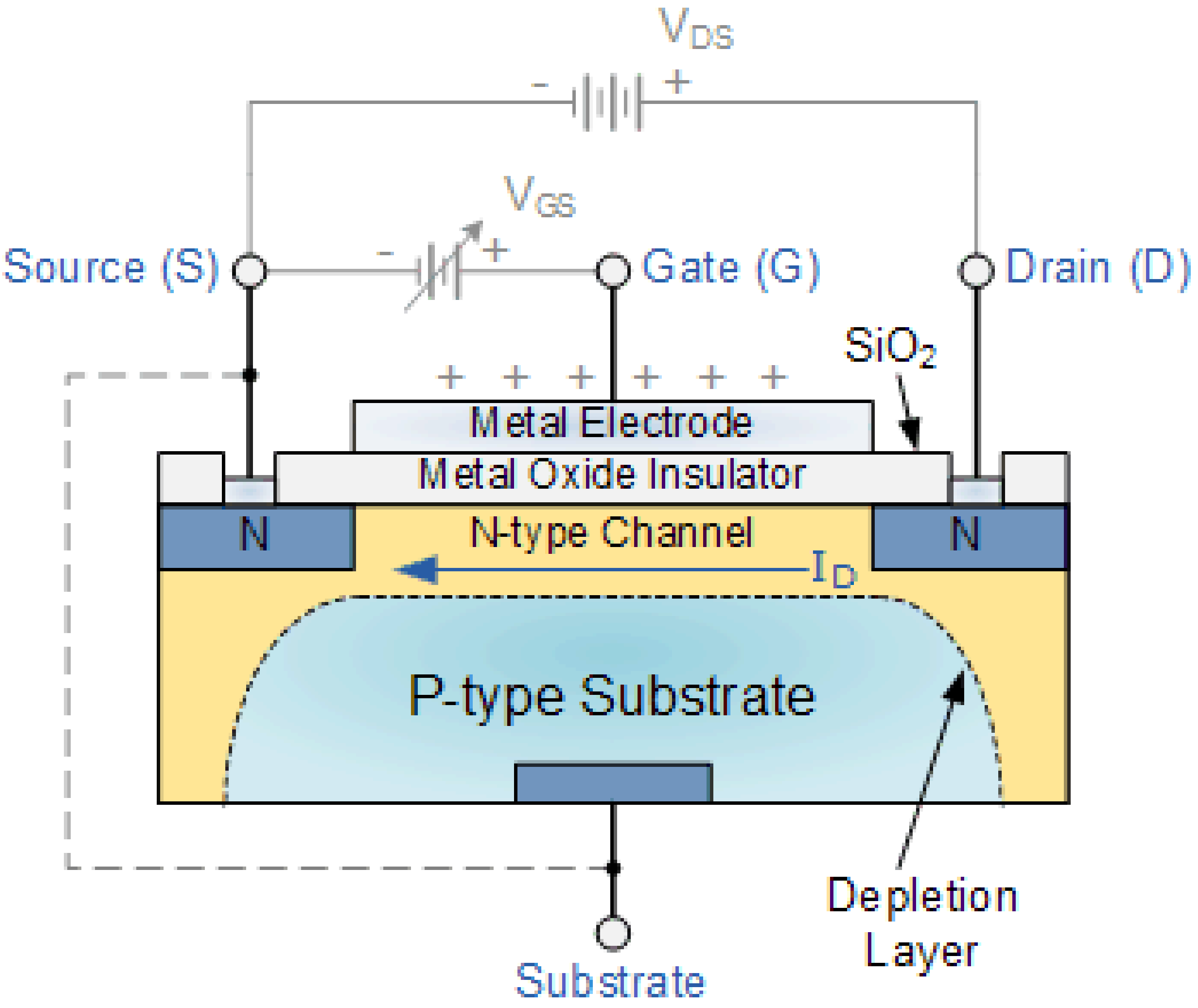

Gate
Source
Drain
Gate Oxide
n+
n+
p
Body



Gate = 0
OFF (no connection between source and drain)

Gate = 1
ON (channel between source and drain)



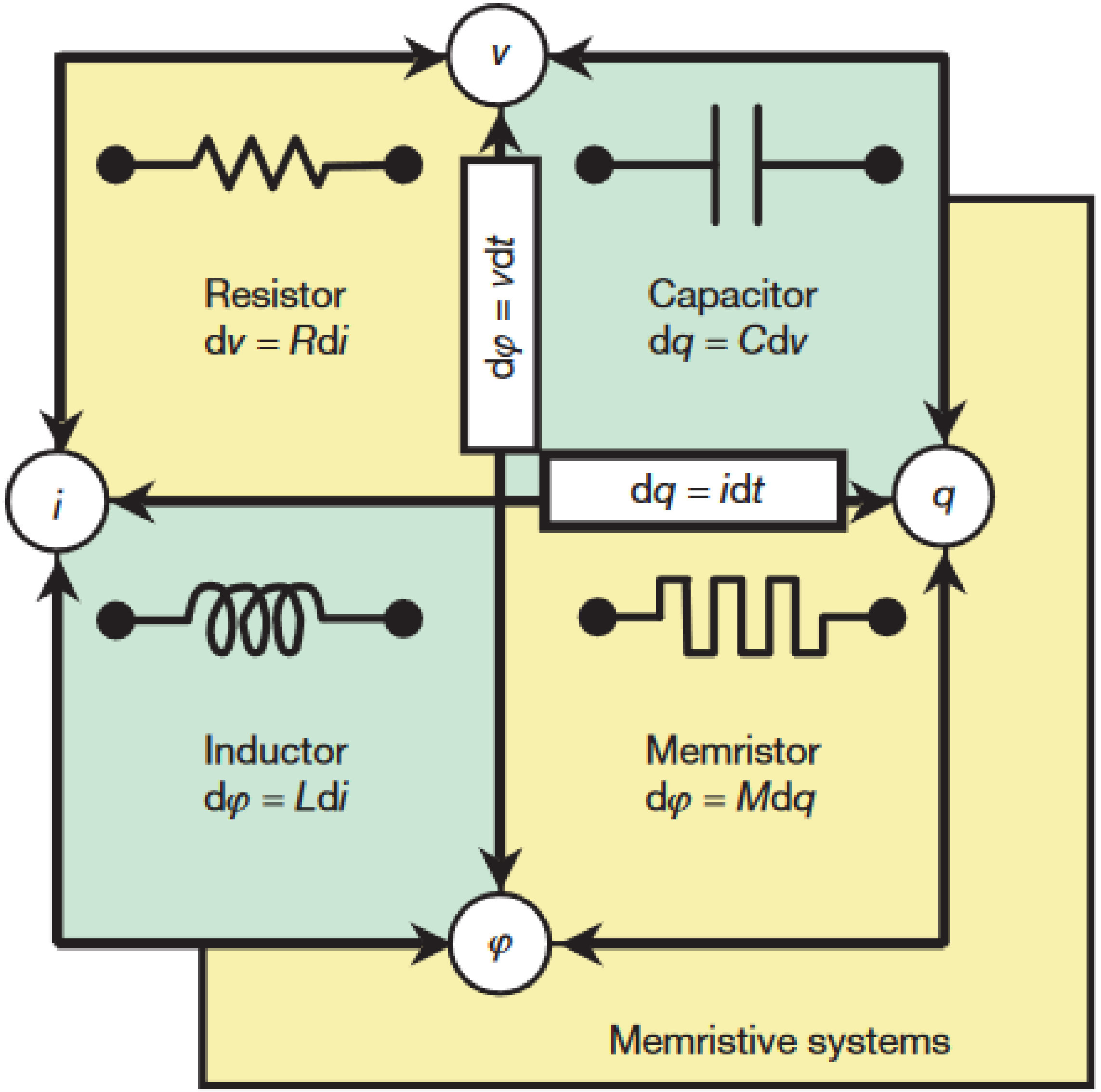


https://www.youtube.com/watch?v=rkbjHNEKcRw

3. Resistor-type memory

- Resistive random-access memory (RRAM), also known as resistive switching (RS) device or **memristor**, is a promising nonvolatile memory considered to be a potential candidate for next generation data storage.
- In the conventional silicon-based electronic memory, data are stored based on the amount of charge stored in the memory cells.
- **In Resistive electronic memory,** the data is stored in an entirely different way, for instance, based on the different **electrical conductivity states (ON and OFF states) in response to the applied electric field**.
- Unlike **transistor and capacitor memories**, a resistor-type memory does not require a specific cell structure (e.g., field-effect transistor; FET)
- The electrical bi-stability of resistor-type memories usually results from the changes in **intrinsic properties of electroactive materials** in response to the applied voltage or electric field, such as **charge transfer, phase change, conformation change**, and **redox reaction.**

Memristor (Memory Resistor)



Anyone who ever took an electronics laboratory class will be familiar with the **fundamental passive circuit elements**: the **resistor, the capacitor and the inductor**. However, in 1971 Leon Chua reasoned from symmetry arguments that there should be a fourth fundamental element, which he called a memristor (short for memory resistor)

The existence of Memristor is Experimentally proved in 2008, by R. Stanley Williams.

The four fundamental two-terminal circuit elements: resistor, Capacitor, inductor and memristor.
R : Resistance, C : Capacitance
L : Inductance, M : Memristance

R. Stanley Williams

Hewlett Packard Enterprise Company Chair Professor

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Texas A&M University

TEXAS A&M UNIVERSITY Engineering

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Published: 01 May 2008

The missing memristor found

Dmitri B. Strukov, Gregory S. Snider, Duncan R. Stewart & R. Stanley Williams

Nature **453**, 80–83 (2008) | Cite this article

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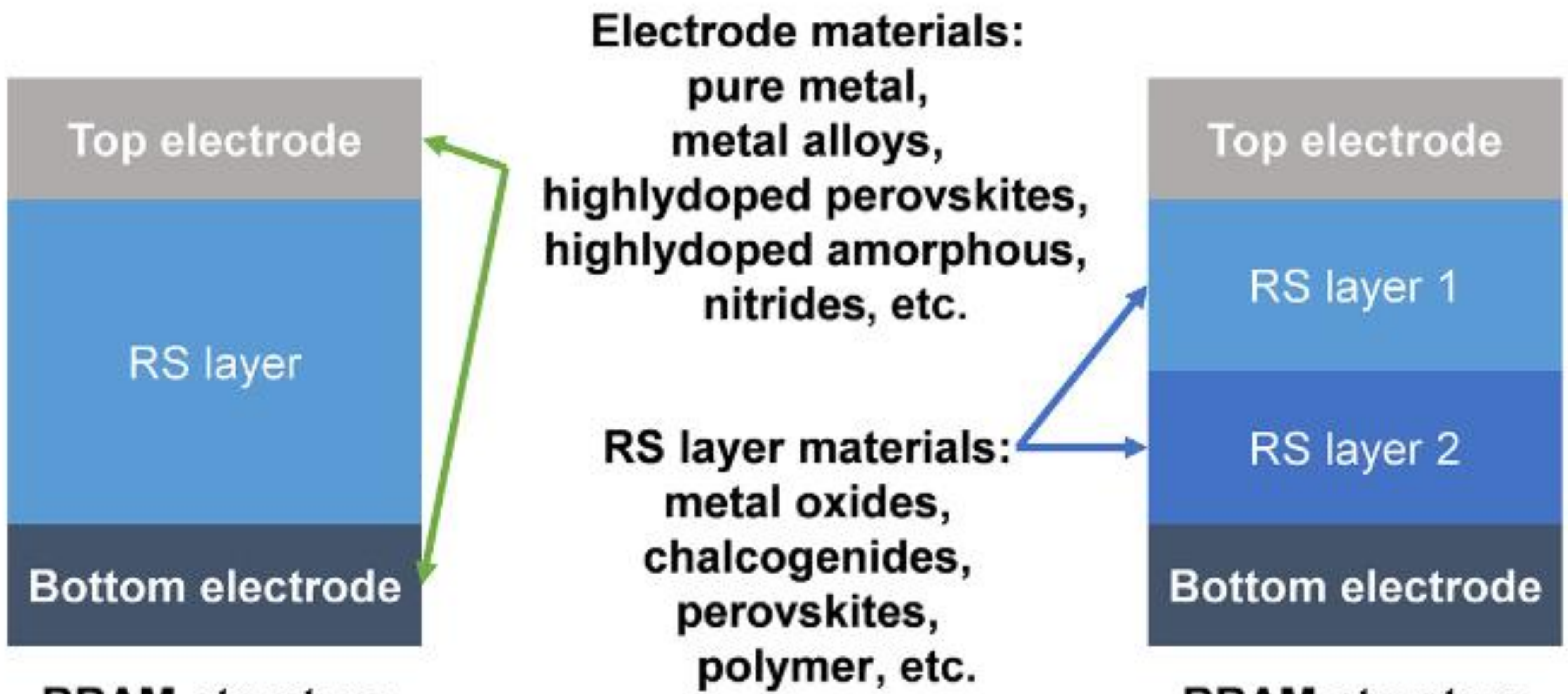
Resistor-type memory mechanism:

I. A resistive random-access memory (RRAM) consists of a resistive switching memory cell having a **metal- insulator-metal structure** generally referred to as MIM structure.

II. The structure comprises of an insulating layer (I) sandwiched between the two metal (M) electrodes. The schematic and the cross-sectional view of a RRAM cell is shown in Figure a, and b , respectively.

III. The application of the external voltage pulse across the RRAM cell enables a transition of the device from a high resistance state (HRS), or OFF state generally referred as logic value '0' to a low resistance state (LRS), or ON state generally referred as logic value '1' and vice versa.

IV. The switching of the RRAM cell is based on the growth of conductive filament (CF) inside a dielectric. The CF is a channel having a very less diameter of the order of nanometers which connects the top and the bottom electrodes of the memory cell. A low resistance state (LRS) with high conductivity is obtained when the filament is connected and the high resistance (HRS) results when the filament is disconnected with a gap between the electrodes.



RRAM structure (with 1 RS layer)

RRAM structure (with 2 RS layers)

Charge Transfer (CT), :CT can be clarified as a process of partial transfer of electronic charge from the donor (D) to the acceptor (A) moiety in the electron D-A system by applying a suitable voltage, which can result in a sharp increase in conductivity

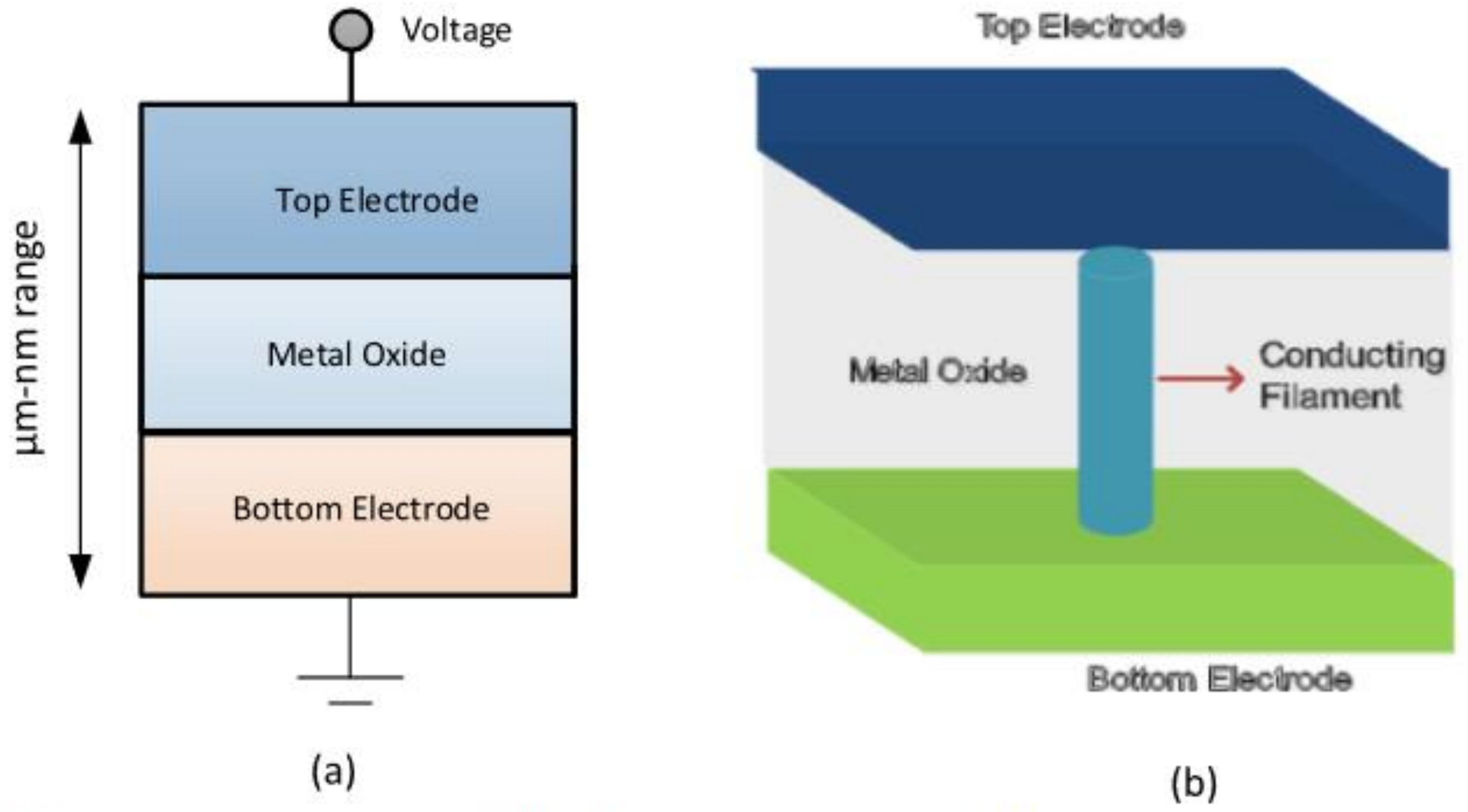
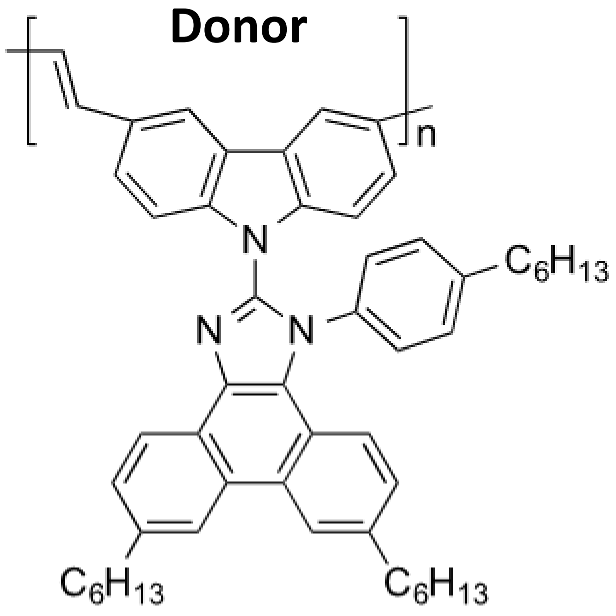


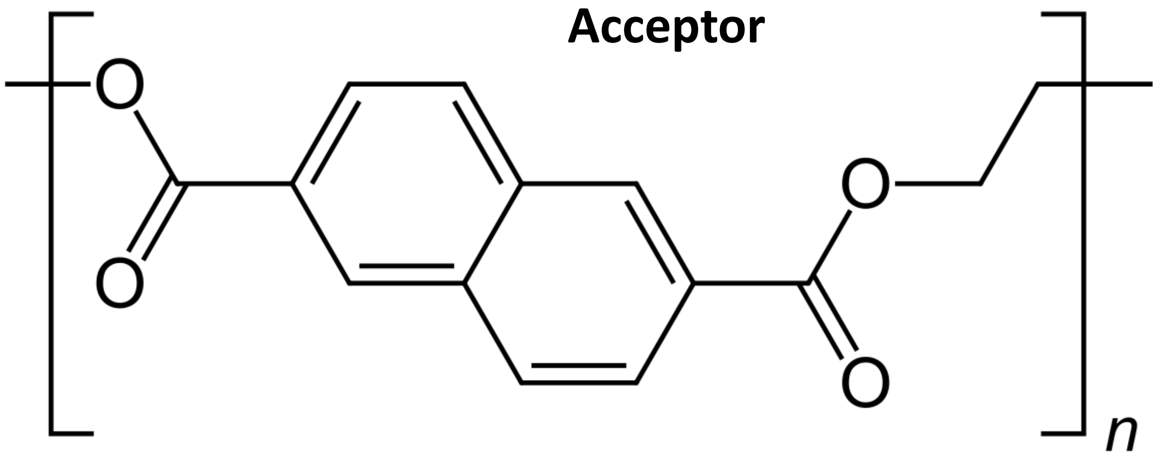
Fig. 3 a Schematic of metal-insulator-metal structure for RRAM. **b** Cross-sectional view of RRAM

Example for the molecules having Donor-Acceptor, Conjugated Polymer, poly(arylenevinylene), consisting of carbazole (Car) with pendent phenanthrol [9,10-d]imidazole (P6-Car).

The flexible P6-Car device with the sandwich configuration of poly(ethylene-2,6-naphthalate) (PEN)/Al/P6-Car/Al revealed volatile SRAM characteristic, which can be operated at low voltages with high ON/OFF current ratios (more than 104) and excellent durability. The high steric hindrance between carbazole donor and phenanthro[9,10-d]imidazole side chain leads to a weak electric charge separated state and easy recombination after turning off the electrical power, resulting in volatile memory characteristics.



P6-Car



poly(ethylene-2,6-naphthalate) (PEN)/

Charge Transfer (CT), :CT can be clarified as a process of partial transfer of electronic charge from the donor (D) to the acceptor (A) moiety in the electron D-A system by applying a suitable voltage, which can result in a sharp increase in conductivity .

Space Charge Traps : When the interface between electrode and polymer is ohmic and the polymer is trap-free, the carriers near the electrode will accumulate and build up a space charge channel. Mutual repulsion between individual charges restricts the total charge injected into the polymer, and the resulting current is defined as space charge-limited current (SCLC).

Filament Conduction : Particularly, when the ON state current is highly localized to a small area within the memory device, the phenomenon can be termed "filament conduction". It has been suggested that filament conduction is confined to device physical damage in RRAM

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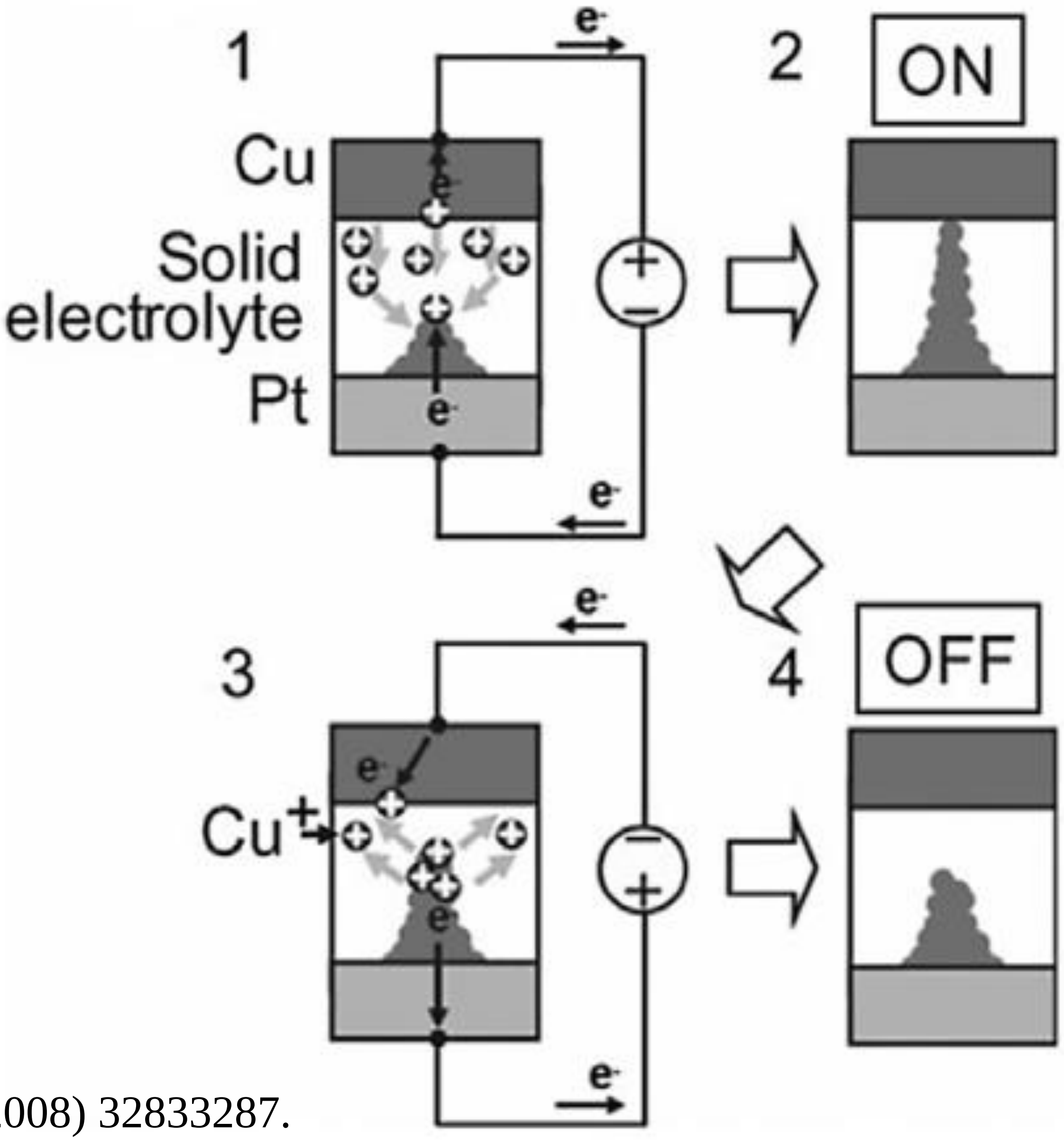
(A) Schematic of the switching mechanism of the $Cu/Cu_{2-\alpha}/Pt$ device, single filament formation is assumed in the $Cu_{2-\alpha}$ switching layer.

The RS (resistive Switching) of the $Cu/Cu_{2-\alpha}/Pt$ is attributed to the formation and rupture of a single Cu filament. At positive voltage bias on the Cu electrode, the metal Cu is oxidized to Cu^{+} at the interface between the Cu electrode and the $Cu_{2-\alpha}$ electrolyte. Afterward, the Cu^{+} migrates toward the Pt inert electrode and finally reduced to Cu metal, forming Cu filament. The rate-limiting step is the migration of Cu^{+} in the electrolyte



IEEE Trans. Electron. Devices 55 (11) (2008) 32833287.

Optical Storage Devices:
Optical storage devices are flat, round disks which spins around its center. The difference with magnetic storage devices is that in optical storage devices LASER light is used to read and write data in disks. Examples are CD, DVD etc.

Magnetic Storage Devices:
The most common type of storage device is magnetic storage device. In magnetic storage devices, data is stored on a magnetized medium. Magnetic storage use different patterns of magnetization to in a magnetizable medium to store data.

Basic Differences Between Optical and Magnetic Storage Devices:

#	Optical Storage Devices	Magnetic Storage Devices
1	Stores data as patterned image	Stores data in magnetic form
2	Optical storage devices offer lesser capacity	Magnetic storage devices offer much higher capacity
3	Requires LASER light to read and write data onto the disc	Doesn't require LASER heads to read and write data
4	Slower data read and write	Faster data read and write
5	Data on the disk will not be damaged by magnetic fields	Magnetic field can destroy the data stored on Magnetic storage devices
6	Optical storages can be readable, writable and re-writable	Magnetic storage devices are always readable and re-writable
7	Optical storage devices require additional drives to function	Almost all magnetic storage devices comes with built-in drives
8	Easy and safe to take around	Not as safe as optical storage devices to take around

Electrical Memory Devices

I. Transistor-Type Electronic Memory

Inorganic transistors are widely used in conventional semiconductor memory

- Ex: SRAM cell, flash memory cell.

Organic (including polymer) transistors are also of great potential for memory applications

- Ex: OFET type memory devices.

II. Capacitor-Type Electronic Memory

- Capacitors can store charges on two parallel plate electrodes under an applied electric field. Based on the amount of charge stored in the cell, the bit level (either “0” or “1”) can be encoded accordingly. When the medium between the electrodes is merely a dielectric, the stored charge will be lost eventually.
- Example; DRAM using a dielectric capacitor is volatile memory ferroelectric capacitors, (FeRAM) is non-volatile memory

III. Resistor-Type Electronic Memory

- Resistor-type memory is based on the change of the electrical conductivity of materials in response to an applied voltage (electric field). Devices incorporating switchable resistive materials are generically classified as resistor-type memory, or resistive random-access memory (RRAM).

- Resistor-type electronic memory usually has a simple structure with an organic/polymer thin film sandwiched between two electrodes on a supporting substrate (glass, silicon wafer, plastic or metal foil). The configuration of the top and bottom electrodes can be either symmetric or asymmetric, with aluminum, gold, copper, p- or n-doped silicon, and ITO being the most widely used electrode materials.

Materials used in various Memory Devices

- **Types of Organic-Based Electrical Memory Devices**

1. Organic molecules: Organic electronic memory devices based on organic molecules such as acene derivatives including naphthalene, anthracene, tetracene, pentacene, perylene, p-quaterphenyl and p-quinquephenyl.

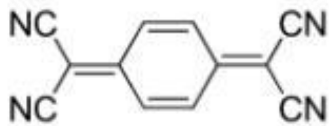
Ex: Device with the structure of a single layer of N,N′-di(naphthalene-l-yl)-N,N′ diphenyl-benzidine (NPB) embedded between ITO and Ag electrodes.

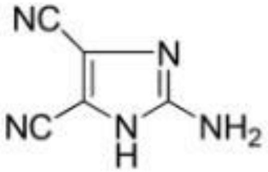
2. Organometallic complexes:

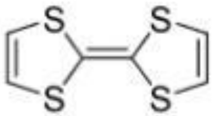
Electrical memory based on Charge Transfer phenomena uses organometallic complexes.

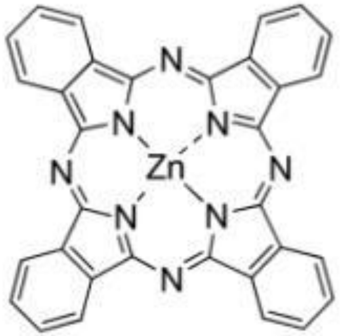
Ex: i. Copper and 7,7,8,8-tetracyanoquinodimethane (TCNQ) complex (Cu-TCNQ)- device with the structure Cu/Cu-TCNQ/Al.

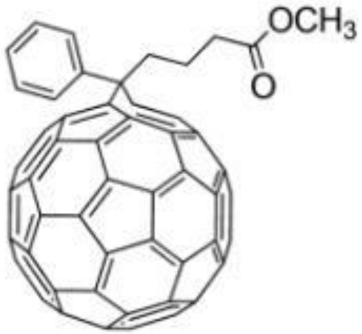
ii. Methanofullerene 6,6-phenyl C61-butyric acid methyl ester (PCBM) as the organic electron acceptor, and tetrathiafulvalene (TTF) as the organic electron donor.


TCNQ

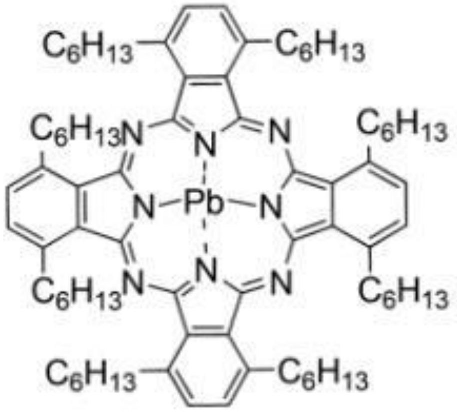

AIDCN

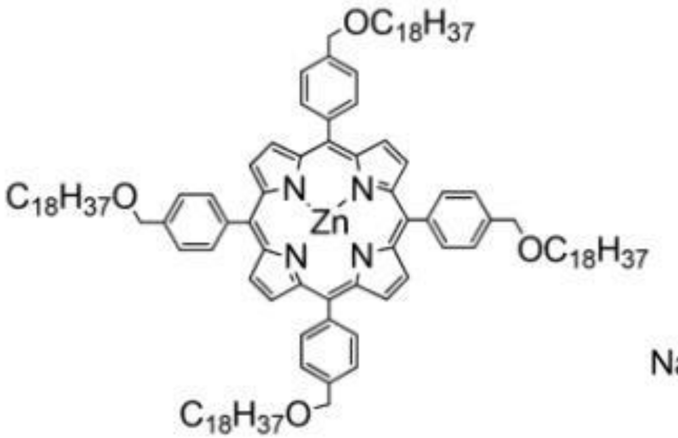

TTF


ZnPc


PCBM


DBC


PbPc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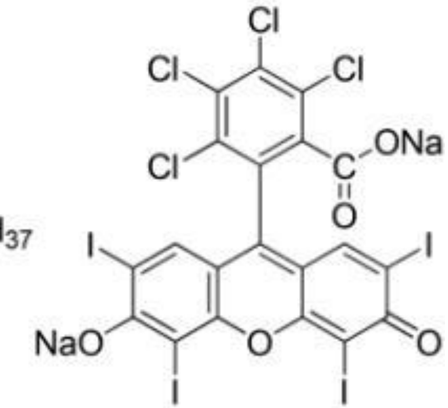

RB

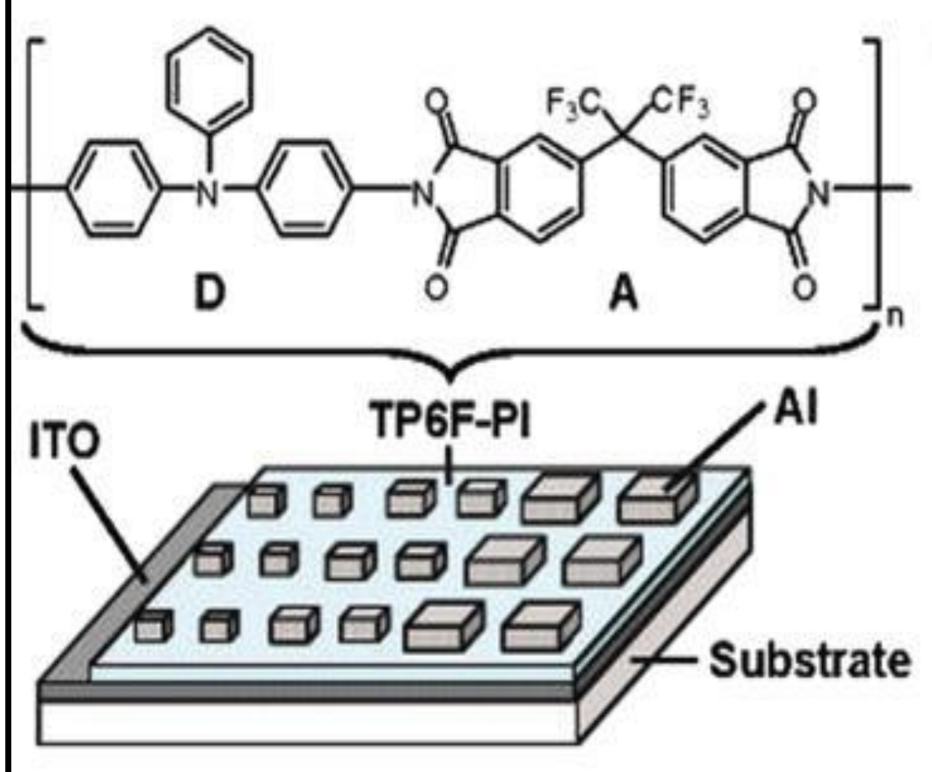
Chemical structures of the both organic and organometallic molecules used for organic memory devices.

3. Polymeric molecules

Polymer memory refers to memory technologies based on the use of organic polymers, which is based on electron donors and acceptors. The polymer memory are low-cost and high-performance, and have the potential for 3D stacking and mechanical flexibility.

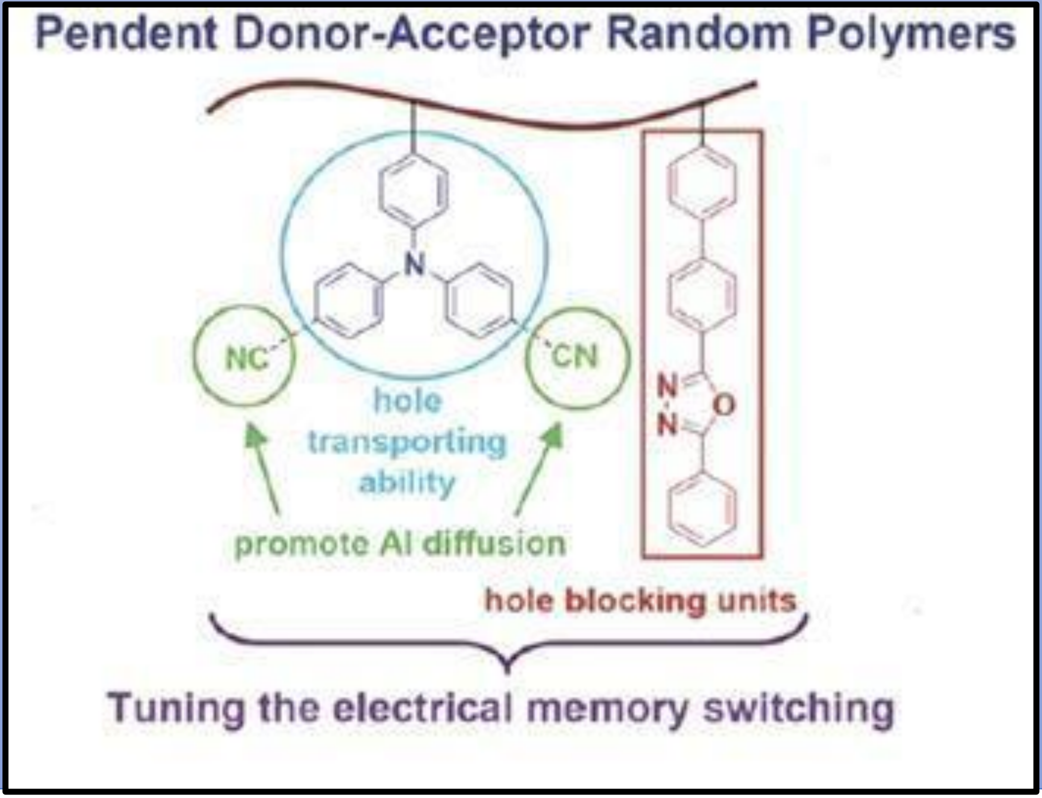
Ex: Functional Polyimides: Functional polyimides (PIs) are one of the most attractive polymeric materials for organic electrical memory applications. In functional PIs, phthalimide acts as the electron acceptor, and electron donors (triphenylamine or carbazole moieties) are introduced to form a D–A structure (first reported in 2006).

Molecular structure (top) of functional PI (TP6F-PI) and schematic diagram (bottom) of single-layer memory device.



Non-Conjugated Polymers with Pendants: Non-conjugated polymers with pendent electroactive donors, acceptors and chromophores are another kind of polymer material favourable for electronic memory.

- Ex; Al/polymer/ITO, polymer-PVK-AZO-2CN and PVK-AZO-NO2(PVK-polyvinyl carbazole, AZo- azobenzene



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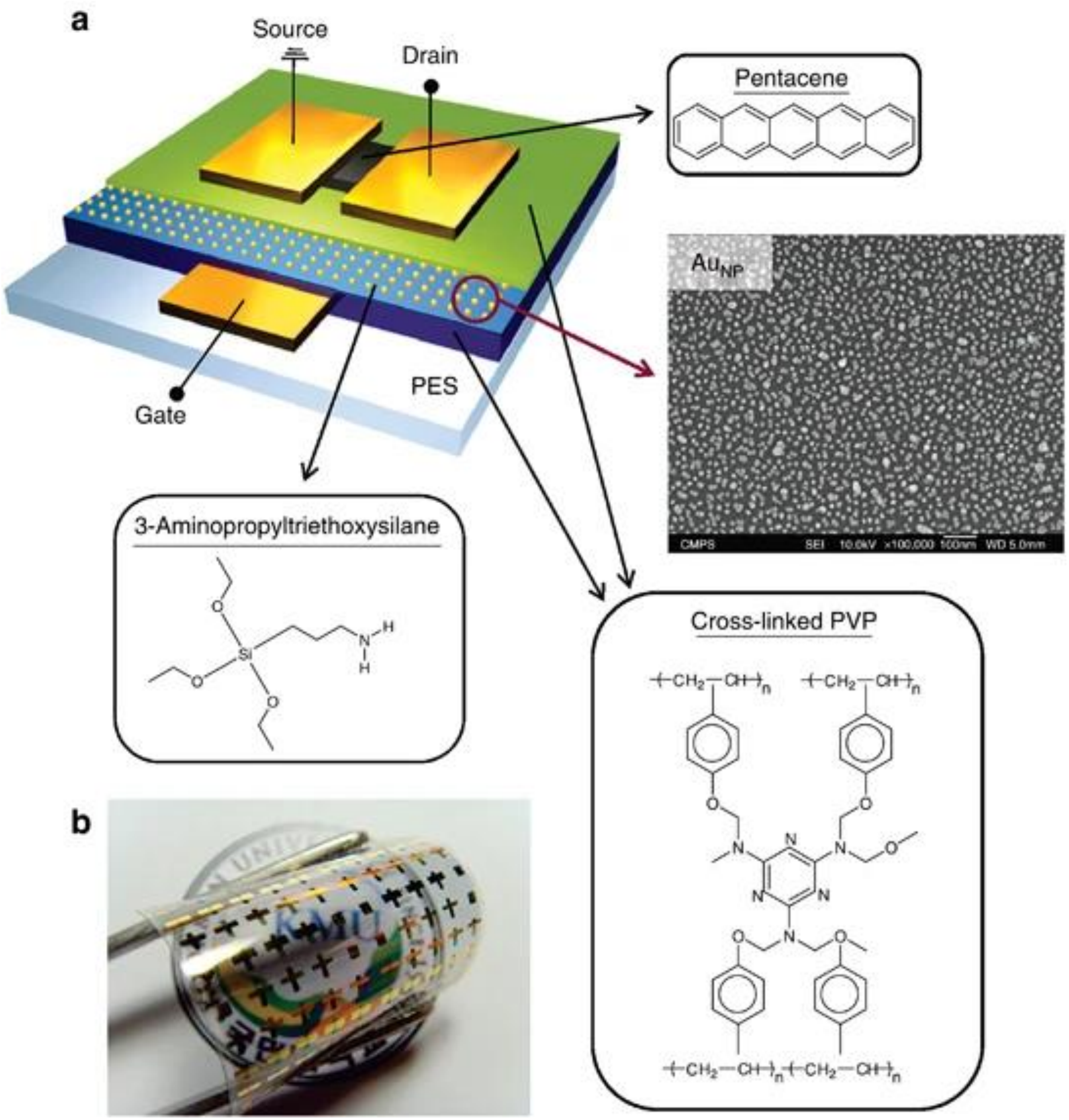
Polymers in Transistor memory device

(**a**) Three-dimensional schematic diagram of the flexible hybrid memory device architecture. Patterned Ti/Au on a PES plastic substrate was used as the gate electrode, and cross-linked PVP layers were used as the blocking and the tunneling organic dielectric layers. The self-assembled gold nanoparticle charge storage layers were formed on the APTES-coated PVP blocking dielectric layer. **A pentacene active layer** and gold source/drain contacts were formed to make the organic transistor-based memory devices. The chemical structures of the organic layers are shown in the figure. (**b**) Photograph of a fabricated flexible organic memory device. The device size is 3 × 3 cm^2.



4. Inorganic/organic nanocomposites

- Generally, organic–inorganic hybrid materials are composed of organic layers containing **fullerenes, carbon nanotubes, graphene, metal nanoparticles, semiconductor nanoparticles** or inorganic quantum dots (QDs).
- Non-volatile memory devices based on hybrid inorganic/organic nanocomposites have emerged as excellent candidates for promising applications in next-generation electronic and optoelectronic devices. The simplest structure for **a hybrid memory device fabricated utilizing the solution method is a single-polymer layer embedded with inorganic nanomaterials and sandwiched between two metal electrodes, as shown in below Figure**.
- Generally, the hybrid nanocomposites are formed by dissolving inorganic nanomaterials and a polymer matrix simultaneously in a certain organic solvent with a relatively high volatility. Fabrications of single-layer-structured nonvolatile memories based on various organic/inorganic hybrid nanocomposites have been reported.

Organic–Carbon Allotrope Hybrid Materials: For organic electronic memory applications, Fullerene and its derivatives have been widely used as electron acceptors to form charge transfer (CT) complexes with polymer-containing electron donors, such as thiophene, fluorene, carbazole and aniline derivatives.

- Ex; **rGO/P3HT:PCBM/Al, Al/Polystyrene:C60/Al**

Organic–Inorganic Nanocomposites: Hybrid electronic memory devices have been developed using organic composites containing metal nanoparticles, quantum dots and metal oxide nanoparticles. Inorganic species used in these memories include,

- semiconductor nanoparticles (ZnO, CdSe, Si, CuO and so on) and metal nanoparticles (Au, Ag, FeNi and so on).

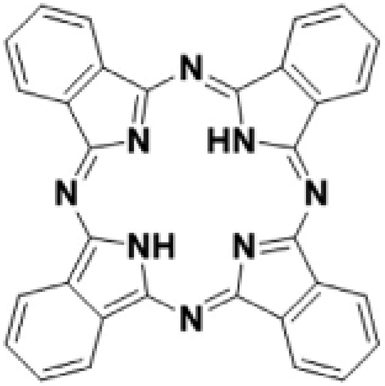
- Both insulating polymers, such as polyimide (PI), poly(methylmethacrylate) and polystyrene, and conducting polymers, such as poly(N-vinylcarbazole) and poly(2-methoxy-5-(2-ethyhexoxy)-1,4-phenylene vinylene), are used as a matrix for the inorganic nanoparticles.

Organic and hybrid photo-electro-active polymer for memories

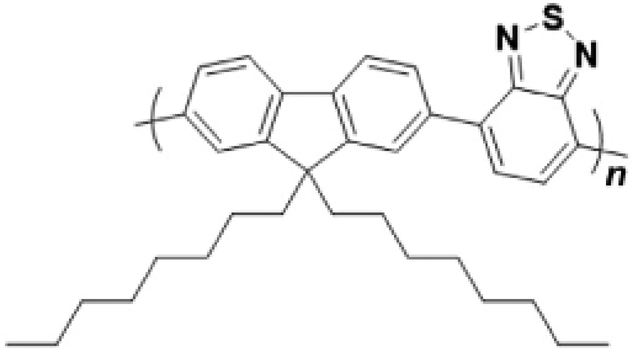
Photoconductive semiconductors are one of the most important optoelectronic mate-rials that have broad application prospects. Generally, light-induced excitons will be generated in these semiconductors by absorbing photons with a well-distinct energy. Excitons can be further converted into free electrons and holes, which change the electrical conductivity of materials resulting from the increase of the carrier density. The concentration of generated electrons and holes can also be con-trolled by wavelength, duration, and intensity of light, with the HOMO-LUMO bandgap of photoconductive semiconductors often falling into the range of UV-VIS-NIR spectrum.

By utilizing optoelectronic materials as active layer materials, the device characteristic can be modulated by both electrical and optical signals. The introduction of light signal can not only reduce program voltage for lowing energy consumption, but also enlarge on/off current ratio for facilitating precise detection of resistance state. In addition, optoelectronic dual-modulated memory also allows far greater storage densities and diversifies the function of device

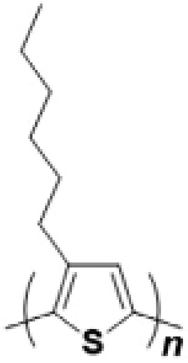
The most studied photoconductive semiconductors in optoelectronic memory devices



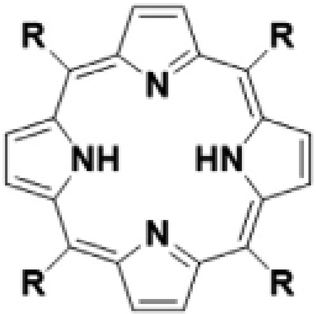
Phthalocyanines



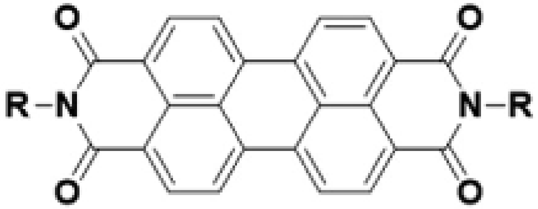
F8BT



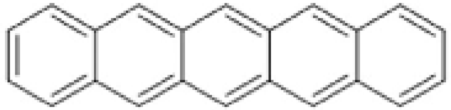
P3HT



Porphyrins



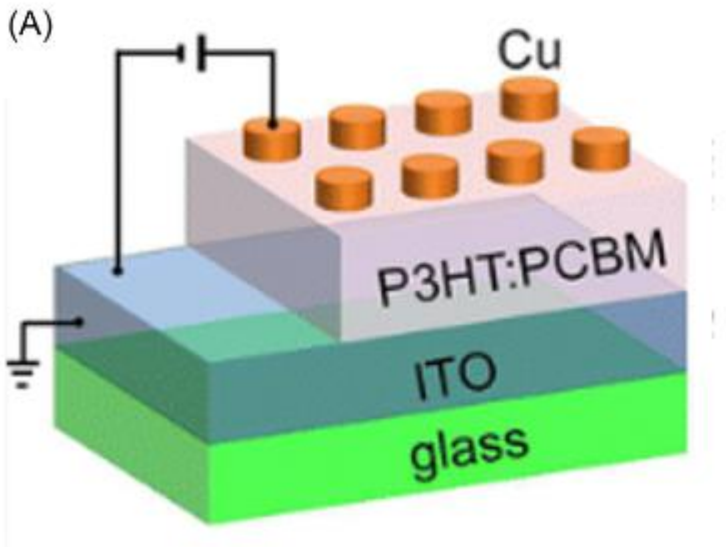
Perylene diimieds

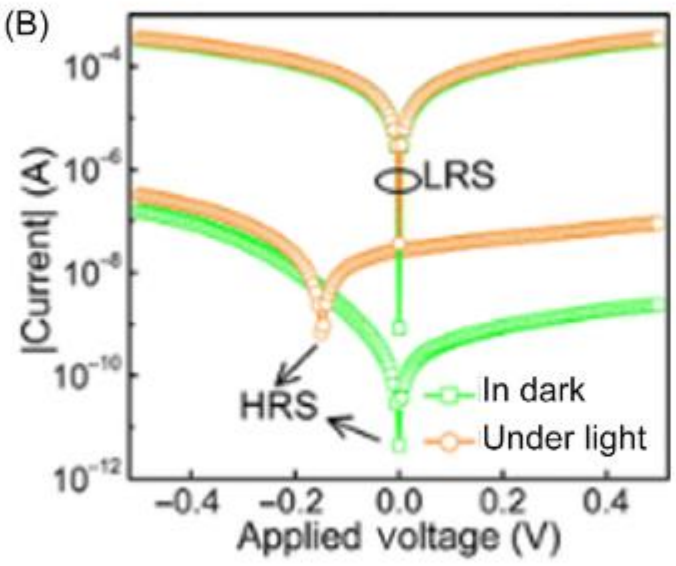


Pentacene

Photo-electro material-based memory device:

Ex: A mixture of poly(3-hexylthio-phene) (P3HT) and [6,6]-phenyl C61-butylric acid methyl ester (PCBM) as storage medium and fabricated Cu/P3HT:PCBM/ITO resistive memory device, which showed a nonvolatile rewritable memory performance with an on/off ratio of $10^{3.}$ However, the light illumination can induce the production of an open circuit voltage of 20.15 V in HRS and it will eliminate in LRS . It is demonstrated that dynamic formation/rupture of Cu filament in the device is responsible for the observed resistive switching phenomenon.

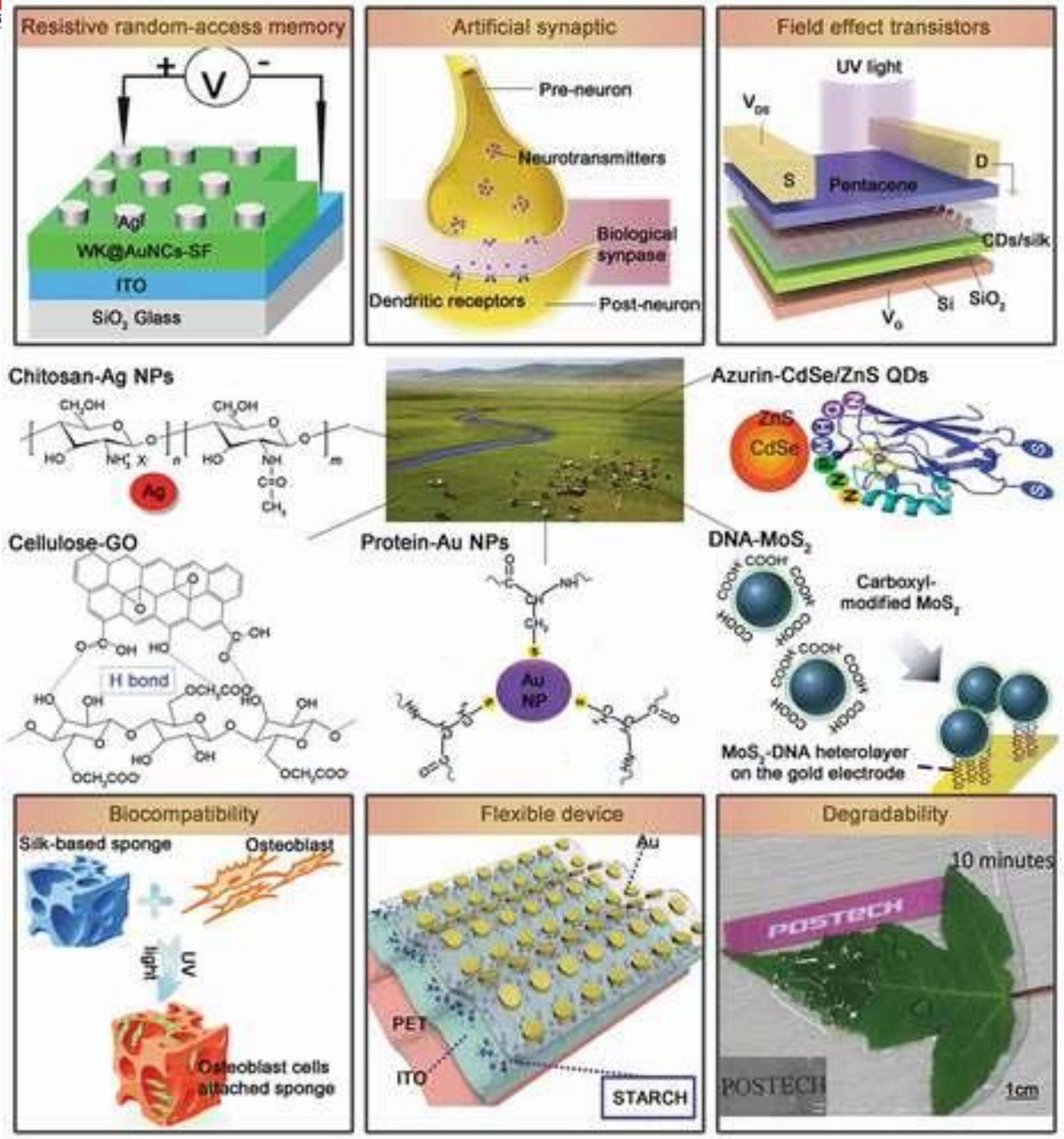




Gao, C. Song, C. Chen, F. Zeng, F. Pan, J. Phys. Chem. C 116 (33) (2012) 1795517959.

Bio-composite based memory devices

- Natural biomaterials are potential candidates for the next generation of green electronics due to their biocompatibility and biodegradability.
- The application of bio composite systems in information storage has further promoted the progress of environmentally benign bioelectronics.
- Certain organic materials and biomacromolecules possess great potential for application in biocompatible, low cost and disposable electronic devices.
- Devices using sericin protein, natural regenerated silk fibroin protein as the functional material are examples of used for the fabrication of memory devices.



DNA treated with cationic surfactant cetyltrimethylammonium (CTMA) to form a **DNA-CTMA polymer,** and then embedded with Ag NPs using photochemical reactions. The ultraviolet light can effectively adjust the properties of the composite polymer, so that the device showed excellent WORM performance [App Phys Lett. 2011;99(25):253301.]

A flexible resistive memory comparable to traditional metal oxide memories, in which Au NPs/silk protein fibers composite acted as an intermediate layer. [Nanotechnology. 2013;24(34):345202.]

Data storage devices based on various natural biomolecules, including protein, saccharide, DNA, RNA, and virus.

Biomolecules	Device terminology	Device type	Structure	ON/OFF ratio	Cycle number	Retention time
Protein	Ferritin	RRAM	Pt/PAH-Ferritin Multilayer/Ag	10^6	300	10^4
	Silk fibroin	RRAM	Ag/silk fibroin/Au	10^5	30	10^4
Saccharide	Chitosan	RRAM	Ag/Ag-doped chitosan/Pt	10^5	100	10^4
	Maltoheptaose	Flash memory	Au/pentacene/maltoheptaose/ SiO_2/Si	10^6	/	3.6×10^4
DNA	CuO-DNA-Al	RRAM	Au/CuO-DNA-Al/Au/Si	50	100	10^3
RNA	RNA	Molecular memory	QD-STV/RNA/Au	100	/	10^6
Virus	Tobacco mosaic virus (TMV)	RRAM	Al/TMV-Pt nanoparticles/Al	10^3	400	10^4

Outline of building memory devices from bio composite electronic materials: different kinds of biocomposite materials will participate in the construction of memory devices with different structures and properties.
(Ref https://doi.org/10.1080/14686996.2020.172539)

Disadvantages:

Biomaterials have a weak electron transfer function and are not compatible with traditional semiconductor device manufacturing processes; therefore biomaterial-based degradable electronic products have many difficulties to overcome in order to achieve industrial feasibility.

Characteristics of Computer storage devices

- · Volatility : Whether the stored data will remain or not, when the power supply is disconnected.
- · Differentiation: Whether it's a Dynamic random access memory or static memory.
- · Accessibility : Whether it's Random-access or Sequential access
- · Addressability : Whether it's a Location-addressable, File addressable, or Content-addressable.
- · Mutability : Whether it's a Read/write storage or mutable storage, Read-only storage, or a Slow write, fast read storage.

New, high-performance memory is urgently required to keep up with the growing demands of information technology. Fortunately, new memory technologies are expected to increase memory performance and accelerate the information revolution.

Characteristics of Memory Devices

Location : The memory can either be stored externally with the help of some devices or internally.

- **Capacity :** The amount of data a device can store is called capacity. It is measured as a byte (1 byte = 8 bits, 1 bit is either 0 or 1).
- **Access Method:** The way of searching the storage devices is called the access method.
- **Unit of Transfer:** The measure of data is different in internal and external devices
- **Performance :** The performance of any memory device depends upon the rate at which data is transferred, the time taken by the device to carry out the process and the access time.

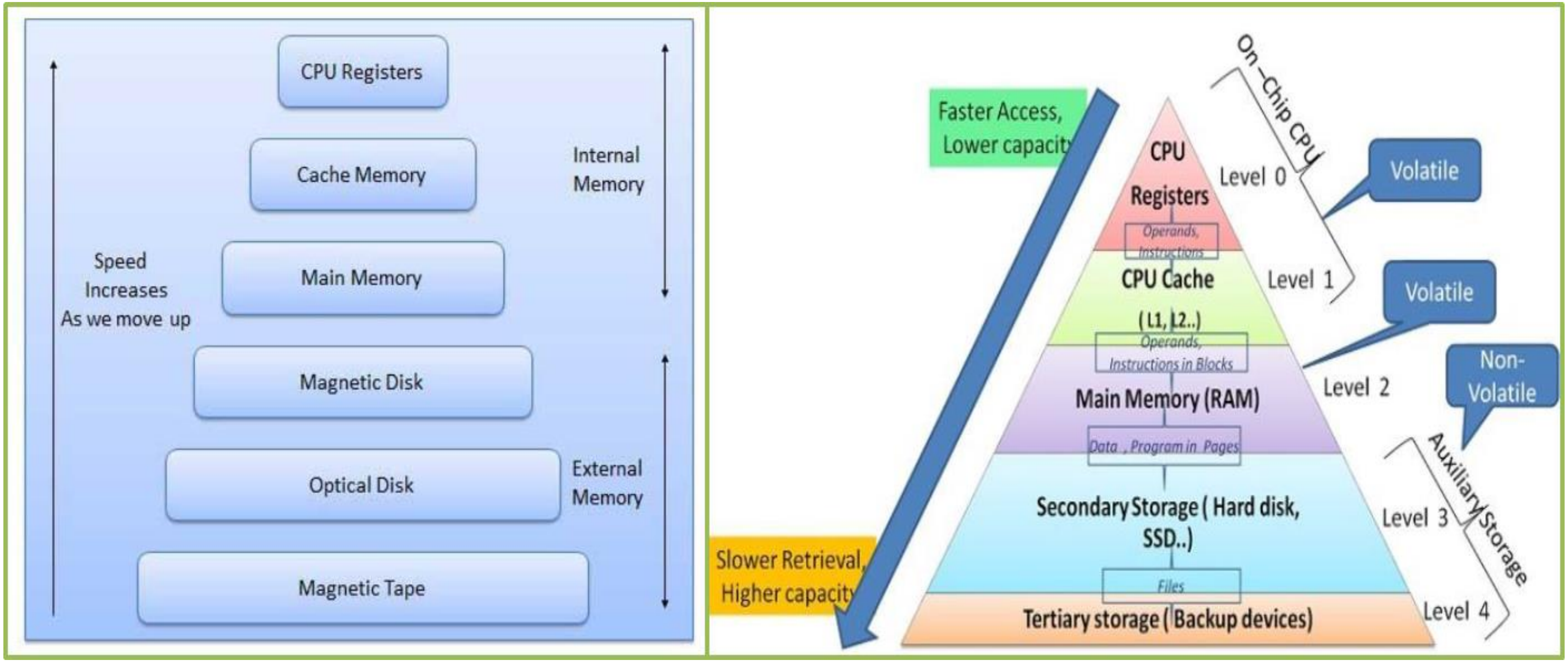
Memory Devices:
History of organic/polymer electronic memory devices

Since the 1940s, many storage forms based on diverse natural phenomena have been documented. A computer system often has many types of storage, each with a specific function. Due to their unusual electrical characteristics, amorphous semiconductors and disordered structures attracted a lot of attention in the 1960s.

- In 1968 - Pb/polydivinylbenzene/Pb bistable electrical switching device as an information storage device.
- In 1969 - Tetracene films sandwiched between metal electrodes.
- In 1970 - Phthalocyanines and polystyrene - bistable switching materials.
- In 1970 - Polymer thin films prepared by glow-discharge polymerization.
- In 1980 - Thin films of ferroelectric materials began exhibiting non- volatile memory effects.

Introduction

Memory is the electronic holding place for the instructions and data a computer needs to reach quickly. It's where information is stored for immediate use. Memory is one of the basic functions of a computer, because without it, a computer would not be able to function properly.



Contd.,

- In 1995- Fabrication of ferroelectric films by the Langmuir–Blodgett (LB) technique. Polymer ferroelectric random access memory (FeRAM) as a promising memory technology has been achieved
- In 2001- An organic transistor memory device using a sexithiophene oligomer as the conductor and an inorganic ferroelectric material as the gate insulator were demonstrated.
- Ferroelectric organic and polymer materials have also been utilized as gate insulators in field-effect transistors (OFETs).
- High performance all-organic or polymer transistor memory devices have been demonstrated

In 2003-A WORM type memory device based on polymer fuses was demonstrated

- The memory element consists of a thin film p–i–n silicon diode and a conductive polymer fuse, composed of poly (ethylene dioxythiophene) (PEDOT) oxidatively p-doped by poly (styrene sulfonic acid) (PSS).
- Polymer memory devices based on charge transfer effects from doping of a polymer matrix by electron donors, such as 8-hydroxyquinoline (8HQ), tetrathiafulvalene (TTF), polyaniline (PANI), poly-3-hexylthiophene (P3HT), or electron acceptors such as gold nanoparticles, copper metallic filaments and phenyl C61-butyric acid methyl ester (PCBM), have been reported.

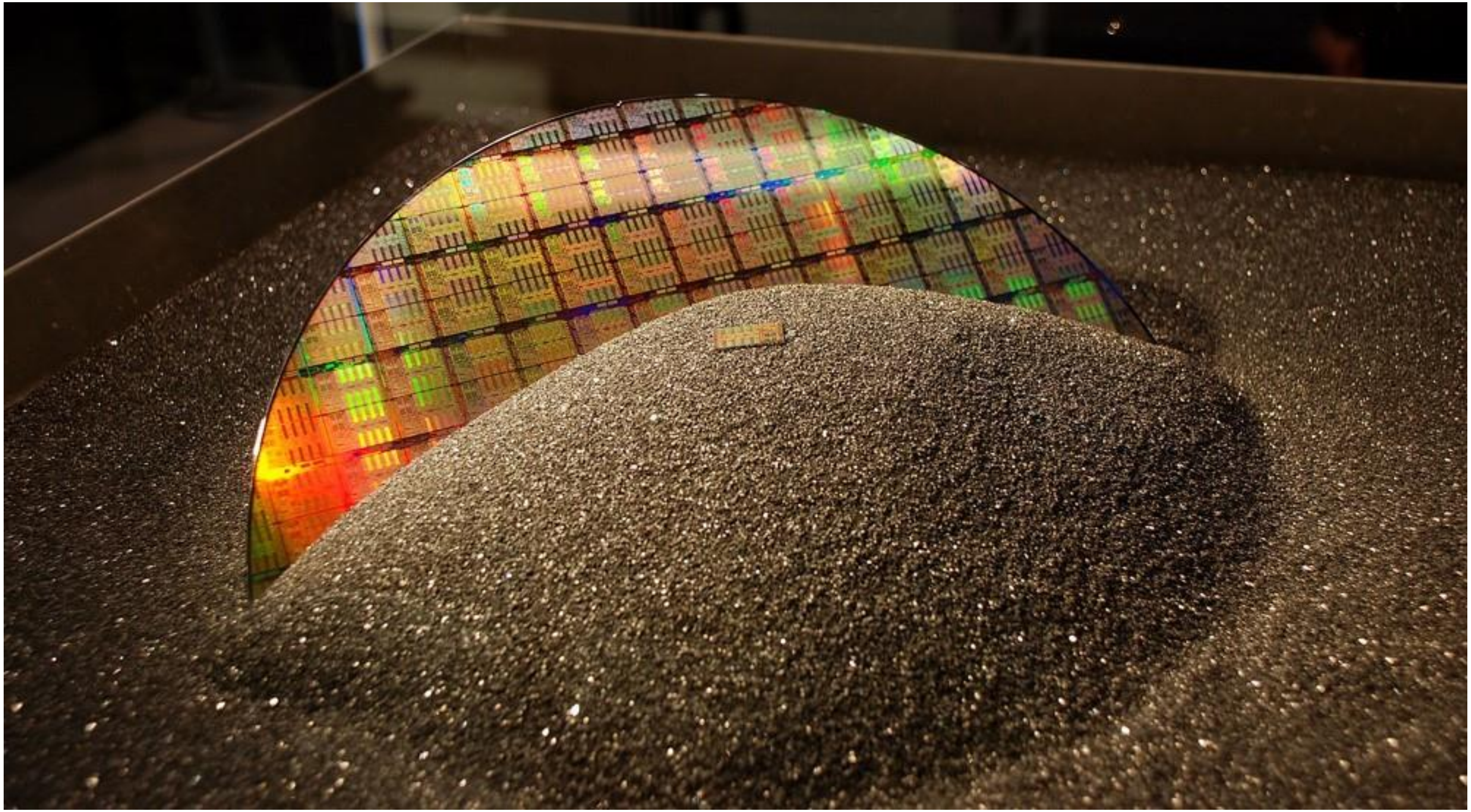
Contd.,

- In 2005-Multilevel conductance switching in poly[2-methoxy-5-(2′-ethyl-hexyloxy)-1,4-phenylene vinylene] (MEH-PPV) films.

- In 2011-A polymer memristor was first reported in cobalt(iii)-containing conjugated (CP) and non-conjugated (NCP) polymers with an azo-aromatic backbone.

  - Single crystals of a cyclodextrin-based metal–organic framework (MOF) infused with an ionic electrolyte and flanked by silver electrodes can act as memristors.

- Recent; organic-based resistive memory materials, biodegradable memory devices



Semiconductor Manufacturing Process

https://www.youtube.com/watch?v=Bu52CE55BN0
https://www.youtube.com/watch?v=cjx55LNnbNQ
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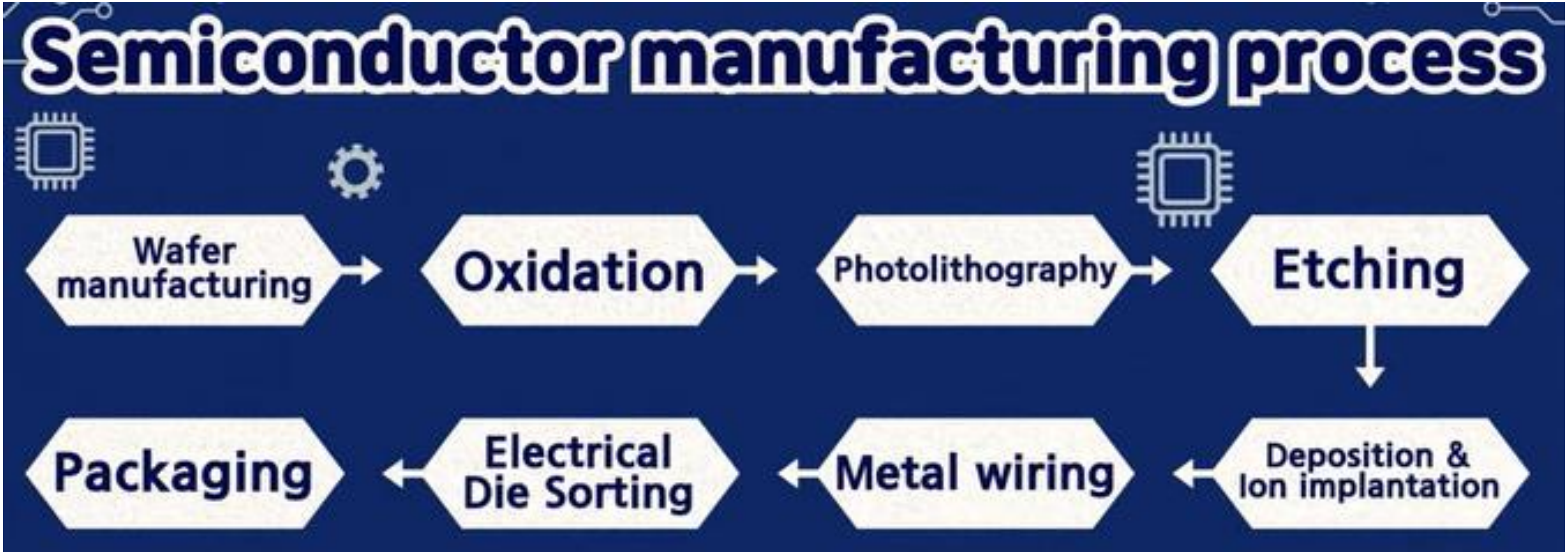
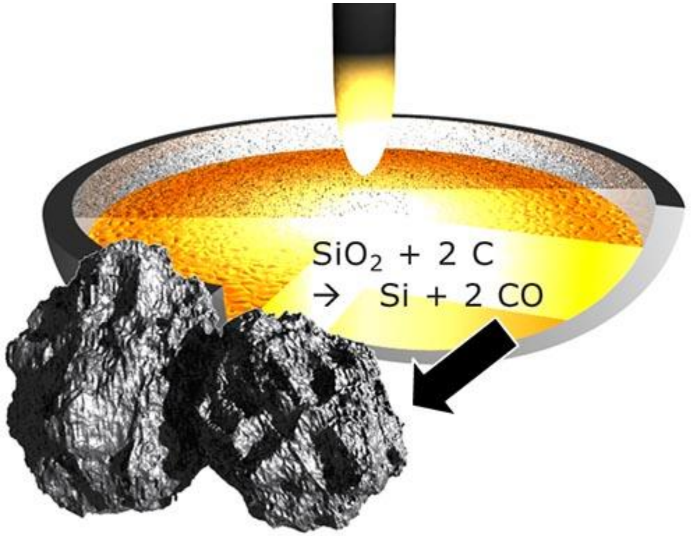


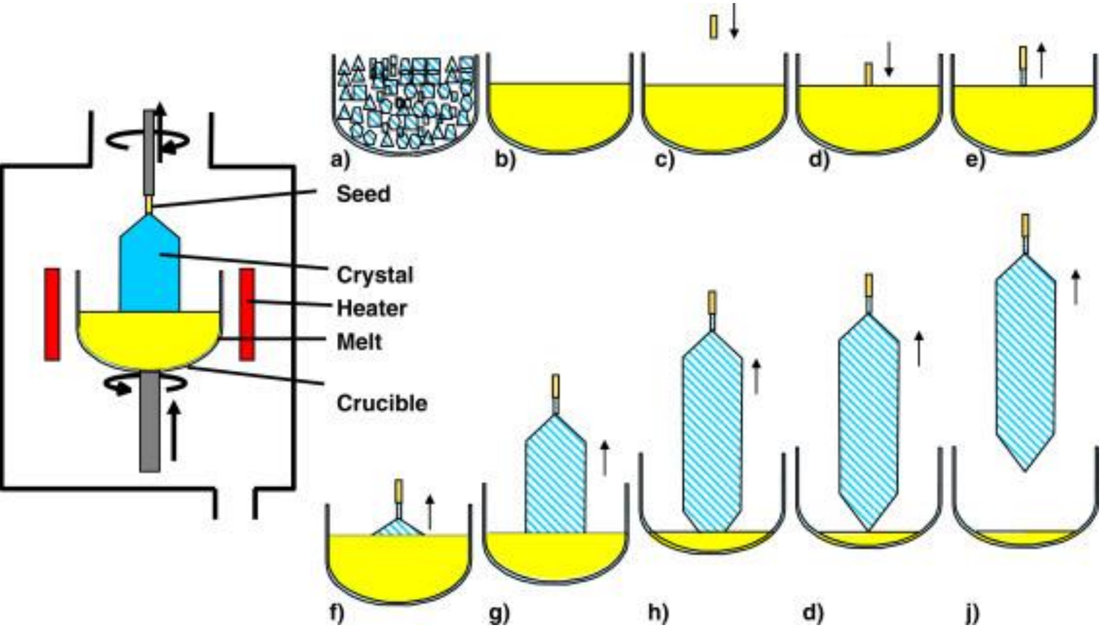
Silicon being the most abundant element in nature, just after oxygen. Its environmentally friendly properties are a bonus. Once silicon is extracted from sand, it needs to be purified before it can be use. First, it is heated until it melts into a high-purity liquid then solidified into a silicon rod, 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. The thin slice obtained through cutting process is called “die” that is an unprocessed “raw wafer‟. The die surface is uneven and polished to remove surface defects through grinding and chemical etching processes then to smooth surface trough polishing to obtain mirror-smooth finish

Step 1. Wafer manufacturing Processing

1. Sand (SiO_2) is heated at 2000 deg in the presence of carbon produces 98% Si
2. Then 98% Si is further heated at 900 deg in hydrogen atmosphere, to produce 99.999% Si
3. The 99.999% Si heated to melt in inert atmosphere and using Czochralski method, Si Ingots are crystallised.



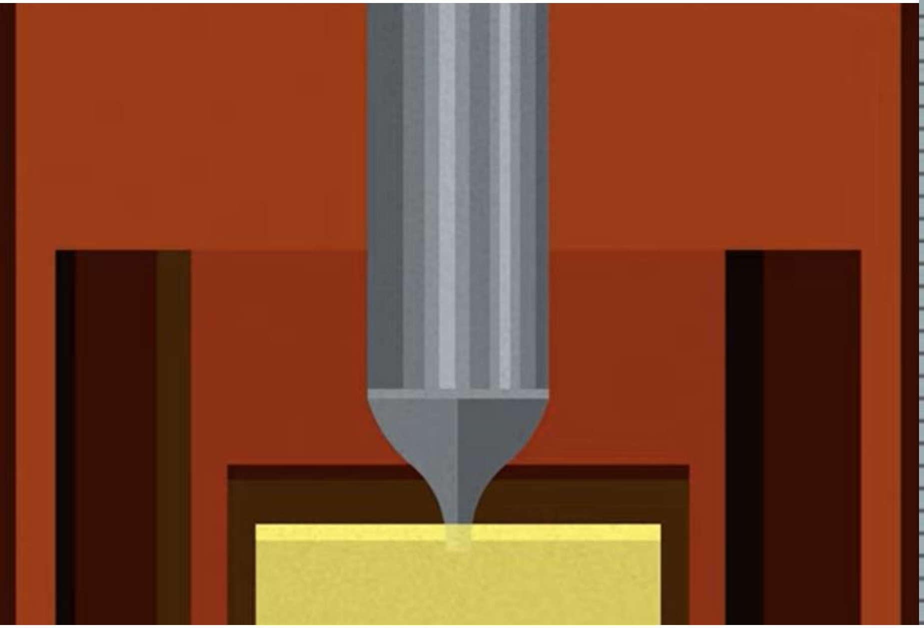
Czochralski (chokh-RAL-skee) process

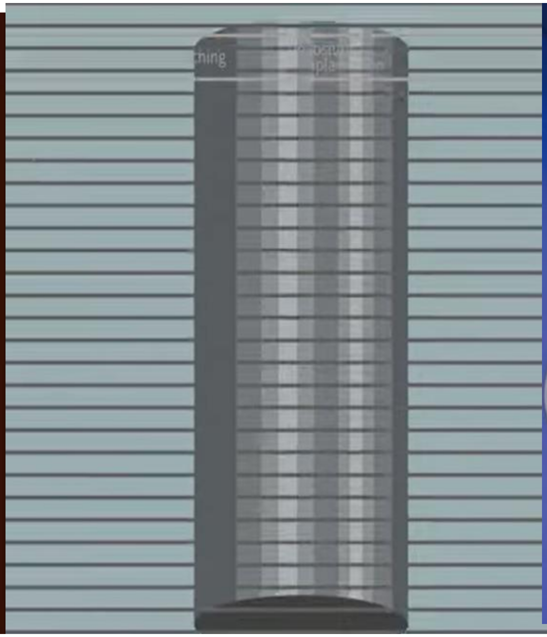


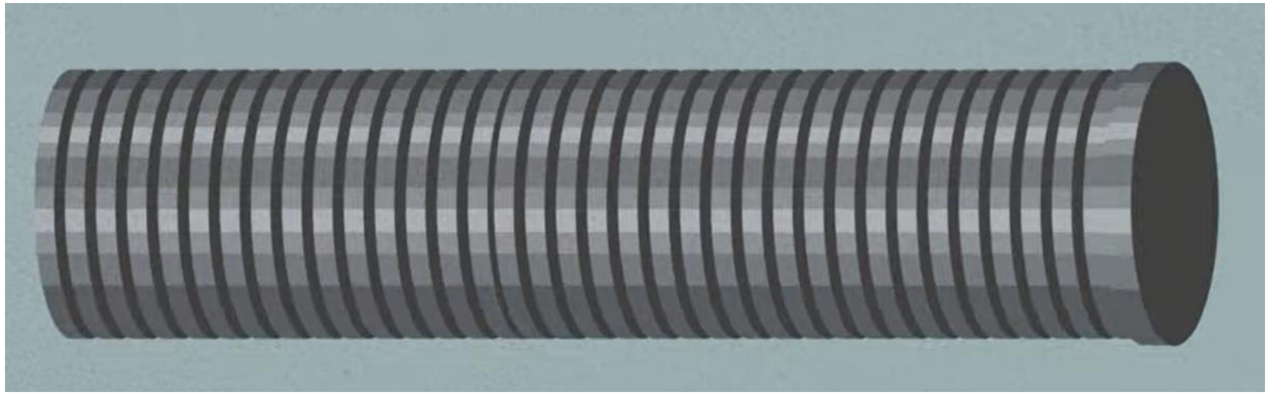
At the beginning of the process, the feed material is put into a cylindrically shaped crucible and melted by resistance or radio-frequency heaters. After the feed material is completely molten a seed crystal with a diameter of typically a few mm is dipped from top into the free melt surface and a small portion of the dipped seed is melted. A melt meniscus is formed at the contact interface between seed and melt. Then, the seed is slowly withdrawn from the melt (often under rotation) and the melt crystallizes at the interface by forming a new crystal portion. During the further growth process, the shape of the crystal, especially the diameter, is controlled by carefully adjusting the heating power, the pulling rate and the rotation rate of the crystal. Usually an automatic diameter control is applied.

https://www.sciencedirect.com/topics/chemistry/czochralski-process

Step 1. Wafer manufacturing Processing





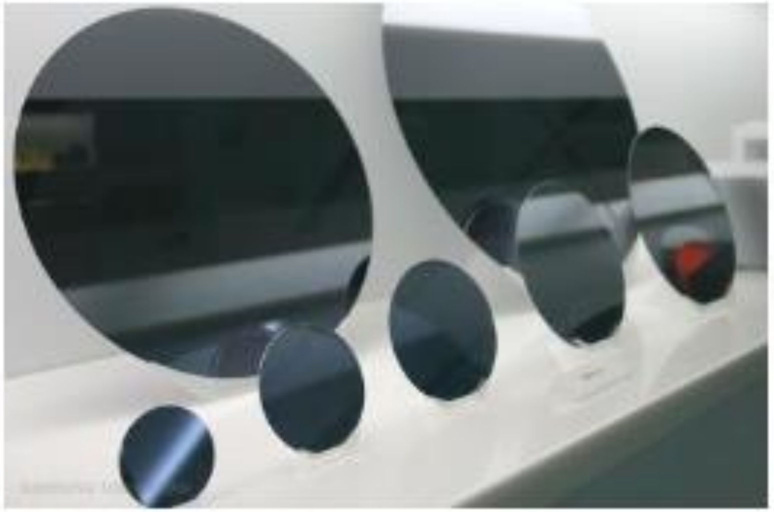


Step 1. Wafer manufacturing Processing

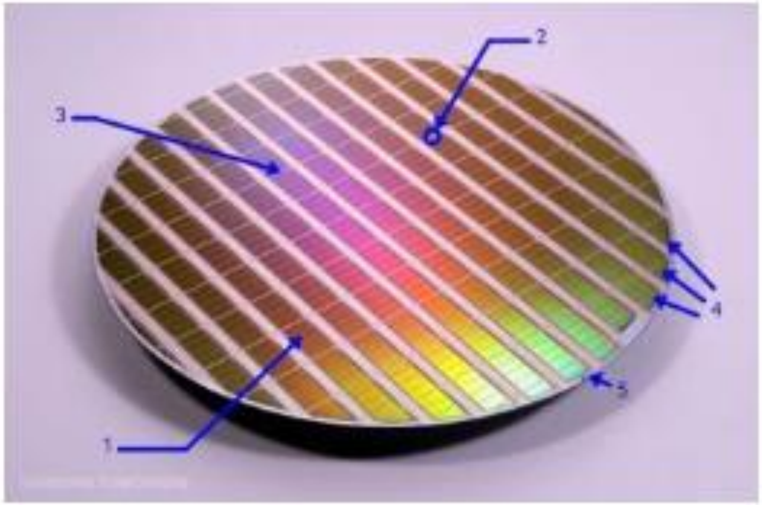
Typical wafer is made out of extremely pure silicon (99.9999999% or higher)

Step 1. Wafer manufacturing Processing

Wafers are placed and etched in a carrier cage that rotates in an etching solution to completely remove the damaged surface resulting from the previous slicing and lapping. Acid is used for etching solution, but combination with alkaline is recently used.



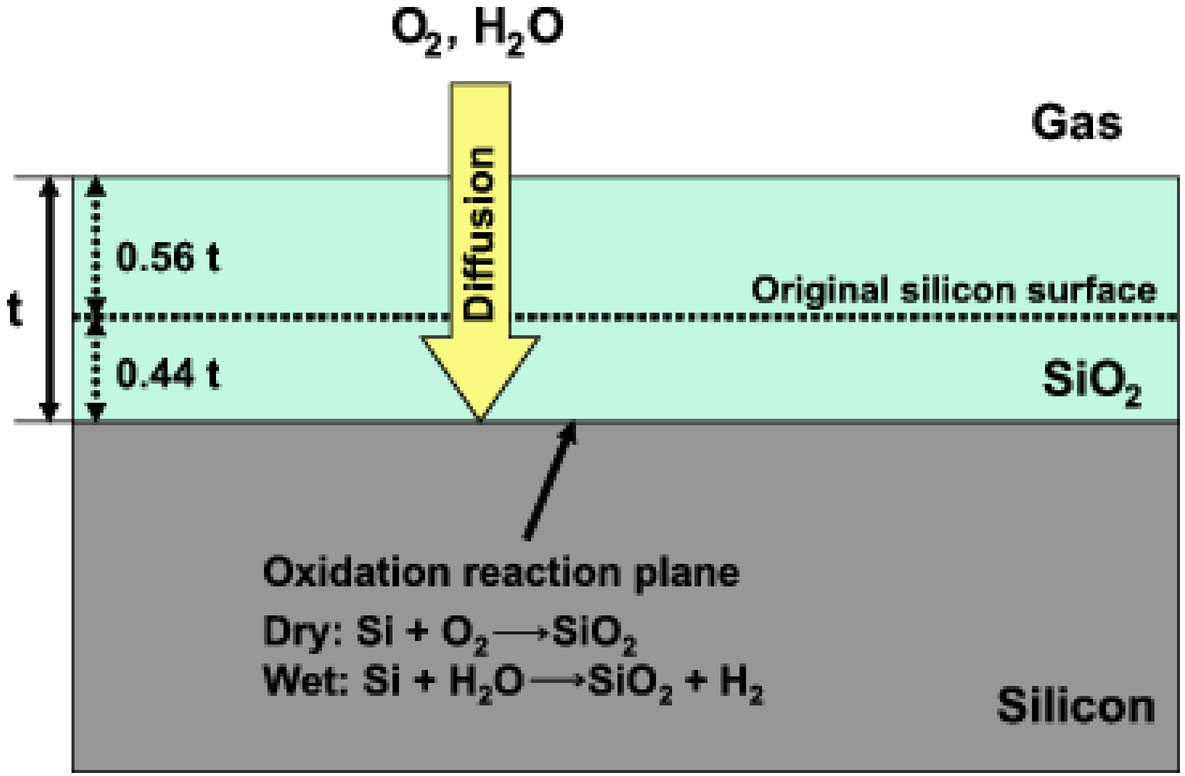
Si wafer



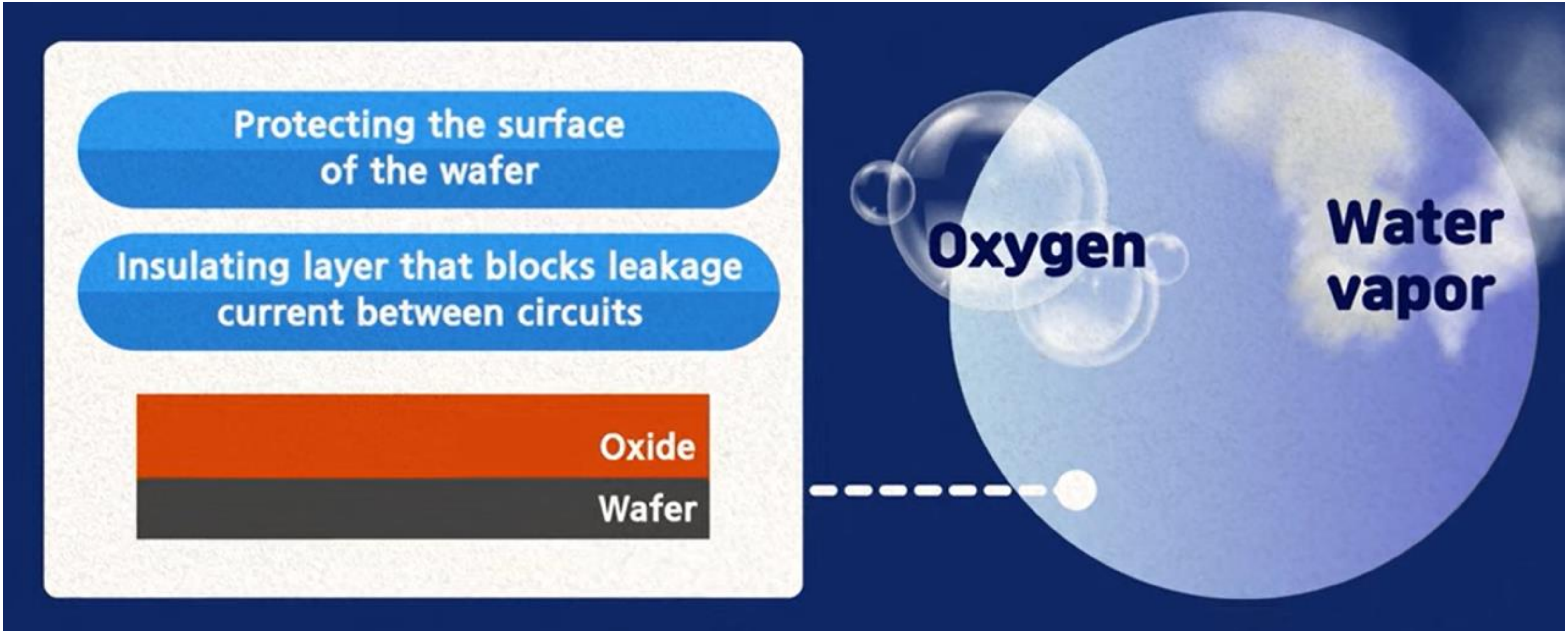
finished wafer

Step 2. Oxidation Si Wafer

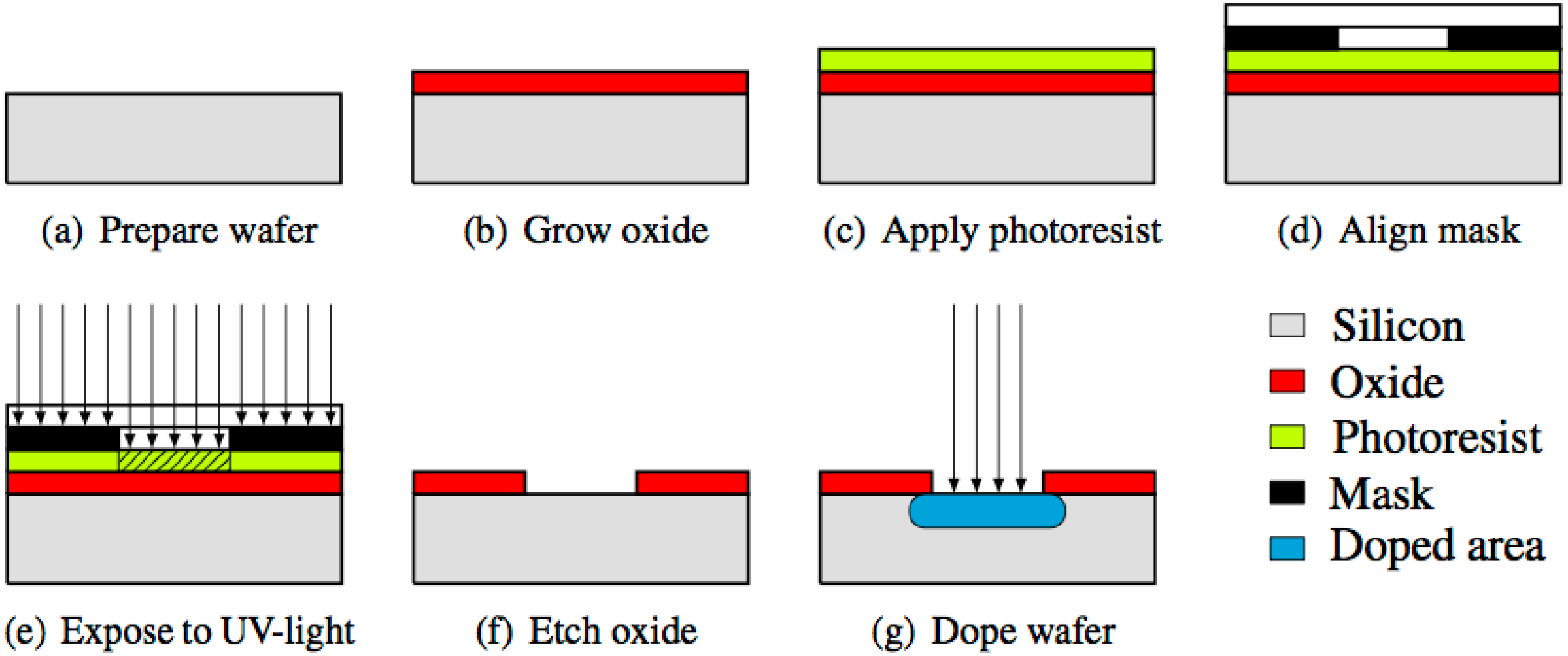
oxidation is the process by which a film of silicon dioxide, SiO_2, is grown on the surface of a silicon wafer. The oxidation process **creates an SiO_2 layer, which serves as an insulating layer that blocks leakage current between circuits**. The oxide layer also protects the silicon wafer during the subsequent ion implantation and etching processes



Step 2. Oxidation Si Wafer

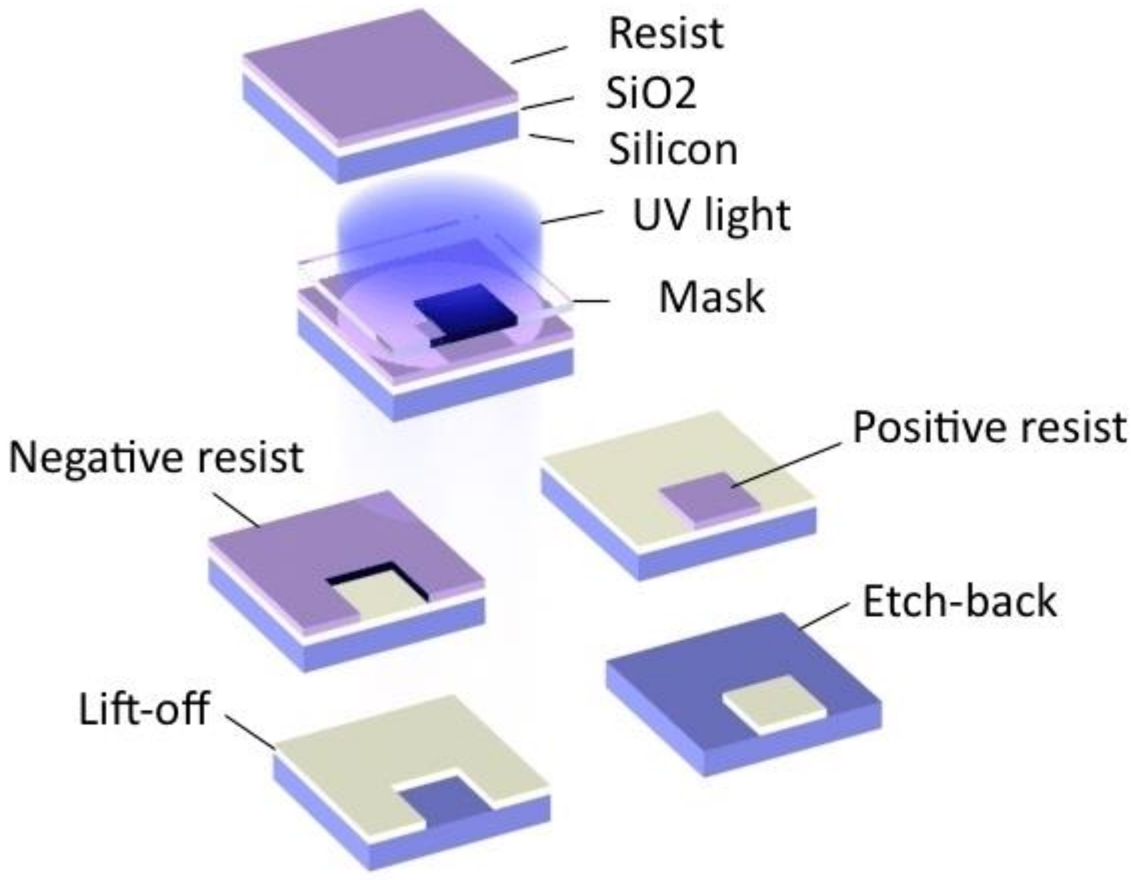


Step 3. Photolithography



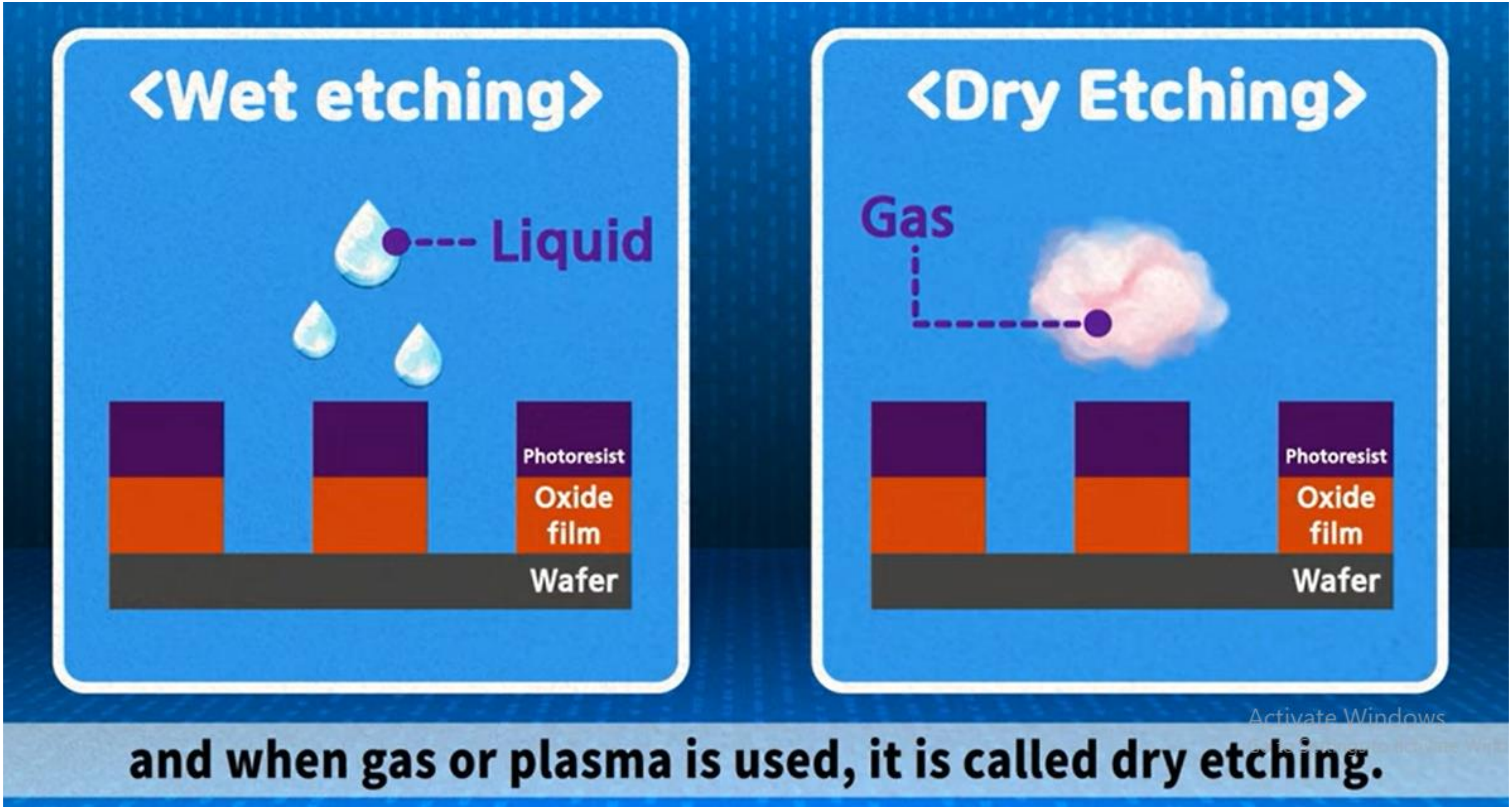
The mono-crystal silicon wafer is polished in order to obtain a substrate with its surface as regular and flat as possible. The top of the wafer is then prepared for photolithography by covering it with an insulating layer to serve as a mask, typically an oxide, and a subsequent covering film of protective material which is sensitive to light, called photoresist. A photomask with the circuit pattern for one layer of the chip is loaded and aligned with the wafer. The exposure process of the wafer to intense UV light through the mask allows to remove the exposed photoresist area. The unprotected insulating material is then striped away using a chemical etching process and the remaining photoresist is removed by a developer solution

Step 4. Etching

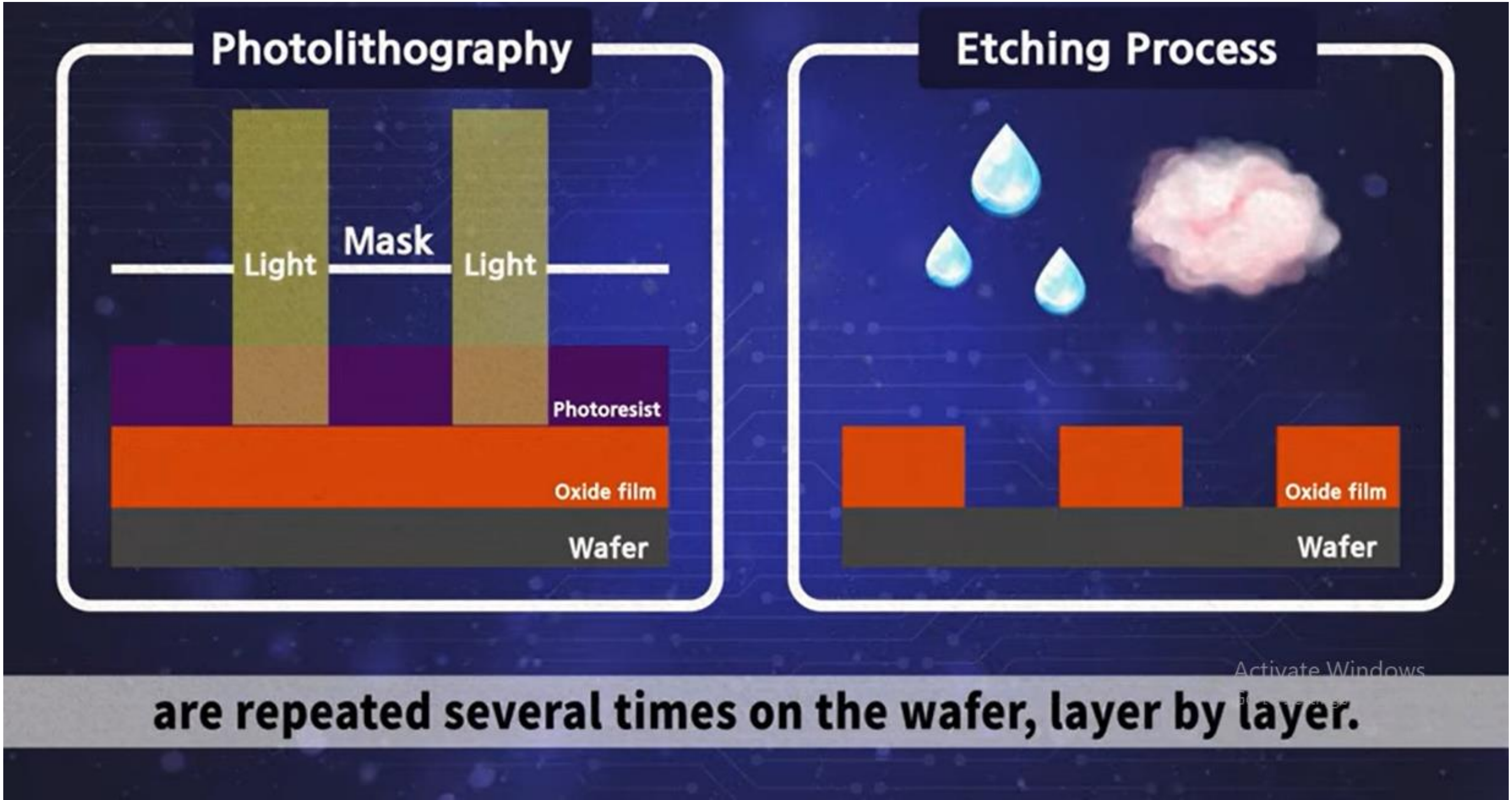


The wafer can be immersed in a bath of etchant, which must be agitated to achieve good process control. For instance, buffered hydrofluoric acid (BHF) is used commonly to etch silicon dioxide over a silicon substrate. Different specialised etchants can be used to characterise the surface etched.

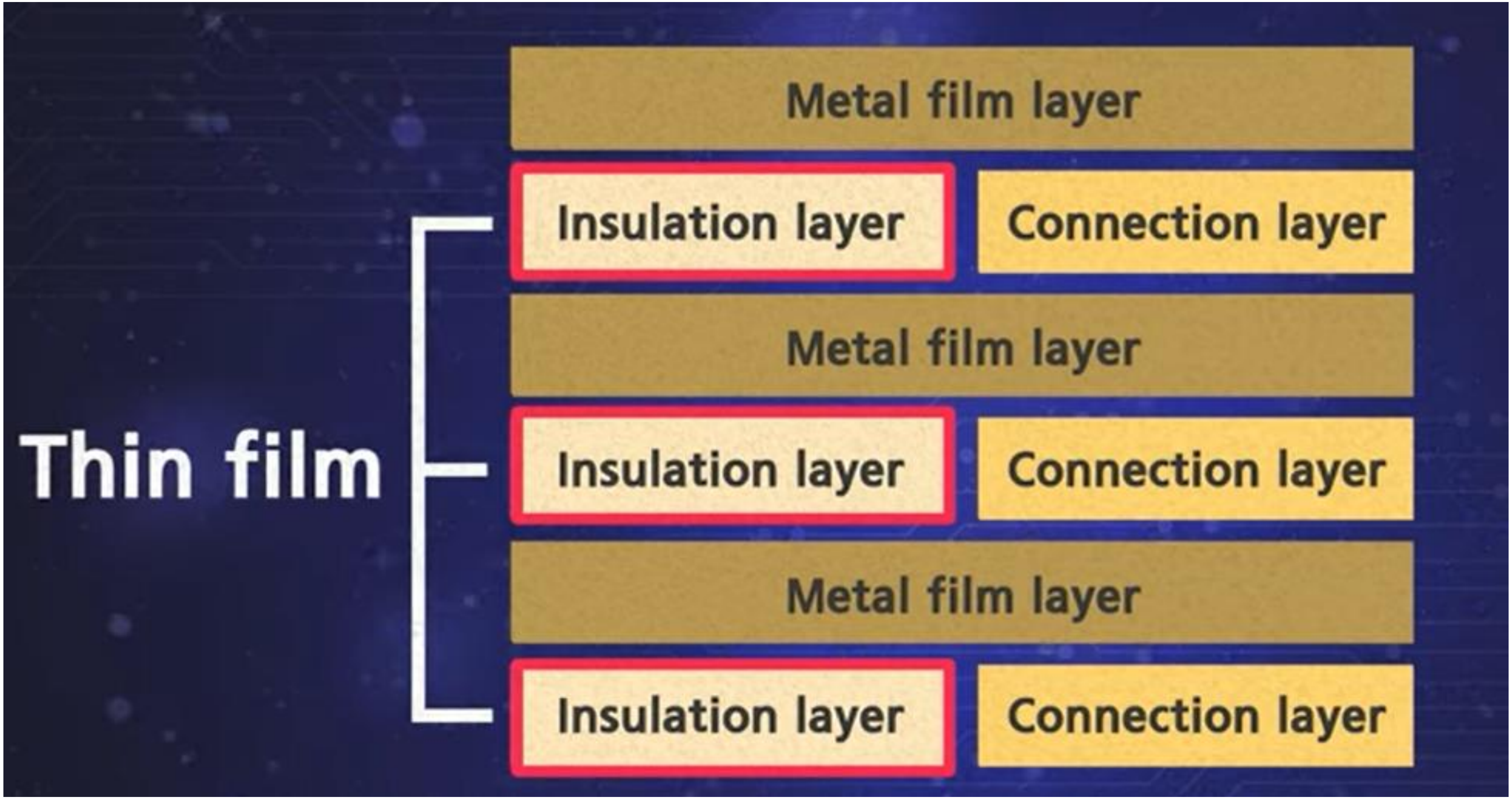
Step 4. Etching



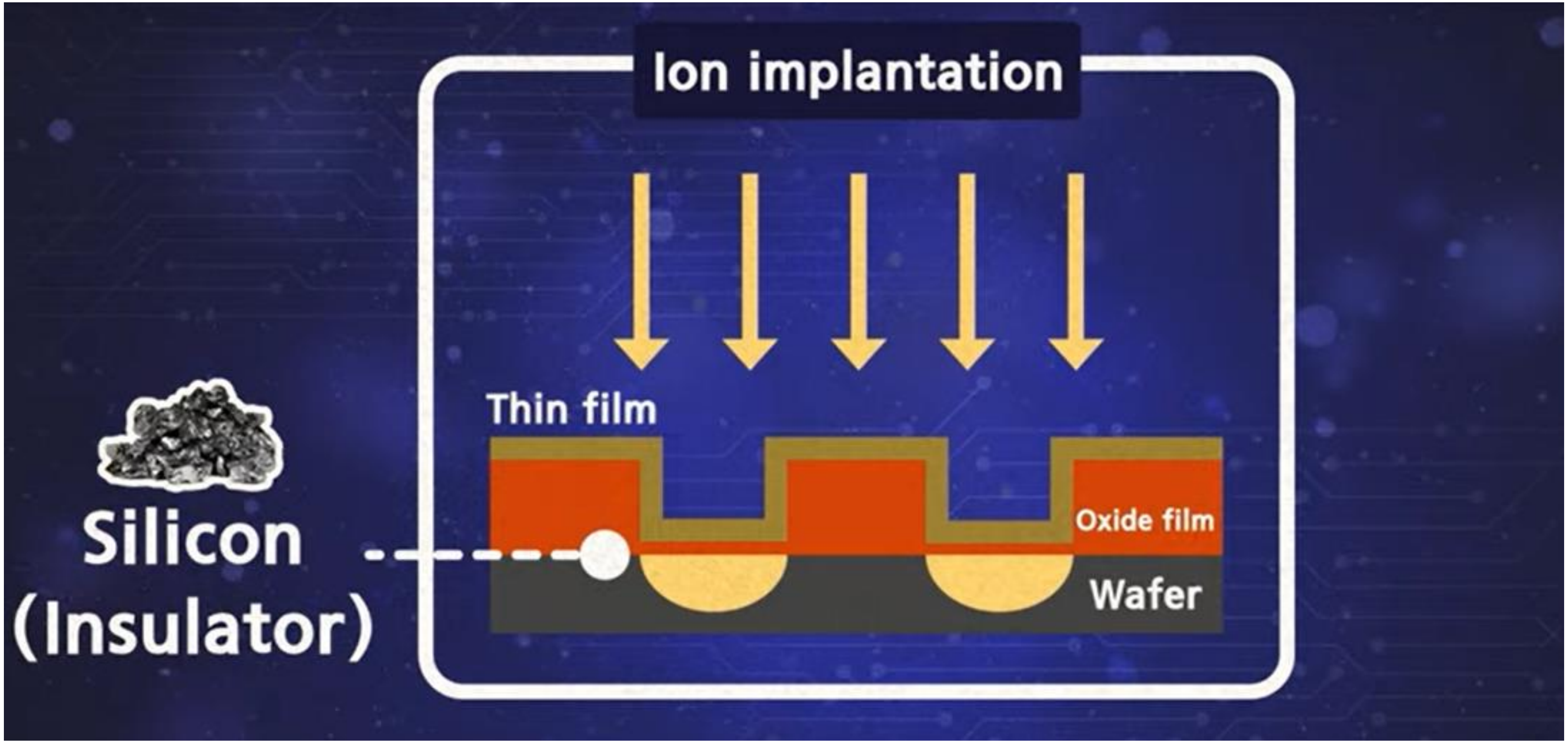
Step 5. Film deposition and Implantation



Step 5. Film deposition and Implantation

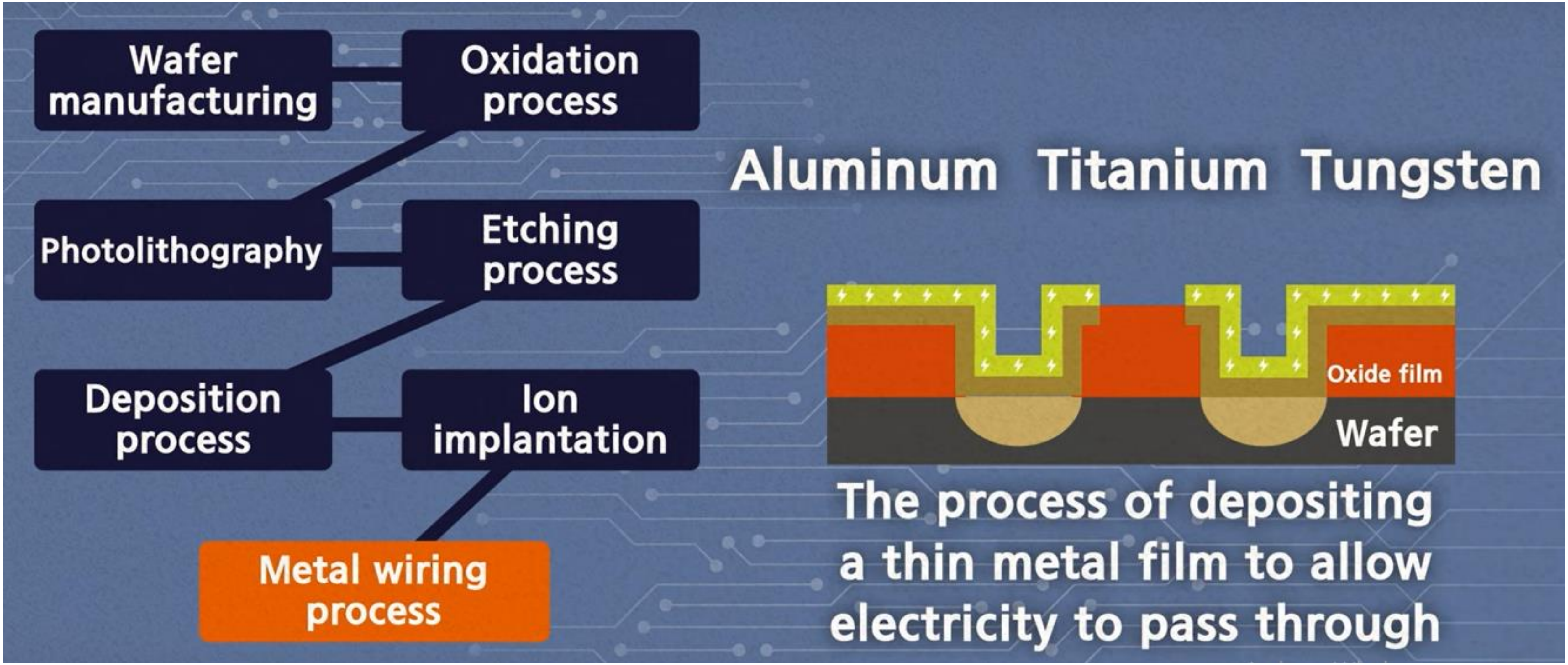


Step 5. Film deposition and Implantation



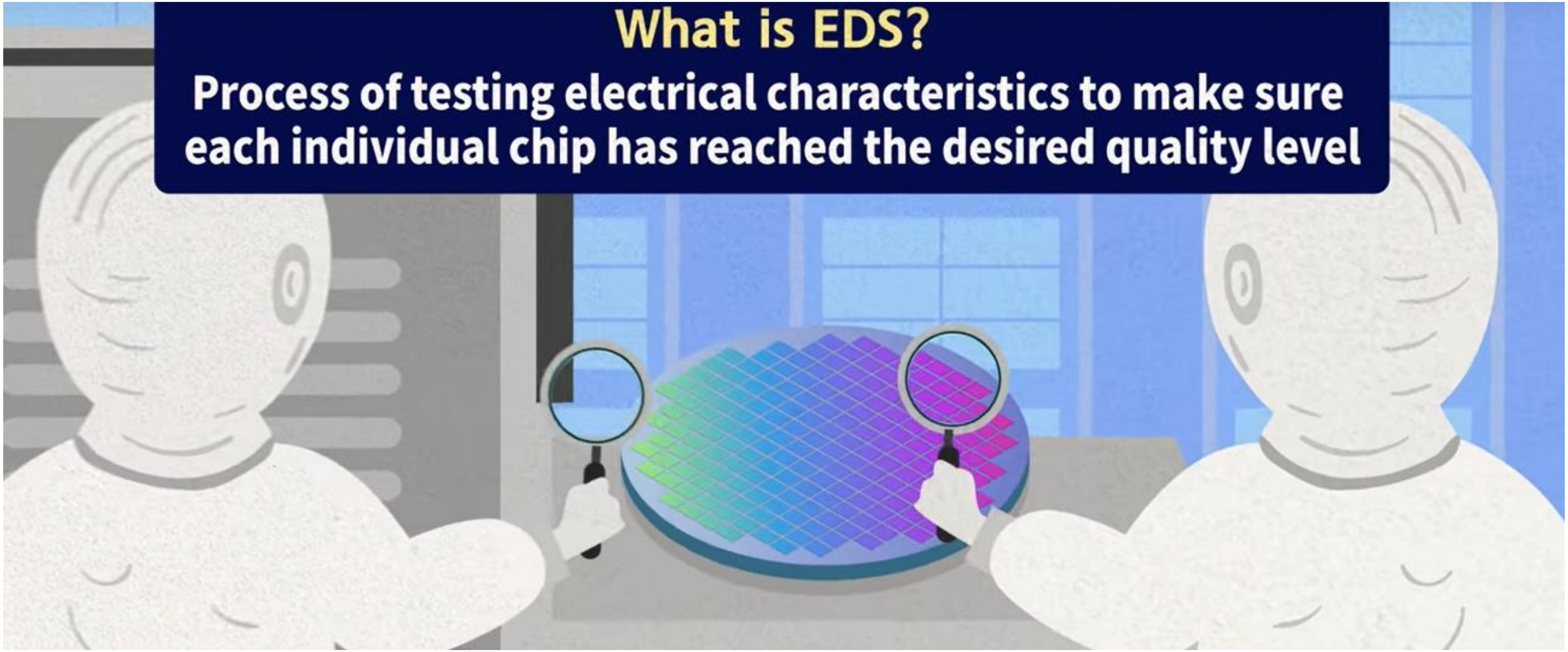
Wafer implantation, also known as "ion implantation", is a process that uses ions of an element to change the physical, chemical, or electrical properties of a target. During the wafer implant process, ions are accelerated in an electric field, generating a beam that is shot out at the wafer

Step 6. Metal wiring for electrical connections

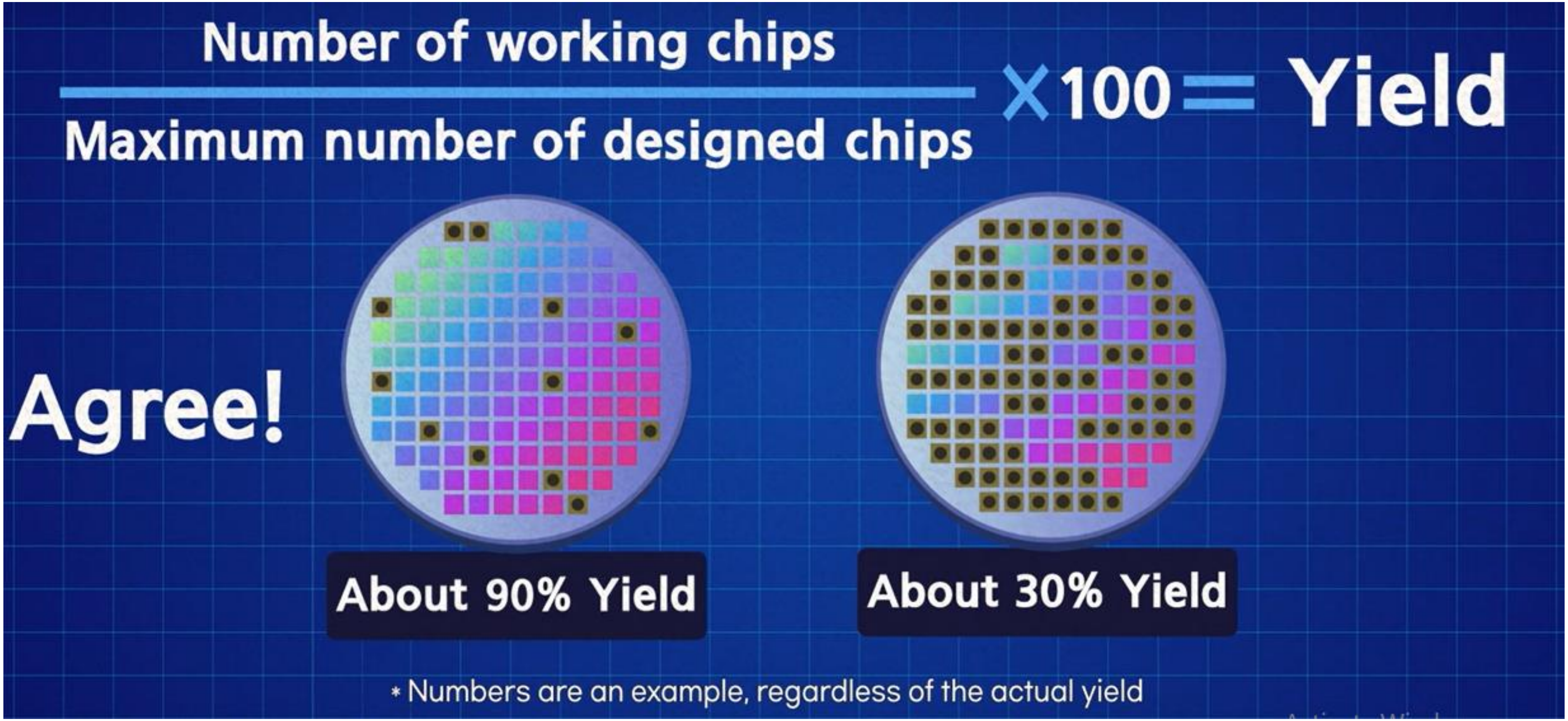


Step 7. Electronic Die sorting (EDS)

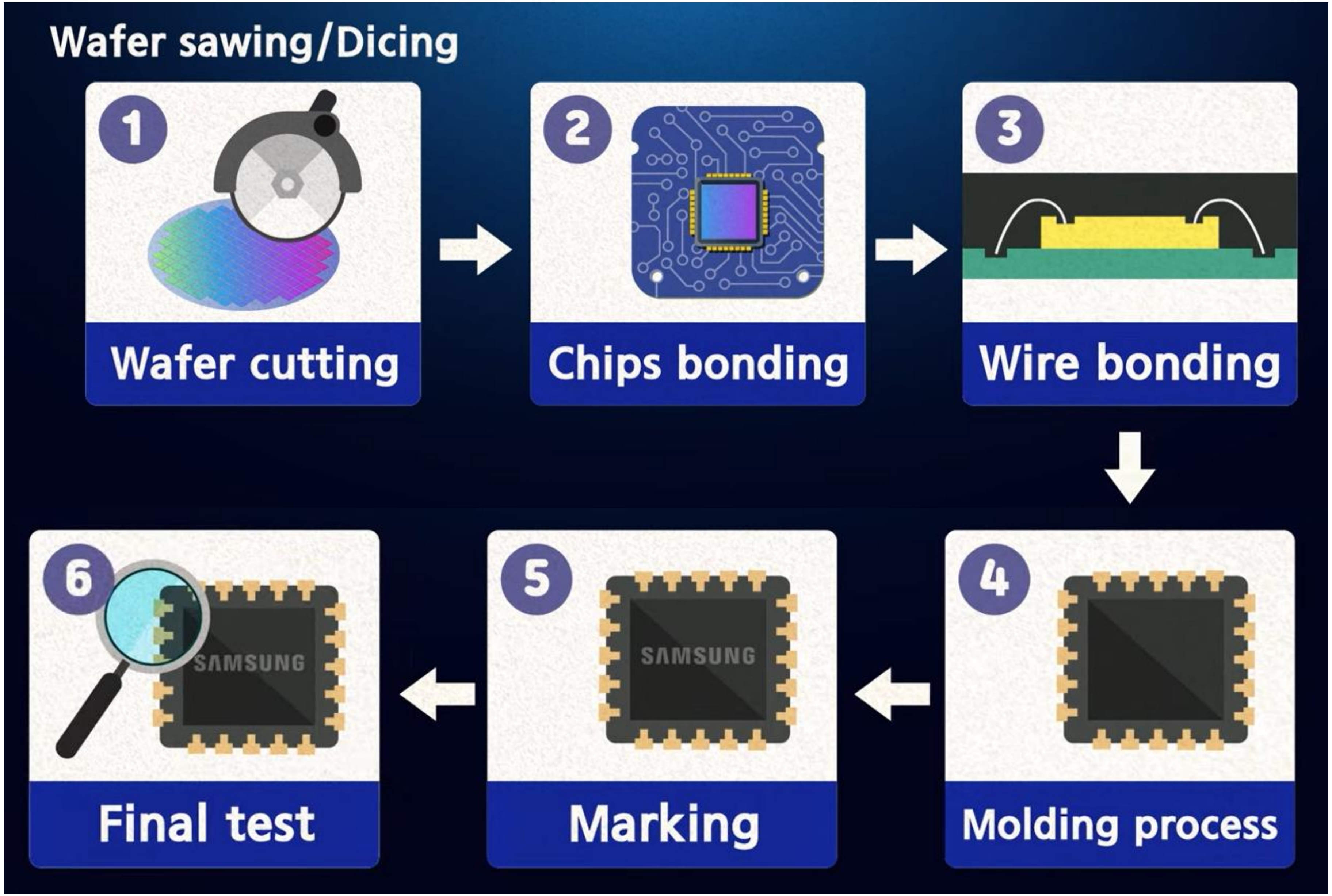
The main goal of the test is to check whether the quality of the semiconductor chip meets a certain standard, thereby eliminating the defective products and improving the reliability of the chip.

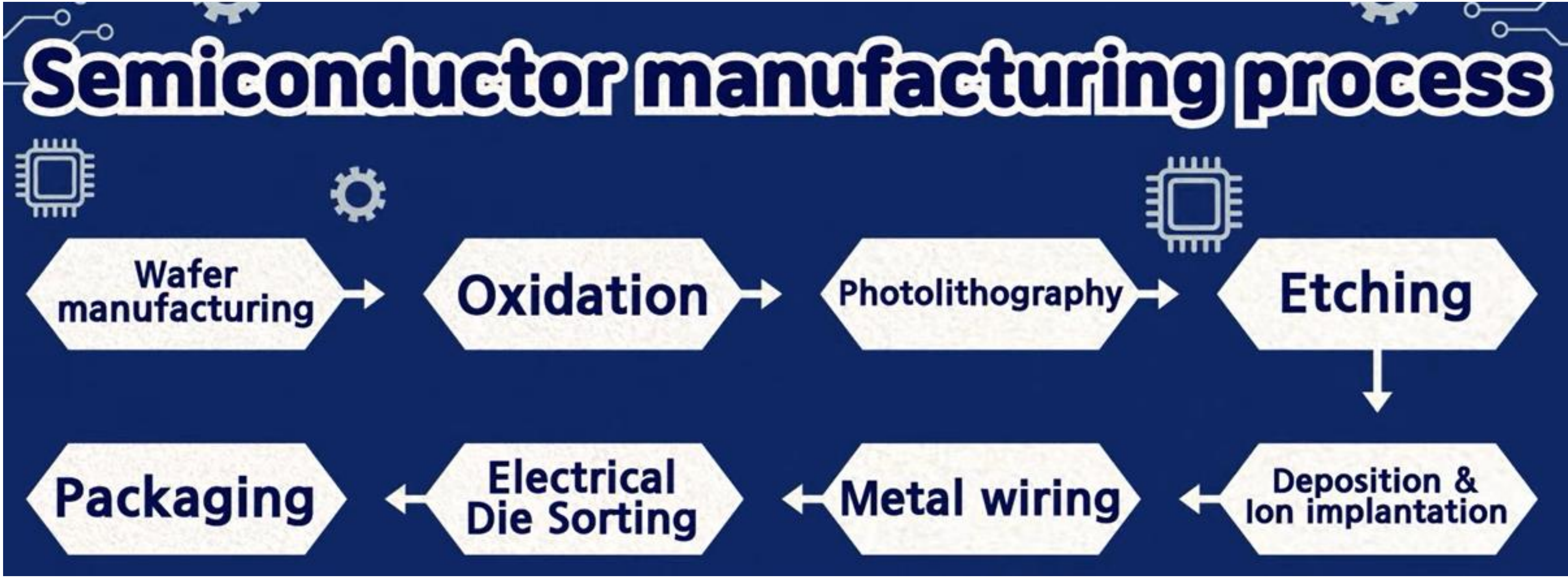


Step 7. Electronic Die sorting (EDS)

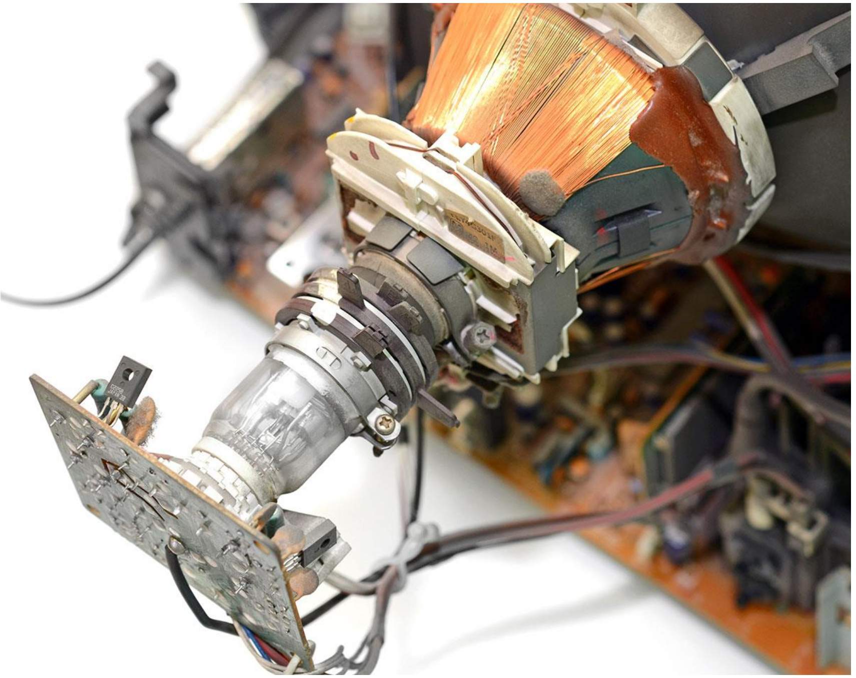


Step 8. Packing



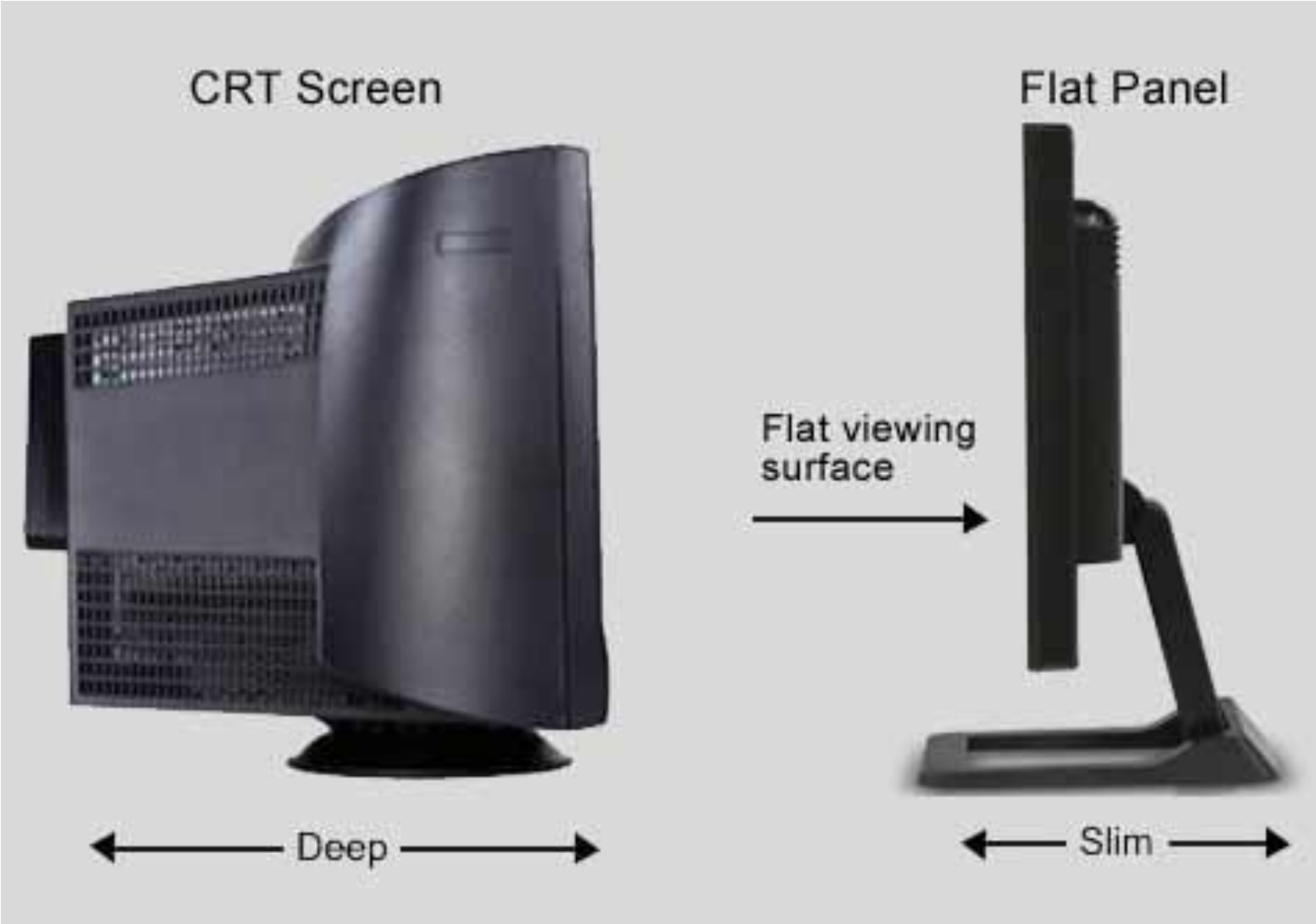

Semiconductor manufacturing process
Wafer manufacturing
Oxidation
Photolithography
Etching
Deposition & Ion implantation
Metal wiring
Electrical Die Sorting
Packaging

Materials for Display and Memory



Cathode Ray Tubes (CRT): A cathode-ray tube is a vacuum tube containing one or more electron guns, which emit electron beams that are manipulated to display images on a phosphorescent screen.

. CRT draws more power than LCD and are also bigger and heavier


CRT Screen
Flat Panel
Flat viewing surface
Deep
Slim

Unit-III- Materials for display technology

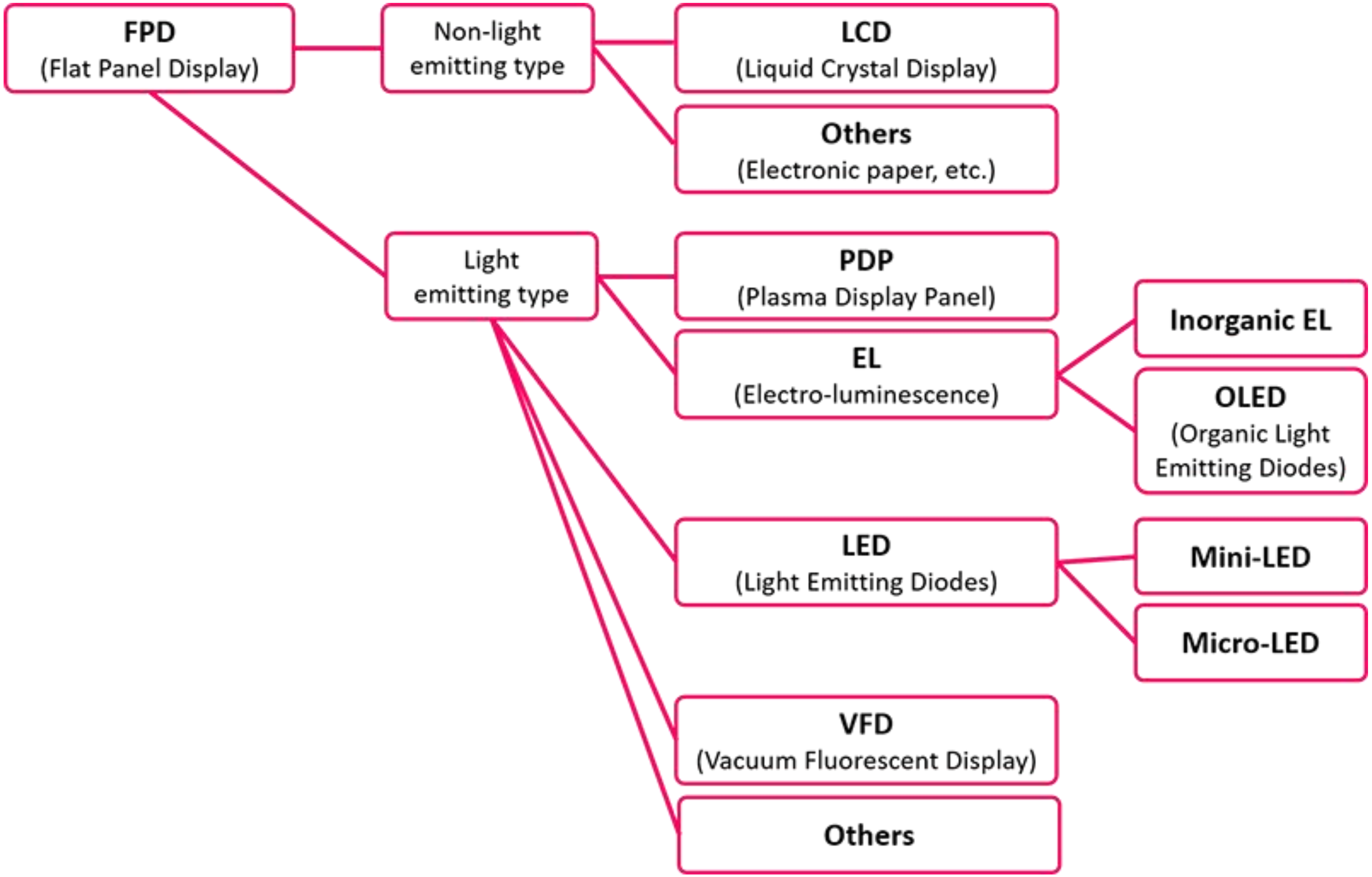

World's 1st
240Hz OLED
OLED
Provided by Samsung
SAMSUNG DISPLAY


Face not recognised. Touch twice to try again.
Google • now
2433
1:37
Wed, 23 Jan


05:17 AM
Mon May 17
MAY 2021

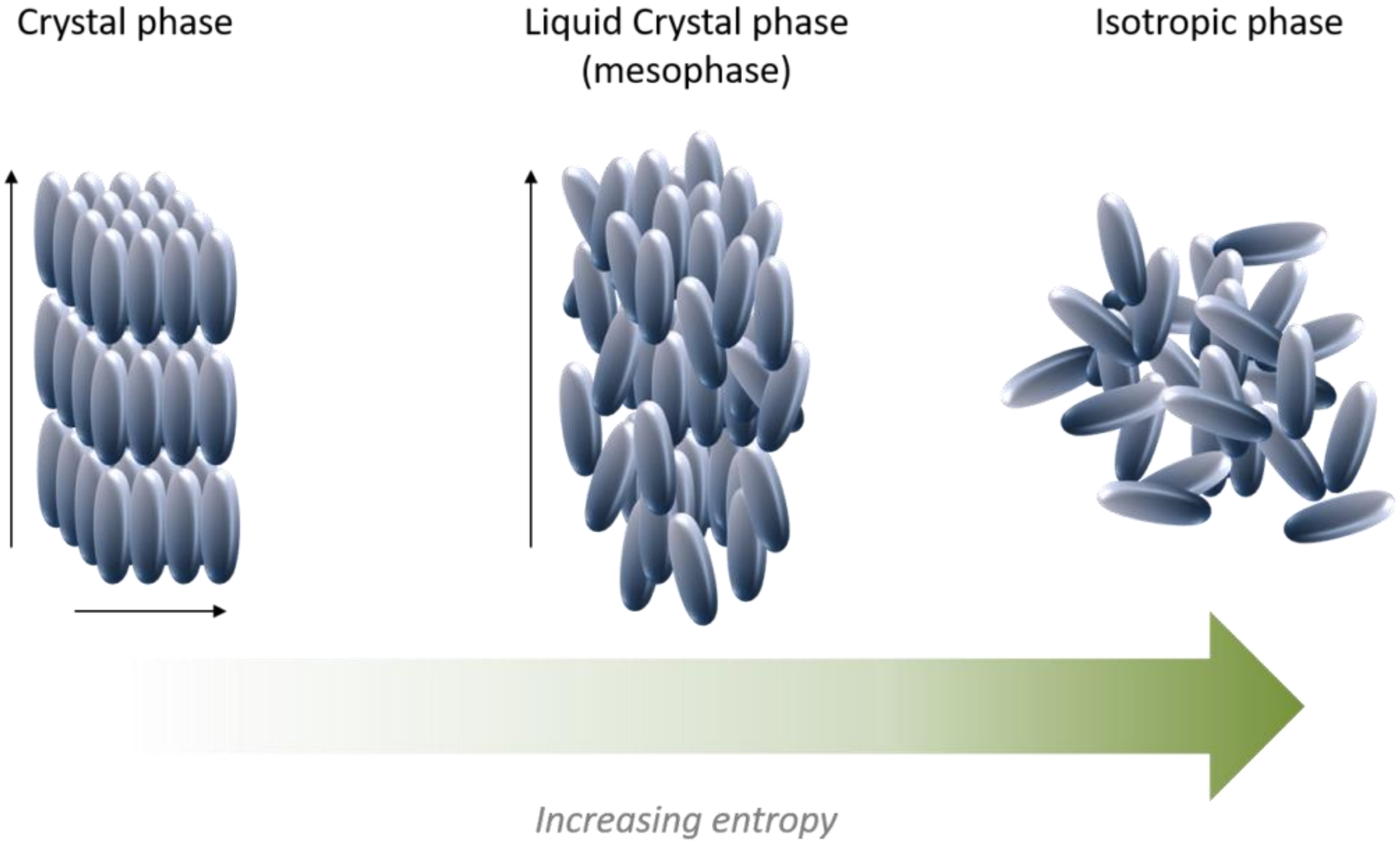

ANDROIDLEO.COM


04:37
ANDROIDLED.COM
3 AUG
SAMSUNG
FLEX
ANDROIDLED.COM


FPD
(Flat Panel Display)
Non-light emitting type
LCD
(Liquid Crystal Display)
Others
(Electronic paper, etc.)
Light emitting type
PDP
(Plasma Display Panel)
EL
(Electro-luminescence)
Inorganic EL
OLED
(Organic Light Emitting Diodes)
LED
(Light Emitting Diodes)
Mini-LED
Micro-LED
VFD
(Vacuum Fluorescent Display)
Others

Liquid Crystals for LCDs

Liquid crystals are state of matter which has properties between those of conventional liquids and those of solid crystals.

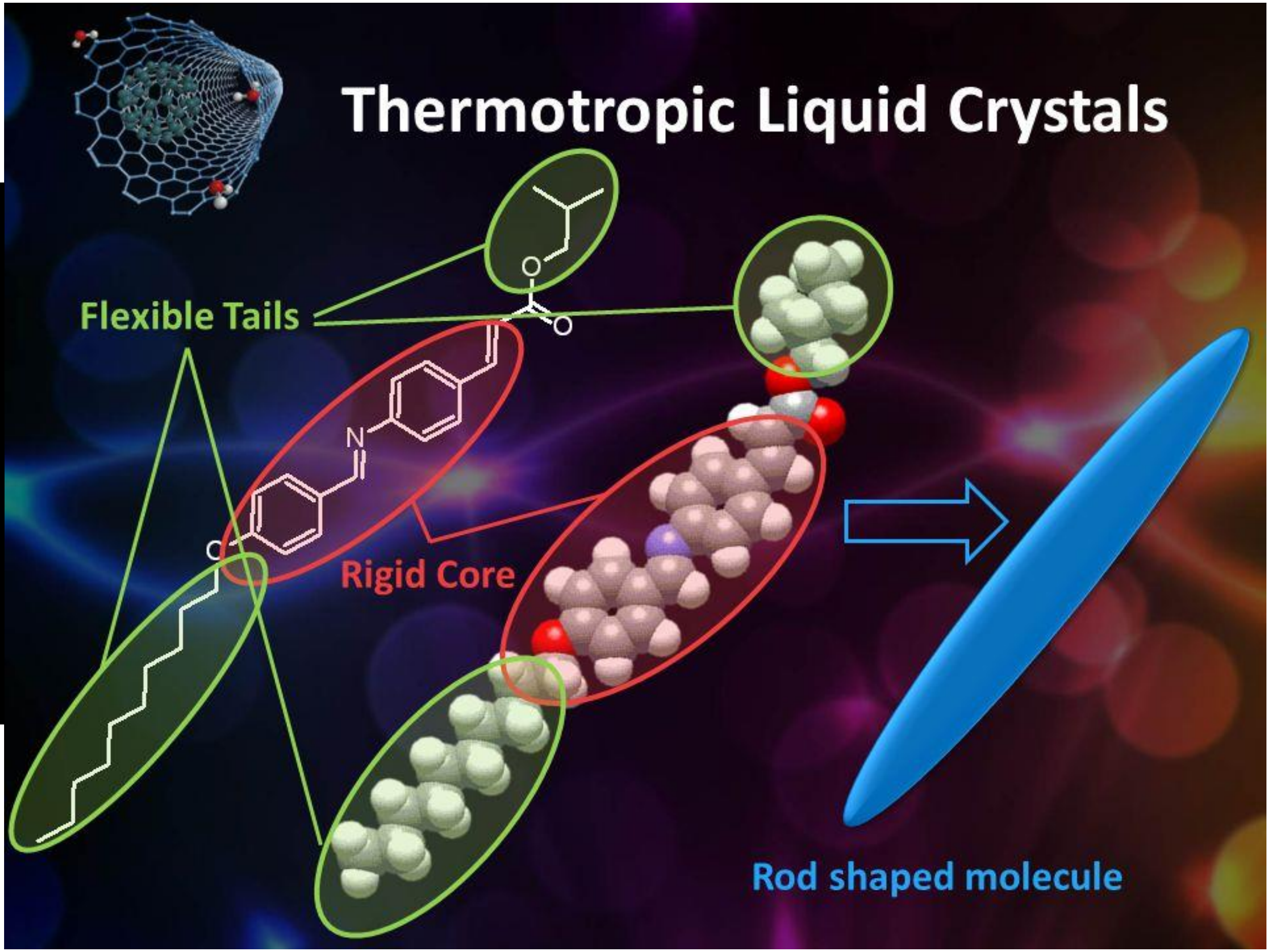


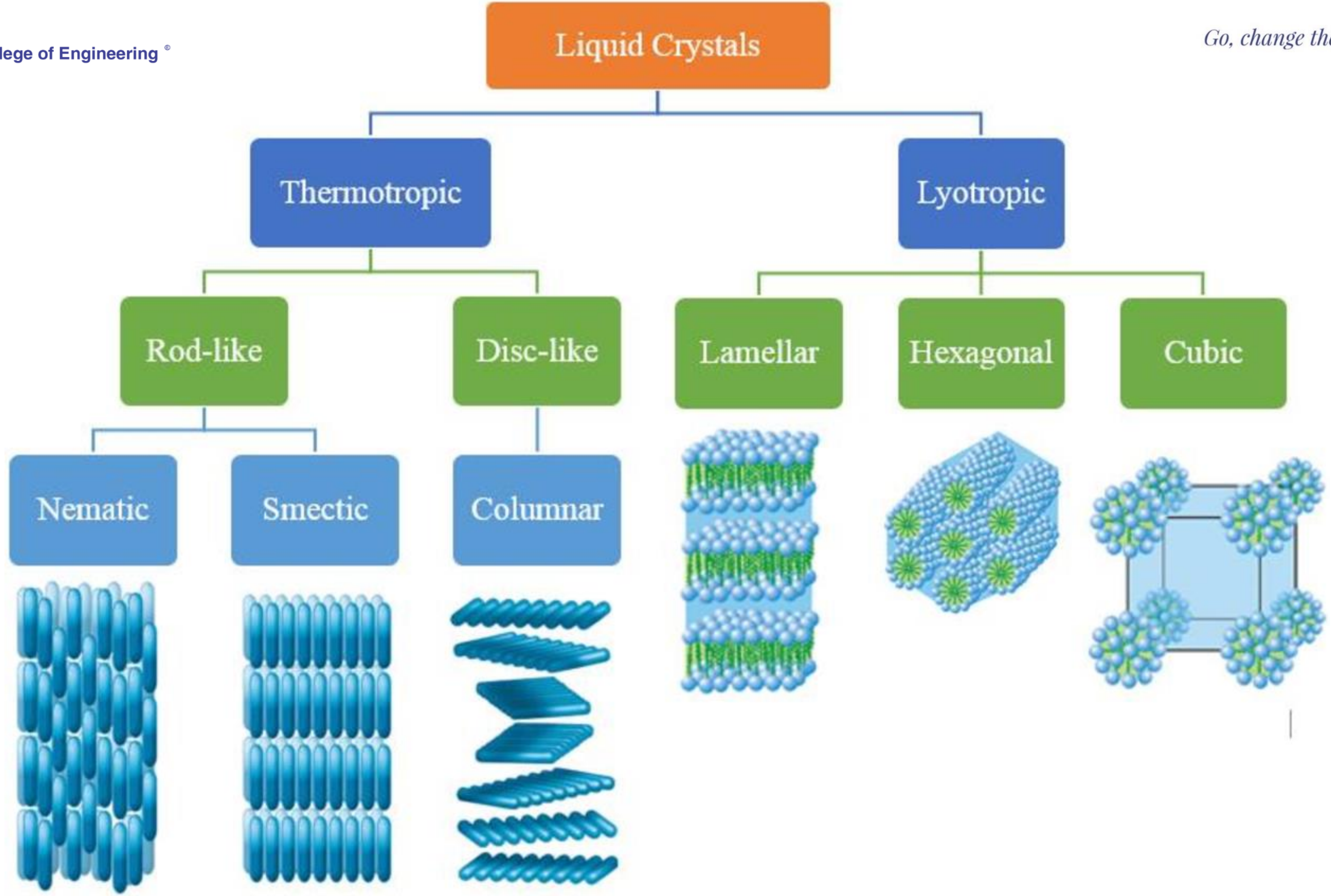
Thermotropic

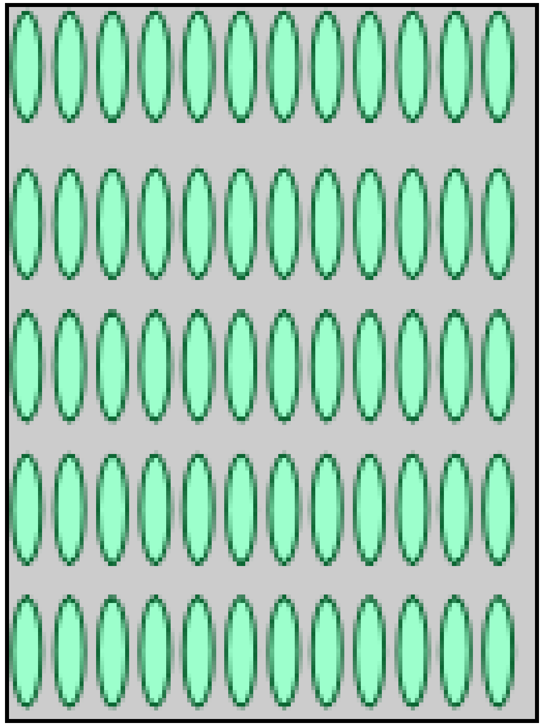
- Phase transition depends on temperature
  - Nematic
  - Smectic
  - Cholesteric

Lyotropic

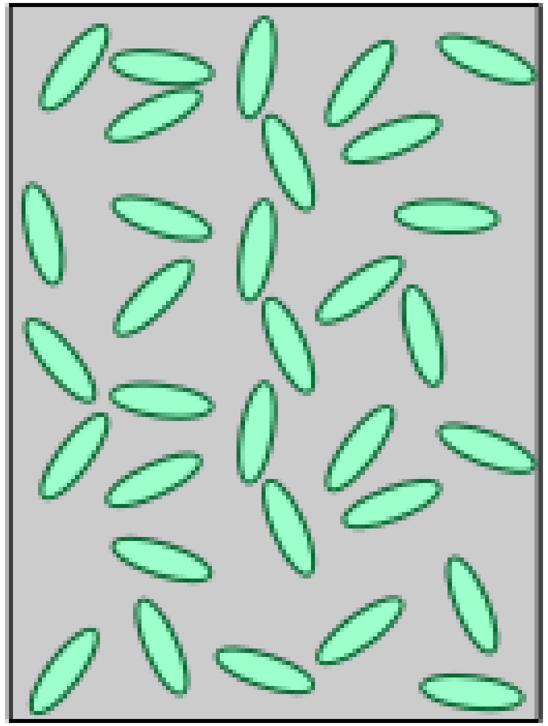
- Phase transition depends on temperature & concentration



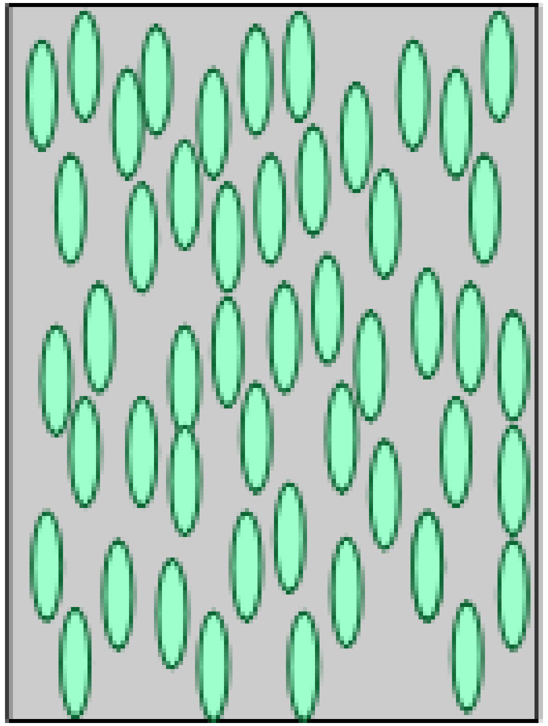

Liquid Crystals
Thermotropic
Lyotropic
Rod-like
Disc-like
Lamellar
Hexagonal
Cubic
Nematic
Smectic
Columnar



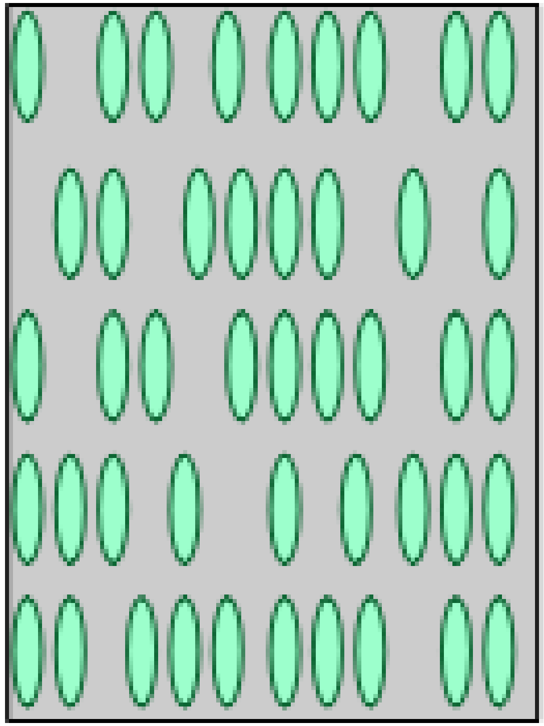
Solid phase: orientation and periodicity



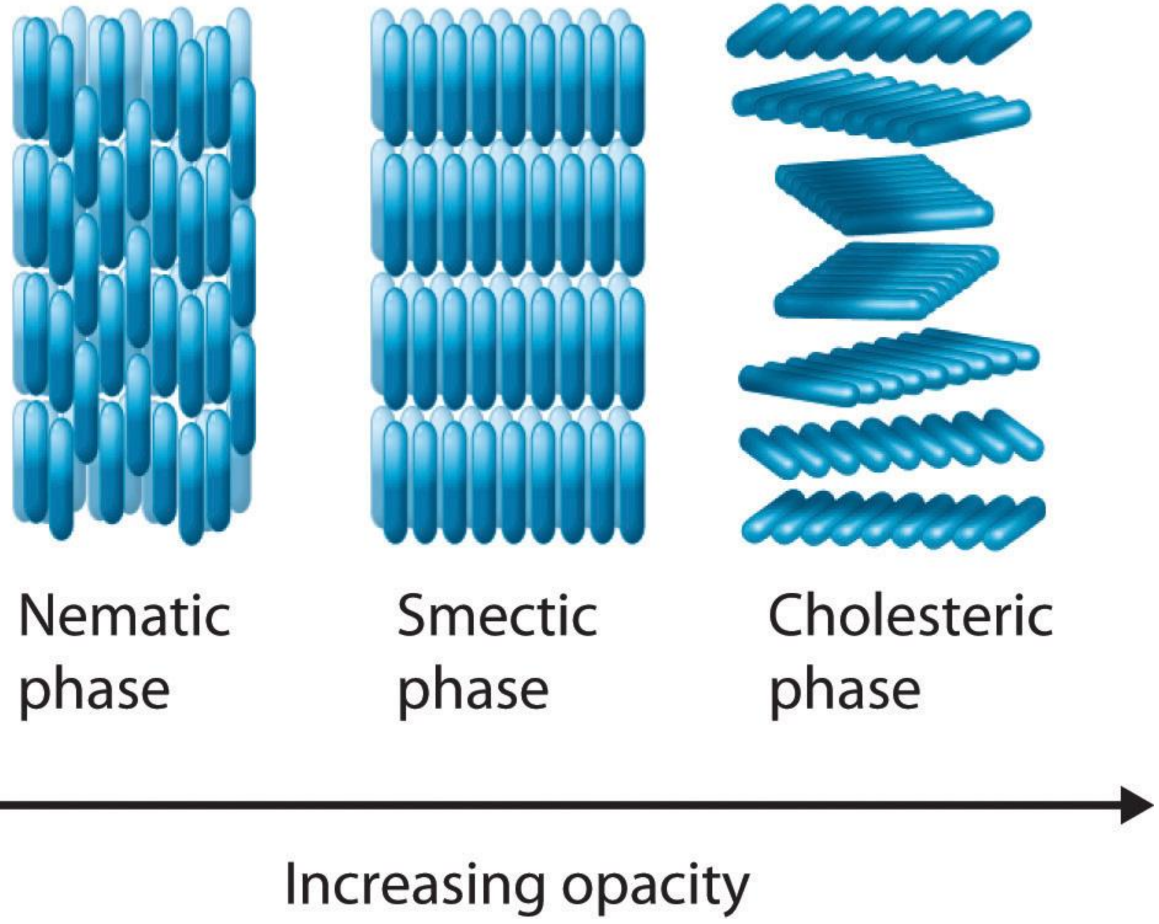
Liquid phase: no orientation or periodicity

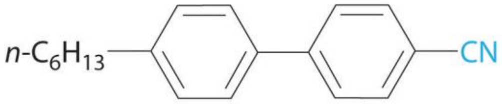
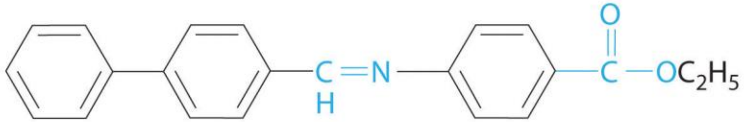
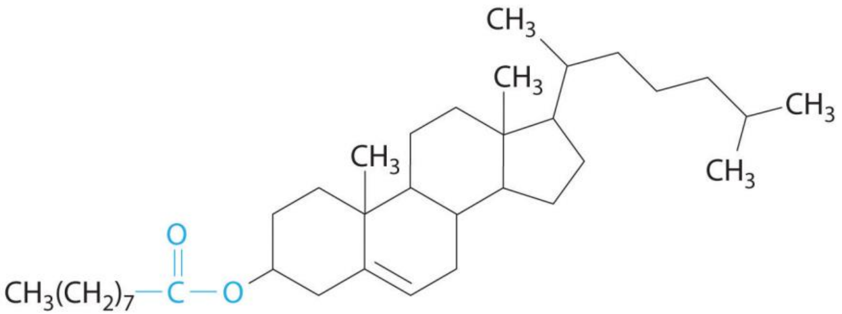


Nematic phase: orientation, no periodicity



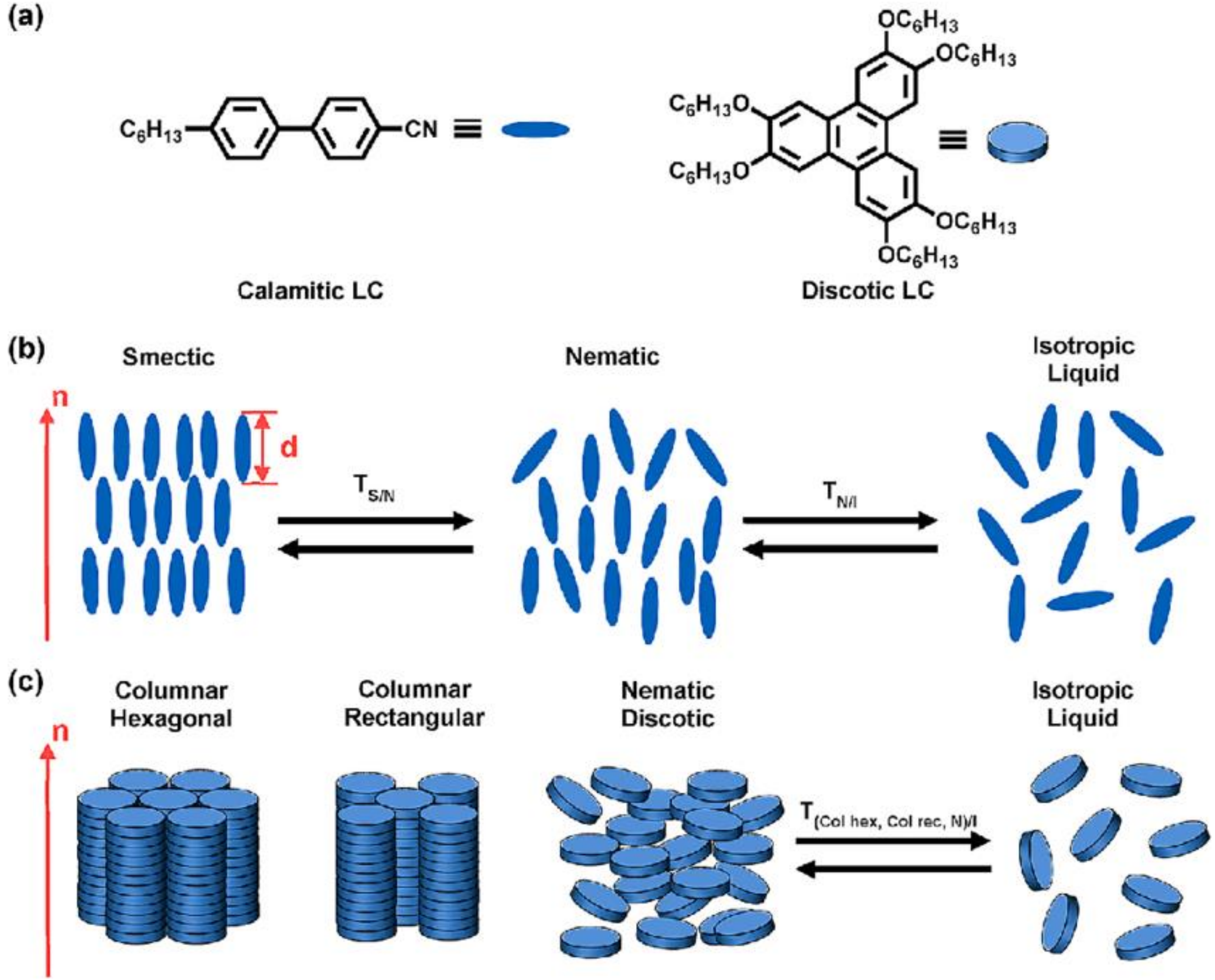
Smectic phase: orientation with some periodicity



Structure	Liquid Crystal Phase	Liquid Crystalline Temperature Range (°C)
	Nematic	14–28
	Smectic	121–131
	Cholesteric	78–90

Metallotropic liquid crystals

The addition of long chain soap-like molecules leads to a series of new phases that show a variety of liquid crystalline behavior both as a function of the inorganic-organic composition ratio and of temperature. This class of materials has been named metallotropic.

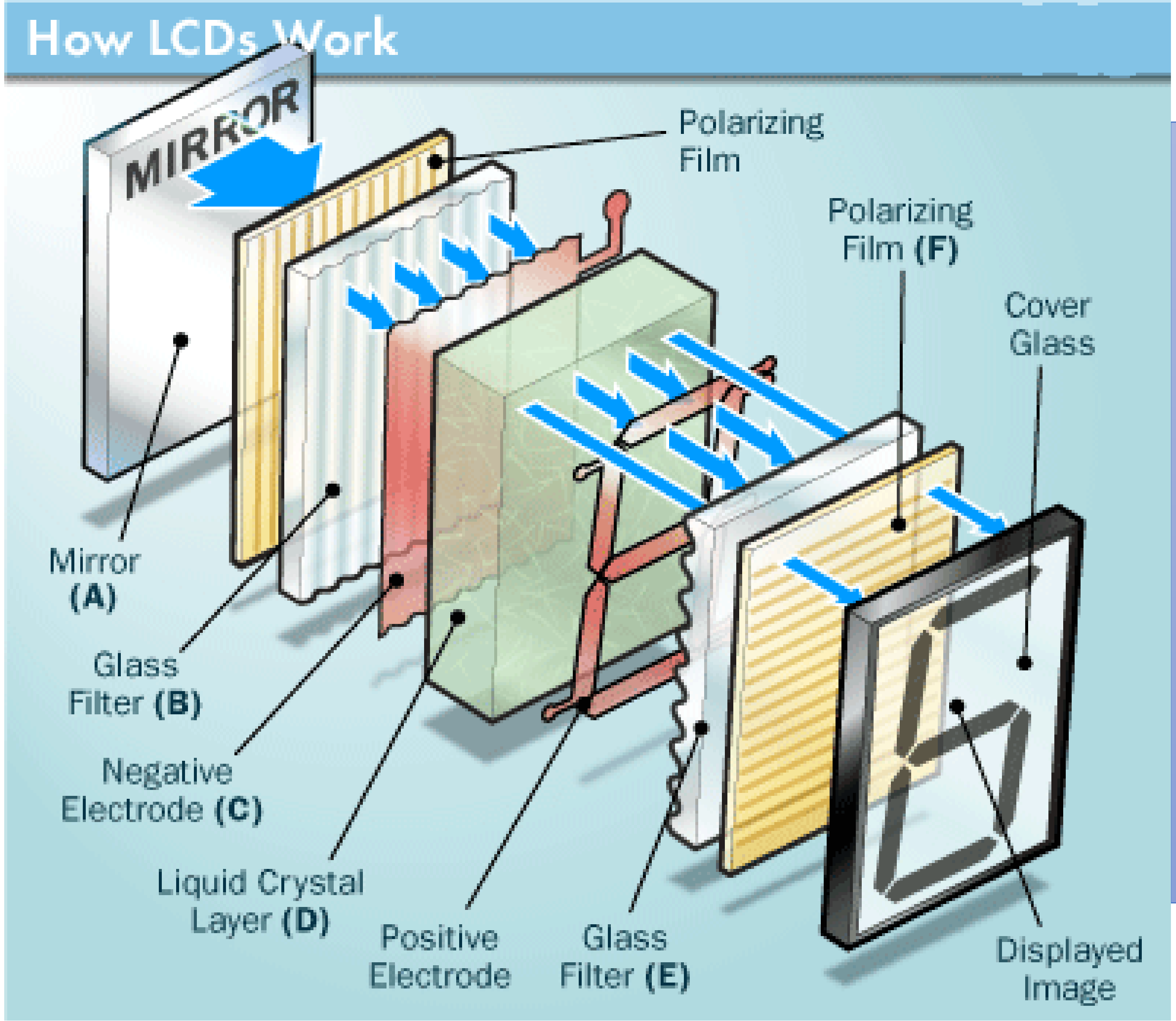


How these liquid crystals are used to obtain images in LCDs ??

Let us understand..!!

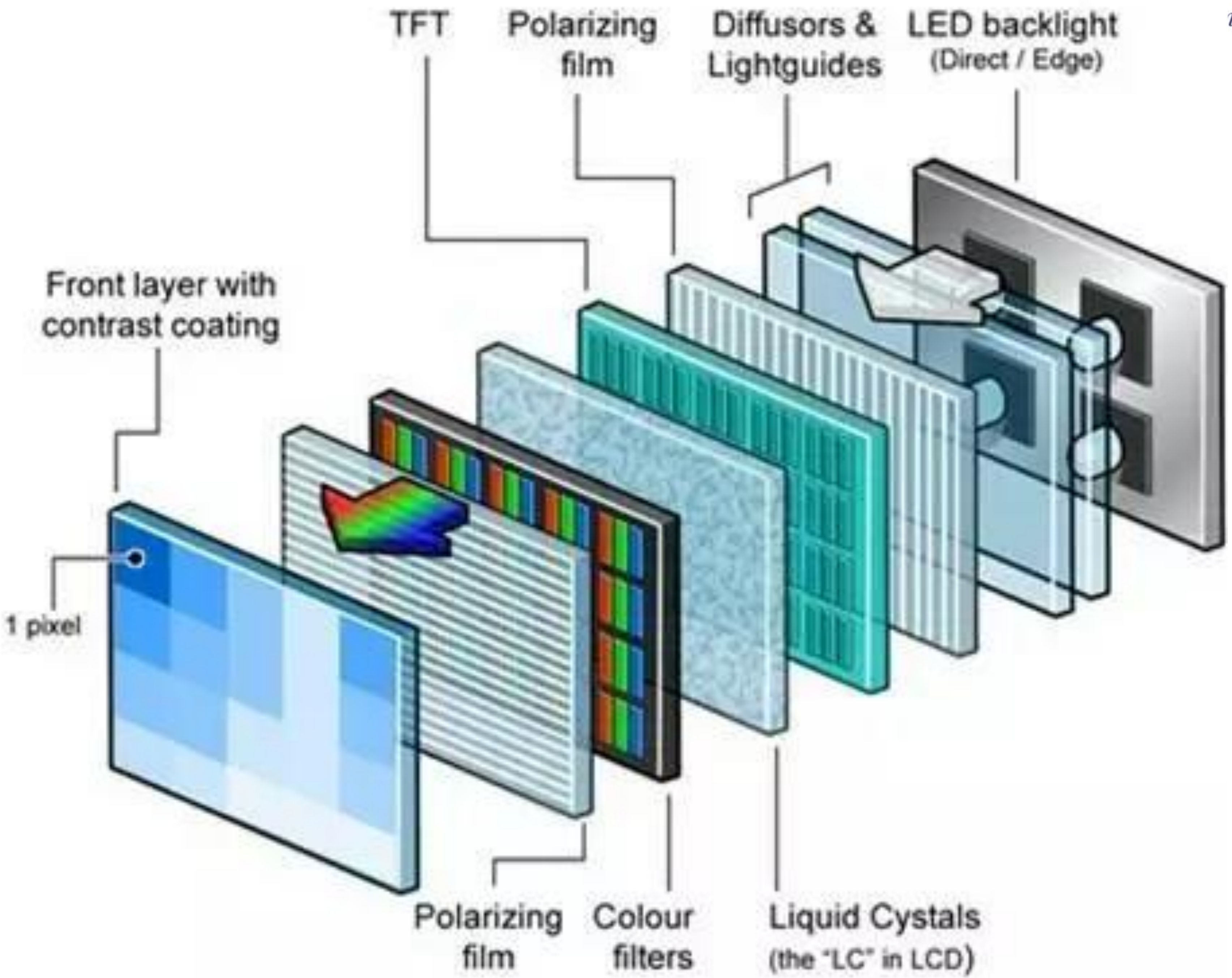
Liquid Crystal Display Devices

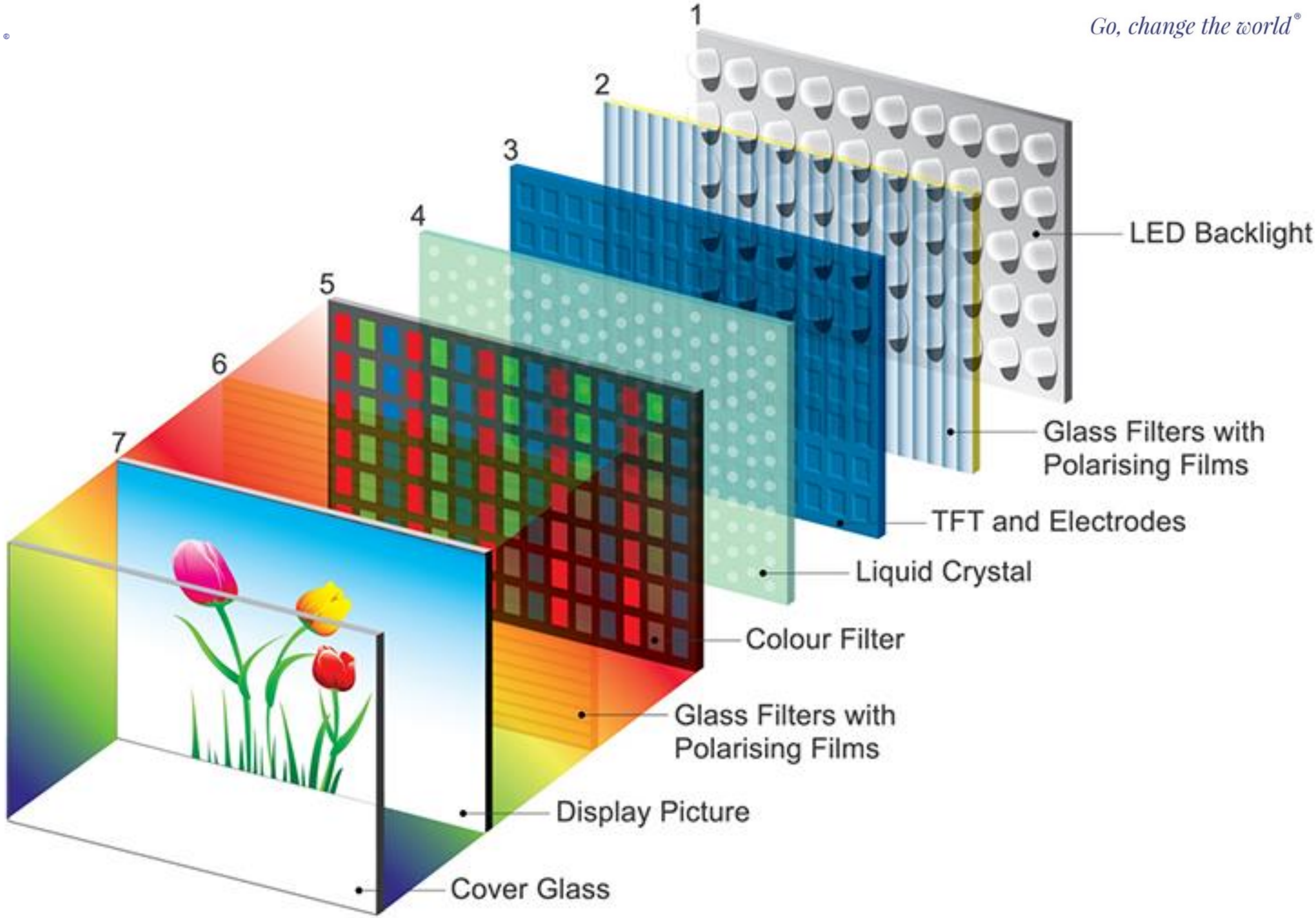
Go, change the world



Components

1) Light Source and Mirror (A)
2) Vertical Polarizer
3) Glass Filter (B)
4) Negative Electrode (C)
5) Liquid Crystal Layer (D)
6) Positive Electrode
7) Glass Filter (E)
8) Horizontal Polarizer
9) Cover Glass to display final image


TFT
Polarizing film
Diffusors & Lightguides
LED backlight (Direct / Edge)
Front layer with contrast coating
1 pixel
Polarizing film
Colour filters
Liquid Cystals (the "LC" in LCD)

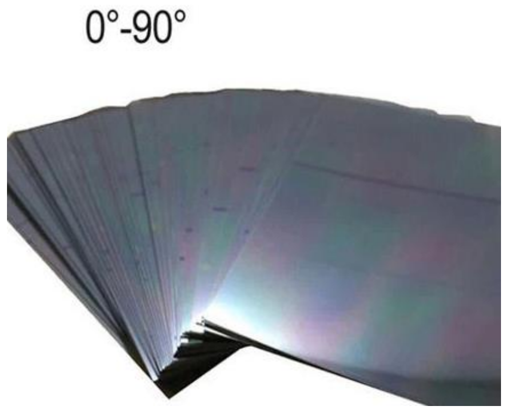

1
2
3
4
5
6
7
LED Backlight
Glass Filters with Polarising Films
TFT and Electrodes
Liquid Crystal
Colour Filter
Glass Filters with Polarising Films
Display Picture
Cover Glass

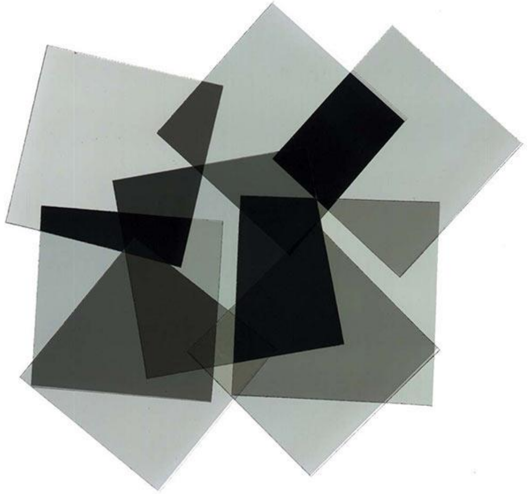
Role of each Components of Liquid Crystal Display Devices

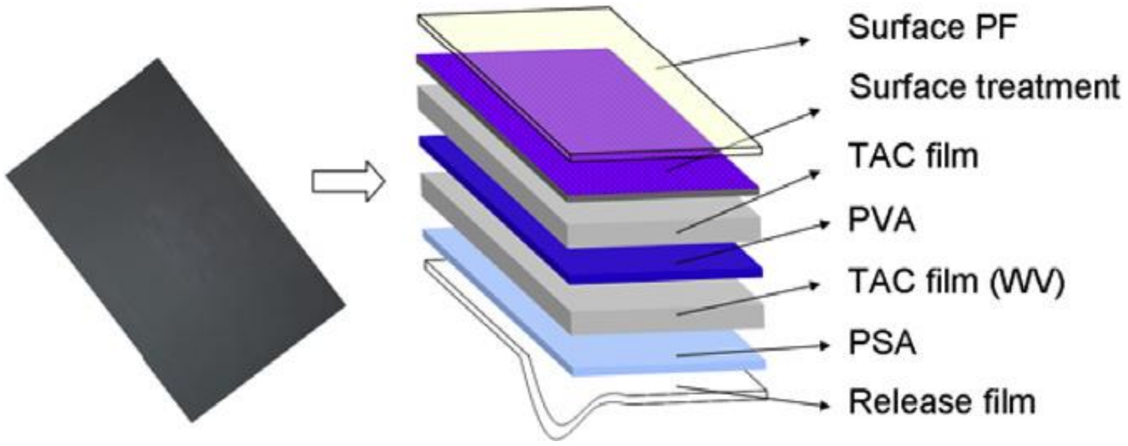
1. **Light Source and Mirror (A)** : Liquid crystals don't emit their own light, therefore for illumination a backlight is used along with reflective mirror. Ex: Light sources for backlights such as cold cathode fluorescent lamps (CCFLs), external electrode fluorescent lamps (EEFLs), hot-cathode fluores- cent lamps (HCFLs), flat fluorescent lamps (FFLs), and light-emitting diodes (LEDs) are used.

2. **Polarizer (A)** : which can control the polarization direction of a specific beam. When the natural light passes through the polarizer, the light whose vibration direction is perpendicular to the passing axis of the polarizer will be absorbed. Only the polarized light whose vibration direction is parallel to the passing axis of the polarizer will be absorbed.

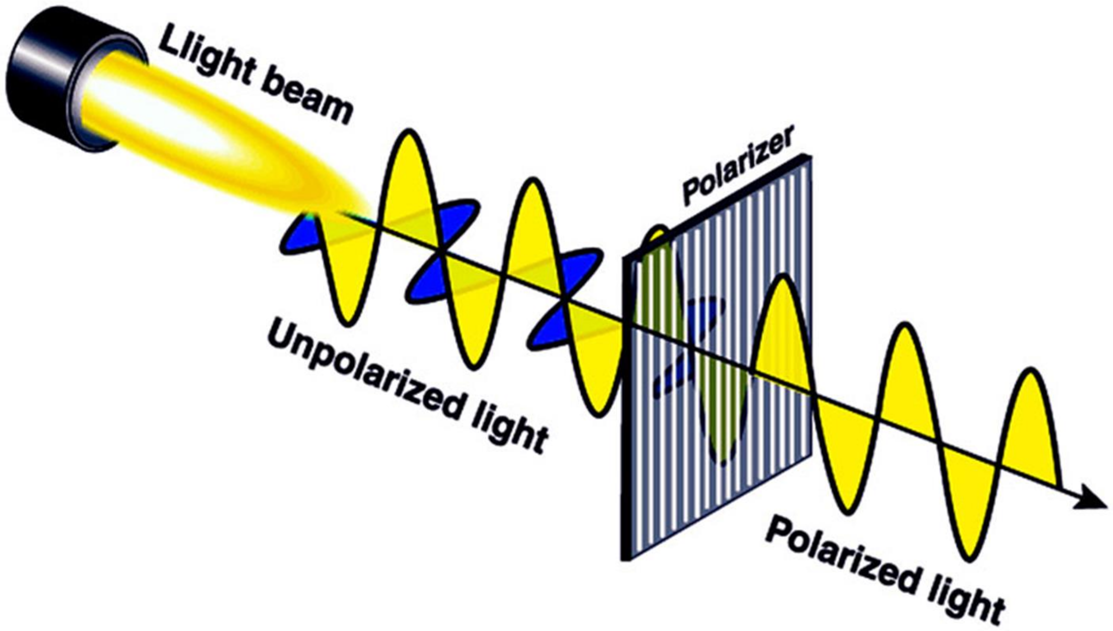
Note: Polarizers accounts about 20%-30% of LCD display manufacturing cost





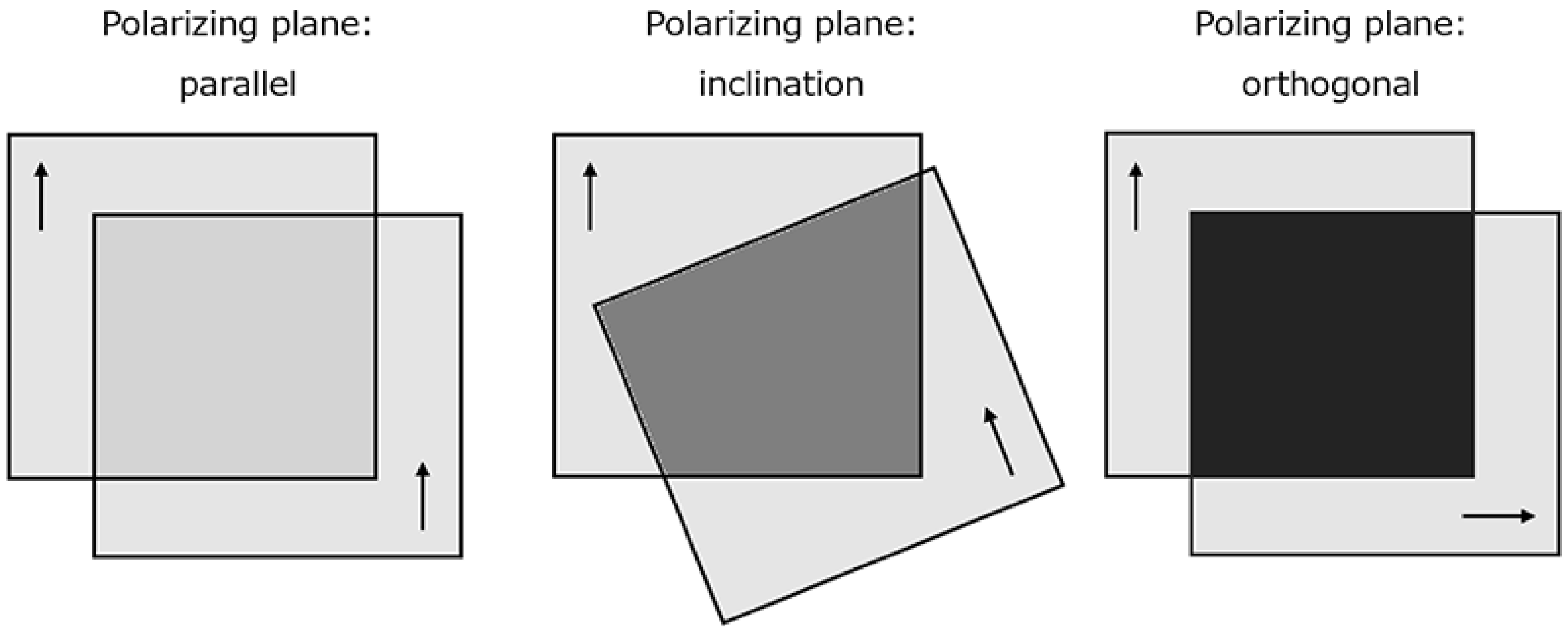


PVA + TAC + PSA Film+ Release Film



Polarizer: It is made of PVA (polyvinyl alcohol) film after dyeing and stretching using **Tri-acetyl cellulose (TAC) films (protective films) and** Pressure sensitive adhesive (*PSA*) , *polyester film* for a release film

Control of Screen Brightness by Using Polarizers

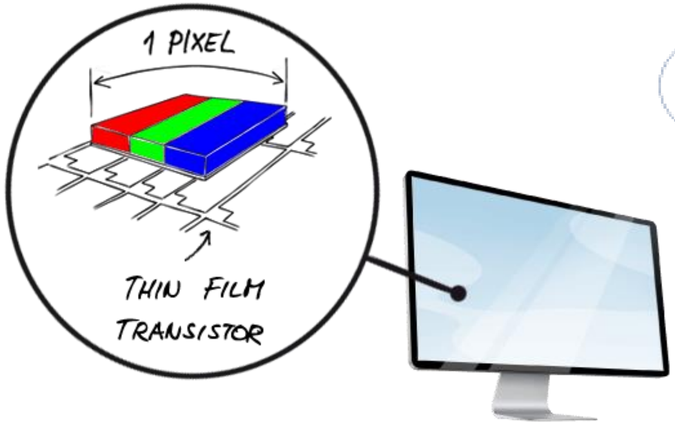


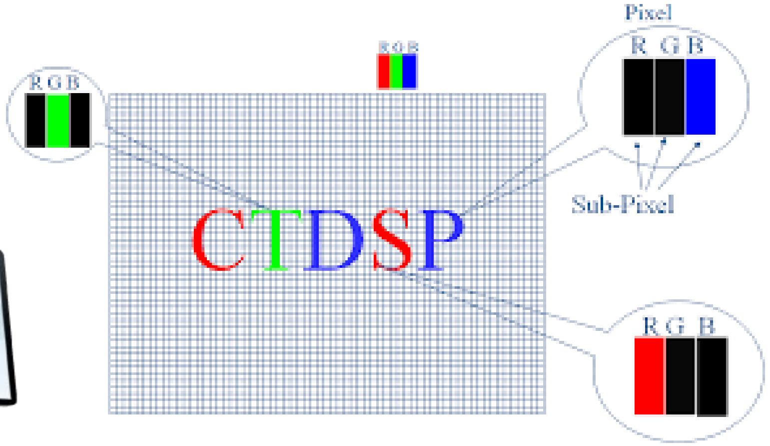
https://www.toyo-visual.com/en/products/fpdcf/fpd.html

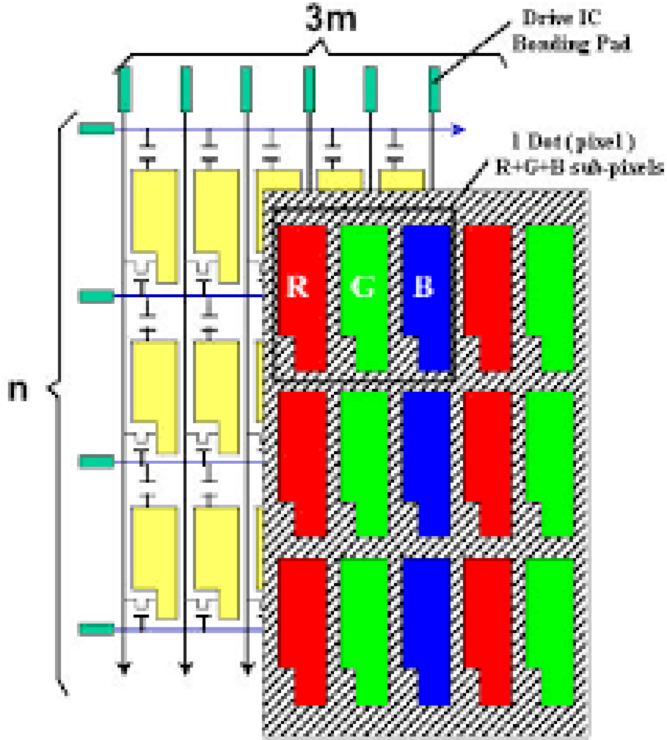
3. **Glass Filter**: UV blocking glass *acts as a mirror to ultraviolet radiation and helps preserve the performance, visibility and clarity of an LCD display : Polycarbonate based glass is used*

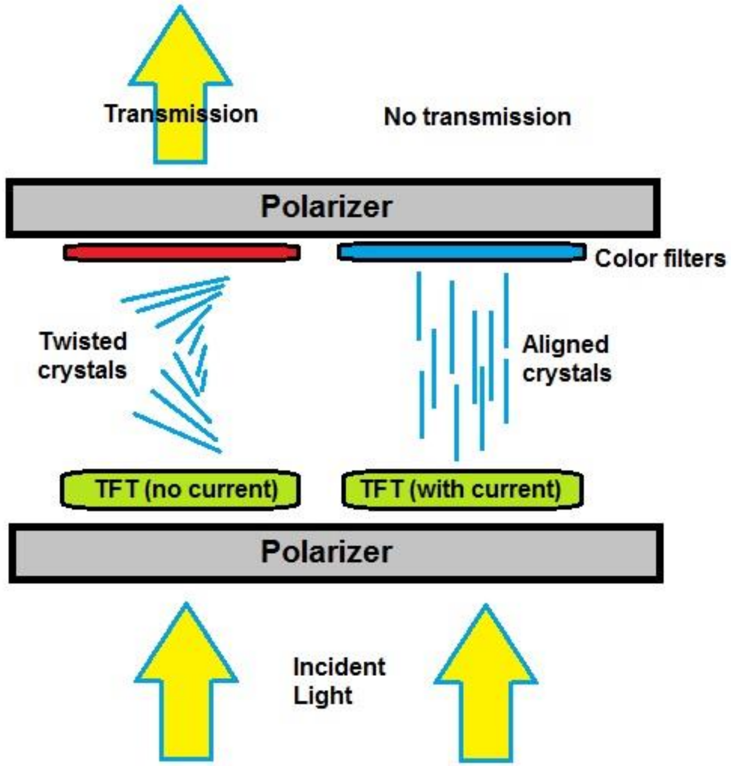
4. **Electrodes + TFT :** Electrodes are the controlling factors of the liquid crystal behavior, and thus also the light behavior.
Thin-film transistors (*TFTs*) is attached to the *electrodes* in contact with the LC layer.
A TFT is a kind of semiconductor device. It **serves as a control valve to provide an appropriate voltage onto liquid crystals for individual sub-pixels.**
The transistors in a TFT LCD enable the active maintenance of the signal within a pixel without interference with neighboring pixels, Each pixel is a small capacitor with a layer of insulating liquid crystal sandwiched between transparent conductive indium tin oxide ITO layers.

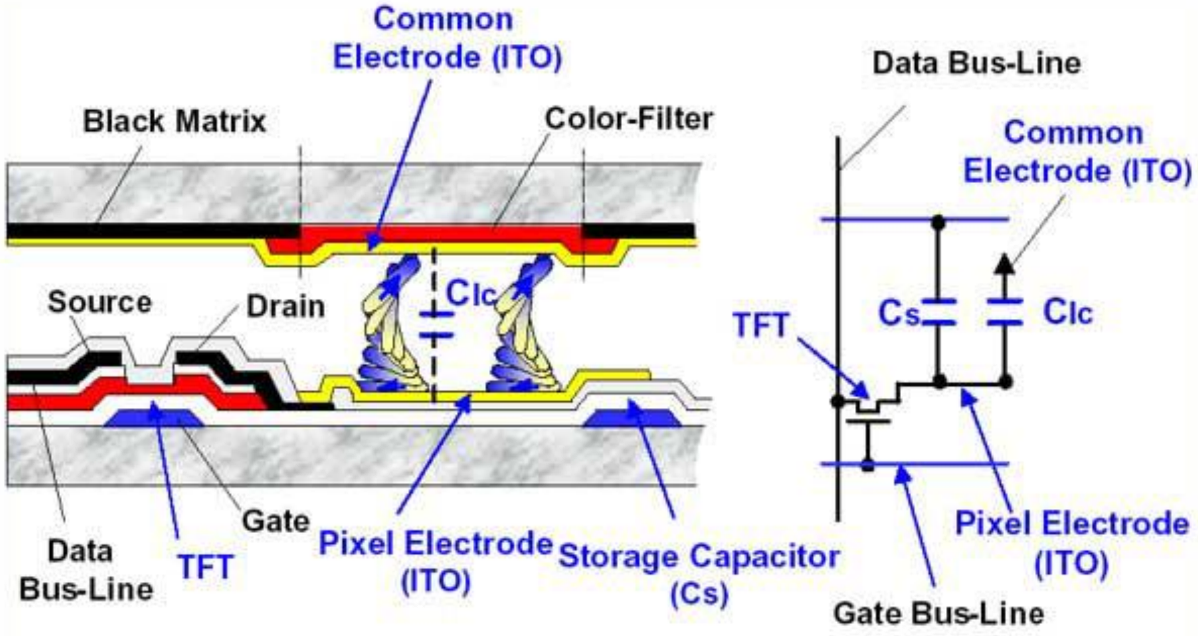
- TFT is an abbreviation for "Thin Film Transistor".
- A TFT is a kind of semiconductor device. It serves as a control valve to provide an appropriate voltage onto liquid crystals for individual sub-pixels.
- **An LCD consists of many pixels.** A pixel consists of three sub-pixels (Red/Green/Blue, RGB).
- 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 basically made up of layers of thin films and act as a switch to control the flow of electric current required to turn ON/OFF the pixel. Thin film transistor (TFT) is also responsible to alter the brightness and colours of a pixel by regulating the flow of current.


1 PIXEL
THIN FILM
TRANSISTOR

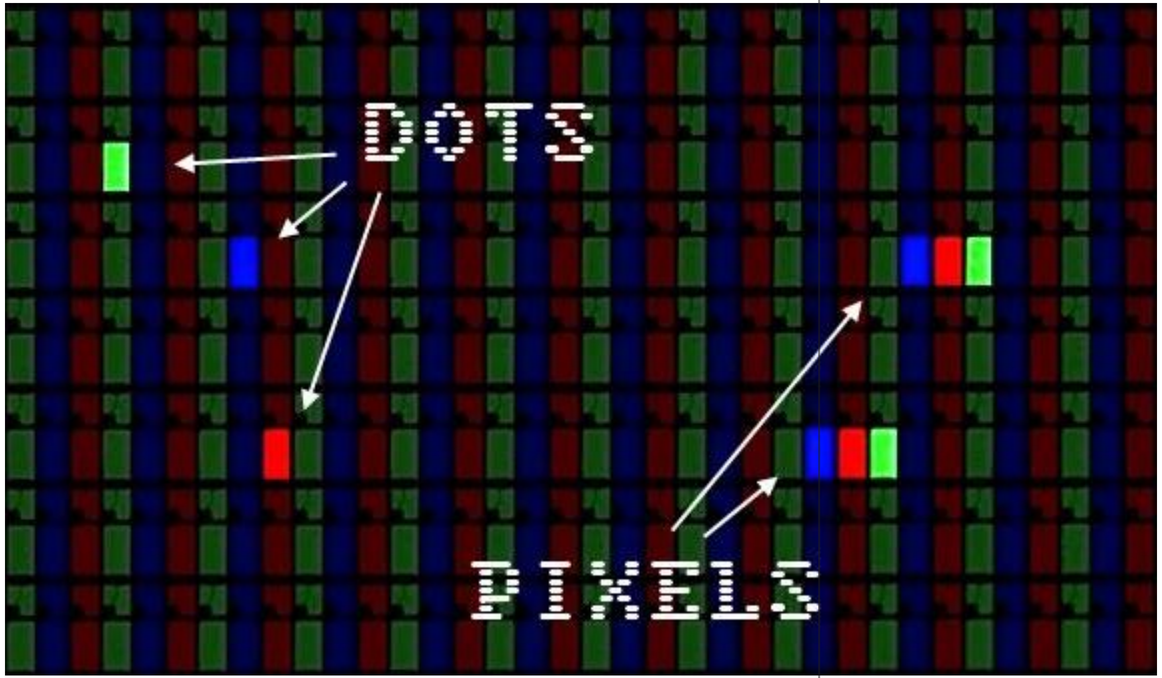

RGB
RGB
Pixel
R G B
Sub-Pixel
CTDSP
R G B

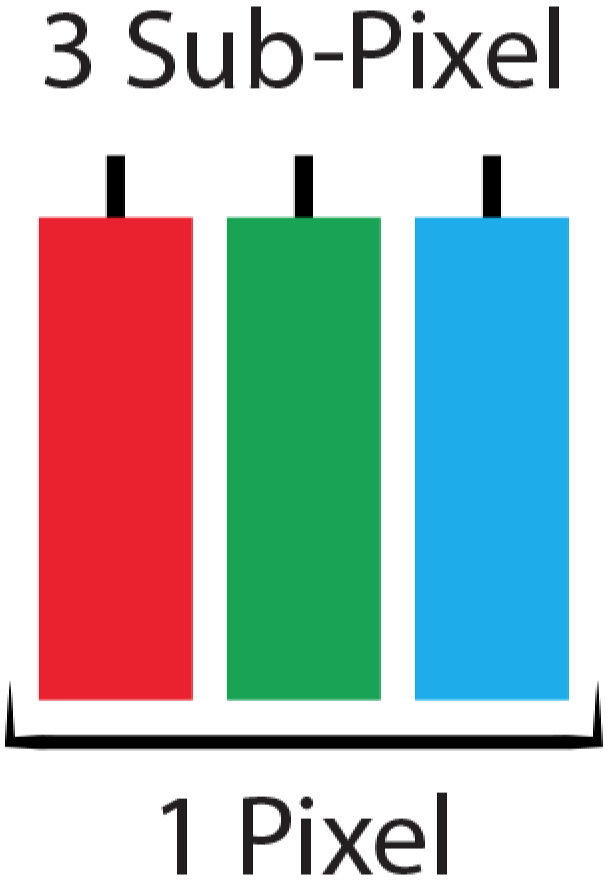

3m
Drive IC
Bonding Pad
1 Dot (pixel)
R+G+B sub-pixels
n
R
G
B

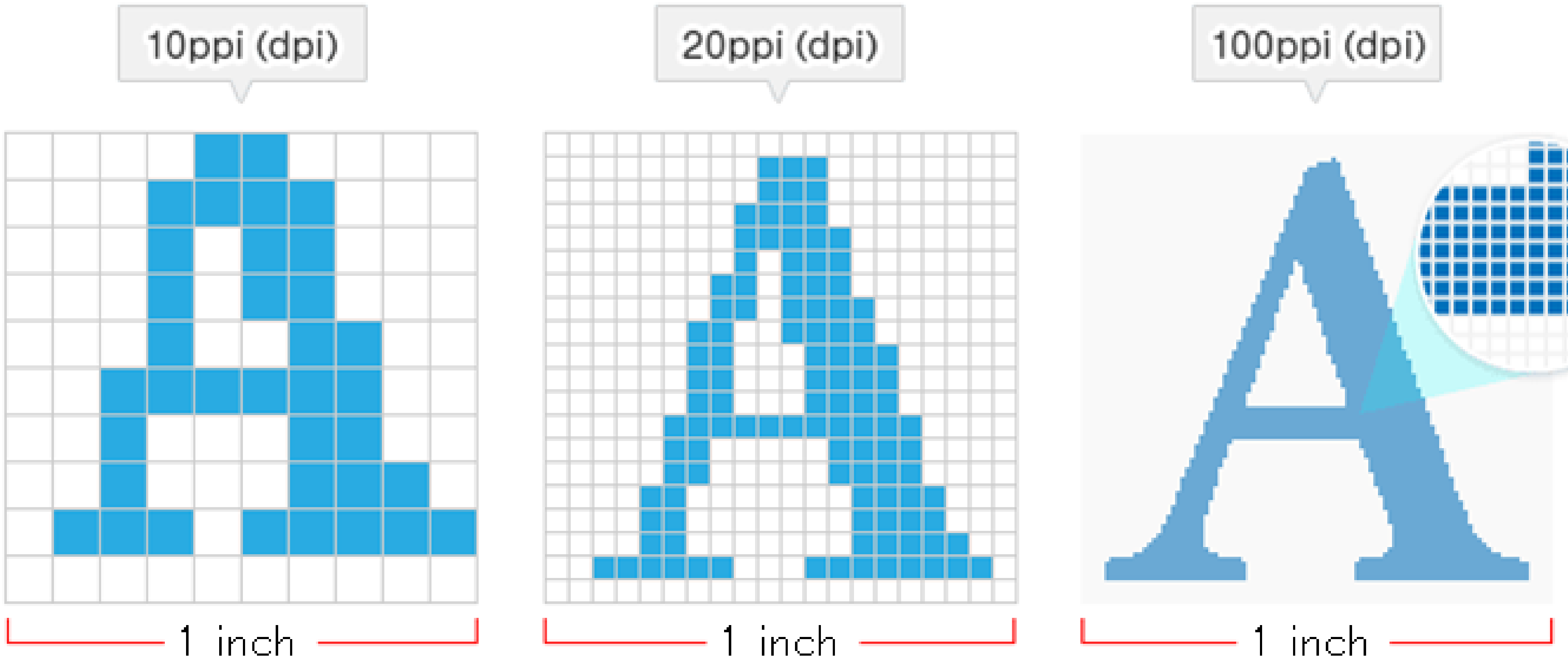

Transmission
No transmission
Polarizer
Color filters
Twisted
crystals
Aligned
crystals
TFT (no current)
TFT (with current)
Polarizer
Incident
Light


Common
Electrode (ITO)
Black Matrix
Color-Filter
Data Bus-Line
Common
Electrode (ITO)
Source
Drain
Clc
TFT
Cs
Clc
Gate
Data
Bus-Line
TFT
Pixel Electrode
(ITO)
Storage Capacitor
(Cs)
Pixel Electrode
(ITO)
Gate Bus-Line

Structure of a pixel







Pixels per inch (PPI) : PI stands for **Dots per Inch**

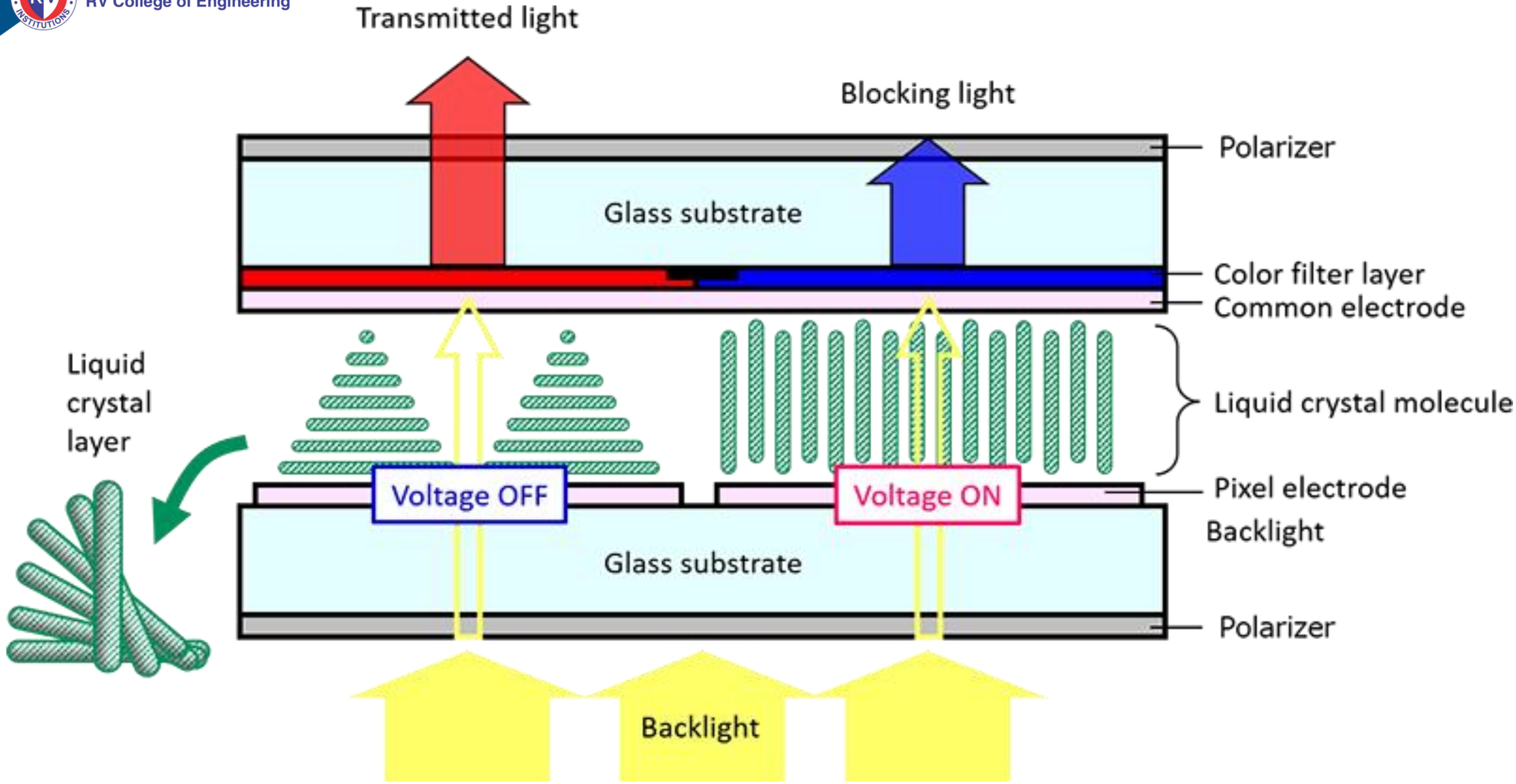
5. **Liquid Crystal layer**: The role of the liquid crystal layer is to act as a "shutter" to control whether light is transmitted or not.

Here, the crucial factor is the control of liquid crystal molecules by applying voltage.

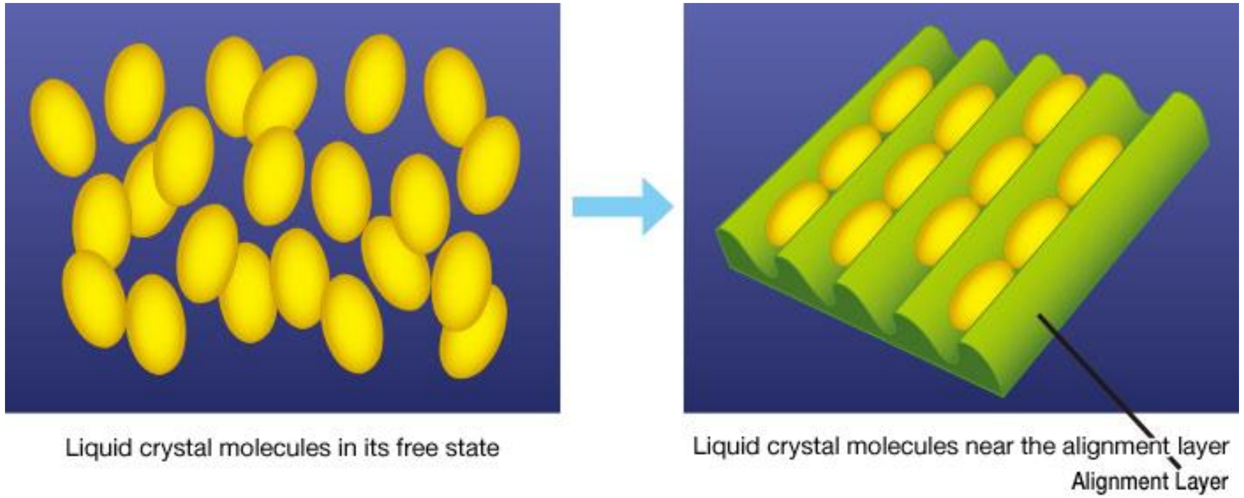
Since liquid crystal molecules line up parallel to the direction of an electric current, when voltage is applied to the liquid crystal molecules, the helical structure induced by the alignment layers dissolve and light cannot pass through the second polarizer.

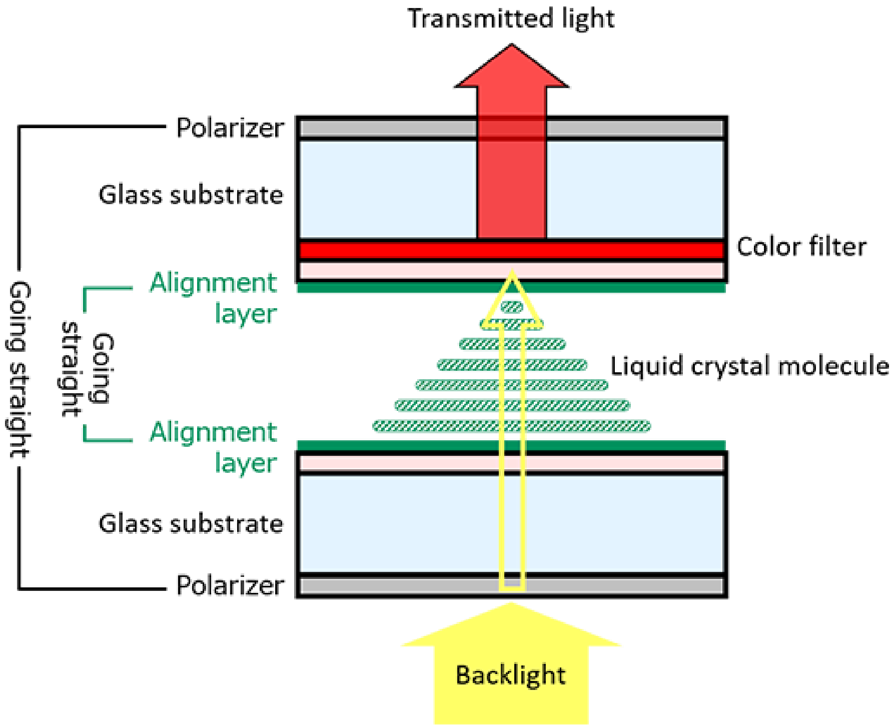
Therefore, when you want light to be transmitted, you just have to turn the voltage off and when you want light to be blocked, you only need to turn the voltage on.

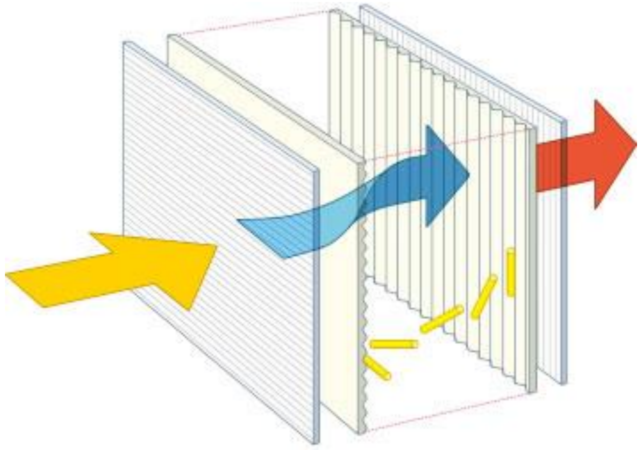
This way it is possible to express light and dark on the screen. Moreover, as we can adjust the helical formation of the molecules by adjusting the voltage, it is also possible to control the contrast density in each subpixel.


Transmitted light
Blocking light
Polarizer
Glass substrate
Color filter layer
Common electrode
Liquid crystal layer
Liquid crystal molecule
Voltage OFF
Voltage ON
Pixel electrode
Backlight
Glass substrate
Polarizer
Backlight

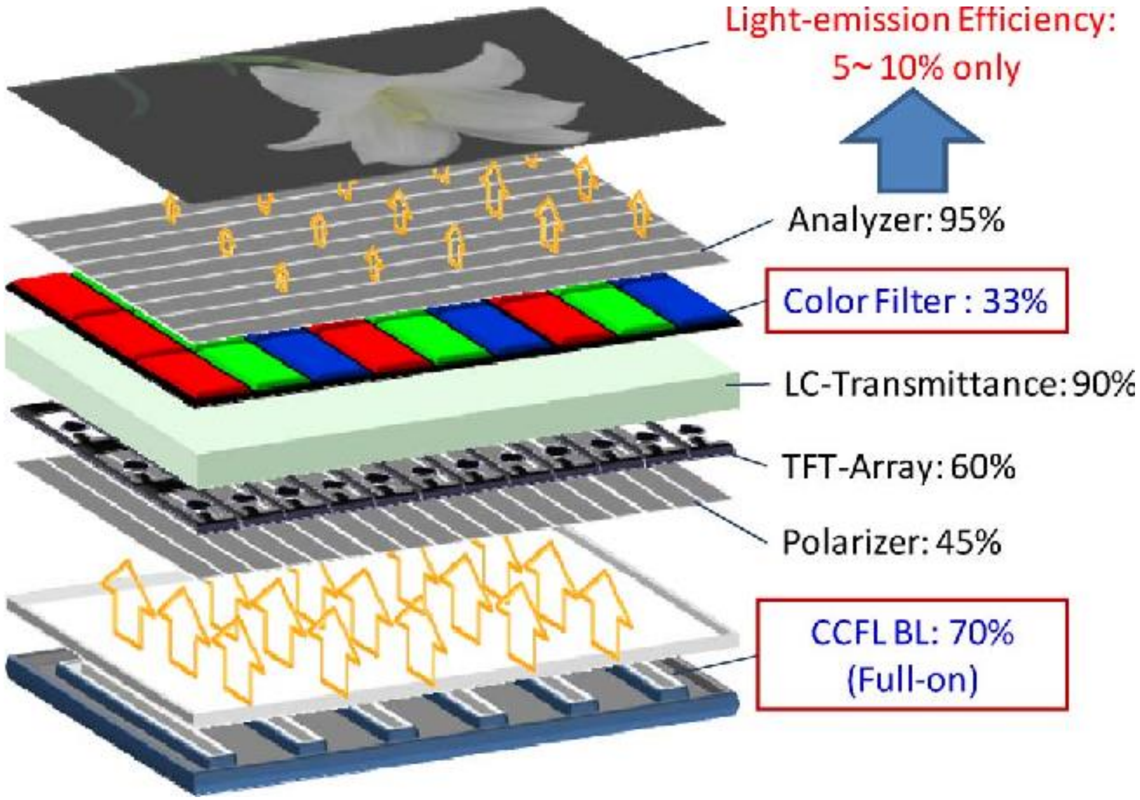
6. **Liquid Crystal Alignment layers**: In an actual LCD, the angles of the polarizers are fixed and cannot be rotated. So we need to adjust the polarization of light by controlling the liquid crystal layer located in the middle of the display. To achieve that the furrowed plate **(Alignment layers)** is placed nearby, the molecules line up regularly according to the direction of the furrows.

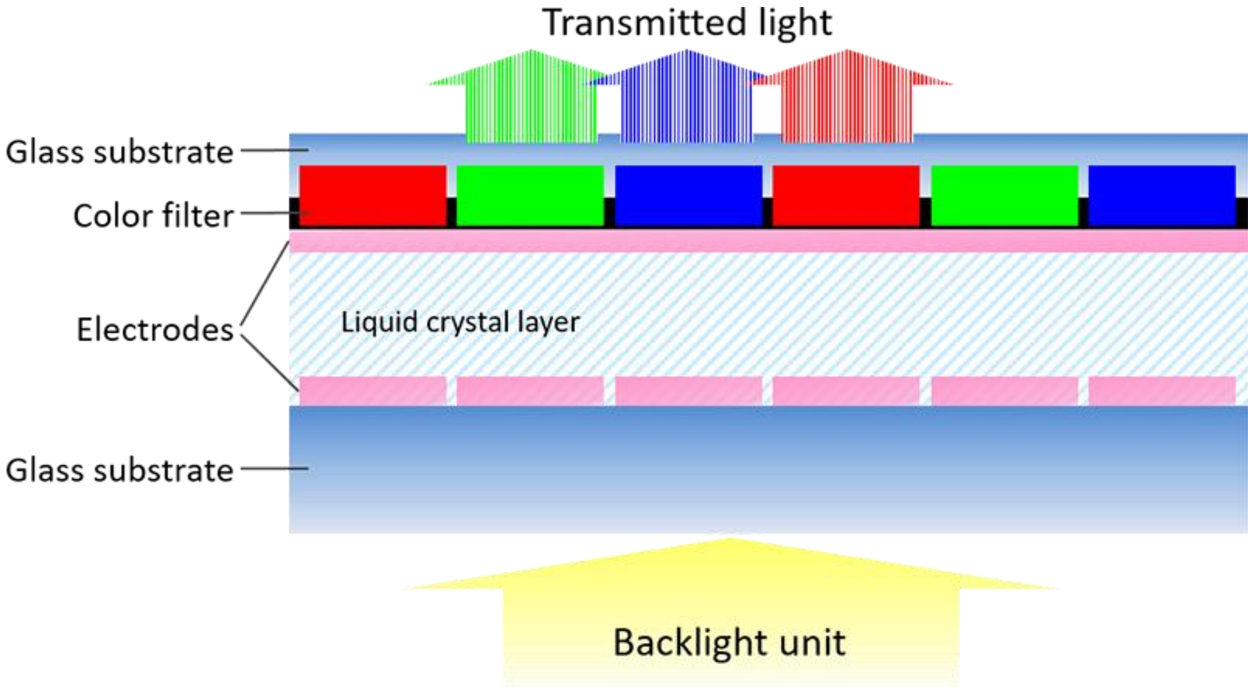




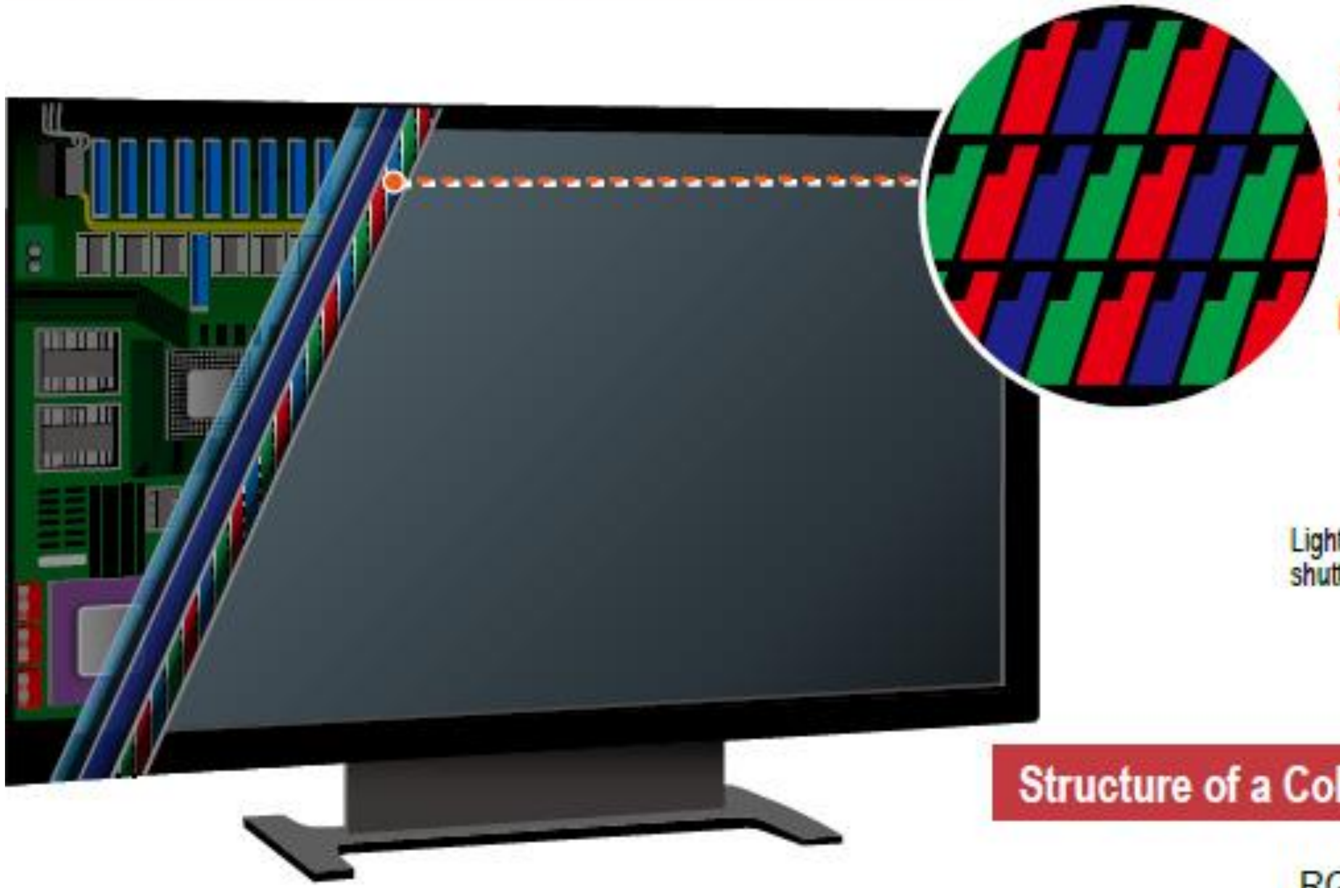


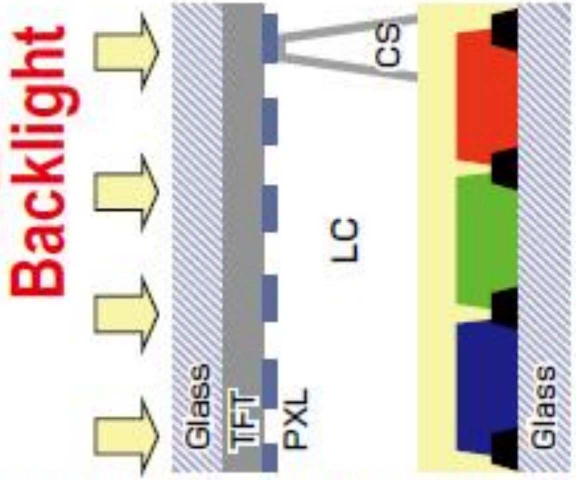
7. **Color Filters**: A color filter consists of a slim glass substrate and color resist. Three types of color resist, red (R), green (G) and blue (B) are used to form a lattice pattern on the glass. Each spot of color resist is called a subpixel. The subpixels are divided from its adjacent subpixel by a black matrix (BM) in order to prevent the colors from being mixed. These colors are created using pigments





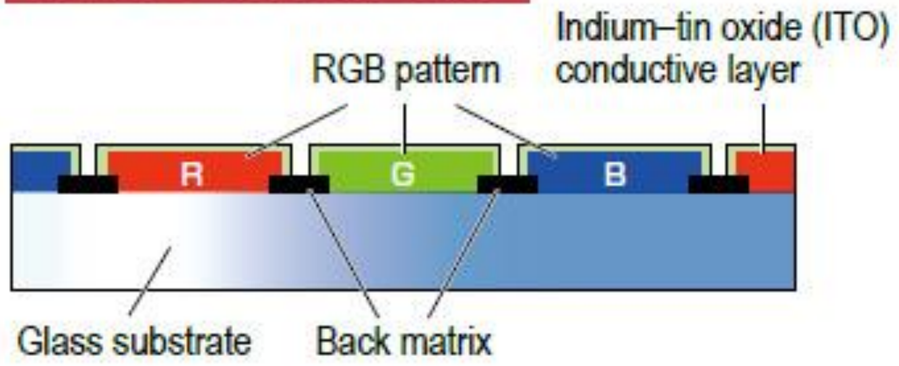
Composition of an LCD and the Role of Pigments





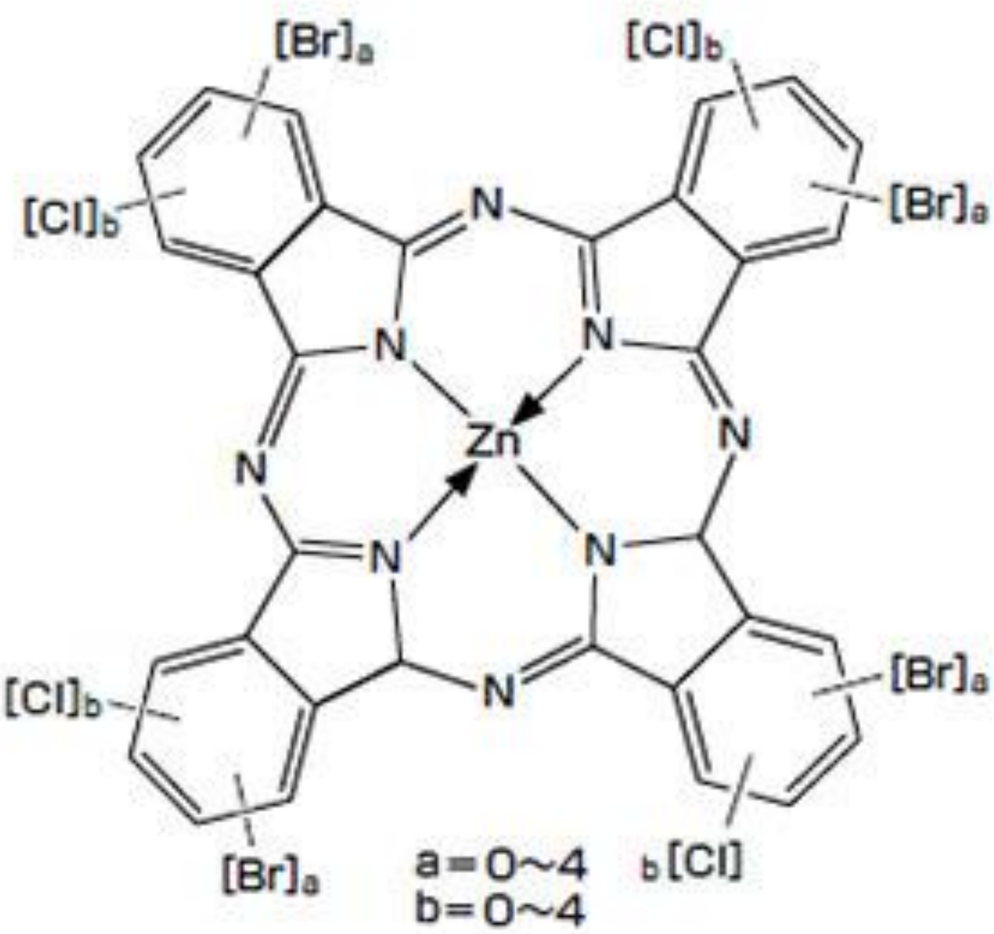
Light emitted from the backlight is modulated by an LC shutter and colored as it passes through the color filter.

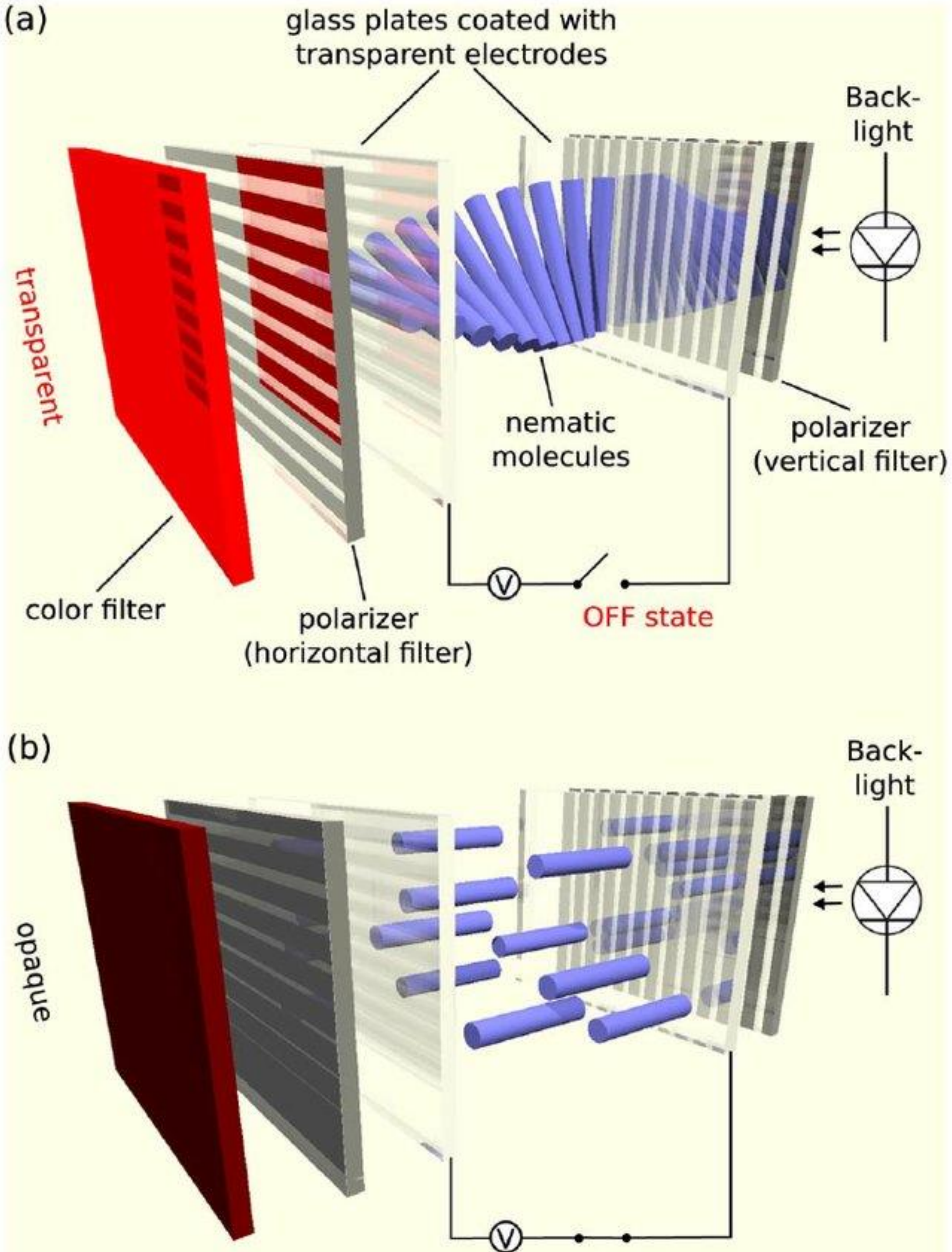
Structure of a Color Filter



https://www.dicglobal.com/en/csr/special/2018/special01.html

Chemical structure of green pigments, which are particularly popular among smartphone manufacturers





Principle of operation of a normally white TN LCD panel. When no electric field is applied (a), the helical structure of the LC molecules rotates the vertically polarized light so that it can pass the second, horizontal polarizer. When an electric field is applied (b), the molecules tend to align with the electrical field, distort and finally break the helical structure so that the backlight is blocked by the horizontal polarizer and the respective subpixel appears opaque. doi:10.1371/journal.pone.0044048.g001

Working Principle of liquid crystal display:

- It is flat panel display (FPD), which works on the principle of filtering, blocking and transmitting the light through liquid crystals layers followed by RGB color filters , polarizer and display. Unlike LEDs, OLEDs, it doesn't emit light.
- It mainly consists of white light source, polarizer, electrodes with TFT array, liquid crystals layer, RGB color filters and display glass with front cover.
- The light emitted by light source is made to pass though vertical polarizer. Then the polarized light from the vertical polarizer transmits though the transparent electrodes, which are embedded with thin film transistors (TFT) and enters to liquid crystal layer.
- The liquid crystals acts as “Shutter” for light, based on orientation of LC, the light is stopped or transmitted further.

Working Principle of liquid crystal display: contd.....

- By applying the voltage of TFT-Electrodes, the orientation of LC can be controlled. The LC optical property depends on their orientation with respect the incident polarized light.
- When no voltage applied between transparent electrodes, liquid crystal molecules are aligned in parallel with the glass surface, and light is transmitted easily.
- However, when voltage is applied, LC change their orientation and they turn vertical to the glass surface, blocks the light.
- Therefore, the intensity of light transmission can be controlled by varying the voltage and the orientation of LC molecules.
- The light transmitted via the LC layer, is further passed though RGB color filters (in case of color LCD). The color filters allow specific light to pass though second polarizer (horizontal), and falls on the display glass, which results into the image.

Tabular representation of characteristics of LCD

Characteristic	Twisted-Nematic Display
Voltage	3 V
Total current	6 μA
Frequency	30 to 1,500 Hz
Operating temperature	-15 °C to +60 °C
Total capacitance	2 nF
Rise time	100 ms
Contrast ratio	50 : 1

Advantages of LCD

The heat generated during operation is less as compared to CRT and LED display.
The power consumption by an LCD is very less in comparison to other display devices.
LCDs can be suitably used with MOS integrated circuits.
The overall cost of the device is low.

Disadvantages of LCD

It needs an external source of light for displaying the image.
Its operating temperature range is limited that lies in between 0 to 60°C.
LCDs are less reliable display units.
The image visibility relies on light intensity.

Applications of LCD

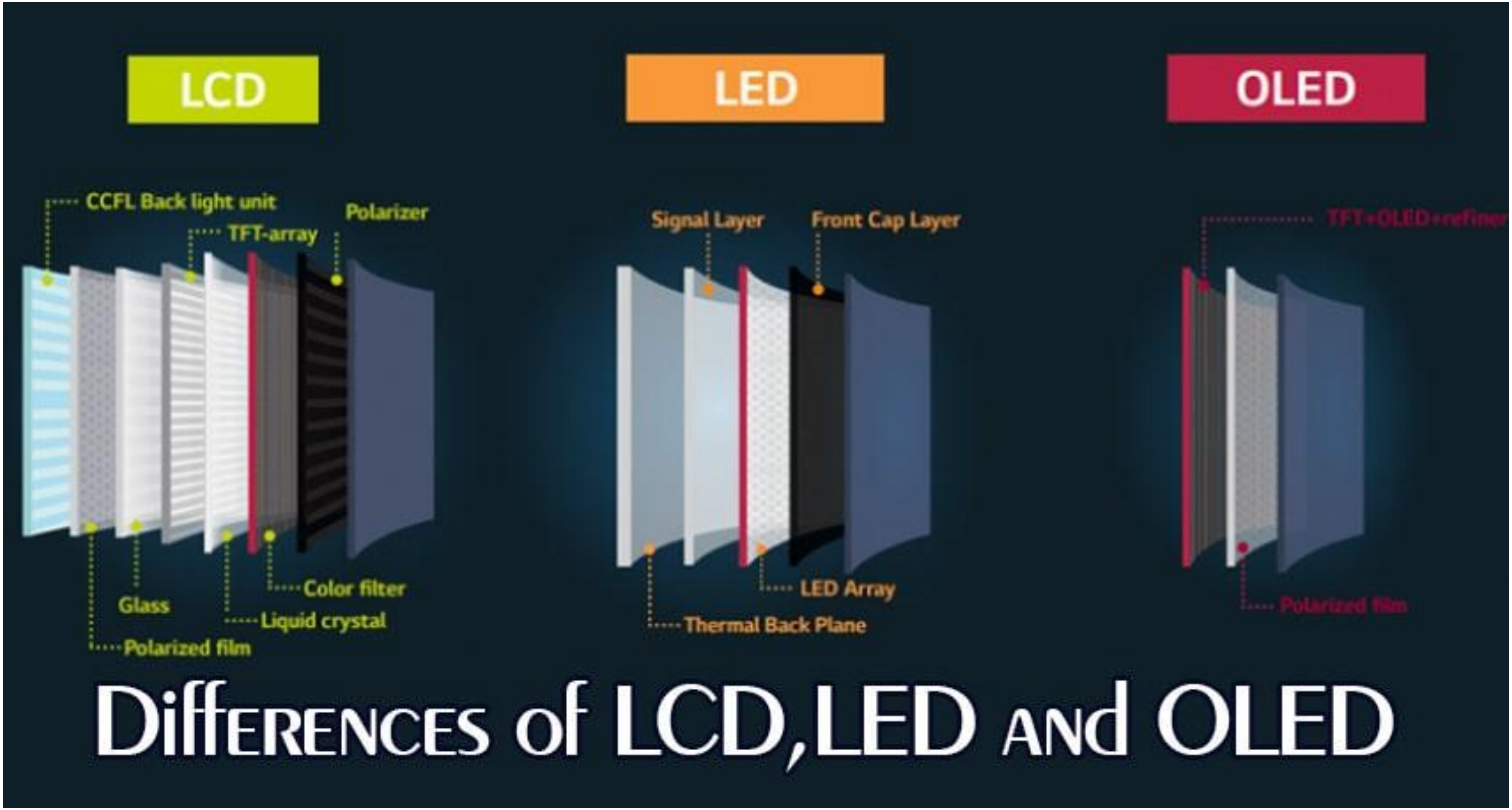
LCD finds its major applications in displaying the images on the screens of various electronic gadgets like television, calculator, computer monitor etc. These are also used in digital watches and mobile screens. These are also used in visualizing RF waves in transmission through waveguides and in medical applications like in liquid crystal thermometers etc.

Technology	TFT LCD	OLED	Micro LED
Light Source	LCD backlight	Self emmit	Self emmit
Cost	Low	Medium	High
Power Consumption	High	60%–80% of LCD	30%-40% of LCD
Brightness	Low	High	High
Efficiency	Low	Medium	High
Lifespan	Long	Medium	Long
Contrast	Low	High	High
Response Time	ms	µs	ns

You Tube Videos_ LED/OLED:

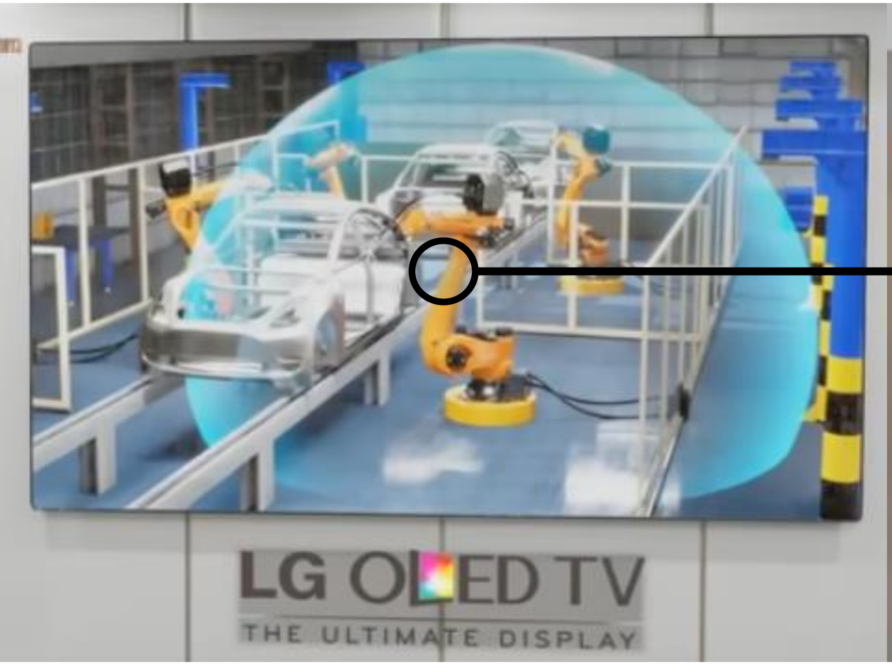
https://www.youtube.com/watch?v=xAMhX3Drq14
https://www.youtube.com/watch?v=9BDTtcRMxpA
https://www.youtube.com/watch?v=4y7p9R2No-4
https://www.youtube.com/watch?v=Gx-JVoOFYhs

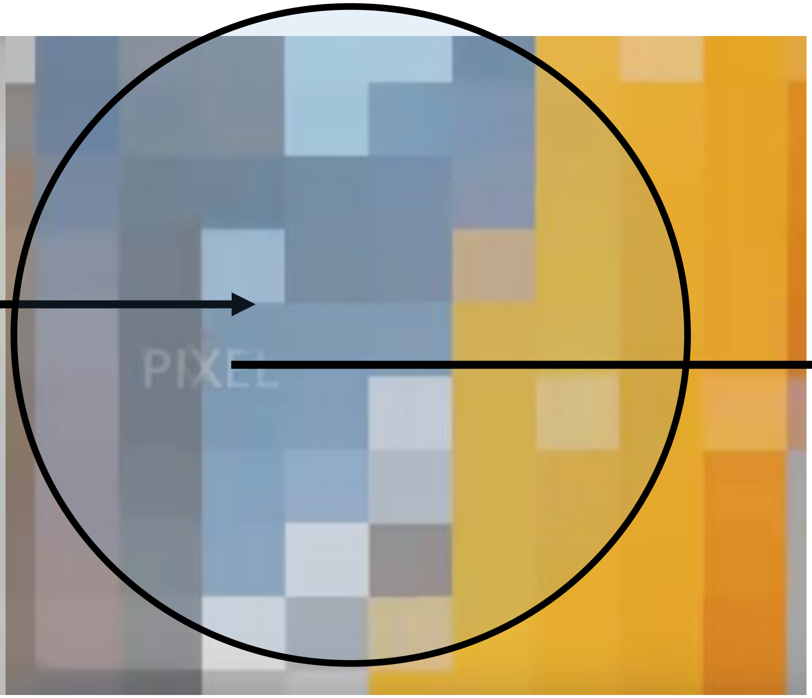

LED

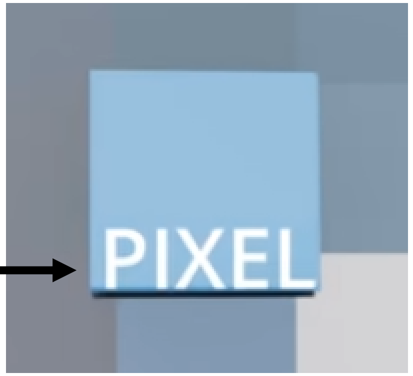

LCD
LED
OLED
CCFL Back light unit
TFT-array
Polarizer
Glass
Color filter
Liquid crystal
Polarized film
Signal Layer
Front Cap Layer
LED Array
Thermal Back Plane
TFT+OLED+refiner
Polarized film
Differences of LCD, LED and OLED

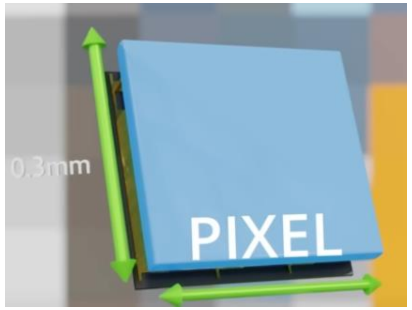
LED Display

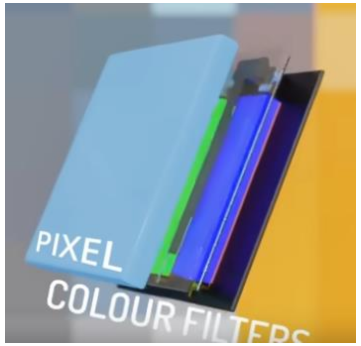
LED is short for Light Emitting Diode. An LED emits light as a result of electroluminescence. It is also known as “cold light” as, unlike with OLD incandescent bulbs, the light is not produced by heating a metal filament. The diode, on the other hand, emits light when flowing through two specially coated silicon semiconductors. It is one of the most energy-efficient and power-saving ways to produce light.

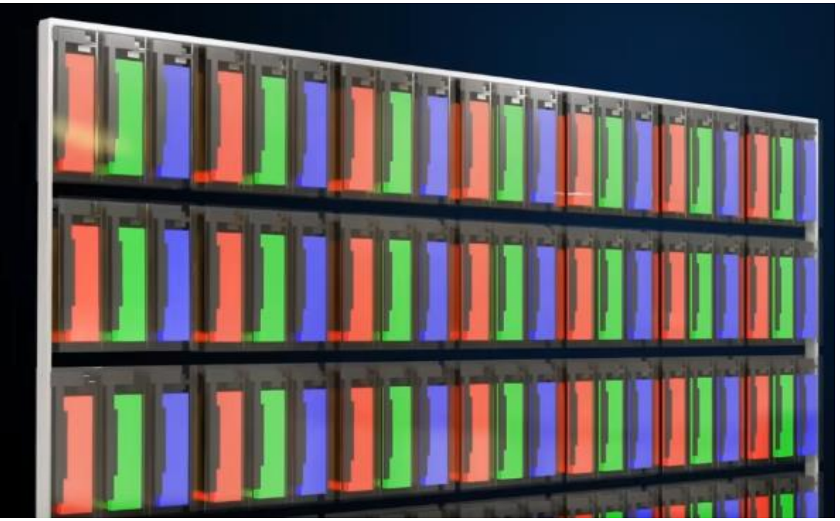

LG OLED TV
THE ULTIMATE DISPLAY

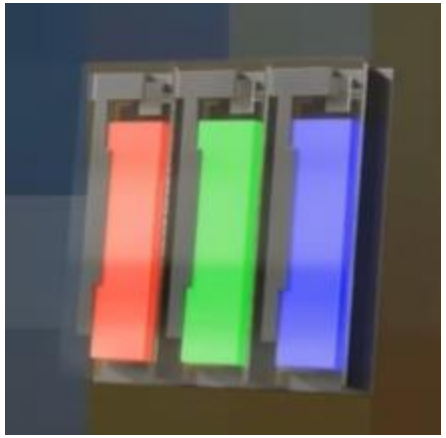

PIXEL


PIXEL

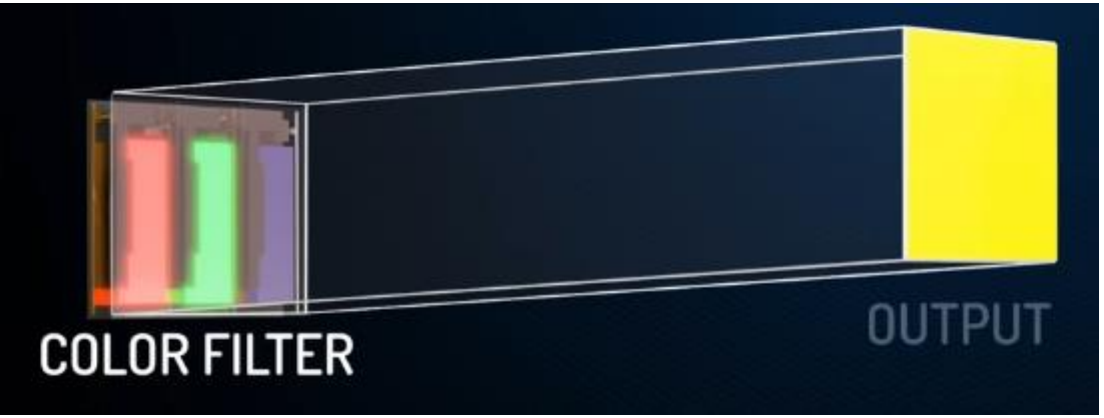

0.3mm
PIXEL

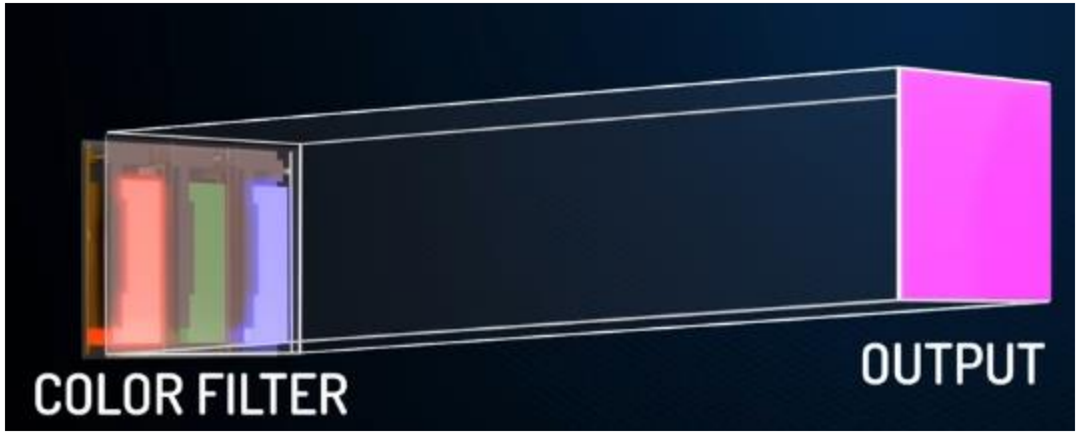

PIXEL

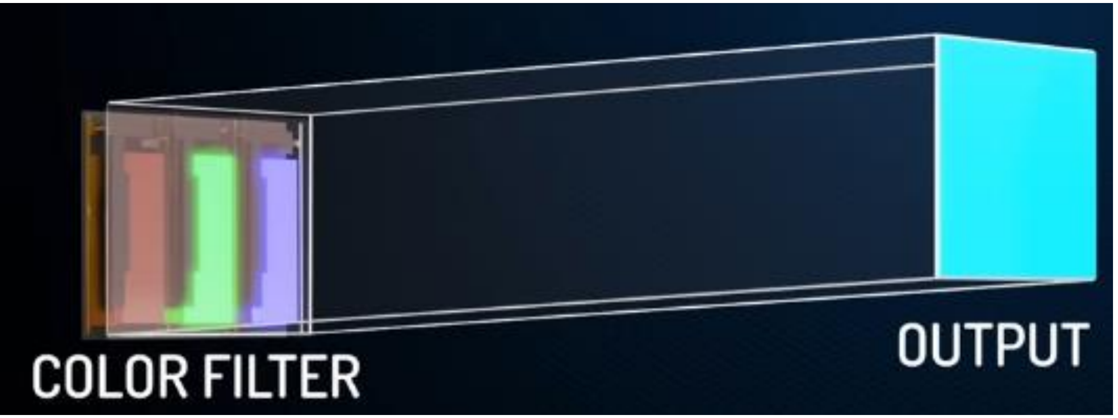


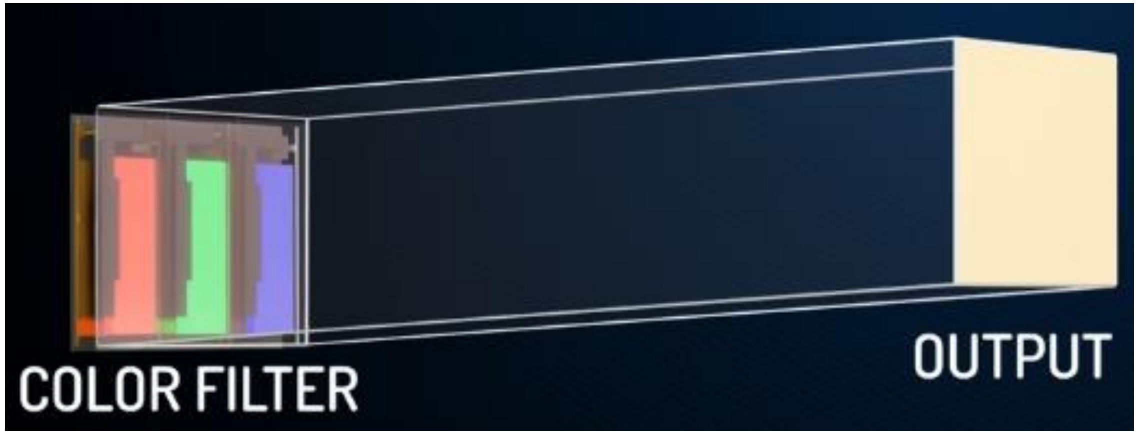



PIXEL
COLOUR FILTERS

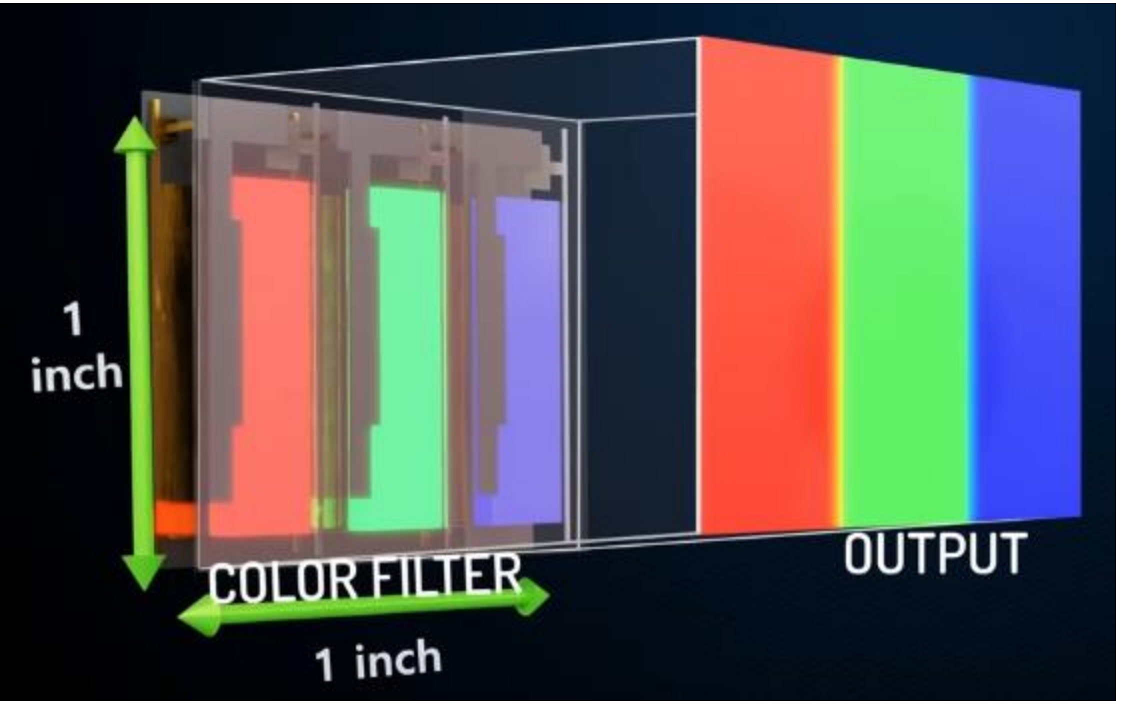








Each Pixel electrode is applied with different voltage, and hence different intensity of colors are emitted

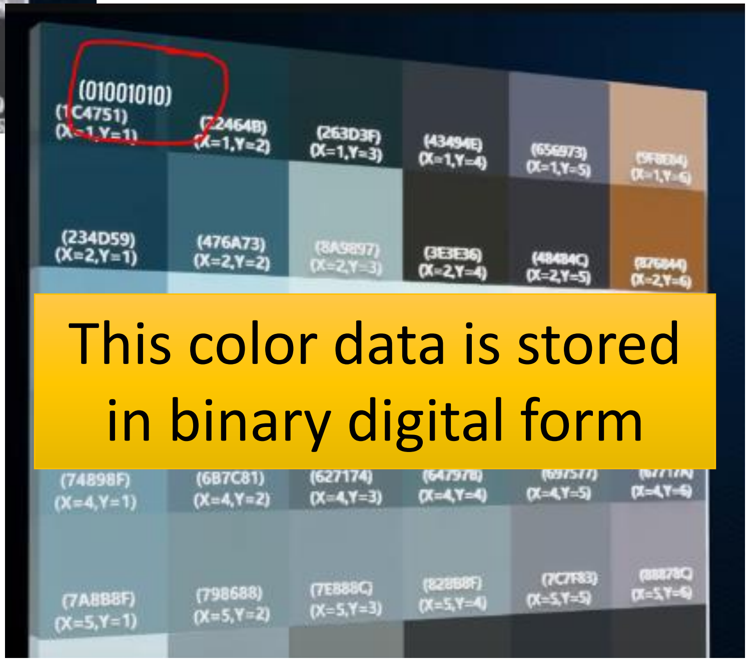


If the Pixel size is big, 1 inch then we can clerly see all the R G B colors

Pixel size is reduced , so that the three different colors are overlapped, and appears one color to our eyes (limited visual resolution of human eye) It con't differentiate the sub-pixels

Each pixel is represented with some codes-color data

How color codes are programmed in LEDs



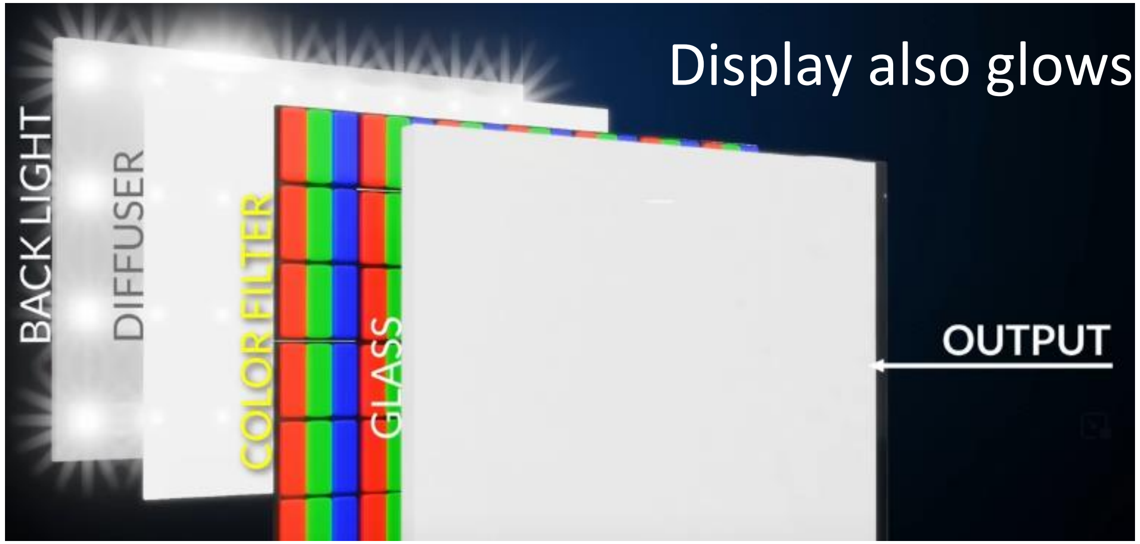
This color data is stored in binary digital form

In case of LCD

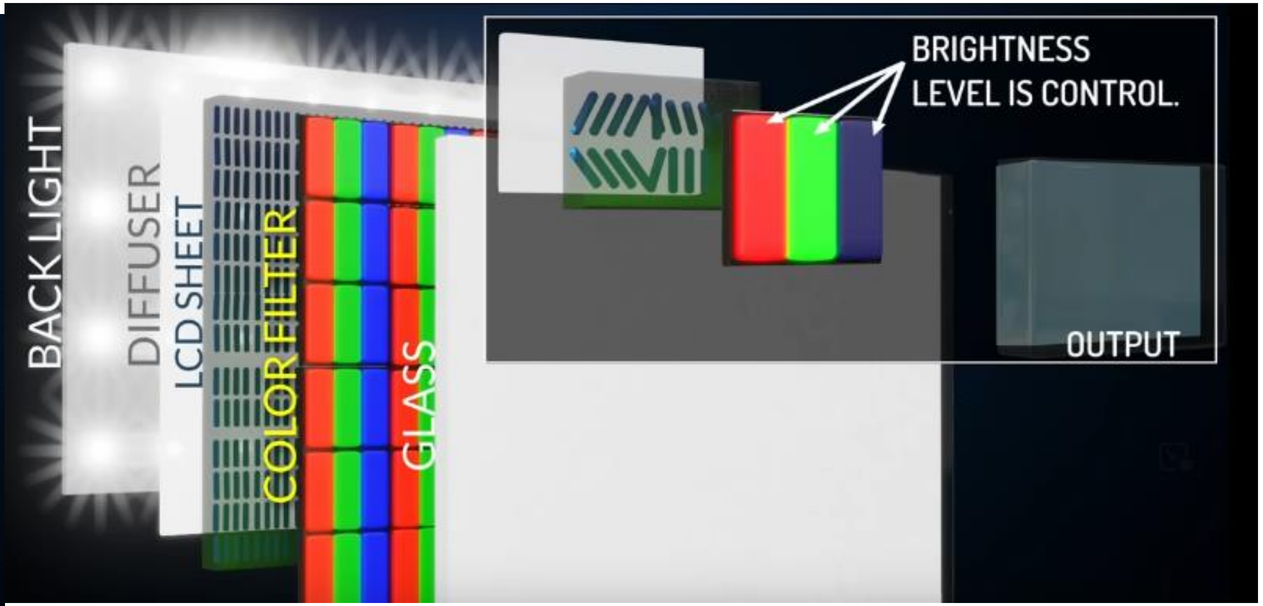
Back light is OFF

no colour image on display

Back light is ON



Display also glows



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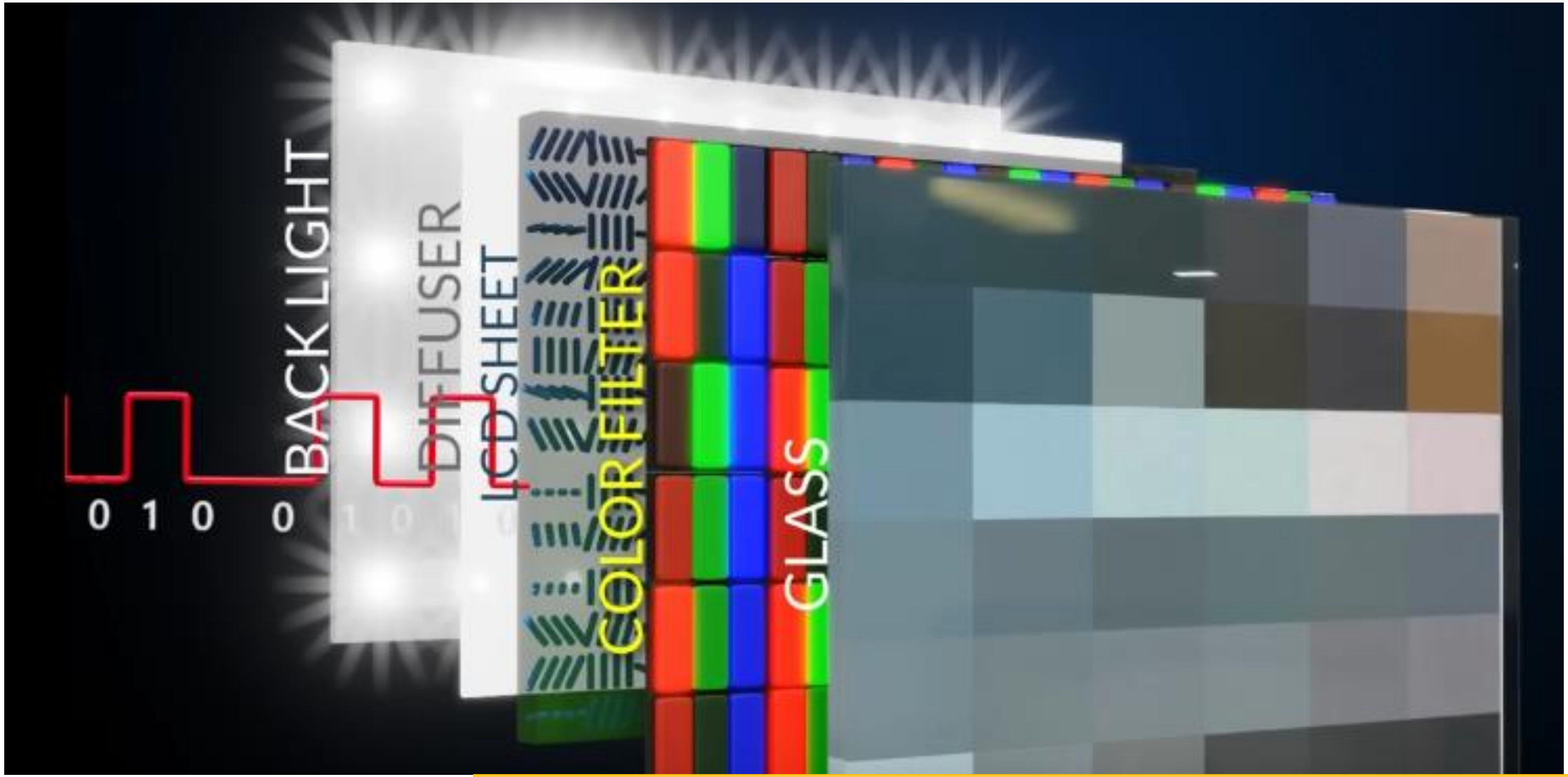
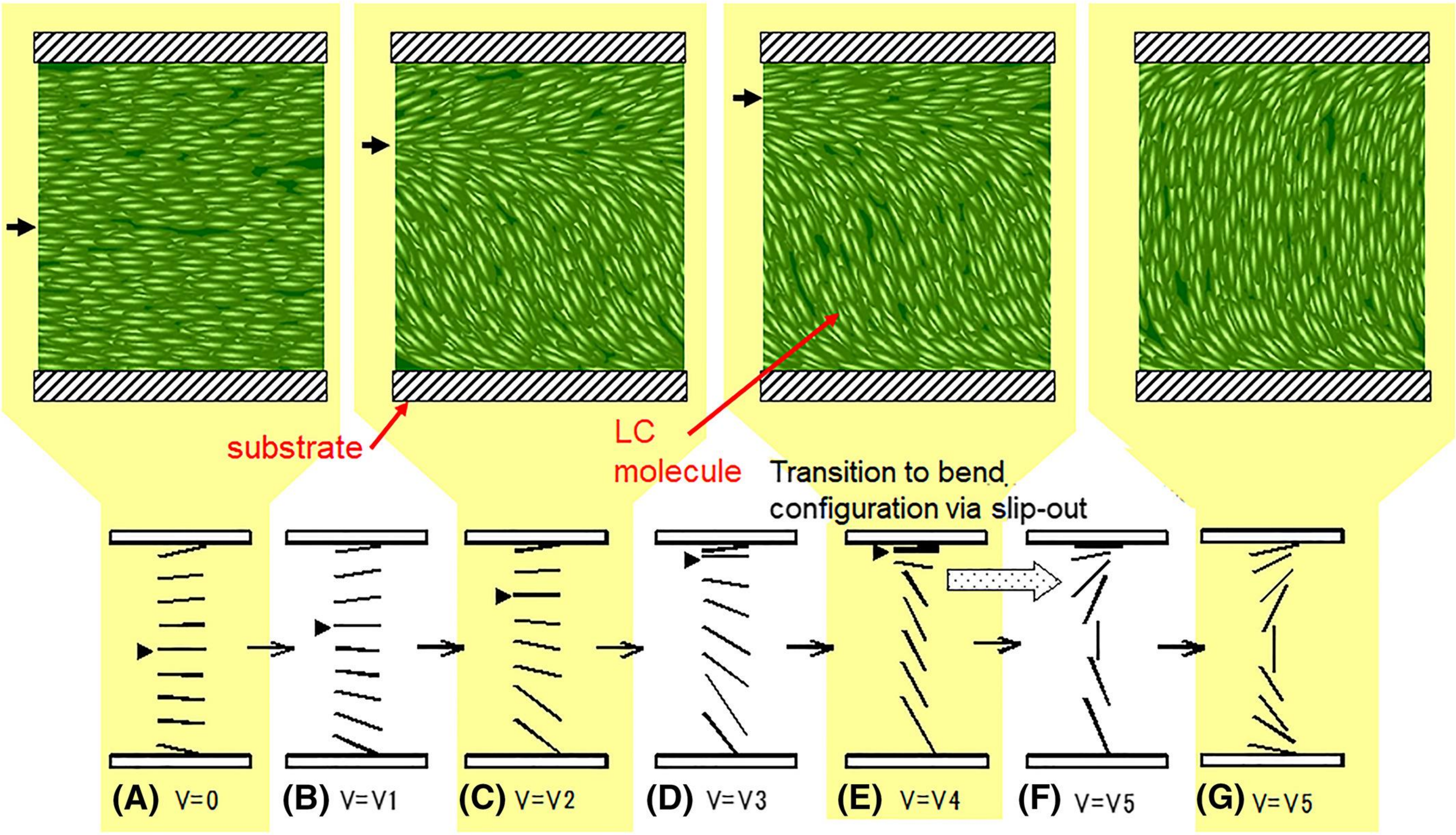
In case of LCD

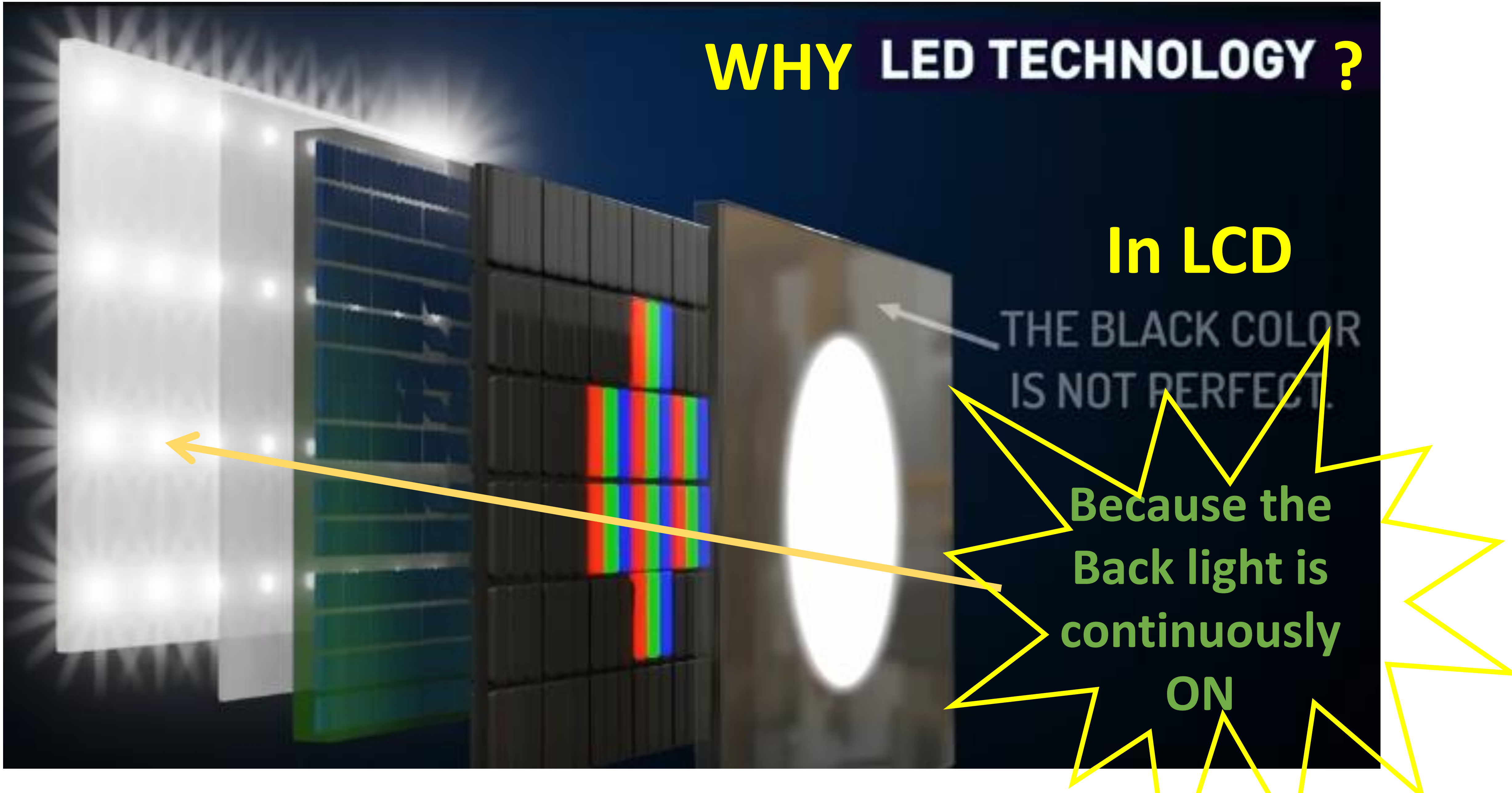
This color data is stored in digital form, is stored in the form of electrical signal in LCD electrode, when different potentials as per signals applied, the LC orients and block the light, and hence differentiate the colors of pixel on display

In case of LCD

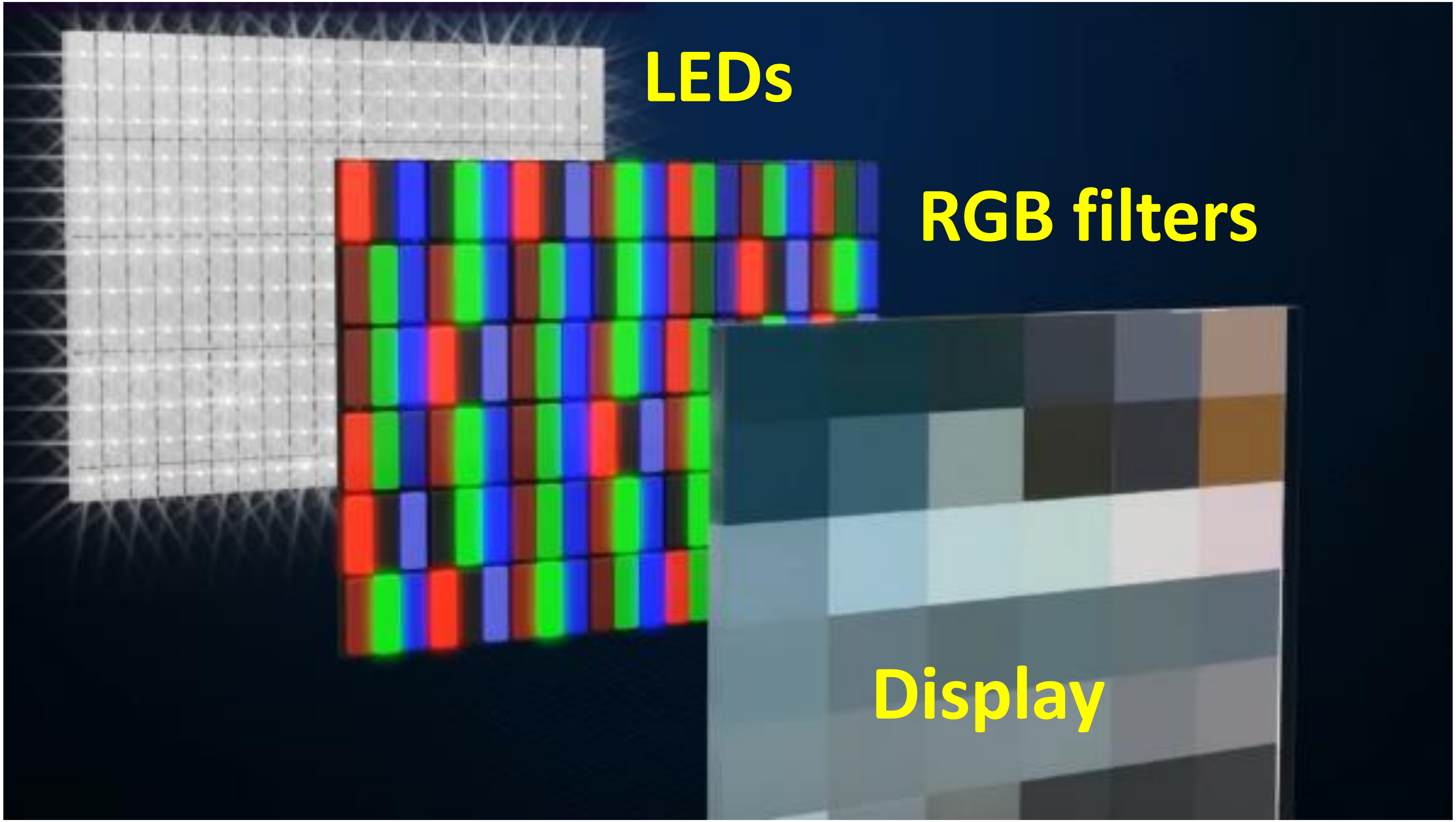


In this way the original image is produced in LCD

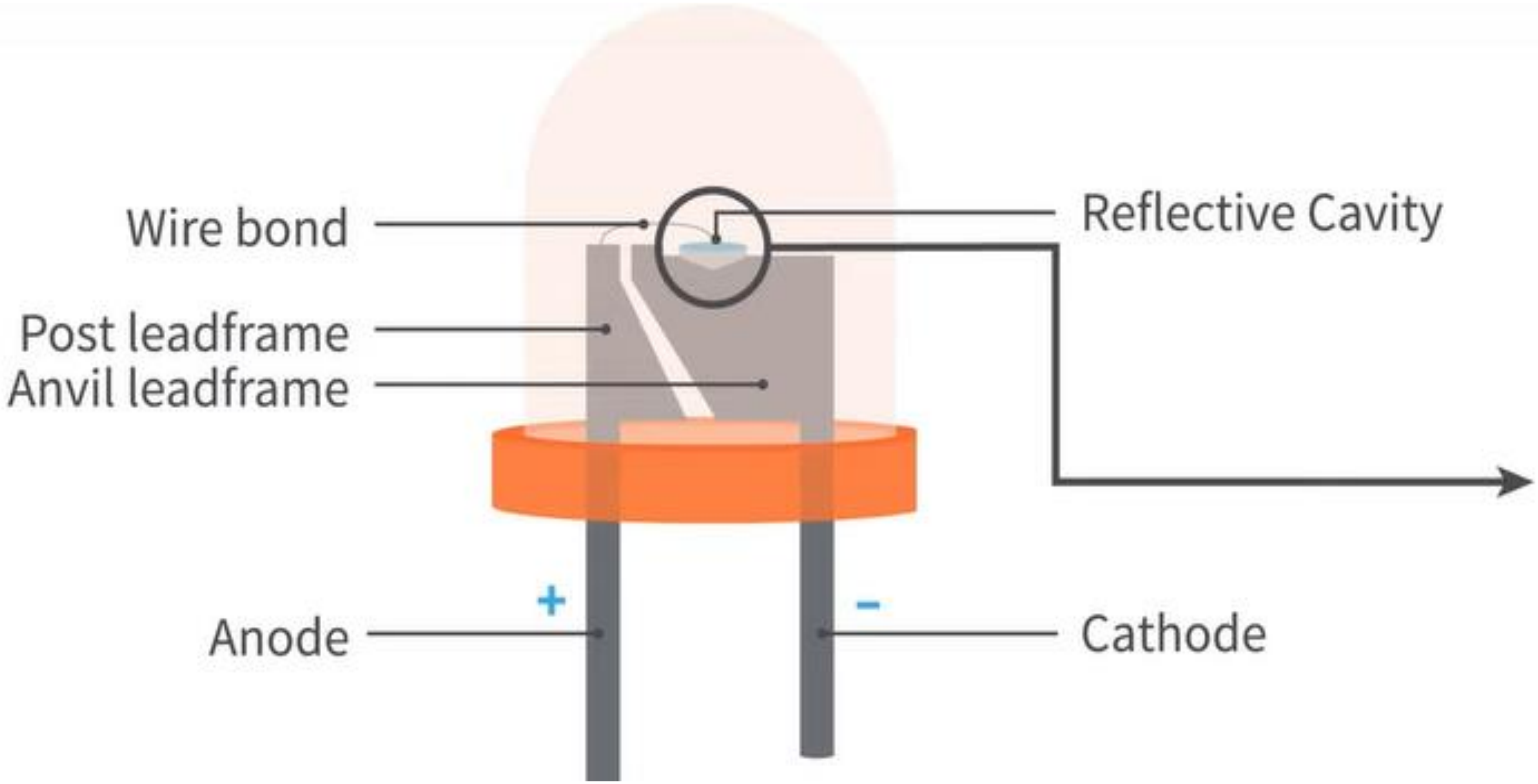

substrate
LC
molecule
Transition to bend
configuration via slip-out
(A) V=0
(B) V=V1
(C) V=V2
(D) V=V3
(E) V=V4
(F) V=V5
(G) V=V5


WHY LED TECHNOLOGY ?
In LCD
THE BLACK COLOR IS NOT PERFECT.
Because the Back light is continuously ON

LED display components and working

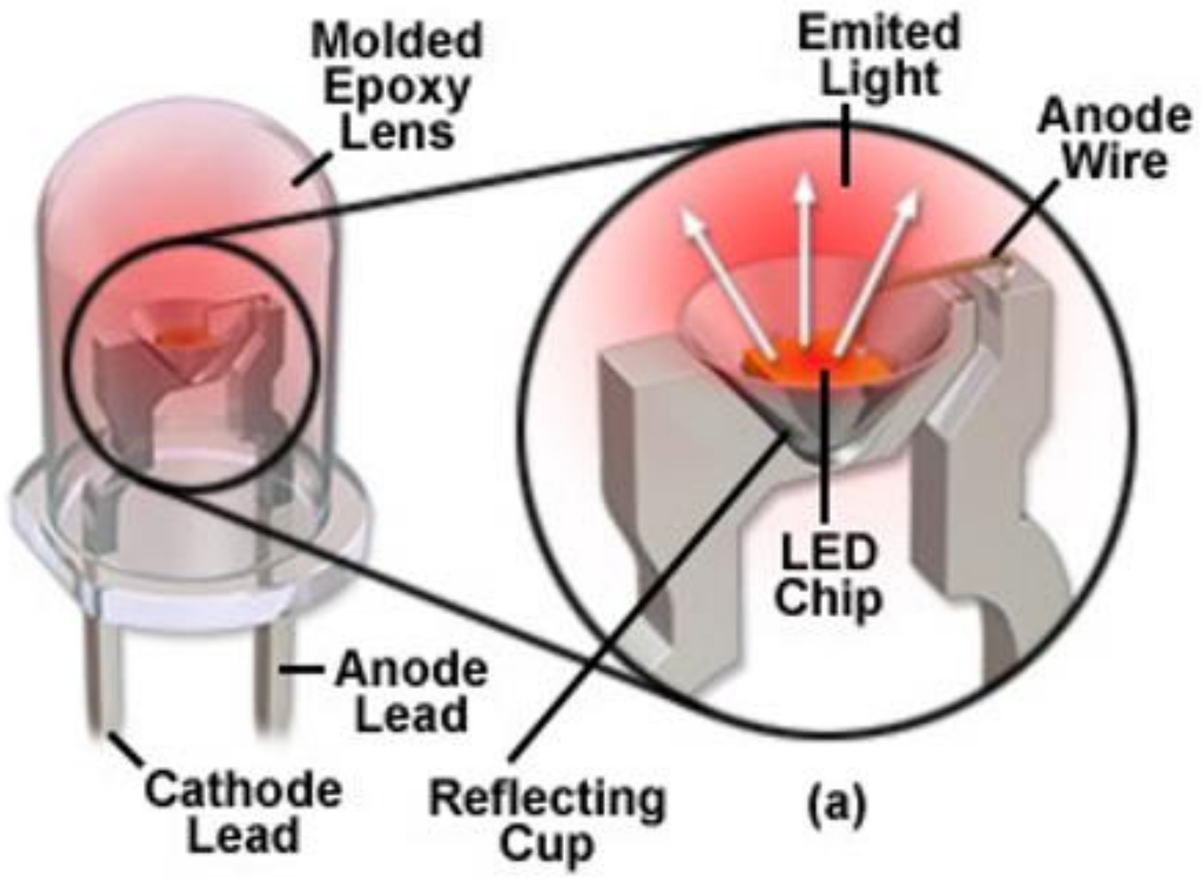


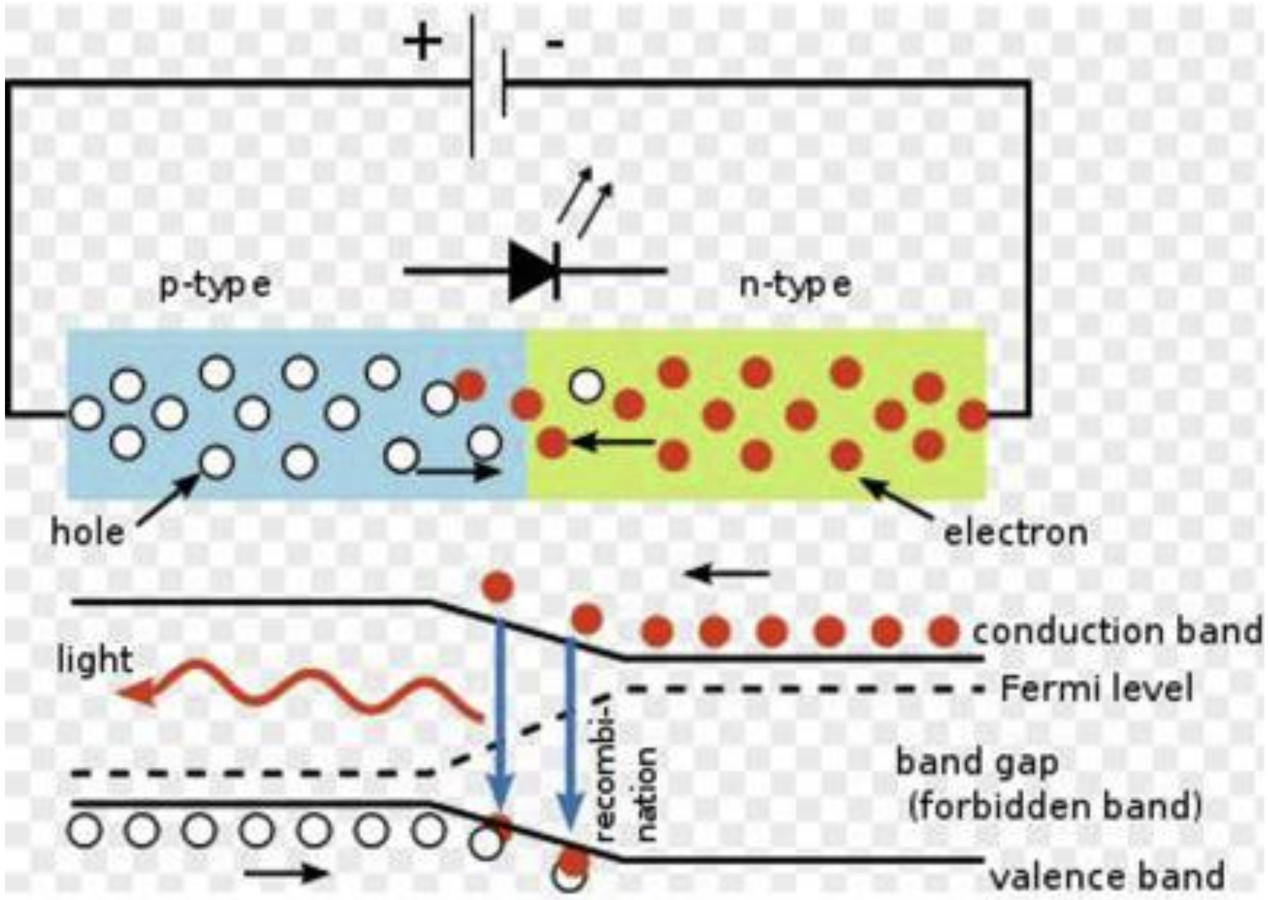
LEDs chips and PN diode



The two primary materials used in LEDs are aluminium gallium indium phosphide alloys and indium gallium nitride alloys. Aluminium alloys are used to obtain red, orange and yellow light, and indium alloys are used to get green, blue and white light

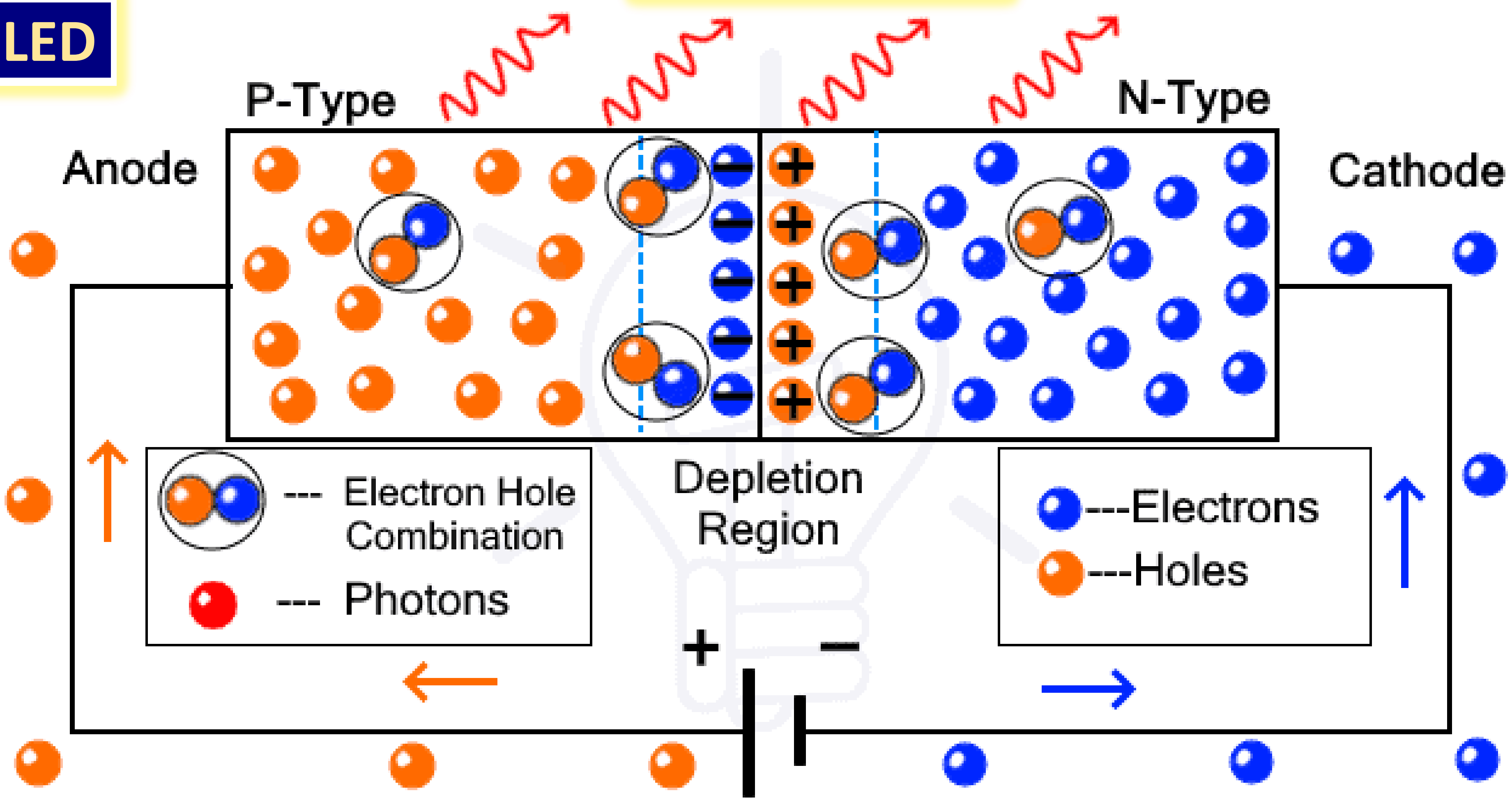
LEDs chips and PN diode



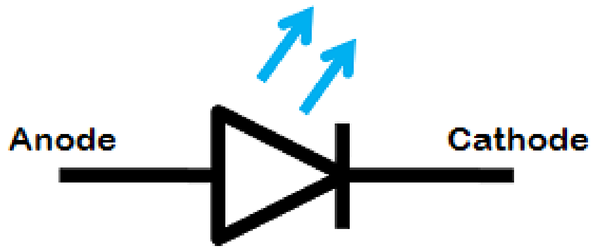


Working of LED

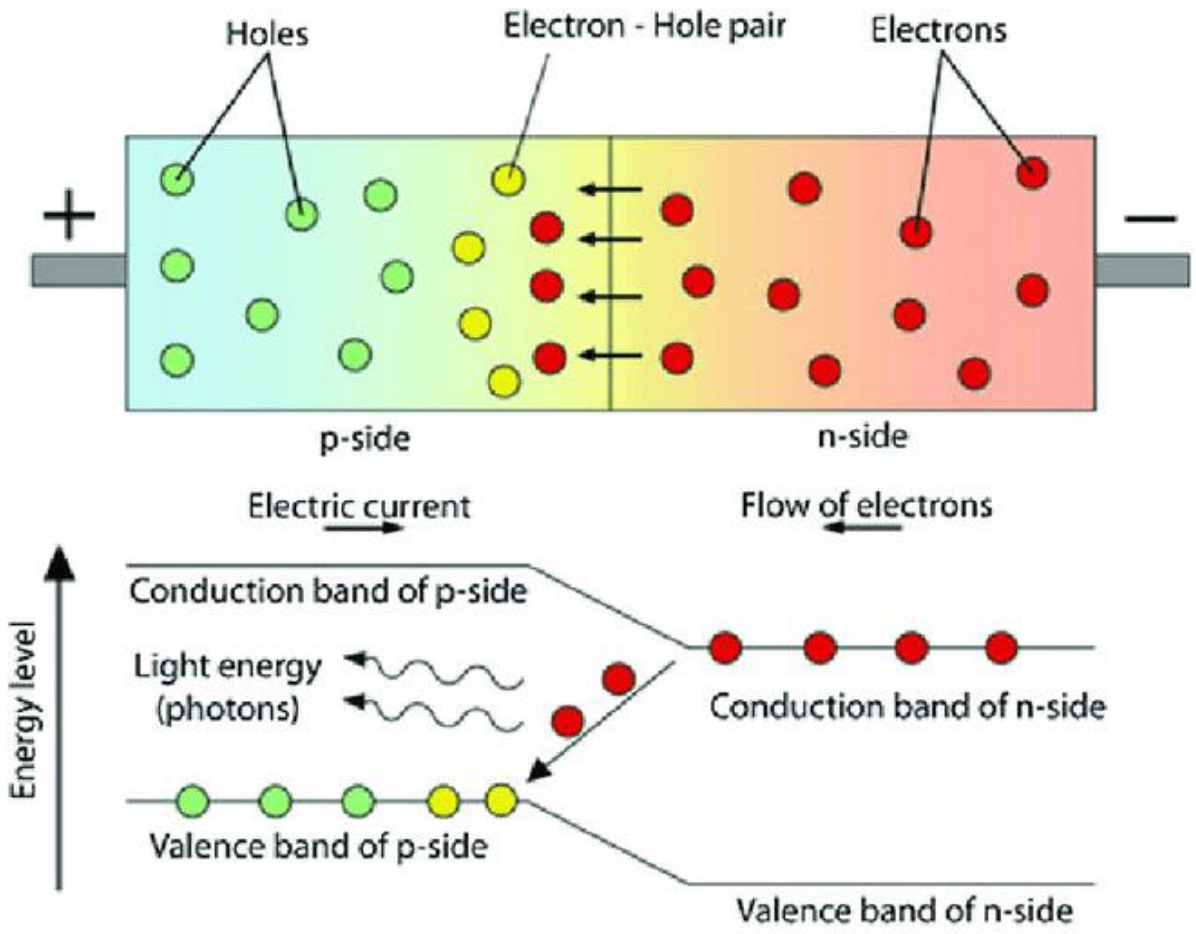
Light emitted



Voltage Applied



LED symbol



LEDs are semiconductor diodes, which are electronic devices that permit current to flow in only one direction. The diode is formed by bringing two slightly different materials together to form a PN junction. A PN junction is used to inject carriers (holes and electrons) into the active layers from p-type layer and n-type layer. As this occurs, energy is released in the form of light that is emitted by the LED. Since LED lighting systems don't radiate heat the way an incandescent or CFL light bulb does, the heat produced from the power going into the product must be drawn away from the LEDs

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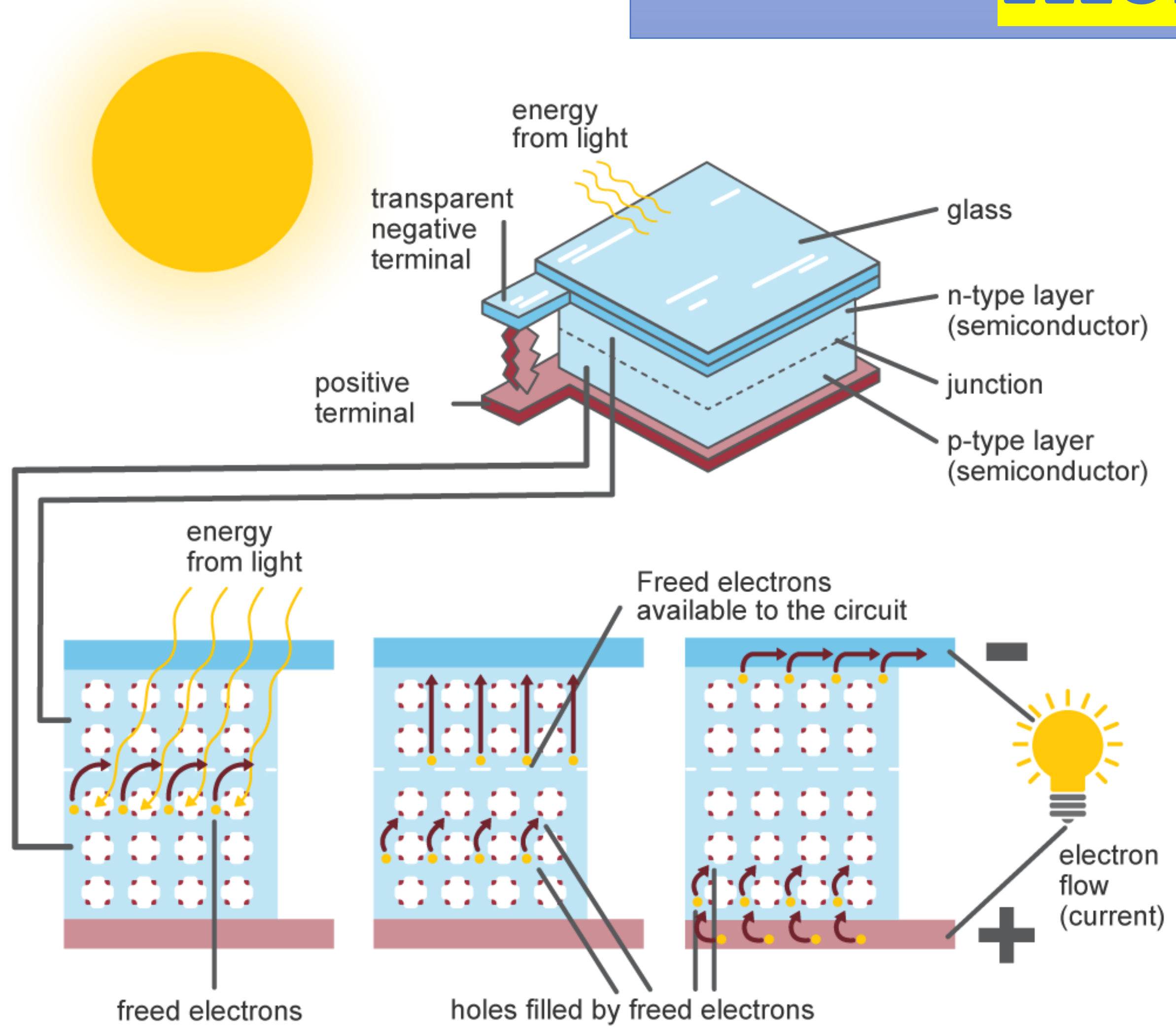
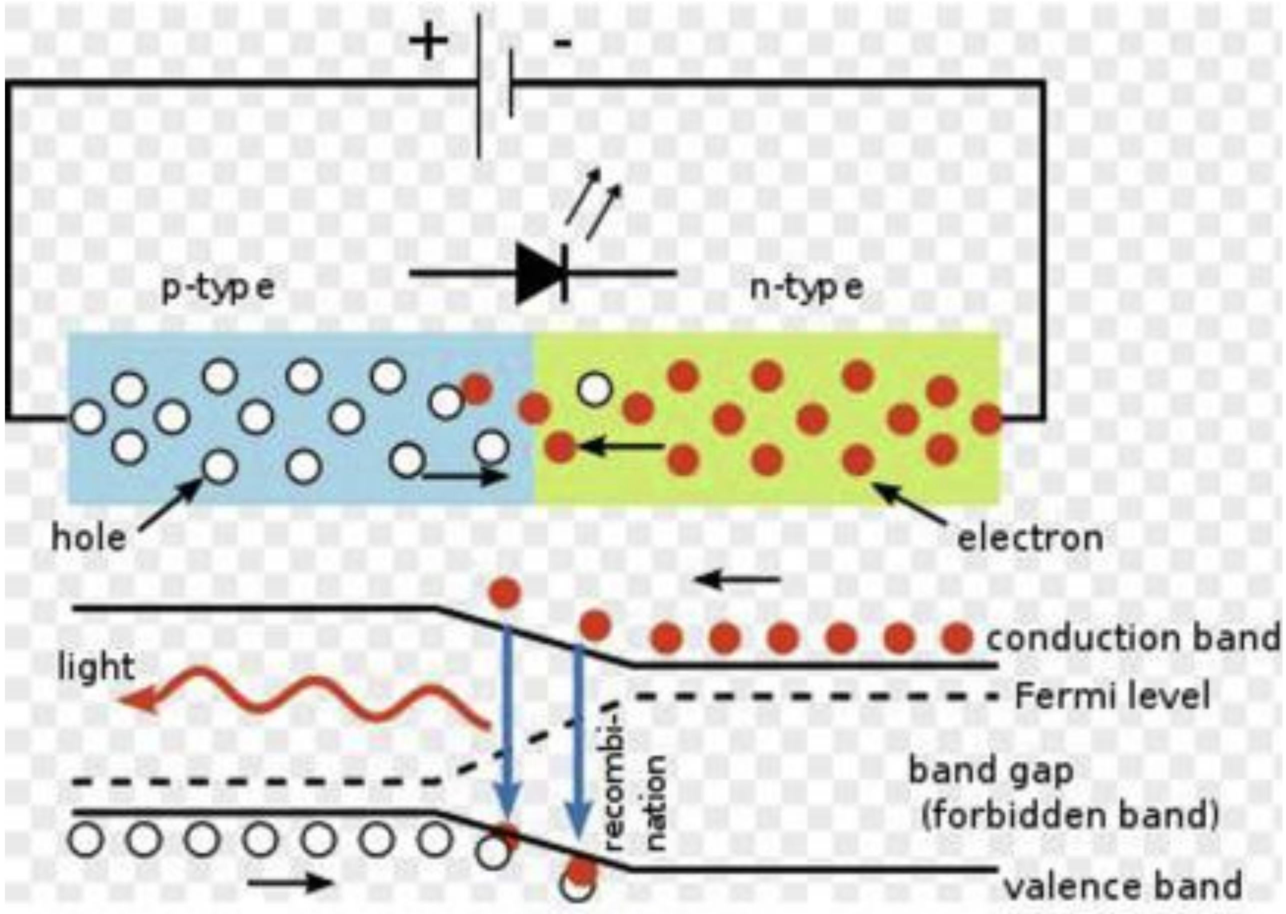
PHOTOVOLTAIC VS ELECTROLUMINESCENT DEVICES

Inside a photovoltaic cell



Source: U.S. Energy Information Administration



Working Principle of LED display:

It is also flat panel display (FPD), which works on the principle of transmitting the light emitted by LED layers through individual pixels and RGB color filters. An LED bulb produces light by passing the electric current through a semiconducting material (gallium arsenide phosphide)—the diode (PN junction)—which then emits photons (light) through the principle of electroluminescence.

It mainly consists of LED light source followed by transparent electrodes with TFT array embedded , RGB color filters and display glass with front cover.

The light emitted by LED light source is made to pass through the RGB color filter. The intensity of the light passing though RGB is responsible for creating new combinations of colors. This can be optimized or controlled by variating current flow in the LED chips. The color filters, which allow specific light to pass though and falls on the display glass, which results into the image.

Disadvantages of LED:

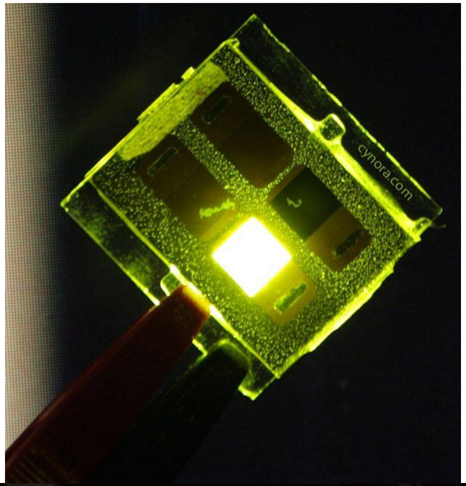
- It requires high power.
- Its preparation cost is high.
- LED is not suitable for large area display because of its high cost.
- It cannot be used for illumination purposes.

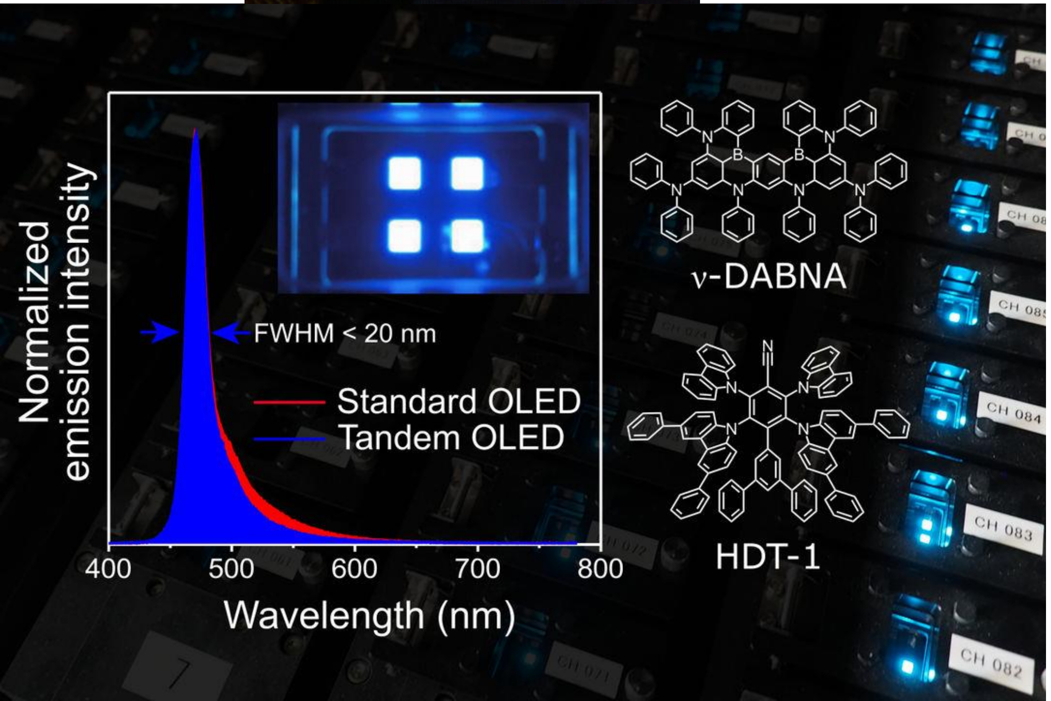
Organic light emitting diodes (OLED's)

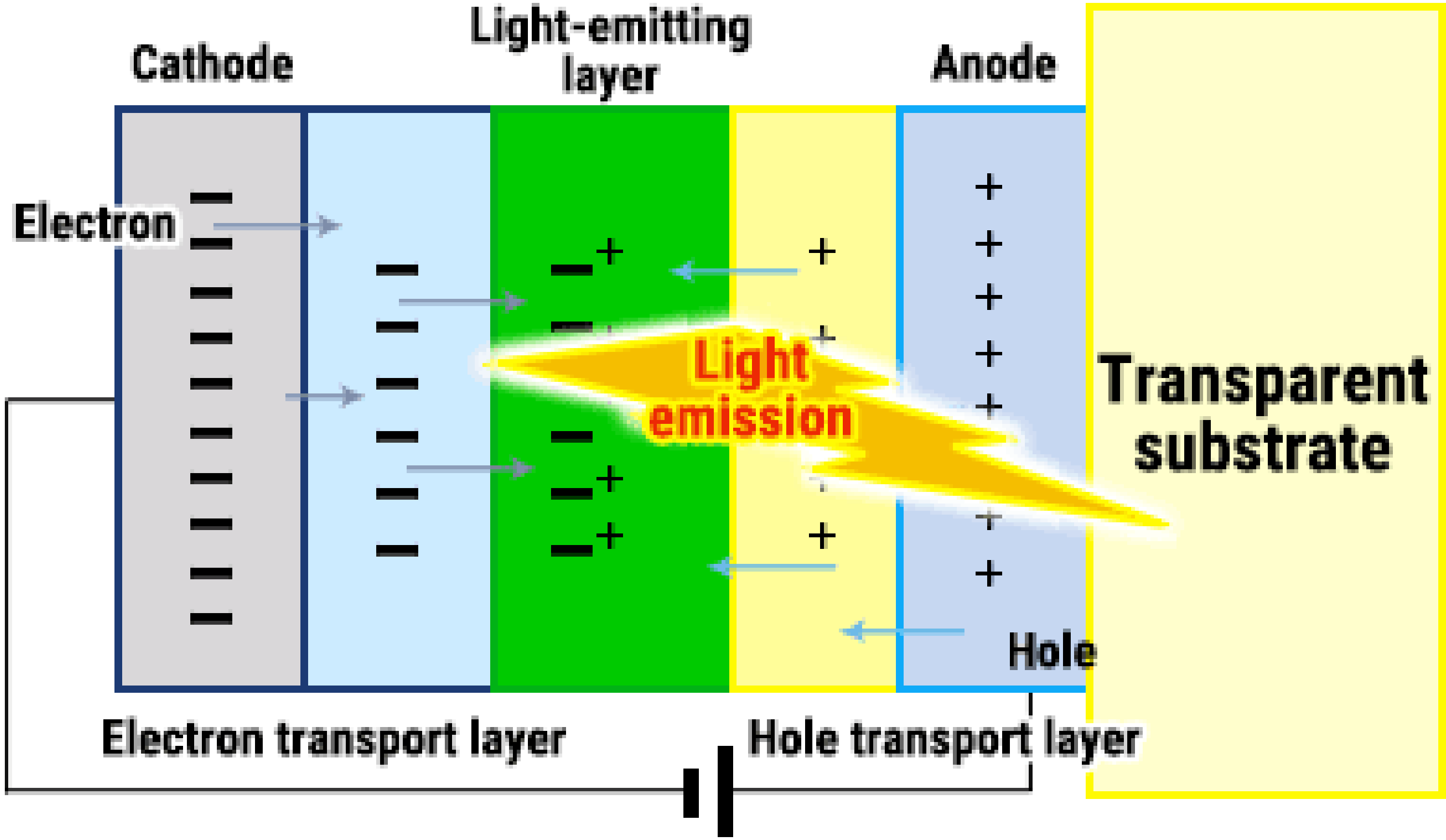
OLED : It is also flat panel display, which consist of a series of light emitting thin films of functional organic films composed of hydrocarbon chains, rather than semiconductors (like LEDs). An OLED is a thin film optoelectronic device with organic materials (small molecules, dendrimers, or polymeric substances) sandwiched between two electrodes, the anode and cathode, all deposited on a substrate.

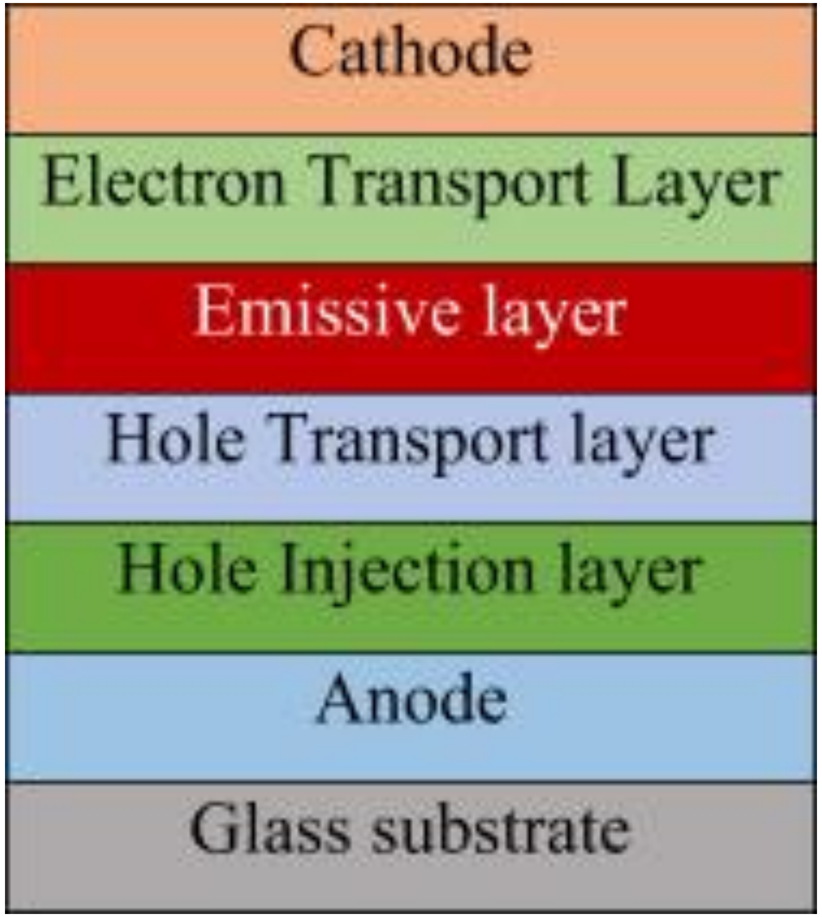
Construction and components of OLEDs

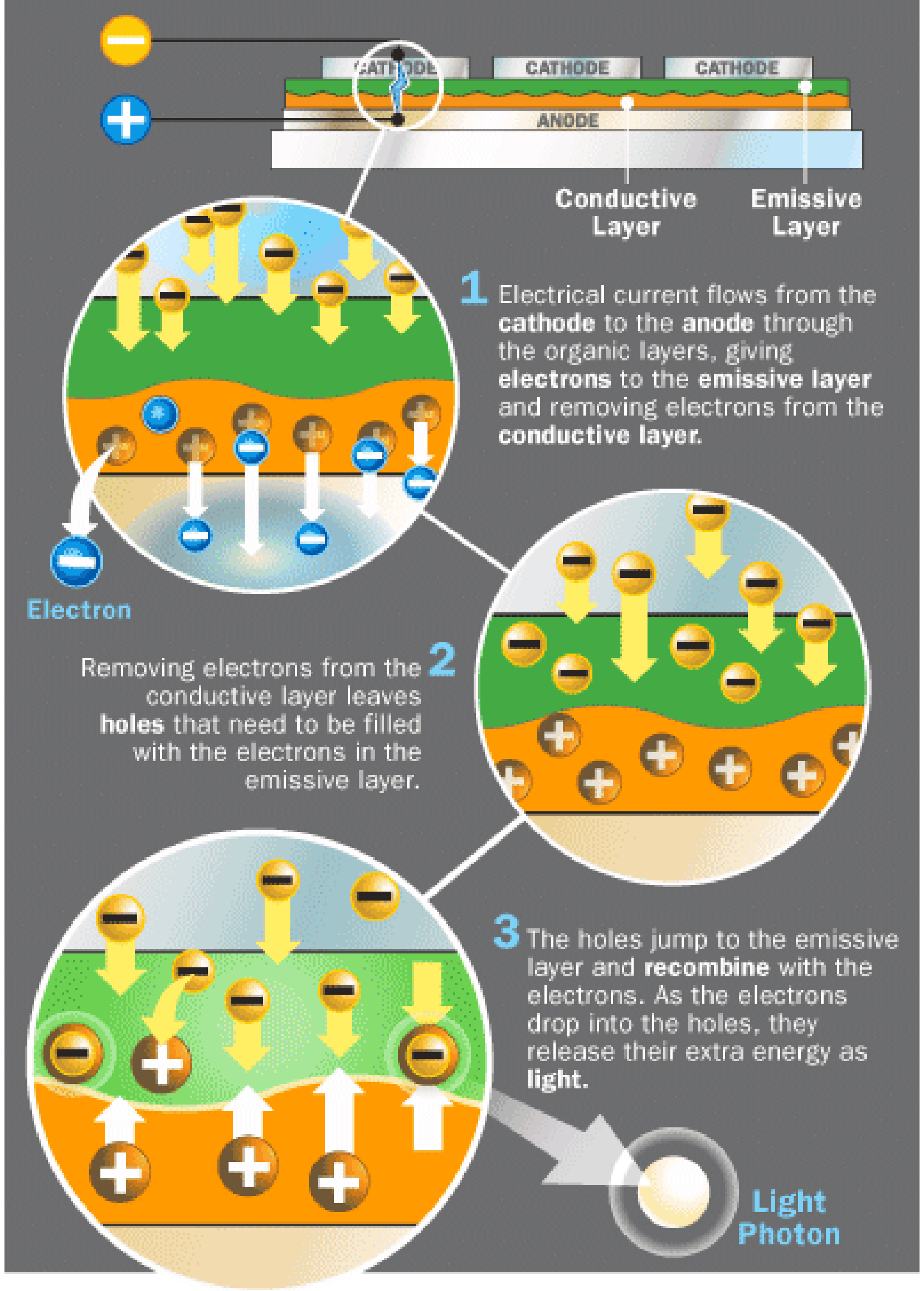
The OLED contains three basic layers: the cathode, anode and organic layer. In early OLEDs, the organic layer consisted of an emissive layer and a conductive layer. When a current is passed through the material, electrons are generated at the cathode, and “holes” are generated at the anode. These electrons and holes recombine at emissive layer and emit the light.

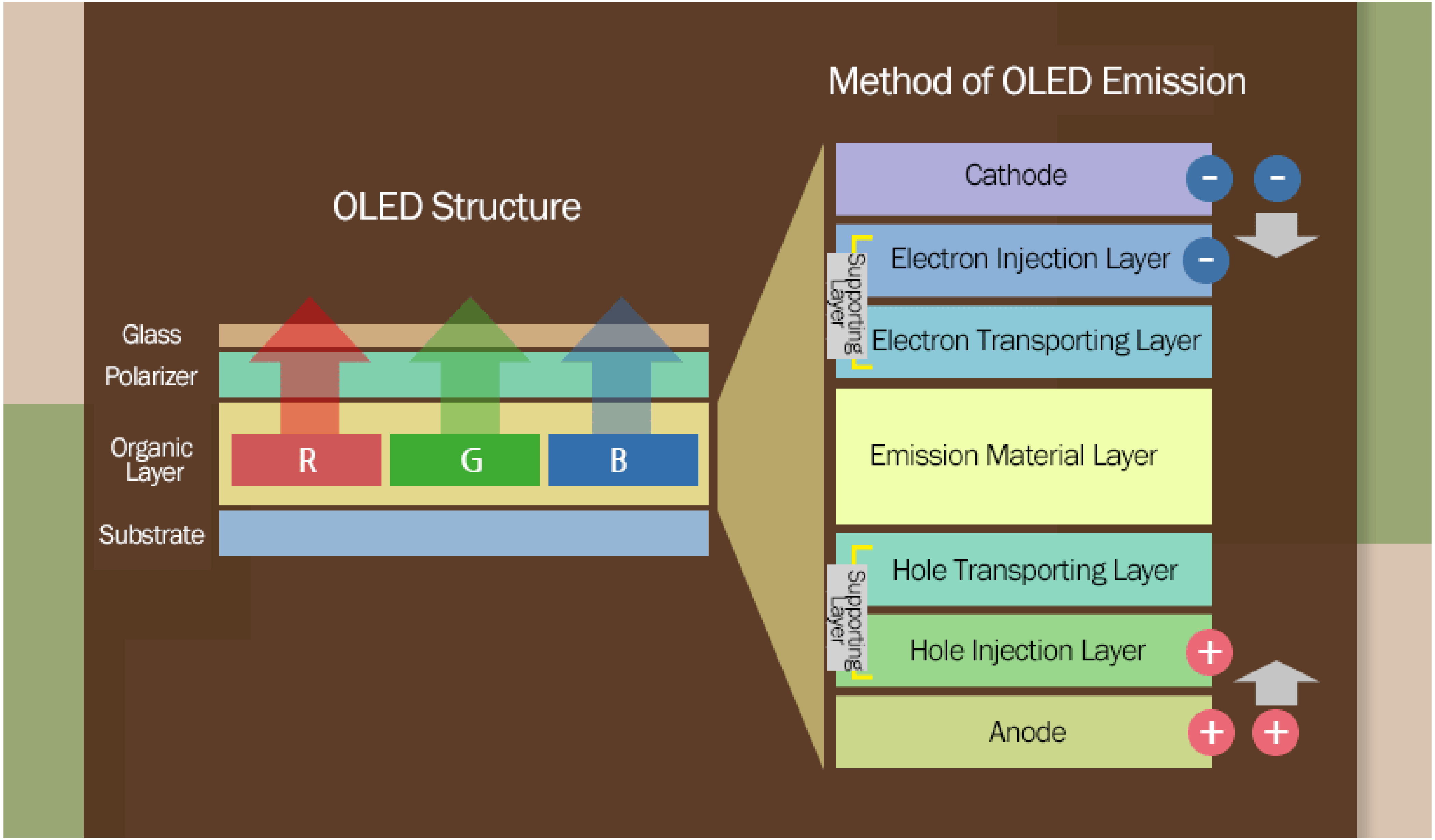



Normalized emission intensity
FWHM < 20 nm
Standard OLED
Tandem OLED
400
500
600
700
800
Wavelength (nm)
ν-DABNA
HDT-1


Cathode
Light-emitting layer
Anode
Electron
Light emission
Transparent substrate
Hole
Electron transport layer
Hole transport layer


Cathode
Electron Transport Layer
Emissive layer
Hole Transport layer
Hole Injection layer
Anode
Glass substrate

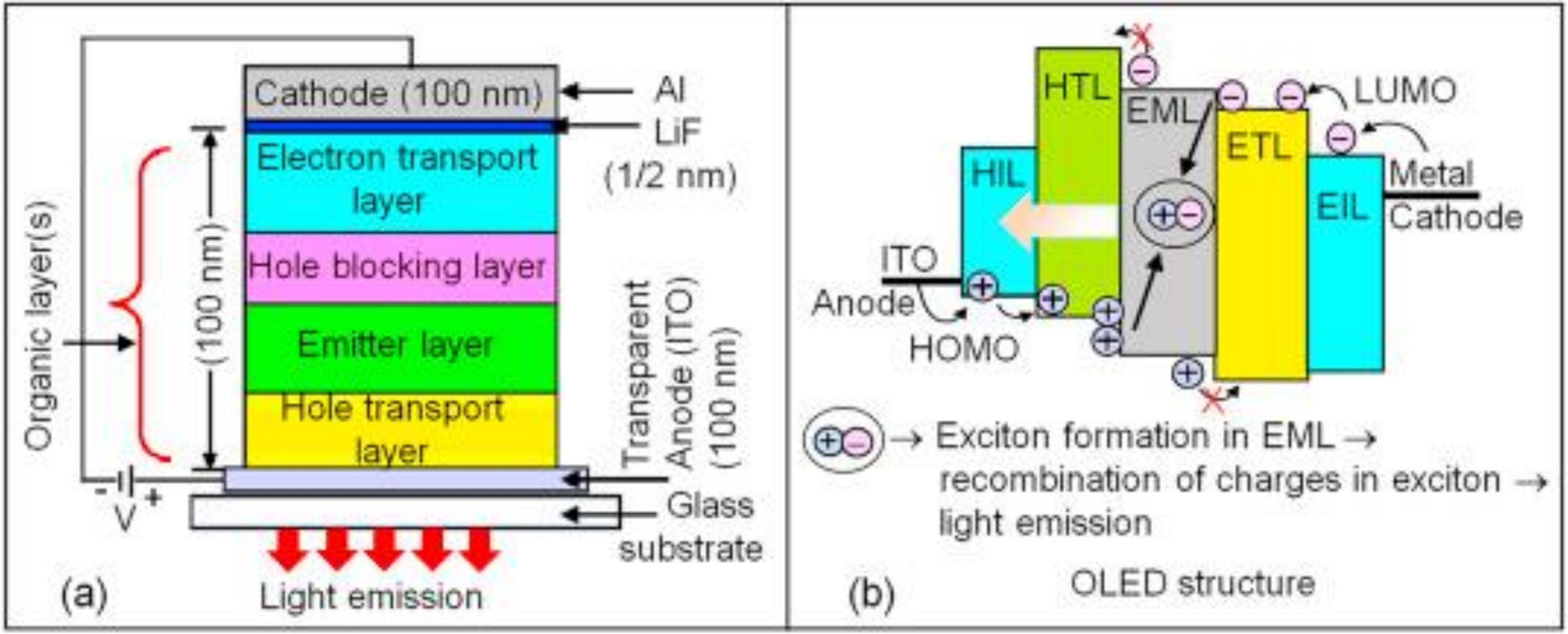

CATHODE
CATHODE
CATHODE
ANODE
Conductive Layer
Emissive Layer
1 Electrical current flows from the **cathode** to the **anode** through the organic layers, giving **electrons** to the **emissive layer** and removing electrons from the **conductive layer.**
Electron
Removing electrons from the conductive layer leaves **holes** that need to be filled with the electrons in the emissive layer. 2
3 The holes jump to the emissive layer and **recombine** with the electrons. As the electrons drop into the holes, they release their extra energy as **light.**
Light Photon


Method of OLED Emission
OLED Structure
Glass
Polarizer
Organic Layer
Substrate
R
G
B
Cathode
Electron Injection Layer
Supporting Layer
Electron Transporting Layer
Emission Material Layer
Hole Transporting Layer
Supporting Layer
Hole Injection Layer
Anode

Working Principle of OLED

Components and working:

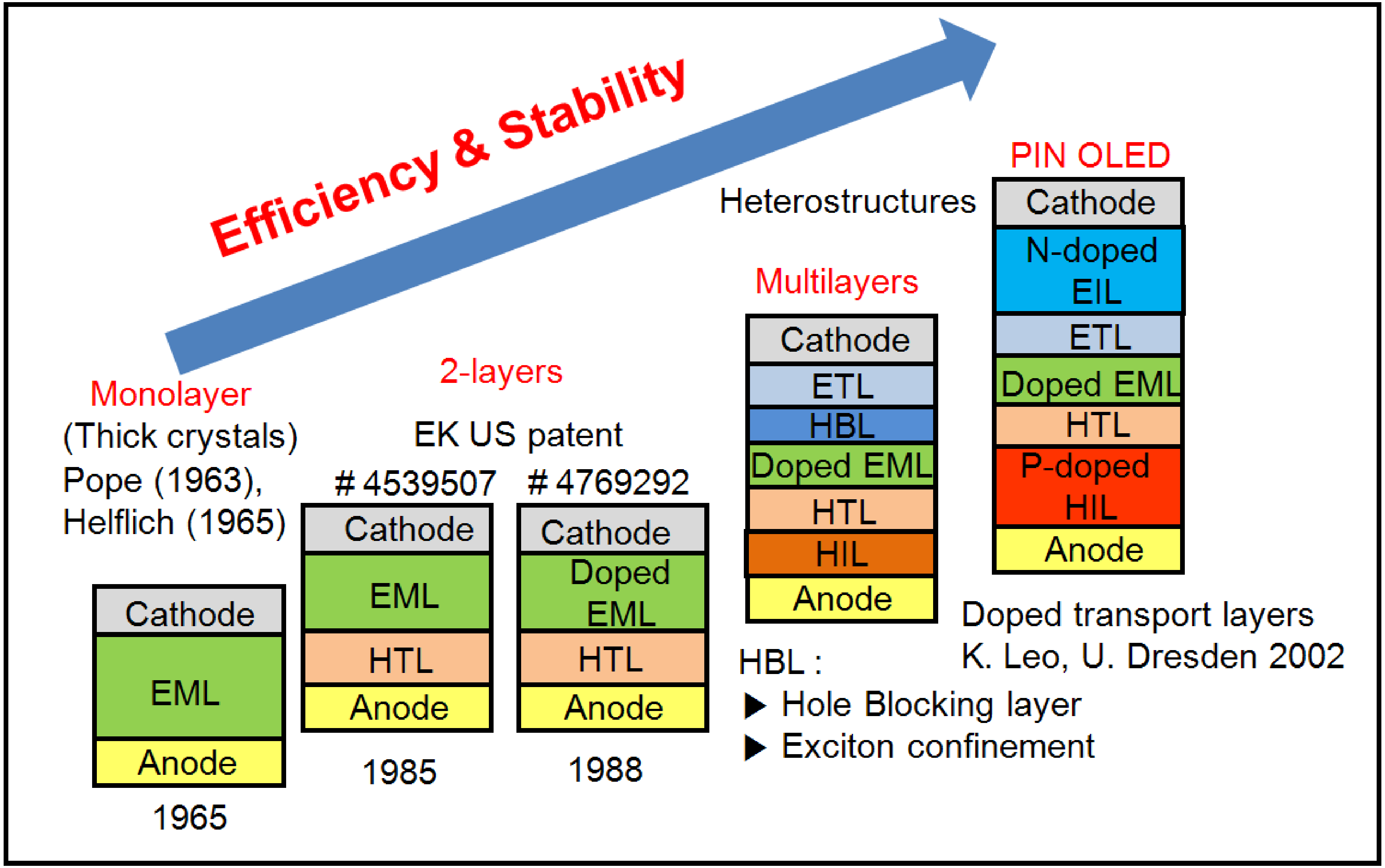
- The organic molecules are electrically conductive with conductivity levels ranging between insulators and conductors and hence they are considered as organic semiconductors.
- The anatomy of OLEDs can be single-layer, two-layer, triple-layer, or multilayer OLEDs.
- A single-layer OLED is made up of a single organic layer sandwiched between the cathode and the anode. This layer should have hole transport, electron transport, and emission capabilities. In this case, the injection of both the carriers should be the same; otherwise, the device will result in low efficiency because the excess of electrons or holes cannot combine.
- However, in a two-layer OLED, one organic layer is explicitly chosen to transport holes and the other layer is chosen to transport electrons, namely hole transport layer (HTL) and electron transport layer (ETL), respectively. Recombination of the hole–electron pair takes place at the interface between the two layers, generating electroluminescence.



https://doi.org/10.1016/j.rser.2020.110043

Organic layers in the structure of OLED display serve as a light emitter, consist of an emissive layer and ones that support light emission. The latter, supporting layers including Hole Injection Layer (HIL) and Hole Transport Layer (HTL) as well as Electron Injection Layer (EIL) and Electron Transport Layer (ETL), enable easier injection and transport of holes and electrons into Emissive Layer (EML).

Electrons that migrate from the cathode and holes from the anode are transported into and combined in the Emission Material Layer (EML). To work this out, injection layers help electrons and holes quickly inject, while transport layers support fast transport of electrons and holes.


Efficiency & Stability
Monolayer
(Thick crystals)
Pope (1963),
Helflich (1965)
Cathode
EML
Anode
1965
2-layers
EK US patent
4539507
4769292
Cathode
EML
HTL
Anode
1985
Cathode
Doped EML
HTL
Anode
1988
Heterostructures
Multilayers
Cathode
ETL
HBL
Doped EML
HTL
HIL
Anode
HBL :
▶ Hole Blocking layer
▶ Exciton confinement
PIN OLED
Cathode
N-doped EIL
ETL
Doped EML
HTL
P-doped HIL
Anode
Doped transport layers
K. Leo, U. Dresden 2002

OLED technology advantages:

- **Flexible:** It is possible to make OLED displays flexible
- **Very thin:** can be made very thin, making them very attractive for TV and computer monitor.
- **Colour capability:** It is possible to fabricate OLED displays that can generate all colours.
- **Power consumption:** The power consumed by an OLED display is generally less than that of an LCD
- **Bright images:** OLED displays can provide a higher contrast ratio than that obtainable with an LCD.
- **Wide viewing angle:** With many displays, the colour becomes disported and the image less saturated as the viewing angle increases. Colours displayed by OLEDs appear correct, even up to viewing angles approaching 90°.
- **Fast response time:** As LCDs depend upon charges being held in the individual pixels, they can have a slow response time. OLEDs are very much faster. A typical OLED can have a response time of less than 0.01ms.

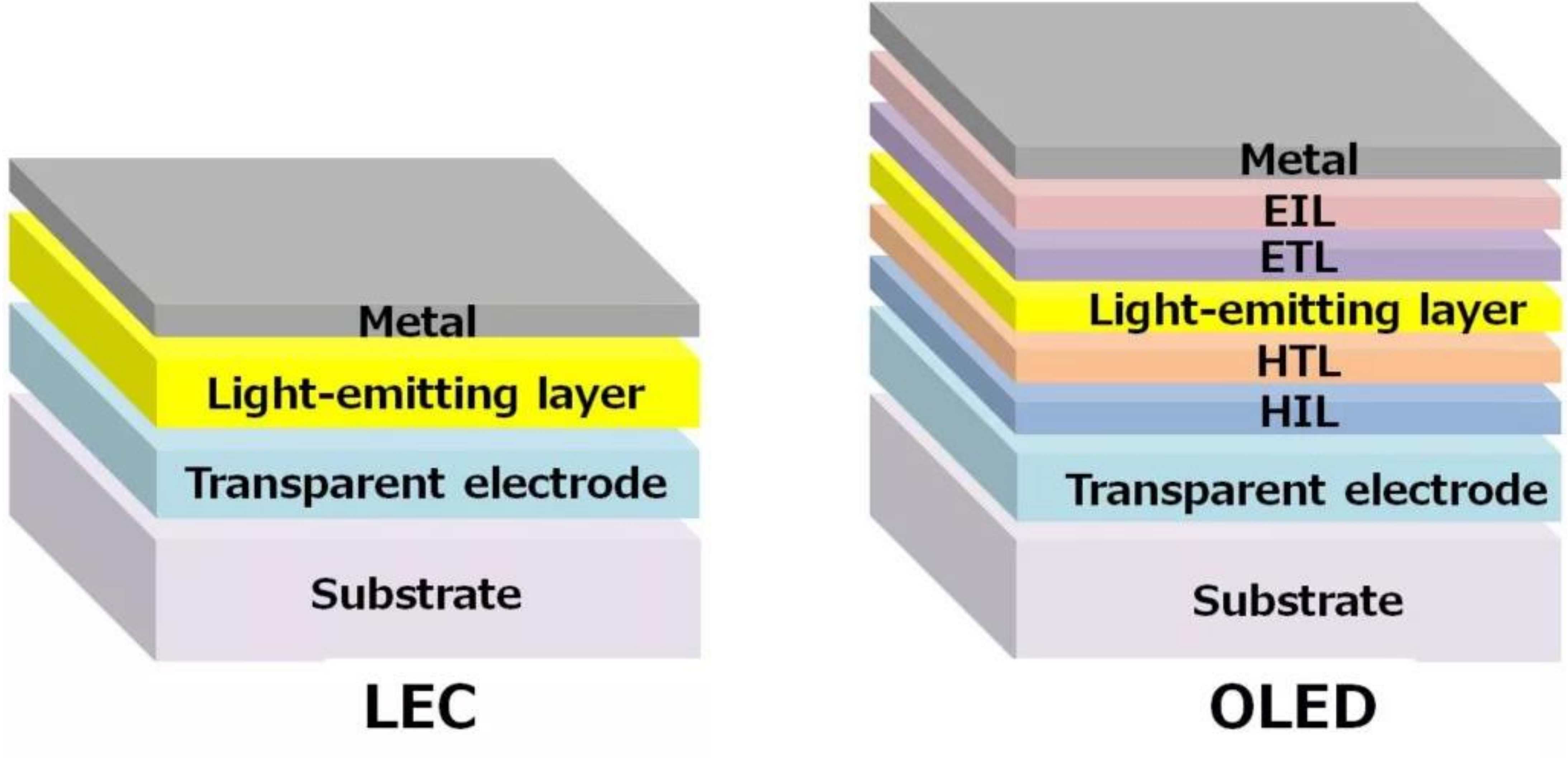
OLED technology disadvantages:

- Moisture sensitive: Some types of OLED display can be sensitive to moisture.
- **Limited life:** The lifetime of some displays can be short as a result of the high sensitivity to moisture. This has been a limiting factor in the past.
- **Power consumption:** Power consumption can be higher than an equivalent LCD when white backgrounds are being viewed as the OLED needs to generate the light for this which will consume more power. For images with a darker background power consumption is generally less.
- **Lifespan:** The lifespan of the OLED displays is a major problem. Currently they are **around half that of an LCD, being around 15 000 hours.**
- **UV sensitivity:** OLED displays can be damaged by prolonged exposure to UV light. To avoid this a UV blocking filter is often installed over the main display, but this increases the cost.
- OLEDs, still employ air sensitive electrodes requiring rigorous encapsulation, are usually vacuum deposited, and possess a complex multilayer architecture that adds to the cost of fabrication

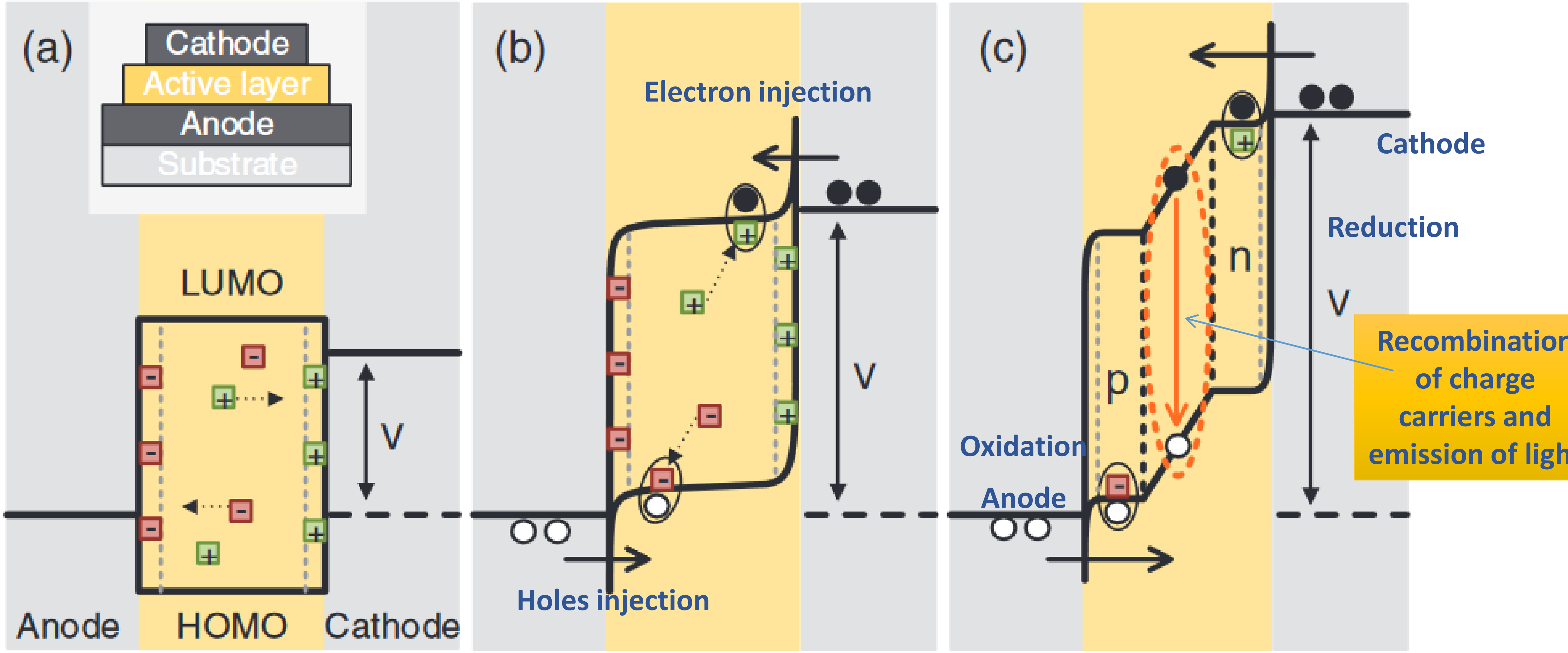
Light emitting electrochemical cells

- Light-emitting electrochemical cells (LECs or LEECs)) are a promising new type of lighting device, consisting of a single-layer electroluminescent material in an ionic environment.
- In the mid-1990s Pei and co-workers discovered that the properties of OLEDs can be drastically altered by mixing high concentrations of mobile ions with a conjugated polymer and a solid electrolyte.
- LECs comprise ionic species in the active layer, which leads to the omission of additional organic charge injection and transport layers and reactive cathode materials, thus LECs impress with their simple device architecture.
- LECs are usually composed of two metal electrodes (air-stable electrodes, such as gold, silver, or aluminum,) connected by (e.g. sandwiching) an organic semiconductor containing mobile ions.
- They operate with low voltages, which allows for high power efficiencies, and air-stable electrodes, which simplifies the encapsulation requirements.
- The luminescent material is either a conjugated light-emitting polymer in combination with inorganic salts or an ionic transition-metal complex (iTMC) used in polymer-based LECs (PLECs) or iTMC-LECs

Device comparison of LEEC and OLED



Operation mechanism of LEECs



Energy level diagram to underline the LEC working principle: a) directly after device turn-on / low applied voltages, b) after formation of EDLs as well as c) after formation of p- and n-doped regions.

Ekaterina Nannen et al, Adv. Funct. Mater.2020, 30, 1907349, DOI: 10.1002/adfm.201907349

Operation mechanism of LEECs

1. Under applied voltage the ionic components, present in the active layer, start moving due to the electrical field toward the oppositely charged electrodes (Figure a).

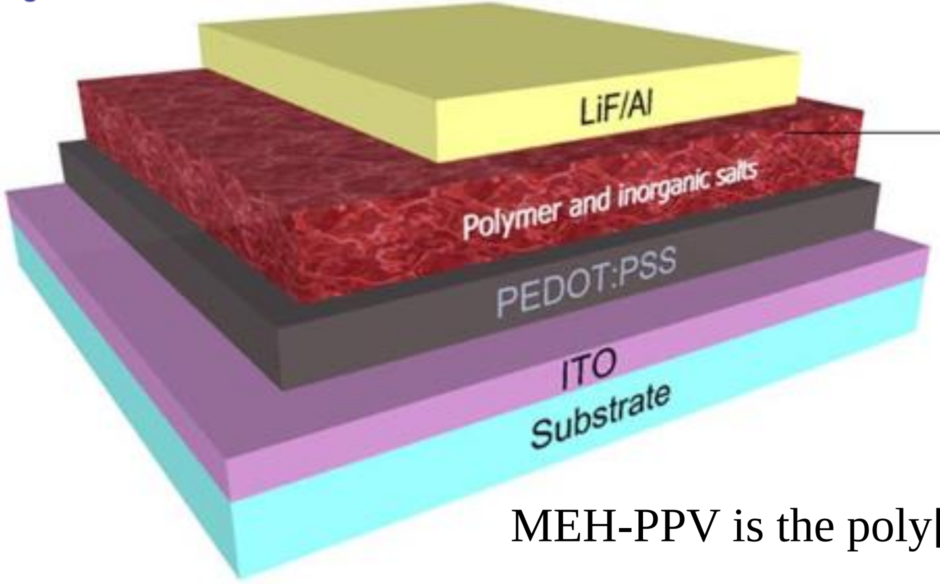
2. The accumulated ions form so called electronic double layers (EDLs), which facilitate the charge injection (electrons at cathode and holes at anode) into the active layer via tunneling processes (Figure b).

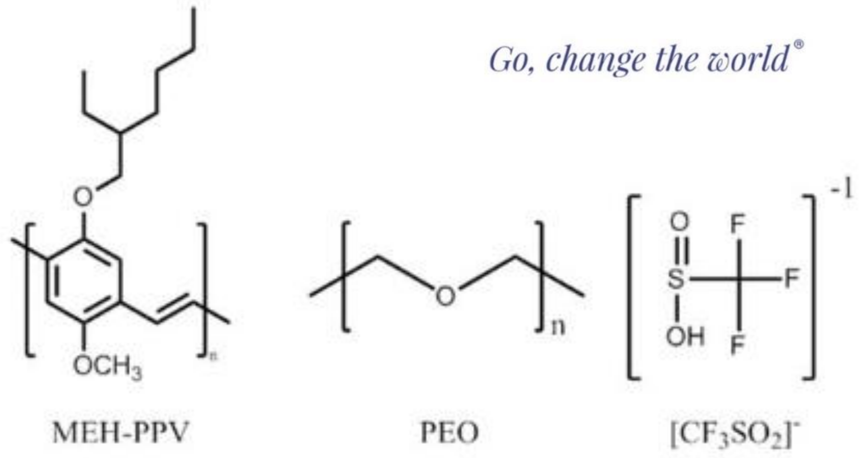
3. The injection of charge carriers (electrons and holes) lead to the oxidation at anode and reduction at cathode, of the organic molecules, which is compensated by anions and cations, respectively.

4. This results in the formation of electrochemically p- and n-doped regions, which are conductive and grow with increasing applied voltage and/or operation time.

5. The injected and transported charge carriers recombine radiatively in the remaining intrinsic region (Figure c). As a result the light is being emitted by the cell.

a)



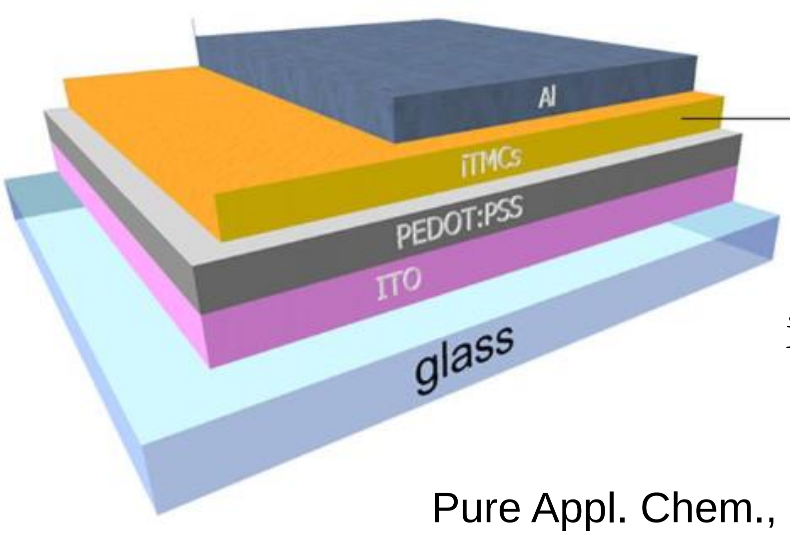


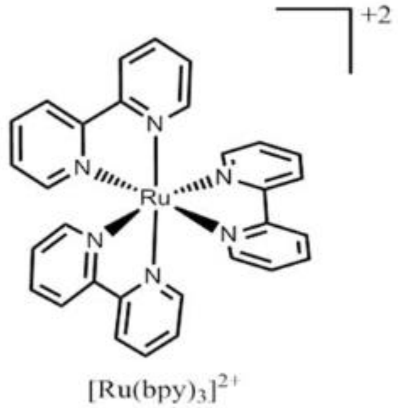
PEO is poly-(ethylene oxide)

MEH-PPV is the poly[5-(2'-ethylhexyloxy)-2-methoxy-1,4-phenylene vinylene

[CF 3SO3]– is trifluoromethyl sulfonate

b)



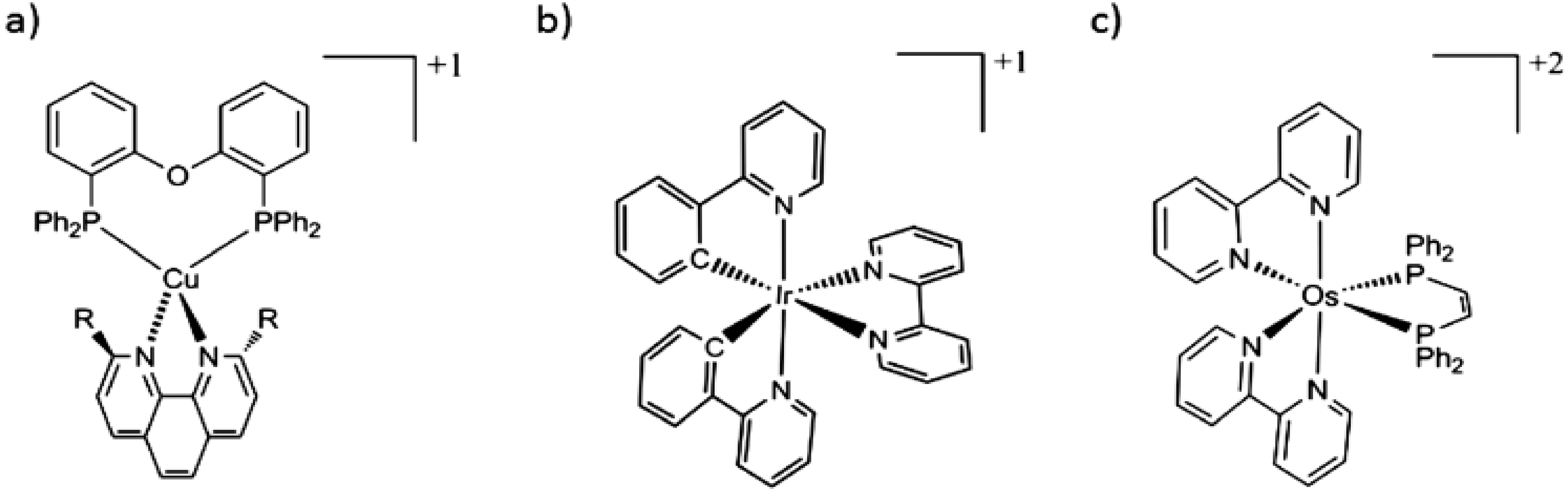


iTMC-LECs. [Ru(bpy) 3]2+ where bpy is 2,2'-bypiridine

Two Types of PEC: Schematic representation of a typical (a) PLEC and (b) iTMC-LEC.

Pure Appl. Chem., Vol. 83, No. 12, pp. 2115–2128, 2011. doi:10.1351/PAC-CON-11-07-20

Chemical structure of several iTMCs conventionally used as the unique electroactive material in LECs



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Advantages of LECs

- 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). Similarly, the device can still be operated at low voltages.
- Recently 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).
- In a planar device configuration, internal device operation can be observed directly.

Question Bank

1. What is electronic memory ?
2. What does 0 and 1 represents in the memory devices?
3. Explain the classification of electronic memory?
4. Discuss the types of memory devices?
5. Give an examples for volatile and non-volatile memory devices.
6. What is Cache Memory? Highlight its significance.
7. What is transistor? Explain the data storage mechanism in NPN transistor.
8. How many transistors are there in a 1GB Static Random Access Memory (SRAM)?
9. Discuss the principle and working of resistor type memory storage device.
10. What is memristor?
11. Explain the the switching mechanism of the $Cu/Cu_{2-\alpha}/Pt$ memristor device, used in RRAM.
12. Compare Optical and Magnetic storage devices with examples.
13. Write the structure of TCNQ, PCBM and Pentacene molecules used in memory devices.
14. Give and examples for polymer, inorganic and organometallic based materials used in memory devices.
15. What are photo-electro-active polymer for memories? Give an examples.
16. Explain the significance of bio composite based memory devices with suitable example.
17. Describe the semiconductor chips manufacturing process.
18. What are liquid crystals? Explain types and their characteristics.
19. Discuss the working principle and significance of all the components of liquid crystal display (LCDs) with schematic diagram.
20. What is Pixel in display technology? Highlight its significance.
21. Highlight the role of polarizer, liquid crystal, and TFT electrodes in LCDs.
22. List the advantages and limitations of LCDs.
23. Describe the construction and working principle of organic light emitting diode with the schematic diagram used in OLED display devices.
24. List the advantages and disadvantages of OLED.
25. Explain the electroluminescent mechanism of light emitting electrochemical cell (LEEC) with schematic diagram.
26. Write a schematic representation of PLEC and iTMC-LEEC.
27. List the applications of LEECs.