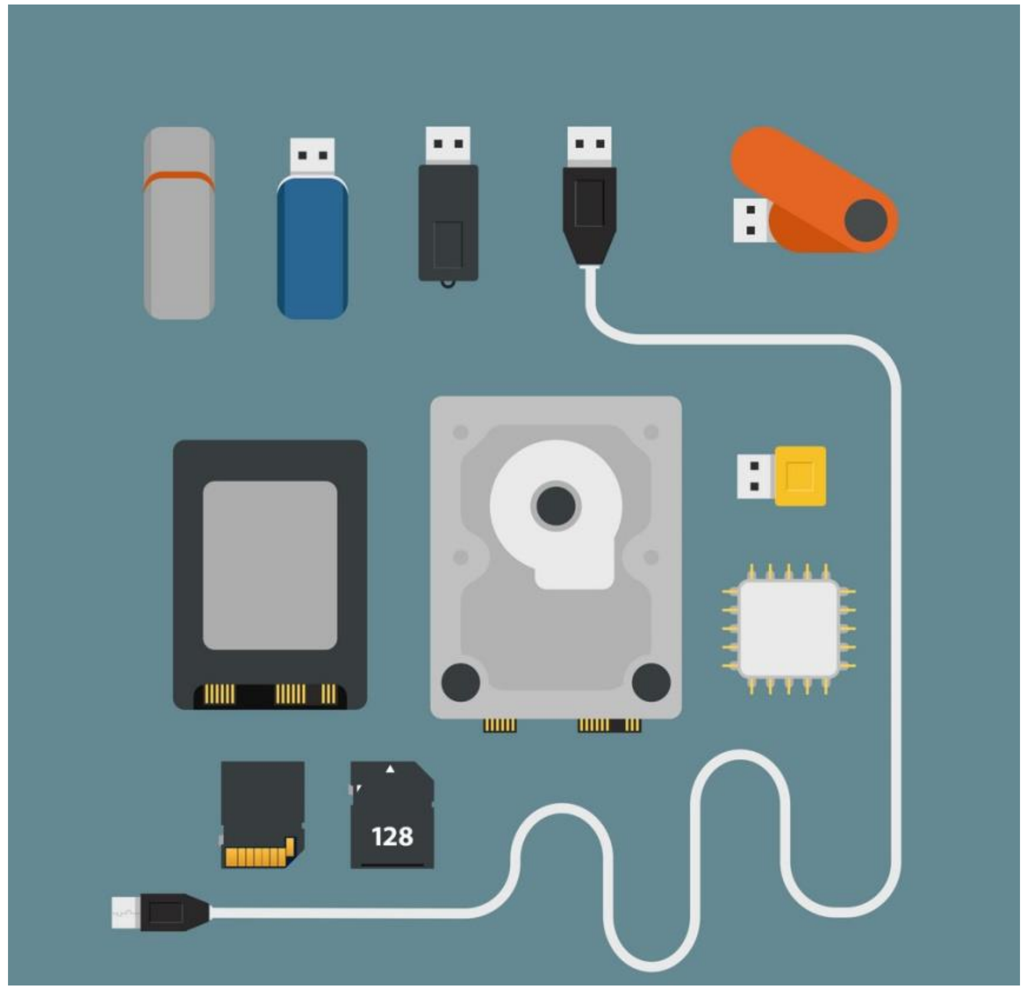
UNIT-III

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

Memory storage

Computer storage devices:
The storage device is a hardware device that is used to store data and information. They Provide one of the core functions of the modern computer. Every desktop computer, laptop, smartphone, and tablet will have some kind of storage device within it. It can be inside or outside of the computer or the main device. They come in different sizes and shapes depending on the needs and functionalities.

Computer storage or memory devices



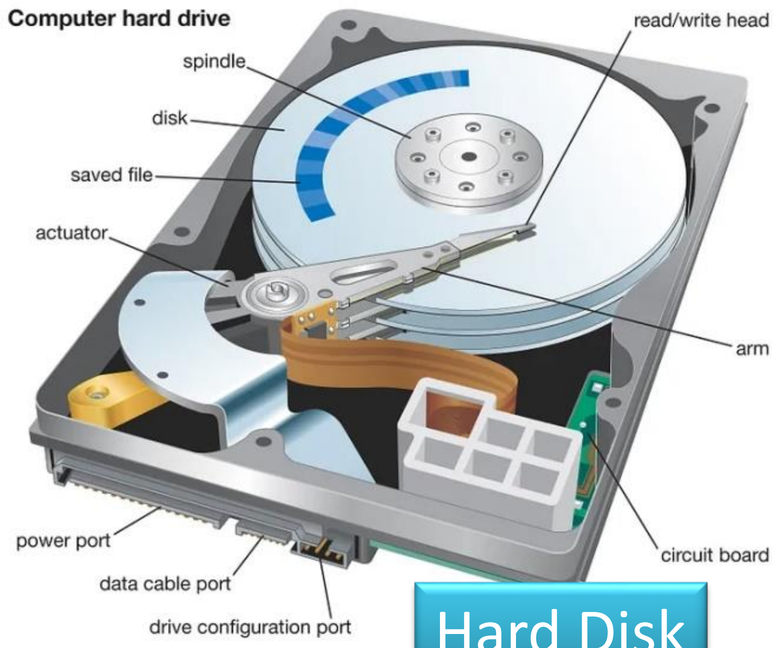
Memory storage devices

Internal Hard disk

External Hard disk

Magnetic tape

Floppy Disk



Hard Disk

Memory Card

Online Cloud storage devices

Pen drive

Characteristics of memory devices

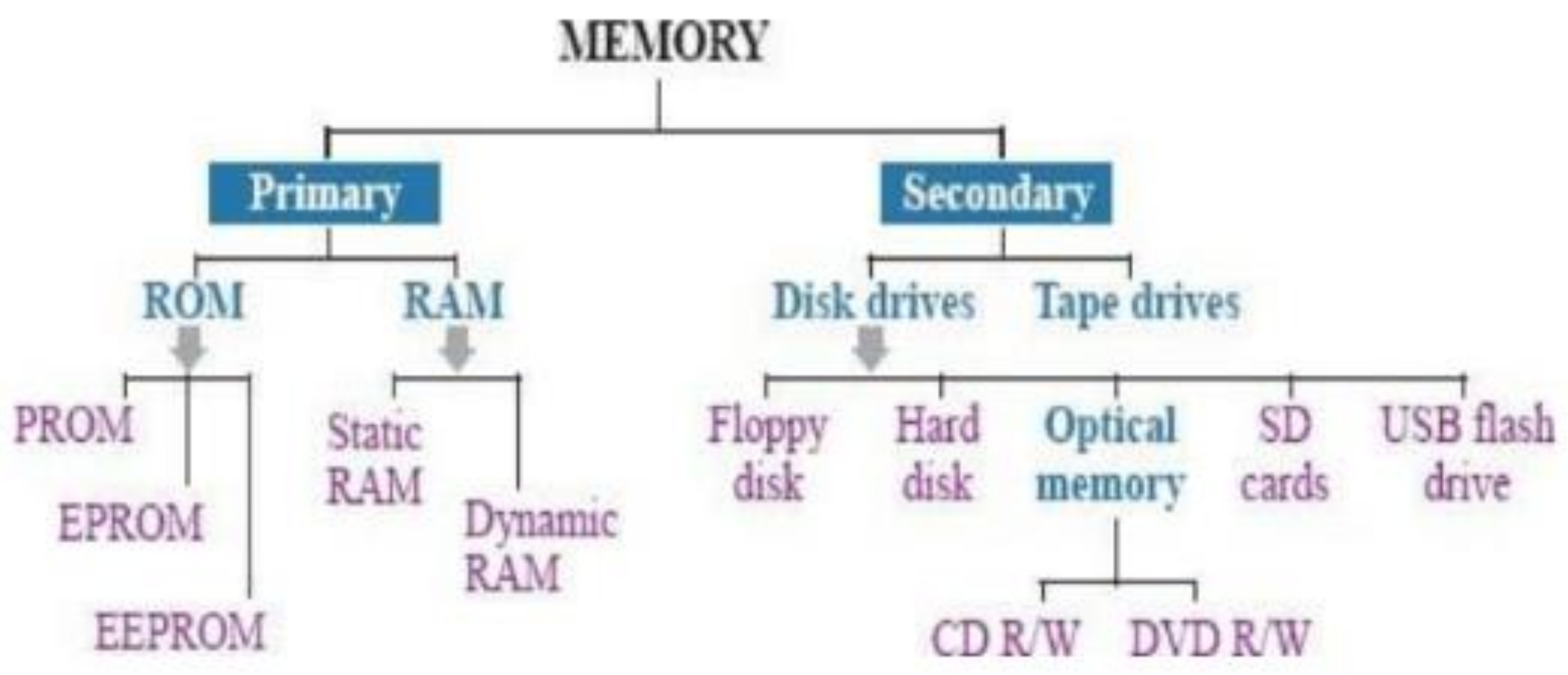
Location: The memory can either be stored externally with the help of some devices or internally.

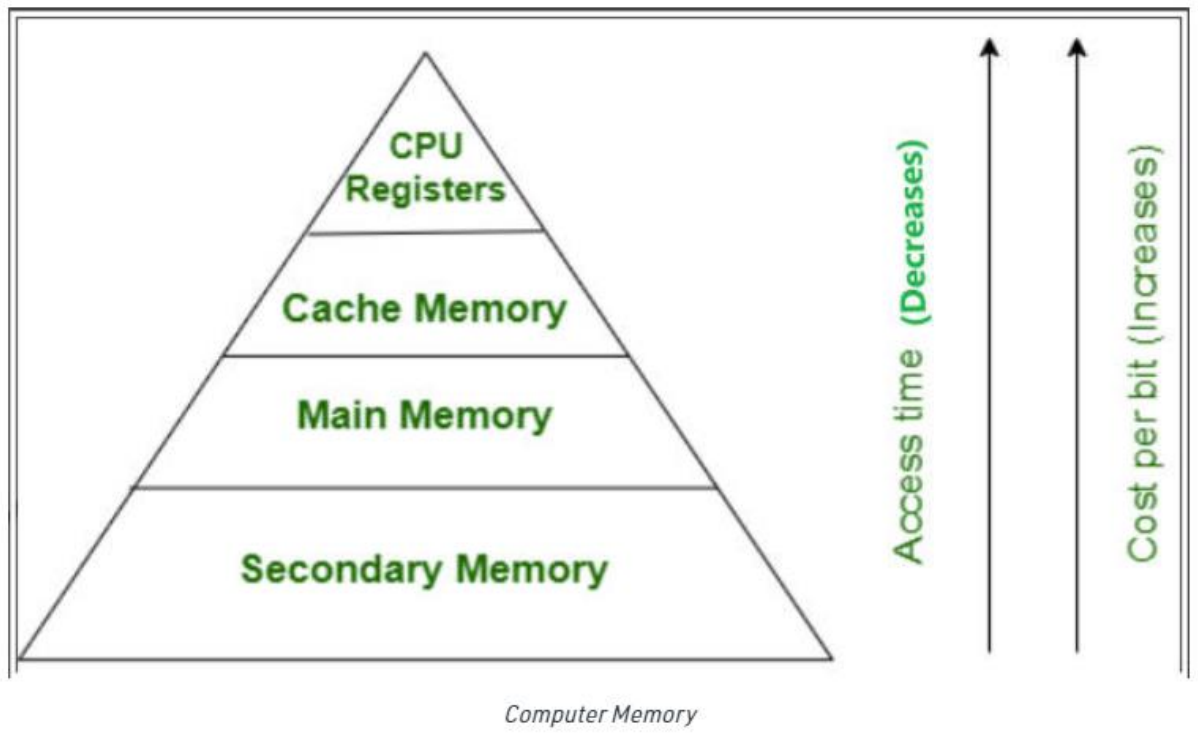
Capacity: The amount of data a device can store is called capacity. It is measured as a byte (1 byte = 8 bits, 1 bit is either 0 or 1).

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.

Classification of memory devices

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)





Difference between primary and secondary 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

Primary memory

It is used to store data and programs or instructions during computer operations. It uses semiconductor technology and hence is commonly called semiconductor memory.

Types of primary memory

1. RAM (Random Access Memory)

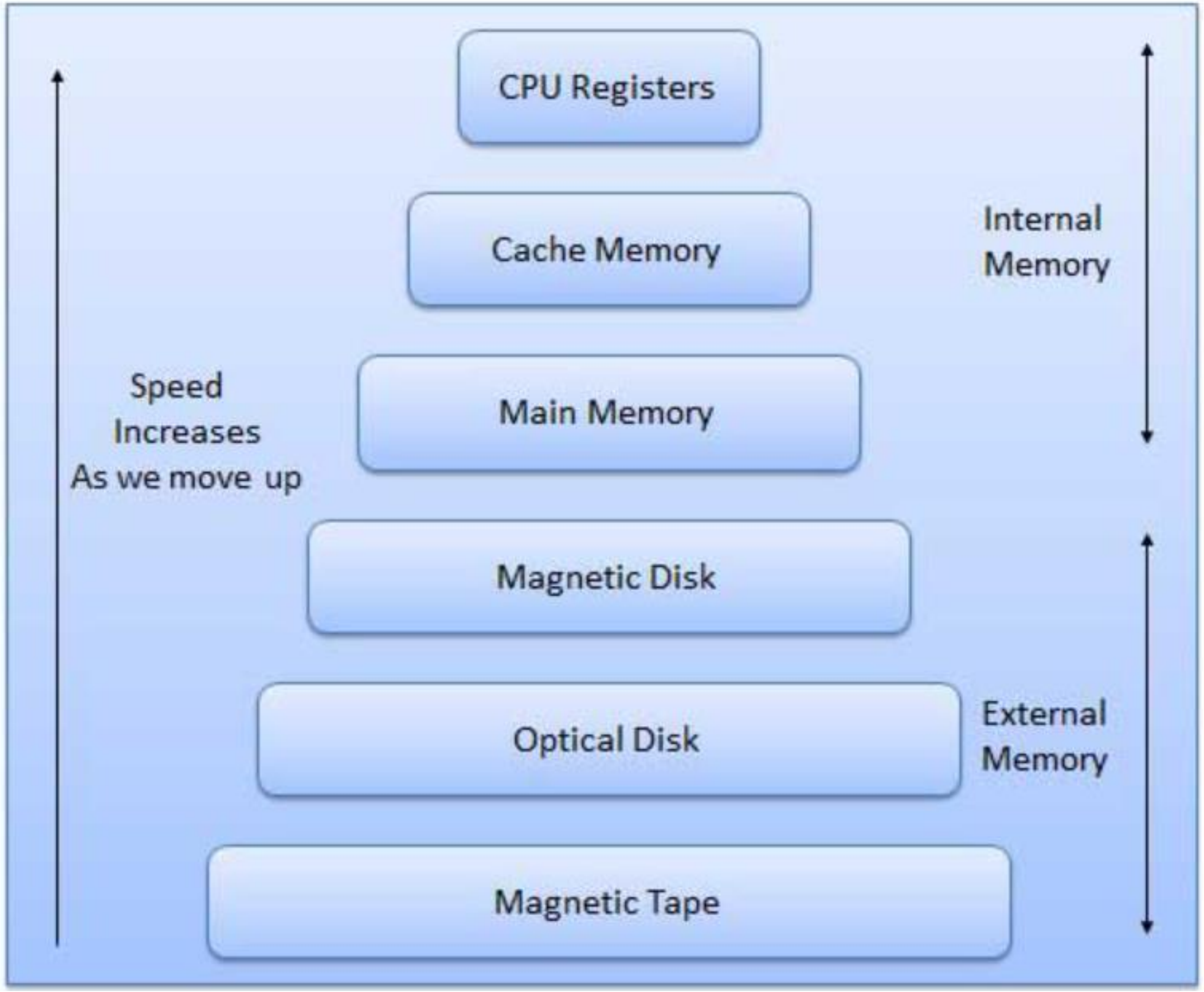
(i) S RAM (Static RAM)
(ii) D RAM (Dynamic RAM)

2. 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

(i) MROM(Masked ROM)
(ii) PROM (Programmable Read Only Memory)
(iii) EPROM (Erasable Programmable Read Only Memory)
(iV)EEPROM (Electrically Erasable Programmable Read Only Memory)

Introduction to memory devices



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.

Secondary memory

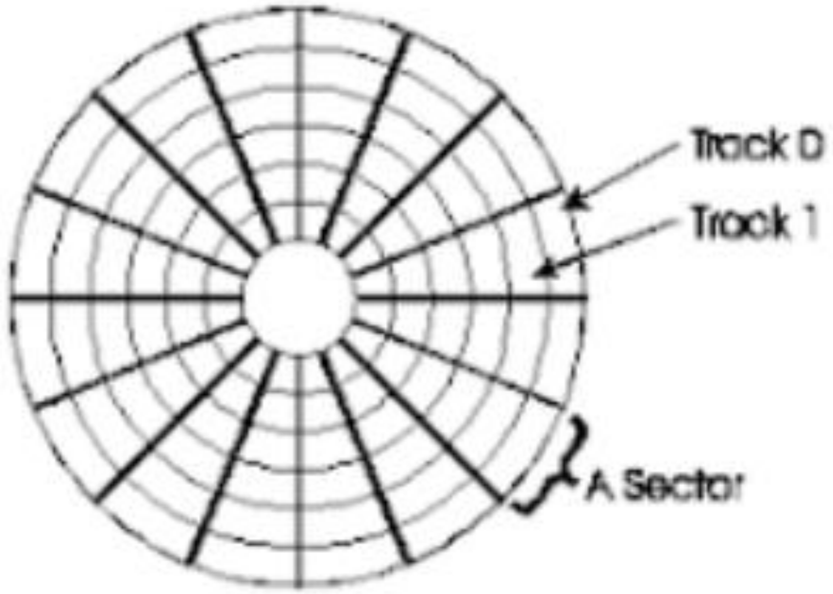
(i) Magnetic Tapes: Magnetic tape is a long, narrow strip of plastic film with a thin, magnetic coating on it that is used for magnetic recording. Bits are recorded on tape as magnetic patches called RECORDS that run along many tracks. Typically, 7 or 9 bits are recorded concurrently. Each track has one read/write head, which allows data to be recorded and read as a sequence of characters. It can be stopped, started moving forward or backward, or rewound.

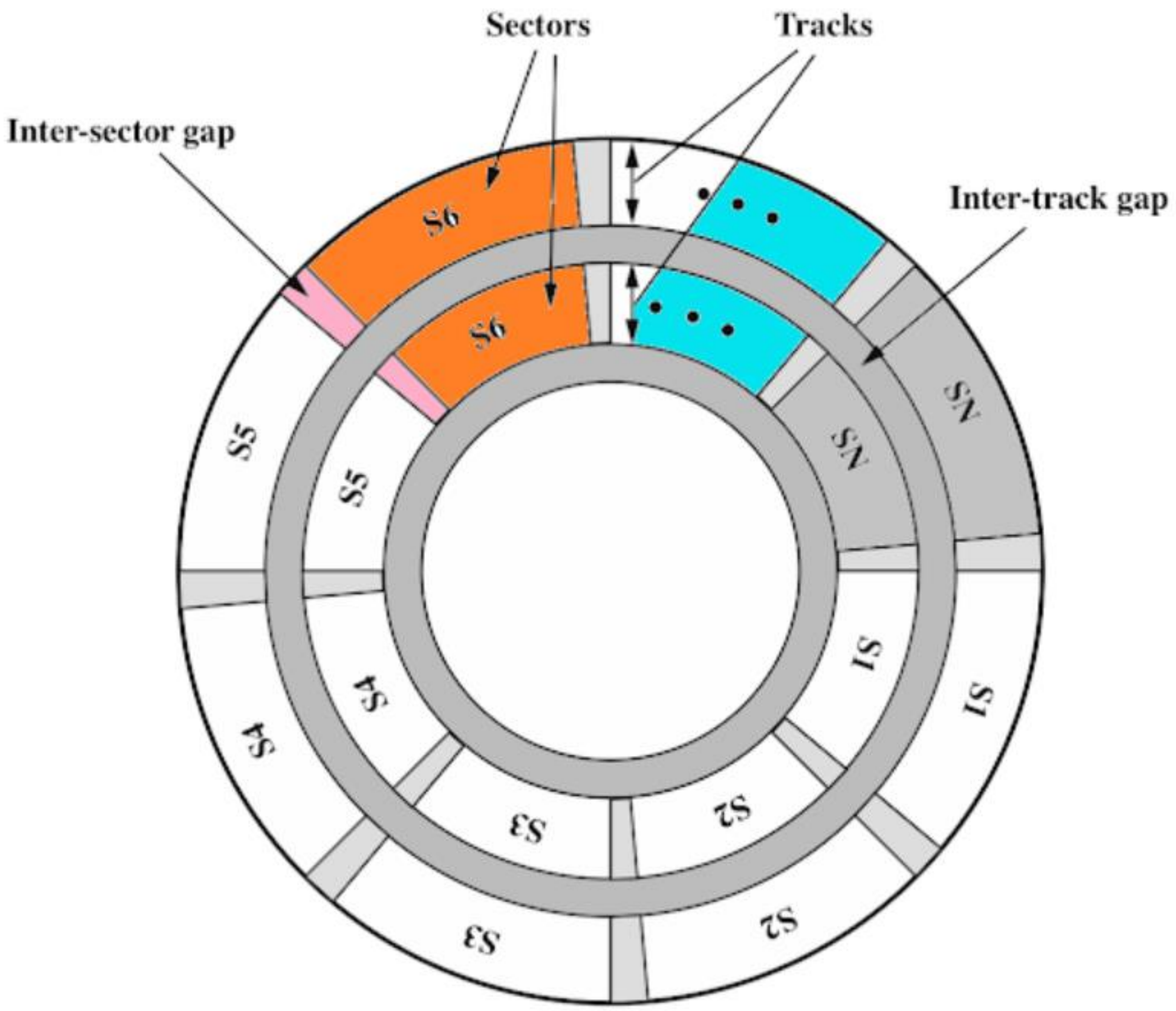
[Fritz Pfleumer with his magnetic tape machine (1931)]

Austro-German engineer Fritz Pfleumer (1881 – 1945) coated 16 mm wide paper strips with fine granules of iron powder as a medium for magnetic recording. He received a patent in 1928 for his “sound paper machine” that he licensed to AEG, Berlin.

Types of secondary memory

(ii) Magnetic Disks: A magnetic disc is a circular metal or a plastic plate and these plates are coated with magnetic material. The disc is used on both sides. Bits are stored in magnetized surfaces in locations called tracks that run in concentric rings. Sectors are typically used to break tracks into pieces.





(iii) Optical Disks: It's a laser-based storage medium that can be written to and read. It is reasonably priced and has a long lifespan. The optical disc can be taken out of the computer by occasional users.

Types of Optical Disks

CD – ROM

It's called Compact Disk. Only read from memory

- Information is written to the disc by using a controlled laser beam to burn pits on the disc surface.
- It has a highly reflecting surface, which is usually aluminium.
- The diameter of the disc is 5.25 inches.
- 16000 tracks per inch is the track density.

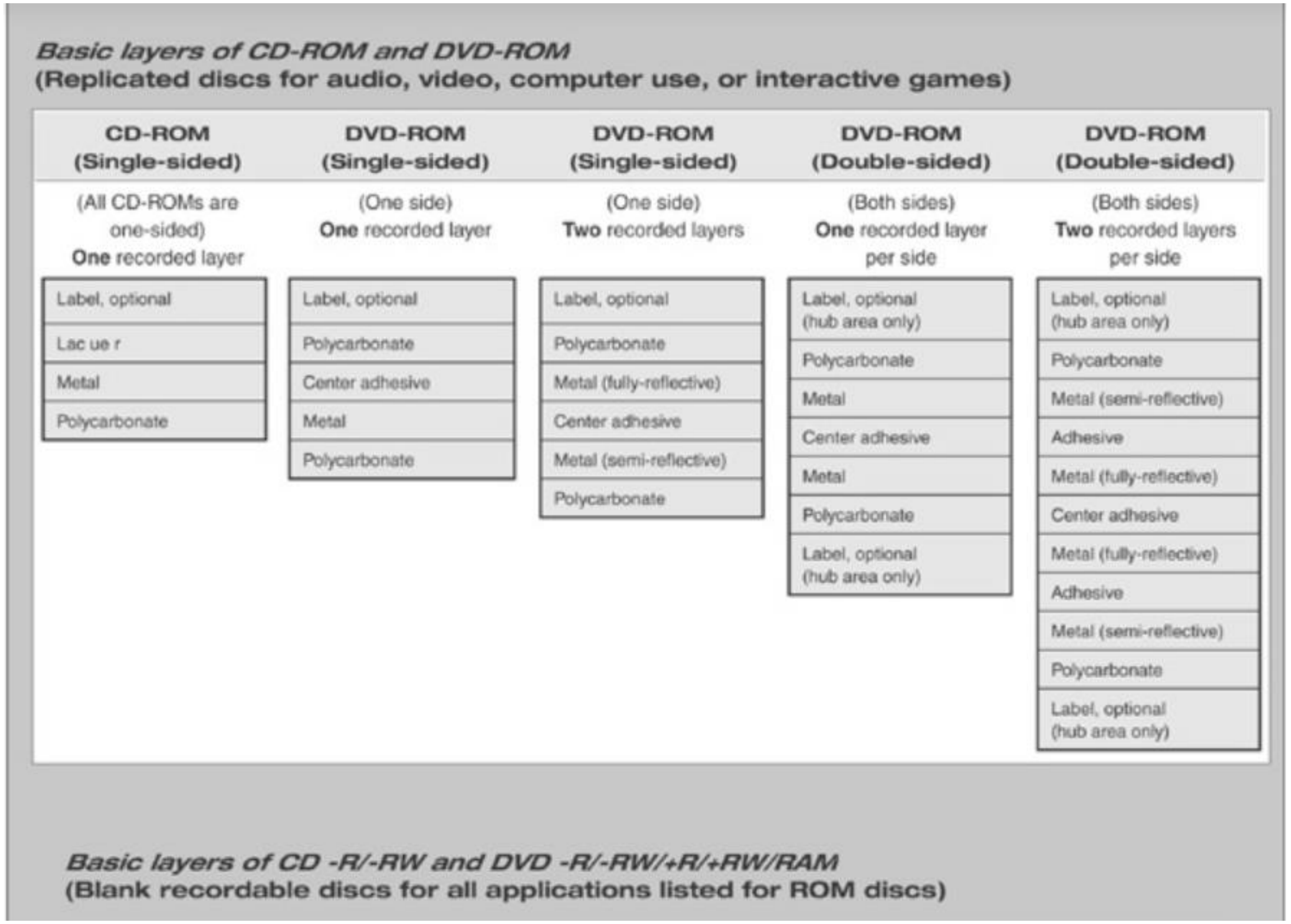
- The capacity of a CD-ROM is 600 MB, with each sector storing 2048 bytes of data.
- The data transfer rate is about 4800KB/sec. & the new access time is around 80 milliseconds

DVDs

The term —DVD‖ stands for —Digital Versatile/Video Disc and there are two sorts of DVDs:

(i) DVDR (writable)

(ii) DVDRW (Re-Writable)

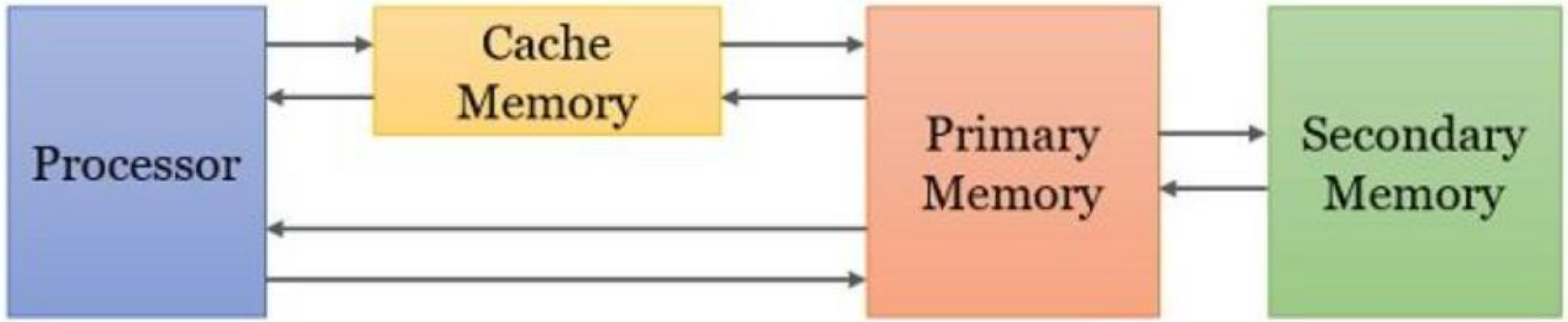


DVD-ROMS (Digital Versatile Discs)
These are read-only memory (ROM) discs that can be used in a variety of ways. When compared to CD-ROMs, they can store a lot more data. It has a thick polycarbonate plastic layer that serves as a foundation for the other layers. It’s an optical memory that can read and write data.

DVD-R: It is a writable optical disc that can be used just once. It’s a DVD that can be recorded. It’s a lot like WORM. DVD-ROMs have capacities ranging from 4.7 to 17 GB. The capacity of 3.5 inch disk is 1.3 GB.

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



Cache Memory Diagram

- The capacity of the cache ranges from 2 KB to a few MB.

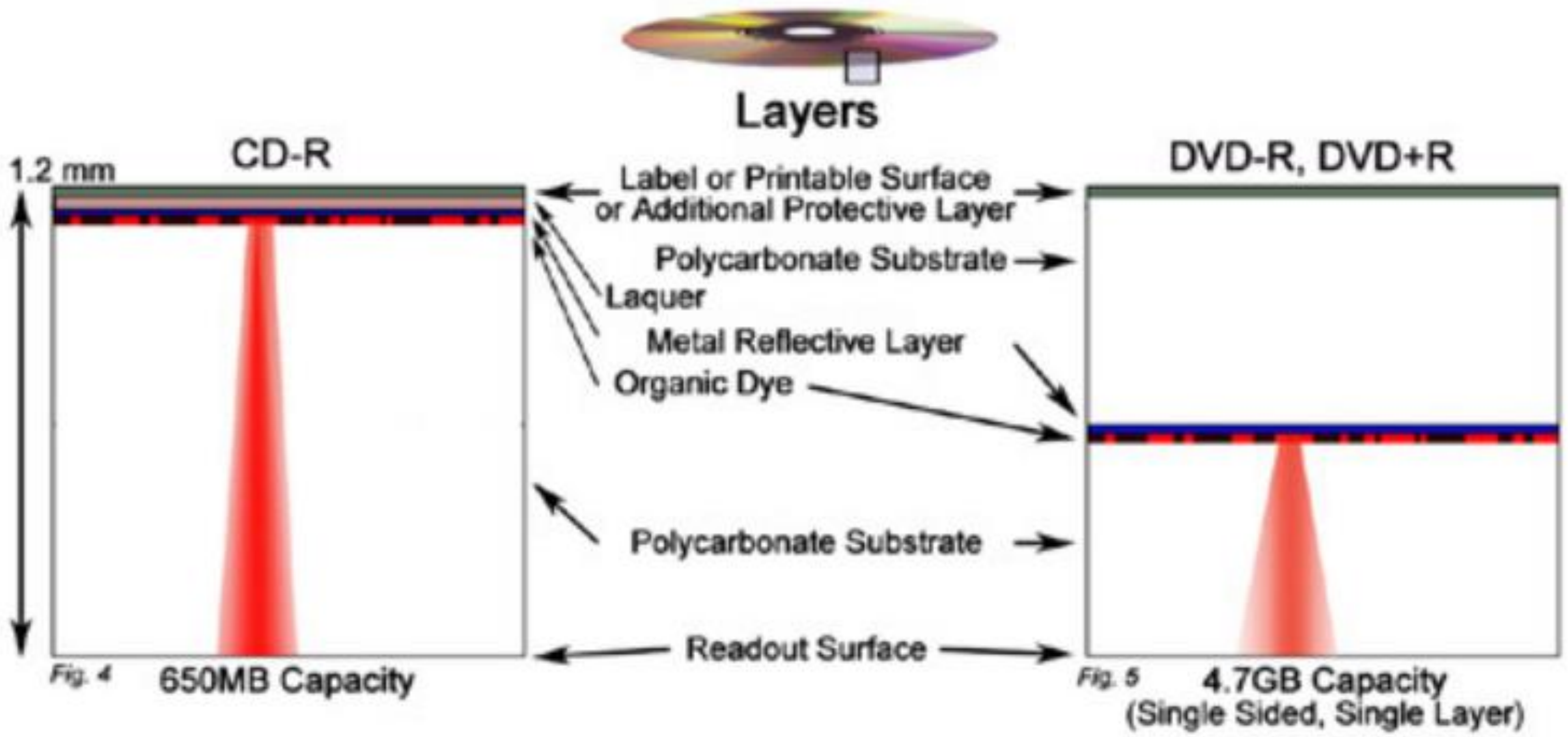
Cache memory

Advantages of Cache memory

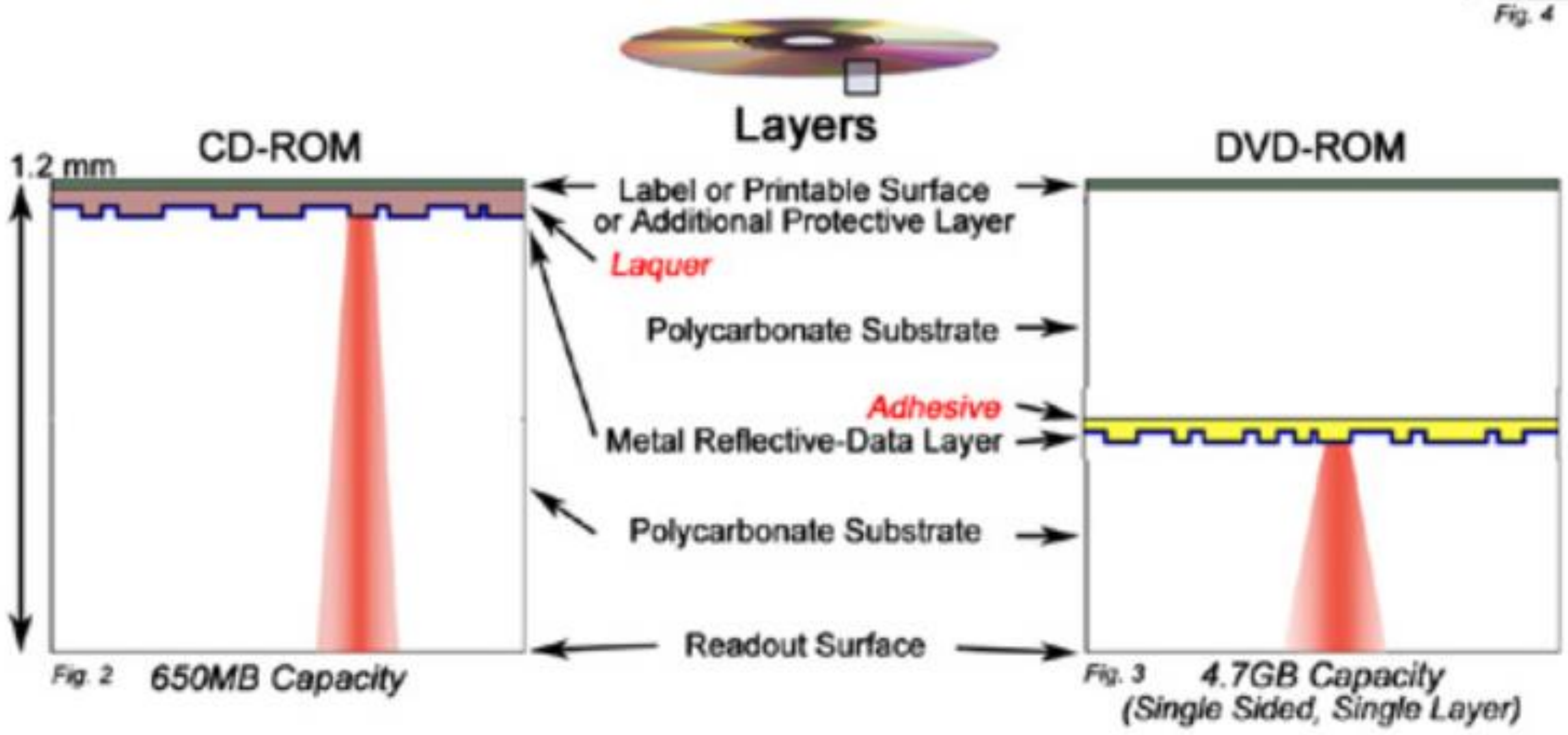
- It is faster than the main memory.
- When compared to the main memory, it takes less time to access it.
- It keeps the programs that can be run in a short amount of time.
- It stores data in temporary use.

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.

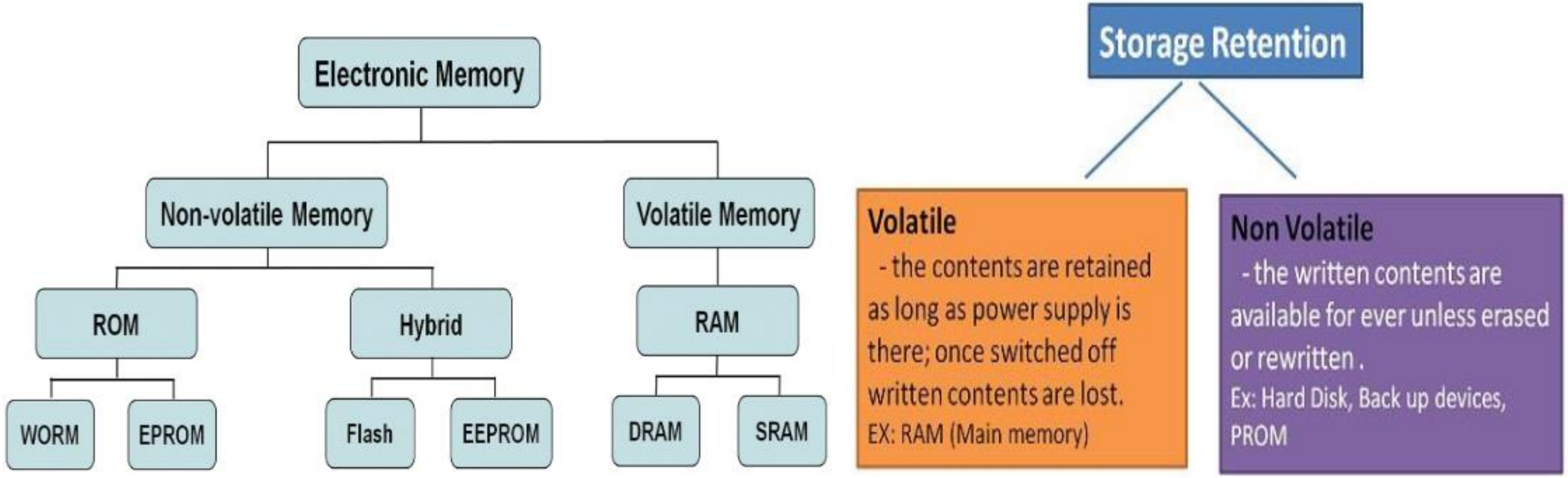


Layers that make up R discs



Layers that make up ROM discs

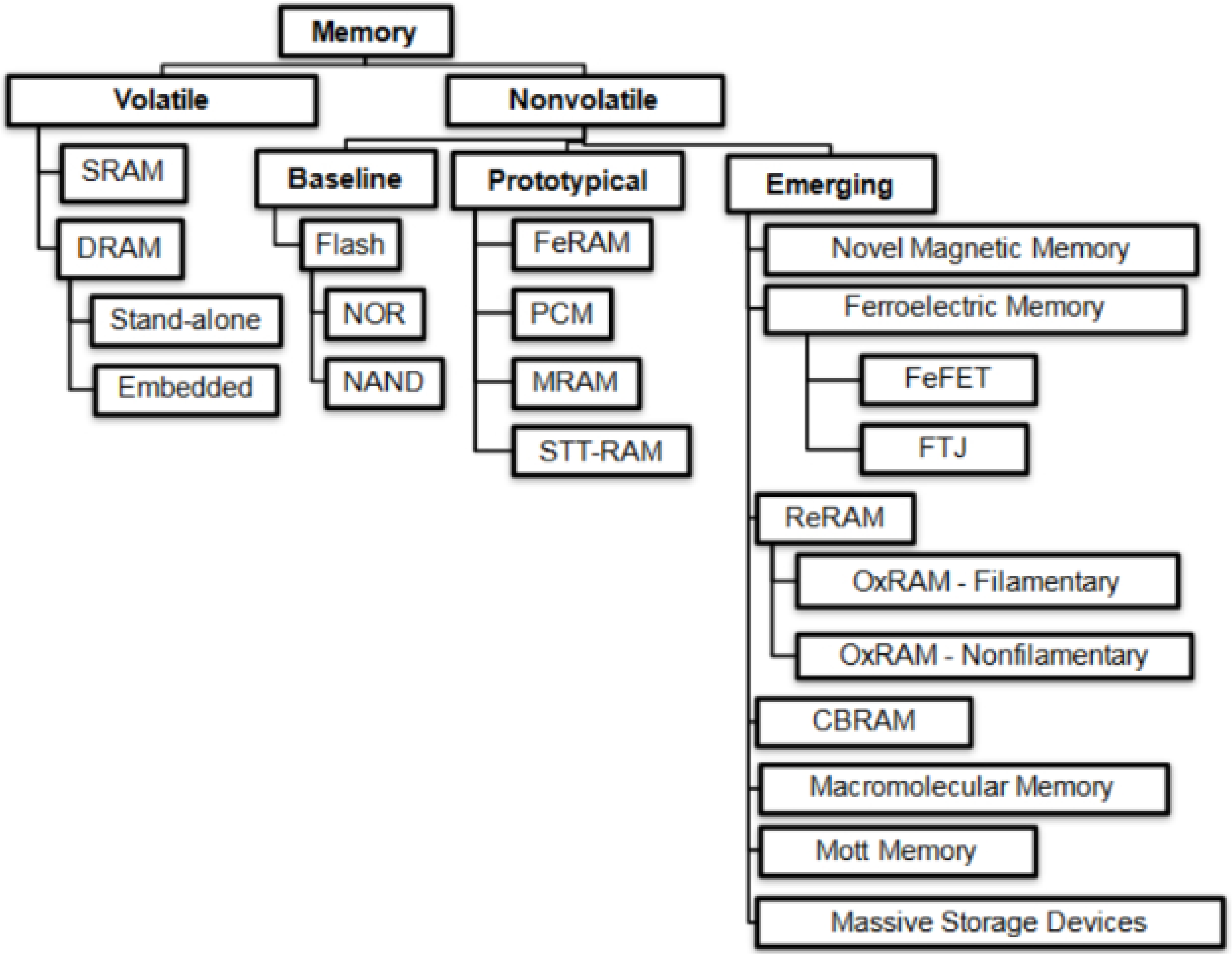
Electronic memory



- Volatile memory loses the stored information unless it is provided with a constant power supply or refreshed periodically with a pulse.

- Non volatile memory can retain stored information even after power is removed.

Taxonomy of 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.

Contd.,

- 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

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 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 silver electrodes can act as memristors.
- Recent; organic-based resistive memory materials, biodegradable memory devices.

Classification of Electronic Memory

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

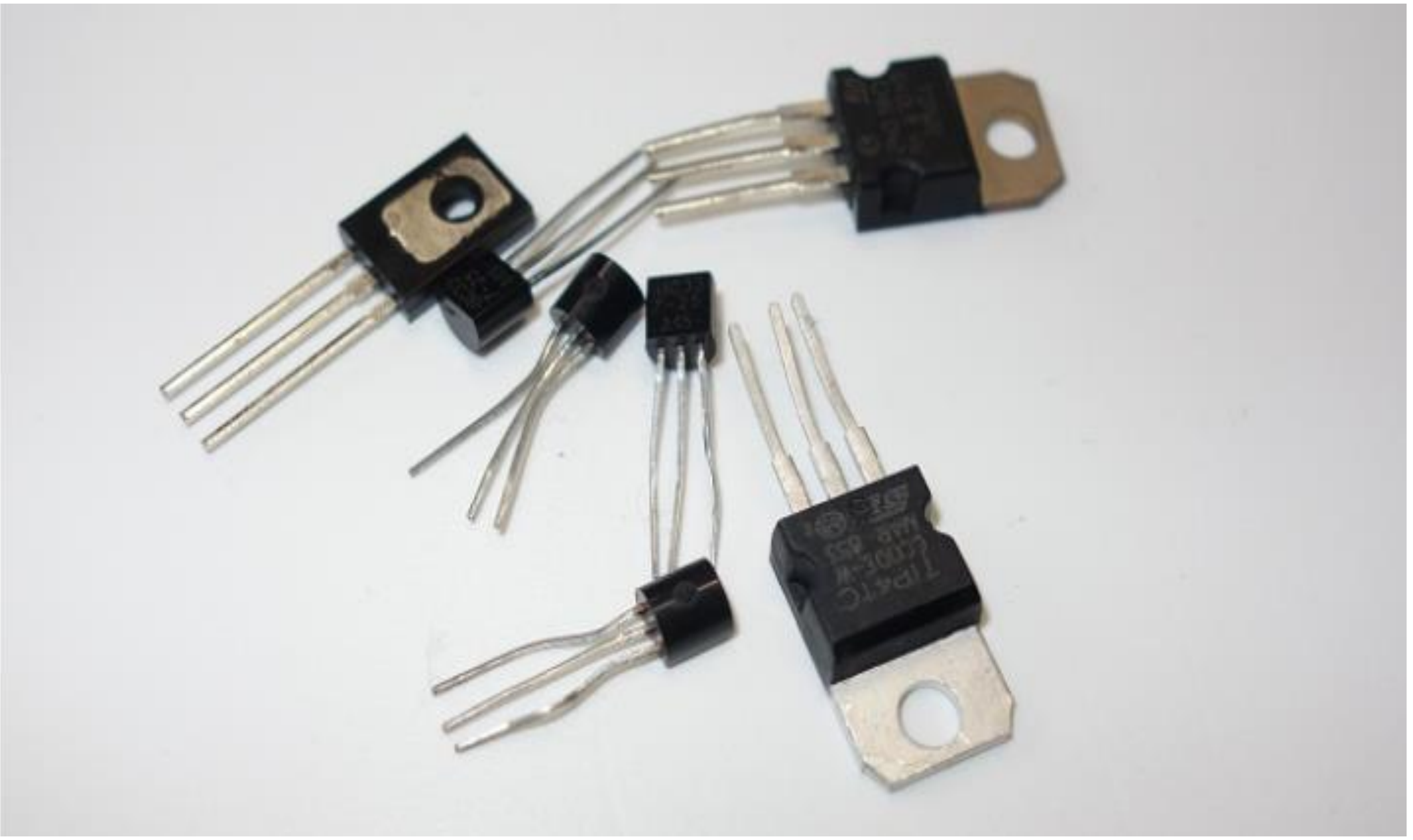
Memory Devices: Classification of memory devices;

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

1. Transistor-type Electronic Memory

1. A transistor is a semiconductor device used to amplify or switch electrical signals and power.

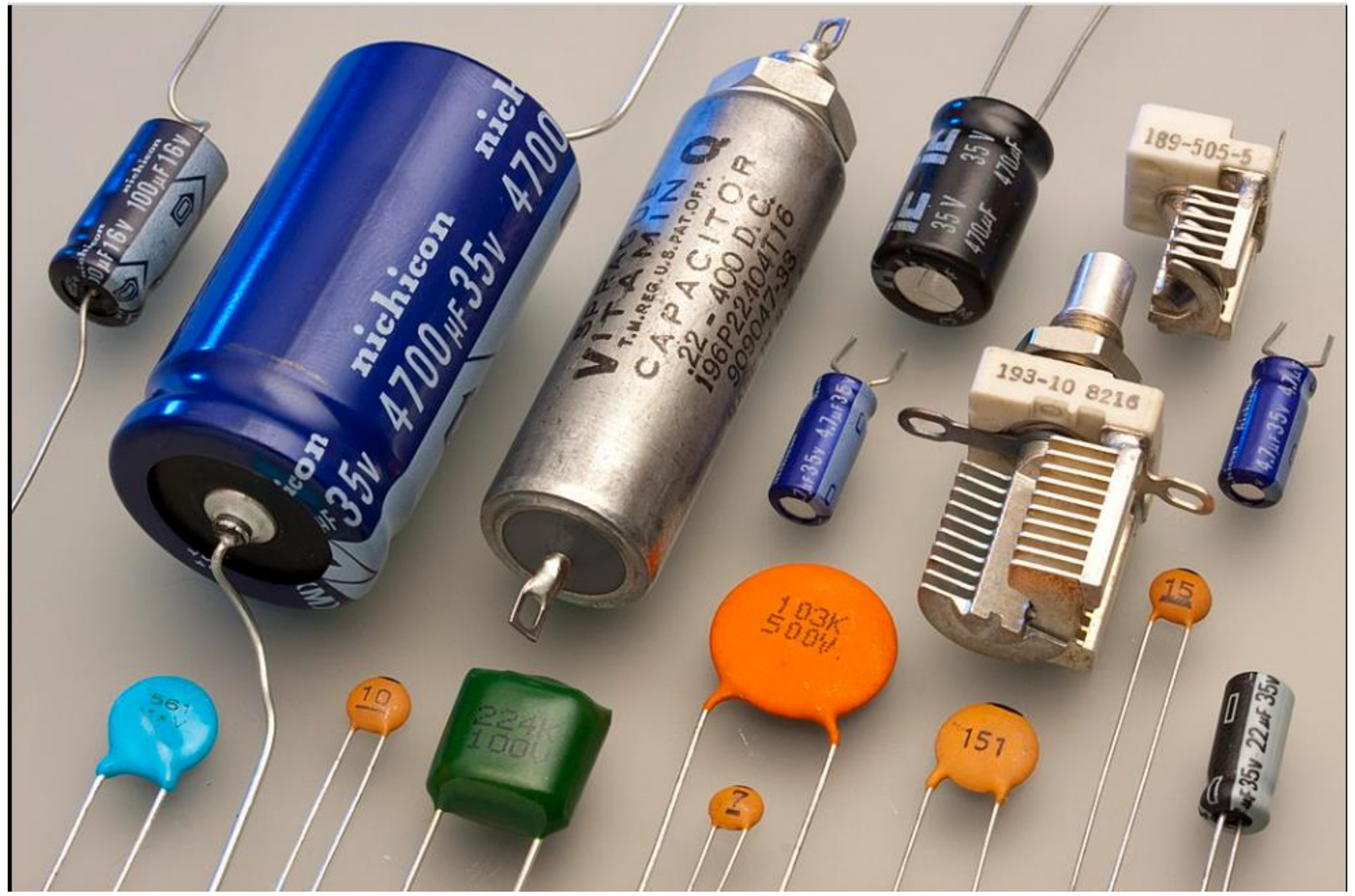
- It is composed of semiconductor material, usually with at least three terminals for connection to an electronic circuit.
- Ex: MOSFET and OFET



2. 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.

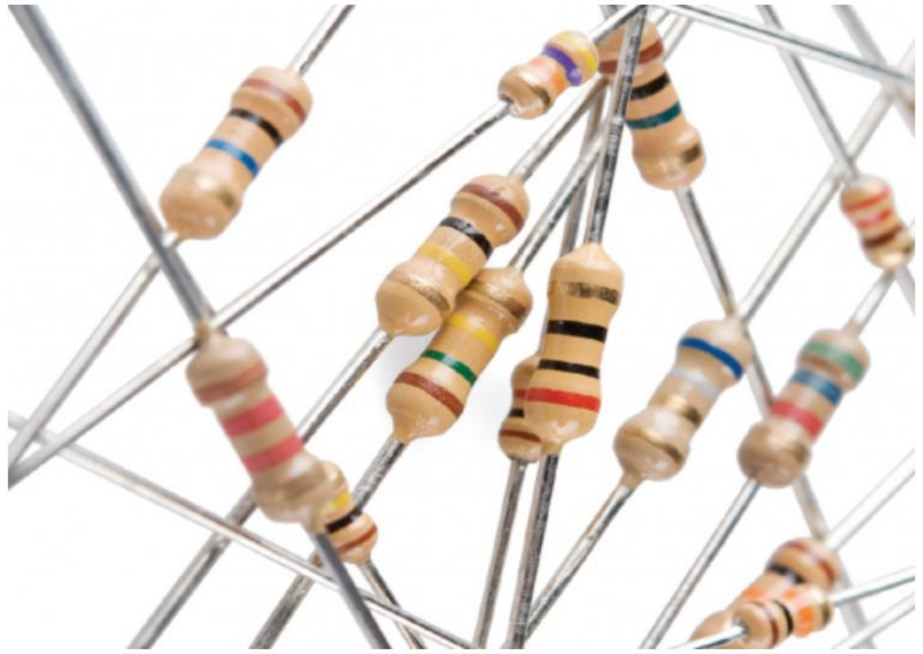
Example; DRAM using a dielectric capacitor is volatile memory ferroelectric capacitors, (FeRAM) is non-volatile memory



3. Resistor-type Electronic Memory

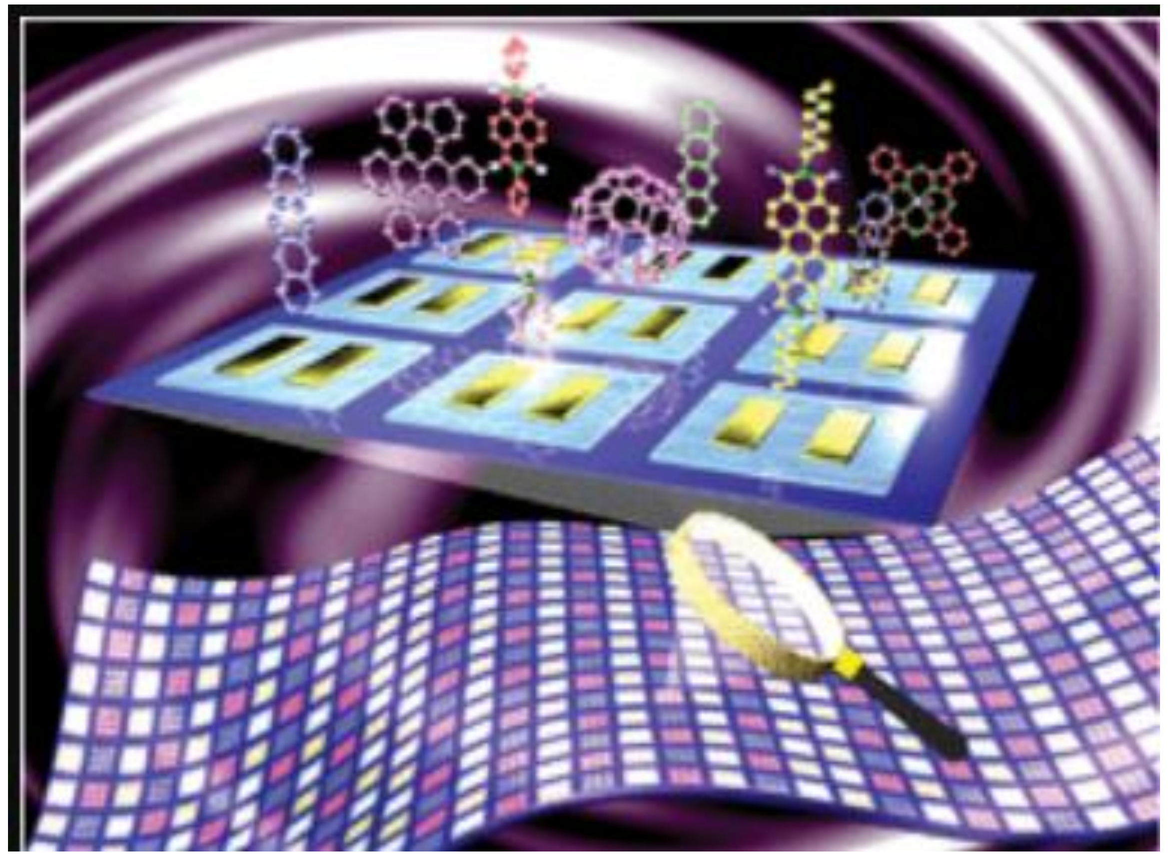
Resistor-type memory is based on the change of the electrical conductivity of materials in response to an applied voltage (electric field). Devices incorporating switchable resistive materials are generically classified as resistor-type memory, or resistive random-access memory (RRAM).

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.



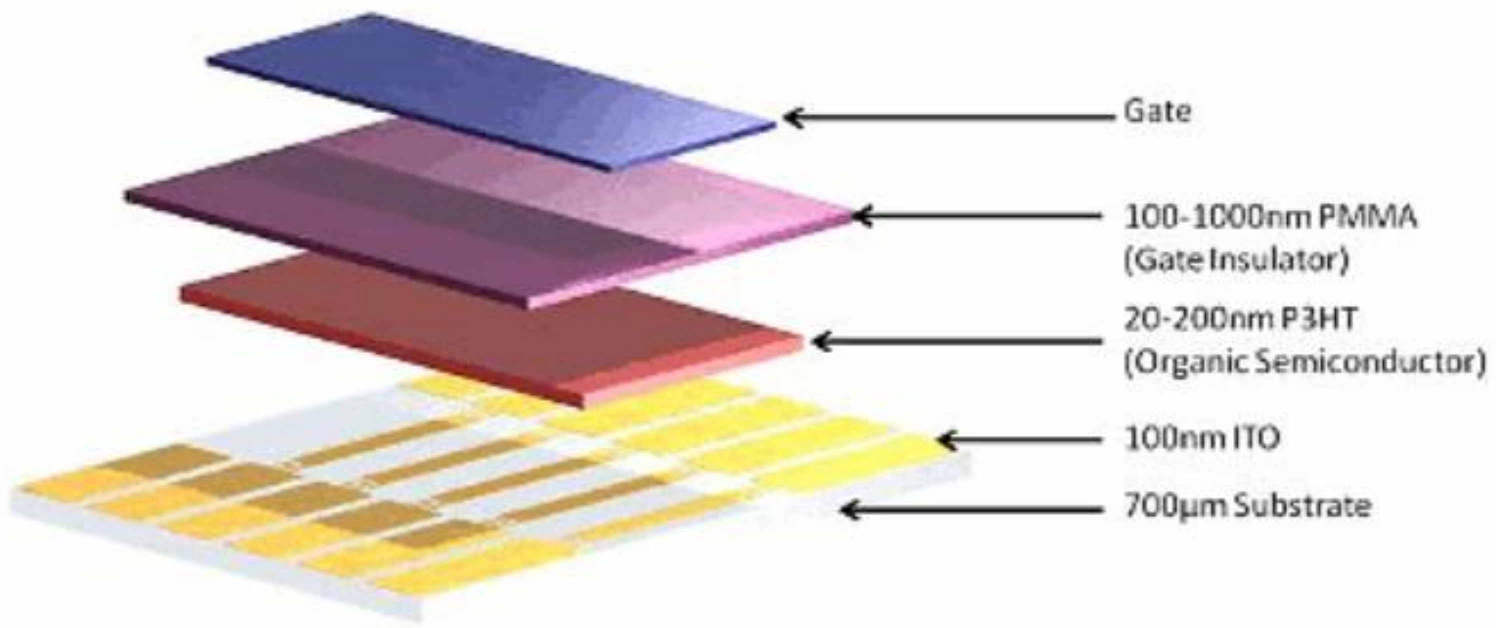
Transistor-type Electronic Memory

Organic Field Effect Transistor Memory (OFET)



OFETs require the following three components:

- Semiconductor
- Dielectric (insulator)
- Contacts (gate, drain, and source)



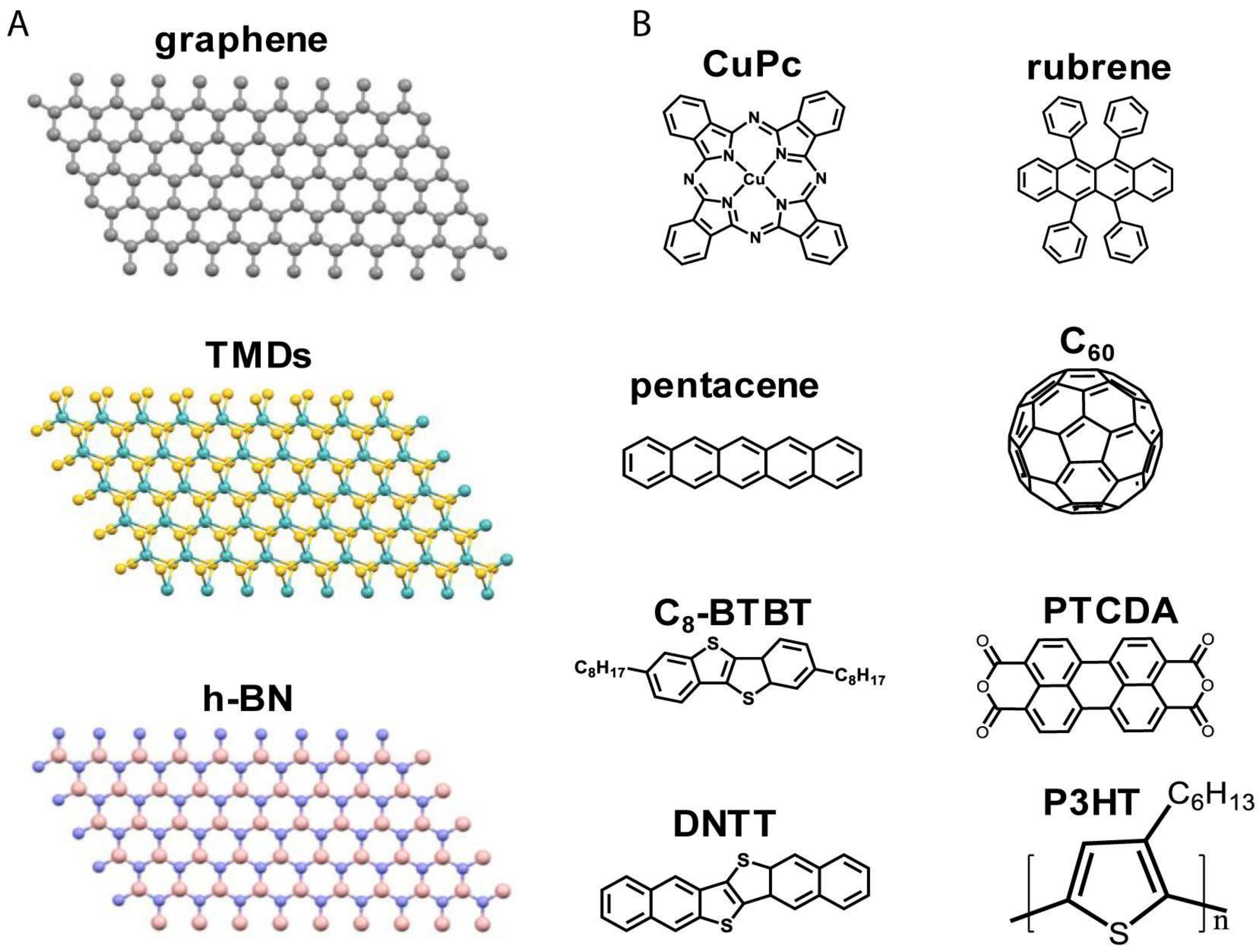
Applications: the display drivers, smart cards, electronic identification tags (such as radio frequency identification RFID tags), organic active-matrix displays, electronic paper, etc

- **Fabrication:** The thin semiconducting layer can be deposited with solution processes (spin coating, drop casting, etc.) or vacuum process (thermal evaporation). Semiconductor layer must be contacted with source/drain electrodes and the dielectric layer must be contacted with gate contacts so it is also called gate dielectric.

Source/drain electrodes are always metal contacts, whereas gate electrodes can be a metal or a conducting polymers

https://doi.org/10.1016/B978-0-12-813351-4.00025-0

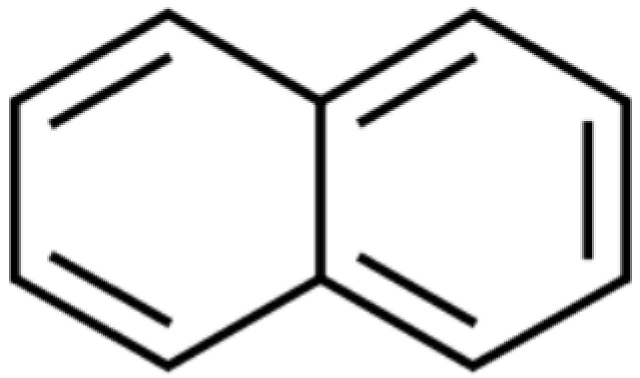
Commonly used 2D materials for OFET



Types of Organic-Based Electrical Memory Devices

I. Organic molecules: Organic electronic memory devices based on organic molecules were first reported in several acene derivatives including naphthalene, anthracene, tetracene, pentacene, perylene, p-quaterphenyl and p-quinquephenyl.

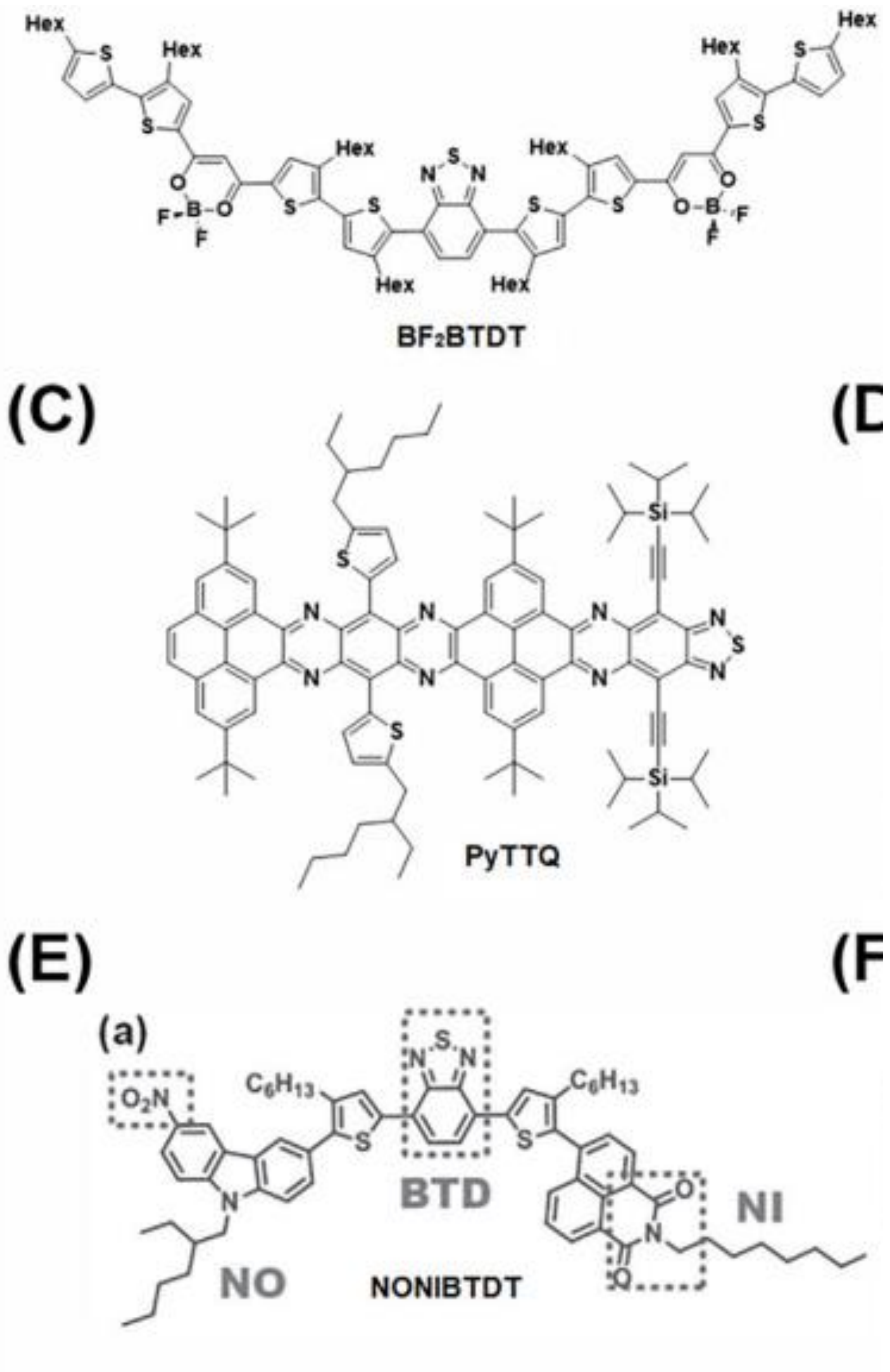
Ex: Device with the structure of a single layer of N,N'-di(naphthalene-l-yl)-N,N' diphenyl-benzidine (NPB) embedded between ITO and Ag electrodes.

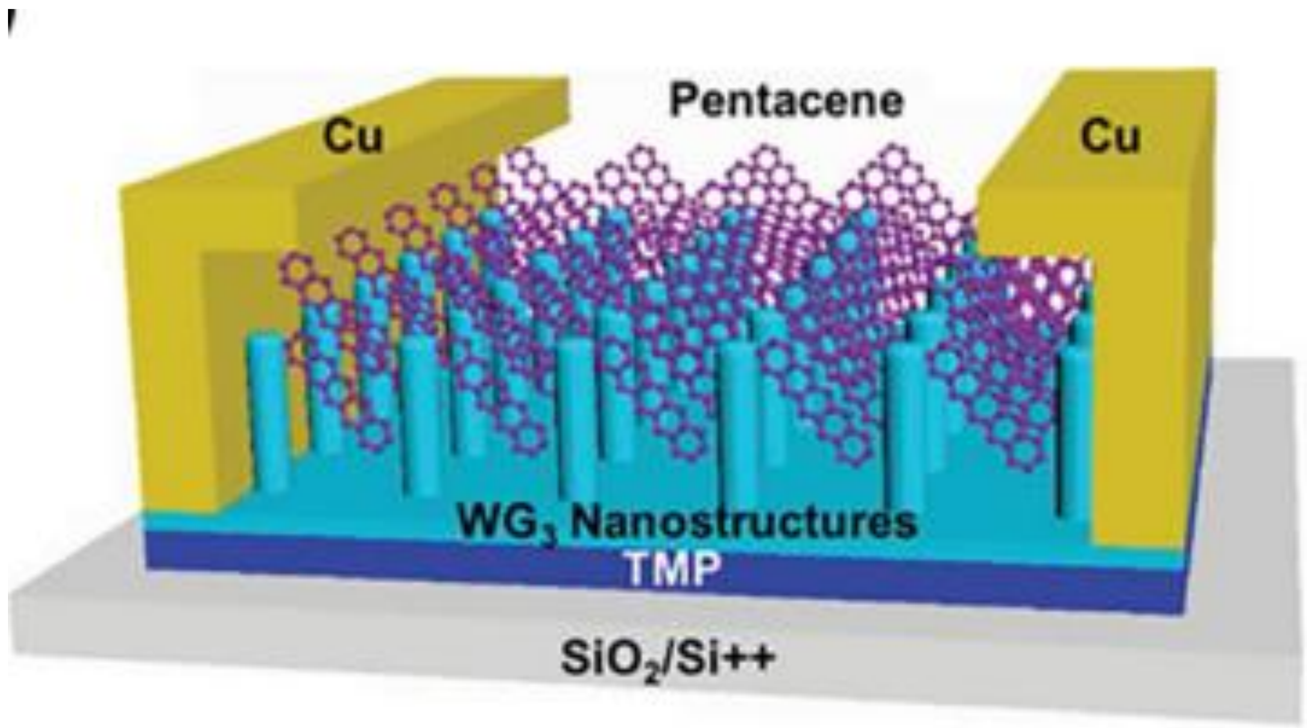


Acene derivatives

Types of Organic-Based Electronic Memory Devices

Organic molecules for electrical memory devices



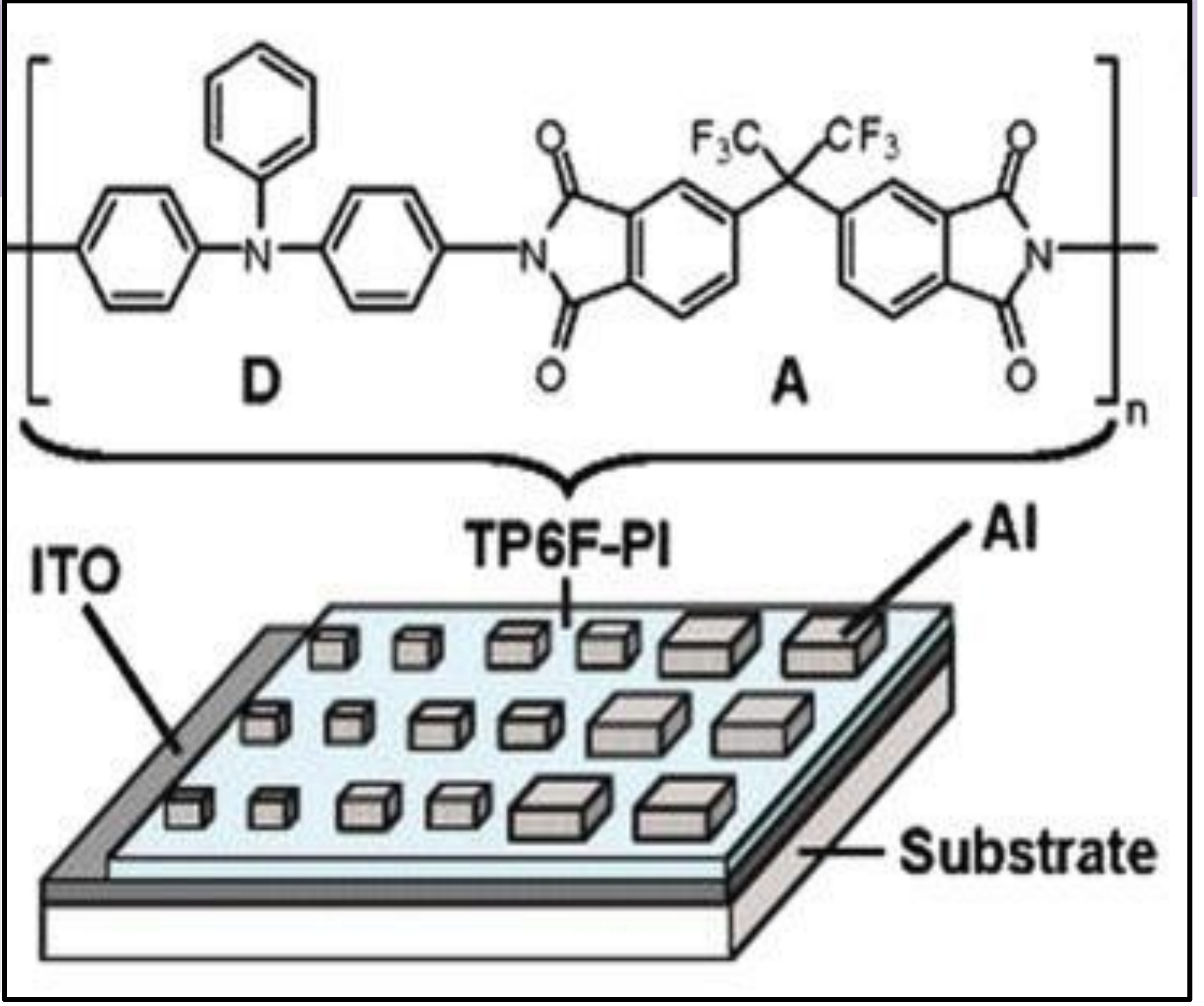


2. Electronic memory devices based on polymeric molecules

Polymer memory refers to memory technologies based on the use of organic polymers. The molecular structure of polymeric materials can be tailored using electron donors and acceptors. The properties of polymer memory are low-cost and high-performance, and have the potential for 3D stacking and mechanical flexibility.

a) 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).

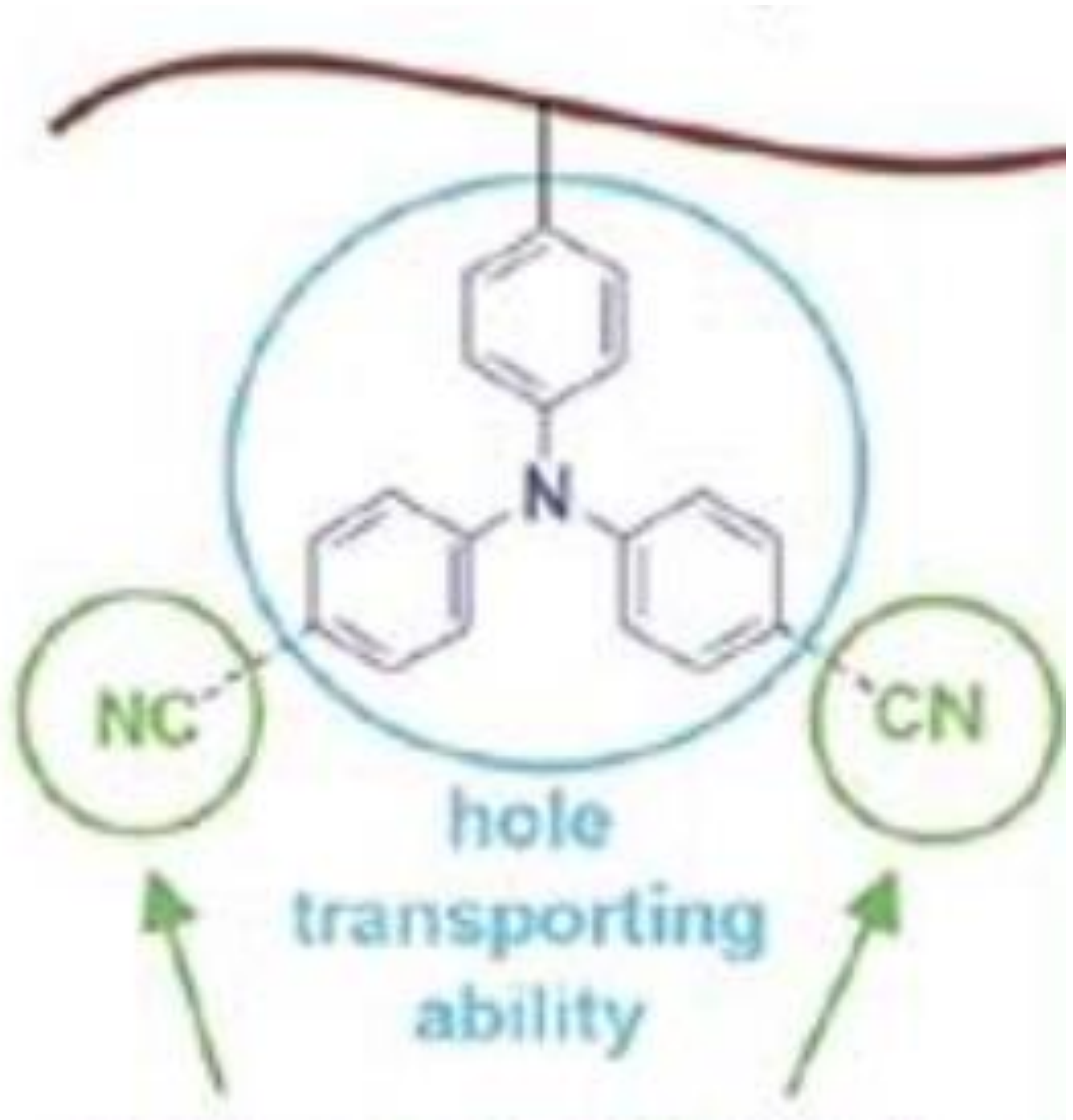
Example; Molecular structure (top) of functional PI (TP6F-PI) and schematic diagram (bottom) of single-layer memory device.



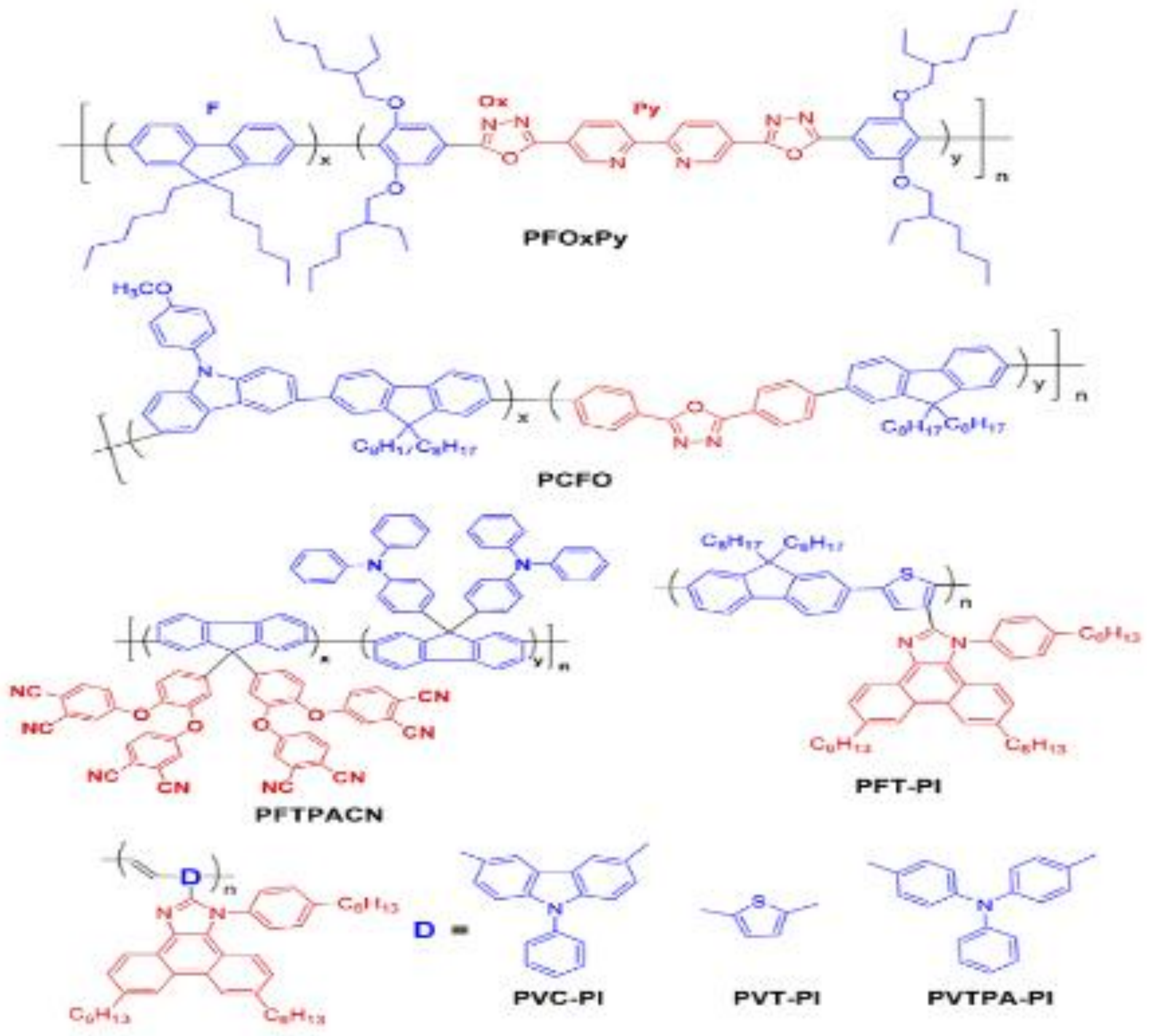
Non-Conjugated Polymers with Pendants

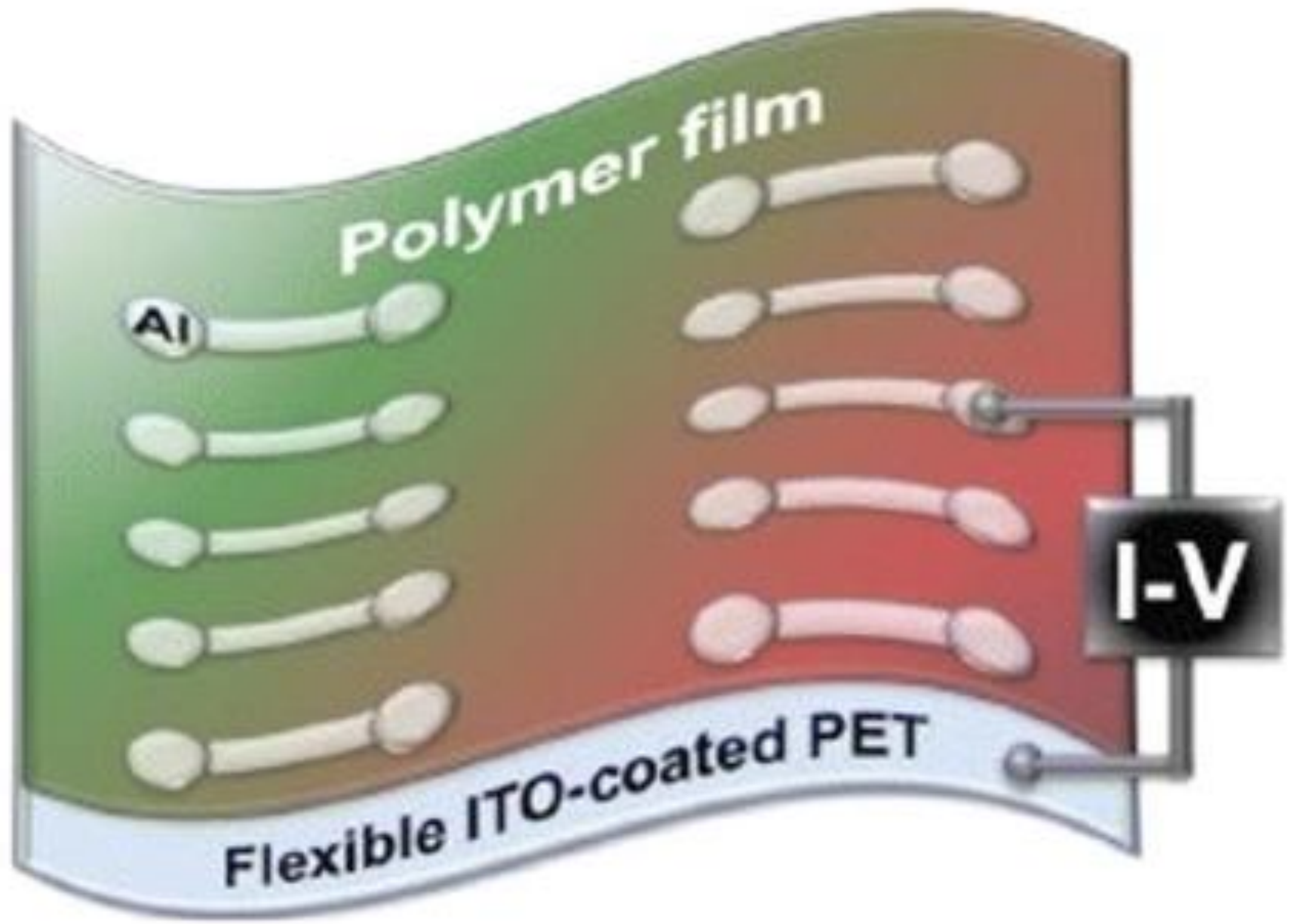
Ex: Al/polymer/ITO, polymer-PVK-AZO-2CN and PVK-AZO-NO_2(PVK- polyvinyl carbazole, AZo- azobenzene)

Pendant Donor – Acceptor Polymer



Conjugated Polymers





Electrical memory devices based on 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.

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.

Electrical memory devices based on inorganic/organic nanocomposites

a) **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.

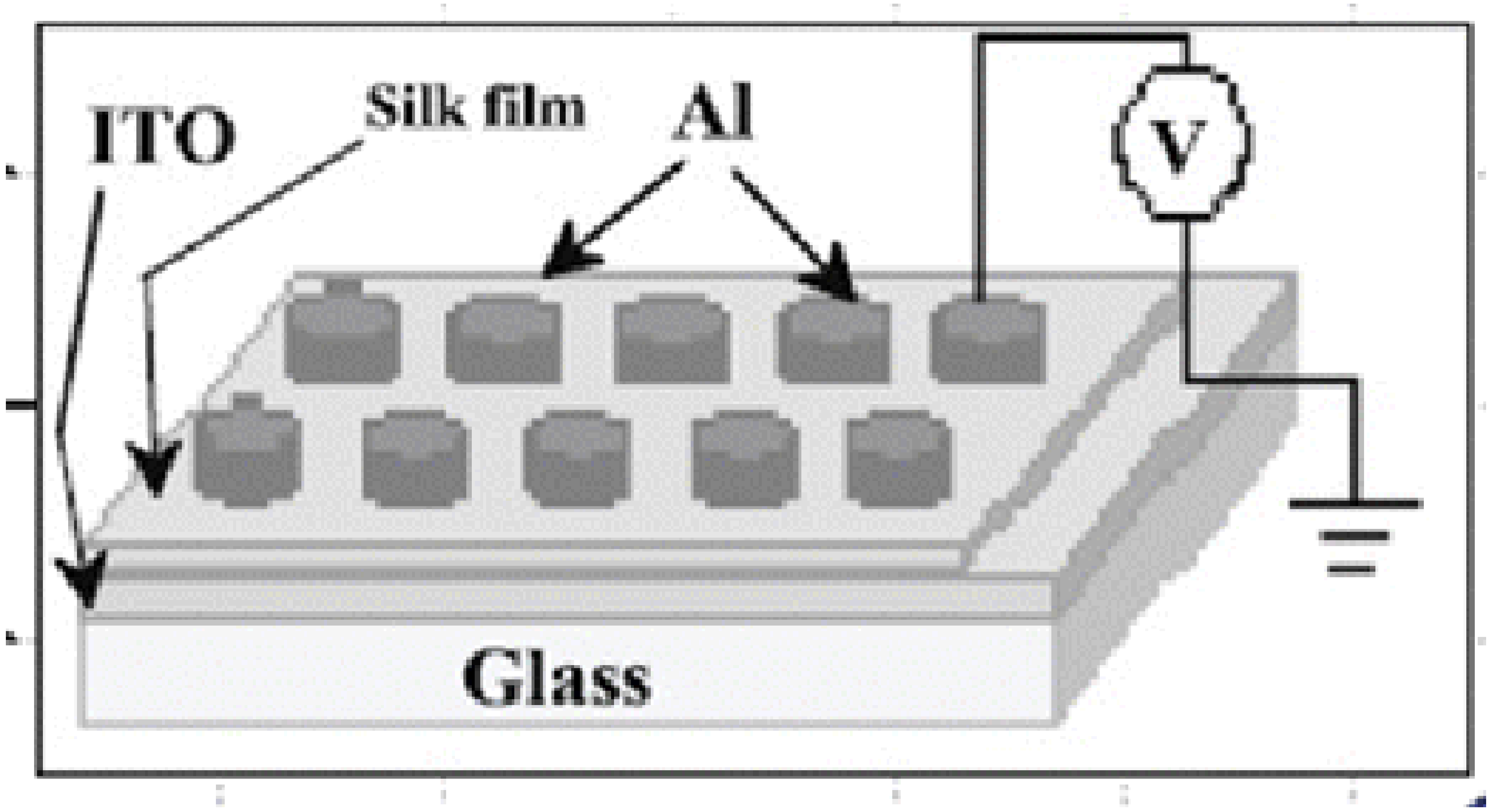
Ex; rGO/P3HT:PCBM/Al, Al/Polystyrene:C60/Al

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

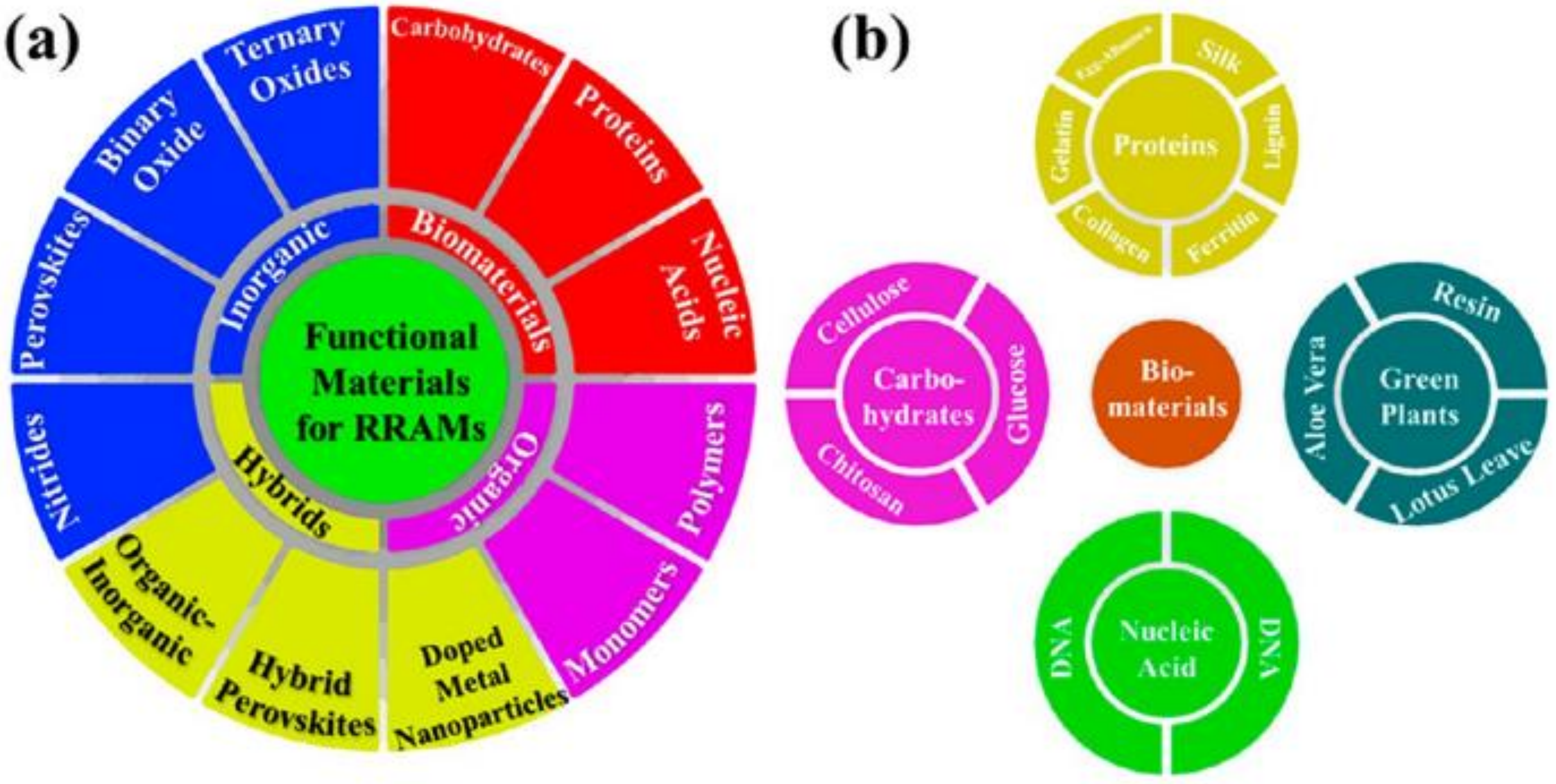
semiconductor nanoparticles (ZnO, CdSe, Si, CuO and so on) and metal nanoparticles (Au, Ag, FeNi and so on).

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.

Bio-composite based memory devices



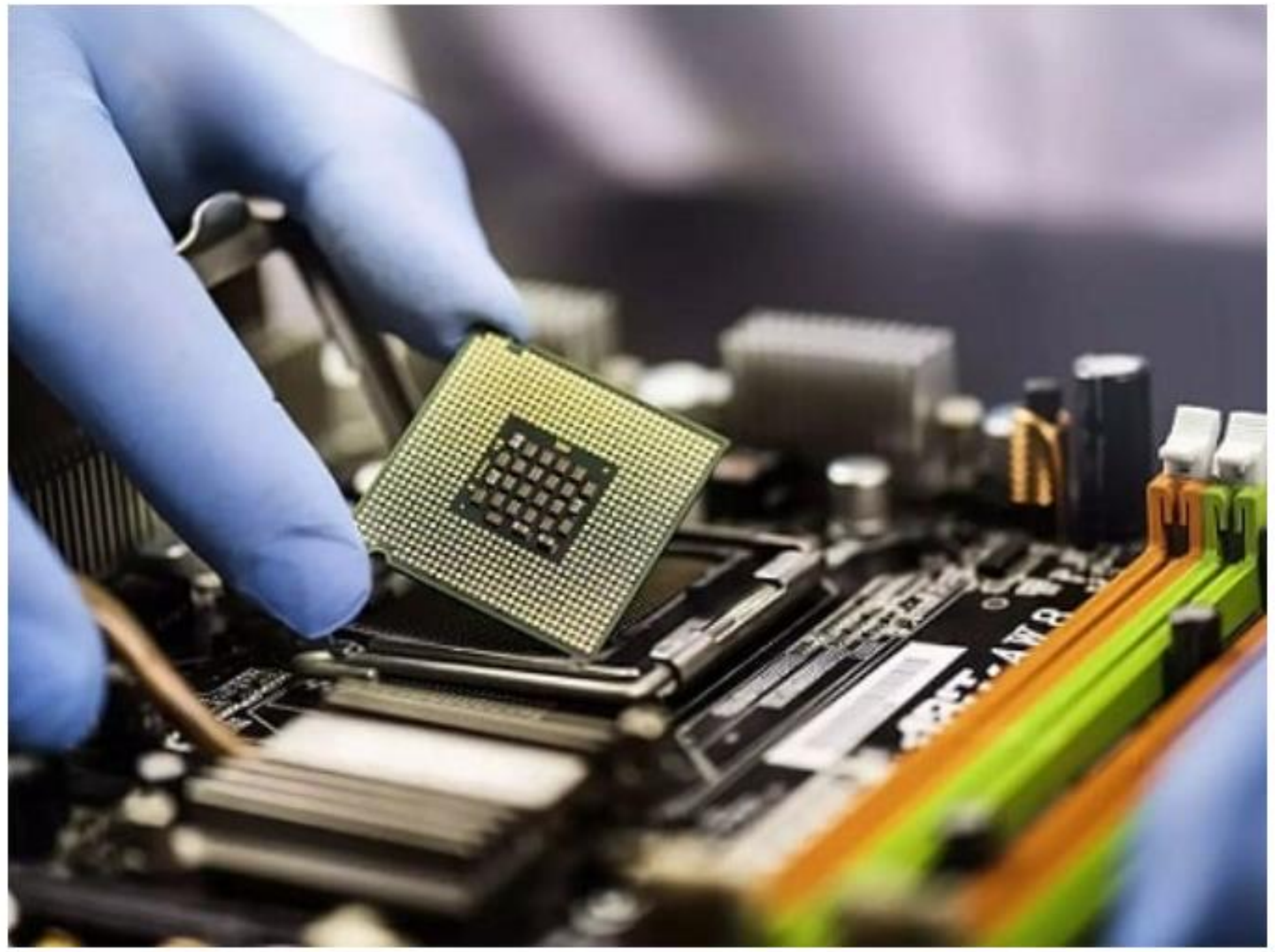
Biomaterial-Based Memory Devices

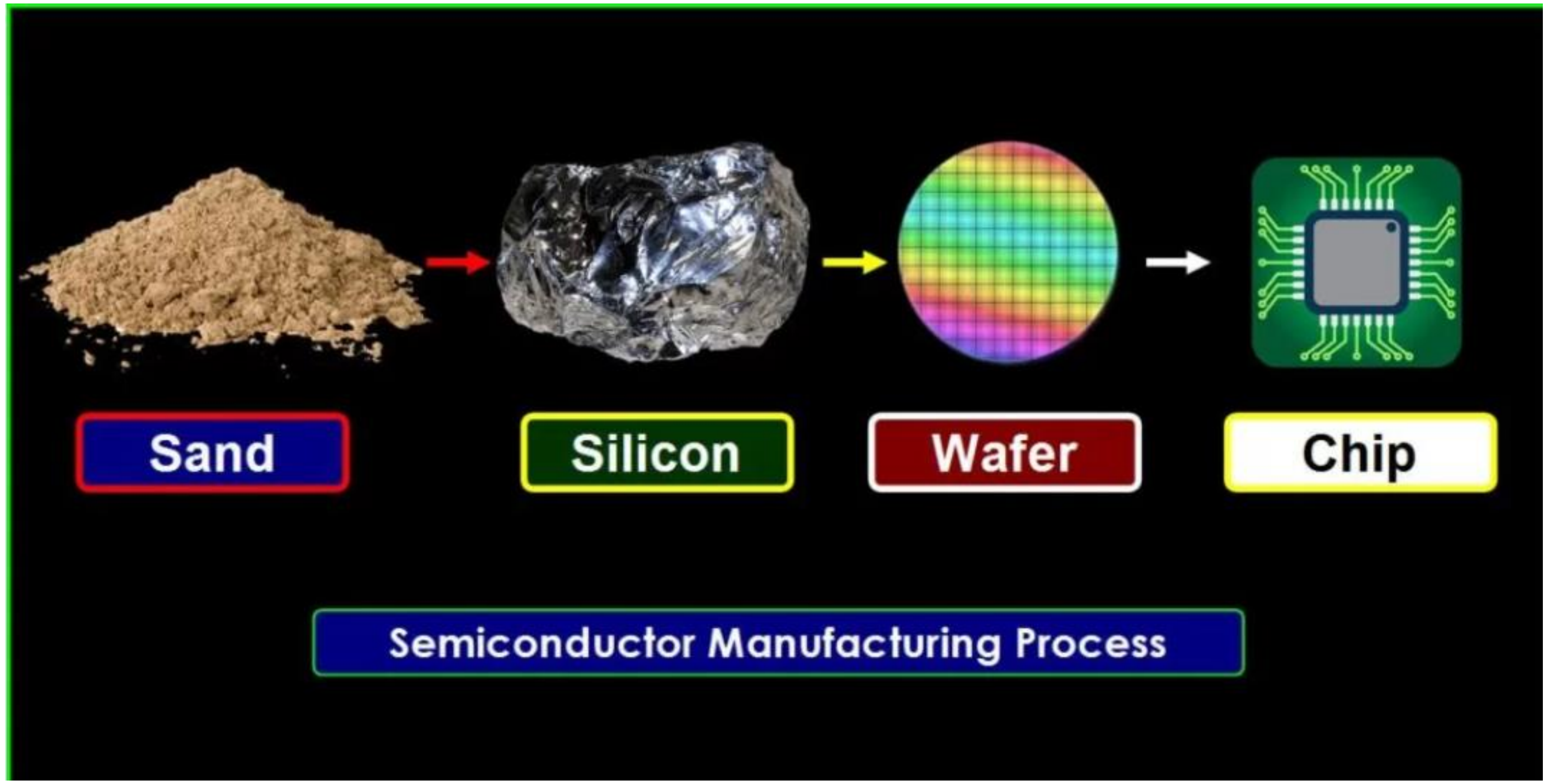


(a) Various materials used for RRAMs in general including inorganic semiconductors, organic semiconductors, biomaterials, and their hybrid composites.

(b) Classification of biomaterials used as the functional layer of bio-RRAMs including proteins, carbohydrates, nucleic acid, and green plants.

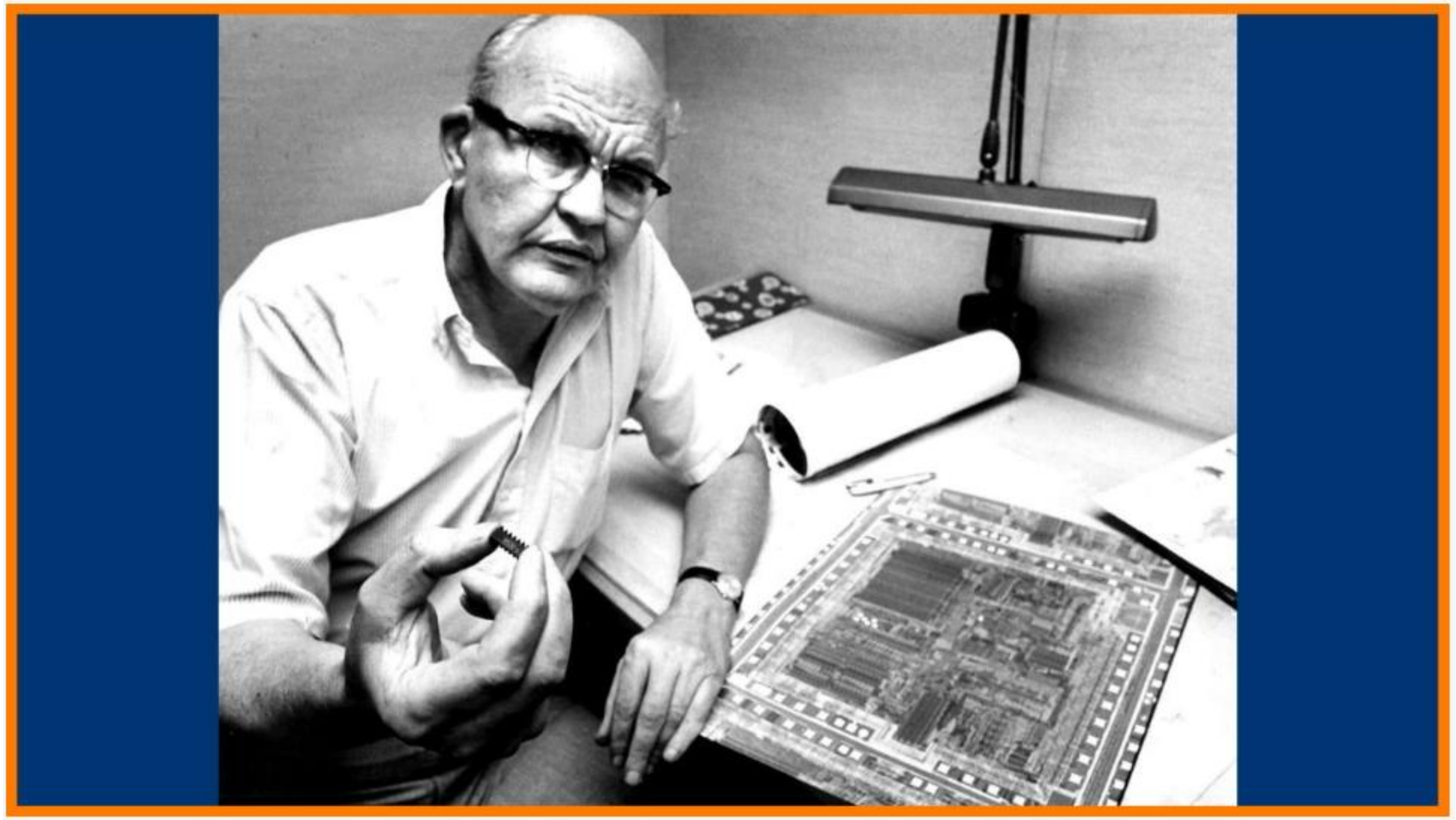
Manufacturing of semiconductor chips



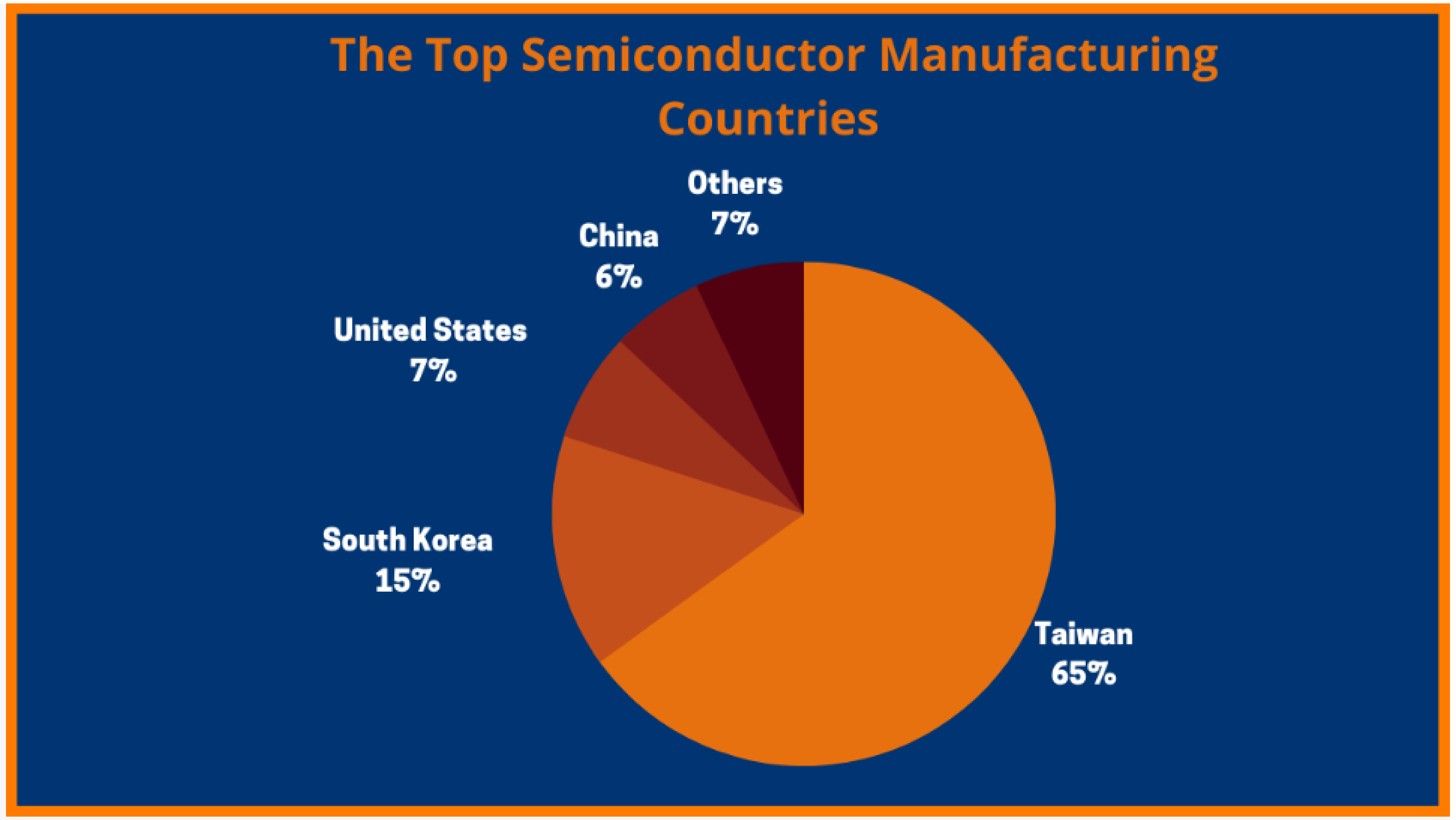


Semiconductor chips

Semiconductor chips



Jack Kilby - Inventor of Semiconductor Chips

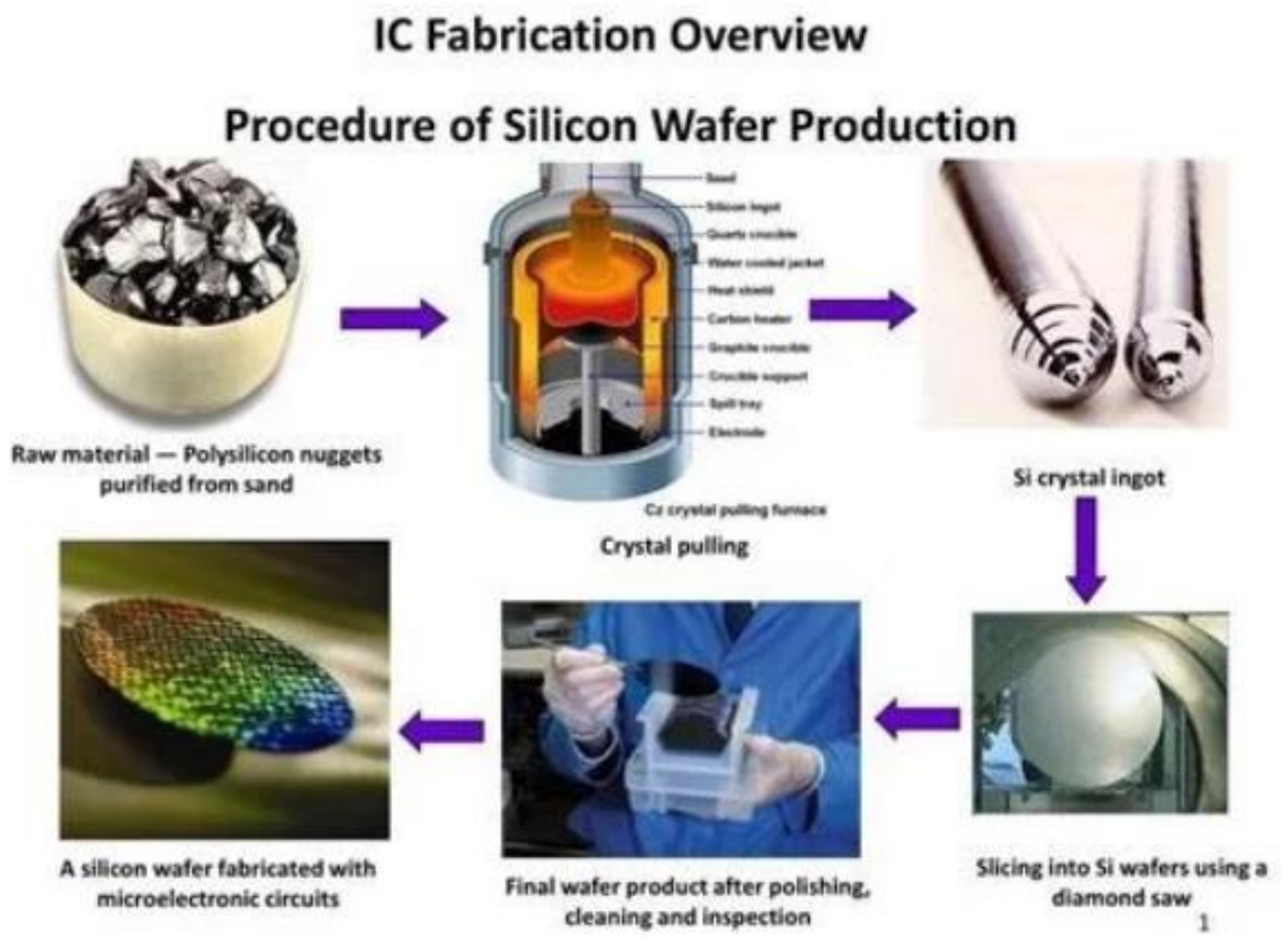


Countries dominating semiconductor production.

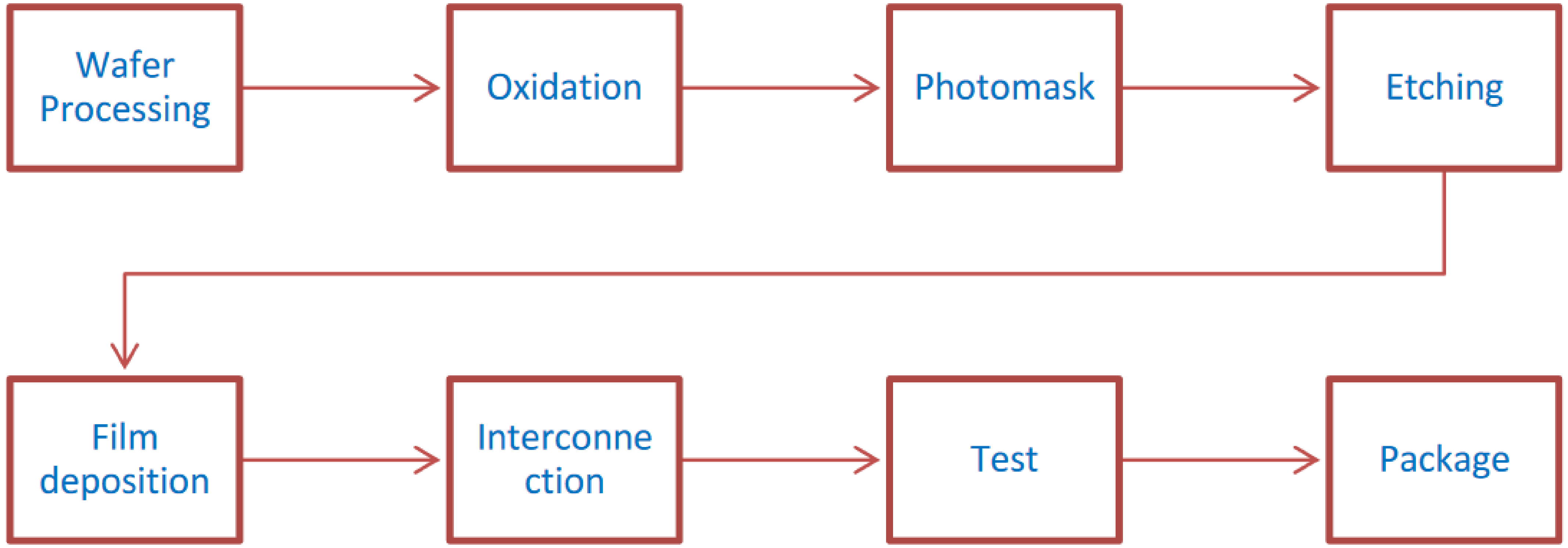
Top 8 semiconductor producing companies

Name of the Company	Country	Type
Intel	United States	IDM
Samsung	South Korea	IDM
TSMC	Taiwan	Foundry
SK Hynix	South Korea	IDM
Micron	United States	IDM
Qualcomm	United States	Fabless
Nvidia	United States	Fabless
Infineon	Germany	IDM

Manufacturing of semiconductor chips

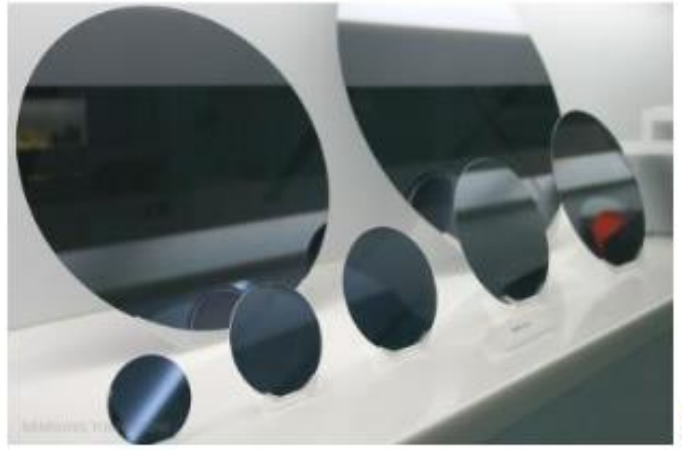


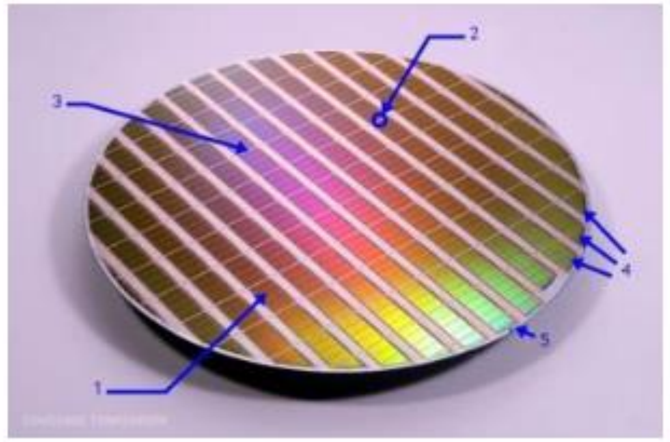
Manufacturing of semiconductor chips



Step#	Process	What Happens
1.	Wafer	Foundation for Semiconductor.
2.	Oxidation	Create Oxide Film on Wafer Surface.
3.	Photolithography	Draw Circuit Design on Wafer.
4.	Etching	Remove Unnecessary Materials.
5.	Deposition and ion implementation	Coating thin film at a desired molecular or atomic level onto a wafer.
6.	Metal wiring	Allows electricity to flow by depositing a thin metal film.
7.	EDS	Process of testing to ensure flawless semiconductor chips.
8.	Packaging	Final wafer are cut into individual semiconductor chips.

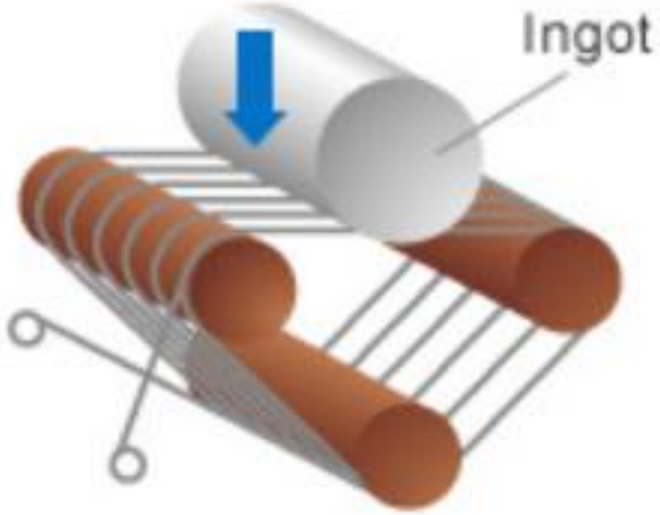
Wafer Processing


Si wafer


finished wafer

1. Slicing

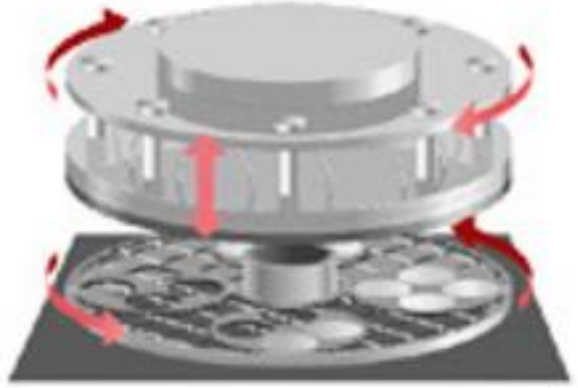

Wire saw machines



Slicing by wire saw

2. Lapping

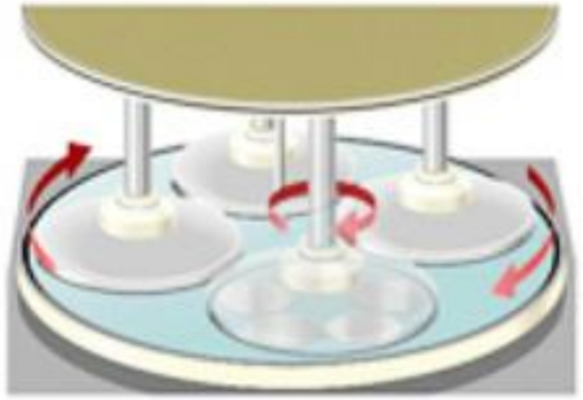

Lapping machines


Structure of lapping machine

Manufacturing of semiconductor chips

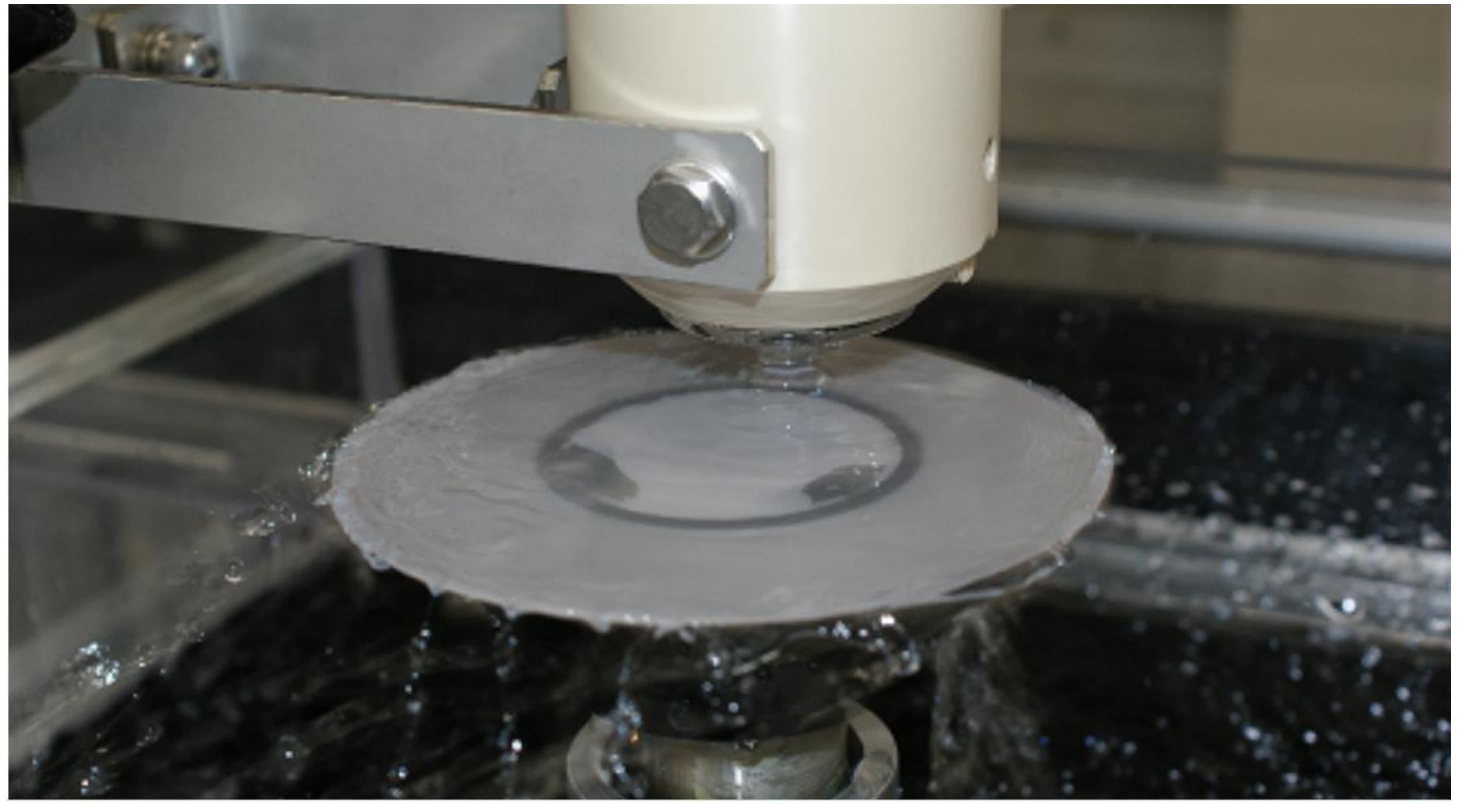
3. Polishing

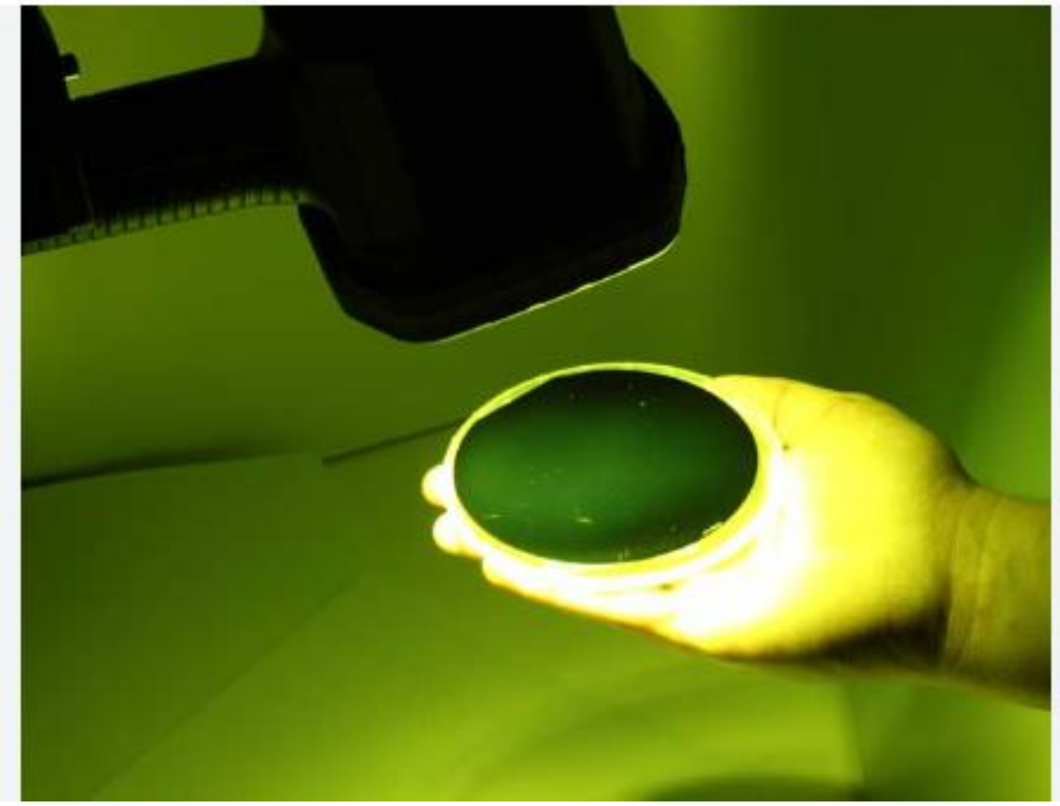
Polishing machines



Structure of polishing machine

4. Cleaning and inspection

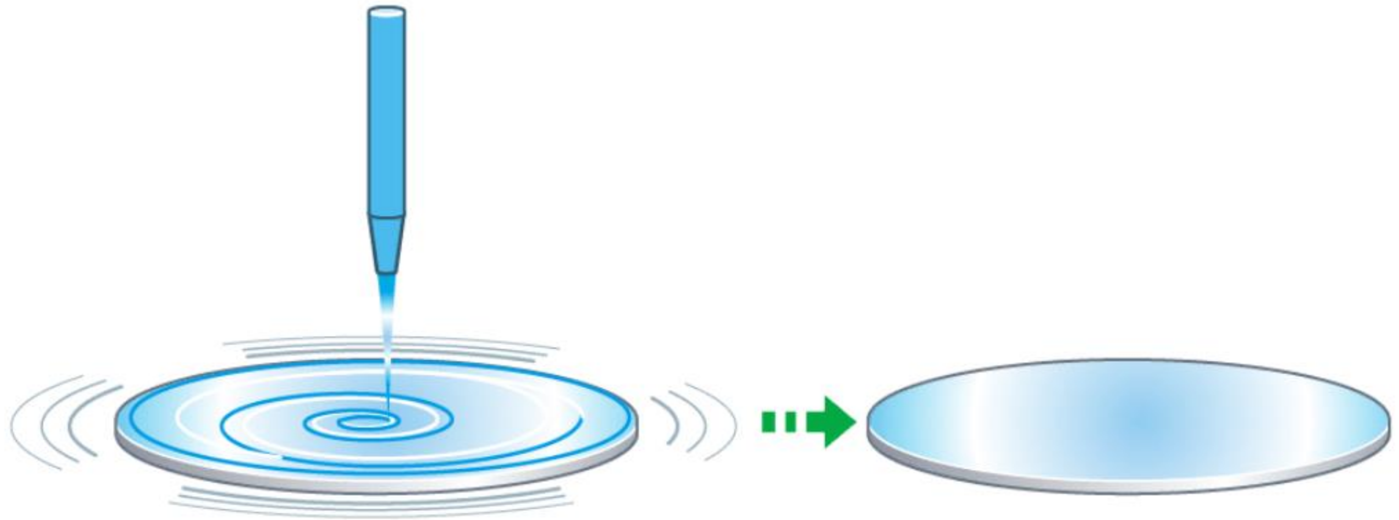


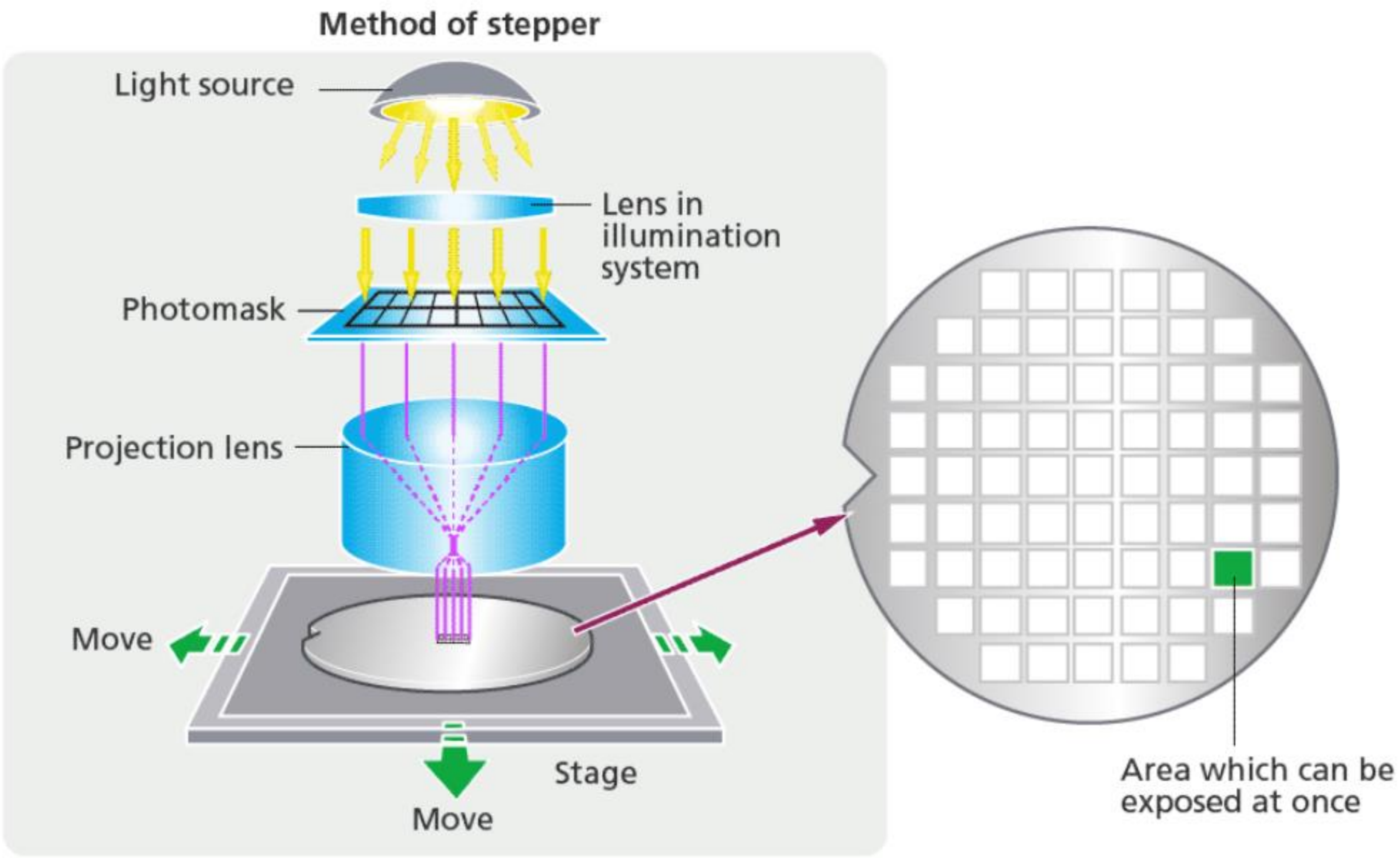


Oxidation

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

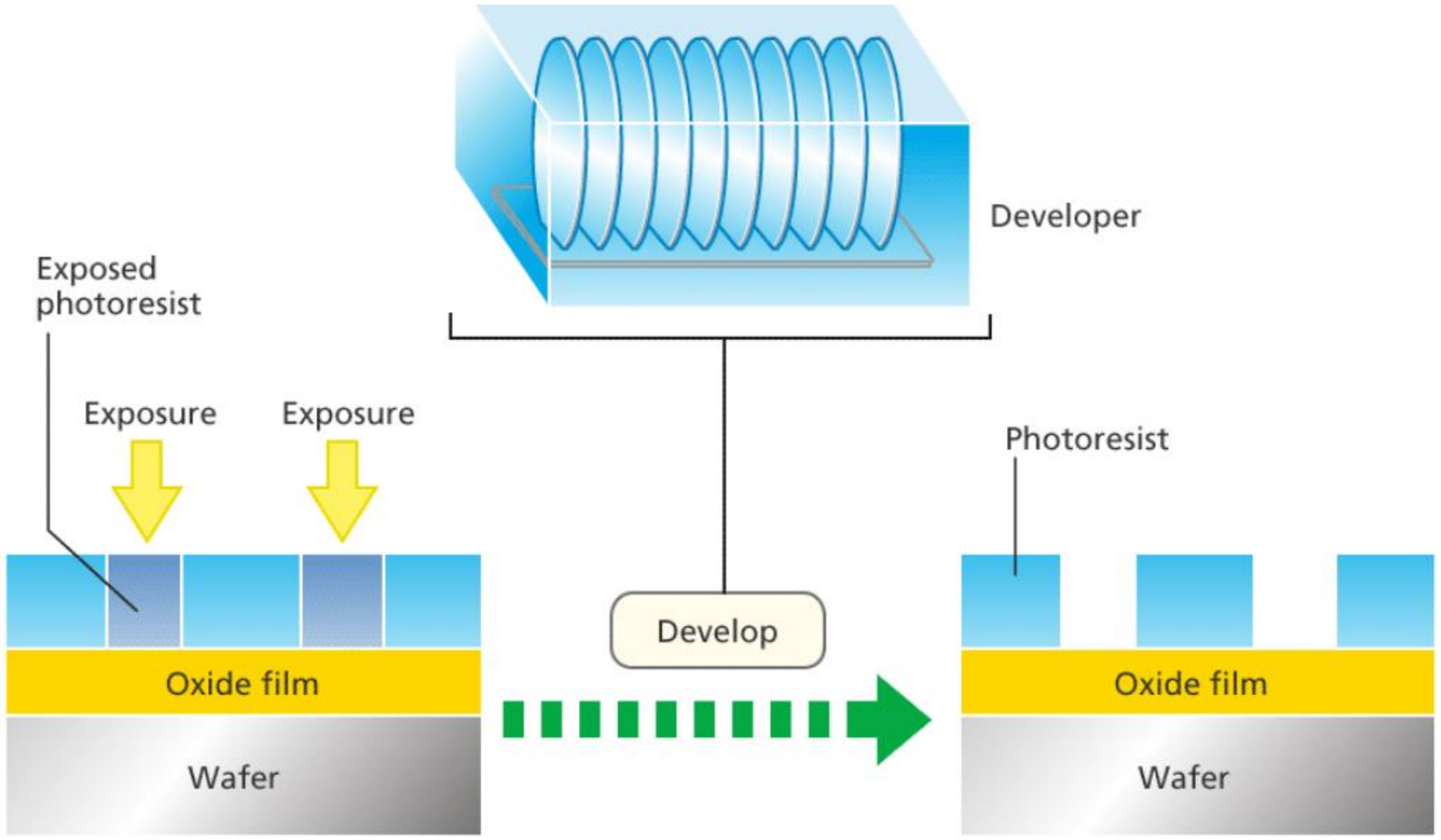
Photomask

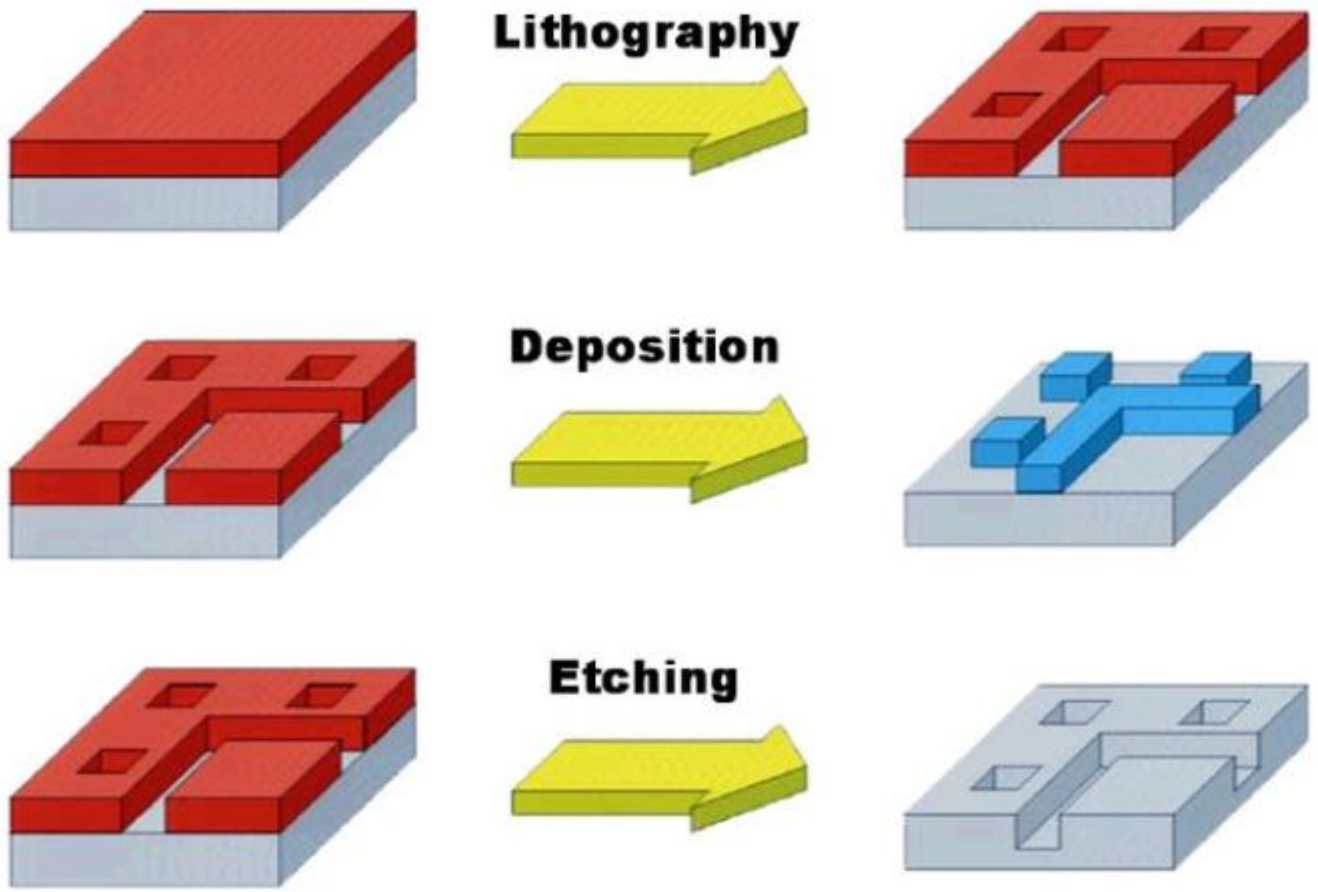




Manufacturing of semiconductor chips

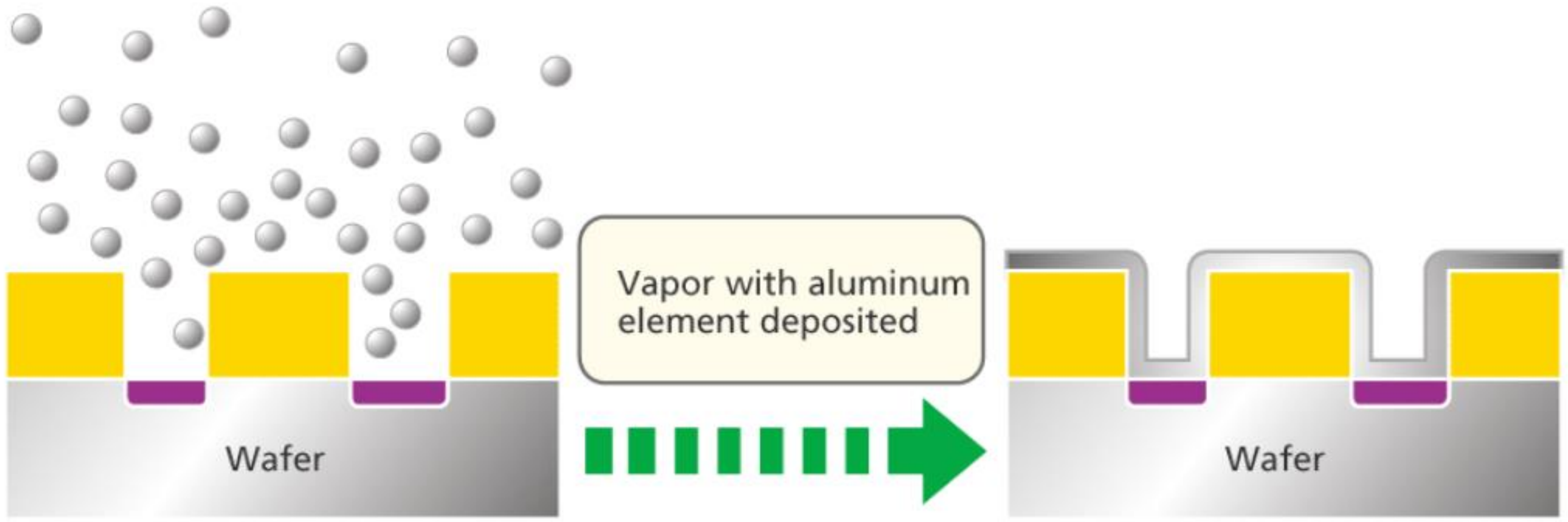
Developing





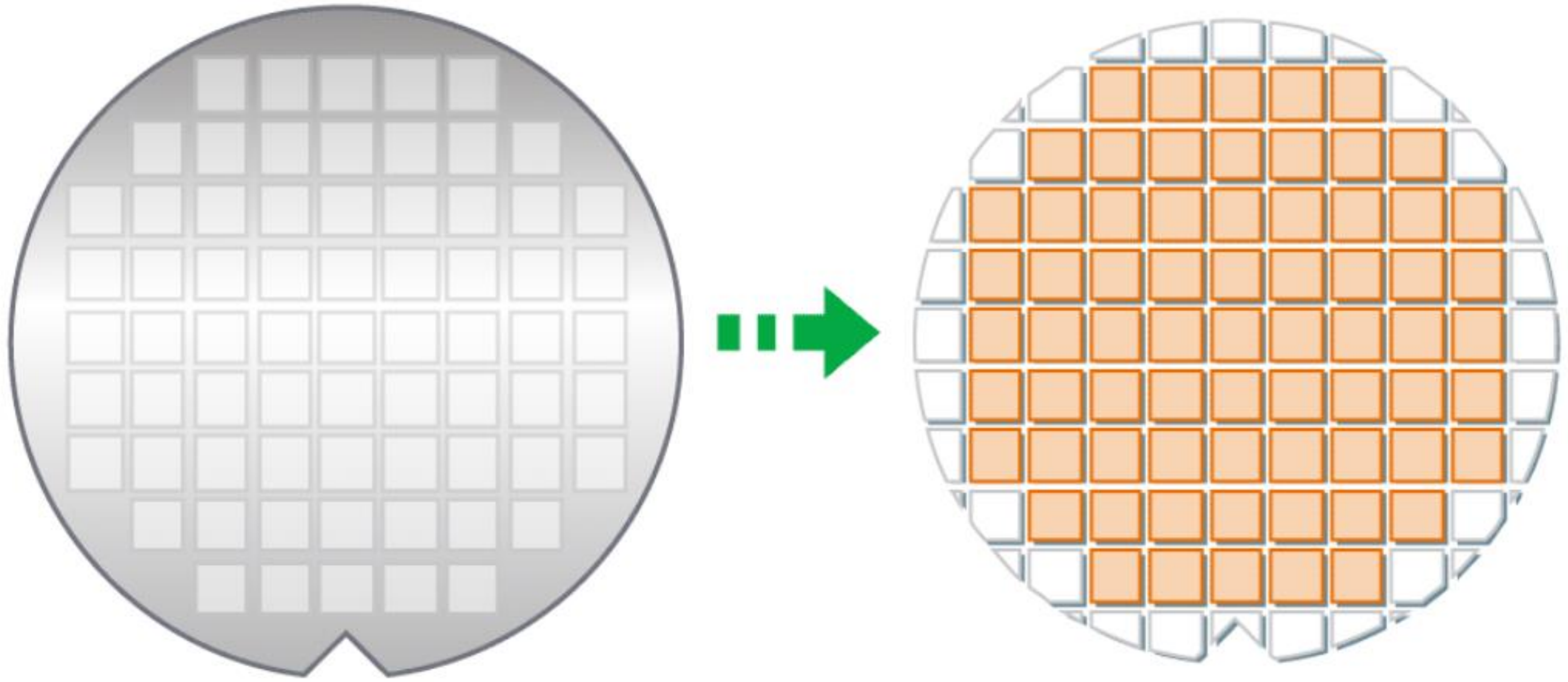
Manufacturing of semiconductor chips

Wiring

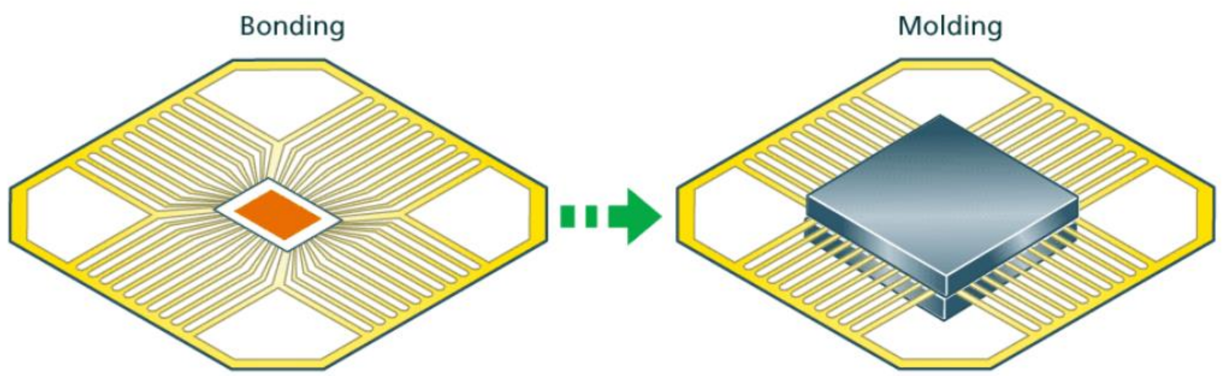


Manufacturing of semiconductor chips

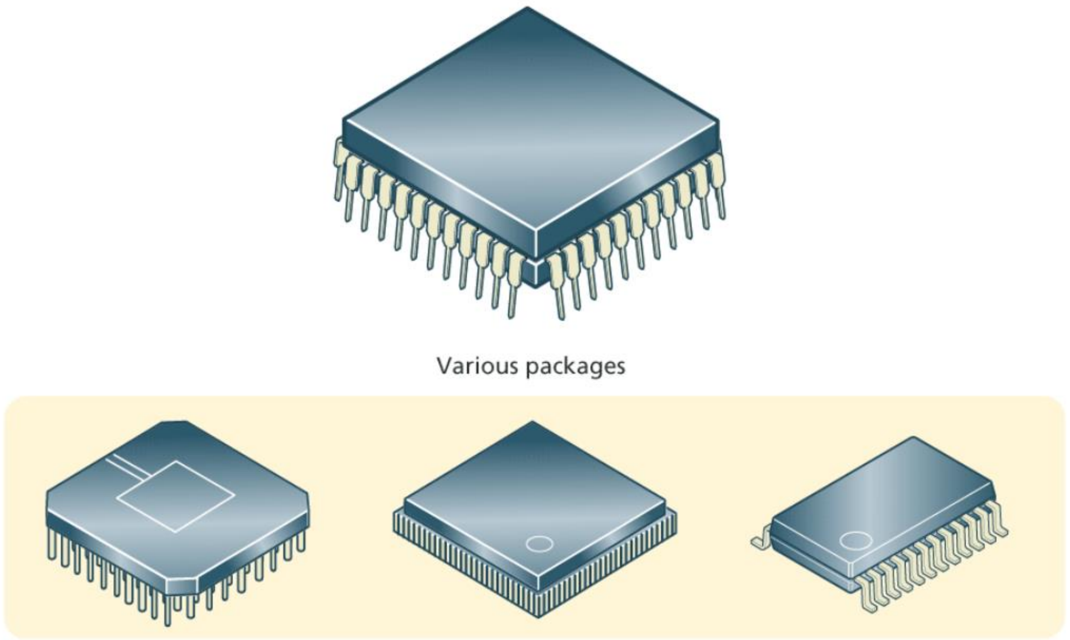
Dicing



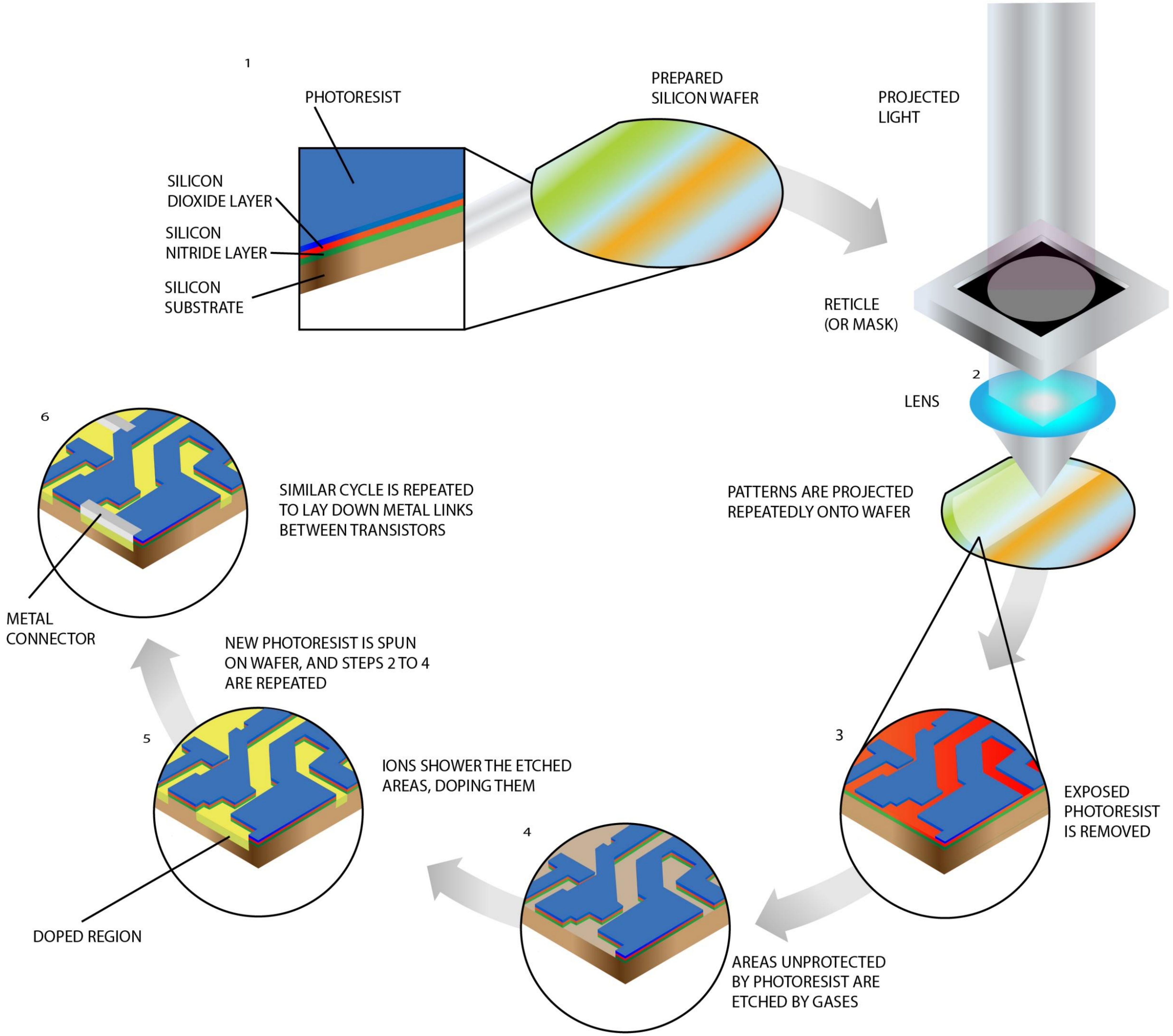
Bonding / Molding



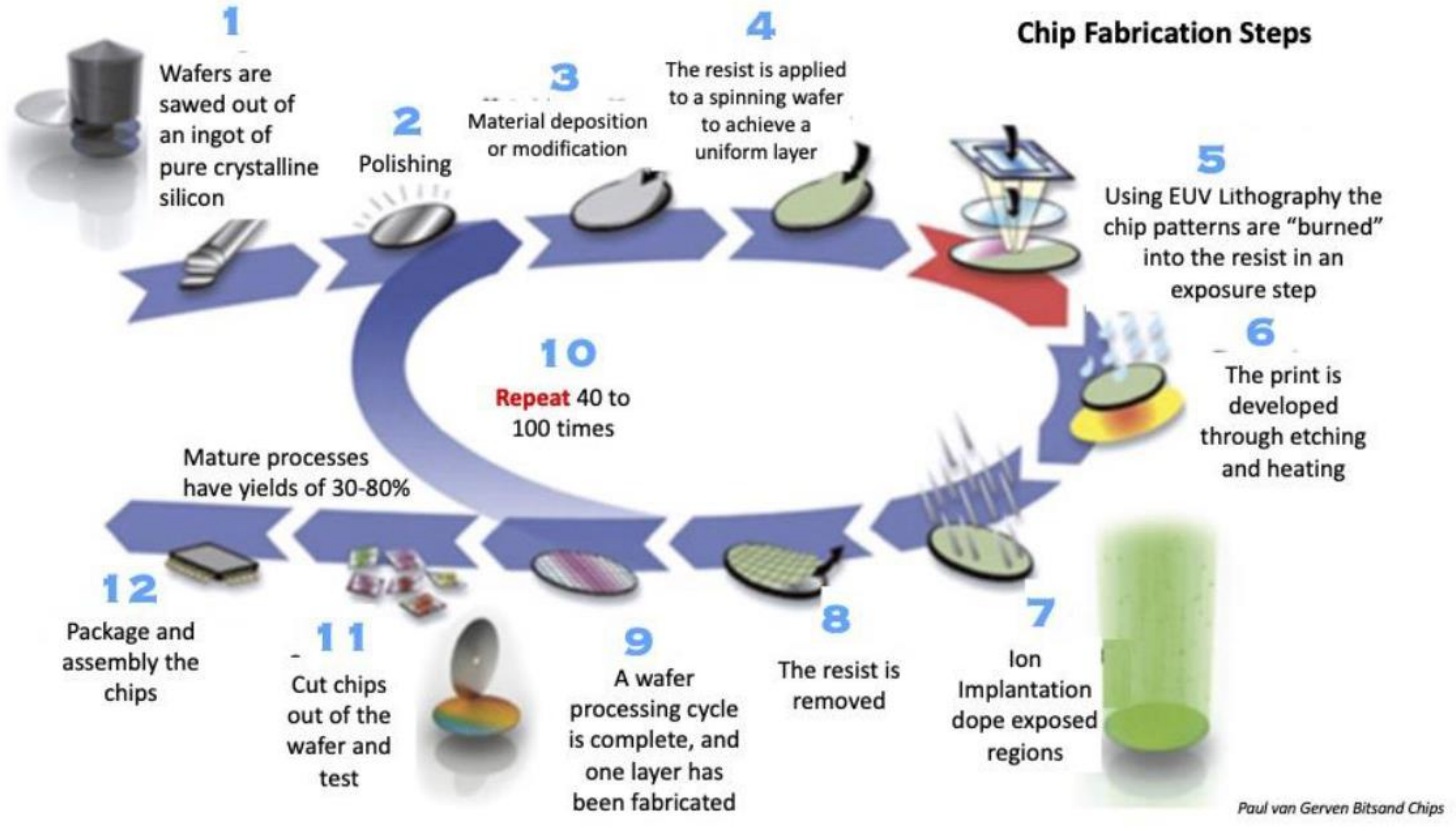
Semiconductor completion



Wafer Processing

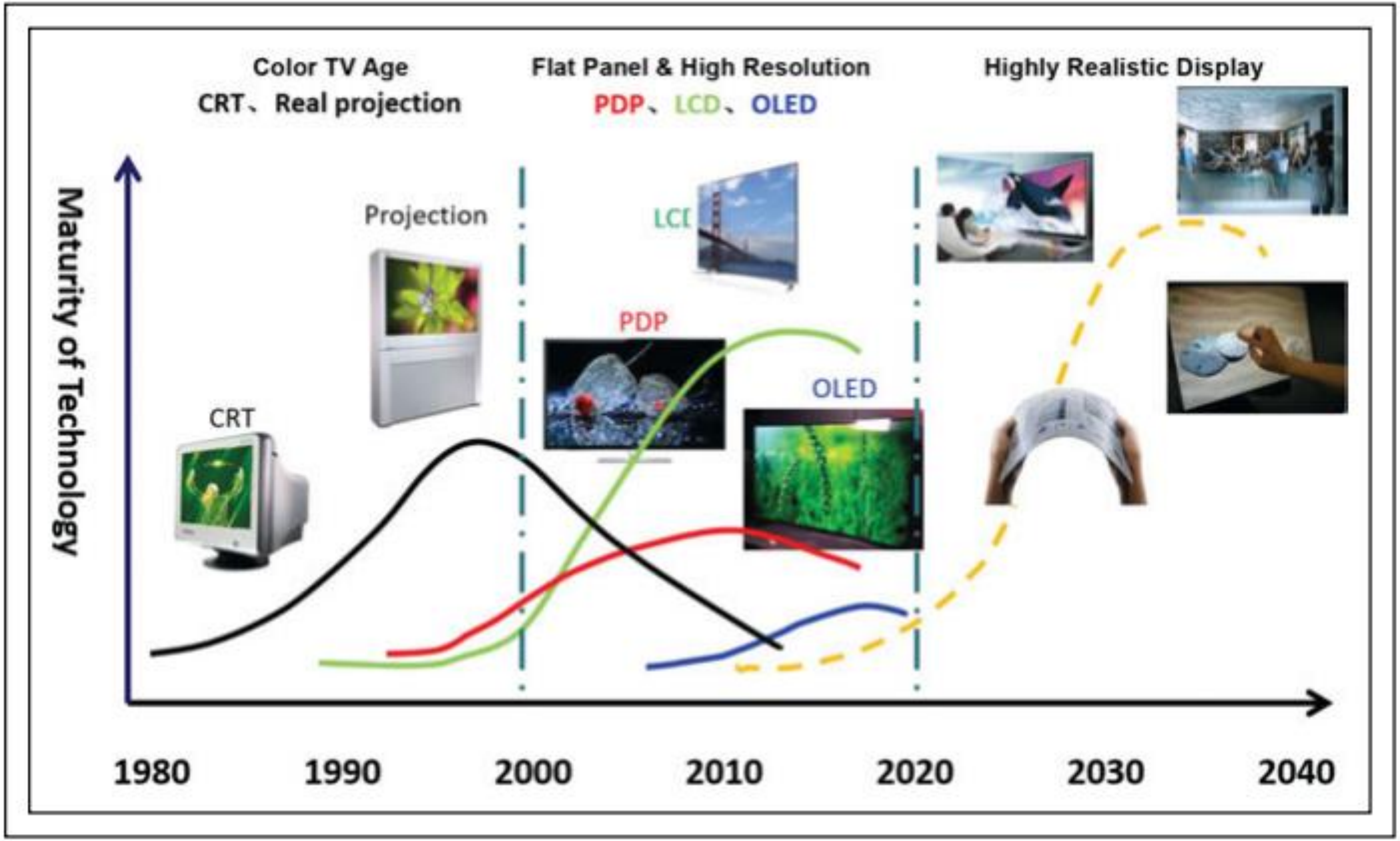


Manufacturing of semiconductor chips

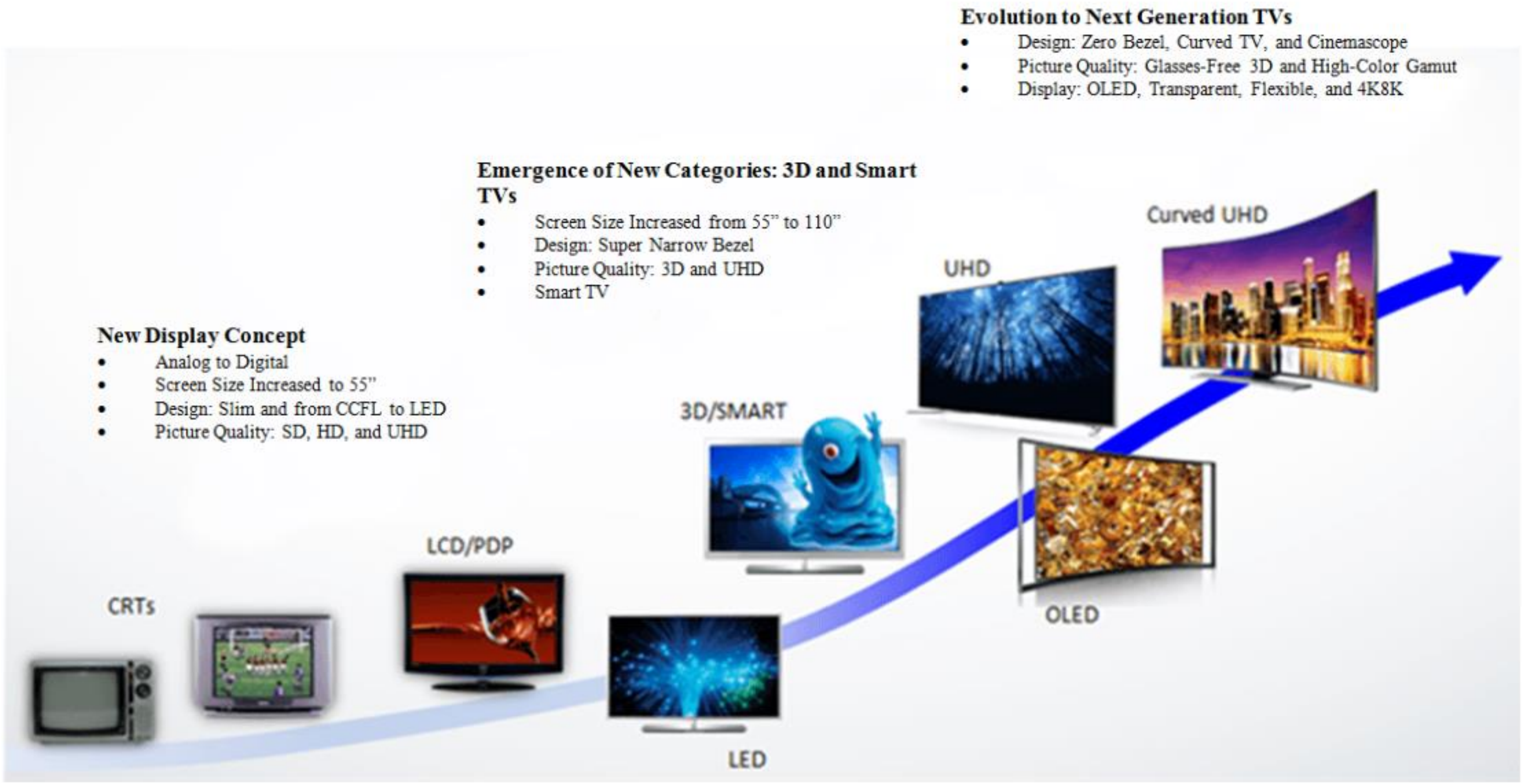


Display technology

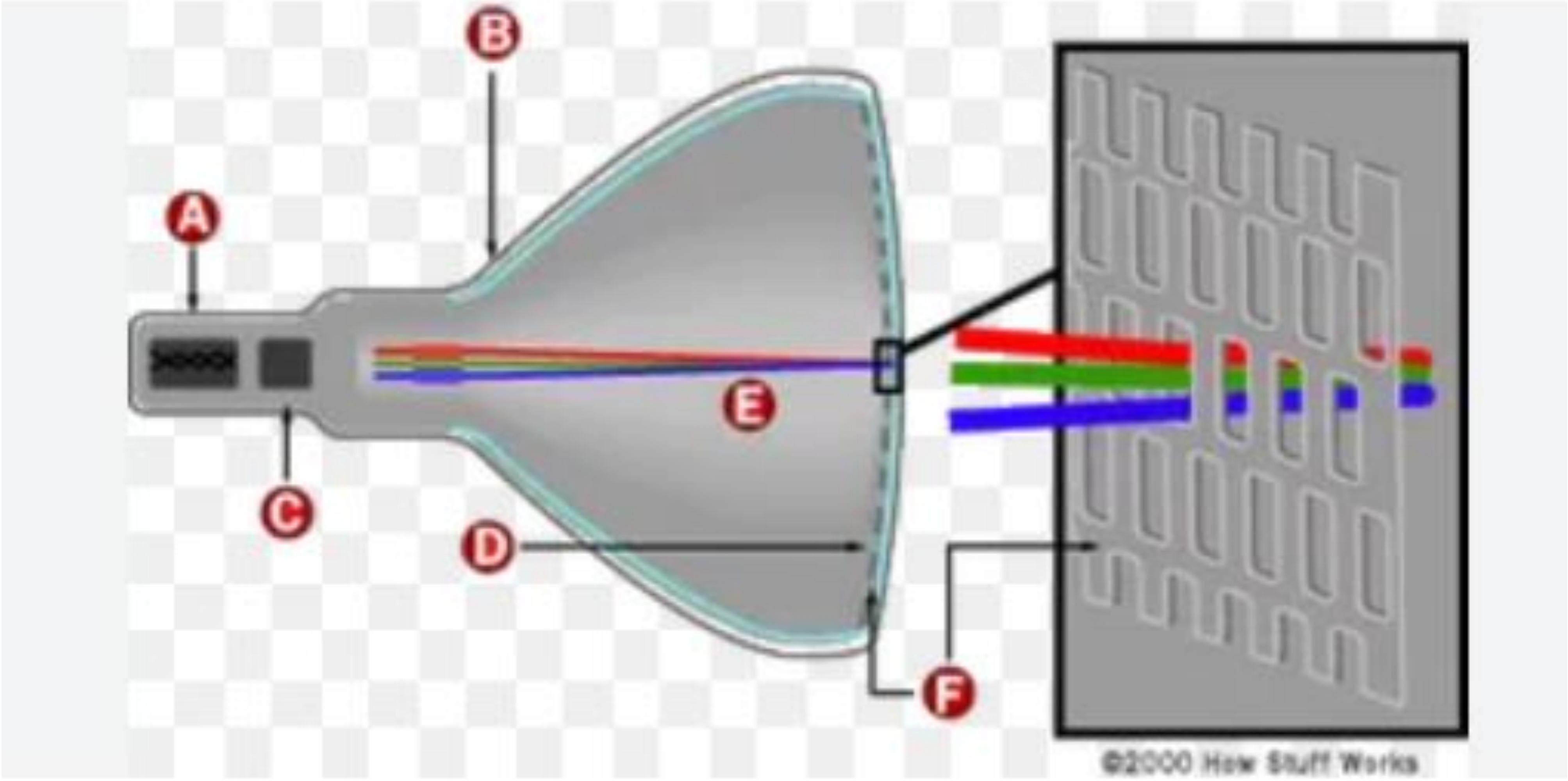
Evolution of Display Technology



Evolution of Display Technology



Cathoday Ray Tube (CRT) Display

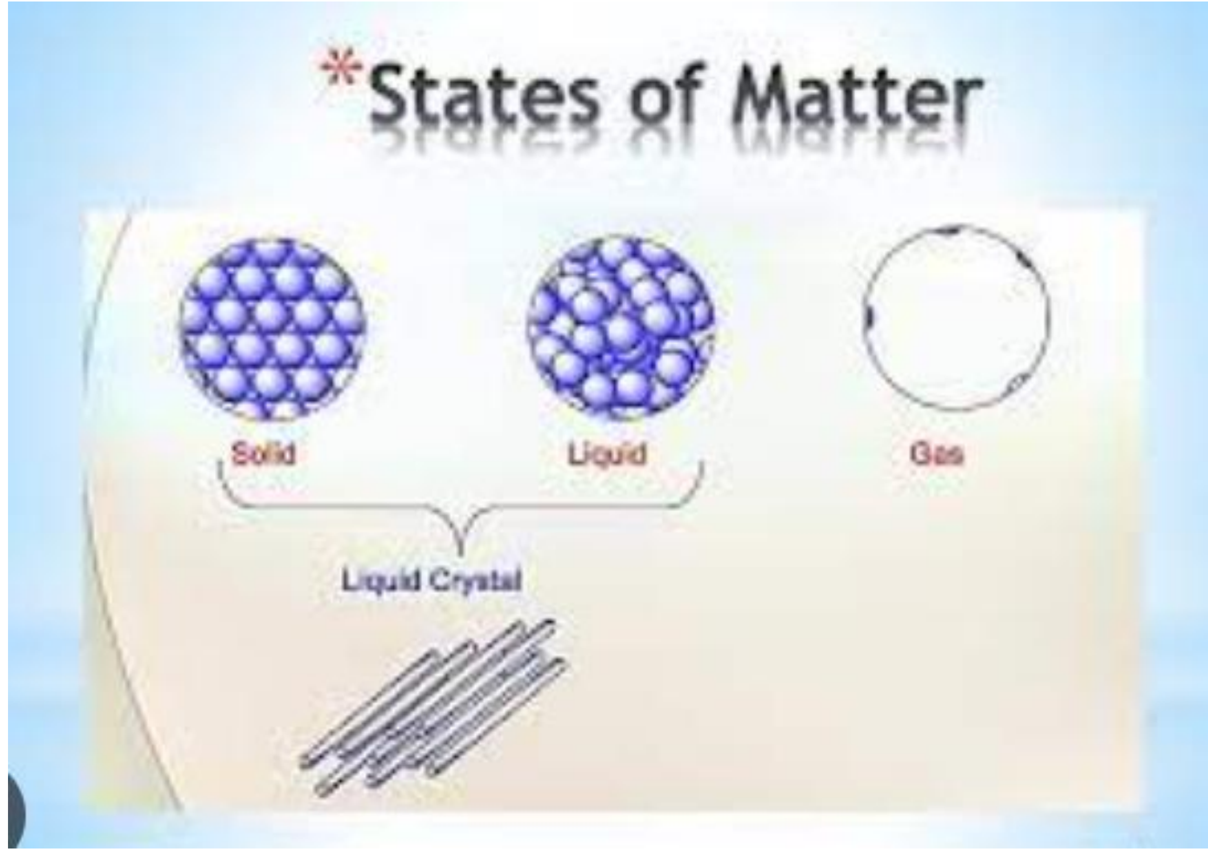


Pros	Cons
It has a faster response time.	Consume more electricity.
Can produce more colors.	They take up more space.
It is less expensive.	They are large, bulky, and heavy.

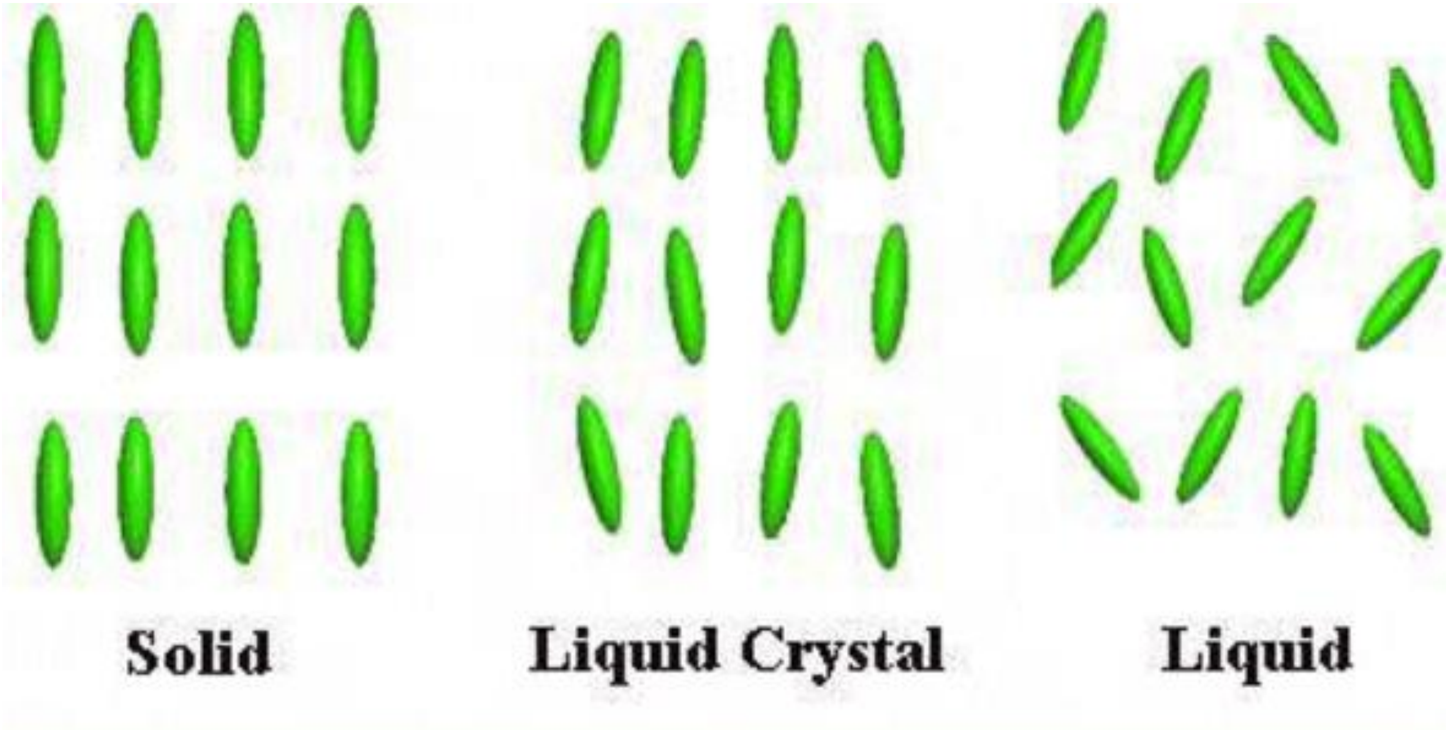
Liquid Crystal Display (LCD)

Liquid Crystals

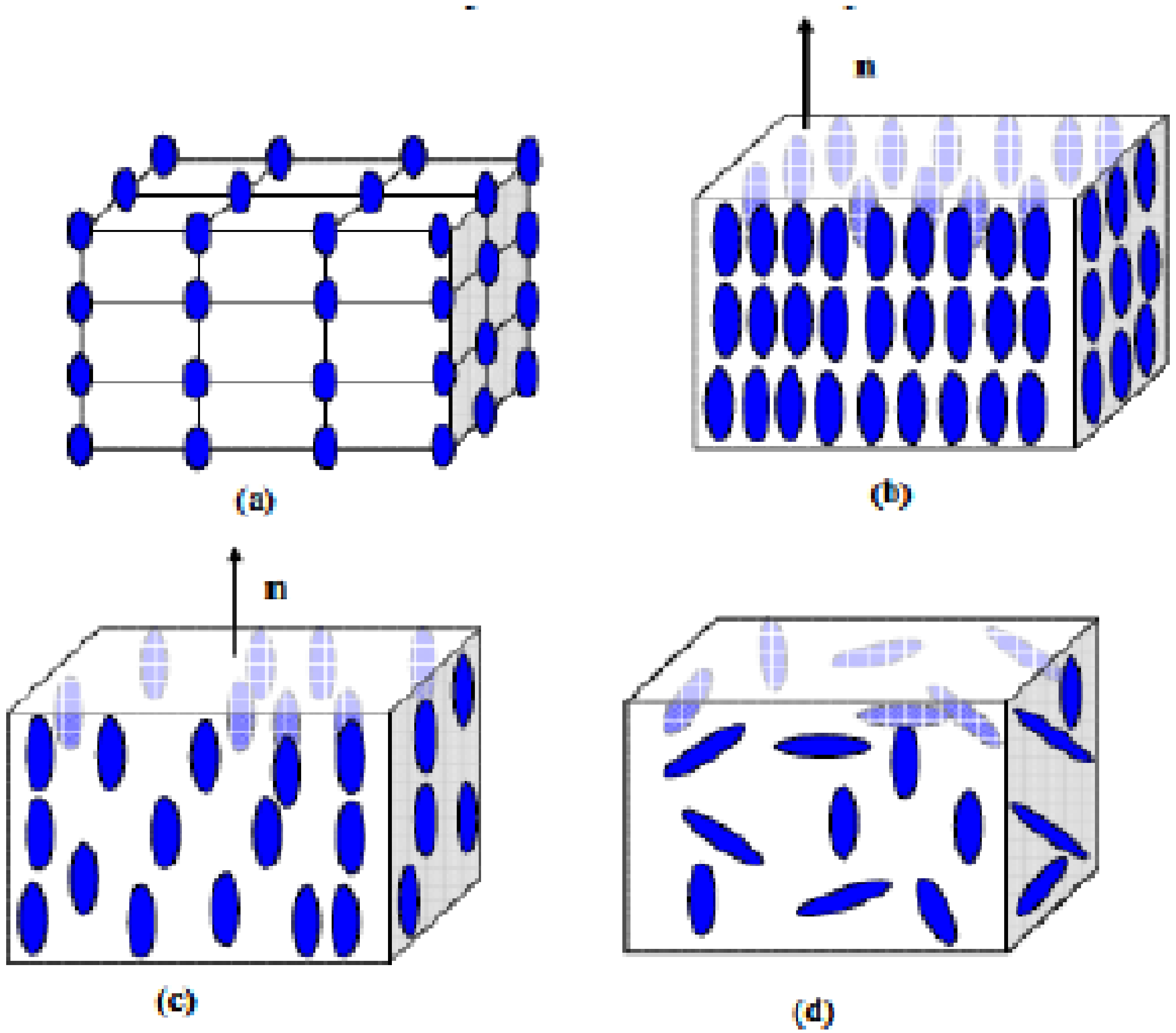
When Friedrich Reinitzer first observed the liquid crystal structure and behaviour of the cholesterol from carrots in 1888, a world of liquid crystal technology was opened.



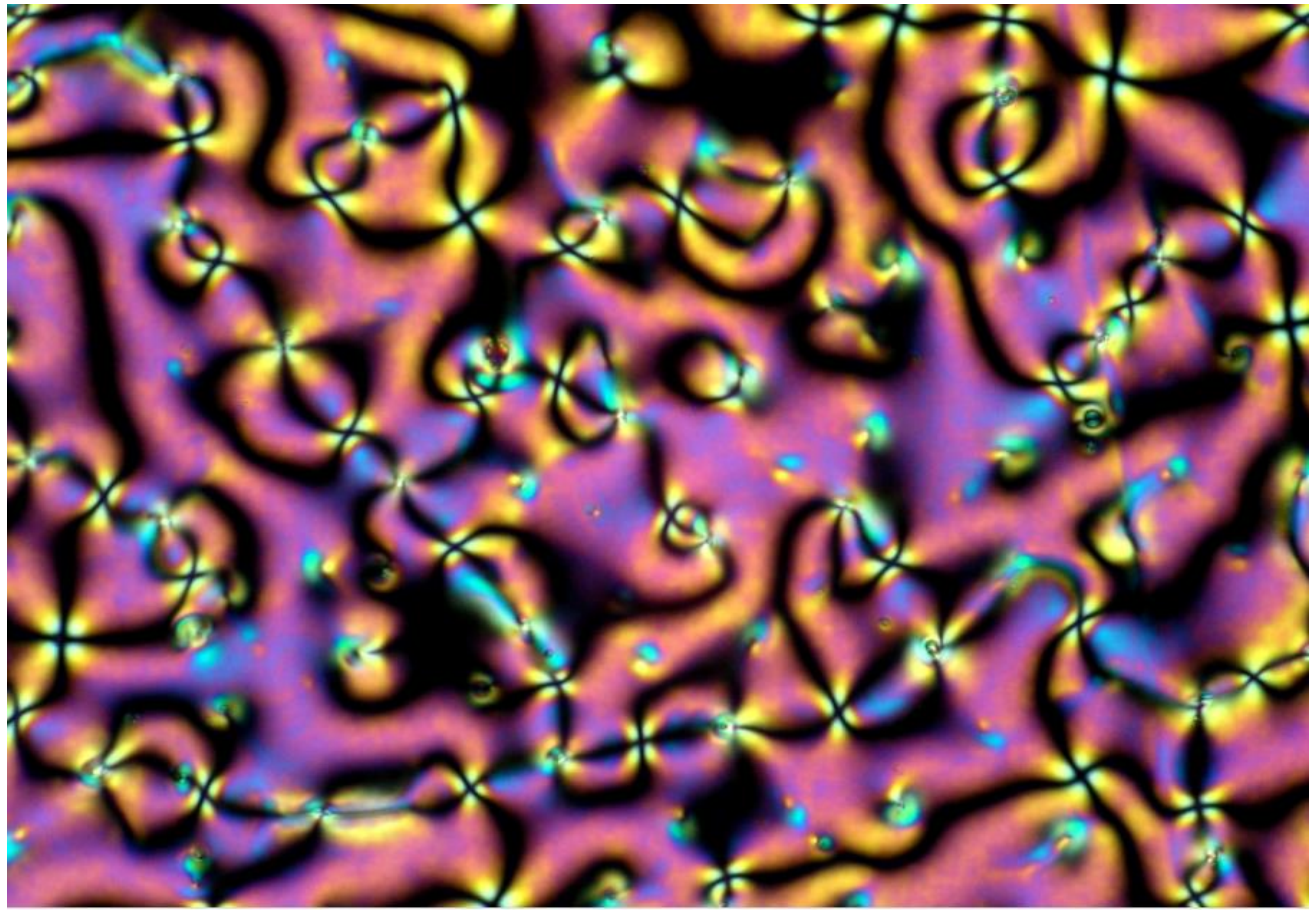
Reinitzer

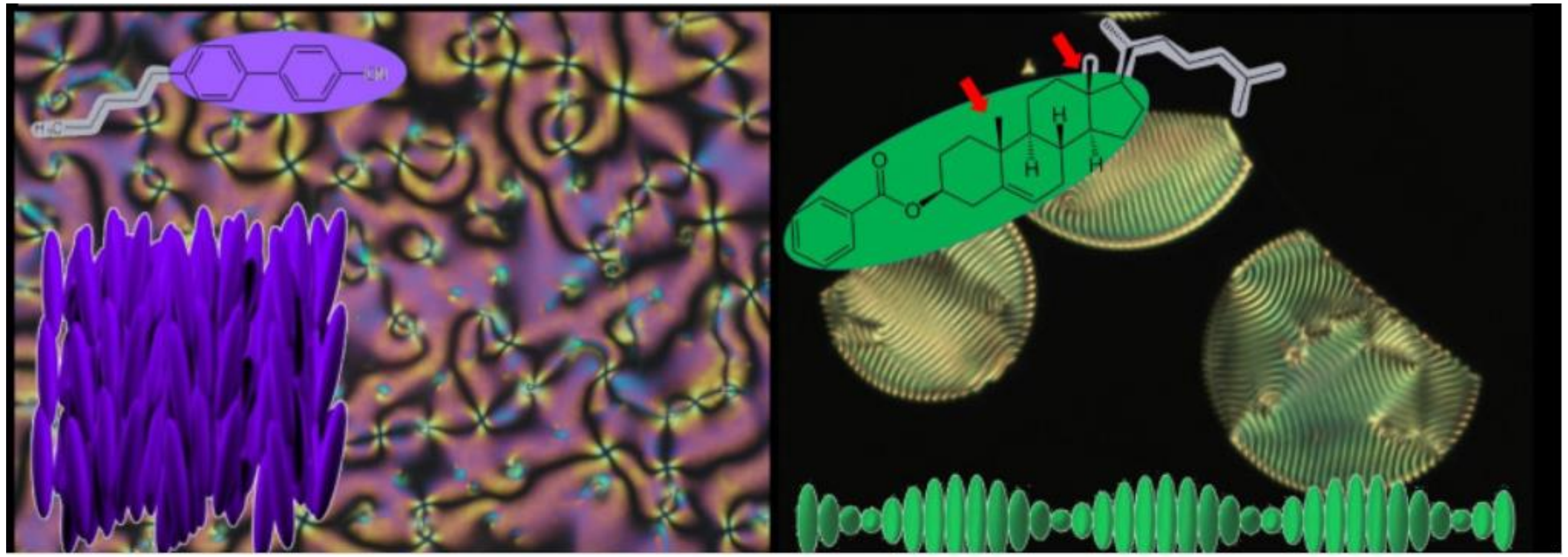


Liquid Crystals

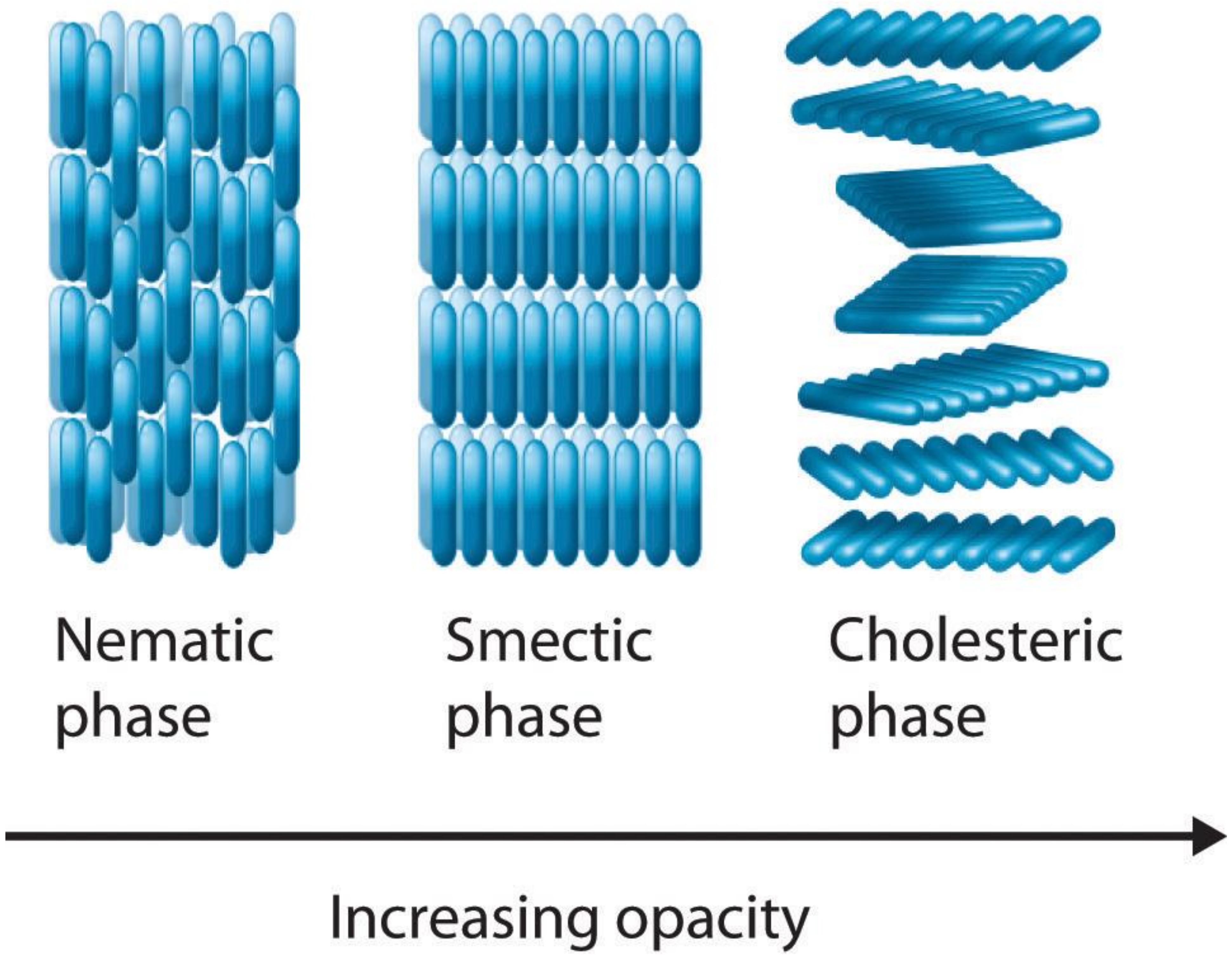


a) Crystals, b) & c) liquid crystals and d) liquid state





Classification of Liquid Crystals



- **Nematic liquid crystal**: They have molecules parallel to each other like soda straw but they are free to slide or roll individually
- **Smectic liquid crystal**: The molecules in this type are also arranged parallel but these are arranged in layers. The layers can slide on each other.
- **Cholesteric liquid crystal**: Like nemetic they also have molecules parallel but arranged in layers. Due to sliding of layers it form spiral structure.

Classification of Liquid Crystals

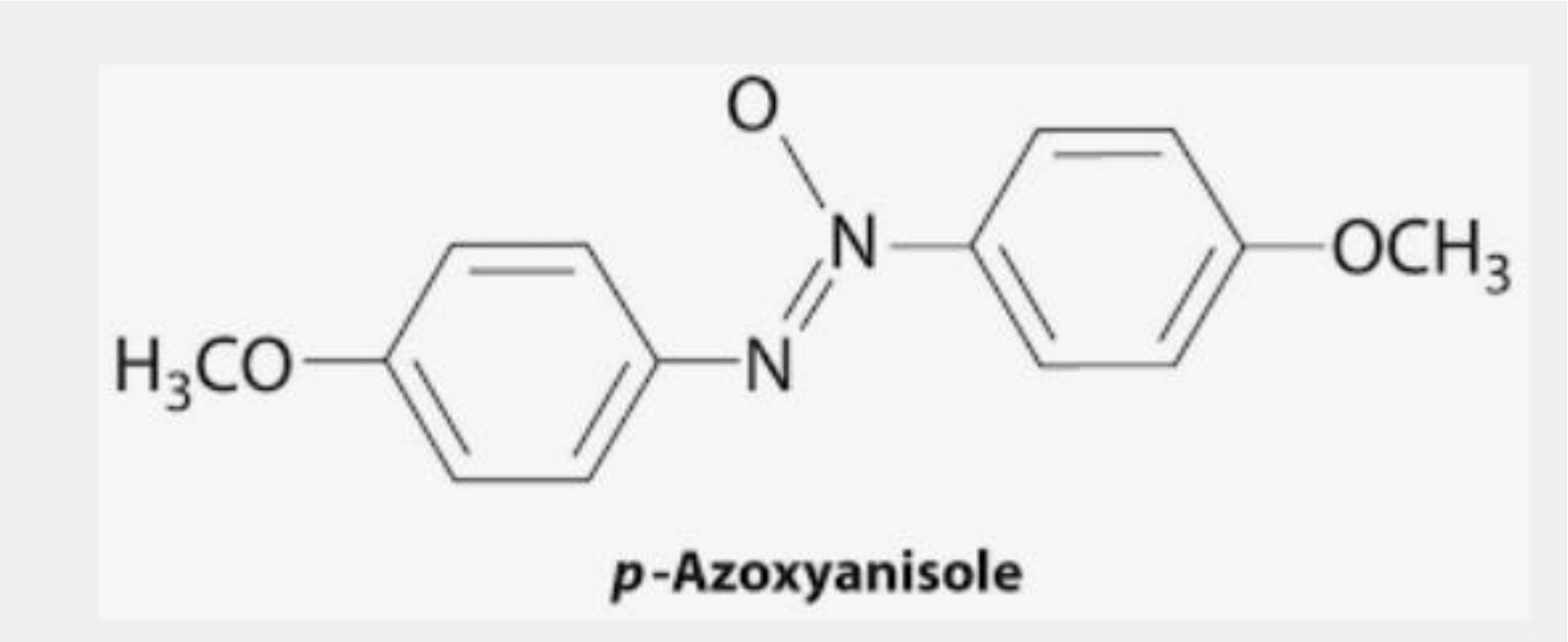
I. thermotropic, II. lyotropic and III. metallotropic.

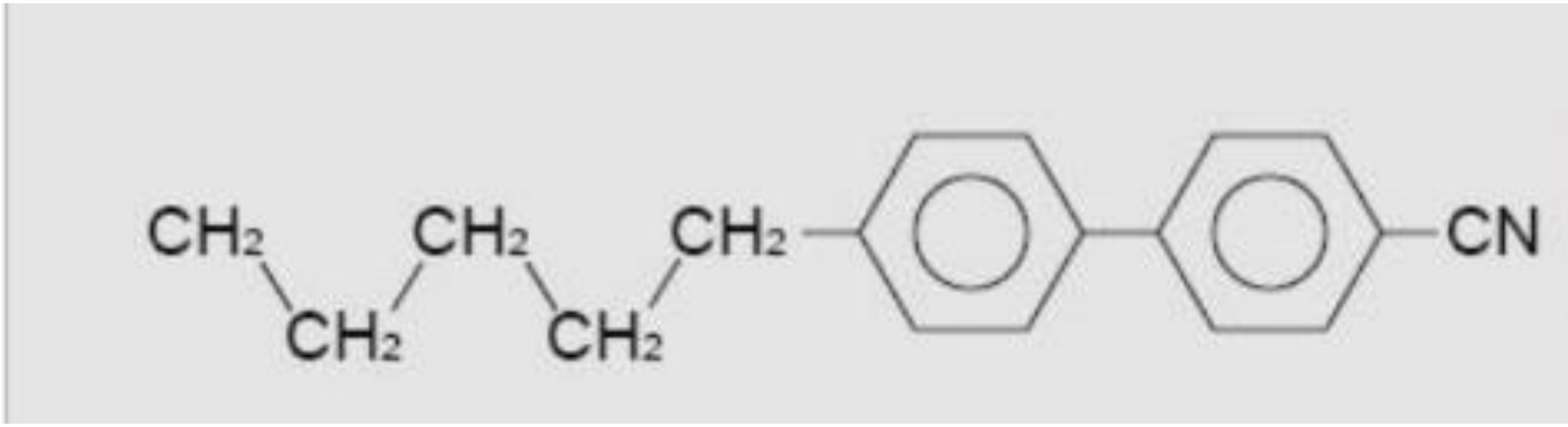
Thermotropic and lyotropic liquid crystals consist mostly of organic molecules, although a few minerals are also known. Thermotropic LCs exhibit a phase transition into the LC phase as temperature changes.

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

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

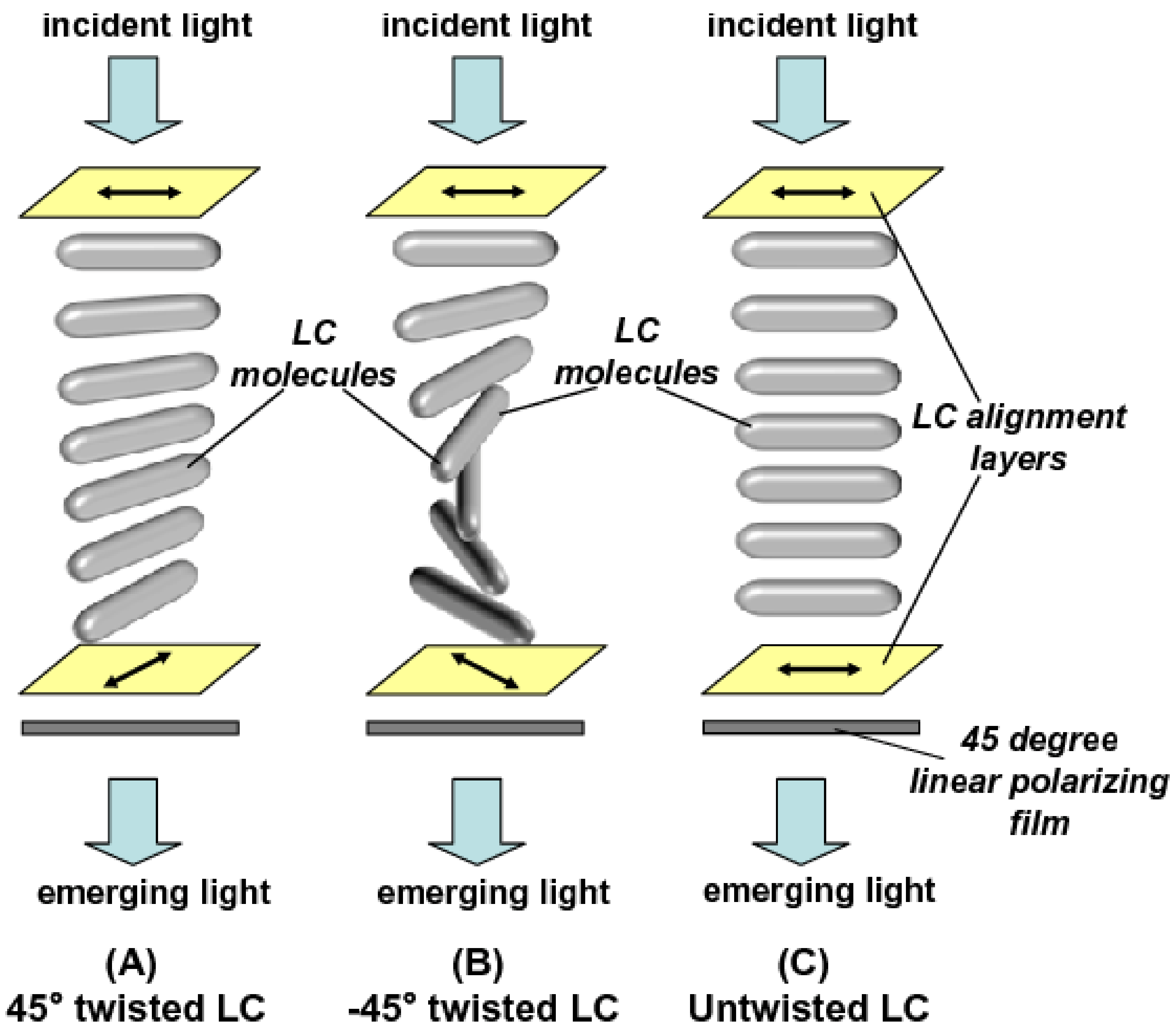
Examples of liquid crystal



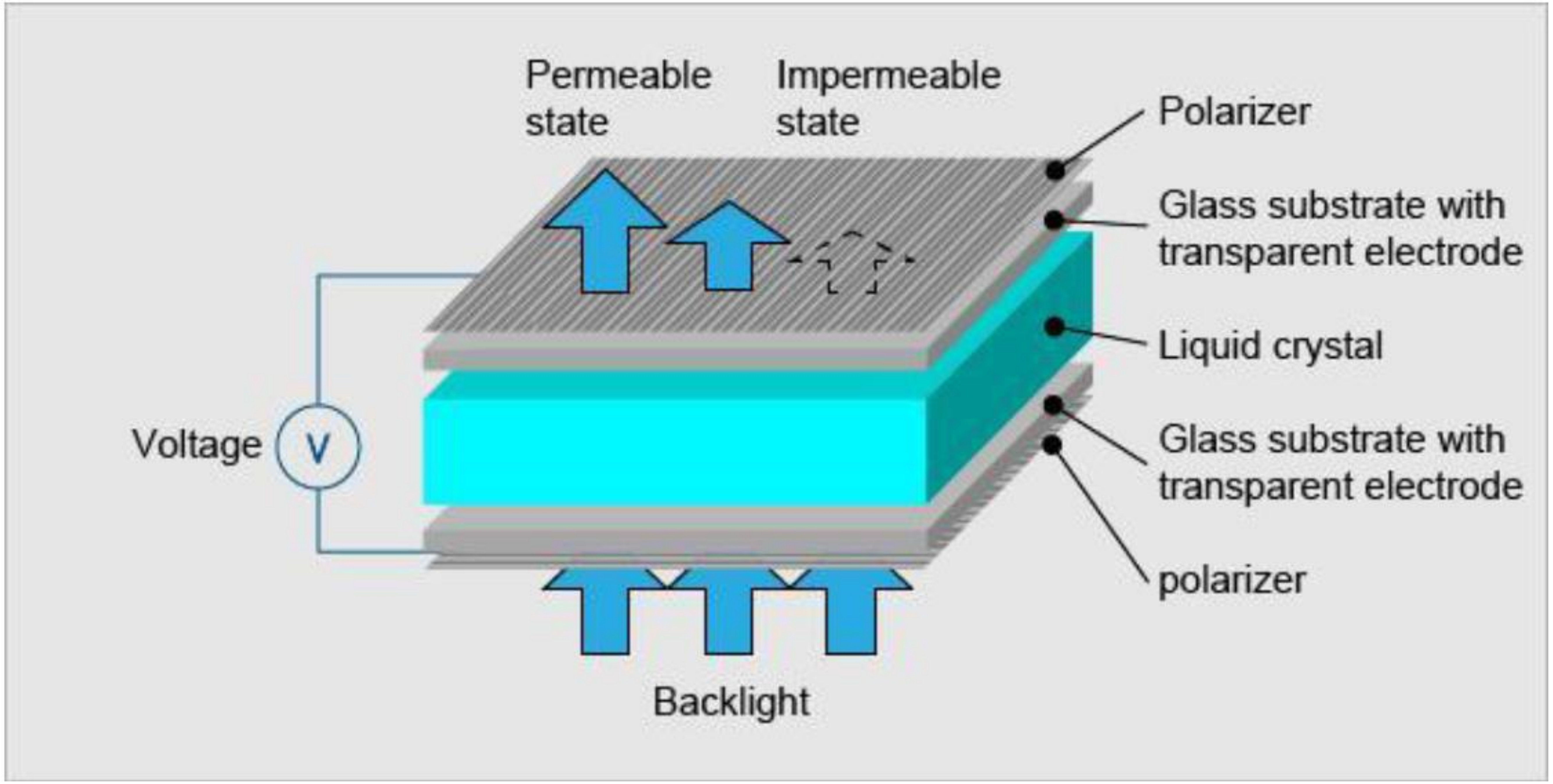


(4-pentyl-4‟-Cyanobiphenyl)

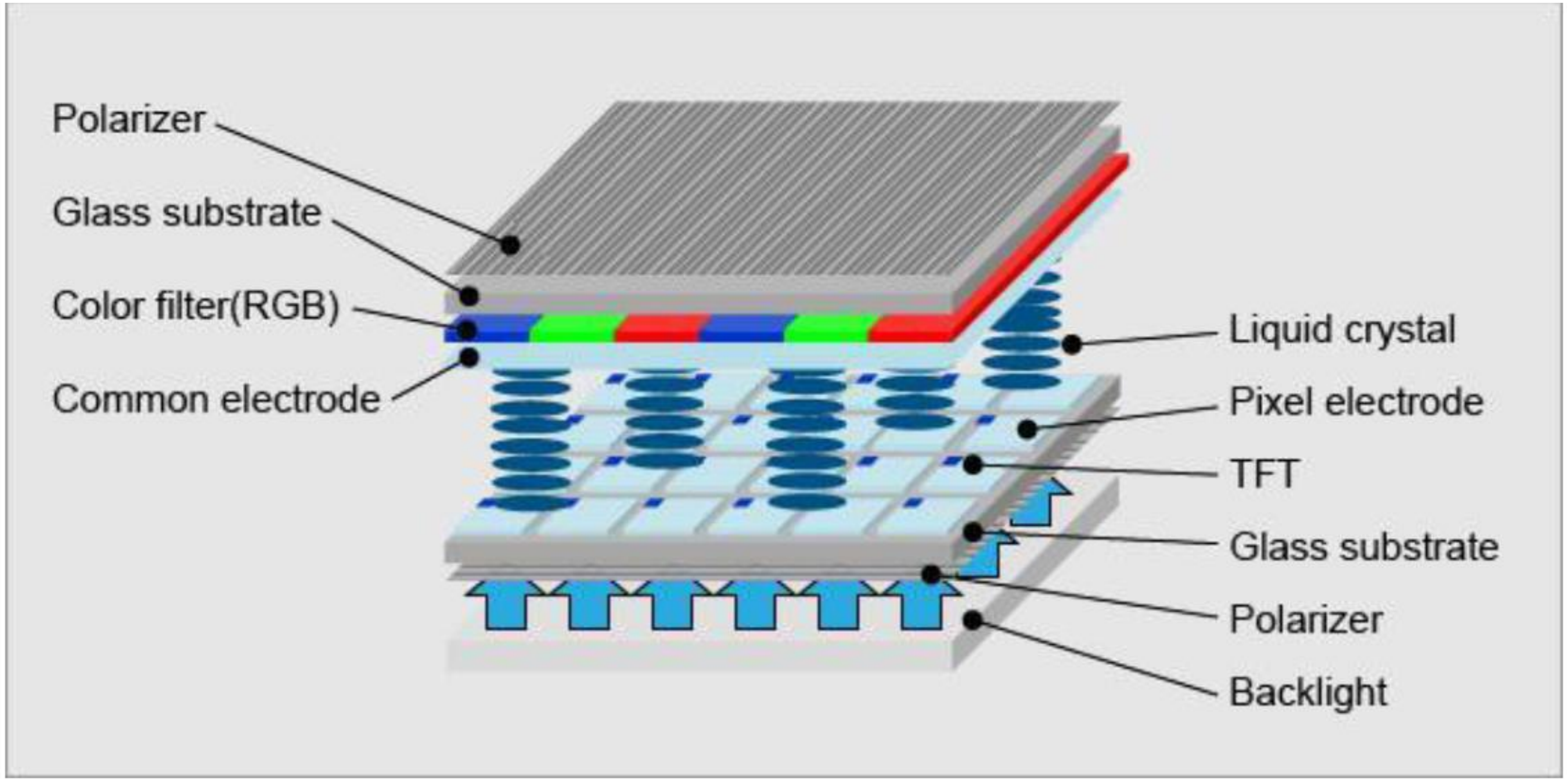
Polarization of light by liquid crystal



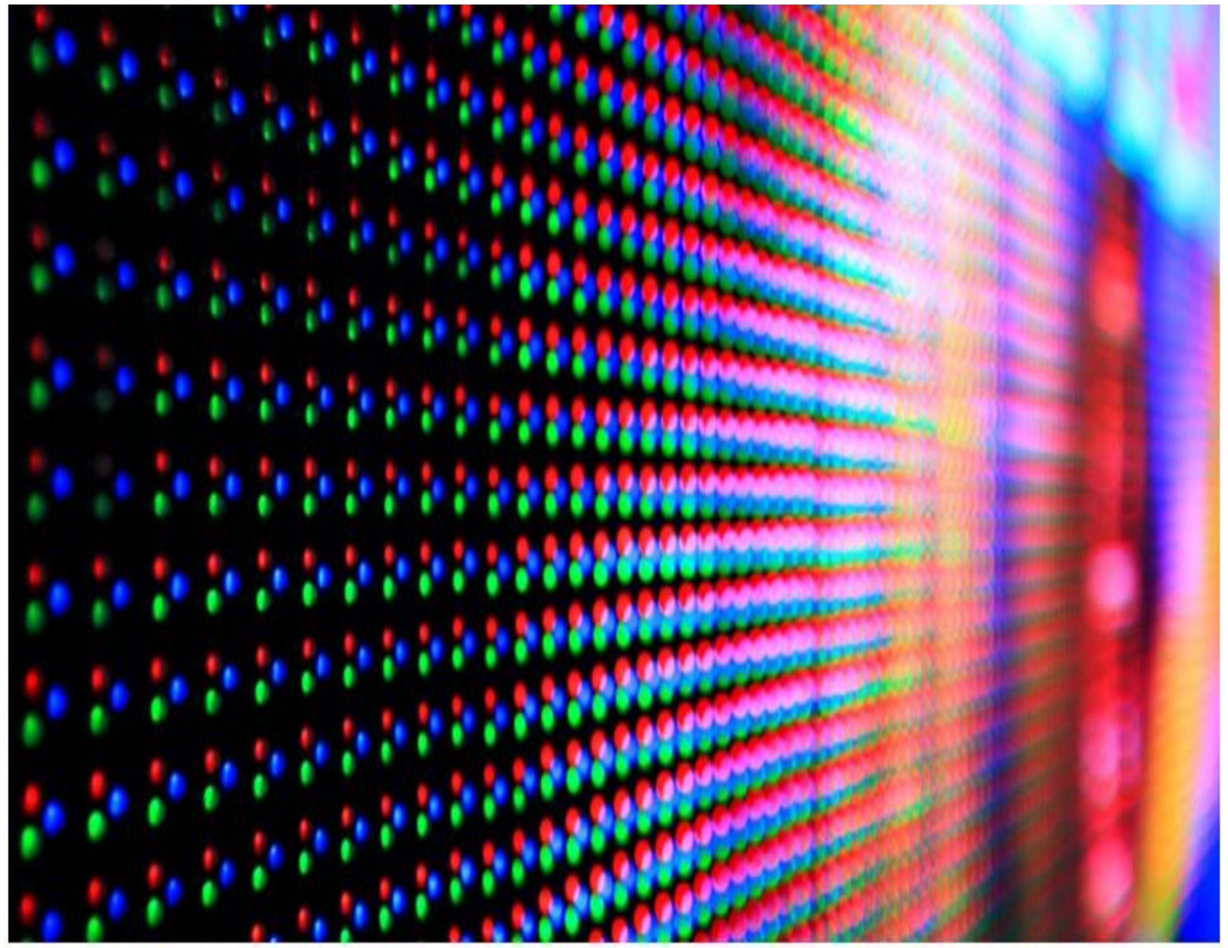
Principle of liquid crystal display



Principle, construction & working of a LED

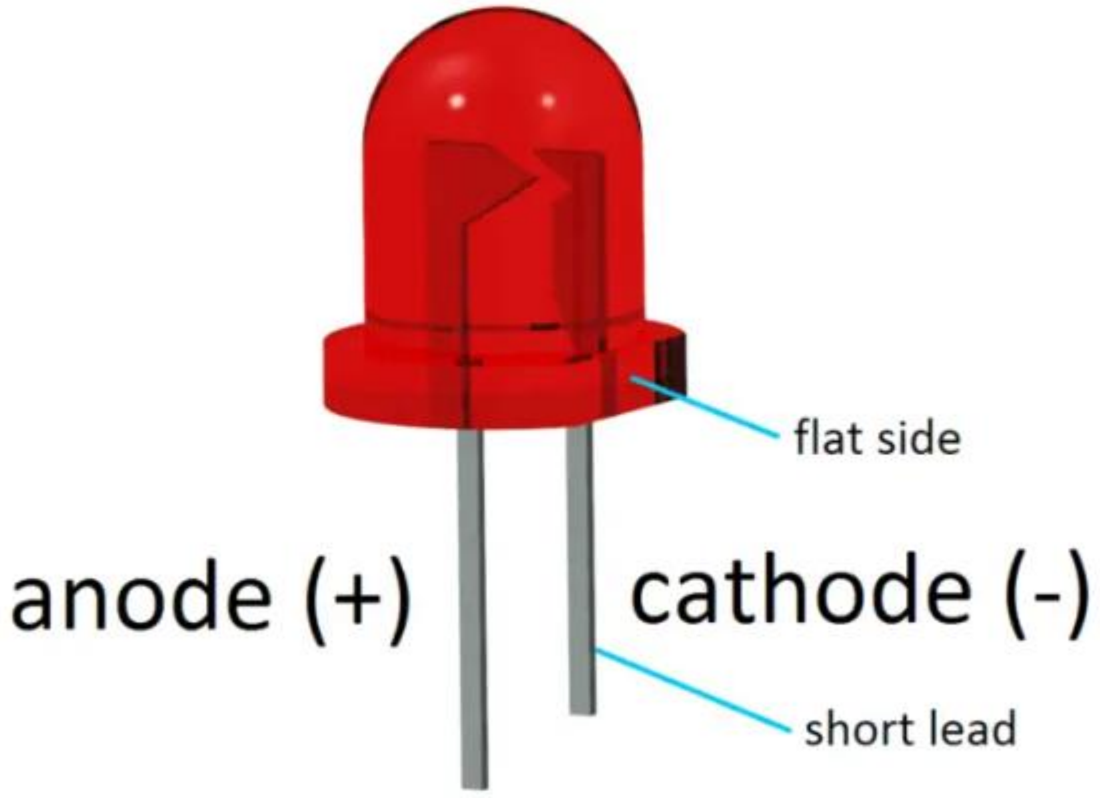


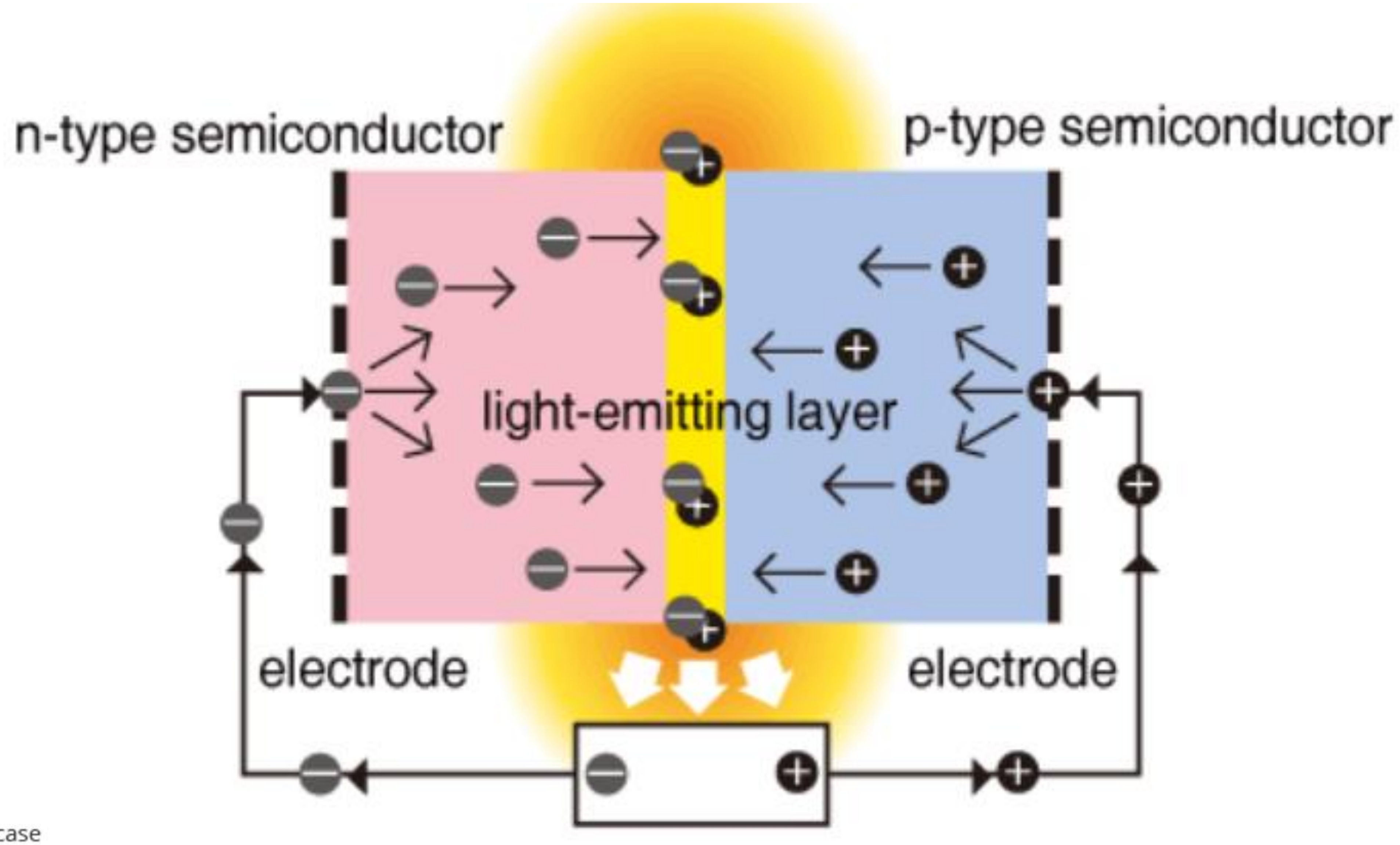
Light Emitting Diodes (LED)

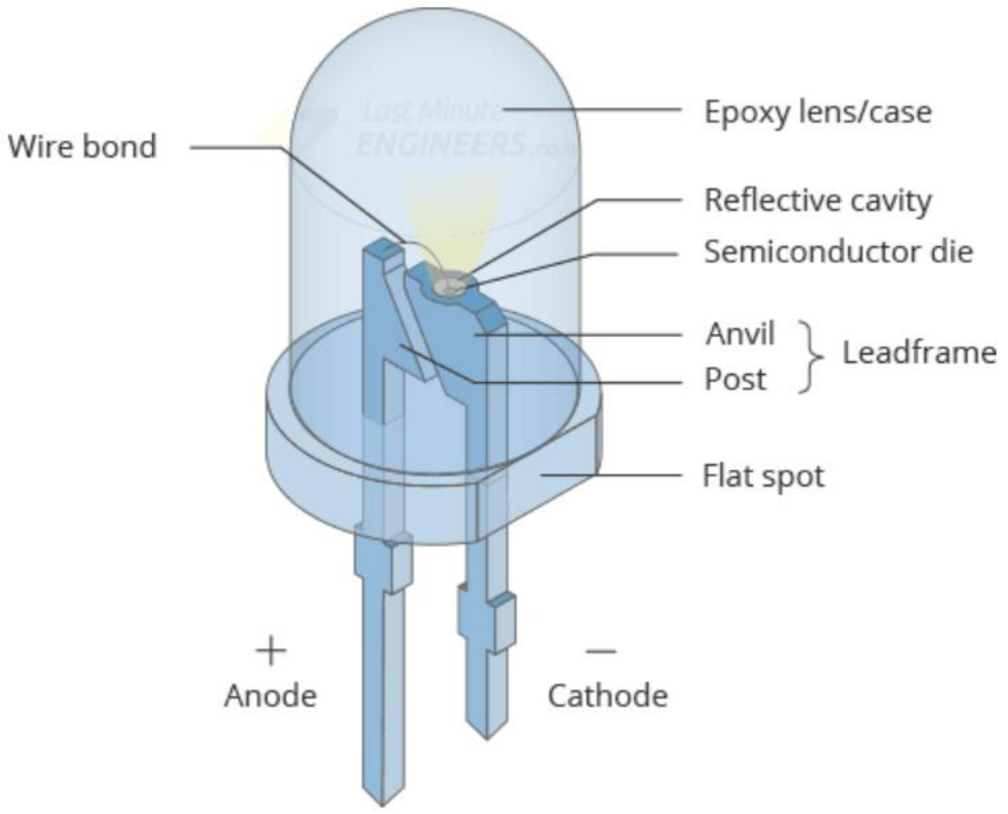


- Lifespan (50,000 hours)
- Improved Environmental Performance
- The Ability to Operate in Cold Conditions
- No Heat or UV Emissions
- Design Flexibility
- Low Voltage Operation

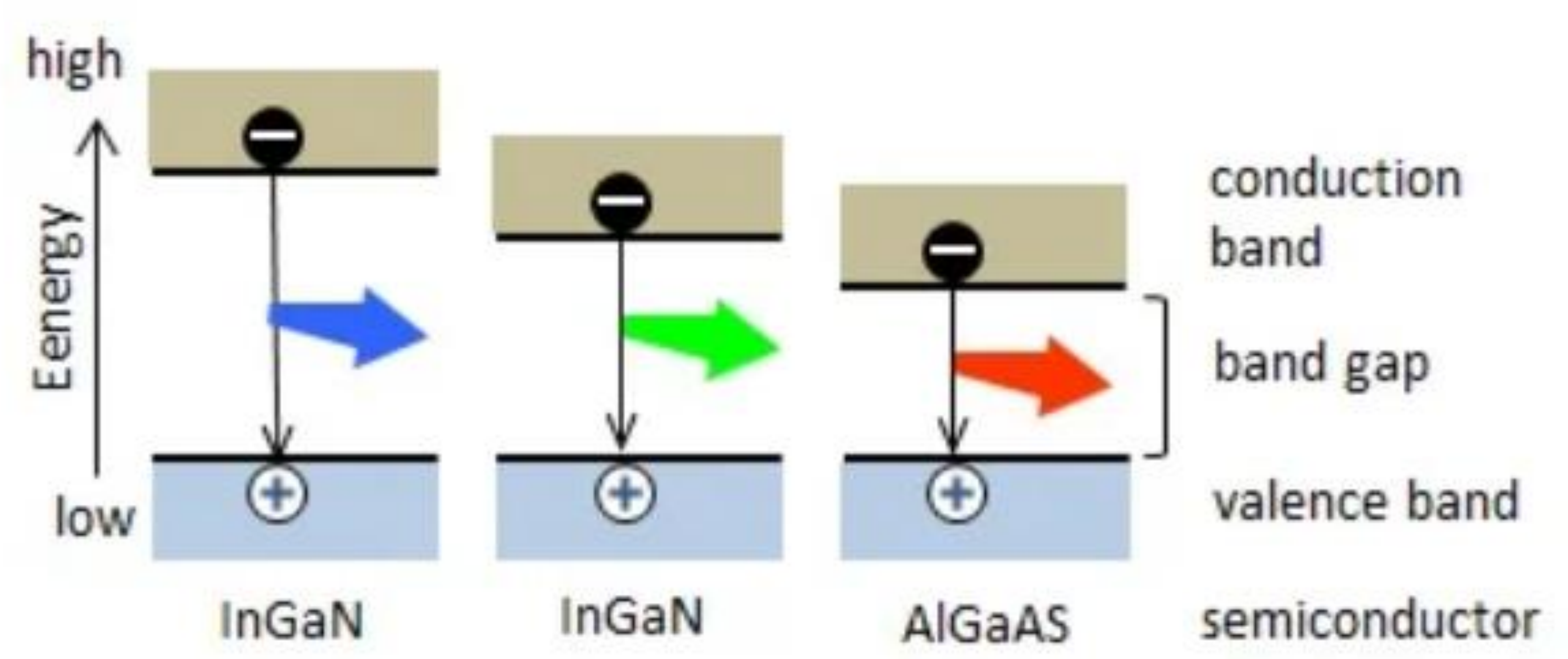
Working mechanism of LED



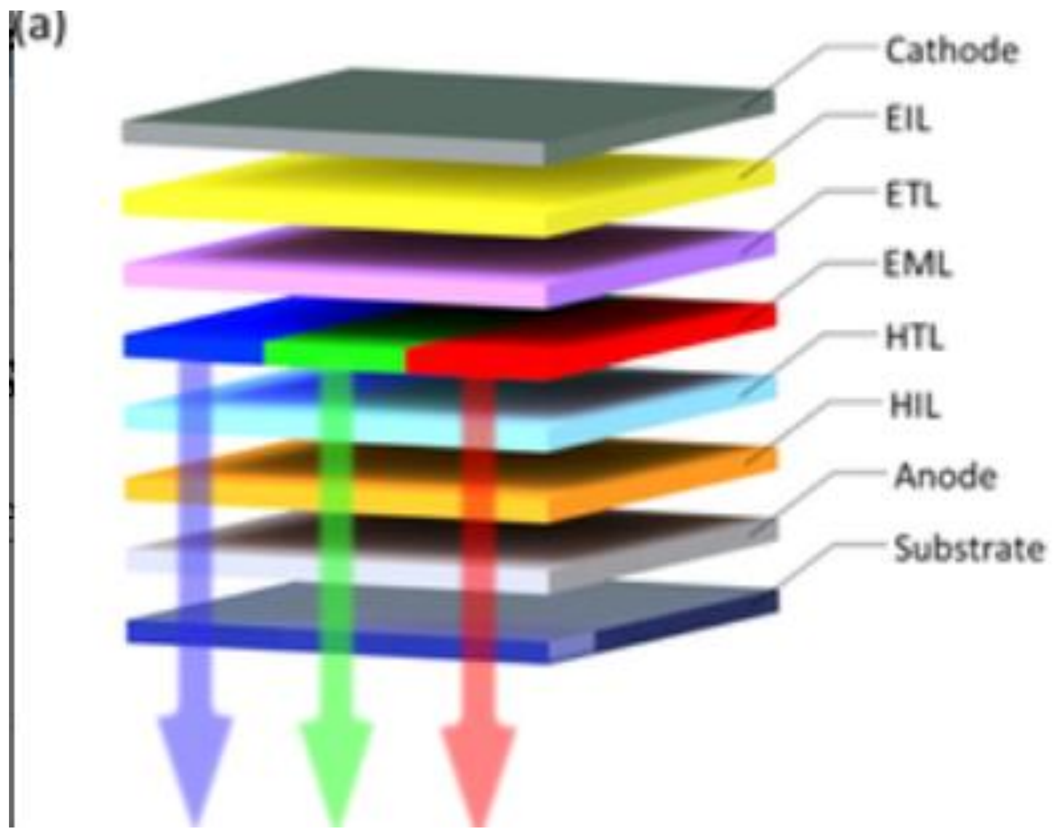


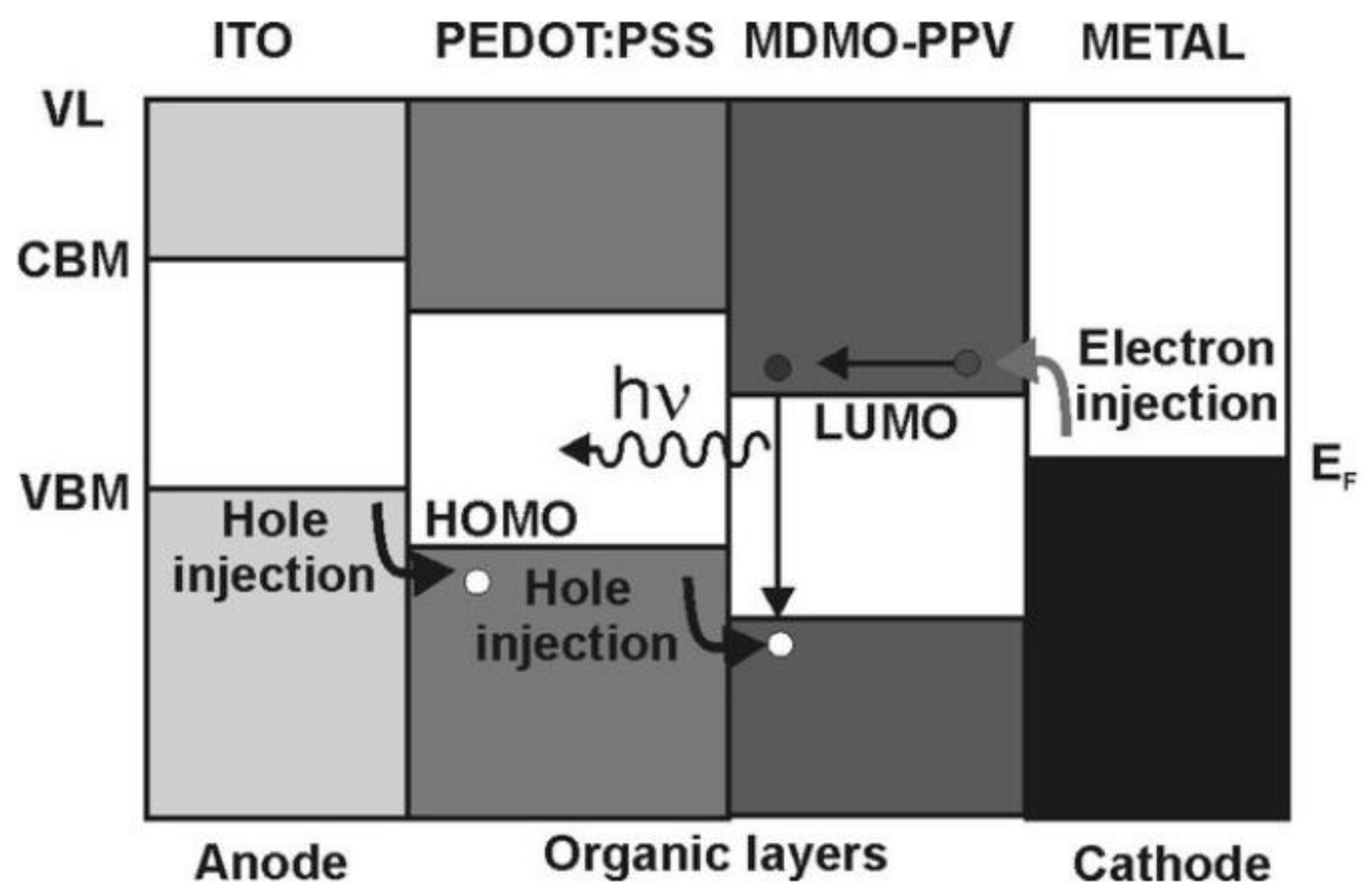


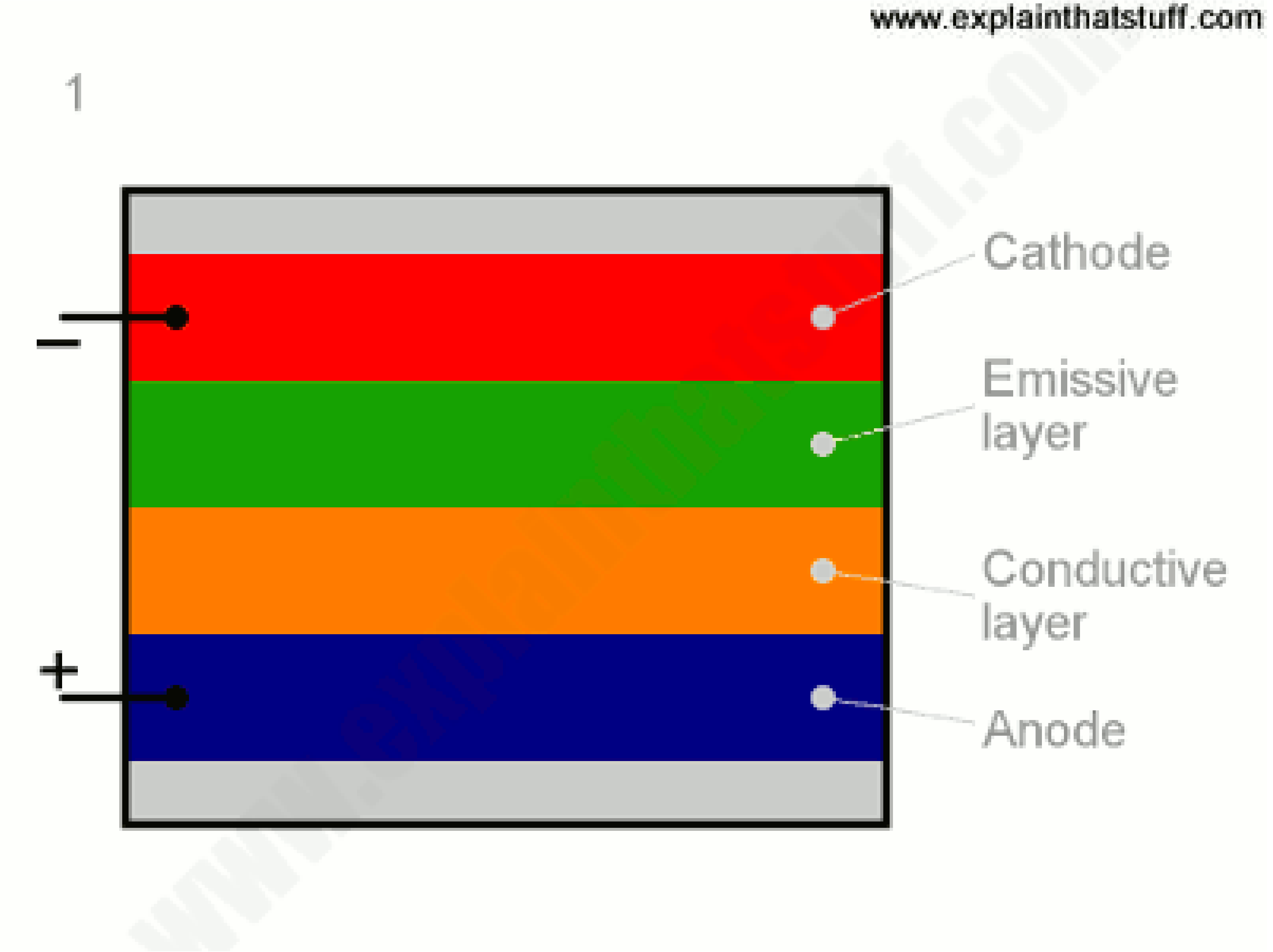
What causes differences in LED colors?



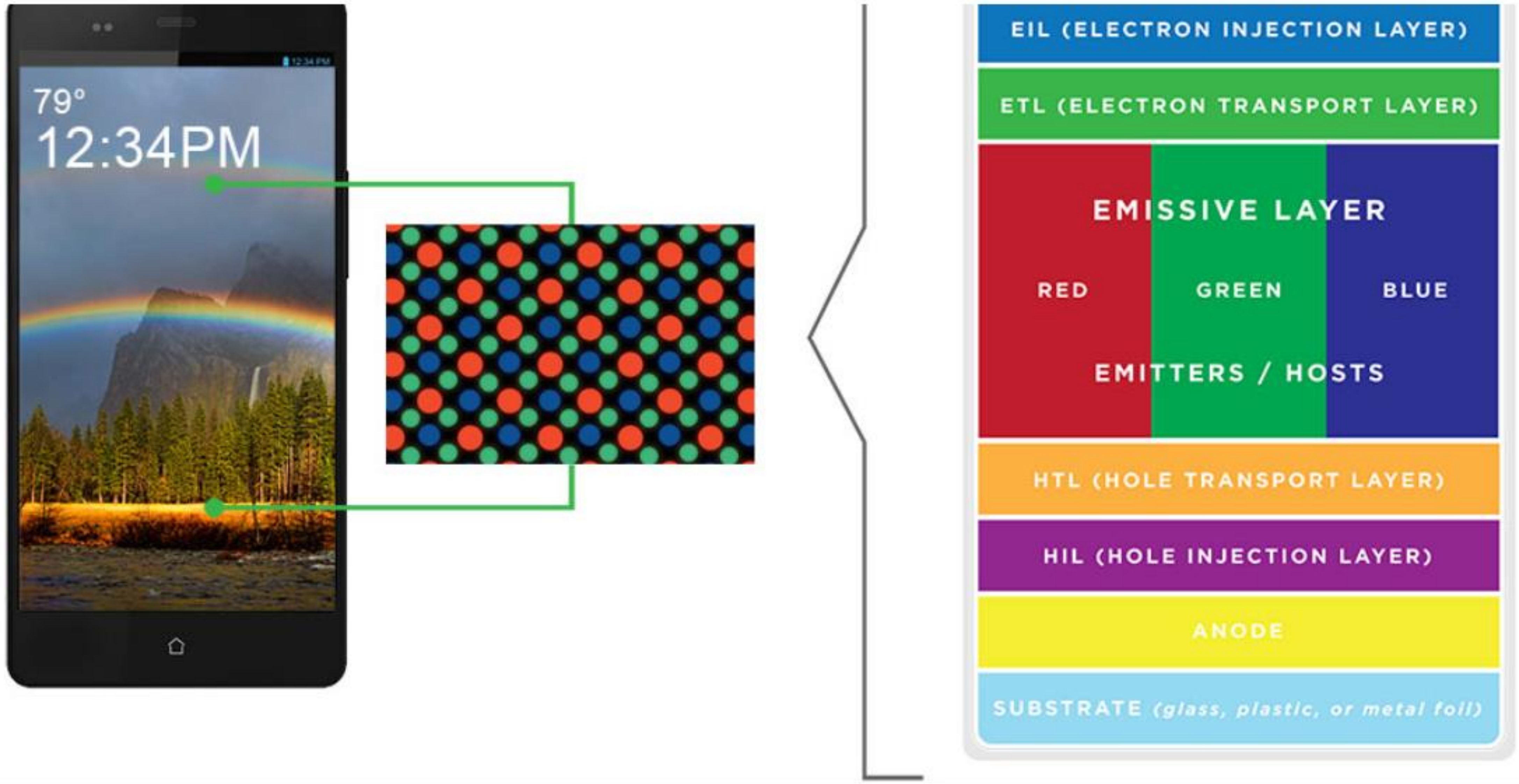
Organic Light Emitting Diodes (OLED)







Organic Light Emitting Diodes (OLED)



Light Emitting Electrochemical Cell (LEC)

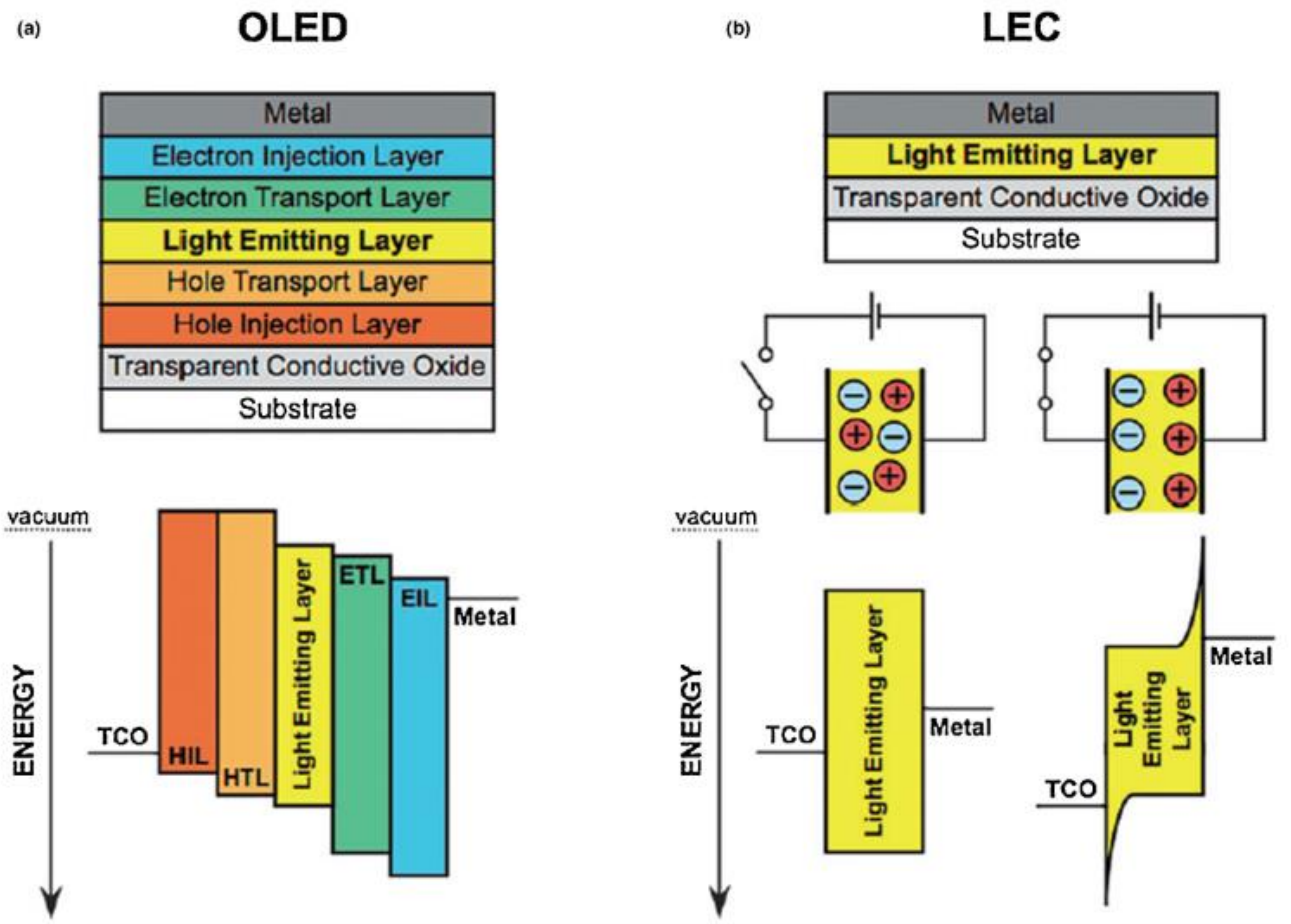
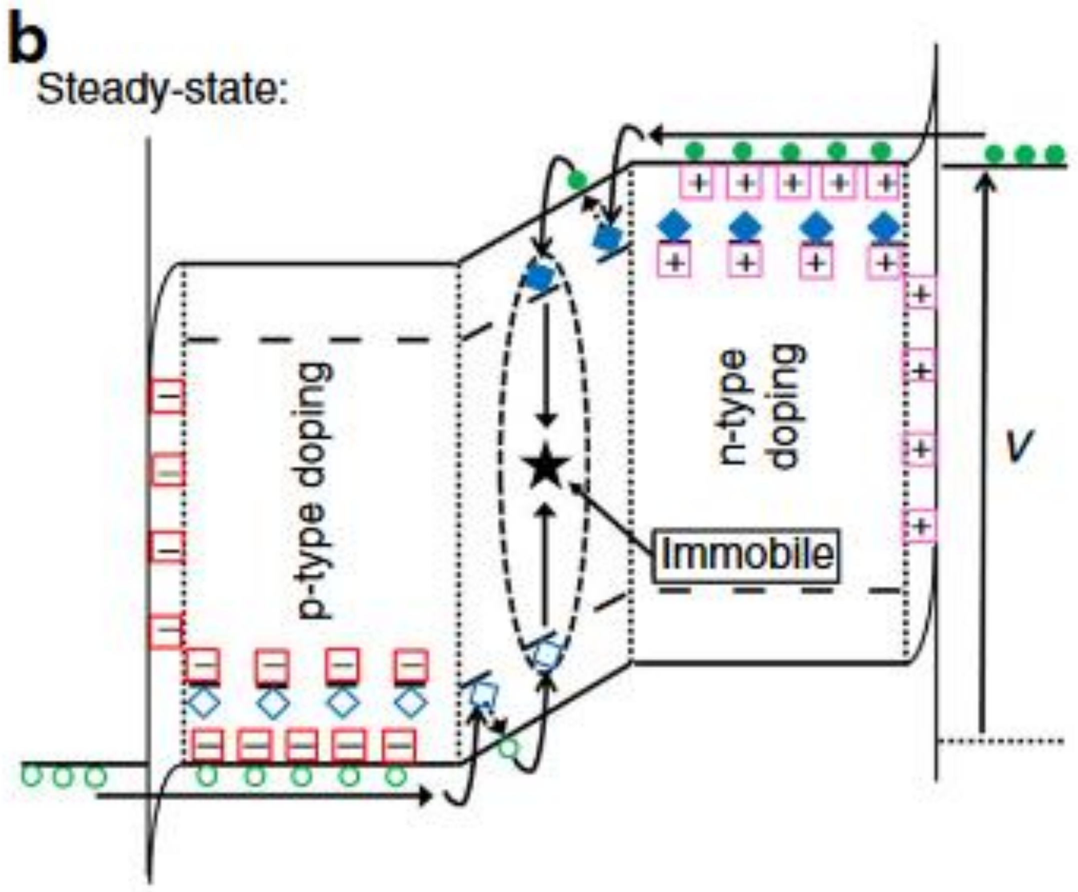
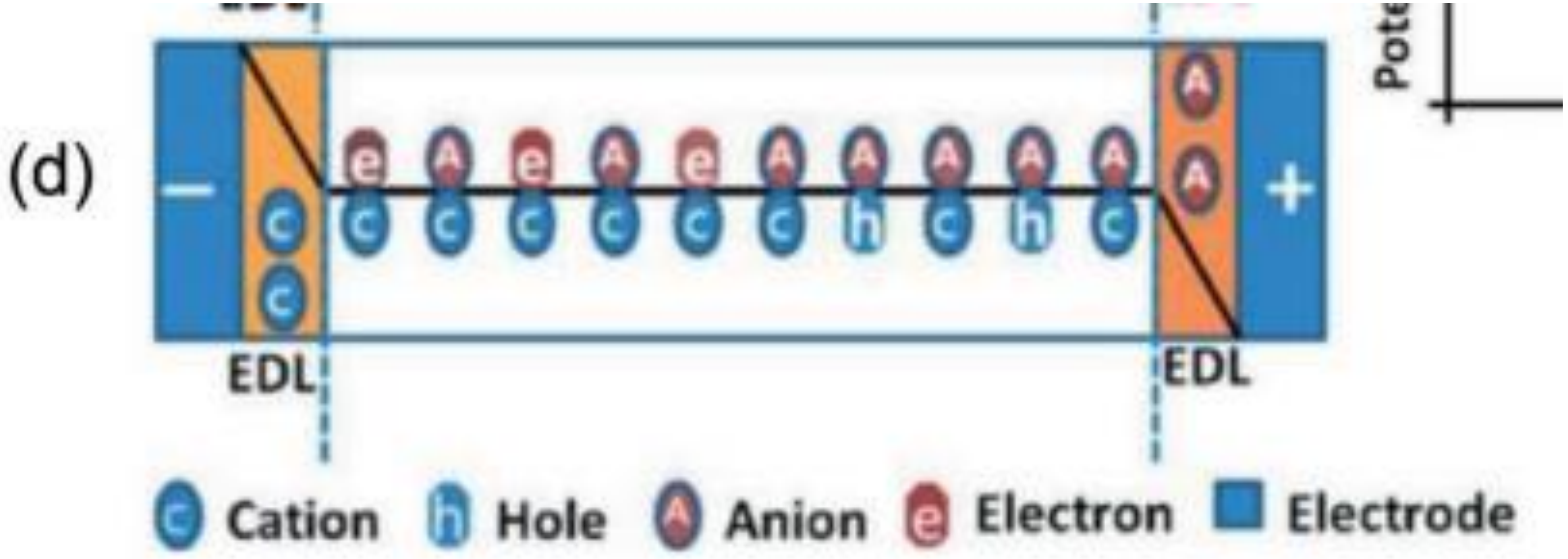


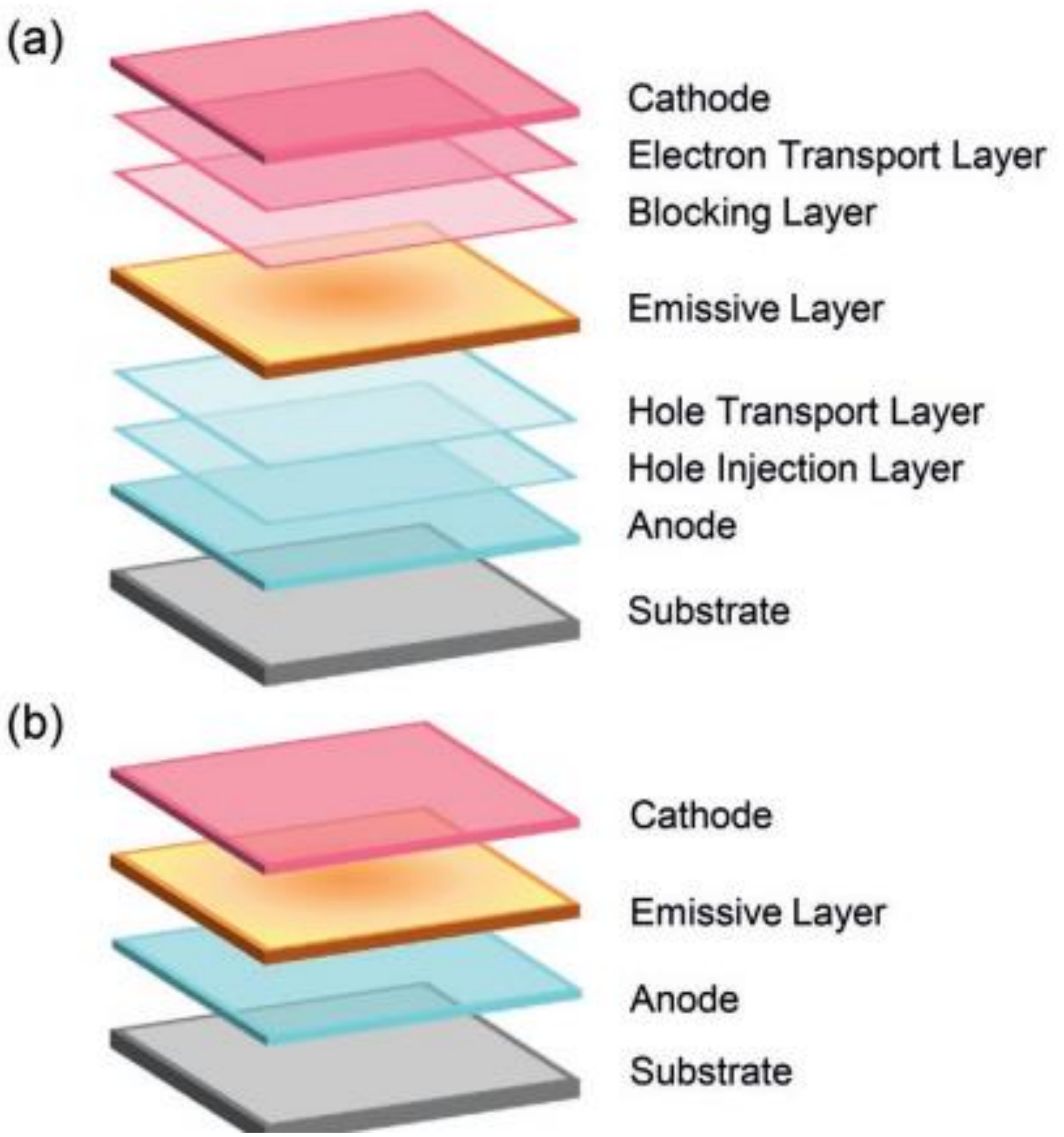
FIGURE 1

(a) Schematic representation of a state-of-the-art OLED. (b) A state-of-the-art LEC. OLEDs require multiple layers, some of them processed by evaporation

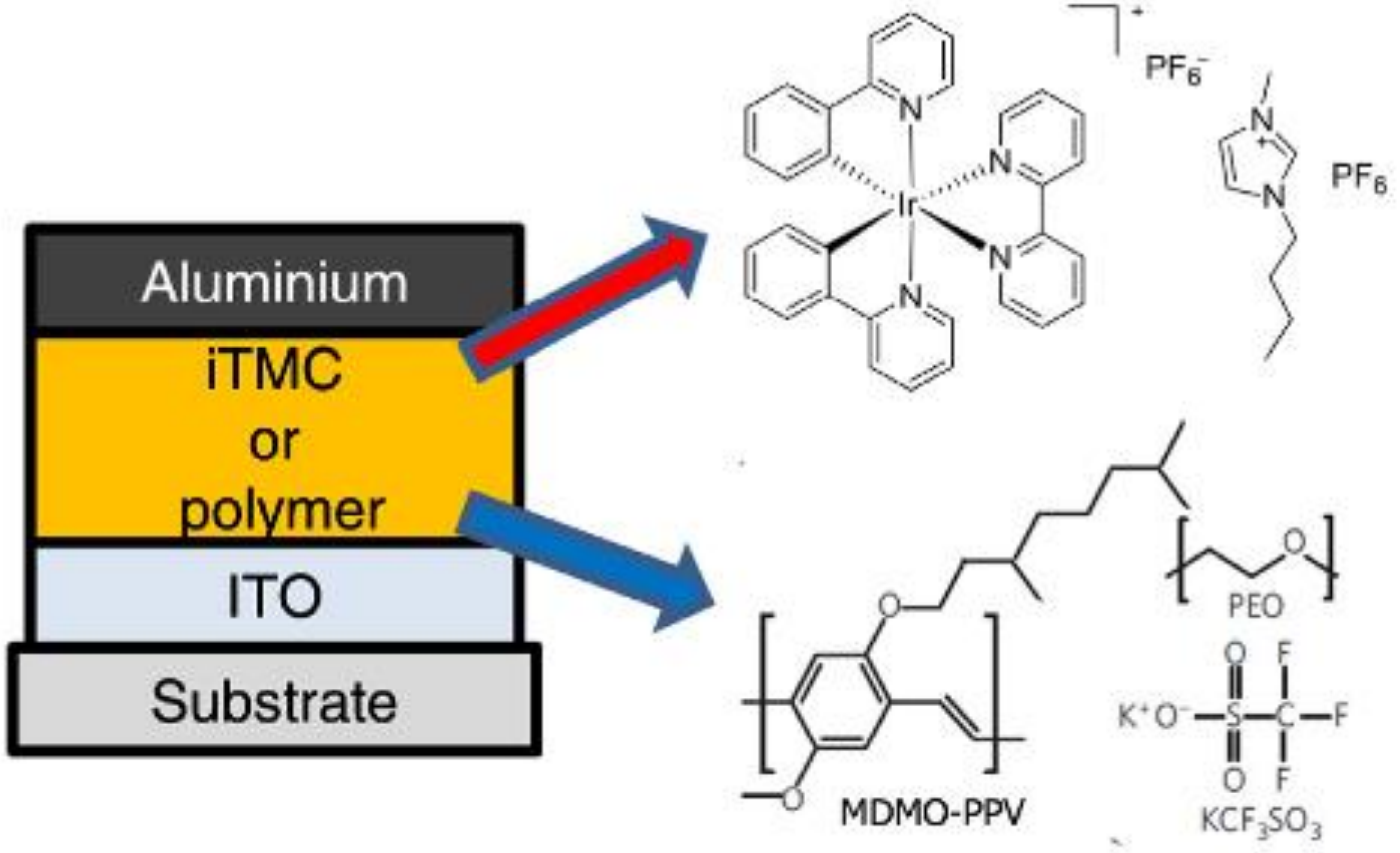
Working principle of LEC







Examples for LEC



(a)