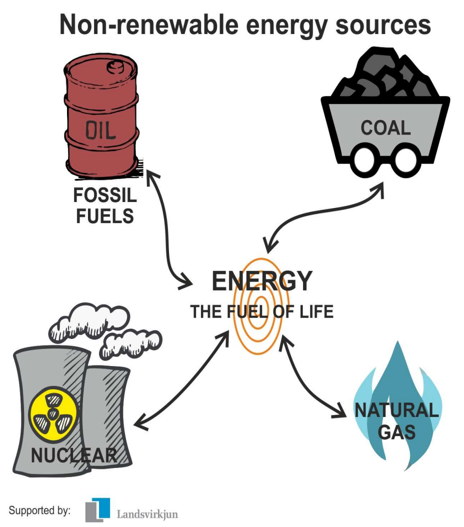
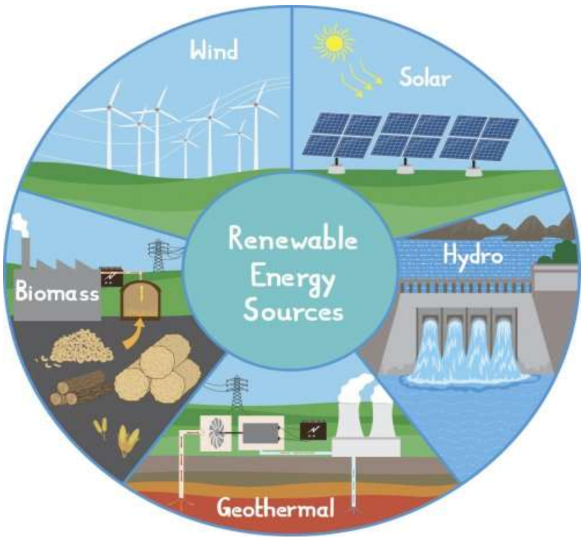
ENERGY





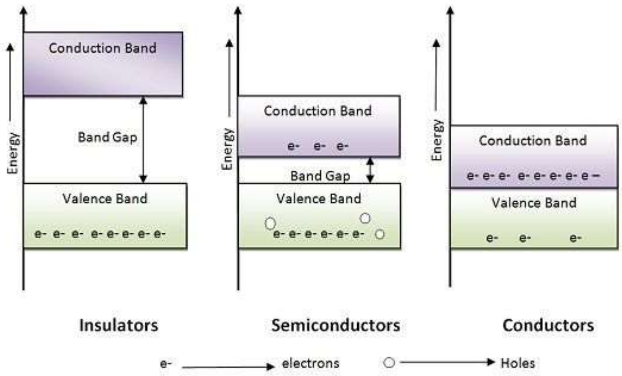
Solar Cell

Semiconductor???

❖ **Photovoltaic effect:**

Light energy → electrical energy.

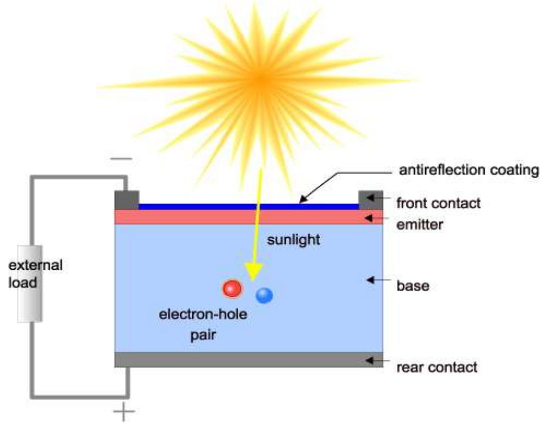
❖**Active light absorbing material: Semiconductor: Silicon, Perovskite, Polymer, Dye etc.**



Solar Cell/ Photovoltaic cell

Basic component of a solar cell:

- ❖ **Light Absorber:** converting incident photons to electron and holes.
- ❖ **Carrier Collector/s:** capturing the carriers (electron and holes).
- ❖ **Metal Contacts:** transferring the carriers to the circuit.



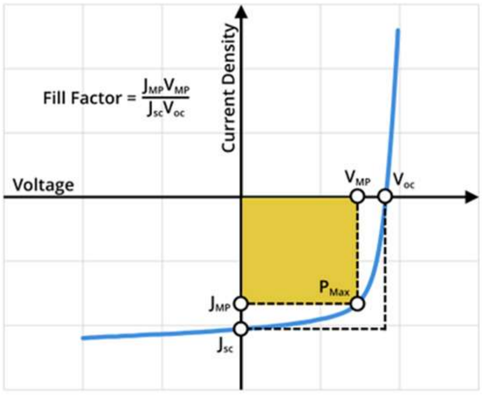
Criteria for Materials to be Used in Solar Cell

- ❖ **Must have band gap from 1ev to 1.8ev.**
- ❖ **It must have high optical absorption.**
- ❖ **It must have high electrical conductivity.**
- ❖ **The raw material must be available in abundance and the cost of the material must be low.**

Materials Used in Solar Cell

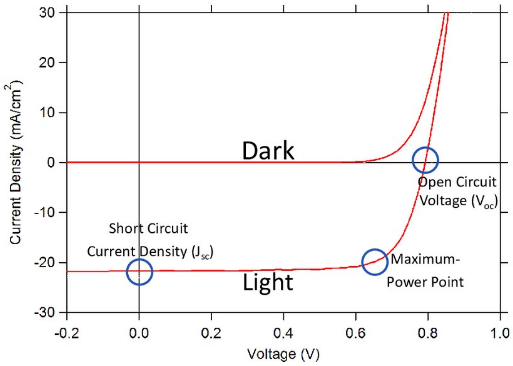
- ❖ **The materials which are used for this purpose must have band gap close to 1.4ev. Commonly used materials are-**
- ❖ **Silicon.**
- ❖ **GaAs.**
- ❖ **CdTe.**
- ❖ **$CuInSe_2$**

V-I Characteristics of a Photovoltaic Cell



$$PCE = \frac{P_{out}}{P_{in}} = \frac{J_{sc}V_{oc}FF}{P_{in}}$$

Jsc→ Short circuit current density
Voc→ Open circuit voltage
FF→ Fill factor
Pin→ Incident power



Advantages of Solar Cell

❖ **No pollution**
❖ **Long lasting**
❖ **Less maintenance cost.**

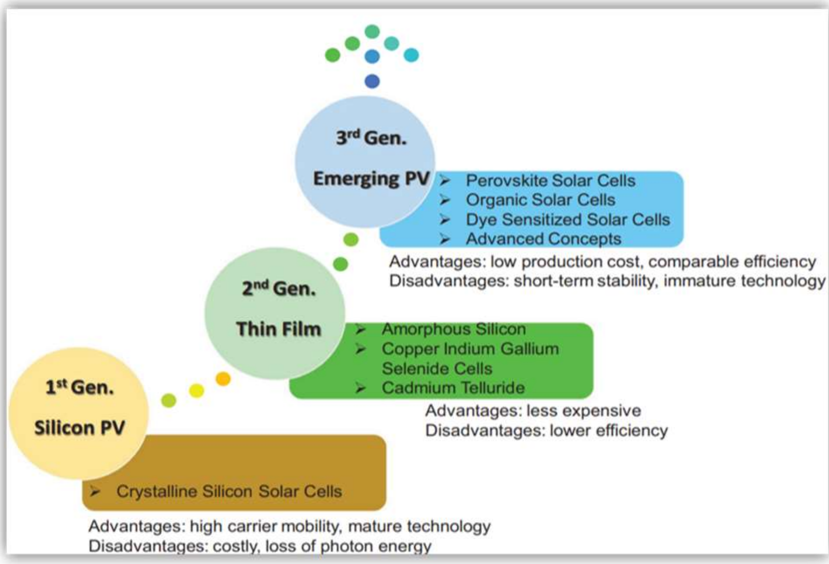
Disadvantages of Solar Cell

❖ **High capital cost**
❖ **During cloudy day, the energy cannot be produced and also at night we will not get solar energy.**

Application of Solar Energy

❖ **Domestic usage**
❖ **Space application**
❖ **H_2 fuel generation**
❖ **Wearable devices**

Generation of Solar Cell



Silicon Solar Cell

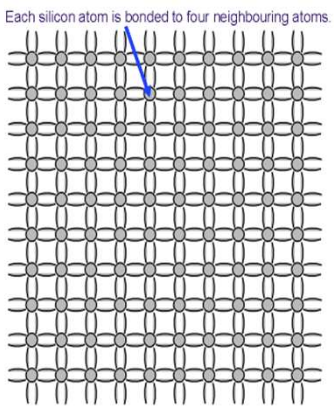
Based on type of crystal used, silicon solar cell can be classified in three type
1 Monocrystalline Silicon Cells
2 Polycrystalline Silicon Cells
3 Amorphous Silicon Cells

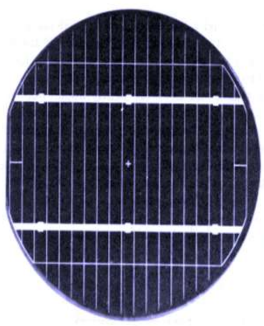
Monocrystalline silicon cells is produced from pure silicon. Since the monocrystalline Silicon is pure and defect free, the efficiency of cell will be higher.

Polycrystalline solar cell, liquid silicon is used as a raw materials and polycrystalline silicon was obtained followed by solidification process. The materials contains various crystalline size. Hence efficiency of this type cell is less than monocrystalline cell

Amorphous Silicon is obtained by depositing silicon film on the substrate like glass plate. The layer thickness amounts to less than 1 m that's why their efficiency is lower than other two type of cells. This are mainly use in smart watches and pocket calculators

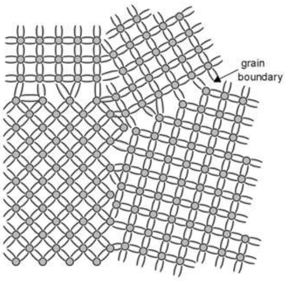
Single Crystalline Silicon





Multi Crystalline Silicon

Slab of multicrystalline silicon after growth. The slab is further cut up into bricks and then the bricks are sliced into wafers.

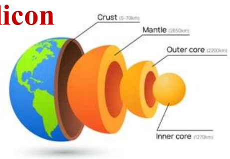


At the boundary between two crystal grains, the bonds are strained, degrading the electronic properties.

A 10 x 10 cm² multicrystalline wafer. The wafer has been textured so that grains of different orientation show up as light and dark.

Refining Silicon

SiO_2 - Most abundant mineral in the earth's crust



The manufacture of the hyper pure silicon for photovoltaics occurs in two stages

Stage 1 : Metallurgical Grade Silicon

The silica is reduced (oxygen removed) through a reaction with carbon in the form of coal, charcoal and heating to **1500-2000 °C** in an electrode arc furnace.

$$SiO_2 + C \rightarrow Si + CO_2$$

Quartzite – SiO_2

Metallurgical silicon

Electronic Grade Silicon

- A small amount of the metallurgical grade silicon is further refined for the semiconductor industry. Powdered MG-Si is reacted with anhydrous HCl at 300 °C in a fluidized bed reactor to form $SiHCl_3$

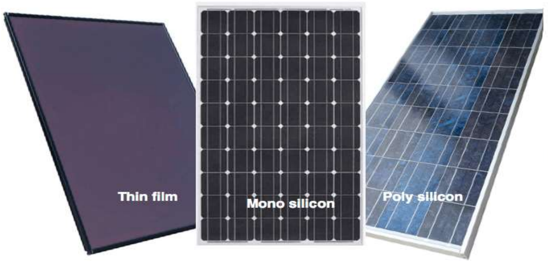
$$Si + 3HCl \rightarrow SiHCl_3 + H_2$$

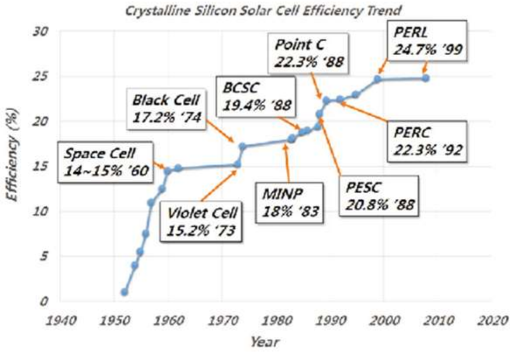
- During this reaction impurities such as Fe, Al, and B react to form their halides (e.g. $FeCl_3$, $AlCl_3$, and BCl3).
- The $SiHCl_3$ has a low boiling point of 31.8 °C and distillation is used to purify the $SiHCl_3$ from the impurity halides.
- The resulting $SiHCl_3$ now has electrically active impurities(such as Al, P, B, Fe, Cu or Au) of less than 1 ppba.

Finally, the pure $SiHCl_3$ is reacted with **hydrogen at 1100°C for ~200 – 300 hours** to produce a very pure form of silicon.
$SiHCl_3 + H_2 \rightarrow Si + 3\ HCl$

Terms for Crystalline Silicon Solar Cells

Descriptor	Symbol	Grain Size	Common Growth Techniques
Single crystal	sc-Si	>10cm	Czochralski (CZ) float zone (FZ)
Multicrystalline	mc-Si	1mm-10cm	Cast, sheet, ribbon
Polycrystalline	pc-Si	1μm-1mm	Chemical-vapour deposition
Microcrystalline	μc-Si	<1μm	Plasma deposition





Advantages

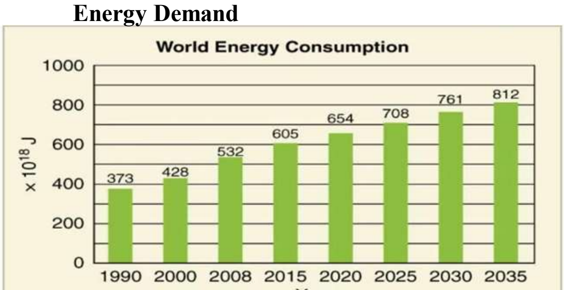
- Matured PV technology
- Highly Durable
- Have highest commercial efficiency
- potentially could be used indoors (amorphous)

Disadvantages

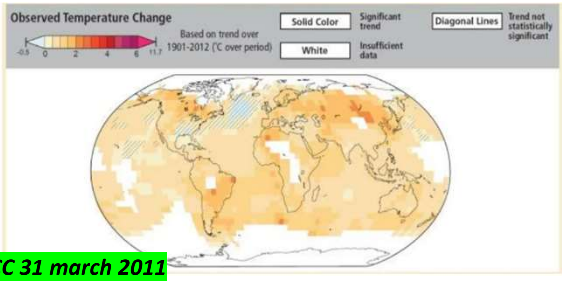
- Very expensive
- There is lots of waste materials produced when silicon is removed during processing
- At high temperature performance degrade

Motivation

Energy Demand

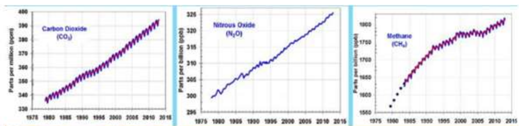


Us energy information admin



IPCC 31 march 2011

Green House Effect



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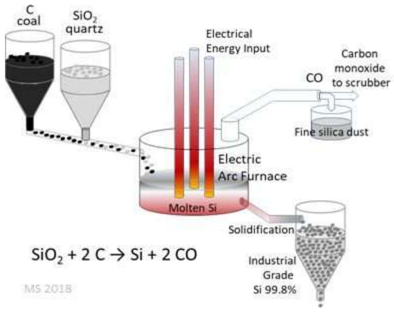
Alternative to silicon solar cell

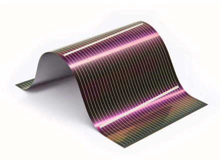
Drawbacks of Silicon PV

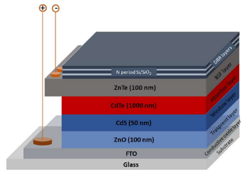
- High chemical energy of SiO2
- High Temperature Required MP 1500
- High Purity
- Not flexible, limited availability of materials
- Low absorption (thick solar cell)

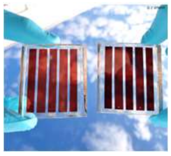
Alternative

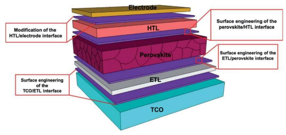
- Thin film solar cell (ncSi, CdTe,CIGS)
- Dye Sensitize solar cell (DSSC)
- Organic Solar cell
- Perovskite (Pb, Sn)











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WHY ORGANIC SOLAR CELLS ?

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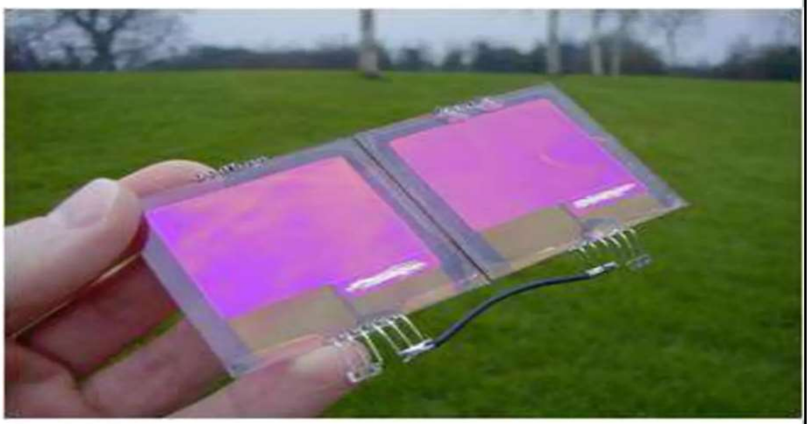
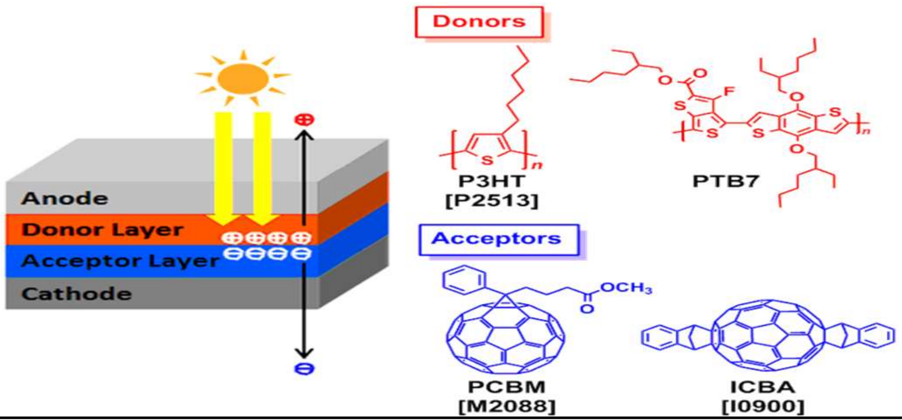


- ➢Ease of Processing
- ➢Mechanical flexibility
- ➢Economically viable
- ➢Safer environment
- ➢Unlimited availability
- ➢Less expensive than inorganic materials (Si).
- ➢Compatibility (thin cells)

Organic Photovoltaic Cells

- An organic photovoltaic cell is a class of solar cell that uses conductive polymers or small organic molecule for light absorption and charge transport.
- This small organic molecule can donate or accept electron



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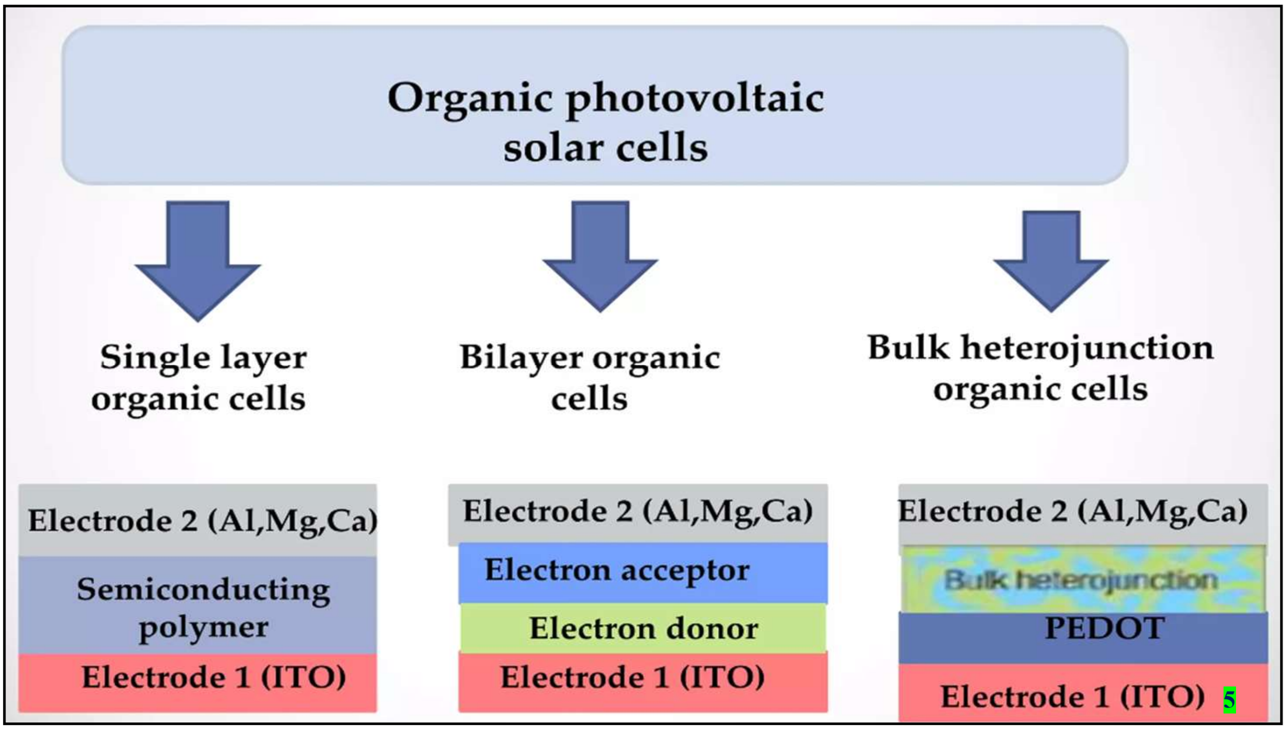

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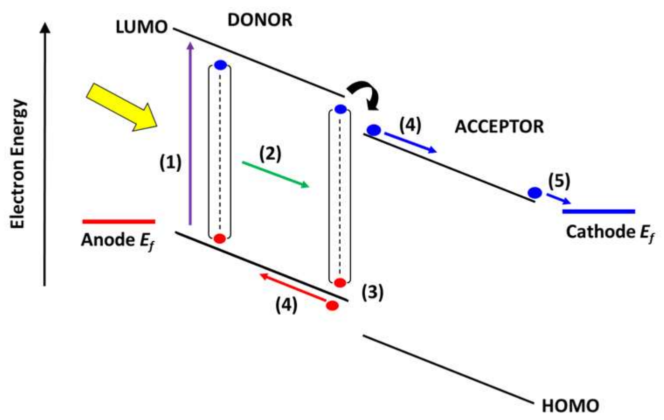
Working Principle of Organic Solar Cell



1.Light absorption to form an exciton.
2.Exciton diffusion to the heterojunction.
3.Exciton dissociation at the organic heterojunction.
4.Charge carrier transport to electrodes.
5.Charge carrier extraction.

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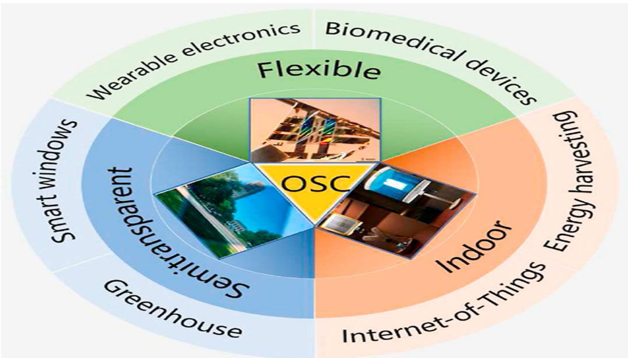
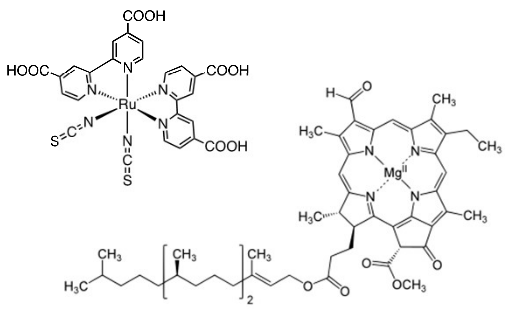


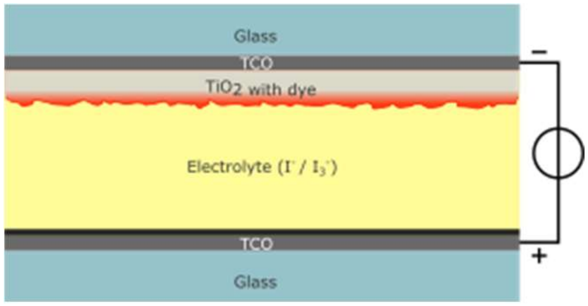
❖**Advantage**
❖**Flexible!**
❖**can be deposited on different materials**
❖**Many possible combinations**
❖**Inexpensive to produce**

❖ **Disadvantage**
❖**Low efficiency (at least so far)**
❖**Not very stable**
❖**No effective protective coatings yet**

Dye Sensitized Solar Cell (Grätzel cell)

- A dye sensitized Solar cell is a new kind of relatively low cost solar cell with great potential as its materials are considerably cheaper and it is simple to make.
- It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a *photoelectrochemical* system
- DSSCs are made of three parts: dye, TiO_2, and liquid electrolyte





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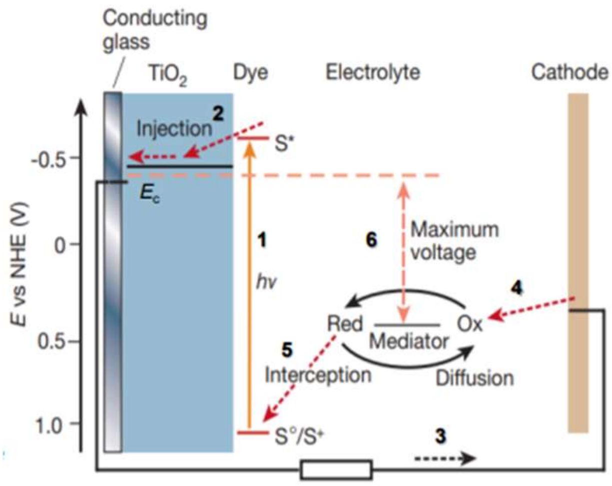
Working principle of DSSC

1. Photo-excitation of dye
2. Injection of e to semiconductor conduction band (CB)
3. e - transport through CB, TCO and external circuit
4. Electrolyte reduced at cathode
5. Dye regenerated by electrolyte
6. Cell voltage corresponds to ΔV between CB edge energy (Ec) and redox potential of electrolyte



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Advantage

- ❖ Easy to make
- ❖ Semi-flexible and semi-transparent
- ❖ Work in low light
- ❖ potentially could be used indoors

Disadvantage

- ❖ Low efficiencies (so far)
- ❖ Requires expensive materials like Pt
- ❖ Uses liquids electrolyte which have temperature stability issues… to makes it difficult to use in all weather

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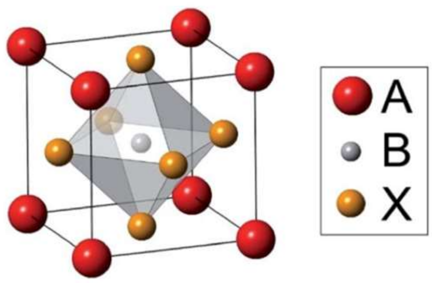
Perovskite Solar Cell



ABX_3 type of materials ($CaTiO_3$)

- ❖ **A site : Organic/ Inorganic cation: monovalent (MA, FA, Cs)**
- ❖ **B site : Heavy metal cation : divalent (Pb^{+2}, Sn^{+2})**
- ❖ **X site: Anions : Halides (I^-, Br^-, Cl^-)**

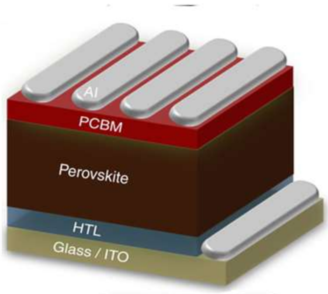
Why Perovskite solar cell ?

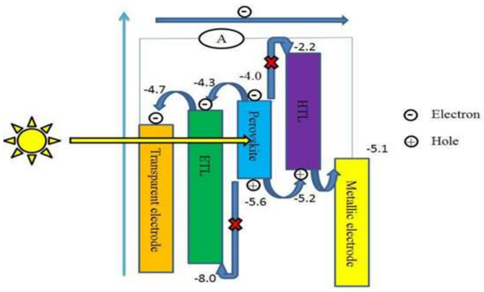
- ❖ **Facile low temperature solution-based fabrication method**
- ❖ **Superior absorption coefficient,**
- ❖ **Tunable bandgap**
- ❖ **Better charge carrier lifetime**
- ❖ **Low exciton binding energy**
- ❖ **High efficiency**

Disadvantage of Perovskite :

- ❖ **Ion migration**
- ❖ **Environmental and health Problem**
- ❖ **Chemical &Thermal stability Issues**

Device Structure perovskite solar cell





- ❖ Metal electrode: aluminium
- ❖ Hole transport layer: NiO_x , PEDOT: PSS
- ❖ Absorber layer: Methyl Ammonium Lead Halide($CH_3NH_3PbX_3$)
- ❖ Electron transport layer: $PC_{61}BM$, ICBA, C_{60}
- ❖ Possible absorber layers: $CH_3NH_3PbI_3$, $CH_3NH_3PbBr_3$, etc.,

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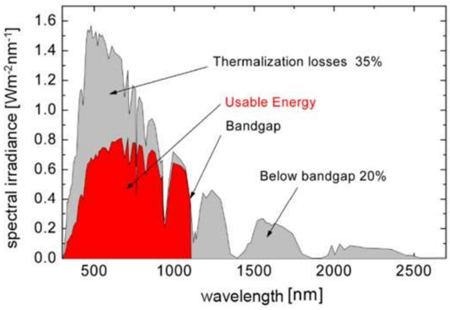
Tandem Solar cell

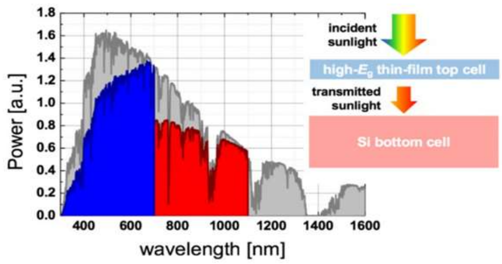
- ❖ Tandem solar cell are comprised of two or more cells and are designed to absorb the entire range of the solar light by the successive cells

Why Tandem Solar Cell

- ❖ Thermalization losses
- ❖ Sub-band gap losses
- ❖ Surpassing Shockley-Queisser Limit

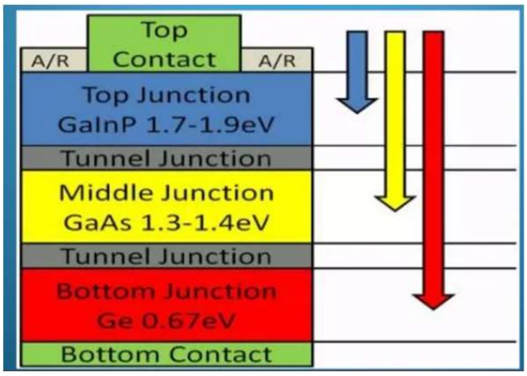


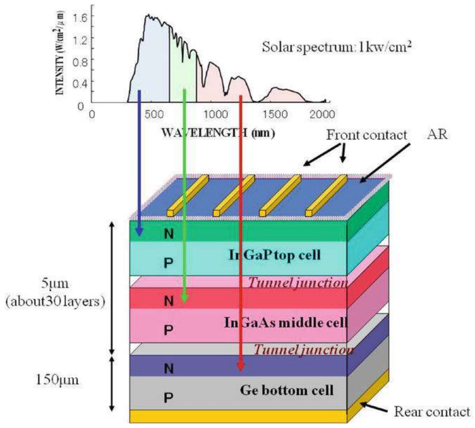
After Tandem

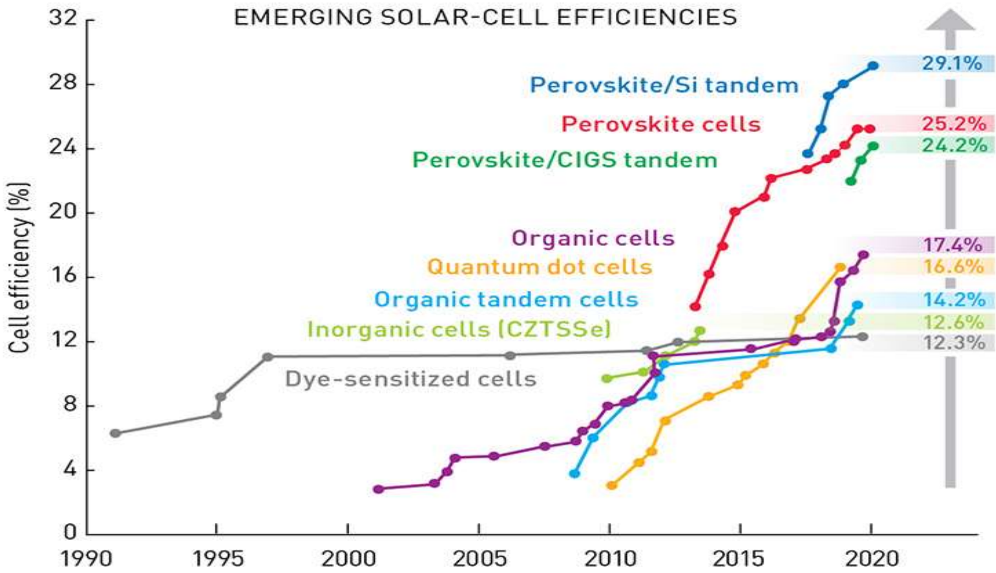


Structure of Tandem Solar Cell

❖ At the Top cell the band gap is highest to absorb the low wave length radiation.
❖ Then decreases the bottom cell is of lowest band gap materials. It will absorbed the most radiation and gives the maximum current







OLED as Next Generation Lighting Source

By

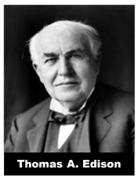
Ramesh Babu .Y

Under the supervision of Prof. Parameswar K. Iyer

Centre for Nanotechnology
Indian Institute of Technology Guwahati

Motivation

- 1880: Introduction of incandescent bulb.
- The incandescent bulb produces light by the passage of an electric current through a filament material
- …..a technical breakthrough that brought new light and comfort into people's everyday. lives



Advantages	*Disadvantages*
➢ Good color rendering: CRI of 100 ➢ Cheap to produce ➢ No quantity of toxic materials	➢ Not energy efficient ➢ not useful for lighting large areas

Motivation

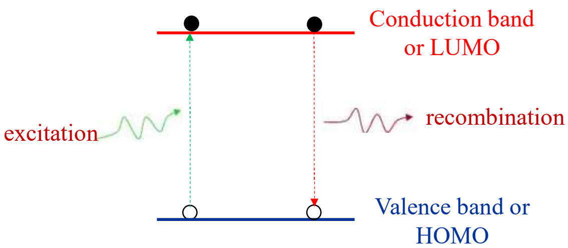
- In 1937 General Electric demonstrated the first fluorescent lamp (fluorescent tube)
- The fluorescent lamp produces light by the passage of an electric current flowing through a vapor of mercury.

Advantages	*Disadvantages*
The luminous efficacy is several times higher than the incandescent bulb	Lack good quality contain mercury not useful for lighting large areas

- *Considering the low efficiency of incandescent light bulbs, and the poor color quality of the fluorescent lamp, it is evident that there is the potential for a substantial energy saving by switching to a highly **energy efficient, large area** and **eco-friendly** lighting solutions.*

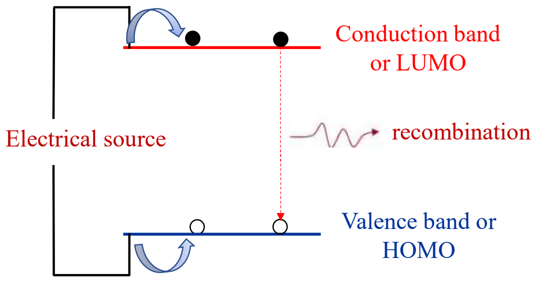
Introduction to Solid State Lighting (SSL)

- In the past decades, a new class of light sources has emerged, referred to as solid state lighting (SSL).
- An SSL device produces visible light by means of **electroluminescence.**



When excited by **Photo**ns, we get **Luminescence**

Hence we call it **Photoluminescence**



We get **Luminescence** due to the injection of electrons and holes by **Electrical** source,

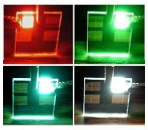
Hence we call it **Electroluminescence**

Types of SSL

Based on the semiconducting material used solid state lighting devices can be divided into two types:

- Inorganic
- Organic

Inorganic LED

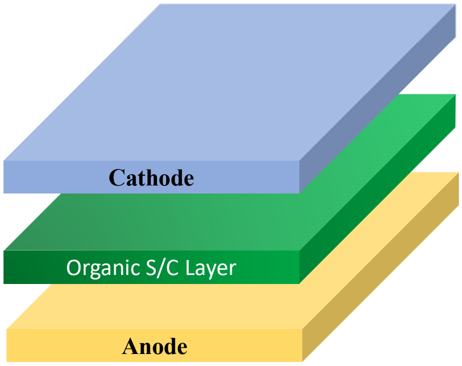


Organic LED

Inorganic	Organic
Uses inorganic crystalline materials as active layer, limited materials	Uses organic materials as active layer, unlimited materials
Generally, point sources	Can be fabricated in large area
Highly efficient, high lifetime, mature technology.	New technology, hold the promise of exhibiting a very good CRI.

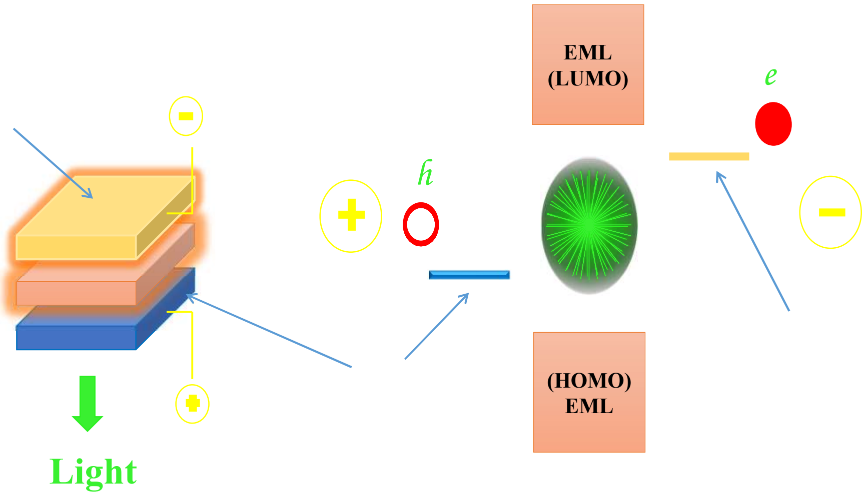
Organic Light Emitting Diode

An OLED is a solid-state device made by placing a series of organic thin films between two electrodes.

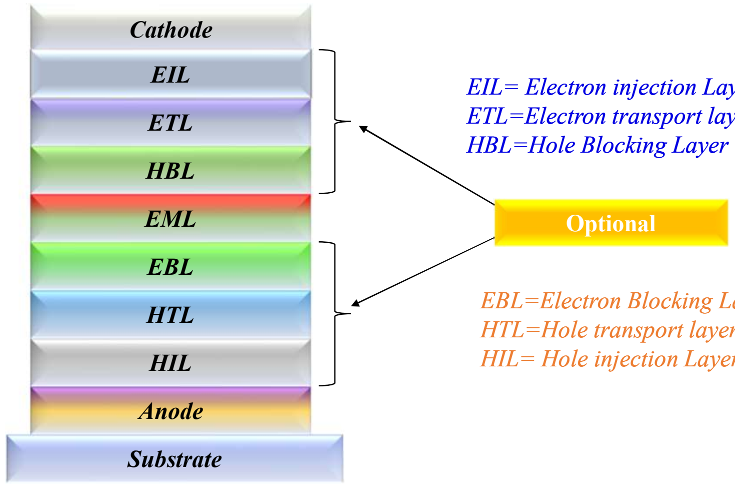


- In order for light to escape from the device, at least one of the electrodes must be transparent.
- The intensity of the light emitted is controlled by the amount of electric current applied by the electrodes, and the light's color is determined by the type of emissive material used

Working Principle of OLED



Multilayer OLED

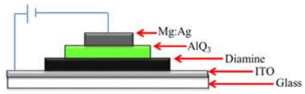


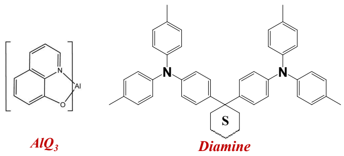
EIL= Electron injection Layer
ETL=Electron transport layer
HBL=Hole Blocking Layer

EBL=Electron Blocking Layer
HTL=Hole transport layer
HIL= Hole injection Layer

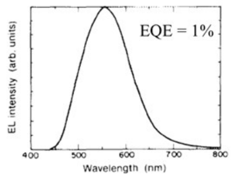
OLED Vs. PLED

First OLED





AlQ_3 *Diamine*



ITO/Diamine/AlQ_3/Mg:Ag

Tang C. W. *et al.* ***Appl. Phys. Lett.*** 1987, ***51***, 913–915

First PLED

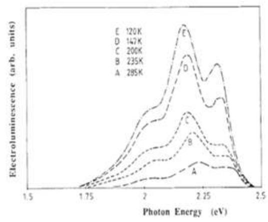


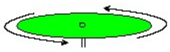
FIG. 4 Spectrally resolved output for an electroluminescent device at various temperatures.

"We demonstrate here that poly(p-Phenylene vinylene), prepared by way of a solution processable precursor, can be used as the active element in a large-area light emitting diode. The combination of good structural properties of this polymer, its ease of fabrication, and light emission in the green yellow part of the spectrum with reasonably high efficiency, suggest that the polymer can be used for the development of large-area light emitting displays"

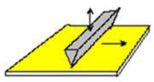
J. H. Burroughes *et al.* ***Nature,*** 1990, **347**

Fabrication Techniques

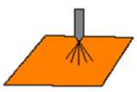
Solution Processing :Polymer



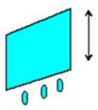
Spin Coating



Doctor Blade

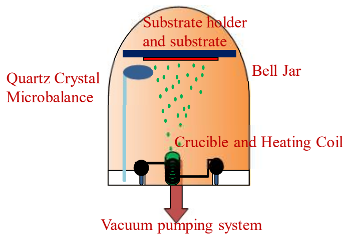


Ink Jet Printing

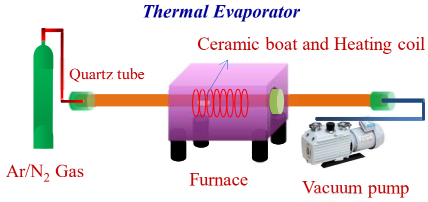


Dip Coating

Evaporation: Small Molecules



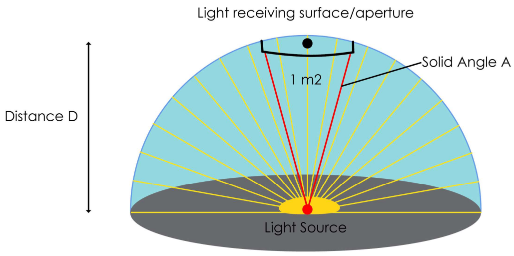
Thermal Evaporator



Organic Vapor Phase Deposition

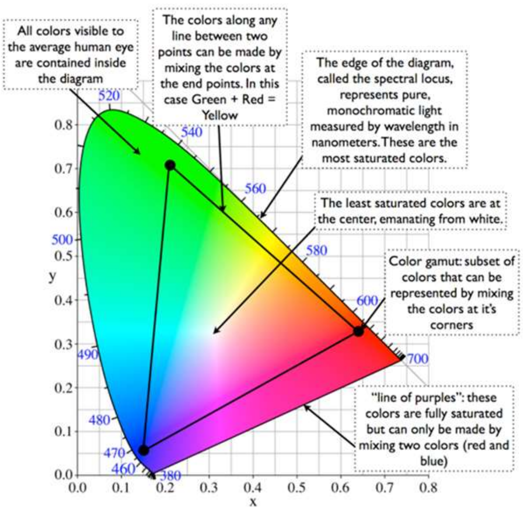
Characterization Parameters

Luminous intensity is a measure of the wavelength-weighted power emitted by a light source in a particular direction per unit solid angle. The SI unit of luminous intensity is the candela (cd), an SI base unit.



Luminance is a photometric measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that passes through, is emitted or reflected from a particular area, and falls within a given solid angle. The SI unit for luminance is candela per square metre (cd/m^2).

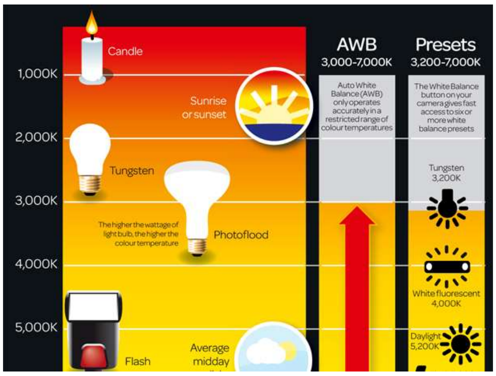
CIE & Color Temperature



Anatomy of a CIE Chromaticity Diagram

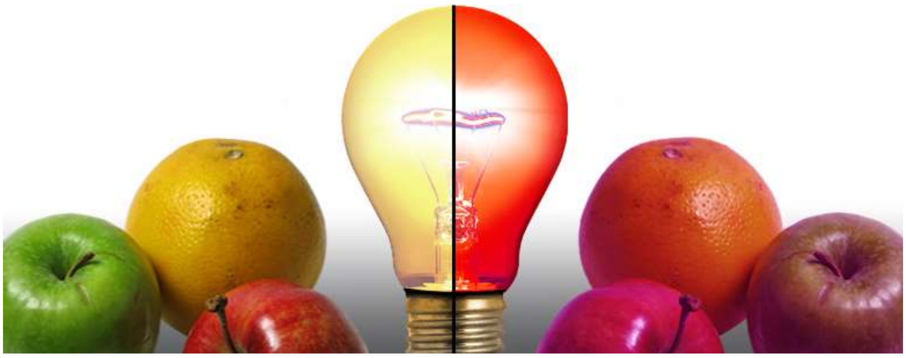
Color Temperature: Temperature at which a black body would emit radiation of the same color as a given object

- **Color temperatures over 5,000K are called cool colors**
- **Color temperatures (2,700–3,000 K) are called warm colors**



Color Rendering Index (CRI)

A color rendering index (CRI) is a quantitative measure of the ability of a light source to reveal the colors of various objects faithfully in comparison with an ideal or natural light source



CRI<70

CRI>80

Efficiency

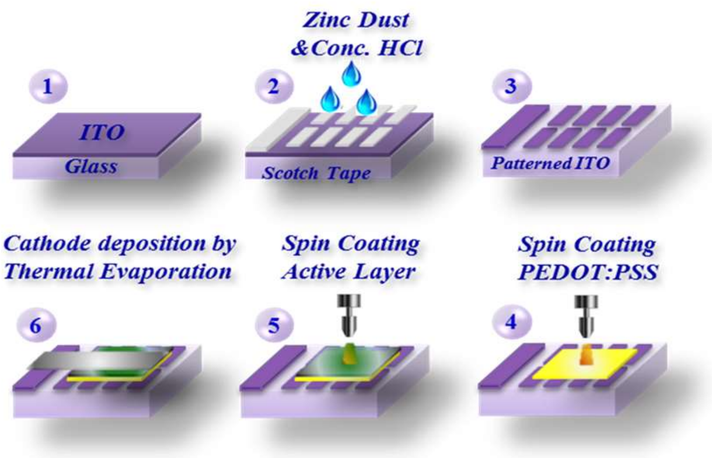
Luminous Efficiency: **Luminous intensity (in candela, cd), or luminance at a given current density (J) by equation**

$$LE = L/J.$$

It is measured in candela per ampere.

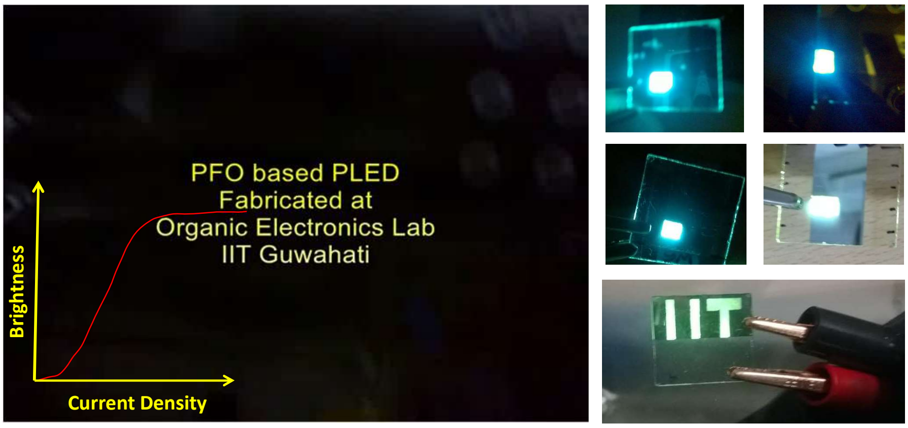
Power Efficiency: **Luminous flux output (in lumen) per input power of the device,**
It is measured in lumen per watt.

Quantum Efficiency: **Ratio between generated photons and the injected electron–hole pairs in the device**



OLED
Fabrication Technique

Some of the polymer LEDs fabricated by our group at Organic electronics lab



Our sincere thanks to the Department of Science and Technology for their financial support

Basics of Organic Field Effect Transistor (OFET)

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WHY TO ORGANIC ELECTRONICS??

Organic electronics

Flexible
Foldable
Light
Low cost
High throughput
Low processing temperature

Inorganic electronics

Rigid
Hard
Heavy
Expensive
High processing temperature

Active materials in organic electronics

Polymers

Oligomers

Small molecules

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History

- Field-effect transistor (FET) was first proposed by **Julius Edgar Lilienfeld** in 1930. He proposed that a field-effect transistor behaves as a capacitor.
- Insulated-gate FET was designed and prepared by **Mohamed Atalla** and **Dawon Kahng** using a metal–oxide–semiconductor (1959).
- The first OFET was reported in 1986 by **Tsumura et al**.

Julius Edgar Lilienfeld

Mohamed Atalla

Dawon Kahng

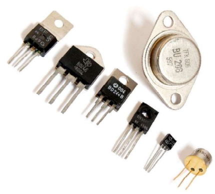
What is Transistor?

Transistor

A device composed of semiconductor material that amplifies a signal or opens or closes a circuit.

Field Effect Transistor

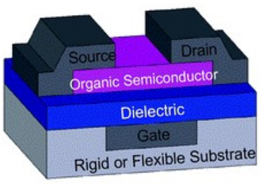
A voltage applied between the gate and source controls the current flowing between the source and drain.



www. diyaudioprojects.com

Organic Field Effect Transistor

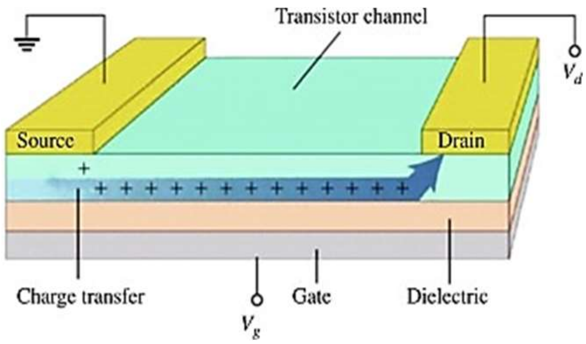
Organic transistors are transistor that use *organic molecules* rather than silicon for their active material. This active materials can be composed of a wide variety of molecules.



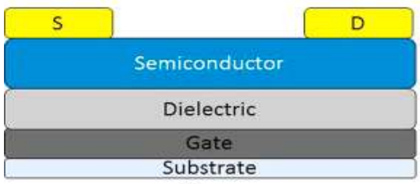
First organic transistor was reported in 1986

What is OFET?

- Three components mainly- Semiconductor, Dielectric (insulator) and Contacts
- Active layer is Organic Semiconductor
- It is a three terminals device
- Contains three electrodes
    1. Gate
    2. Source
    3. Drain

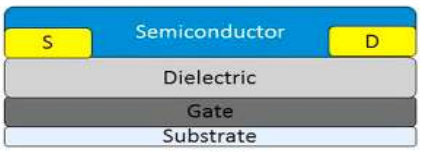


Types of OFET



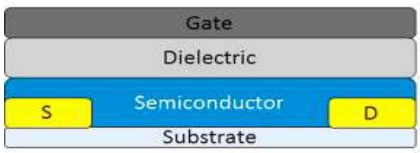
(A)

Bottom gate Top contact



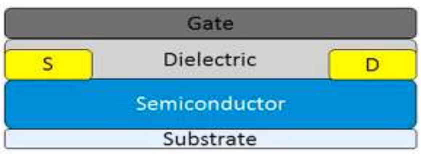
(B)

Bottom gate Bottom contact



(C)

Top gate Bottom contact

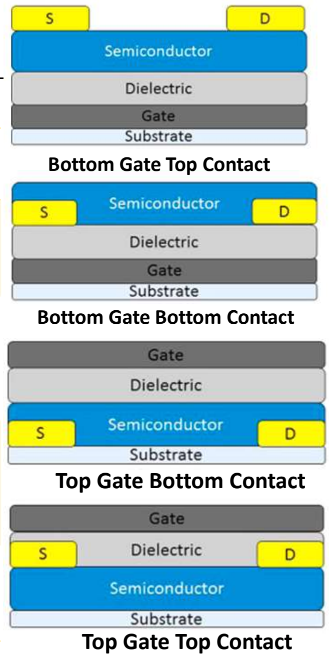


(D)

Top gate Top contact

OFETs Architecture

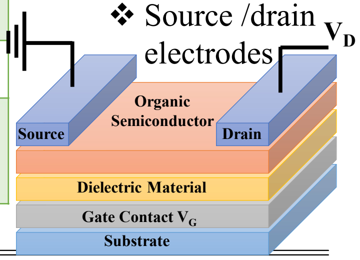
Geometry	Advantages	Disadvantages
(A) Bottom Gate Top Contact	1. Easy to fabricate. 2. Active layer is on the top of the other layers.	1. Portion of the active layer area is exposed to the environment.
(B) Bottom Gate Bottom Contact	1. Easy to fabricate. 2. Active layer is on the top of the metal contacts	1. Most unstable geometry as the whole active layer is exposed to the air.
(C) Top Gate Bottom Contact	1. Environmentally stable device. 2. No need for encapsulation. 3. Lithography can be easily implemented	1. Difficult to deposited all type of dielectric materials. 2. Active layer film can be damaged by dielectric deposition
(D) Top Gate Top Contact	1. Environmentally stable device. 2. No need for encapsulation.	1. Most difficult to fabricate



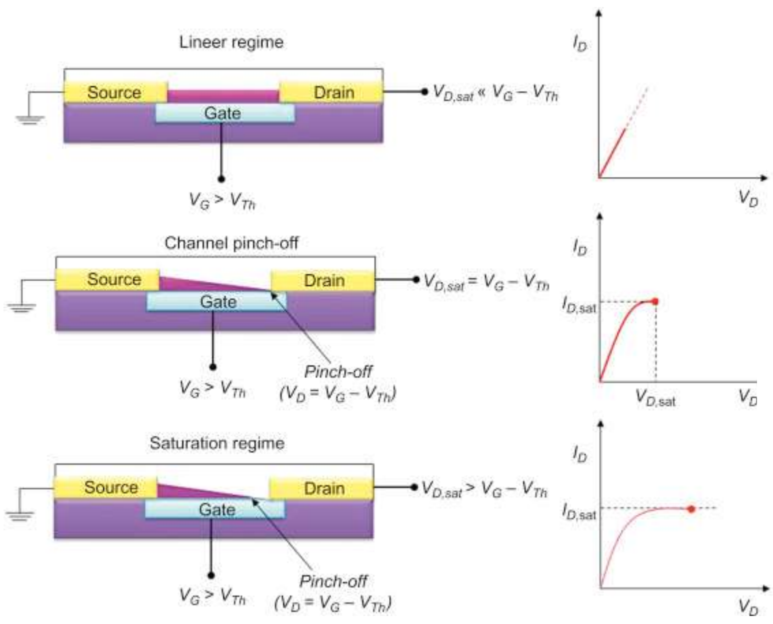
Materials & Requirements

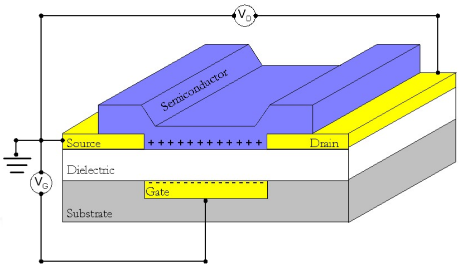
Layers	Requirements
Substrate	Surface should be clean and have low roughness
Gate Metal	➢Work function similar to the active layer ➢Good adhesion with substrate & gate insulator
Gate Insulator	➢High insulation, smooth surface ➢Low surface trap density, no pin holes ➢Low surface energy
OSC	➢Single crystal ➢Large grain, no pin holes
S/D Metal	➢No interface barrier with the OSC ➢High carrier injection, ➢low contact resistance ➢low diffusivity for top contact

- ❖ Substrate
- ❖ Gate electrode
- ❖ Dielectric material
- ❖ Surface modifying agents
- ❖ Organic semiconductors
- ❖ Source /drain electrodes



Working of OFET





Linear $$I_D = \frac{W}{L} C_i \mu (V_G - V_T) V_D$$
when $V_{GS} - V_{Th} >> V_{DS}$

Saturation $$I_{D,sat} = \frac{W}{2L} C_i \mu (V_G - V_T)^2$$
when $V_{DS} = V_{GS} - V_{Th}$

Capacitance per unit area, $C_i = K\varepsilon_o / d$

D1

Parameters in OFET

a. Output characteristics and Transfer characteristics

Output (I_D-V_D) Curve

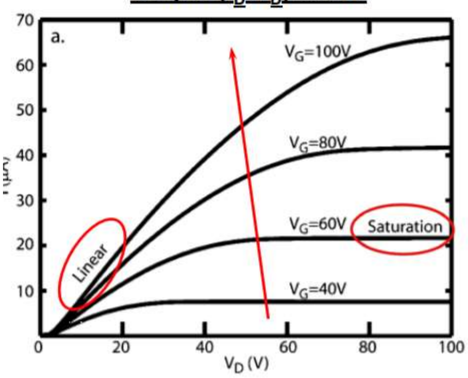


Fig: Output characteristics

Transfer (I_D-V_G) Curve

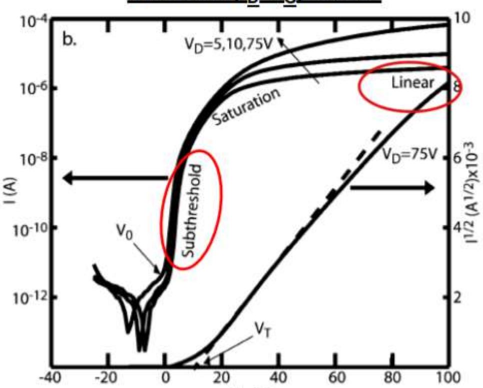


Fig: Transfer characteristics

b. Sub threshold Swing $$S \equiv \frac{dV_G}{d(\log I_D)}$$

c. I_{ON}/I_{OFF}

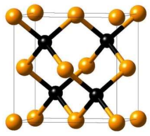
d. Mobility

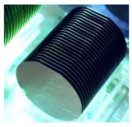
Slide 56

D1 DELL, 30/03/2021

Organic Semiconductors

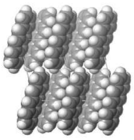
Inorganic Semiconductor

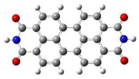




- Strong covalent bonds
- Only crystal property
- Band type charge transport dominant
- High mobility and large mean free path

Organic Semiconductor





- Weak Vander Waals interaction
- π-bond overlapping
- Molecular gas property (molecule's identity)
- Hopping type charge transport dominant
- Low mobility and small mean free path

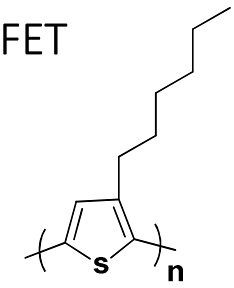
Active Molecules In OFET

p – type organic semiconductors

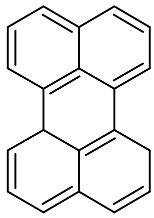
μ (h) = 0.15 cm2/Vs
a

μ (h) = 2.2 cm2/Vs
b

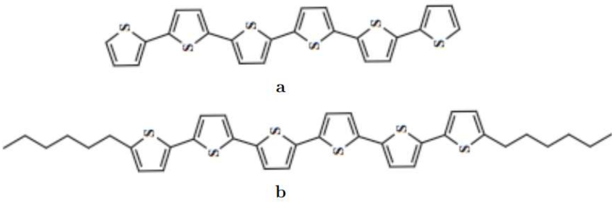
Figure 4: Two linearly-fused benzene chains, tetracene (Figure 4a) and pentacene (Figure 4b). [8]



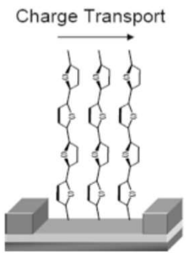
P3HT



Perylene

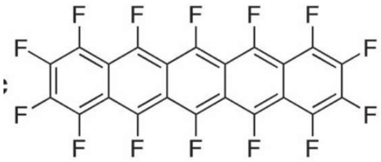


A variety of thiophene-based OSCs, sexithiophene (Figure 5a),
hexyl-substituted sexithiophene (Figure 5b)

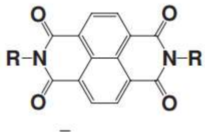


Ideal arrangement of oligothiophene molecules for maximum hole mobility and on/off current ratio [5].

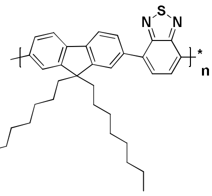
n – type organic semiconductor



Perfluoropentacene



Napthalene diimide

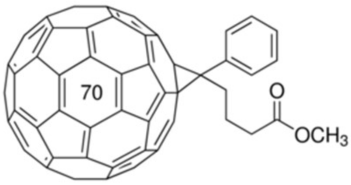


F8BT

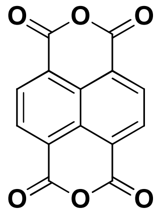
C_{60}

+ TDAE (tetrakis(dimethylamino)ethylene) results in mobility increased by 3 times

Appl. Phys. Lett. **1995**, *67*, 121 .



PCBM



NTCDA

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Stability

Stability of the OFET device:

- ❑ Environmental Stability
- ❑ Electrical Stability

❑ **Environmental Stability:**

- ➢ Air stability
- ➢ Reproducibility
- ➢ Reliability

❑ **Electrical Stability:**

- ➢ Bias Stress Effect
- ➢ Change in Source-Drain Current
- ➢ Threshold Voltage Shift

OFET –Merits and Demerits

Advantage
Cost effective
Large Selection of Material
Lighter and flexible

Disadvantage
Thermal stability
Chemical Stability

In Conclusion

A high performance OFET consist of:

- High on/off ratio
- Higher mobility
- Low threshold voltage
- Maximum output current
- Lower sub-threshold swing

Thermal Evaporator

Spin Coater

Problems

(Home Work)

1. If an n-type OFET contain 100 nm PS as a organic polymer dielectric (K=2) ,calculate the C_i and μ_{sat} of the OFET having threshold voltage 0.5 V and gate to source voltage is 2V. Consider the drain current is 10 nA and W/L ratio is 20.

   Hint:

   (a) In the saturation regime , $I_{DS} = \frac{\mu_{sat} W C_i}{2L}(V_{GS} - V_{Th})^2$ when $V_{DS} = V_{GS} - V_{Th}$

   (b) Capacitance per unit area $Ci = K\varepsilon_o / d$

2. If an p-type OFET contain 100 nm PVA as a organic polymer dielectric (K=10) ,calculate the C_i and I_{DS} of the OFET having threshold voltage -3.5 V and gate to source voltage is -7V. Consider the μ_{sat} of the OFET is 0.08 $cm^2. V^{-1}. s^{-1}$ and W/L ratio is 20.