MODULE 5

SUPER CONDUCTING MATERIALS, SOLAR ENERGY MATERIALS

SUPER CONDUCTING MATERIALS

SUPERCONDUCTOR MATERIALS

- Superconductivity is the phenomenon by which certain metals and alloys exhibit almost zero resistivity (ie., infinite conductivity) when they are cooled to sufficient low temperatures.

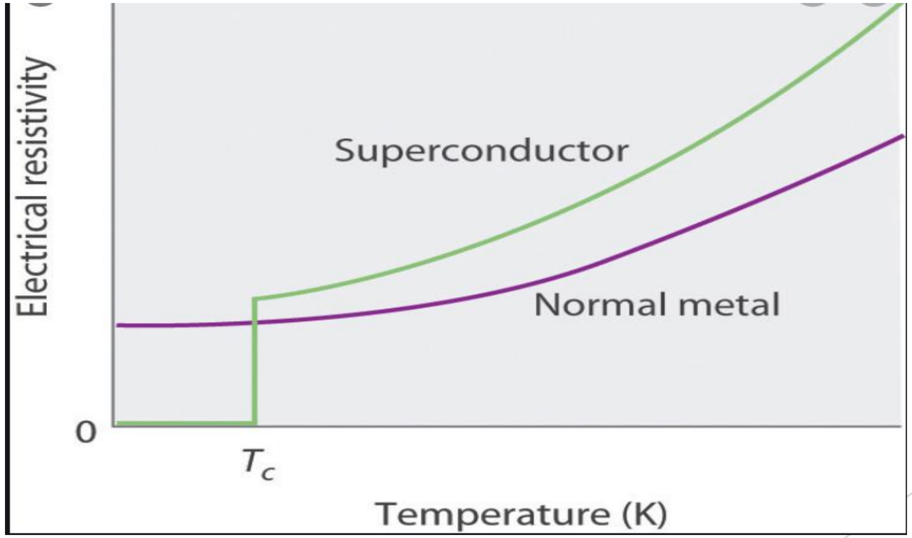
- This specific temperature is called the critical temperature or the transition temperature at which transition from normal to superconducting state of the material takes place.

- This phenomenon was first observed by H K Onnes in 1911 when measuring the electrical conductivity of metals at low temperatures. During the process, he found that when pure mercury was cooled below 4.2K, the resistivity suddenly dropped to zero.

SUPERCONDUCTOR MATERIALS

<u>Transition temperature (T_c):</u>

The transition temperature of a super conducting material is defined as the critical temperature at which the resistivity of the material suddenly changes to zero, i.e., the temperature at which transition from normal to superconducting state of the material takes place.



CHARACTERISTICS OF SUPERCONDUCTOR

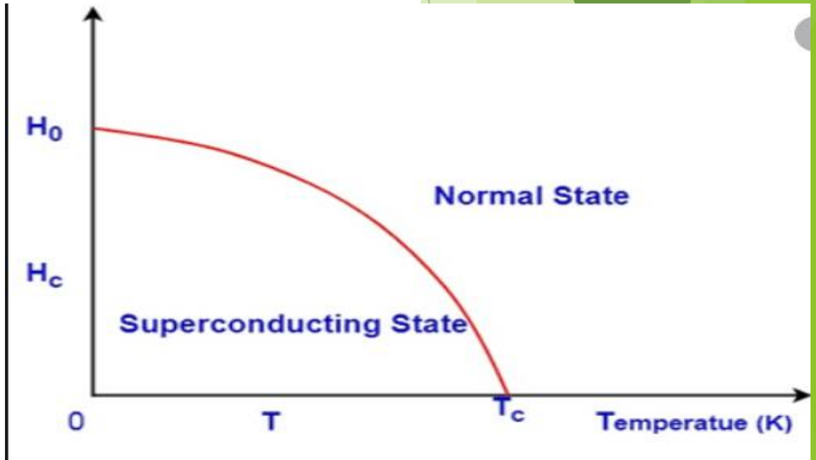
- Super conducting state of a metal mainly depends on temperature and strength of the magnetic field in which the metal is placed.

- Superconductivity disappears when temperature of the specimen is raised above T_c or a strong enough magnetic filed is applied.

- At temperatures below T_c , in the absence of any magnetic field, the material is in superconducting state.

- The electrical resistance of superconductors is zero below the transition temperature.

- When the strength of the magnetic field applied reaches a critical value H_c, the superconductivity disappears.



Variation in critical magnetic field with temperature

CHARACTERISTICS OF SUPERCONDUCTOR

- The dependence of critical field on temperature is given by;

$$H_c(T) = H_c(0)[1 - (\frac{T}{T_c})^2]$$

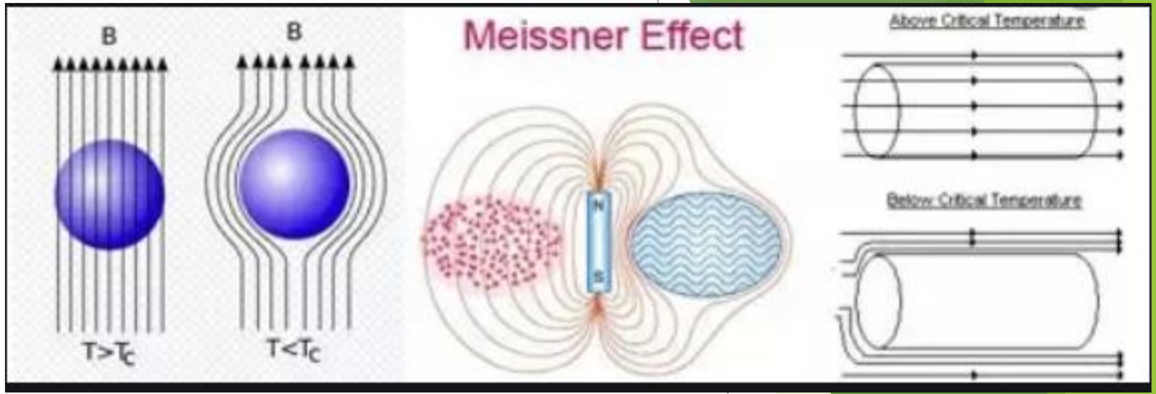
Where, $H_c(0)$ is the critical field at 0K, $H_c(0)$ and T_c are constants and characteristics of a material.

- When a current flows through a superconductor, it give rise to its own magnetic field. As the current is increased to a critical value I_c, the associated magnetic field becomes H_c and the superconductivity disappears.

- Addition of impurities lowers the critical temperature.

- The isotope of a superconducting material is also a superconductor. Maxwell found that T_c is inversely proportional to the atomic masses of the isotopes of a single superconductor.

CHARACTERISTICS OF SUPERCONDUCTOR



MEISSNER EFFECT:

When a weak magnetic field is applied to a superconducting material at a temperature below the T_c, the magnetic flux lines are expelled as in an ideal diamagnet. This effect is called Meissner effect.

- This effect is reversible. When T=T_c, the magnetic induction inside the material is given by;

$$B=\mu_0(H + M)\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

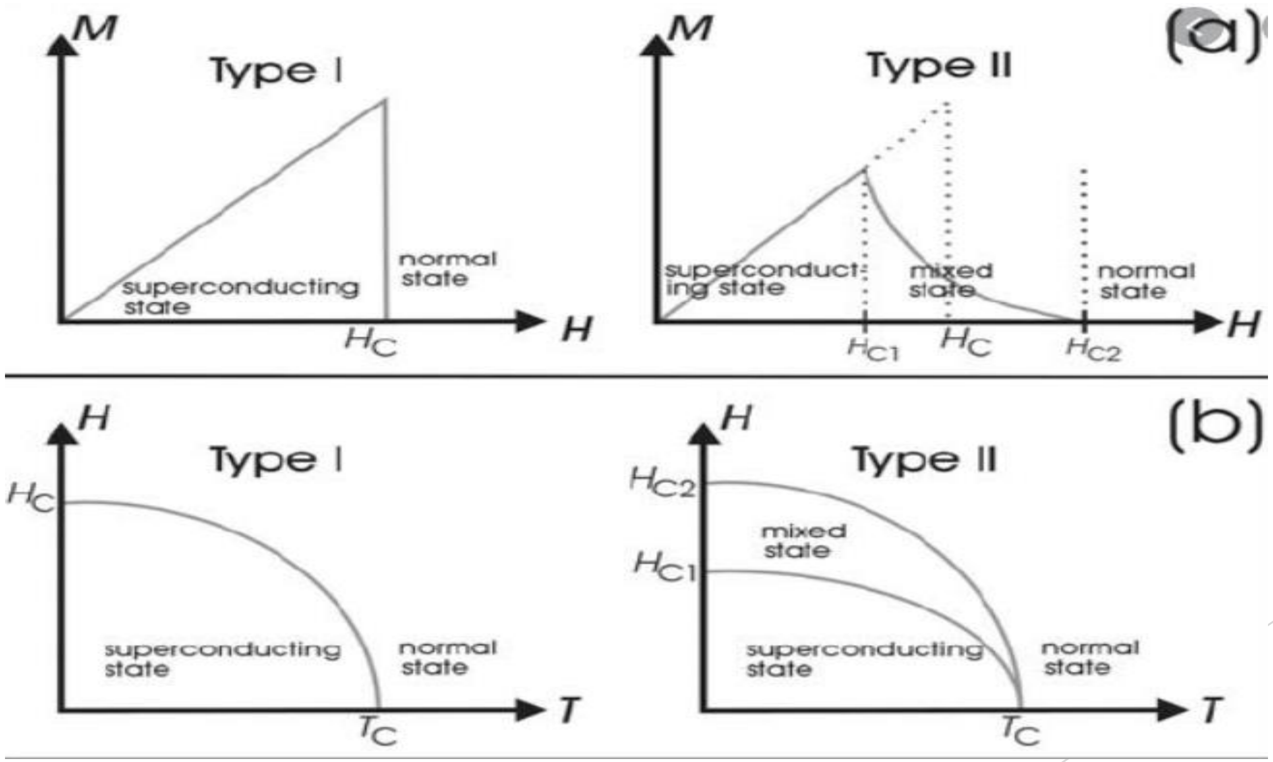
- According to Meissner effect, when the material is superconducting, inside the superconducting material, B=0.

Hence from eqn. (1), H = -M. The material is perfectly diamagnetic and the magnetic susceptibility (χ = M/H) is -1.

TYPES OF SUPERCONDUCTORS

There are two types of superconductors:

- Type I superconductor
- Type II superconductor



TYPES OF SUPERCONDUCTORS

TYPE I SUPERCONDUCTOR

- Superconductors exhibiting complete Meissner effect (perfect diamagnetism) are called type I superconductors
- When the magnetic field strength is gradually increased from its initial value, at H_c the diamagnetism abruptly disappears and the transition from superconducting state to normal state is sharp as shown in figure a.
- Examples are; Pure specimens of Al, Zn, Hg and Sn

TYPES OF SUPERCONDUCTORS

TYPE II SUPERCONDUCTOR (also known as hard superconductors)

- In type II superconductors as shown in figure b, up to field H_{c1} the specimen is in a pure semiconducting state. The magnetic flux lines are rejected.
- When the field is increased beyond H_{c1} (lower critical field), the magnetic flux lines start penetrating.
- The specimen is in a mixed state between H_{c1} and H_{c2} (upper critical field). i.e., Meissner effect is incomplete in the region between Hc1 & Hc2. This region is known as Vortex – region.
- Above H_{c2}, the specimen is in a normal state.
- Examples are; Ta, V and Nb

TYPES OF SUPERCONDUCTORS

High T_c Super conductors

- In a super conductor if the transition temperature is high ie., greater than 20K, then it is called as high temperature super conductors.
- In 1986, Muller and Bednorz discovered high tempertaure super conductivity in **Ceramics**.

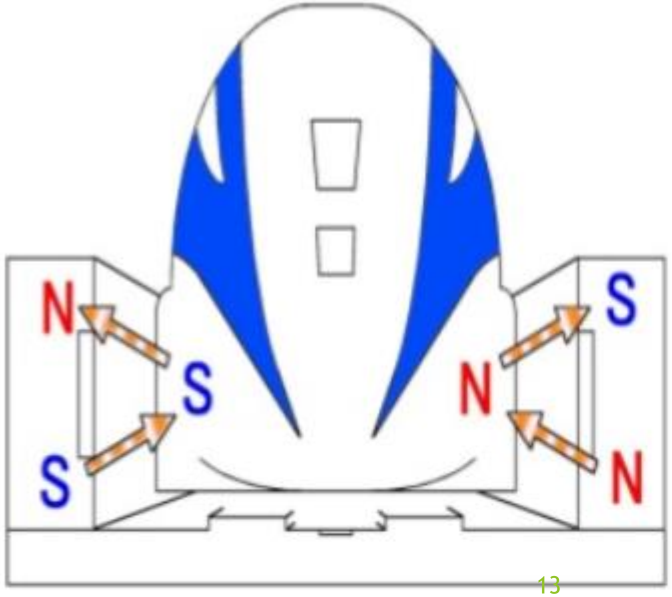
TYPES OF SUPERCONDUCTORS - COMPARISON

TYPE I	TYPE II
The material loses its magnetization suddenly	The material loses its magnetization gradually
They exhibit complete Meissner effect I.e they are completely diamagnetic	They do not exhibit Meissner effect
There is only one critical magnetic field (H_c)	There are two critical magnetic field (H_c) i.e., lower critical field (H_{c1}) and upper critical field (H_{c2})
No mixed state exists.	Mixed state is present.
They are called soft super conductors.	They are called hard super conductors.
Ex: lead, tin, Hg	Ex: Nb-Sn, Nb-zr, Nb-Ti

APPLICATIONS OF SUPERCONDUCTORS

- Superconducting levitation: (Maglev trains)

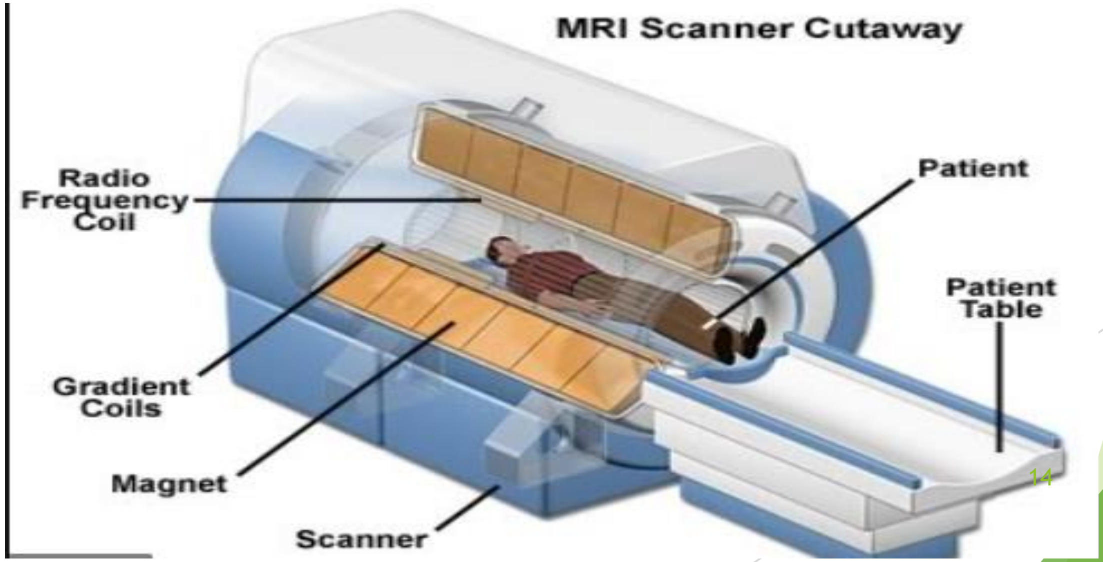
  When a magnet is placed over a super conductor, it floats. This phenomenon is known as Magnetic Levitation. Maglev is a form of transportation that suspends, guides and propels vehicles by means of electromagnetic force.



APPLICATIONS OF SUPERCONDUCTORS

- Medical diagnosis:

  - The superconducting magnet coils produce a large and uniform magnetic field inside the patients body.
  - MRI (Magnetic Resonance Imaging), NMR (Nuclear Magnetic Resonance) Scanning
  - SQUIDs can provide image of heart's magnetic field



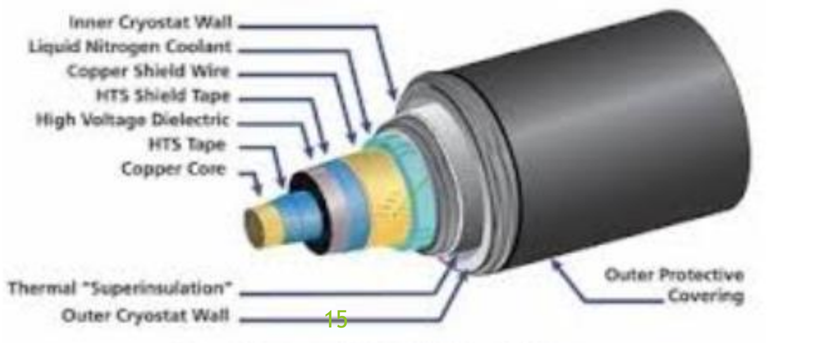
APPLICATIONS OF SUPERCONDUCTORS

- Power Cables:

  Superconducting wires carry up to five times the current carried by copper wires with the same cross section. Superconducting cables are cooled to remove the resistance to the flow of electricity, cutting down on the losses that typically occur during transmission.

- Communication:

  HTS (High Temperature Superconducting) filters will enhance signal-to noise ratios in cellular communications systems leading to reliable communication services with fewer spaced cell towers.



Example Superconductor cable design by Nexans

APPLICATIONS OF SUPERCONDUCTORS

- SQUIDs (Super Conducting Quantum Interference devices):
  - It is an ultra-sensitive instrument used to measure very weak magnetic fields of the order of 10^{-14} tesla.
  - SQUID can be used to detect the variation of very minute signals in terms of quantum flux. It can also be used as storage device for magnetic flux.
  - SQUID is useful in the study of earth quakes, removing paramagnetic impurities, detection of magnetic signals from the brain and heart

- Cryotron:
  - Cryotron is a magnetically operated current switch.

SOLAR ENERGY MATERIALS

SOLAR ENERGY

- Solar energy is the most readily available non-conventional source of energy. It is non-polluting and hence helps in lessening the greenhouse effect.
- Two important conversions of solar energy are;
  - ❑ Photo thermal conversion
  - ❑ Photovoltaic conversion.

PHOTO THERMAL CONVERSION

- In photo thermal conversion solar energy is converted to thermal energy with the help of solar thermal devices such as solar collectors and reflectors.

- Solar thermal devices can be classified into three types:

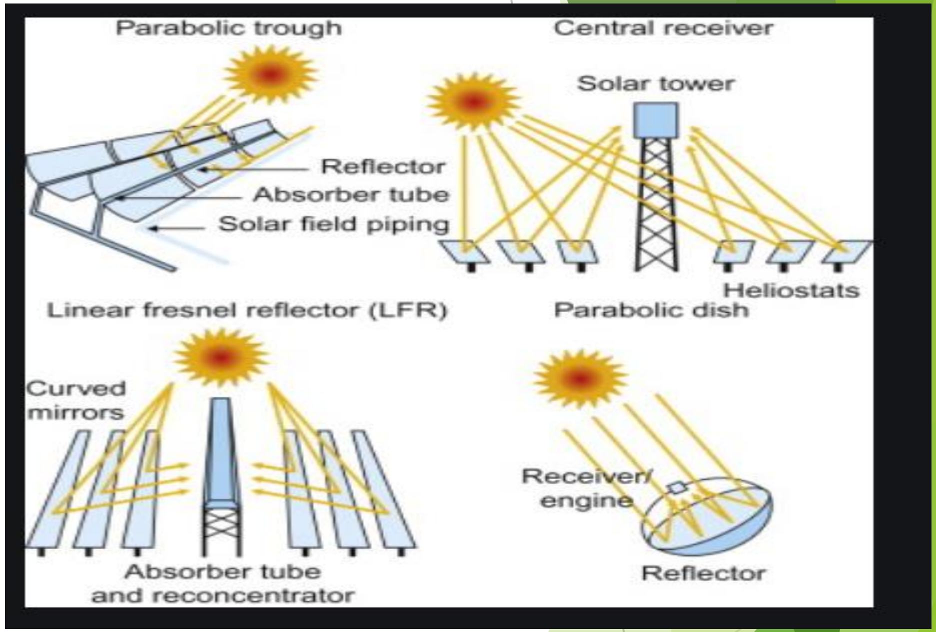
  - Low grade heating devices – upto100°C – they are used in solar water heaters, air heaters, solar cookers° and solar dryers for domestic and industrial applications.
  - Medium grade heating devices - 100°C to 300°C
  - High grade heating devices – above 300°C

- Considering a low energy density in unit area, solar energy must be collected by using appropriate technologies to obtain high photo thermal conversion efficiency.

PHOTO THERMAL CONVERSION

- Concentrating Solar Power (CSP) is the most mature technology among solar thermal technologies.

- CSP technologies can be classified into four types:
  - solar tower
  - parabolic trough collector (PTC)
  - parabolic dish concentrator
  - linear Fresnel reflector.



- Among these technologies, both the solar tower and the parabolic trough collector are occupying an important market position due to their lower operating costs, higher efficiency and flexibility to scale up in large power plants.

PHOTO THERMAL CONVERSION

- The **solar tower** is a point focus technology that uses several sun-tracking mirrors to concentrate sunlight onto a fixed receiver located at the top of the tower. A working fluid is circulated on the receiver to absorb the concentrated solar radiation.

- The **solar power tower** is a type of solar furnace using a tower to receive the focused sunlight.
- It uses an array of flat, movable mirrors (called heliostats) to focus the sun's rays upon a collector tower (the target).
- Newer designs use liquid sodium and molten salts (40% potassium nitrate, 60% sodium nitrate) as the working fluids.
- These working fluids have high heat capacity, which can be used to store the energy before using it to boil water to drive turbines.
- These designs also allow power to be generated when the sun is not shining.

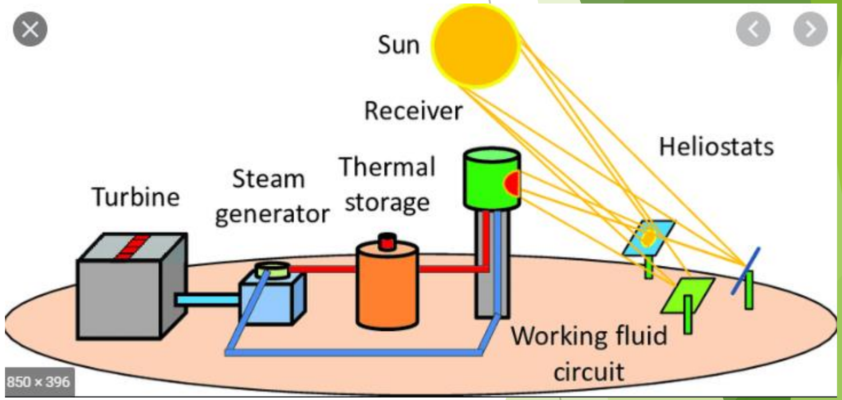


PHOTO THERMAL CONVERSION

- The **parabolic trough** technology is a line focus technology that uses a parabolic reflector to concentrate beam radiation, in which solar selective absorbing coatings (SSACs) is one of the key components.

- Higher temperature capability of the heat-transfer fluid (HTF) in PTC system provides higher efficiency. However, synthetic or mineral oil as a conventional HTF decomposes above 400 °C, limiting the efficiency of power generation.

- Commonly used HTF is the molten salt (60% KNO_3+40% $NaNO_3$) and it has the ability to operate above 550 °C.

- Molten salt is circulated in solar receiver tube and heated from 290 °C to 550 °C.

PHOTO THERMAL CONVERSION

- The heated molten salt is then driven through a series of heat exchangers to produce superheated steam, which is used as a conventional power circle in steam turbine generator.
- The solar receiver tube mainly consists of steel tube and SSAC. It determines the efficiency of photo thermal conversion.
- So, there is a higher requirement for SSAC deposited on the solar receiver tube. It should absorb as much incident sunlight as possible in solar radiation range and emit as little the blackbody thermal radiation as possible in IR range. Also, it can operate normally at a higher temperature.

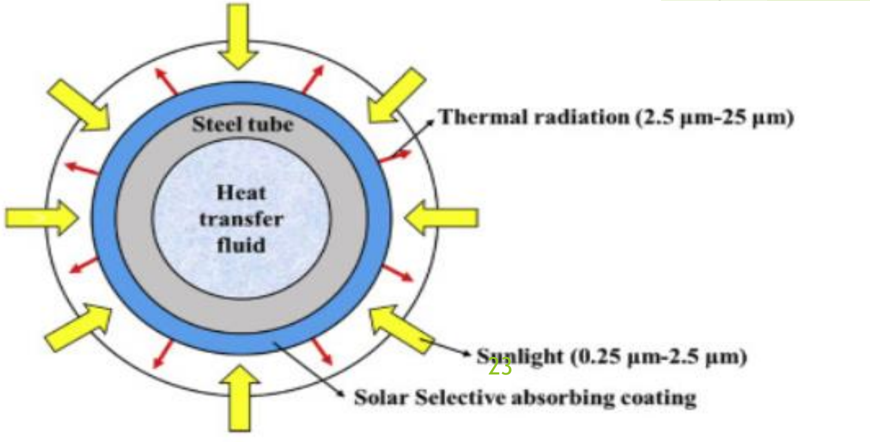


PHOTO THERMAL CONVERSION

SOLAR SELECTIVE COATINGS

- Solar selective absorbing coatings directly harvest solar energy in the form of heat.
- These coatings are highly resistant to humidity or oxidizing atmospheres.
- Repels water more quickly than non coated hydrophilic substances.
- Reduces growth of microorganisms and bacteria.
- Prevents bird fouling and tree sap from sticking to the surface.
- Dust and dirt get washed away with rainwater. Reduces cleaning frequency thus improving efficiency, and cost.
- A single layer is difficult to achieve maximum absorbance. By modifying the structure of coatings, choosing different materials or depositing way, the spectral selectivity of SSAC can generally be optimized

PHOTO THERMAL CONVERSION

SOLAR SELECTIVE COATINGS

- Selective coating is developed by choosing coating layers to maximize solar energy absorption while minimizing thermal emission.
- Some examples of solar selective coatings are black chrome, nickel black, cobalt oxide, copper oxide, selective black.

Selective black

- ❑ **Selective black** is a **silicone based paint** which collects heat better than ordinary black paint which emits a significant amount of heat energy it absorbs. It is designed to absorb wavelengths with greatest heat content.
- ❑ The coating also resists internal fogging of collector.
- ❑ It is available for spray painting which makes it convenient for application on fabricated collector surfaces.

PHOTO THERMAL CONVERSION

SOLAR SELECTIVE COATINGS

Cold mirror coating

- **Cold mirror** is a specialized dielectric mirror that reflects the entire visible spectrum while efficiently transmits the infrared wavelengths.
  - It has good optical characteristics
  - High infrared transmission (up to 2.500nm)
  - High operating temperature
  - Very effective heat/light separation
  - High mechanical stability
  - 100% dielectric optical coating construction

  Typical Applications
  - For lighting systems
  - High reflection mirror for visible light
  - Scanner and bar code mirrors
  - Dielectric Mirrors in sensor technology

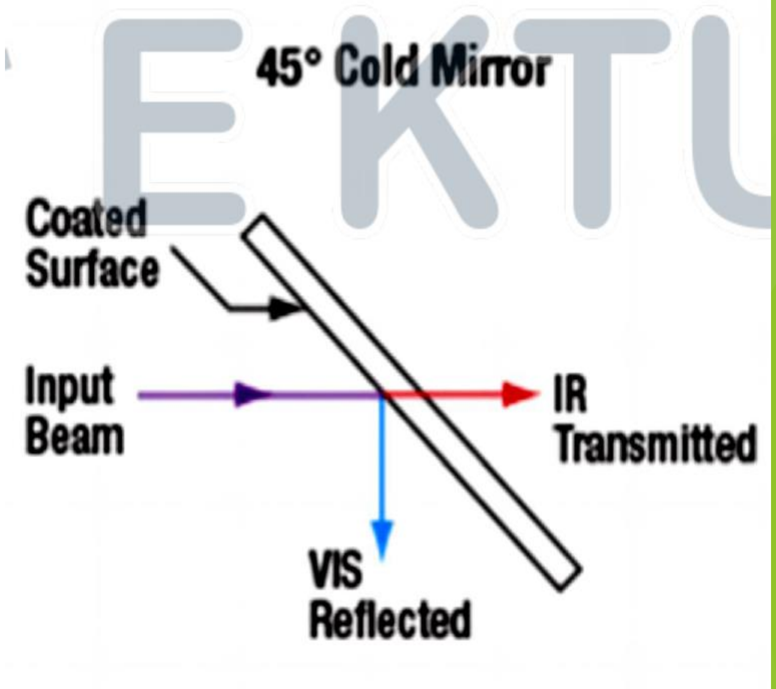
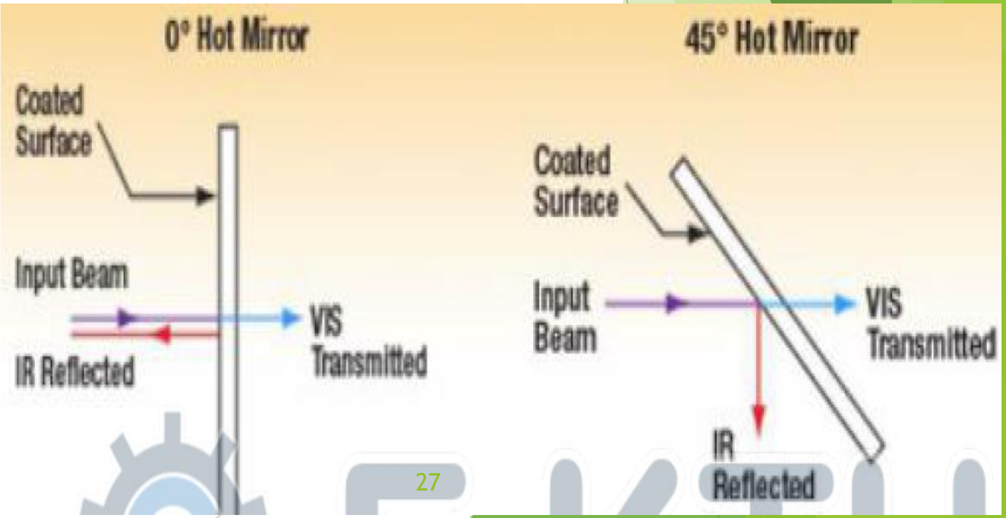


PHOTO THERMAL CONVERSION

SOLAR SELECTIVE COATINGS

Heat mirrors

- These reflect infrared light while allowing visible light to pass through.
- These can be used to separate useful light from unneeded infrared to reduce heating of components in an optical device.
- Heat mirrors are made of-seven layers of **silicon dioxide** and **hafnium oxide** on top of a **thin layer of silver.**



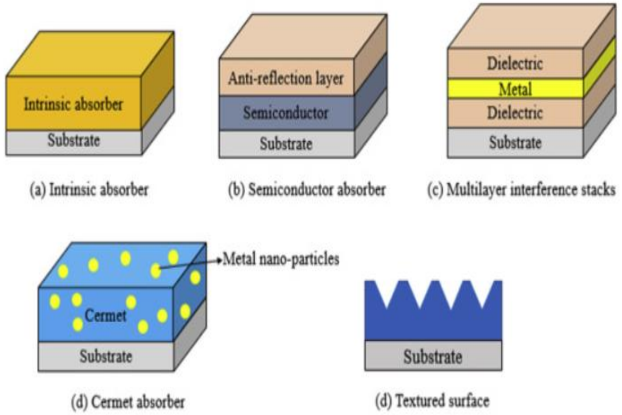
ANTI REFLECTIVE COATINGS

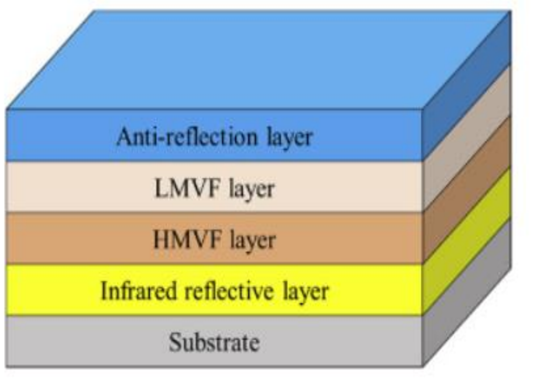
- Anti reflective coatings create double interference by means of a thin film which gives two reflected waves.

PHOTO THERMAL CONVERSION

SOLAR SELECTIVE COATINGS

- Based on the absorption mechanisms and design principles, Solar Selective Absorbing Coatings (SSACs) can be categorized into five different types;
  a) Intrinsic absorber
  b) Semiconductor absorber
  c) Multilayer interference stacks
  d) Cermet absorber
  e) Textured surface.





Double layer cermet structure

- Among these coatings, multilayer interference stacks and cermet absorbers are used widely. The former makes use of the interference effect of light to absorb near the peak of the solar radiation rather than in the infrared band.

PHOTO THERMAL CONVERSION

SOLAR SELECTIVE COATINGS

- Each of multilayer stacks can be composed of metal, dielectrics or metal dielectrics composite.
- By means of surface plasmon resonance and band-to-band transition, the coating has a high spectral selectivity.
- According to different dielectrics used, high temperature coatings can mainly be classified as:
  - Double cermet solar selective coatings,
  - Transition metal nitride multilayer coatings and
  - Transition metal oxide multilayer coatings.
- Double cermet layers can stabilize nano crystalline structures by alloying, while transition metal nitride/oxide layers generally provide superior mechanical properties and thermal stability.

PHOTO THERMAL CONVERSION

SOLAR SELECTIVE COATINGS

- A typical double cermet coating consists of a metal infrared reflective layer, a high and a low metal volume fraction cermet solar absorption layers (HMVF and LMVF), and a ceramic anti-reflection layer (AR). The solar radiation is scattered by the boundaries between the metallic and the dielectric phase.
- Transition metal nitride/oxide multilayer coatings consists of ceramic top layers and metallic bottom layers with gradient layers in between. These coatings have a better stability after annealing in air compared to double cermet coatings.

PHOTO THERMAL CONVERSION

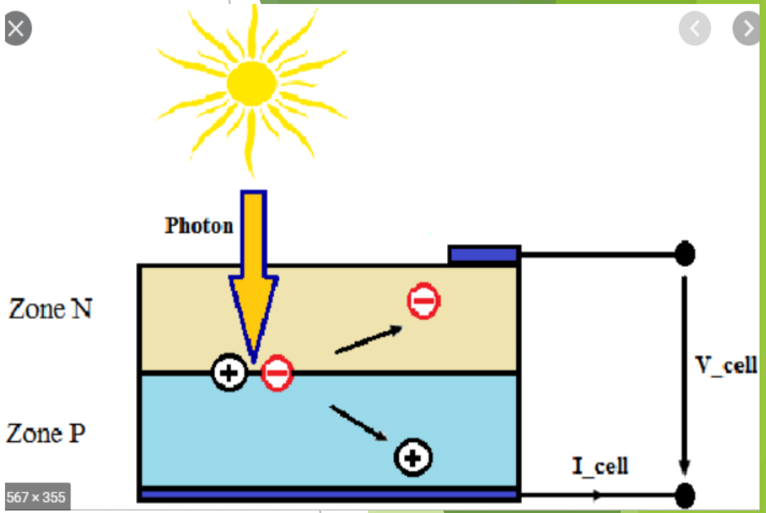
SOLAR SELECTIVE COATINGS

Different types of high-temperature solar selective coatings:

- Double cermet solar selective coatings
- High-temperature transition metal nitride multilayer coatings
  - XAlN/(XAlON) absorbing coatings (X and Y represent Al, Nb, Ti, Cr, Zr)
  - X(Y)SiN/X(Y)SiON absorbing coatings
  - XY(O)N absorbing coating
- High-temperature transition metal oxide multilayer coating
- Pyromark 2500 is a silicone-based high-temperature paint that has been used on central receivers to increase solar absorbance.

PHOTO VOLTAIC CONVERSION

- A photon with energy greater than the band gap energy incident on a semiconductor can excite electrons from the valence band to the conduction band, allowing current flow



- Photovoltaic energy conversion relies on the number of photons that strikes.

- The generation of voltage across the PN junction in a semiconductor due to the absorption of light radiation is called photovoltaic effect.

- **Photovoltaic** (PV) is the **conversion** of light into electricity using semiconducting materials that exhibit the **photovoltaic** effect.

- The Devices based on this effect is called photovoltaic device.

SOLAR CELL

- Solar cell is a photovoltaic device that converts the light energy into electrical energy based on the principles of photovoltaic effect.

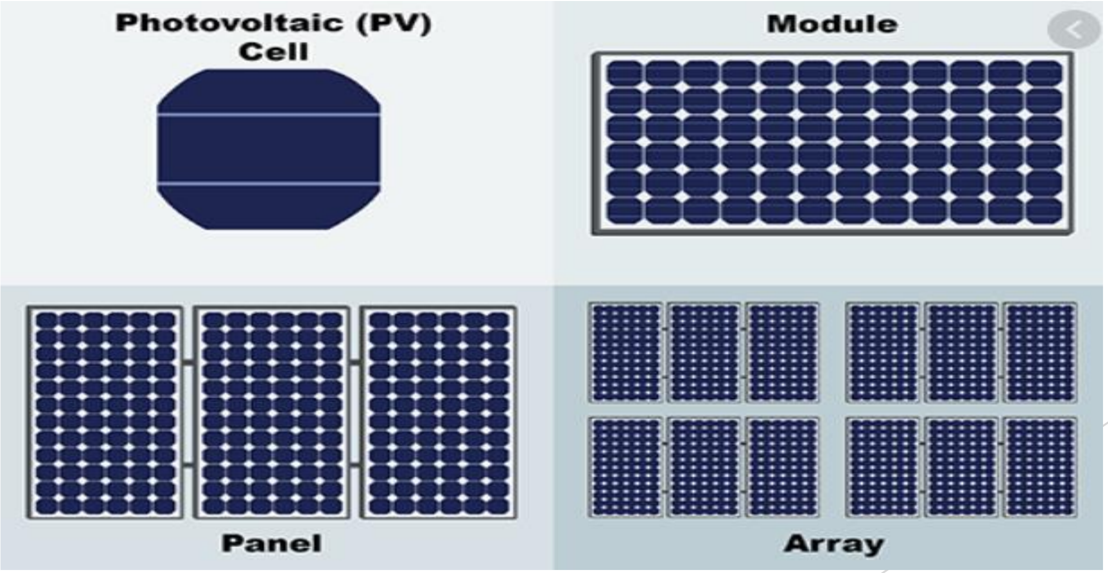
Single solar cell (Silicon)

- The single solar cell constitute the n-type layer sandwiched with p-type layer.
- The most commonly known solar cell is configured as a large-area p-n junction made from silicon wafer.
- A single cell can be used only to light up a small light bulb or power a calculator and is also used in many small electronic appliances such as watches and calculators.

SOLAR CELL

Solar module, solar panel, solar array

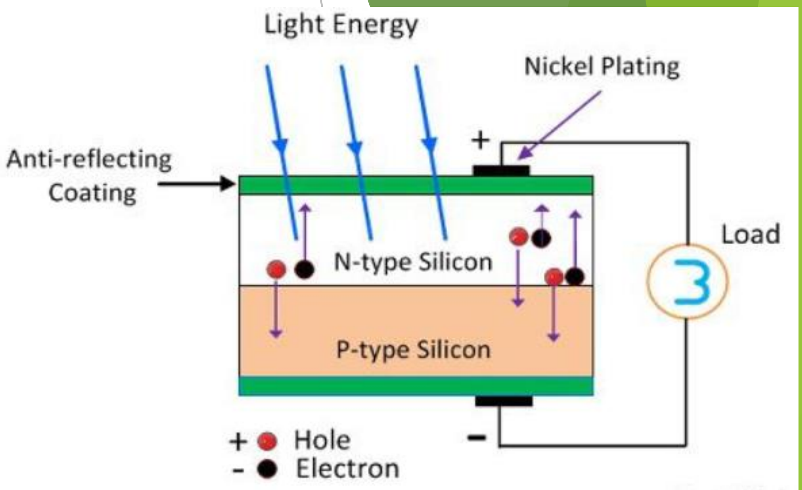
- A solar module consists of interconnected solar cells.
- A solar panel or solar array is the interconnection of number of solar modules to get efficient power.
- These interconnected cells are embedded between two glass plates to protect them from bad weather.
- Since absorption area of module is high, more energy can be produced
- Typical output of a module (~30 cells) is ≈15 V, with 1.5 A current

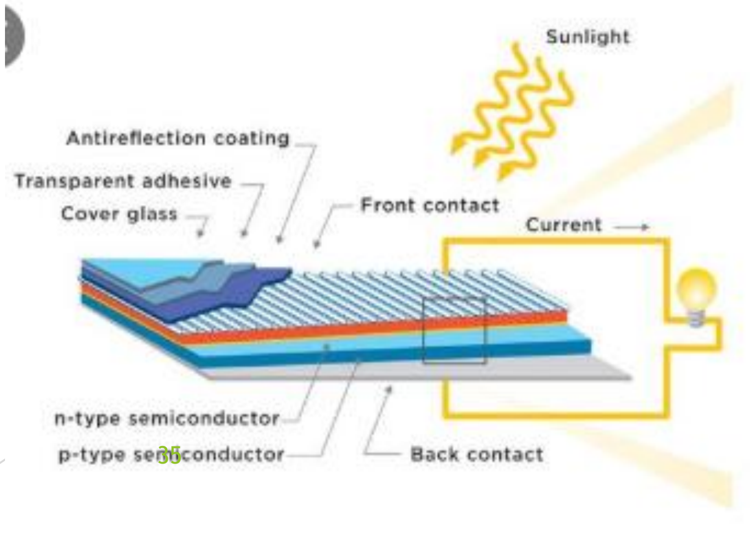


SOLAR CELL

Construction:

- Solar cell (crystalline Silicon) consists of an n-type (emitter) and a p-type (base) semiconductor layer.
- The two layers are sandwiched and hence there is formation of p-n junction.
- The surface is coated with anti-reflection coating to avoid the loss of incident light energy due to reflection.
- Proper metal contacts are made on the n-type and p-type side of the semiconductor for electrical connection.





SOLAR CELL

Working:

- When a solar panel is exposed to sunlight, the light energies are absorbed by semiconductor materials.
- When light falls on the semiconductor surface, the electron from valence band is promoted to conduction band.
- Vacancy position left by the electron in the valence band generates holes.
- The elctrons and holes diffuse across the p-n junction leading to the formation of electron-hole pair.
- As electrons continuous to diffuse, the negative charge build on emitter side and positive charge build on the base side.
- When the PN junction is connected with external circuit, the current flows.

SOLAR CELL

Advantages:

- It is clean and non-polluting source of renewable energy
- Solar cells do not produce noise and are totally silent.
- They require very little maintenance
- They are long lasting sources of energy which can be used almost anywhere
- They have long life time
- There are no fuel costs or fuel supply problems

Disadvantages:

- Solar power cannot be obtained in night time
- Solar cells and solar panels are very expensive
- Air pollution and weather can affect the production of electricity
- They need large area of land to produce more efficient power supply

SOLAR CELL

Applications:

- **Domestic power supply** for appliances include refrigeration, washing machine, television and lighting
- **Ocean navigation aids:** Number of lighthouses and most buoys are powered by solar cells
- **Telecommunication systems:** Radio transceivers on mountain tops, or telephone boxes are solar powered
- **Electric power generation in space**: Provide electrical power to satellites in an orbit around the Earth
- **Solar pumps** are used for water supply.

TYPES OF SOLAR CELL

SILICON SOLAR CELLS

- Based on the types of crystal used, solar cells can be classified as,

  1. Mono crystalline silicon cells
  2. Polycrystalline silicon cells
  3. Amorphous silicon cells

- The **Mono crystalline silicon cell** is produced from **pure silicon** *(single crystal).* Since the Mono crystalline silicon is pure and defect free, the efficiency of cell will be higher (14 – 15%).

- In **polycrystalline solar cell**, **liquid silicon** is used as raw material and polycrystalline silicon was obtained after *solidification process*.

TYPES OF SOLAR CELL

- The materials contain various crystalline sizes. Hence, the efficiency (13 – 15%) of this type of cell is less than Mono crystalline cell.

- Amorphous silicon was obtained by depositing **silicon film** on the substrate like glass plate.

  - The layer thickness amounts to less than 1μm (the thickness of a human hair for comparison is 50-100 μm).
  - The efficiency (5 – 7%) of amorphous cells is much lower than that of the other two cell types.
  - As a result, they are used mainly in low power
  - Equipment such as watches and pocket calculators

TYPES OF SOLAR CELL

GALLIUM ARSENIC SOLAR CELLS

- Gallium arsenide (GaAs) cells consists of thin films made of compounds of two or more elements.

- The GaAs has a band gap of 1.43 eV which is very near to the optimum value of 1.4 eV. Therefore, GaAs cells are among the most efficient single-junction solar cells.

- The maximum efficiency of single-junction GaAs solar cells is 29% (under less solar concentration) and 43% (with solar concentration).

- The efficiency of GaAs is relatively insensitive to increasing temperature, which helps them perform better under concentrated sunlight.

TYPES OF SOLAR CELL

GALLIUM ARSENIC SOLAR CELLS

- They are also less affected by cosmic radiation and since they are thin films, they are lightweight, which gives them an advantage in space applications.
- Gallium is much less abundant in the earth's crust, hence it is a very expensive material.
- Also the difficult processing required to fabricate GaAs cells, make it too expensive for all but space applications and for concentrator systems.

TYPES OF SOLAR CELL

CADMIUM SULPHIDE SOLAR CELLS

- Cadmium Sulphide (CdS) is used as n-layer in hetero junction solar cells.
- Thin-film prototype modules using the n-CdS/p-CdTe hetero junction have efficiencies approaching 17%.
- The equipment needed to manufacture these cells is cheaper than that required for Si, and their relatively higher efficiency makes them attractive candidates for mass production.
- One aspect of CdS/CdTe(p-type layer) cells is the potential hazard to human health and the environment associated with cadmium. Cadmium is a very toxic substance.
- CdS/CdTe modules contain about 6 g of cadmium per square meter of surface area, but it is completely sealed inside of the module so it possess no risk under normal operation.

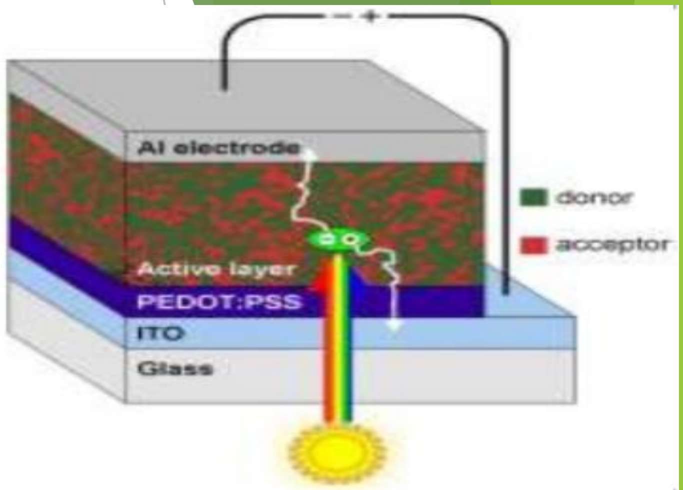
TYPES OF SOLAR CELL

ORGANIC SOLAR CELLS

- Some of the demerits of inorganic solar cells are;
  - Silicon is expensive as compared to organic materials
  - Not flexible
  - Limited availability of inorganic material as compared to organic materials

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

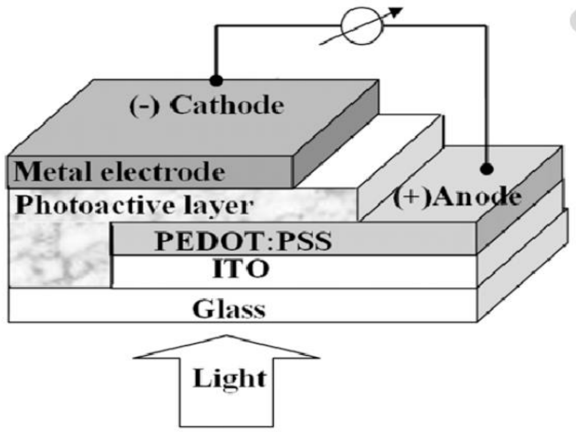
TYPES OF SOLAR CELL



ORGANIC SOLAR CELLS

- Photons absorbed creates exitons (bound electron-hole pair)
- The negative electrode is Aluminum
- Indium Tin Oxide(ITO) is the common transparent electrode
- The substrate is glass
- Current is generated when the resulting free electrons and holes are transported through the donor polymer and acceptor fullerene, respectively, to the electrodes
- It has lower efficiency and shorter life time when compared to inorganic cells.

- Applications
  - Personal mobile phone charger
  - Small home electronics and mobile electronics attachment
  - Power generation



TYPES OF SOLAR CELL

ORGANIC SOLAR CELLS

- Two types of organic solar cells are;
  - Single layer OSC
  - Double layer OSC

Single layer organic solar cell:

- It has only one active layer between cathode and anode.
- The donor and acceptor polymers are merged.
- So distance between electron and hole pair is decreased.

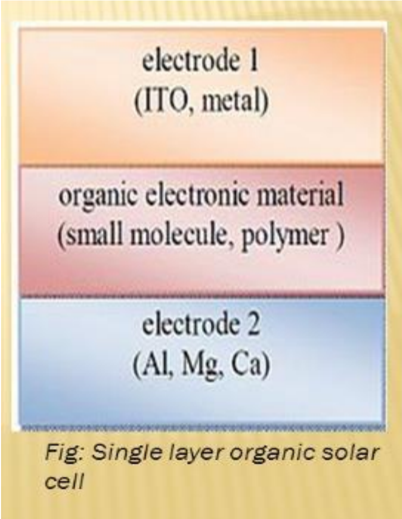


Fig: Single layer organic solar cell