EN671: Solar Energy Conversion Technology

Basics of Solar Photovoltaic

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Outlines

- Basics of PV cells
- PV constructions
- Manufacturing process of solar cells
- Working principle of PV conversion

Solar Photovoltaic Conversion

- The devices used for PV conversion are called Solar cells.
- When solar radiation falls on these devices, it is converted directly into DC electricity.
- **Major advantages**
  - ✓ No moving parts
  - ✓ Requires little maintenance
  - ✓ Work quite satisfactorily with beam or diffuse radiation
  - ✓ Adopted for varying power requirements

Limitations PV Conversion

- Efficiency of solar cell is low
- Solar energy is intermittent
- Cost

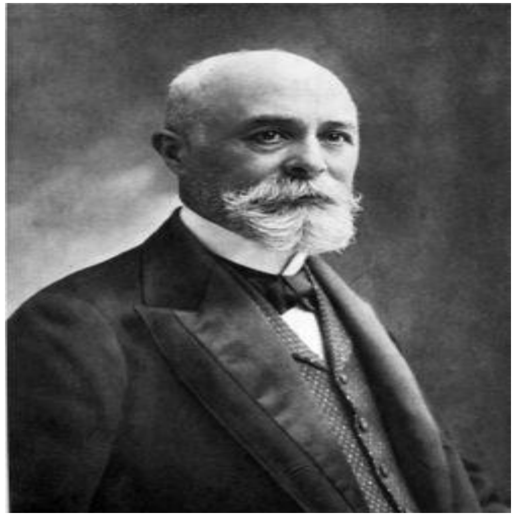
90% of the current commercial production of solar cells are single crystal and multi-crystalline silicon cells

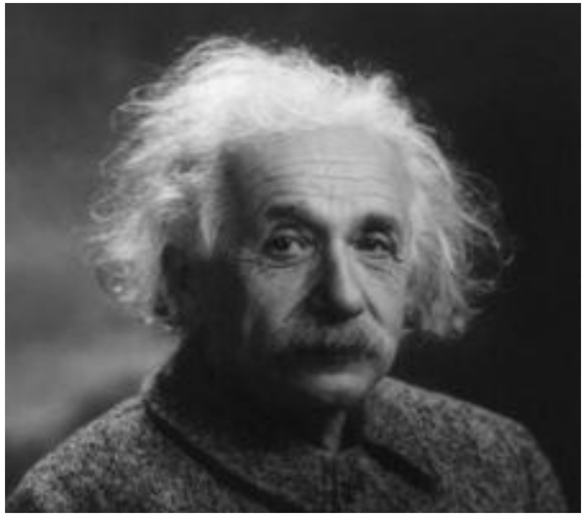
Application of PV Technology

- Space satellites
- Remote radio communication booster stations
- Marine warning lights
- Lighting purposes
- Powering household appliances
- Powering torches, flashlights, wrist watches
- Water pumping (in irrigation), streetlight
- Solar PV power plant
- Solar powered vehicle, Battery charging etc.

Early PV milestones

- 1839: Discovery of the photovoltaic effect - *Edmond Becquerel*
- 1873: Smith discovers the photoconductivity of selenium
- 1883: Fritts develops first selenium cell (1% efficient)
- 1904: Einstein published his paper on the photoelectric effect (along with a paper on his theory of relativity)
- 1921: *Albert Einstein* wins the Nobel Prize for his theories (1904 paper) explaining the photoelectric effect



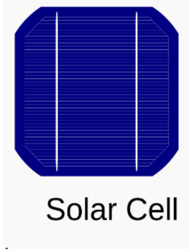


Patented 1st modern solar cell called a "Light sensitive device" - Bell Laboratory

Vanguard I - first PV powered satellite

- Launched – 1958 (4th Artificial Satellite)
- Still orbiting
- Solar Panel: 0.1 W, 100 sq.cm
- Cost: USD1000 per watt

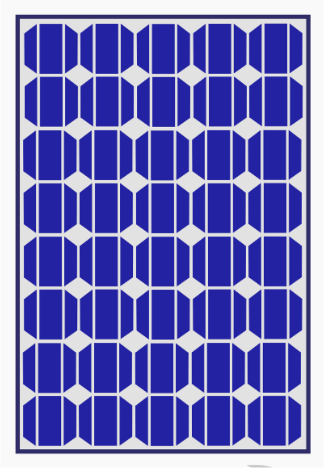
Solar Photovoltaic Cell, Module and PV Array



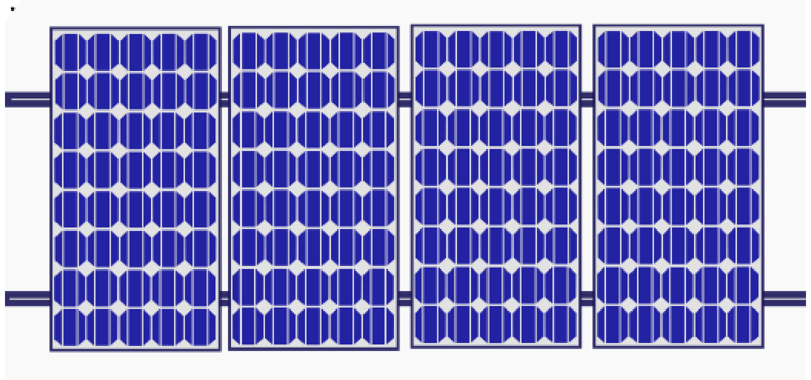
0.5 V and 20-40 mA/cm^2

100 cm^2 produces a current of 2 A

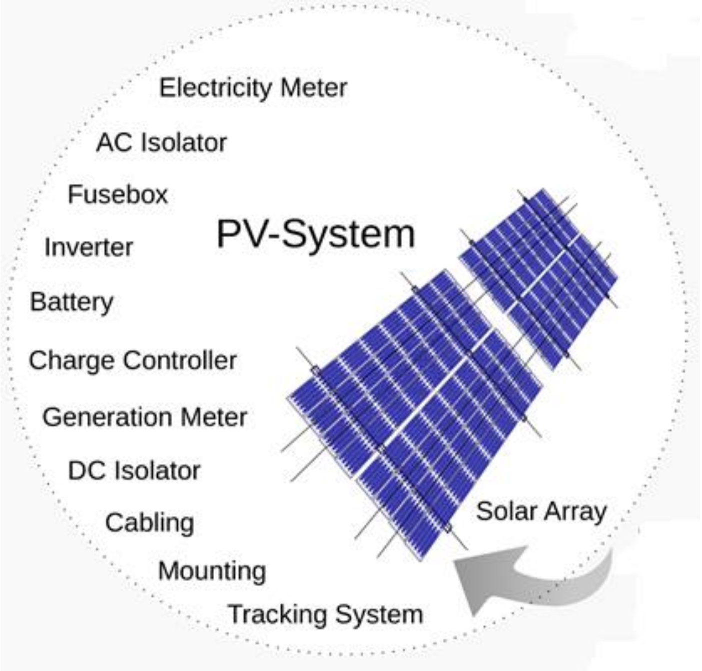
1-2 kWh/m^2 per day



Module



Array



Cell Size and its classification

(a) 100 mm (4 inch) diameter, round single crystalline
(b) 100 cm^2 square single crystalline
(c) 100 mm x 100 mm (4 inch x 4 inch) square multi crystalline
(d) 125 mm x 125 mm (5 inch x 5 inch)square multi crystalline

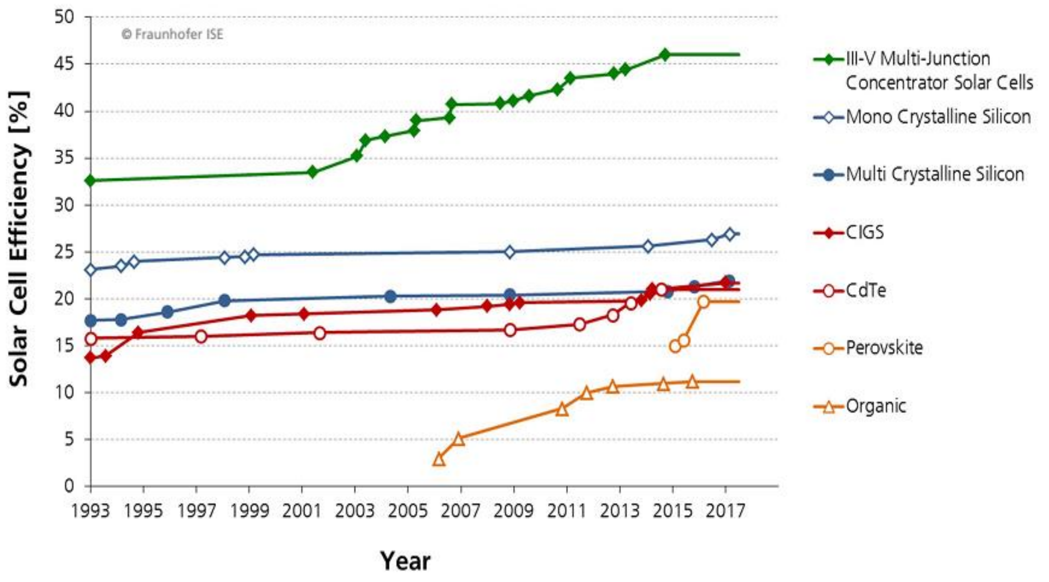
- **Thickness of bulk silicon wafer = 200 to 400 μm**

Classification on the basis of:

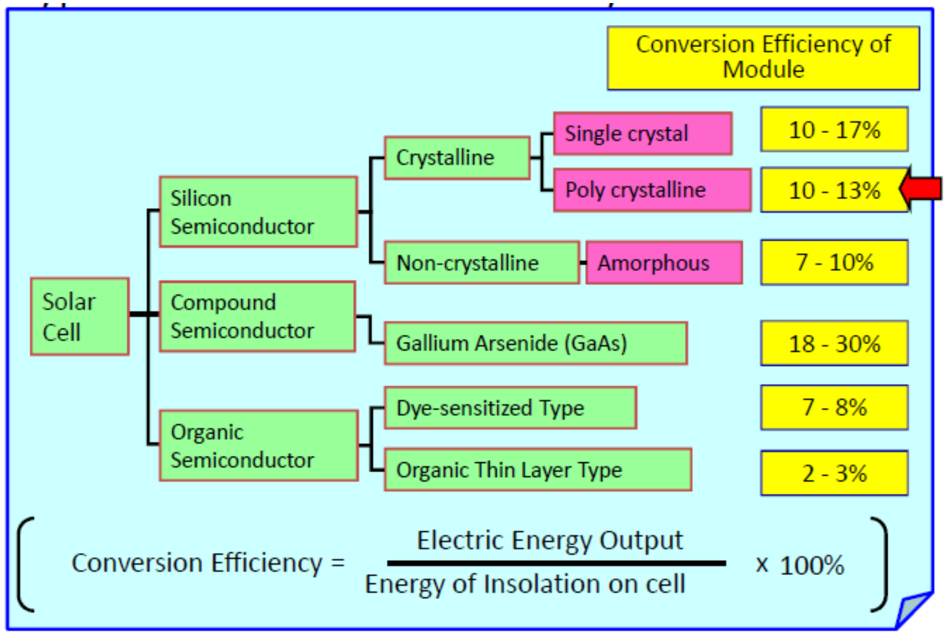
(a) Thickness of the active material (bulk material cell, thin-film cell)
(b) Type of junction structure (*pn* homojunction cell, *pn* heterojunction cell, *pn* multifunction cell, metal-semiconductor (Schottky) junction and *p-i-n* (p type-intrinsic –n type) semiconductor junction)
(c) The type of the active material used in its fabrication (Single crystal silicon solar cell Multicrystalline Silicon Solar Cell, Amorphous Silicon (a-Si) Solar Cell, Gallium Arsenide Cell, Copper Indium (Gallium) Diselanide (CIS) cell, Cadmium Telluride Cell, Organic PV Cell)

PV cells material and its conversion efficiency

- Single crystal silicon solar cell
- Multicrystalline Silicon Solar Cell
- Amorphous Silicon (a-Si) Solar Cell
- Gallium Arsenide Cell
- Copper Indium (Gallium) Diselanide (CIS) cell
- Cadmium Telluride Cell
- Organic PV Cell



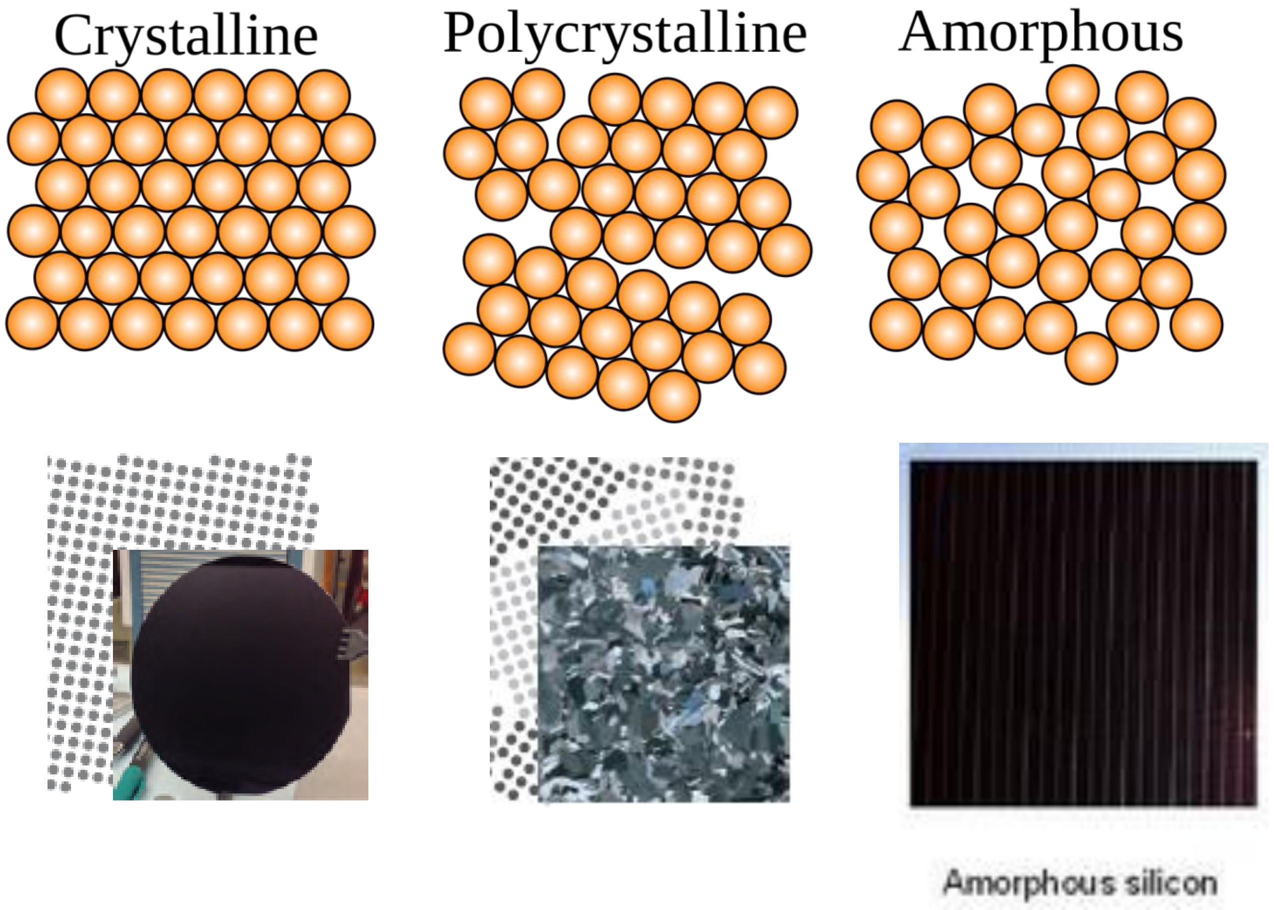
Data: Solar Cell Efficiency Tables (Versions 1-50), Progress in Photovoltaics: Research and Applications, 1993-2017. Graph: Fraunhofer ISE 2017



✓ Combinations of different band-gap materials in the tandem (higher efficiencies).

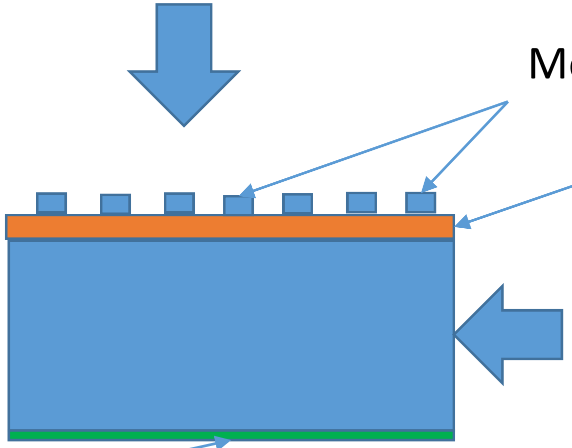
Crystalline, polycrystalline, amorphous structure

- Atoms, molecules, or ions of **crystalline solid** are arranged in a highly ordered microscopic structure, forming a crystal lattice that extends in all directions- give unique properties, particularly mechanical, optical and electrical.
- The opposite of a single crystal is an amorphous structure where the atomic position is limited to short range order only.
- In between the two extremes exist *polycrystalline*, which is made up of a number of smaller crystals known as *crystallites*, and *paracrystalline* phases.



Construction of a PV cell (single crystal si solar cell)

Screen printing of a paste containing 70% silver, organic binder and sintered glass



Metal electrode finger

Diffusion of n-type impurity

Single crystal Si solar cell – wafers, sliced from single crystal p-type doped silicon

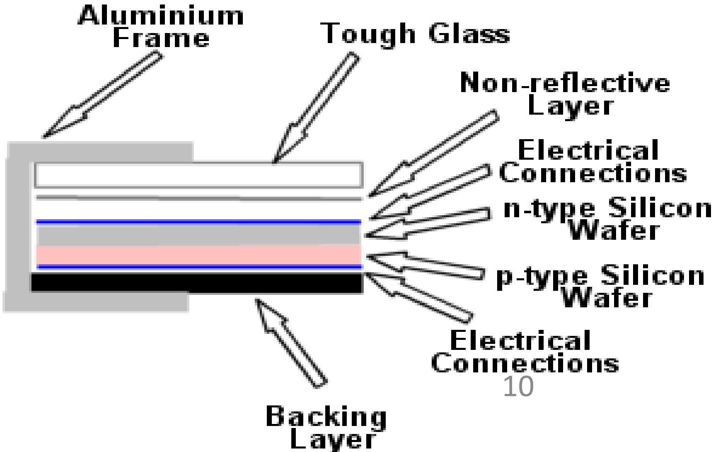
Metal electrode finger

For back contact **a paste containing aluminum is screen printed.**

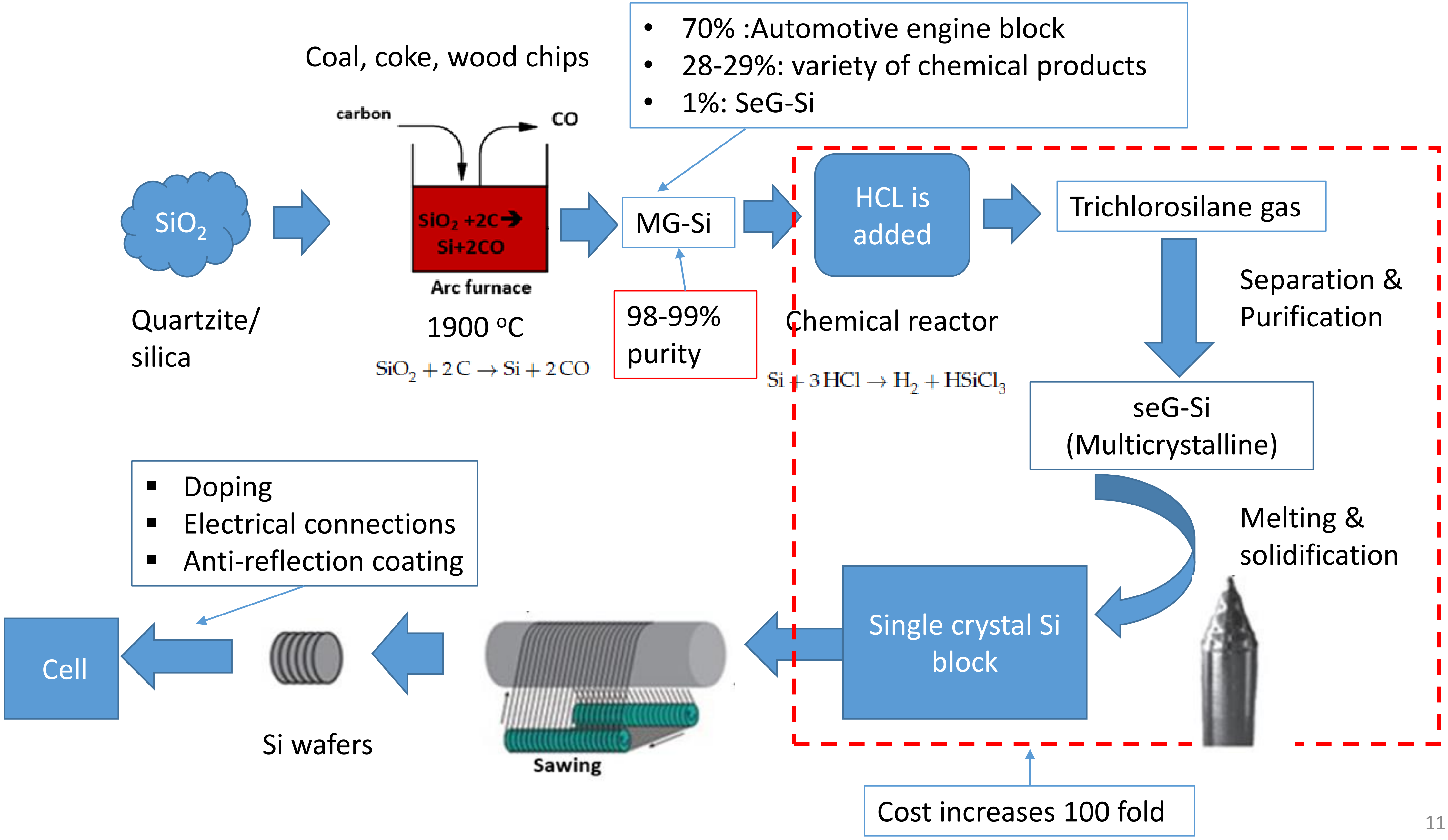
Placed in a furnace at 600-700 ^{o}C

Anti reflection coating of silicon nitride or titanium dioxide of thickness 0.1 micron – applied at the top surface

Cells are encapsulated in a thin transparent material

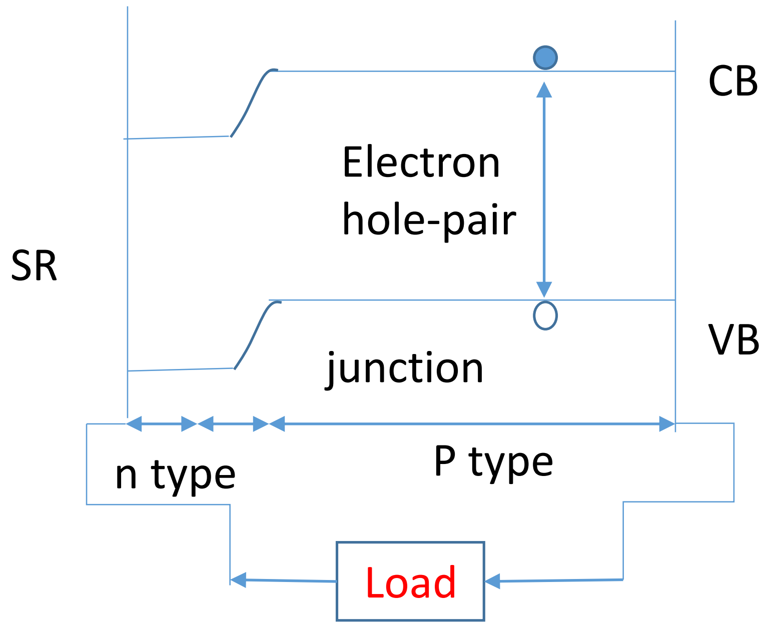


Production process of monocrystalline silicon solar cell



Principle of working of a solar cell

- **Creation of pairs of positive and negative charges in the solar cell by absorbed solar radiation *(cell must be made of a material which can absorb energy associated with the photos of sunlight)***
- **Separation of the positive and negative charges by a potential gradient within the cell**



Material: *semiconductors like silicon, cadmium telluride, gallium arsenide*

Energy of a photon: $E = \dfrac{h \times c}{\lambda}$ Joules

$h = \text{Planck's constant} = 6.62 \times 10^{-27}$ erg-s

$c = \text{velocity of light} = 3 \times 10^{8}$ m/s

$E = \dfrac{1.24}{\lambda}$ eV

h = 6.63 x 10^{-34} Joules-second
1 eV = 1.6 x 10^{-19}Joule

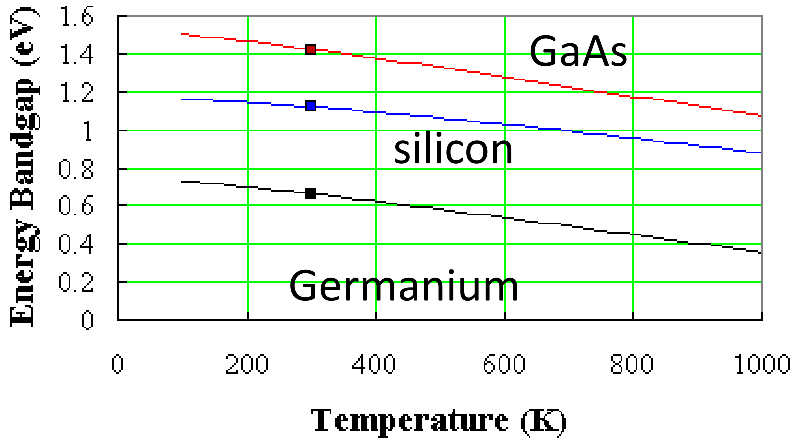
- **VB has electrons at a lower energy level and is fully occupied**
- **CB has electron at a higher energy level and is not fully occupied.**
- Difference between the min energy of electrons in the CB and max energy of the electron in VB is called **band gap energy**

Principle of working of a solar cell

- **Silicon p-type is doped with some trivalent atoms like those of boron,** while silicon of n-type is doped with some pentavalent atoms like those of phosphorous.
- **N-type of silicon has excess electrons, while p-type has excess holes.**
- **When these materials are joined together, excess electrons from the n-type diffuse to recombine with the holes in the p-type**
- Similarly excess holes from p-type diffuse to the n-type as a result n-type material becomes positively charged, while p-type is negatively charges – ***creates built-in potential at the junction***

Material Band gap

- For insulators the energy band gap $(h\nu < E_g)$ is very large, thus the electrons in the valence band cannot reach the conduction band, which results in no conduction of current.
- For a semiconductor $(h\nu > E_g)$, the valence electron can cross this gap on acquiring thermal or light energy
- For Conductor $(E_g \approx 0)$ no forbidden gap exists, and hence electron can easily move to the conduction band.



Variation of the band gap with temperature: $E_g(T) = E_g(0) - \dfrac{aT^2}{T+b}$

At T = 0, $E_g(T) = E_g(0)$ **materials behave as an insulator**

Material	Eg(0) eV	a (eV/K) x 10^{-4}	b (K)
Si	1.166	7.0	636
GaAs	1.519	5.8	204
Ge	0.7437	4.77	235

Q1: Band gap energy in a silicon crystal at 50°C? (1.1 eV)

$$E_g(T) = E_g(0) - \frac{aT^2}{T+b} = 1.166 - \frac{7\times10^{-4}\times(50+273)^2}{(50+273)+636} = 1.1eV$$

Q2: The optimum wavelength of light for photovoltaic generation in a Si cell. (1.12 μm)

$$E = \frac{1.24}{\lambda} \Rightarrow \lambda = \frac{1.24}{1.11} = 1.12\mu m$$

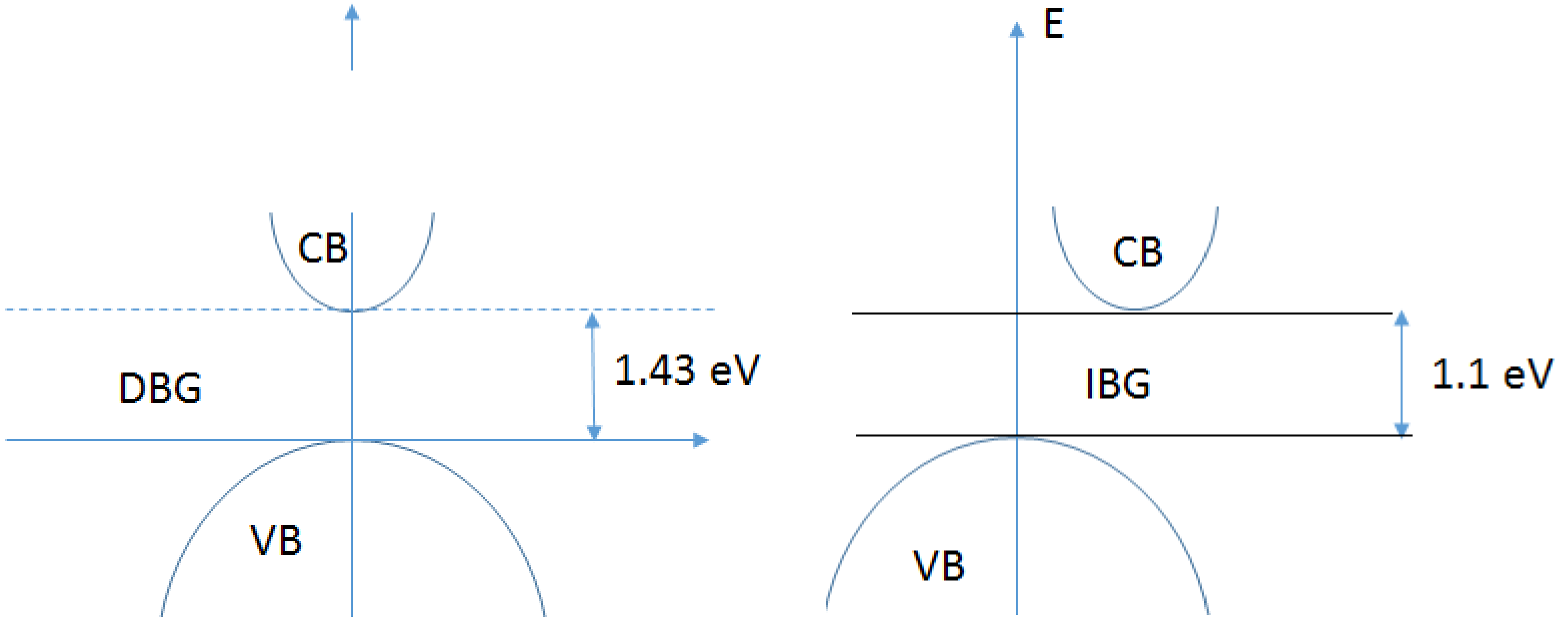
Q3: Calculate the optimum wavelength of light for photovoltaic generation in a CdS cell. (Band gap for CdS is 2.42 eV)

$$E = \frac{1.24}{\lambda} \Rightarrow \lambda = \frac{1.24}{2.42} = 0.512\mu m$$

Direct and Indirect band gap

✓ k-vector that describes the crystal momentum of the semiconductor.

- ✓ If the maximum of the valence band and the minimum of the conduction band occur at the same k-vector, an electron can be excited from the valence to the conduction band without a change in the crystal momentum – DBGM
- ✓ If the electron cannot be excited without changing the crystal momentum - IBGM



For GaAs

For Si

✓ Absorbs photons much more readily

✓ Photons have to travel more distance before getting absorbed

✓ Must be sufficiently thick to absorb the incident light

Loss mechanism

- The two most important *loss mechanisms* in single bandgap solar cells are the inability to convert photons with energies below the bandgap to electricity and thermalisation of photon energies exceeding the bandgap.
- These two mechanisms alone amount to the loss of about half the incident solar energy in the conversion process.
- Thus the maximal energy conversion efficiency of a single junction solar cell is considerably below the thermodynamic limit. This *single bandgap limit* was first calculated by Shockley and Queisser in 1961.

Thank you