SOLAR PV SYSTEMS

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Solar Cells and the Future

- EVERY minute, the sun radiates the earth with more energy than the world's entire population consumes in a year.
- Unfortunately, it is expensive to convert all that sunshine into electricity. Most solar cells are made of inorganic silicon and, require laborious manufacturing processes that involve costly clean rooms. As a result, solar energy costs roughly three to four times as much as electricity from conventional sources.

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Photovoltaic Generators

- Sunlight consists of a spectrum of electromagnetic waves, i.e. a whole range of different wavelengths.
- Light may also be considered to be composed of particles – so called photons- that carry a characteristic energy and momentum.
- The short wavelength blue photons carry a higher energy than a long wavelength red photons.
- It is the particle-like behaviour of light that is needed to understand the photovoltaic effect.
- Conversion of light into electricity in a solar cell is based on this effect

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Solar Cells

- **Solar Cell:** A fundamental power conversion unit of a photovoltaic system. Typically made from semiconductors (newer technologies use polymers and organic materials).
- **Semiconductors:** Materials, both compounds and elements, can be classified according to how well they conduct electricity. Metals → conduct electricity well and insulators → are poor conductors of electricity. ***Semiconductors*** → materials fall in between insulators and metals.

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Semiconductors

- With the development of quantum theory and the band theory description of the electrical properties of elements made it possible to understand what differentiated conductors, insulators and semiconductors in a comprehensive and testable theory.
- Semiconductor elements form a loose band: not quite metals and not quite insulators. Some compounds formed from various crystalline and amorphous mixtures also behave like semiconductors.
- The electrical characteristics of semiconductors can be changed by introducing traces of other elements in minute proportions. The process is known as doping (formation of n-type and p-type semiconductors).
- By applying voltages and bias currents, semiconductors can function as switches forming the basis of transistors and by applying light radiation, semiconductors can function as photovoltaic devices.

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Semiconductors

- Silicon is the most commonly used semiconductor others include:
  - gallium arsenide
  - germanium
  - selenium
  - cuprous oxide
  - lead telluride
  - lead sulphide
  - silicon carbide
  - cadmium telluride
  - indium gallium arsenide nitride
  - copper indium gallium selenium

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Band Gap

- Electrons bound to an atom define a series of distinct energy shells which the electrons could fill, from the lowest energy levels upward in distinct steps or quanta.
- For many atoms aggregated in a crystal structure, the distinct energy shells become bands.

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..... Band Gap

- In conductors the band gap is near zero, while insulators have a relatively high band gap and semiconductors are in the middle.
- The lowest level shells, which may be partially filled, are called the valence band
- The higher unfilled levels are called conduction band.
- The highest filled level of the atom at absolute zero is called the Fermi level. This marks a dividing line between the valence and conduction bands, in the centre of a forbidden energy gap, also known as the band gap.

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….. Band Gap

- The band gap of a semiconductor, measured in electron volts [eV] (1 eV = 1.602 x 10^{-19} J), is the difference between the valence band and the conduction band potentials. Each type of semiconductor has a unique band gap, most of which fall in the range 1.0 to 2.6 eV.

….. Band Gap

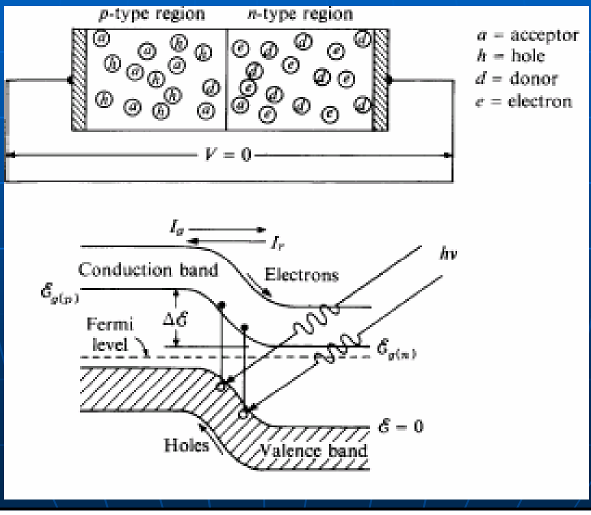
Semiconductor	Band Gap [eV]
• Silicon	1.1
• Gallium Arsenide	1.34
• Copper Indium Delenide	1.0
• Germanium	0.72
• Indium antimonide	0.18
• Cadium Sulfide	2.45
• Zinc Oxide	3.3

….. Band Gap

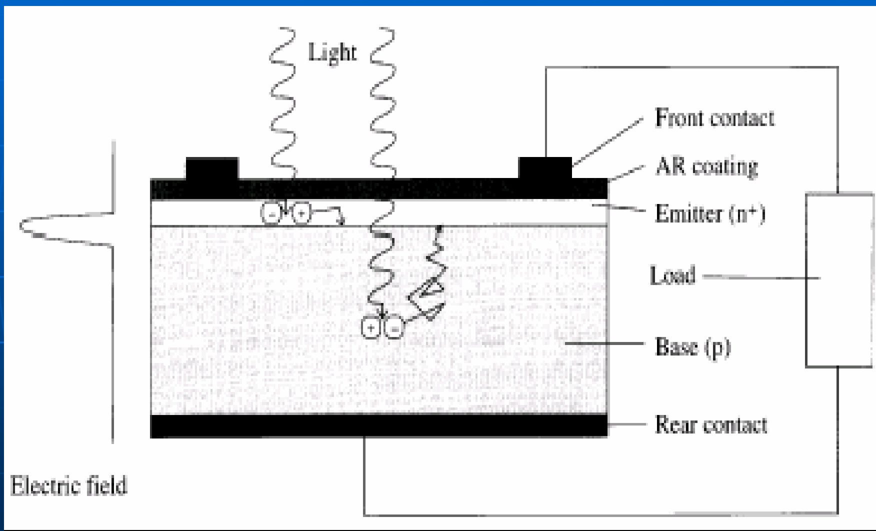
- The point to note here is that a photovoltaic material can only capture those photons which have an energy greater than or equal to the band gap of that material. Silicon, for example, will be transparent to photons with an energy of less than 1.1 eV.
- It might seem therefore, that a very low band gap material should be used, but the strength of the electric field created by the conjunction of n-type and p-type material is also dependent upon the band gap.
- One has to make a trade-off between photon energy and field strength.

p-n Junction

- The photo-conversion device that has attained the highest efficiency is the p-n junction.



Basic Principles of a Solar Cell



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….. Solar Cell

- The bulk of the energy converter is composed of p-type material. Only a front surface layer of the wafer has n-type conductivity. The n-layer is called the emitter and the p-region is called the base. When forming such a so called pn-junction diode structure, electrons from the emitter diffuse instantaneously into the base, and holes from the p-region diffuse into the emitter. This is due to the fact that emitter contains a very high concentration of electrons compared to the base, where as the base is rich in holes. This diffusion of charge carriers leads to the build up of an electric field, resulting internal voltage in the vicinity of the pn-junction. Under equilibrium conditions, the electrical forces due to this field compensate the forces driving the diffusion - thus no electric current flows.

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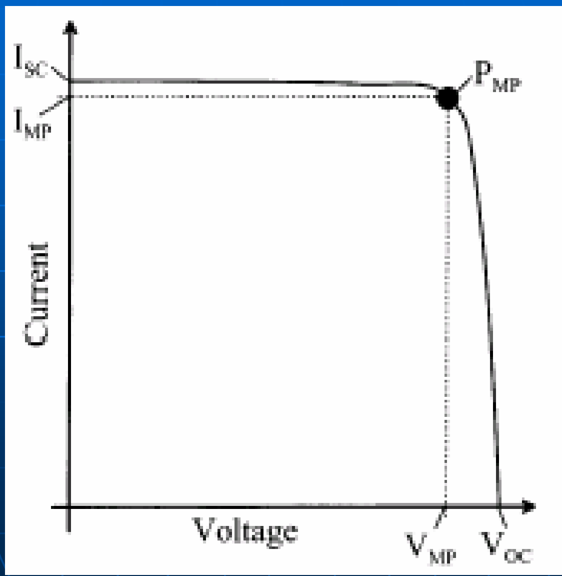
Power Curve

- If light impinges on the solar cell, part of it will penetrate and produce electron-hole pairs, provided the photons have sufficient energy. These added charge carriers result in non-equilibrium condition in the cell. The accumulation of charges at the external electrodes leads to the buildup of an external voltage between the metal contacts. This voltage may then drive the charge carriers through an electrical load. The work delivered to this load is converted solar energy

…… Power Curve

- Under open circuit conditions the maximum voltage, the open circuit voltage V_{oc}, is measured between the contacts. V_{oc} increases with increasing band gap of the material.
- If we directly connect the front and rear metal electrodes electrically, we short circuit the voltage buildup and produce a short-circuit current I_{sc}.
- Due to the fact that under lower band-gap situations more photons are able to excite electron-hole pairs, the short-circuit current increases with decreasing band gap. Maximum power output of a solar cell, $P_{MP} = V_{MP}.I_{MP}$.

…… Power Curve



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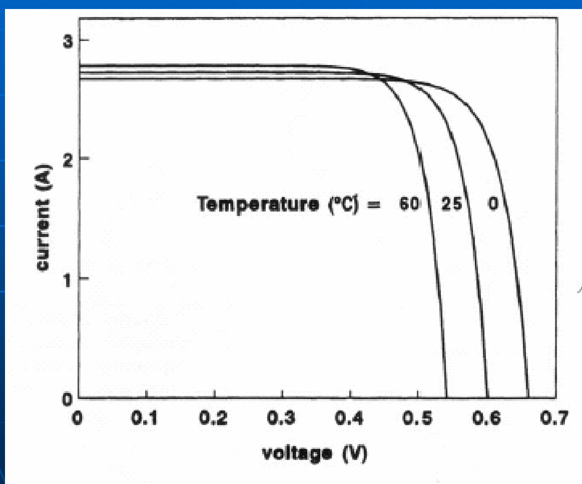
Temperature Effect

- An important effect on the power output from the cell. Voltage decrease: 2.3 mV/^{0}C



Temperature dependence of the *I–V* characteristic of a solar cell

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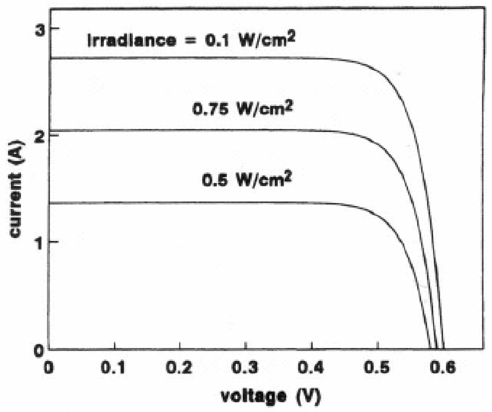
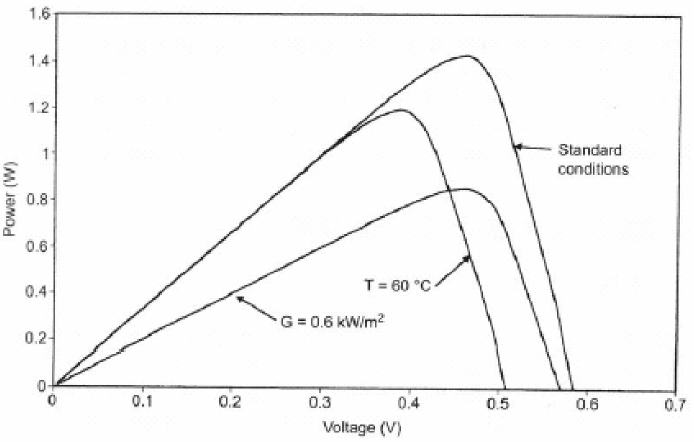
Irradiance Effect

- The light generated current is proportional to the flux of photons with above band gap energy. The short circuit current of a solar cell is directly proportional to the irradiance.



Irradiance dependence of the *I–V* characteristic of a solar cell

Power Characteristics



3.23 Power produced by solar cell as a function of voltage *V* at the terminals

A Solar Cell

- A Typical single silicon PV cell of 100 cm^2 produces 1.5 watts at 0.5 volts DC & 3 A under 1000W/m^2 & AM1.5
- Power out put is proportional to the intensity of sunlight

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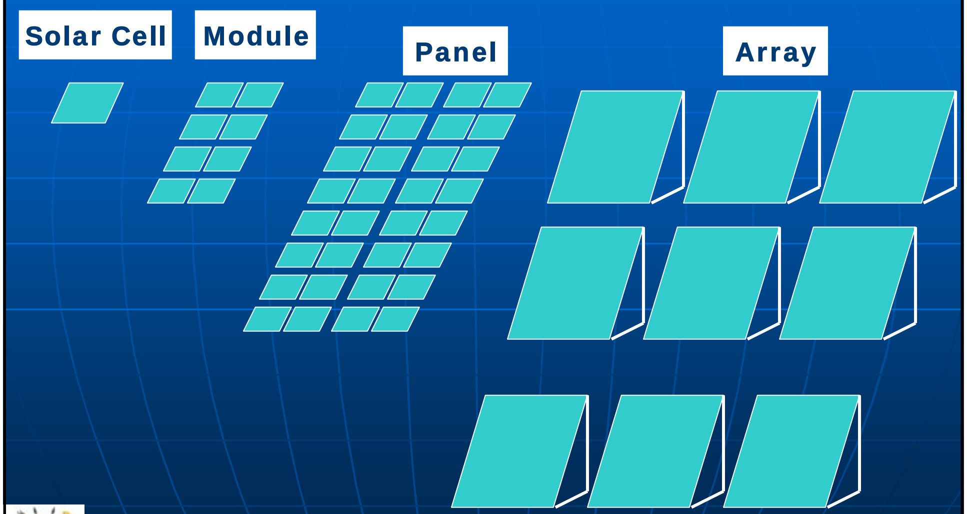
Solar Cells, Panels, modules and arrays



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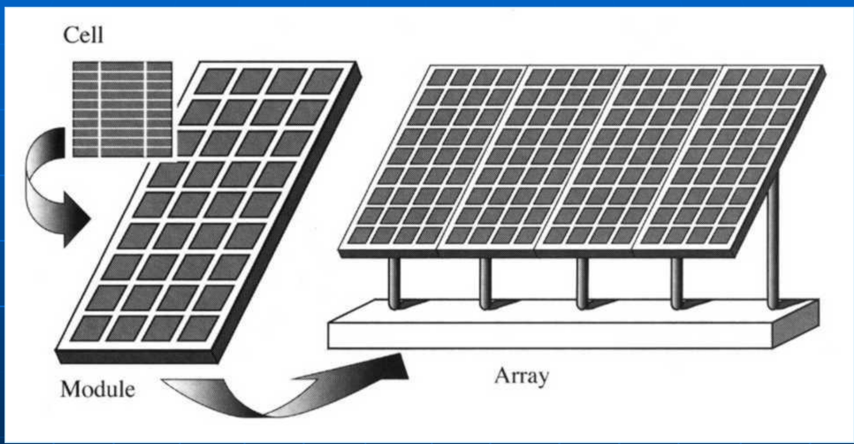

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Structure of PV Modules

- A Solar panel is an interconnection of solar cells : At least 36 cells connected in series to obtain a nominal voltage of 12 V
- Protective front glass sheet: Highly transparent, hardened to resist mechanical damage, easy to clean.
- Sealed back sheet: Protects against moisture, UV and electrical charge

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Blocking & Bypass diodes

- Blocking diodes reduce losses at night and overcast (when PV module works like a diode)
- Some panels have a provision to connect a bypass diode to the terminals. This serves to reduce power loss from partial shading in multi-panel arrays.

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Handling PV Panels

Solar panels should resist all weather, even strong winds, when properly installed, but breakage’s can easily happen during the installation.

- Don't place any objects on the panel
- When packing, transporting or storing the panel, cushion it with styropor, foam or cardboard.
- Stack panels not flat, only on their sides.
- Do not load more than five cartons high

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