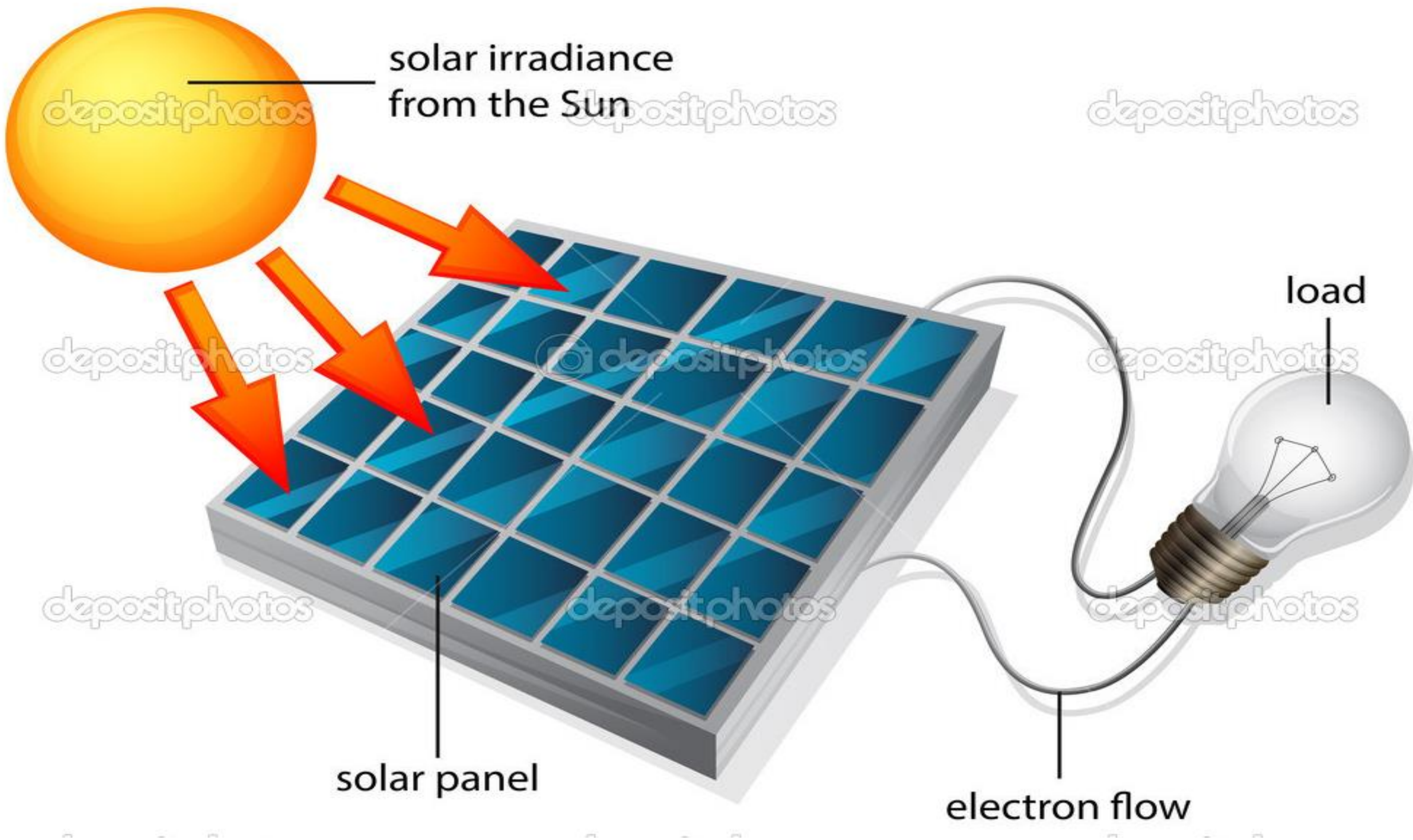
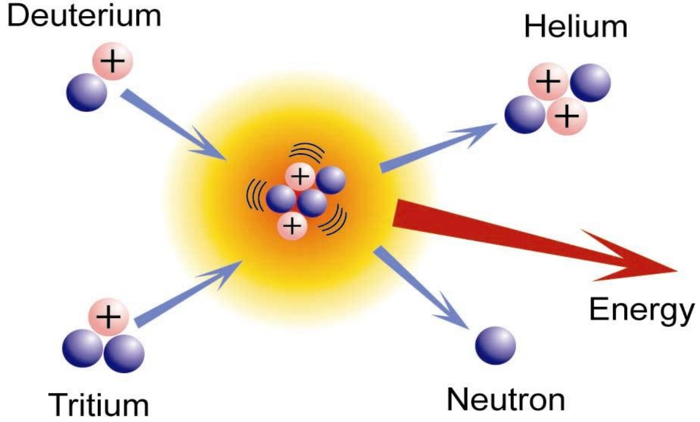
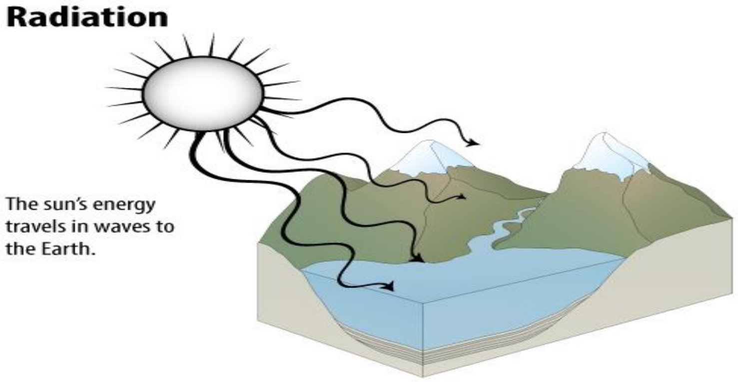
Energy from the Sun



Solar Energy

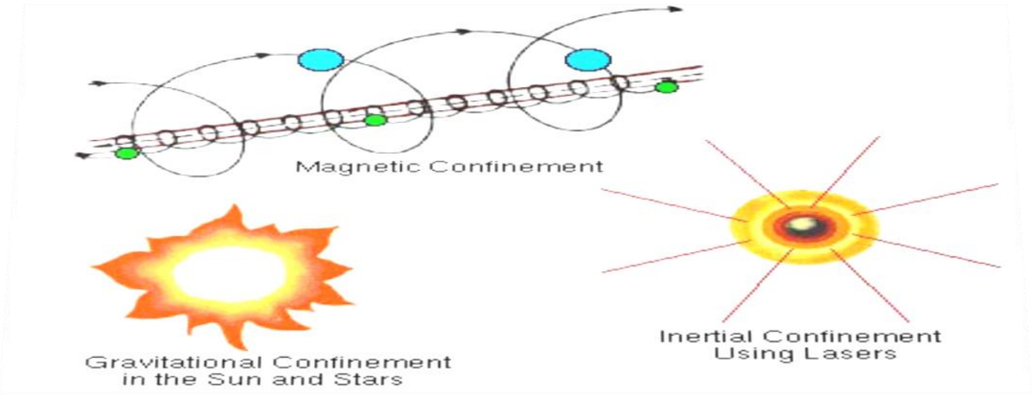




Nuclear Fusion

Solar radiation Energy:

ITER: 500 MW ..International Thermonuclear Experimental Reactor in France by 2020

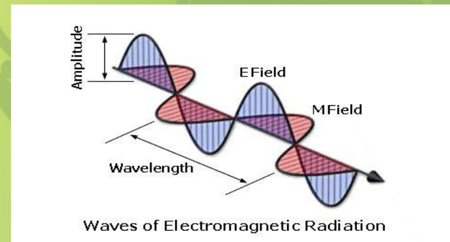


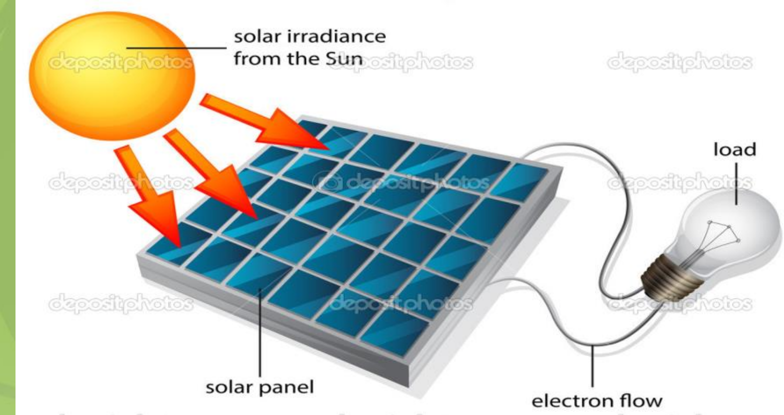
HiPER:

High Power laser Energy Research facility in France

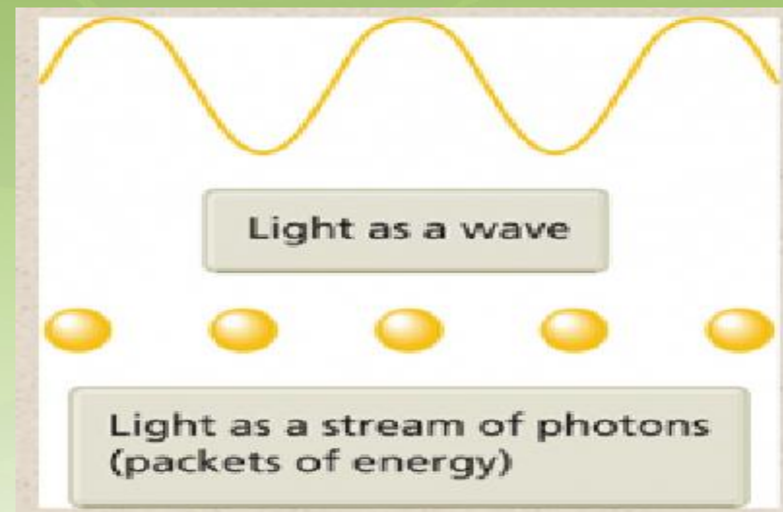
Solar radiation Energy:

$$E_y = E_o \sin(kx - \omega t)$$
$$B_z = B_o \sin(kx - \omega t)$$



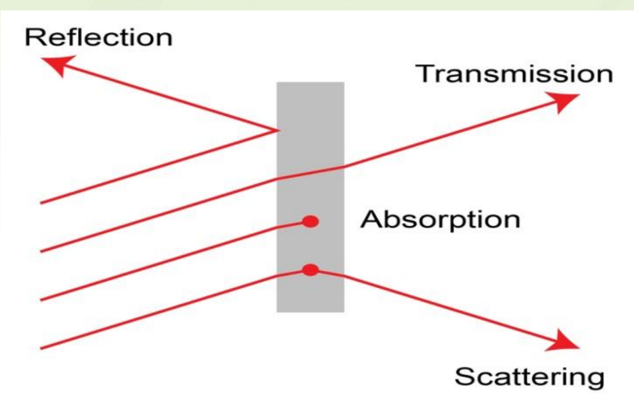


$$I = S_{average} = \langle S \rangle = \frac{E_o B_o}{2\mu_o} = \frac{E_o^2}{2\mu_o c} = \frac{cB_o^2}{2\mu_o}$$

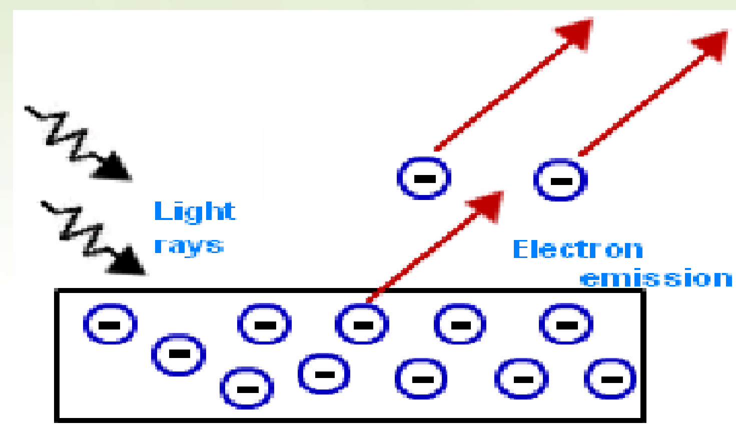


Energy per unit volume ($nh\upsilon$)

How to capture solar radiation energy???

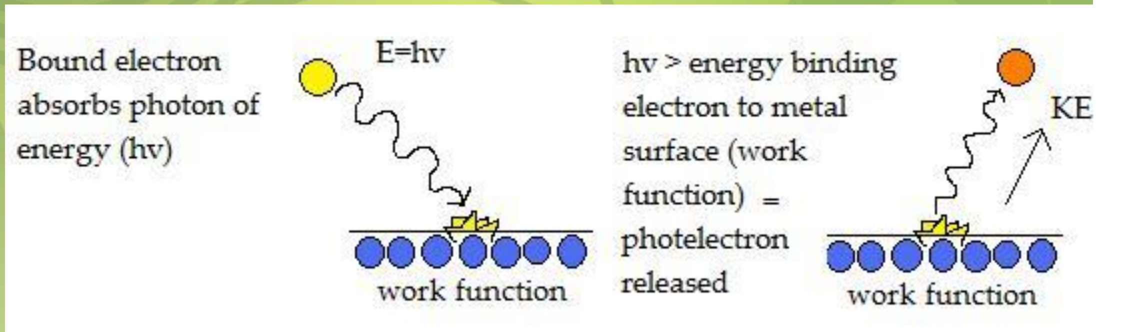


Wave
or
Particle???



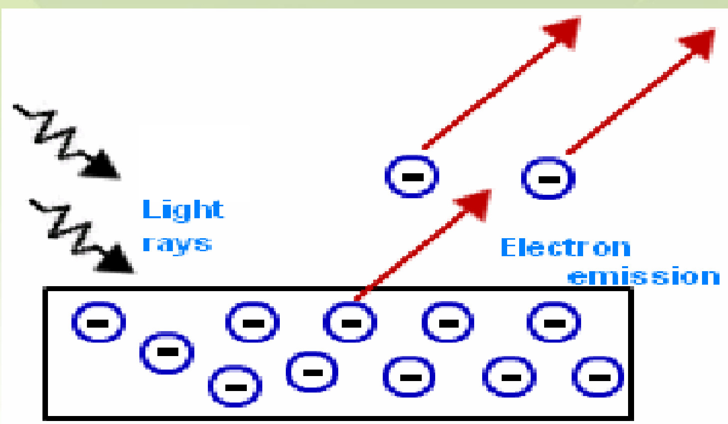
Solar radiation Energy:

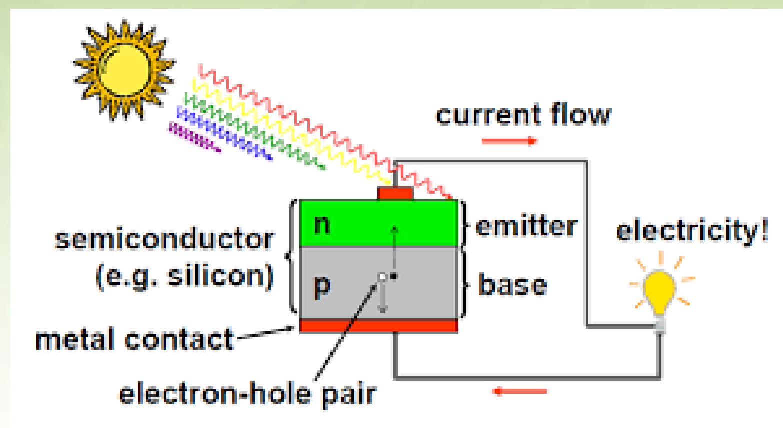
Photo electric effect:



$$K.E = h\upsilon - \varphi$$

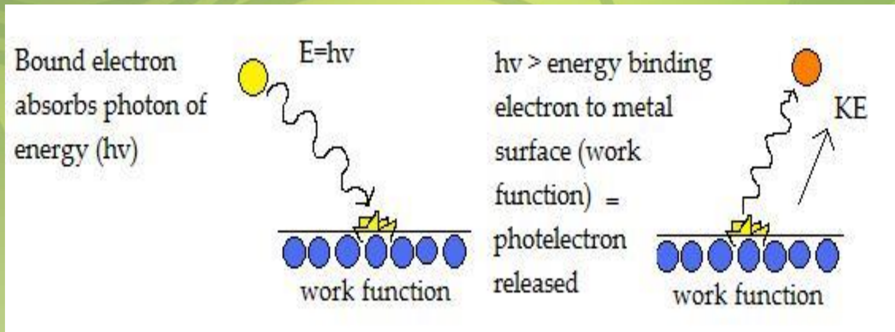
In the photoemission process, if an electron within some material absorbs the energy of one photon and acquires more energy than the work function (the electron binding energy) of the material, it is ejected.





Solar radiation Energy:

Photo electric effect:

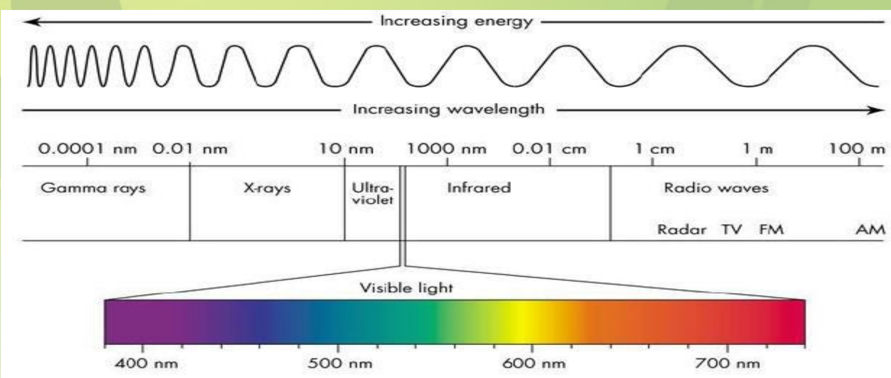


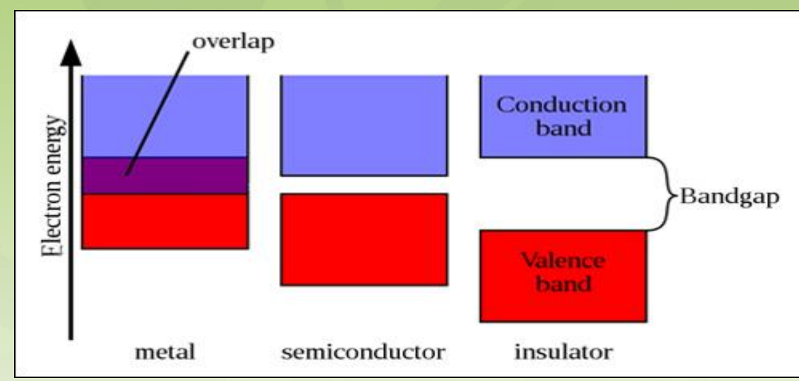
$$K.E = h\upsilon - \varphi$$

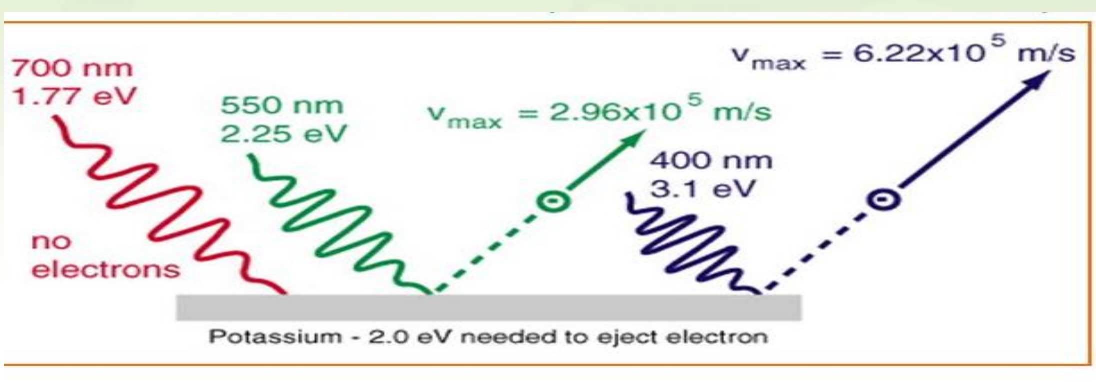
Which frequency???

large frequency

or more no of photon/intensity???



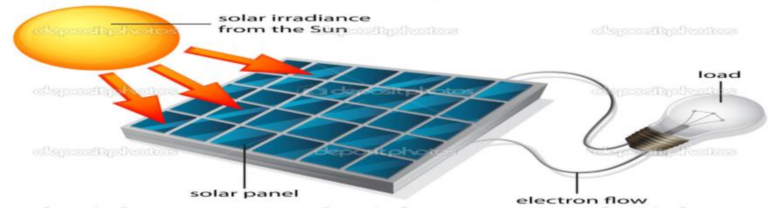


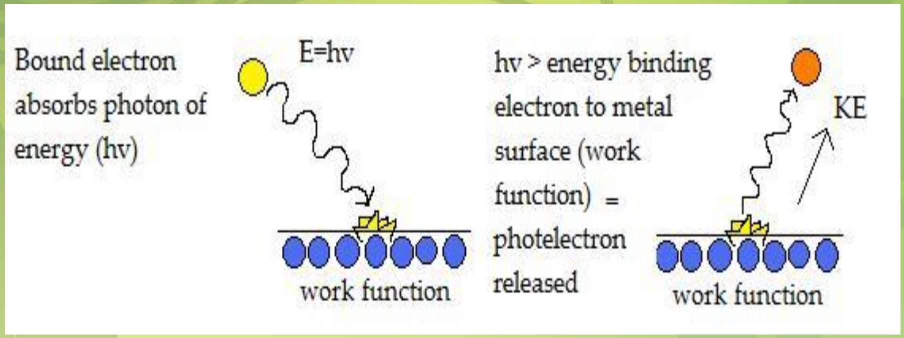


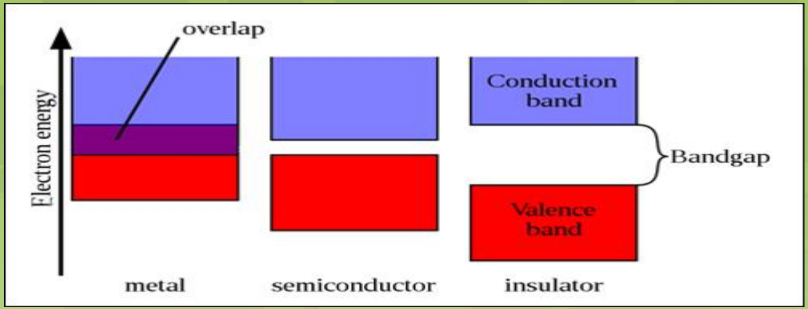
color	wavelength interval
red	700–635 nm
orange	635–590 nm
yellow	590–560 nm
green	560–490 nm
blue	490–450 nm
violet	450–400 nm

Solar radiation Energy:

Photo electric effect: $K.E = h\upsilon - \varphi$

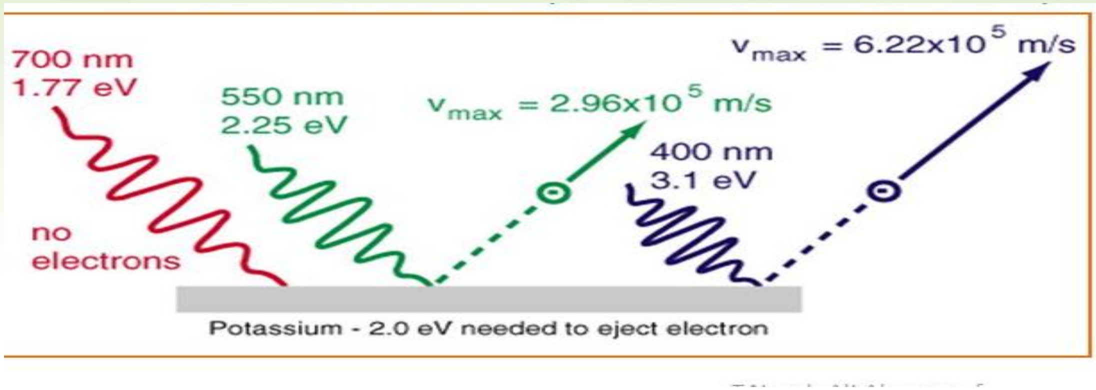






Only photons with an energy higher than the bandgap energy, can knock off electrons and generate electricity. However, if a photon has 1.7 eV and falls onto a 1.1 eV cell, the excess energy (0.6 eV) will be lost in the form of heat.

if you set the bandgap too high, you don't generate a lot of electrons (current) because few photons have so much energy. However, a bandgap too low will generate a lot of electrons, but most of the energy is lost in the form of heat



color	wavelength interval
red	700–635 nm
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yellow	590–560 nm
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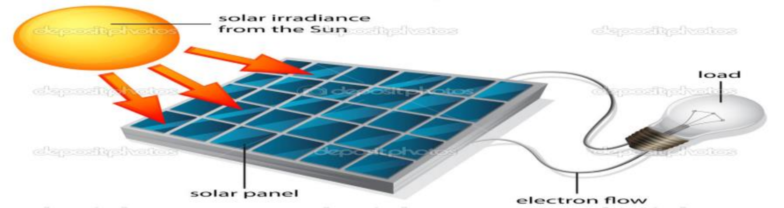
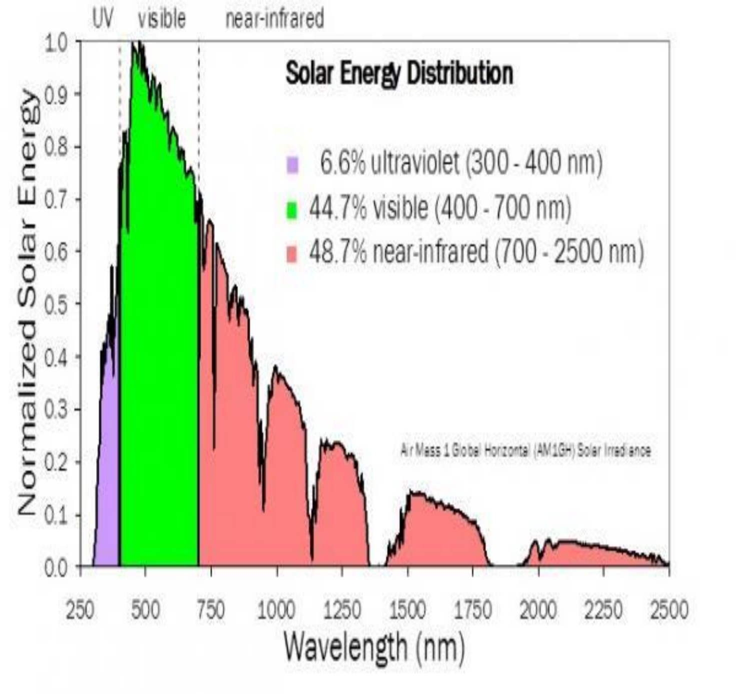
violet	450–400 nm

- Photo electric effect
  - Material
    - Metal/Insulator/Semiconductor???
    - Band gap???
  - Frequency range
    - Absorption ???
    - Photon energy???
  - Free Electron ..... Current
  - Efficiency

- Frequency range



- http://solarcellcentral.com/limits_page.html
- Wavelength range = 400-1200 nm
  Frequency range = 7.5 x 10^{14} - 2.5 x 10^{14} Hz or **750 - 250 THz**
- Photon energy E=hc/λ



- **E (ev) = 1240/λ(nm)**

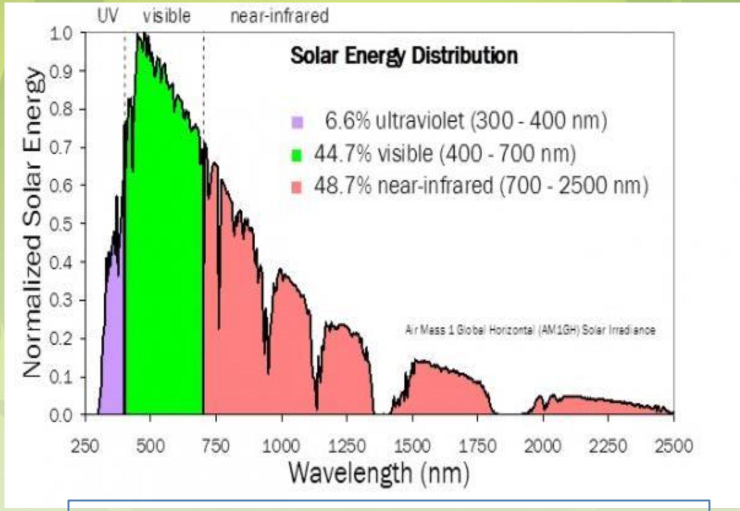
  =3 -1 ev

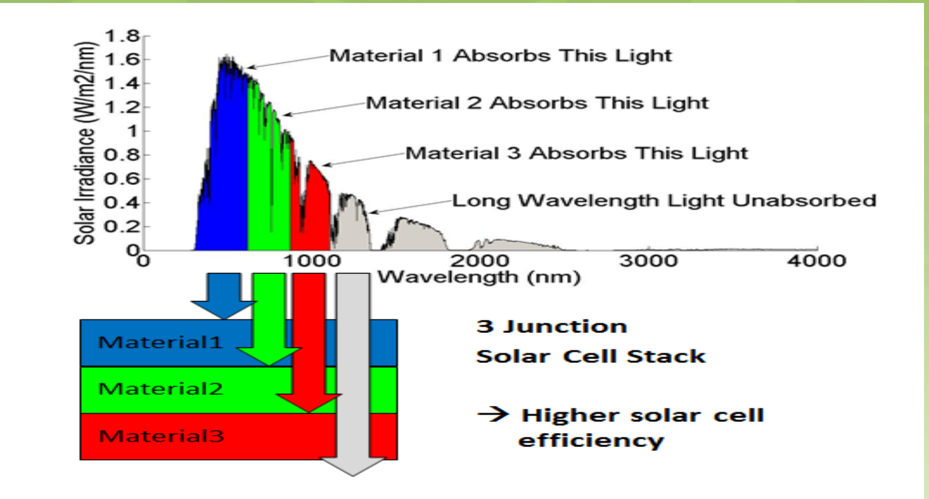
Solar energy spectra… broken/discontinuous???

• Frequency range/ Material/Band Gap

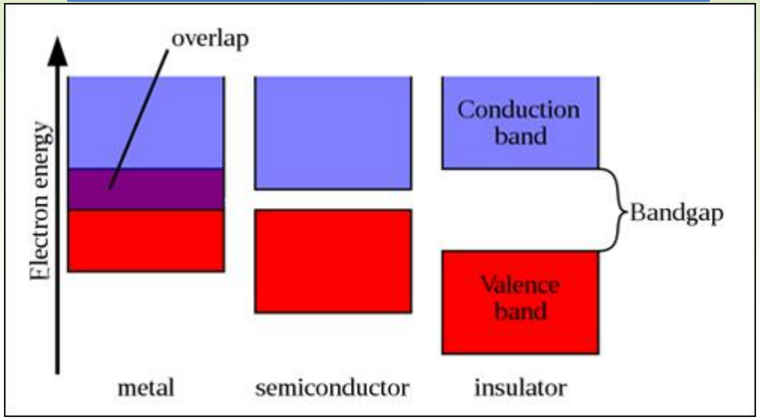
400-1200 nm

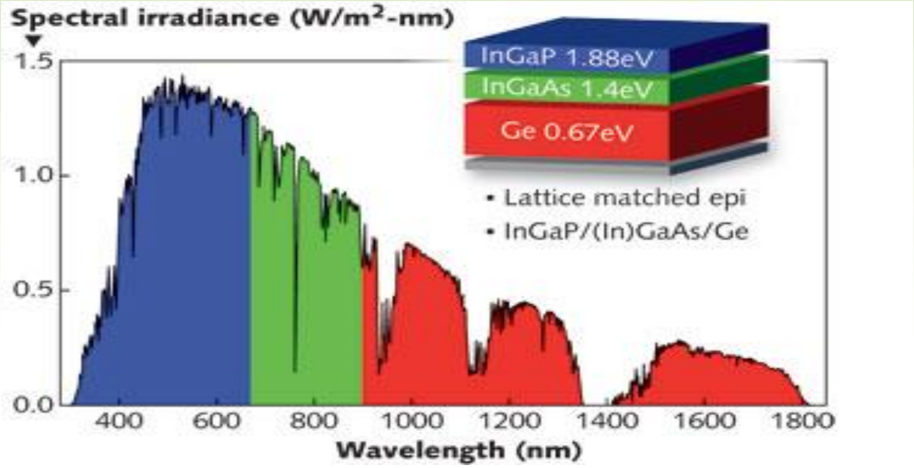
3 -1 ev





Why not conducting metal???





In insulator : the energy band gap between the valence band and conduction band is very large. the photons from the sunlight do not possess this amount of energy to excite the electrons from valence band to conduction band.

In conductors, these band almost overlap each other and hence there are always free electrons. But free electrons does not mean flow of current. Free electrons moving in a specific direction is known as current. In conductors, the free electrons move randomly and hence the relative speed is 0 and also high KE so heating prob.

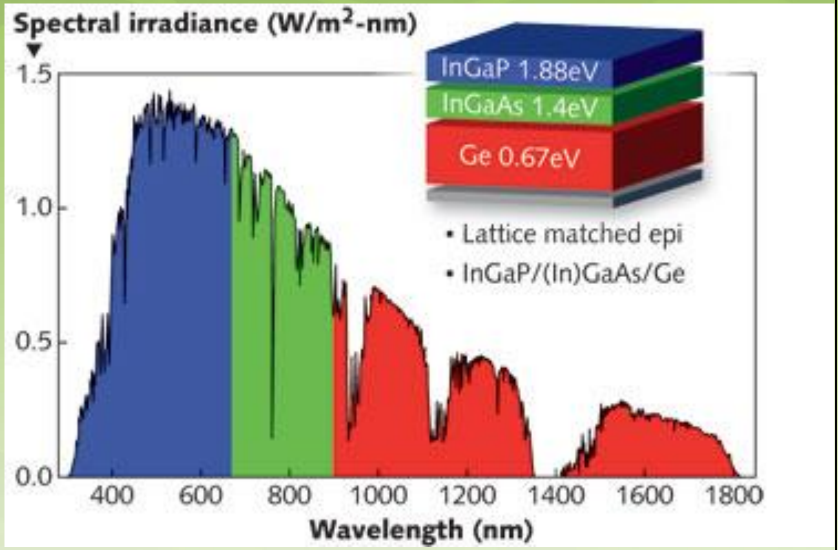
In semiconductors, this gap is less and photons can do the task of exciting the electrons without any problem.
In semiconductors, due to the presence of PN junction, there is a small electric field present within the semiconductors without which the solar cells won't work. In the PN junctions, the electrons and holes try to mix with each other but they are not able to completely mix, Otherwise the junction will become neutral and will be of no use. When few electrons and holes combines with each other and rush towards the opposite charge, repulsive force comes into play due to the heavy rush of similar charges.

A potential barrier is formed and when equilibrium is attained, we find the presence of small amount of electric field within it. This acts as a driving force for the free electrons, all in one direction.

Materials for Solar cell

Solar cells are composed of various semiconducting materials

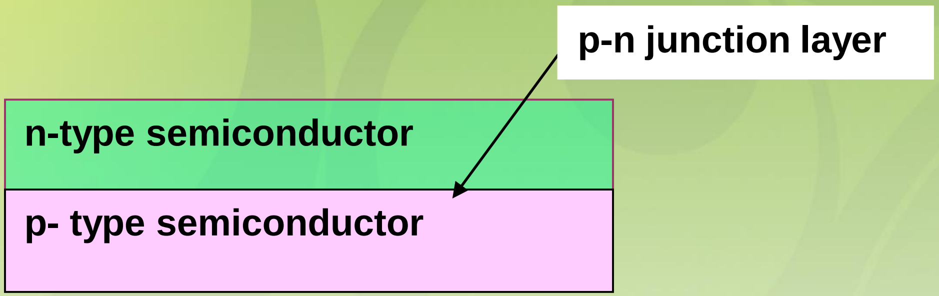
1. Crystalline silicon
2. Cadmium telluride
3. Copper indium diselenide
4. Gallium arsenide
5. Indium phosphide
6. Zinc sulphide



Note: Semiconductors are materials, which become electrically conductive when supplied with light or heat, but which operate as insulators at low temperatures

- Over 95% of all the *solar cells produced* worldwide are composed of the semiconductor material Silicon (Si). As the second most abundant element in earth`s crust, silicon has the advantage, of being available in sufficient quantities.
- To produce a solar cell, the semiconductor is contaminated or *"doped".*
- "Doping" is the intentional introduction of chemical elements into the semiconductor.
- By doing this, depending upon the type of dopant, one can obtain a surplus of either positive charge carriers (called *p-conducting semiconductor* layer) or negative charge carriers (called *n-conducting semiconductor* layer).

- If *two differently* contaminated semiconductor *layers* are combined, then a so-called *p-n-junction results* on the boundary of the layers.



- By doping *trivalent* element, we get p-type semiconductor. (with excess amount of hole)

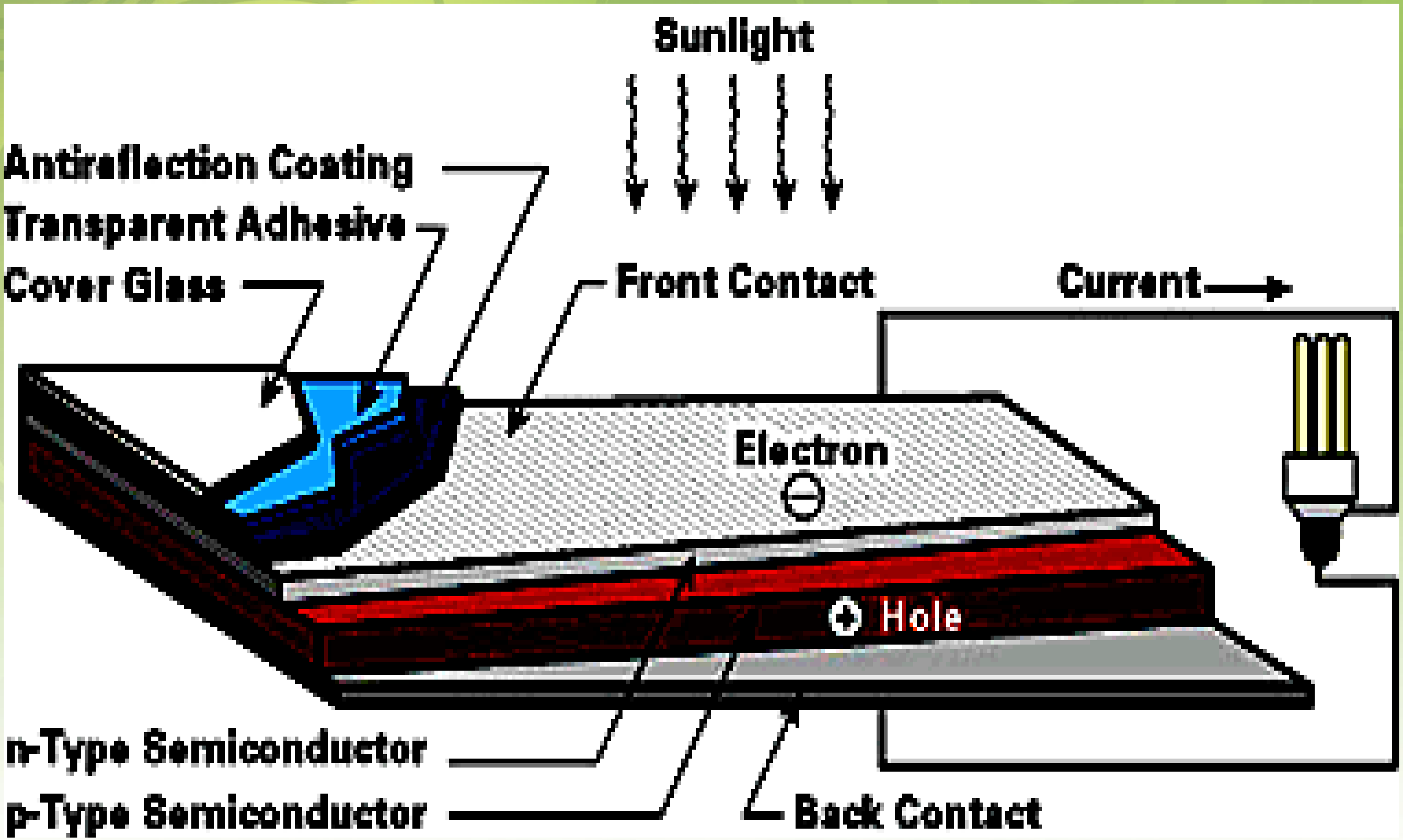
- By doping *pentavalent* element, we get n-type semiconductor (with excess amount of electron)

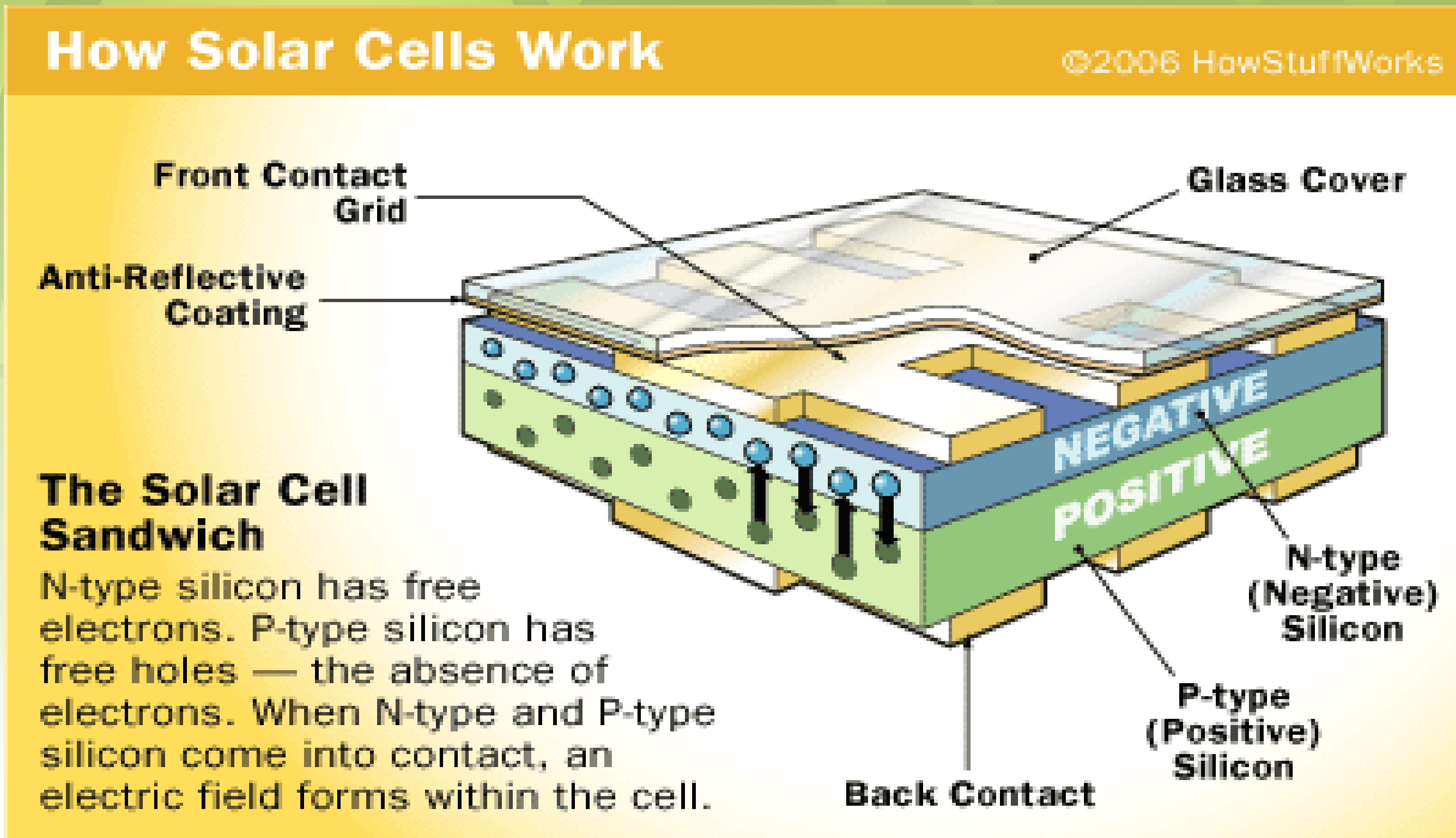
6. Principle, construction and working of Solar cell

Principle: **The solar cells are based on the principles of photovoltaic effect.The photovoltaic effect is the photogeneration of charge carriers in a light absorbing materials as a result of absorption of light radiation.**

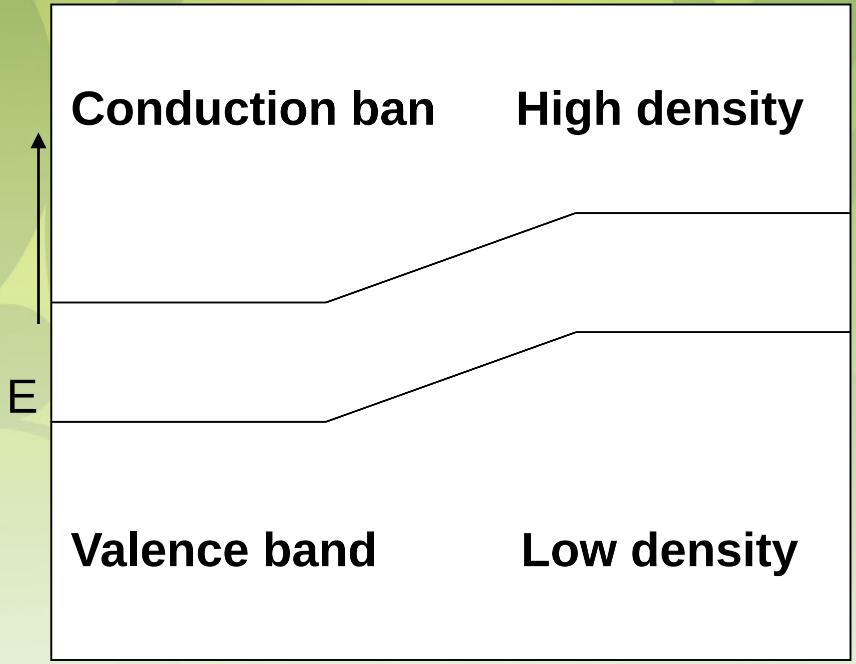
Construction

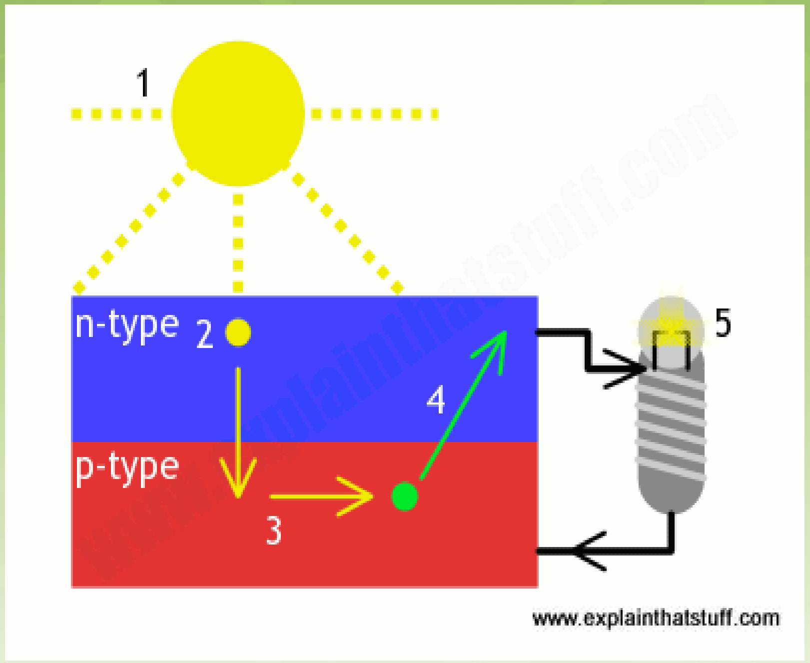
- Solar cell (crystalline Silicon) consists of a *n-type semiconductor (emitter)* layer and *p-type semiconductor layer (base).* The two layers are sandwiched and hence there is formation of p-n *junction.*
- The surface is coated with *anti-refection coating* to avoid the loss of incident light energy due to reflection.


Sunlight
Antireflection Coating
Transparent Adhesive
Cover Glass
Front Contact
Current
Electron
Hole
n-Type Semiconductor
p-Type Semiconductor
Back Contact


How Solar Cells Work
©2006 HowStuffWorks
Front Contact Grid
Glass Cover
Anti-Reflective Coating
NEGATIVE
POSITIVE
The Solar Cell Sandwich
N-type silicon has free electrons. P-type silicon has free holes — the absence of electrons. When N-type and P-type silicon come into contact, an electric field forms within the cell.
N-type (Negative) Silicon
P-type (Positive) Silicon
Back Contact

The mechanism of electricity production- Different stages

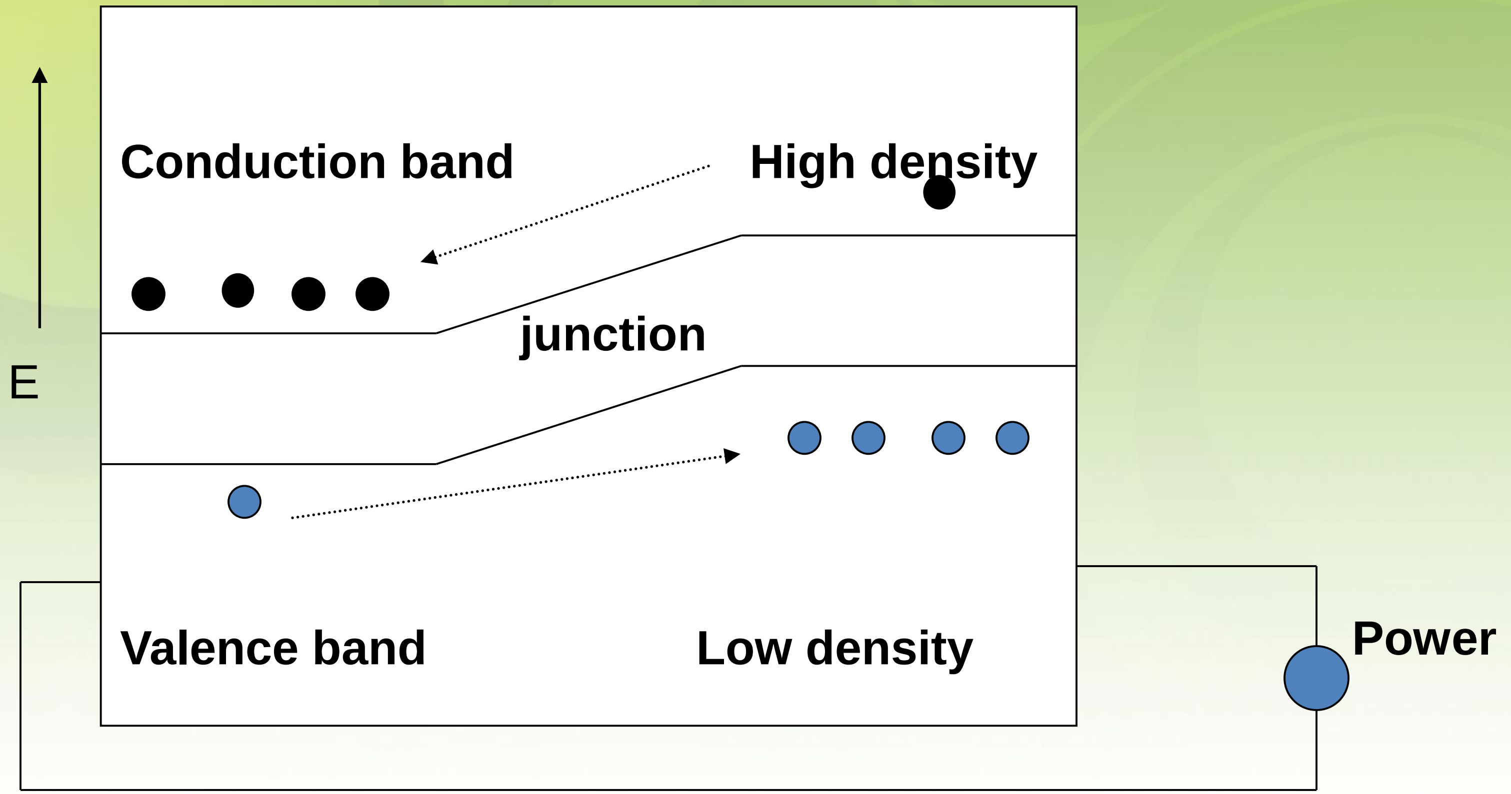




The above diagram shows the formation of p-n junction in a solar cell. The valence band is a low-density band and conduction band is high-density band.

Stage-4

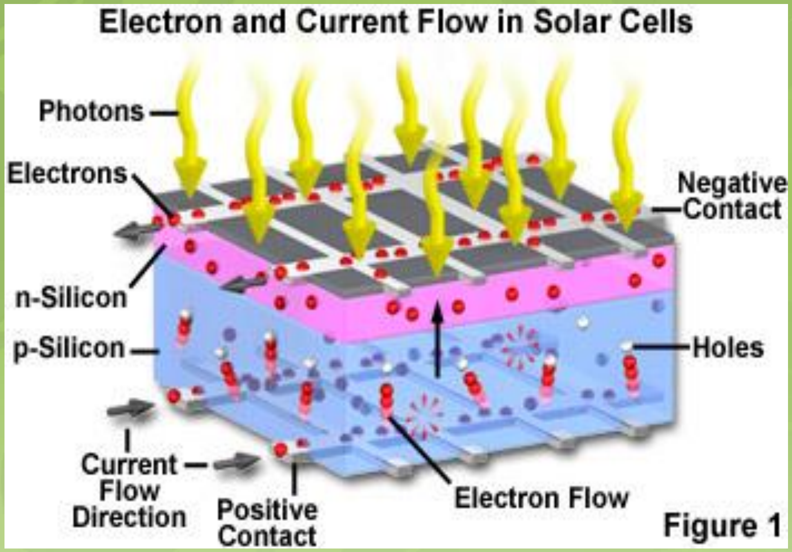
When the PN junction is connected with external circuit, the current flows.



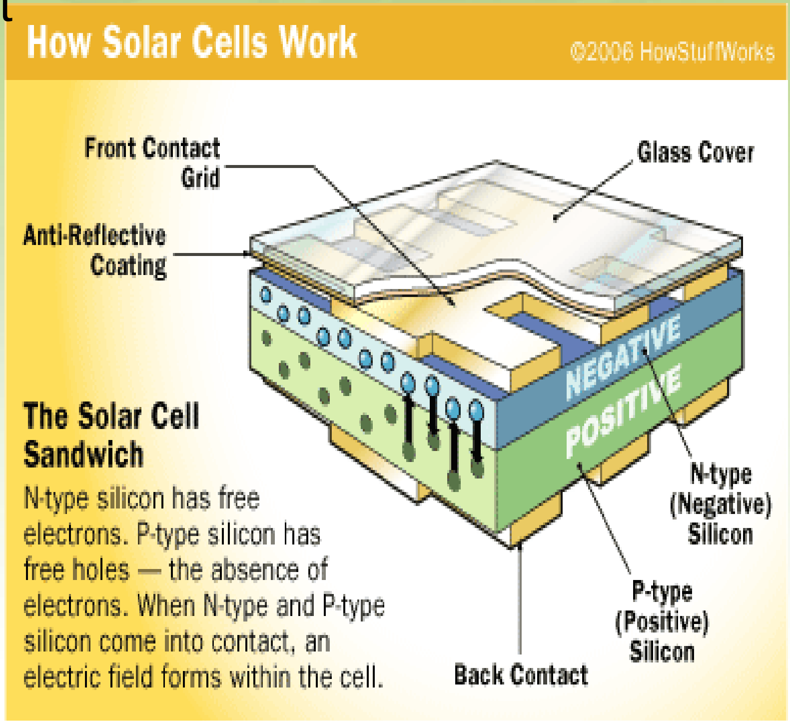
- Photo Current Density:

$$J_{sc} = q \int b_s(E) QE(E) dE$$

$b_s(E)$ is the incident spectral photon flux density.



Q(E) probability that incident photon of energy E will deliver one electron to the external circuit



Q(E) depends on absorption coefficient of solar cell material

- E=hc/λ
- **E (ev) = 1240/λ(nm)**

1.4.2. *Dark current and open circuit voltage*

When a load is present, a potential difference develops between the terminals of the cell. This potential difference generates a current which acts in the opposite direction to the photocurrent, and the net current is reduced from its short circuit value. This reverse current is usually called the *dark current* in analogy with the current $I_{\rm dark}(V)$ which flows across the device under an applied voltage, or *bias*, V in the dark. Most solar cells behave like a diode in the dark, admitting a much larger current under forward bias ($V > 0$) than under reverse bias ($V < 0$). This rectifying behaviour is a feature of photovoltaic devices, since an asymmetric junction is needed to achieve charge separation. For an ideal diode the *dark current density* $J_{\rm dark}(V)$ varies like

$$J_{\rm dark}(V) = J_{\rm o}(e^{\rm qV/k_BT} - 1) \tag{1.3}$$

where $J_{\rm o}$ is a constant, $k_{\rm B}$ is Boltzmann's constant and T is temperature in degrees Kelvin.

The overall current voltage response of the cell, its *current–voltage characteristic*, can be approximated as the sum of the short circuit photocurrent and the dark current (Fig. 1.6). This step is known as the *superposition* approximation. Although the reverse current which flows in reponse to voltage in an illuminated cell is not formally equal to the current which flows in the dark, the approximation is reasonable for many photovoltaic materials and

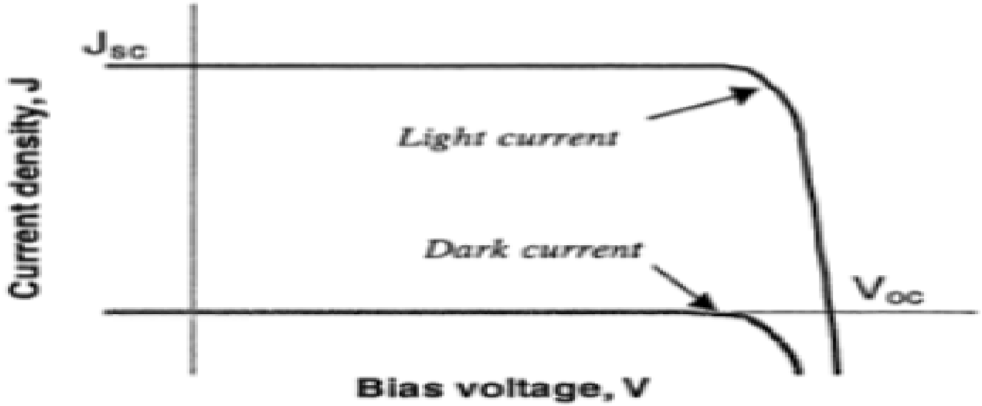


Fig. 1.6. Current–voltage characteristic of ideal diode in the light and the dark. To a first approximation, the net current is obtained by shifting the bias dependent dark current up by a constant amount, equal to the short circuit photocurrent. The sign convention is such that the short circuit photocurrent is positive.

will be used for the present discussion. The sign convention for current and voltage in photovoltaics is such that the photocurrent is positive. This is the opposite to the usual convention for electronic devices. With this sign convention the net current density in the cell is

$$J(V) = J_{sc} - J_{dark}(V)\,, \tag{1.4}$$

which becomes, for an ideal diode,

$$J = J_{sc} - J_o(e^{qV/k_BT} - 1)\,. \tag{1.5}$$

Equation 1.6 shows that V_{oc} increases logarithmically with light intensity. Note that voltage is defined so that the photovoltage occurs in forward bias, where $V > 0$.

Figure 1.6 shows that the current–voltage product is positive, and the cell generates power, when the voltage is between 0 and V_{oc}. At $V < 0$, the illuminated device acts as a photodetector, consuming power to generate a

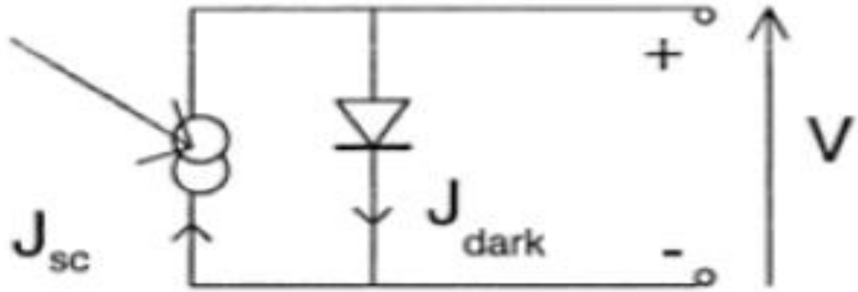


Fig. 1.7. Equivalent circuit of ideal solar cell.

photocurrent which is light dependent but bias independent. At $V > V_{oc}$, the device again consumes power. This is the regime where light emitting diodes operate. We will see later that in some materials the dark current is accompanied by the emission of light.

Electrically, the solar cell is equivalent to a current generator in parallel with an asymmetric, non linear resistive element, *i.e.*, a diode (Fig. 1.7). When illuminated, the ideal cell produces a photocurrent proportional to the light intensity. That photocurrent is divided between the variable resistance of the diode and the load, in a ratio which depends on the resistance of the load and the level of illumination. For higher resistances, more of the photocurrent flows through the diode, resulting in a higher potential difference between the cell terminals but a smaller current though the load. The diode thus provides the photovoltage. Without the diode, there is nothing to drive the photocurrent through the load.

1.4.3. *Efficiency*

The operating regime of the solar cell is the range of bias, from 0 to V_{oc}, in which the cell delivers power. The cell *power density* is given by

$$P = JV\,. \tag{1.7}$$

P reaches a maximum at the cell's operating point or *maximum power point*. This occurs at some voltage V_m with a corresponding current density J_m, shown in Fig. 1.8. The optimum load thus has sheet resistance given by V_m/J_m. The *fill factor* is defined as the ratio

$$FF = \frac{J_m V_m}{J_{sc} V_{oc}} \tag{1.8}$$

and describes the 'squareness' of the J–V curve.

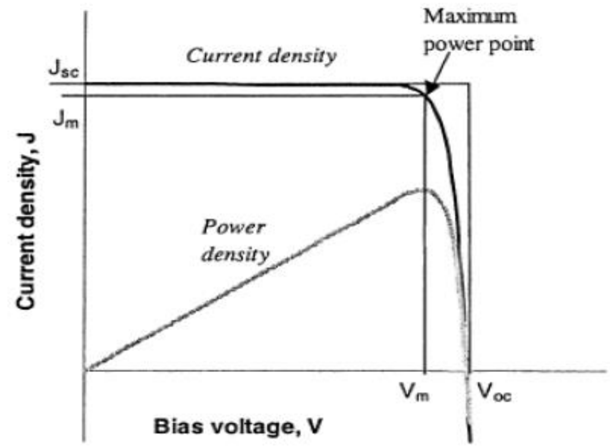


Fig. 1.8. The current voltage (black) and power–voltage (grey) characteristics of an ideal cell. Power density reaches a maximum at a bias V_m, close to V_{oc}. The maximum power density $J_m \times V_m$ is given by the area of the inner rectangle. The outer rectangle has area $J_{sc} \times V_{oc}$. If the fill factor were equal to 1, the current voltage curve would follow the outer rectangle.

Or

Fill factor

$FF = (V_{max}.\ I_{max})/(V_{oc}.I_{sc})$

And efficiency of solar cell

$\eta = V_{max}.\ I_{max}/P_{in}$

The *efficiency* η of the cell is the power density delivered at operating point as a fraction of the incident light power density, P_s,

$$\eta = \frac{J_m V_m}{P_s}. \tag{1.9}$$

Efficiency is related to J_{sc} and V_{oc} using FF,

$$\eta = \frac{J_{sc} V_{oc} FF}{P_s}. \tag{1.10}$$

These four quantities: J_{sc}, V_{oc}, FF and η are the key performance characteristics of a solar cell. All of these should be defined for particular illumination conditions. The Standard Test Condition (STC) for solar cells is the Air Mass 1.5 spectrum, an incident power density of 1000 W m^{-2}, and a temperature of 25°C. (Standard and other solar spectra are discussed

Or

Fill factor

$FF = (V_{max} . I_{max})/(V_{oc}.I_{sc})$

And efficiency of solar cell

$\eta = V_{max} . I_{max}/P_{in}$

- Clean
- Sustainable
- Free
- Provide electricity to remote places

Advantages of Solar Energy