Unit - III

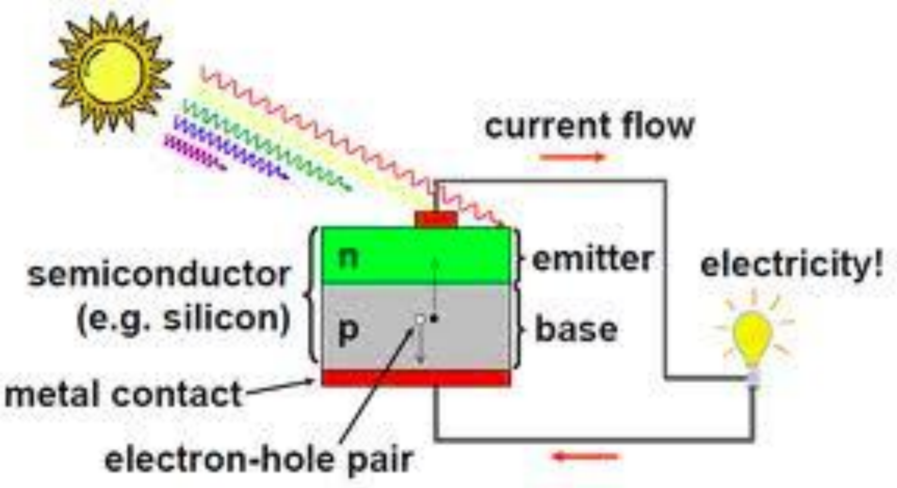
FUNDAMENTALS OF SOLAR CELLS (10hrs) Semiconductor interface, Types, homo junction, hetero junction and Schottky barrier, advantages and drawbacks, Photovoltaic cell, equivalent circuit, output parameters, conversion efficiency, quantumefficiency, Measurement of I-V characteristics, series and shunt resistance, their effecton efficiency, Effect of light intensity, inclination and temperature on efficiency

Physics of solar cell:

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. Electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. A single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts.

The operation of a photovoltaic (PV) cell requires three basic attributes:

- The absorption of light, generating either electron-hole pairs.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.



The solar cell works in several steps:

- **Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.**
- **Electrons are excited from their current molecular/atomic orbital. Once excited an electron can either dissipate the energy as heat and return to its orbital or travel through the cell until it reaches an electrode. Usually silicon is used in two layers, one layer being doped with boron, the other phosphorus. These layers have different chemical electric charges and subsequently both drive and direct the current of electrons.**

- **An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.**
- **An inverter can convert the power to alternating current (AC).**

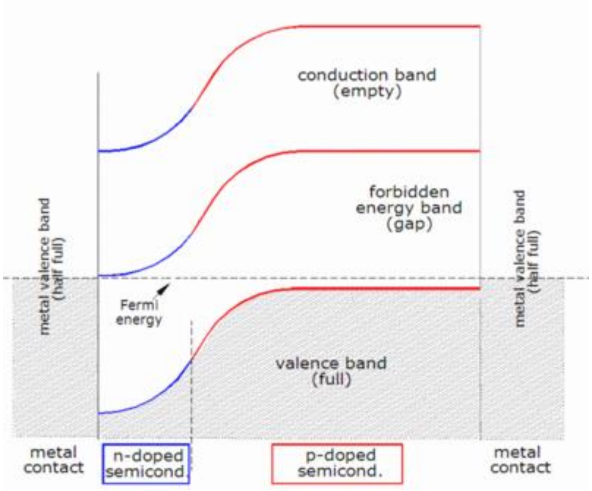
Type of interfaces

Homo, Hetero and Schottky interfaces

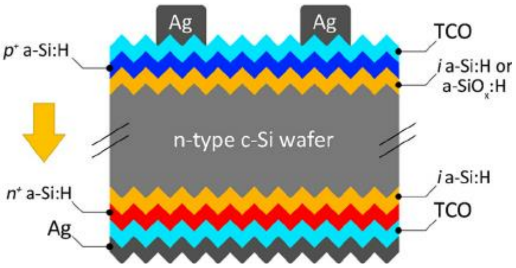
A homojunction is a semiconductor interface that occurs between layers of similar semiconductor material, these materials have equal band gaps but typically have different doping. In most practical cases a homo junction occurs at the interface between an n-type (donor doped) and p-type (acceptor doped) semiconductor such as silicon, this is called a p-n junction.

An n-type to n-type junction, for example, would be considered a homo junction if the doping levels are different.

The different doping level will cause band bending, and depletion region will be formed at the interface.



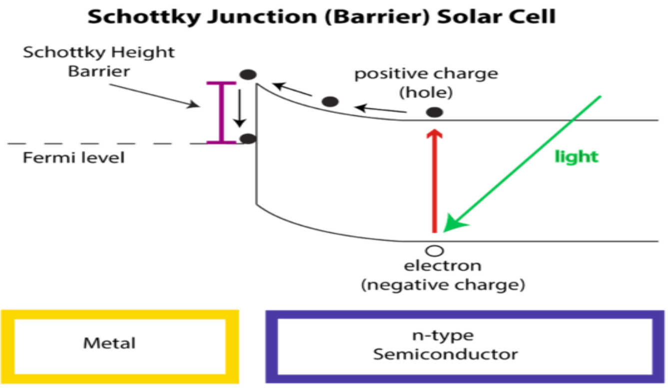
A heterojunction is the interface that occurs between two layers or regions of dissimilar crystalline semiconductors. These semiconducting materials have unequal band gaps as opposed to a homojunction.



Advantages of hetero- junction solar cell.

1. Enhances short-wavelength spectral response 2. Lower series resistance, if first semiconductor is heavily doped without affecting its light transmitting characteristics. 3. High radiation tolerance, if first semiconductor is thick in addition to being high in band gap.

In a basic Schottky-junction (Schottky-barrier) solar cell, an interface between a metal and a semiconductor provides the band bending necessary for charge separation. Due to differing energy levels between the Fermi level of the metal and the conduction band of the semiconductor, an abrupt potential difference is created, and this is a Schottky height barrier.

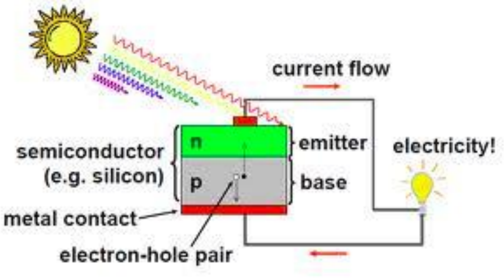


The main advantage of Schottky barrier cell over a junction diode cell are:

(a) Possibility of low temperature processing. (b) Use of polycrystalline materials. © The presence of the depletion region very near the surface reduces the effect of high surface recombination velocity and improve the spectralresponse characteristics.

Photovoltaic Effect

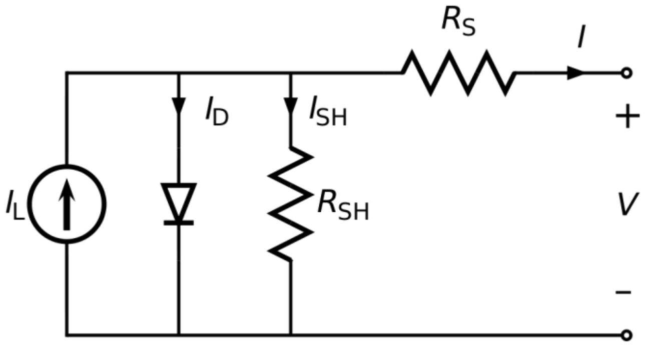
The photovoltaic effect is a process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight.

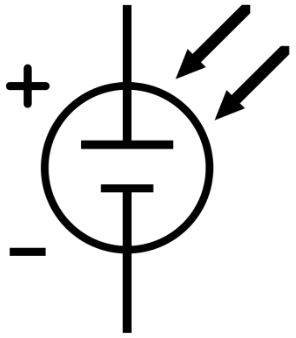


Equivalent circuit of solar cell, Solar cell output parameters,

Equivalent circuit of solar cell

An ideal solar cell may be modelled by a current source in parallel with a diode; in practice no solar cell is ideal, so a shunt resistance and a series resistance component are added to the model. The resulting equivalent circuit of a solar cell is shown on the left. Also shown, on the right, is the schematic representation of a solar cell for use in circuit diagrams.





$$I = I_L - I_D - I_{SH}$$

I = output current (ampere), I_L = photogenerated current (ampere), I_D = diode current (ampere)I_{SH} = shunt current (ampere).

$$V_j = V + IR_S$$

V_j = voltage across both diode and resistor R_{SH} (volt), V = voltage across the output terminals (volt)

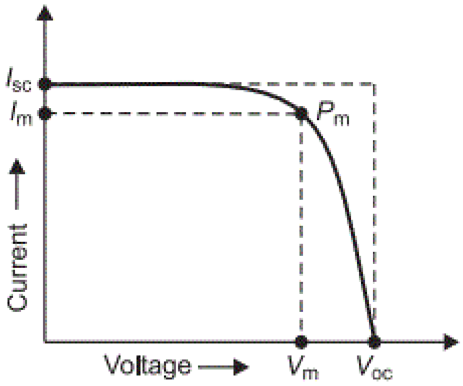
I = output current (ampere), R_S = series resistance (Ω).

Solar cell output parameters

Output parameters help both manufacturers and buyers to compare the performance potential

of solar modules and calculate their efficiency according to our requirements. There are

different key parameters to determine the output performance of a solar PV module:



v-i characteristics of solar cell

1. VOC (V), open-circuit voltage. It is measured by measuring voltage across the terminals of the cell when no load is connected to the cell. This voltage depends upon the techniques of manufacturing and temperature but not fairly on the intensity of light and area of exposed surface. Normally open circuit voltage of solar cell nearly equal to 0.5 to 0.6 volt. It is normally denoted by V_{oc}.
2. VMP (V), The voltage at which maximum power occurs. Voltage at Maximum Power Point is shown in the v-i characteristics of solar cell by V_m.
3. ISC (A), The maximum current that a solar cell can deliver without harming its own constriction. It is measured by short circuiting the terminals of the cell at most optimized condition of the cell for producing maximum output.
4. Imp (A), Current at maximum power point, The current at which maximum power occurs. Current at Maximum Power Point is shown in the v-i characteristics of solar cell by I_m.
5. Pm (W), Maximum Power and Maximum Power Point, Every module has a specific point on its power curve where the product of Amps times Volts yields the greatest Wattage.
6. FF (%), Fill Factor, The ratio between product of current and voltage at maximum power point to the product of short circuit current and open circuit voltage of the solar cell.

$$Fill\ Factor = \frac{P_m}{I_{sc} \times V_{oc}}$$

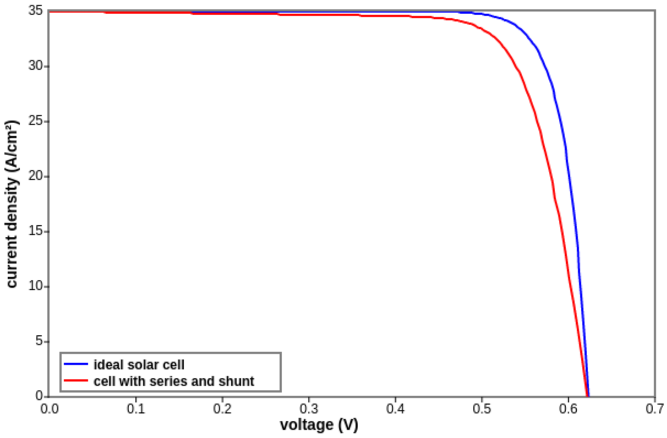
7. Efficiency of Solar Cell It is defined as the ratio of maximum electrical power output to the radiation power input to the cell and it is expressed in percentage. It is considered that the

radiation power on the earth is about 1000 watt/square metre hence if the exposed surface area of the cell is A then total radiation power on the cell will be 1000 A watts. Hence the efficiency of a solar cell may be expressed as

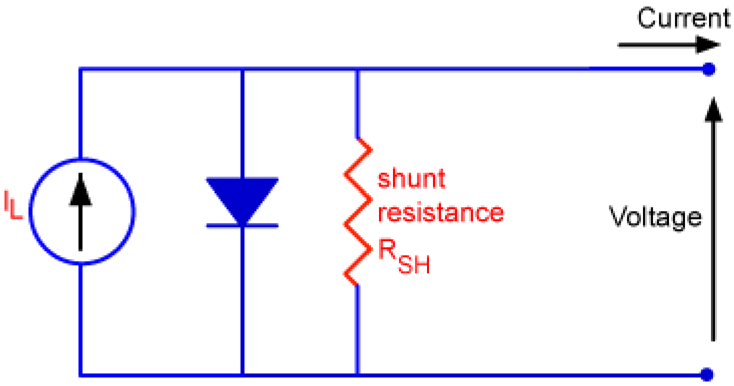
$$Efficiency(\eta) = \frac{P_m}{P_{in}} \approx \frac{P_m}{1000A}$$

Series and shunt resistance, their effect on efficiency

Series and shunt resistances and its effect on cell efficiency

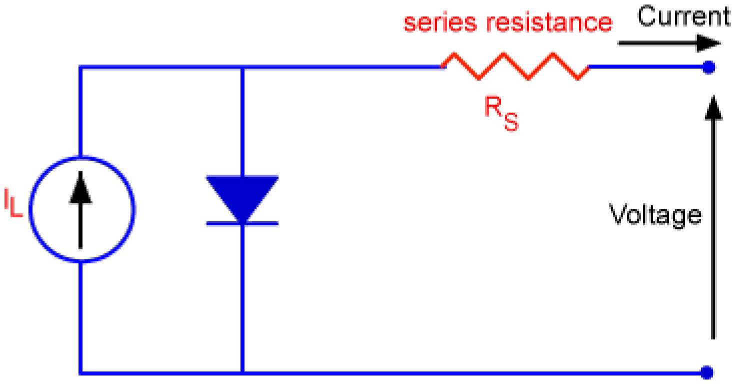


Shunt resistance



Low shunt resistance causes power losses in solar cells by providing an alternate current path for the light-generated current. Such a diversion reduces the amount of current flowing through the solar cell junction and reduces the voltage from the solar cell. The effect of a shunt resistance is particularly severe at low light levels, since there will be less light-generated current. The loss of this current to the shunt therefore has a larger impact. In addition, at lower voltages where the effective resistance of the solar cell is high, the impact of a resistance in parallel is large.

Series resistance: Series resistance in a solar cell has three causes: firstly, the movement of current through the emitter and base of the solar cell; secondly, the contact resistance between the metal contact and the silicon; and finally the resistance of the top and rear metal contacts. The main impact of series resistance is to reduce the fill factor, although excessively high values may also reduce the short-circuit current. Series resistance does not affect the solar cell at open-circuit voltage since the overall current flow through the solar cell, and therefore through the series resistance is zero. However, near the open-circuit voltage, the IV curve is strongly affected by the series resistance.



Increasing the temperature increases the band gap. With increasing temperature reverse saturation current increases and therefore, Voc decreases which decreases the fill factor and hence the efficiency of the solar cell.

Quantum efficiency

The "quantum efficiency" (Q.E.) is the ratio of the number of carriers collected by the solar cell to the number of photons of a given energy incident on the solar cell. The quantum efficiency may be given either as a function of wavelength or of energy. If all photons of a certain wavelength are absorbed and the resulting minority carriers are collected, then the quantum efficiency at that particular wavelength is unity. The quantum efficiency for photons with energy below the band gap is zero.

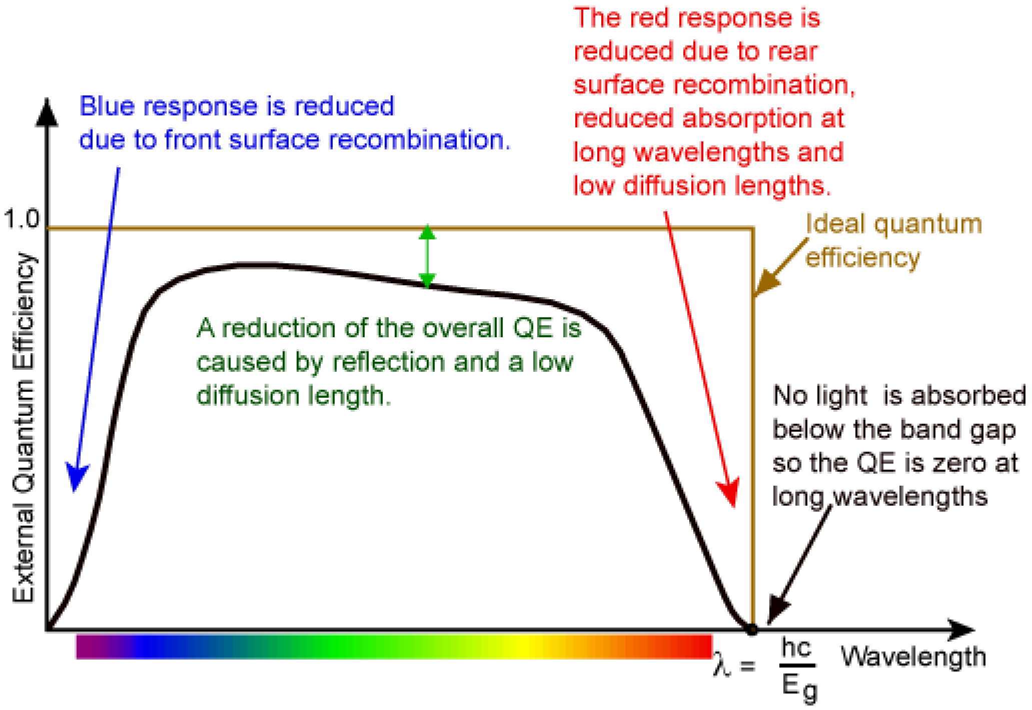
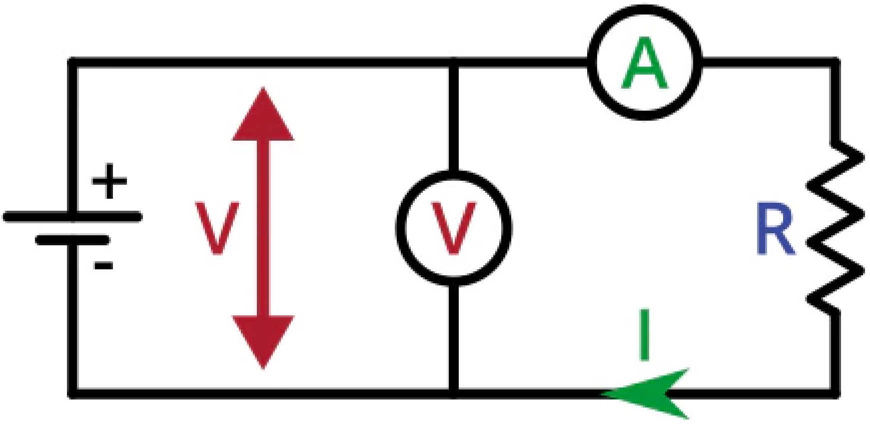


Figure: Quantum efficiency of ideal solar cell

Measurement of IV Characteristics

An I-V curve measurement is performed by applying a series of voltages to the device. At each voltage, the current flowing through the device is measured. The supplied voltage is measured by a voltmeter connected in parallel to the device, and the current is measured by an ammeter connected in series.



Effect of light intensity, inclination and temperature on efficiency

temperature

solar cells are sensitive to temperature. Increases in temperature reduce the bandgap of a semiconductor, thereby effecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is therefore needed to break the bond. In the bond model of a semiconductor bandgap, a reduction in the bond energy also reduces the bandgap. Therefore increasing the temperature reduces the band gap. In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage. The impact of increasing temperature is shown in the figure below.

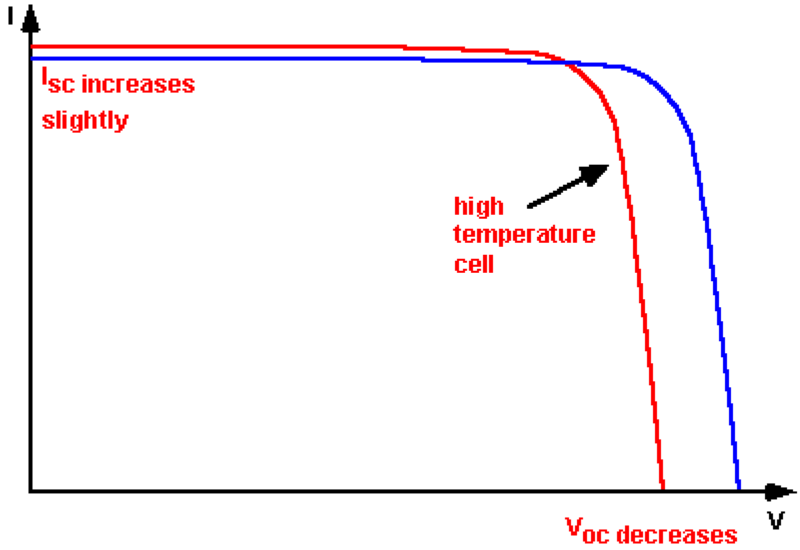


Figure *The effect of temperature on the IV characteristics of a solar cell*

Light intensity

Changing the light intensity incident on a solar cell changes all solar cell parameters, including the short-circuit current, the open-circuit voltage, the FF, the efficiency and the impact of series and shunt resistances. The light intensity on a solar cell is called the number of suns, where 1 sun corresponds to standard illumination at AM1.5, or 1 kW/m^2.

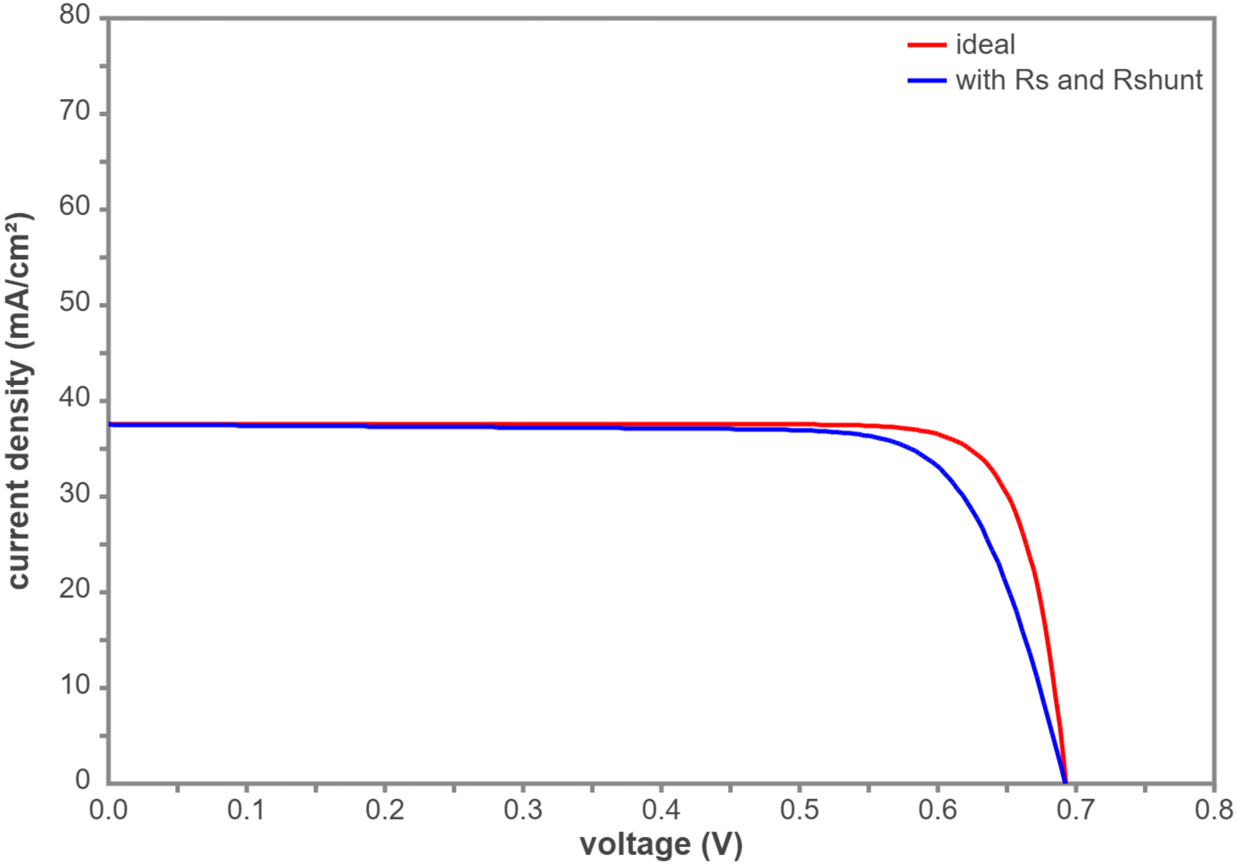


Figure: The effect of concentration on the IV characteristics of a solar cell.

The series resistance has a greater effect on performance at high intensity and the shunt resistance has a greater effect on cell performance at low light intensity.

Inclination

Optimal electricity production occurs when solar panels face south at a tilt equal to 30°. However, even if you lower the tilt of your roof all the way down to 5°, production only decreases by about 10 percent