EE 495-695
4.2 Solar Cell Opreation

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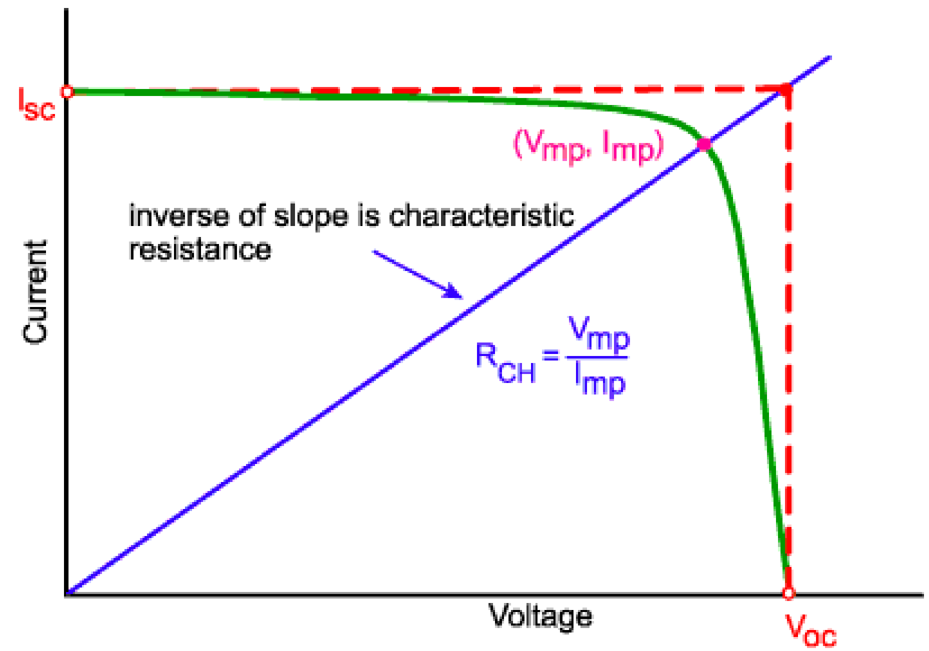
Characteristic Resistance

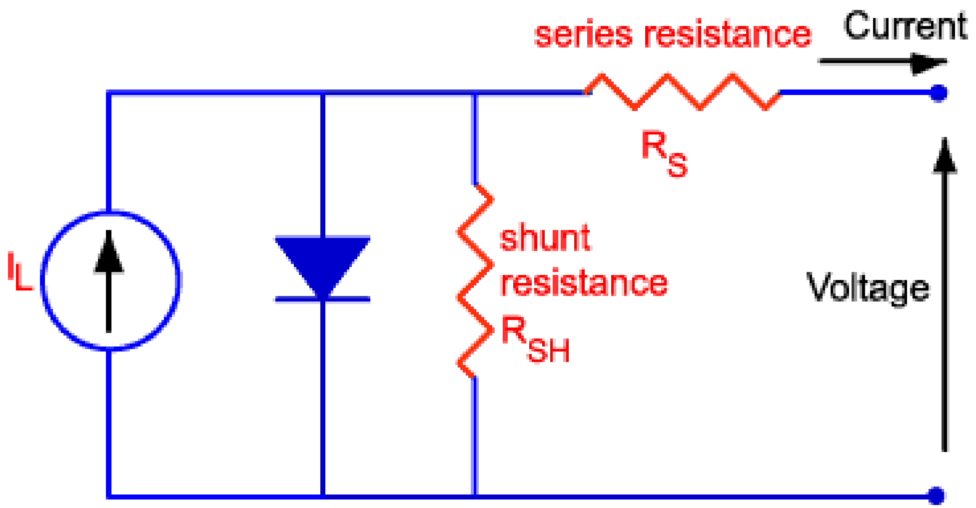
- The characteristic resistance of a solar cell is the output resistance of the solar cell at its maximum power point.
- If the resistance of the load is equal to the characteristic resistance of the solar cell, then the maximum power is transferred to the load and the solar cell operates at its maximum power point.
- The value of this resistance can be approximated by

$$R_{CH} = \frac{V_{OC}}{I_{SC}}$$



Effect of Parasitic Resistances

- Resistive effects in solar cells reduce the efficiency of the solar cell by dissipating power in the resistances. The most common parasitic resistances are series resistance and shunt resistance.
- Series resistance in a solar cell has three causes:
  - the movement of current through the p-n materials of the solar cell;
  - the contact resistance between the metal contact and the silicon;
  - the resistance of the top and rear metal contacts.
- The series resistance reduces the fill factor, but has no impact on the open circuit voltage nor on the short-circuit current.



Effect of Series Resistance

- An equation for the FF as a function of series resistance can be determined by noting that for moderate values of series resistance, the maximum power may be approximated as the power in the absence of series resistance minus the power lost in the series resistance.

$$P'_{MP} \approx V_{MP} I_{MP} - I_{MP}^2 R_S = V_{MP} I_{MP} \left(1 - \frac{I_{MP}}{V_{MP}} R_S\right) = P_{MP} \left(1 - \frac{I_{SC}}{V_{OC}} R_S\right)$$

or $$P'_{MP} = P_{MP}(1 - r_S)$$

where $$r_S = \frac{R_S}{R_{CH}}$$

- Also, since the open circuit voltage and short circuit current are not affected:

$$FF' = FF(1 - r_S)$$

- A straight-forward method of estimating the series resistance from a solar cell is to find the slope of the IV curve at the open-circuit voltage point.

Effect of Shunt Resistance

- Power losses caused by the presence of a shunt resistance, R_{SH}, are typically due to manufacturing defects, rather than poor solar cell design.
- 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.
  - at lower voltages where the effective resistance of the solar cell is high, the impact of a resistance in parallel is large.

Effect of Shunt Resistance

- An equation for the FF as a function of shunt resistance can be determined in a similar fashion as in the case of series resistance:

$$P'_{MP} \approx V_{MP} I_{MP} - \frac{V_{MP}^2}{R_{Sh}} = V_{MP} I_{MP} \left(1 - \frac{V_{MP}}{I_{MP}} \frac{1}{R_{SH}}\right) = P_{MP} \left(1 - \frac{V_{SC}}{I_{OC}} \frac{1}{R_{SH}}\right)$$

or $$P'_{MP} = P_{MP} \left(1 - \frac{1}{r_{SH}}\right)$$

where $$r_{SH} = \frac{R_{SH}}{R_{CH}}$$

- Also, since the open circuit voltage and short circuit current are not affected:

$$FF' = FF \left(1 - \frac{1}{r_{SH}}\right)$$

- A straight-forward method of estimating the shunt resistance from a solar cell is to find the slope of the IV curve at the short circuit current point.

Impact of Series and Shunt Resistances

- In the presence of both series and shunt resistances, the I-V curve of the solar cell is given by;

$$I = I_L - I_0 \exp\left[\frac{q(V + IR_S)}{nkT}\right] - \frac{V + IR_S}{R_{SH}}$$

- The overall fill factor FF is

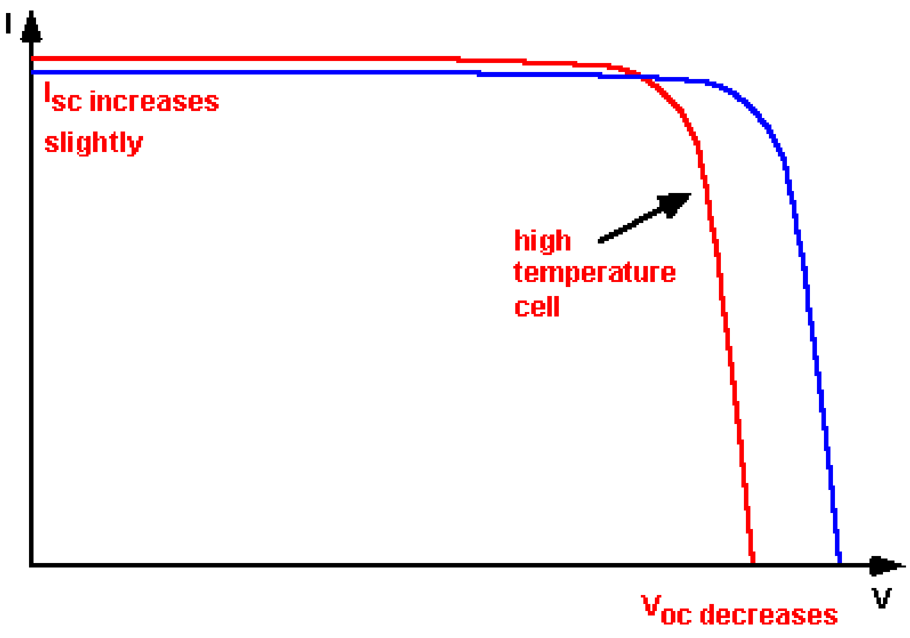
$$FF' = FF(1 - r_s)(1 - \frac{1}{r_{SH}})$$

Effect of Temperature

- Like all other semiconductor devices, solar cells are sensitive to temperature.
  - Increases in temperature reduce the band gap 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 a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage.

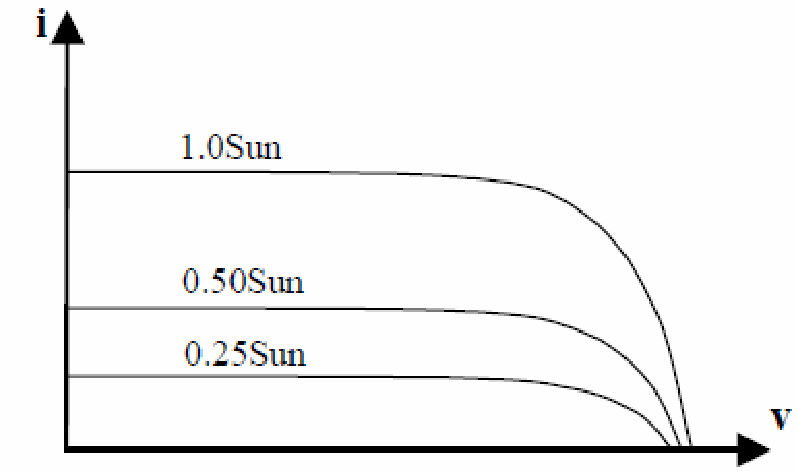
Effect of Temperature

- The open-circuit voltage decreases with temperature because of the temperature dependence of I_0 which is proportional to the square of the intrinsic carrier concentration $(n_i)^2$.
- For silicon devices, the open circuit voltage drops by approximately -2.2 mV/°C.
- The short-circuit current increases slightly with temperature, since the band gap energy decreases and more photons have enough energy to create electron-hole pairs. However, this is a small effect (≈ +0.6 mA/°C)

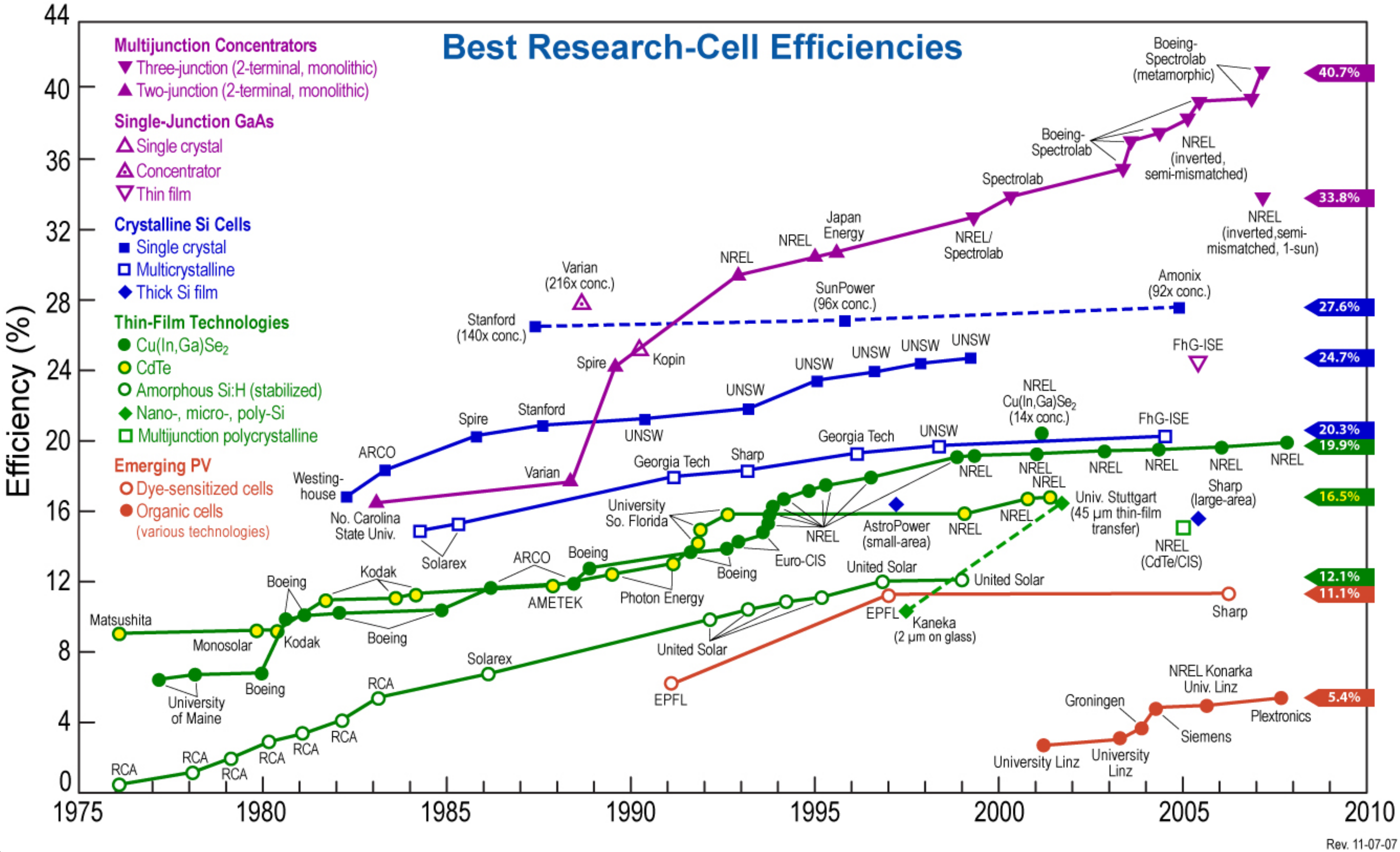


Effect of Light Intensity

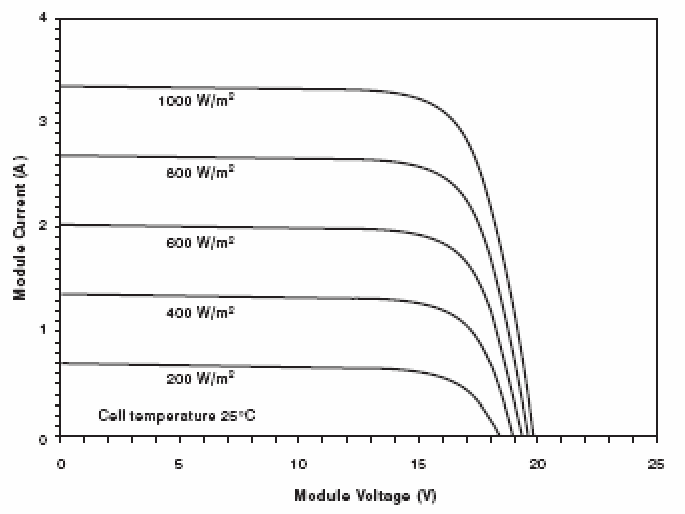
- Changing the light intensity incident on a solar cell changes all solar cell parameters, including the short-circuit current, the open-circuit voltage, the FF, the efficiency and the impact of series and shunt resistances.
- The light intensity on a solar cell is called the number of suns, where 1 sun corresponds to standard illumination at AM1.5, or 1 kW/m^2.
- For example a system with 10 kW/m^2 incident on the solar cell would be operating at 10 suns, or at 10X.
- A PV module designed to operate under 1 sun conditions is called a "flat plate" module while those using concentrated sunlight are called "concentrators".

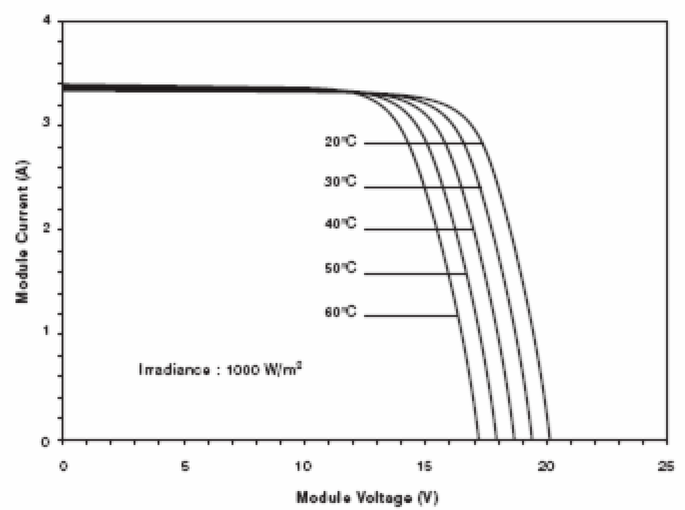


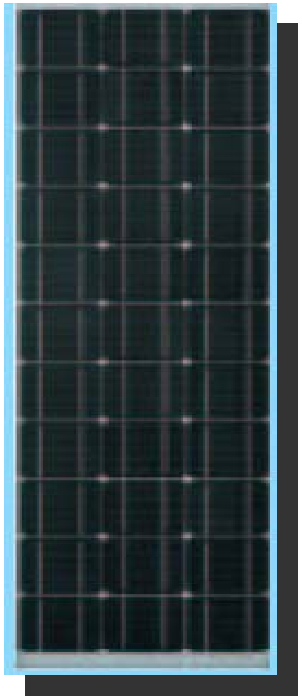
Trend in Cell Efficiencies



Electrical Performance pf of SM50W (13”x48”x1.3”)







Data at Standard Test Conditions (STC)

STC: irradiance level 1000W/m², spectrum AM 1.5 and cell temperature 25°C

Rated power	P_r	50W
Peak power	P_{mpp}	50W
Peak power voltage	V_{mpp}	15.9V
Peak power current	I_{mpp}	3.15A
Open circuit voltage	V_{oc}	19.8V
Short circuit current	I_{sc}	3.35A
Series fuse rating		10A