EELE408 Photovoltaics
Lecture 11: Solar Cell Parameters

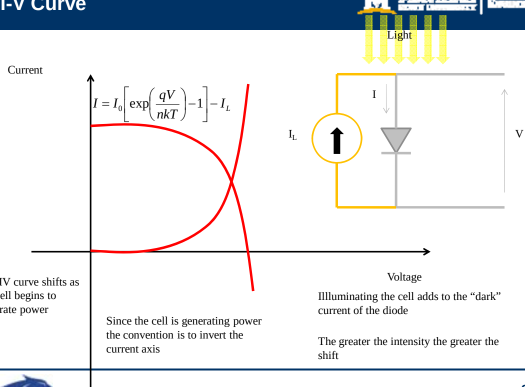
Dr. Todd J. Kaiser
tjkaiser@ece.montana.edu

Department of Electrical and Computer Engineering
Montana State University - Bozeman

Solar Cell Parameters

- Quantum Efficiency $QE = \frac{\text{\# of EHP Collected}}{\text{\# of Photons}}$
- Spectral Response $SR = \frac{\text{Electrical Current Out}}{\text{Optical Power In}}$
- Open Circuit Voltage: Output Voltage with no current flow
- Short Circuit Current: Output Current with no load
- I-V Curve: Plot of the Current versus Voltage for varying loads
- Fill Factor: Ratio of operating current and voltage product to the product of short circuit current and open circuit voltage
- Efficiency $\eta = \frac{\text{Electrical Power Out}}{\text{Optical Power In}}$

I-V Curve



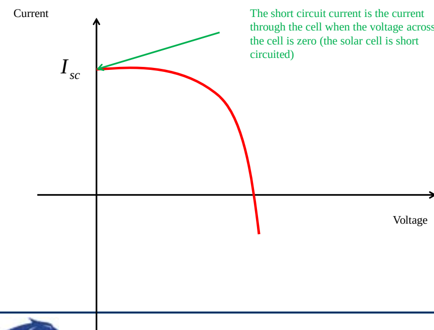
The IV curve shifts as the cell begins to generate power

Since the cell is generating power the convention is to invert the current axis

Illluminating the cell adds to the "dark" current of the diode

The greater the intensity the greater the shift

Short Circuit Current Point



Short Circuit Current Dependence:

- Area of Solar Cell
  - To remove the dependence on solar cell area, it is common to use the Short Circuit **Current Density** (J_{sc} in mA/cm^2)
- Intensity of Light
  - I_{sc} is directly dependent on the number of photons entering the cell
- Spectrum of Light
  - For most measurements the spectrum is standardized to AM1.5
- Optical Properties of the Cell
  - Reflection and absorption
- Collection Probability
  - Chiefly depends on surface passivation and minority carrier lifetime

Approximated Current

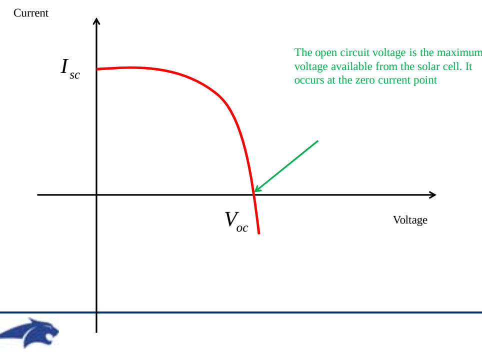
- Comparing solar cells of the same material the most critical material parameters are the surface passivation and diffusion lengths
- Ignoring passivation effects the short circuit current density can be approximated as:
- G: generation rate, L diffusion lengths

$$J_{sc} = qG\left(L_n + L_p\right)$$

Possible Current Density

- Silicon solar cells under illumination at AM1.5 spectrum
  - Maximum possible current density of 46 mA/cm^2
  - Laboratory devices have reached 42 mA/cm^2
  - Commercial silicon solar cells 28-35 mA/cm^2

Open Circuit Voltage Point



Open Circuit Voltage

- Corresponds to the amount of forward bias on the cell due to the bias generated by the illumination of the cell
- Solve for the Voltage when the net current is set to zero

$$0 = I_0\left[\exp\left(\frac{qV_{oc}}{nkT}\right) - 1\right] - I_L$$

$$V_{oc} = \frac{nkT}{q}\ln\left(\frac{I_L}{I_0} + 1\right)$$

Open Circuit Voltage Dependence:

- Light Generated Current
  - Function of the illumination (typically fixed at AM1.5)
- Saturation Current
  - I_0 can vary orders of magnitude
  - Depends on the amount of recombination in the solar cell
- Temperature

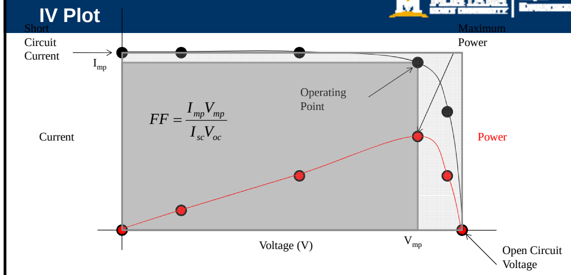
Possible Voltages

- Silicon solar cells under illumination at one sun and AM1.5 spectrum
  - Laboratory devices have reached 720 mV
  - Commercial silicon solar cells 500-600 mV

Power & IV Curve

- Power (Watts) is the rate at which energy (Joules) is supplied by a source or consumed by a load… **It is a rate not a quantity**
- The power output by a source is the product of the current supplied and the voltage at which the current was supplied
- Power output = Source voltage x Source current
  - P=V x I (Watts = Joules/second) = (Volts)x(Amperes)
- By changing the resistance of the load different currents and corresponding voltages can be measured and plotted

IV Plot



Volt (V)	0	0.1	0.3	0.5	0.54	0.57
Current (A)	1.3	1.3	1.3	1.2	0.75	0
Power (W)	0	0.13	0.39	0.6	0.4	0

Fill Factor

- A measure of the "Squareness" of the IV curve
- The largest area rectangle that can fit with in the IV curve divide by the rectangle formed by the product of the maximum current (I_{sc}) and maximum voltage (V_{oc})
- Maximum FF can be calculated by:

$$\frac{d(IV)}{dV} = 0 \Rightarrow V_{mp} = V_{oc} - \frac{nkT}{q}\ln\left\{\frac{V_{mp}}{\frac{nkT}{q}} + 1\right\}$$

Not useful: not closed form and still need I_{mp}

Fill Factor 2

- More commonly used empirical expression

$$FF = \frac{v_{oc} - \ln(v_{oc} + 0.72)}{v_{oc} + 1}$$

$$\text{normalized } V_{oc} : v_{oc} = \frac{q}{nkT}V_{oc}$$

Ideality Factor: "n" Factor

- Measure of the junction quality and types of recombination in the junction
- Small and Simple recombination n=1
- Large and complex n=2
- A high n values degrades the fill factor
- Also high n values means significant recombination and lowers the open circuit voltage

Efficiency

- Most commonly used parameter to compare the performance of one solar cell to another
- Defined as the ratio of energy output by the solar cell to input energy from the sun
- Efficiency depends on:
  - Spectrum
  - Intensity
  - Temperature

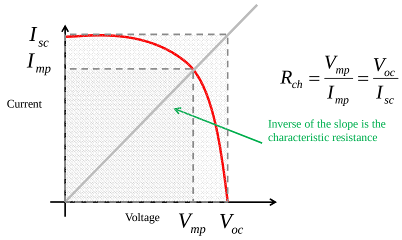
$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{oc}I_{sc}FF}{P_{in}}$$

Efficiency Testing

- Conditions are carefully controlled to compare devices
- Terrestrial Solar Cells
  - AM1.5
  - 25°C
- Space orbiting Earth
  - AM0

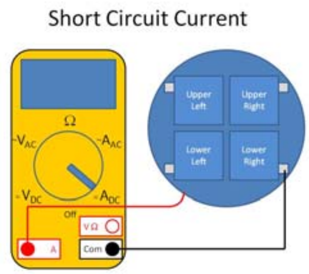
Characteristic Resistance

- The characteristic resistance is the output resistance of the solar cell at its maximum power point

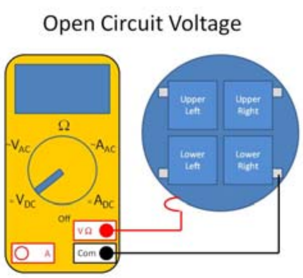


$$R_{ch} = \frac{V_{mp}}{I_{mp}} = \frac{V_{oc}}{I_{sc}}$$

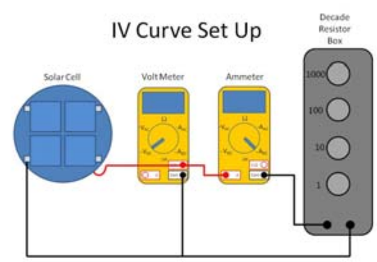
Measuring Short Circuit Current



Measuring Open Circuit Voltage

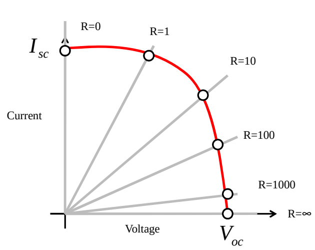


Generating the IV Curve



IV Curve

- Measure Current and Voltage as the load connected to the solar cell is changed



Experimental Setup for IV Curve Generation