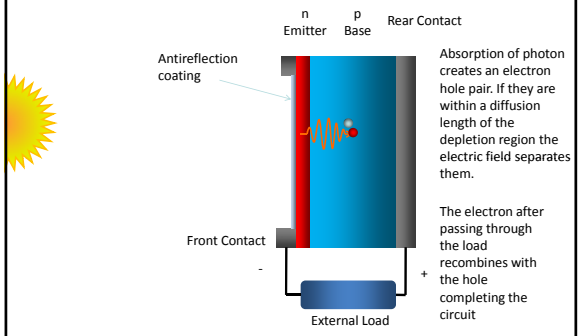
EE580 – Solar Cells
Todd J. Kaiser

- Lecture 08
- Solar Cell Characterization

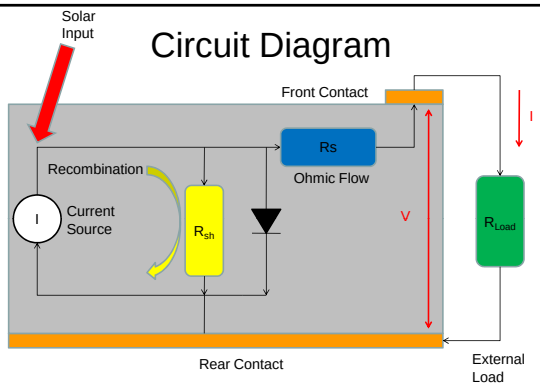
Solar Cell Operation



Solar Cell Electrical Model

- PV is modeled as a current source because it supplies a constant current over a wide range of voltages
- It has p-n junction diode that supplies a potential
- It has internal resistors that impede the flow of the electrons

Circuit Diagram



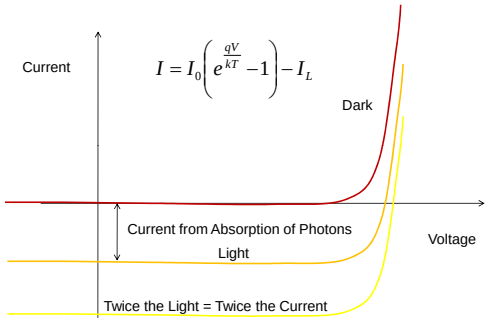
Electrical Losses

- Series Resistance
  (Resistance of Hole & Electron Motion)
  - Bulk Resistance of Semiconductor Materials
  - Bulk Resistance of Metallic Contacts and Interconnects
  - Contact Resistance
- Parallel Resistance or Shunt Resistance
  (Recombination of Hole and Electron)
  - PN junction Leakage
  - Leakage around edge of Junction
  - Foreign Impurities & Crystal Defects

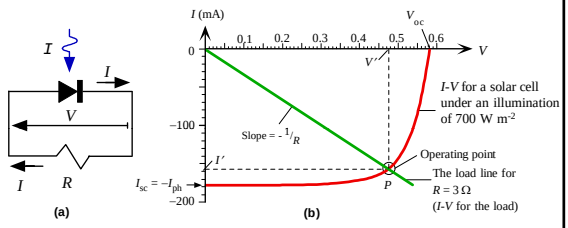
Power & IV Curve

- 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

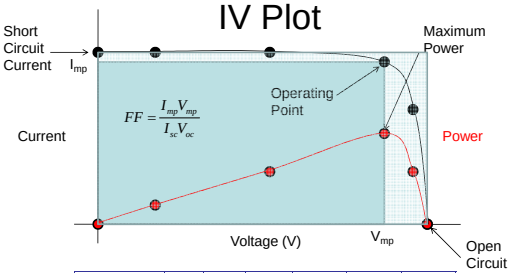
Solar Cell I-V Characteristics



Operating Point

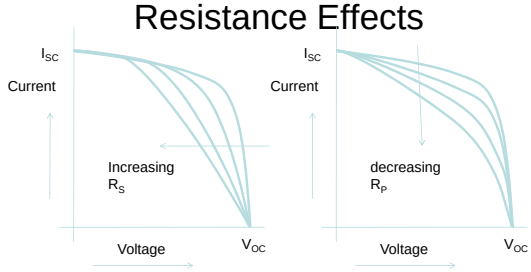


IV Plot



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

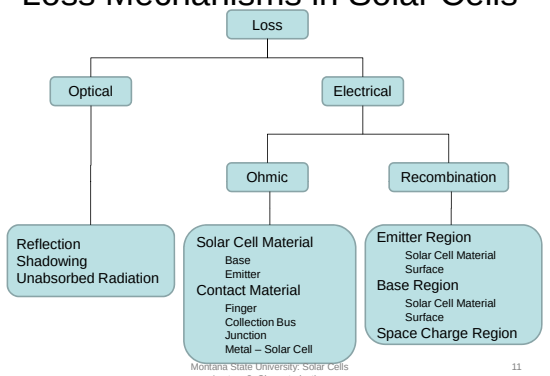
Resistance Effects



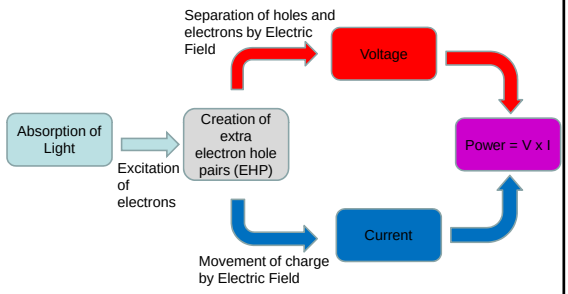
Ideal case $R_S = 0$ and $R_P = \infty$

Both reduce the area of the maximum power rectangle therefore reducing the efficiency and fill factor

Loss Mechanisms in Solar Cells



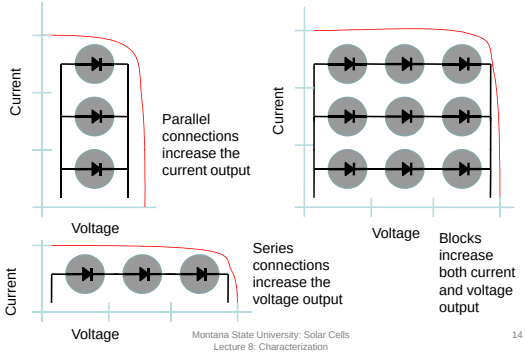
Photovoltaic Effect



Linking Cells

- Solar cells are not usually used individually because they do not output sufficient voltage and power to meet typical electrical demands
- The amount of voltage and current they output can be increased by combining cells together with wires to produce larger area solar modules
- Cells can be connected in a number of ways
  - Strings – where cells are connected in **series**
  - Blocks 2 or more strings connected together in **parallel**
  - Joining 2 or more blocks together

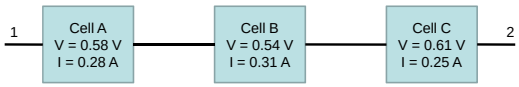
Solar Cell Panels



Calculating Voltage and Current

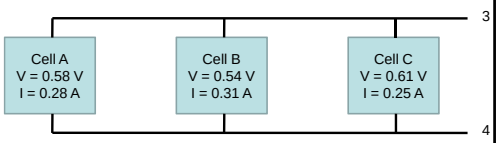
- **Series** connections are made by connecting one cell's n-type contact to the p-type of the next cell
- **Parallel** connections are made by joining each cells n-type contacts together and p-type contacts together
- **Series** connections the voltages add
- **Parallel** connections the current add
- **Series** connections the current flow is equal to the current from the cell generating the smallest current (limited by poorest cell)
- **Parallel** connections the voltage is the average of the cells or string in parallel

Example: Cells Series Connected



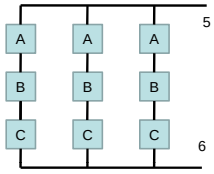
- The voltage across terminals 12 is the sum of the voltages
- $V_{12} = V_A + V_B + V_C = 0.58 + 0.54 + 0.61 = 1.73(V)$
- The current through the cells is restricted by the smallest current produce by any of the cells
- $I_{12} = 0.25\ (A)$

Example: Cells Parallel Connected



- The voltage across terminals 34 is the average of the voltages
- $V_{34} = (V_A + V_B + V_C)/3 = (0.58 + 0.54 + 0.61)/3 = 0.58(V)$
- The current at the terminals 34 is the sum of the currents in each cell
- $I_{34} = (I_A + I_B + I_C) = (0.28 + 0.31 + 0.25) = 0.84(A)$

Example: Block Connected



- The voltage across terminals 56 given by the series voltage already calculated:
- $V_{56} = V_A + V_B + V_C = 0.58 + 0.54 + 0.61 = 1.73(V)$
- The current at the terminals 56 is the sum of the currents in each string already calculated
- $I_{56} = 3(I_{string}) = 3(0.25) = 0.75(A)$

Summary Linking Cells

- Linking modules or batteries is similar to connecting PV cells
  - Series Connections
    - Voltages are added in series connections
    - The current is restricted to the smallest current
  - Parallel connections
    - The currents are added in parallel connections
    - The voltages are averaged from each string
- Solar Cells and Modules are Matched to improve the power generated