Photovoltaic Energy

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IGSS'09
The Institute for Green and Sustainable Science

at Marian University

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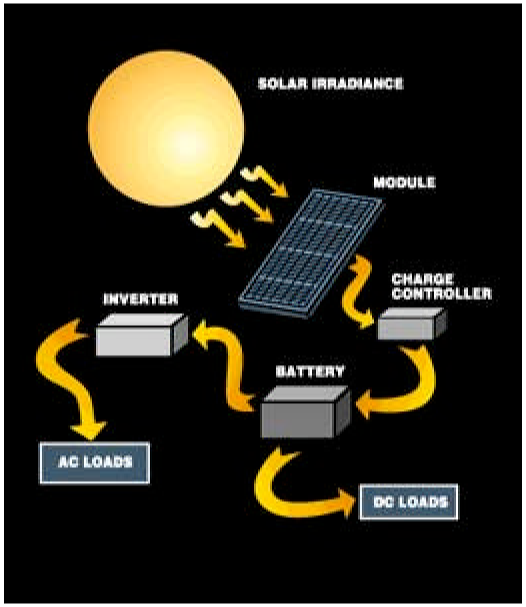
Overview

- Definition
- History
- PV Systems
- Applications
- Limitations
- Future



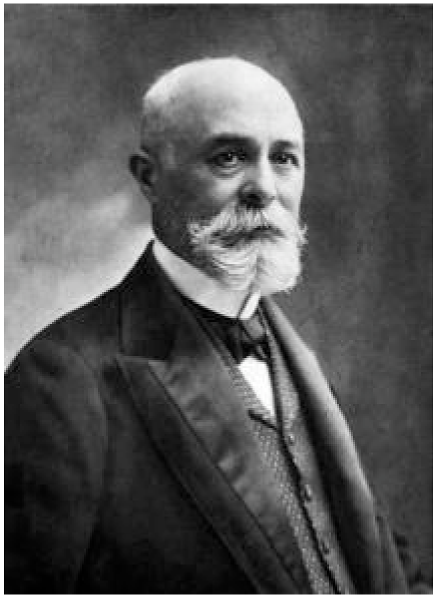
PV Effect

- The production or change of potential between two electrodes separated by a suitable electrolyte or other substance when the electrodes are unsymmetrically illuminated.[1]
- The creation of a voltage (or a corresponding electric current) that is produced by the transfer of electrons from one material to another, which results in the buildup of a voltage difference between two electrodes.[2]

[1] Copeland, Black, & Garrett *The Photovoltaic Effect*, 1941.

[2] *Photovoltaic Effect*, wikipedia.org

History



- Edmund Becquerel (1839)
- Voltage and current produced when a silver chloride electrode was immersed in an electrolytic solution and connected to a counter metal electrode that was illuminated with white light

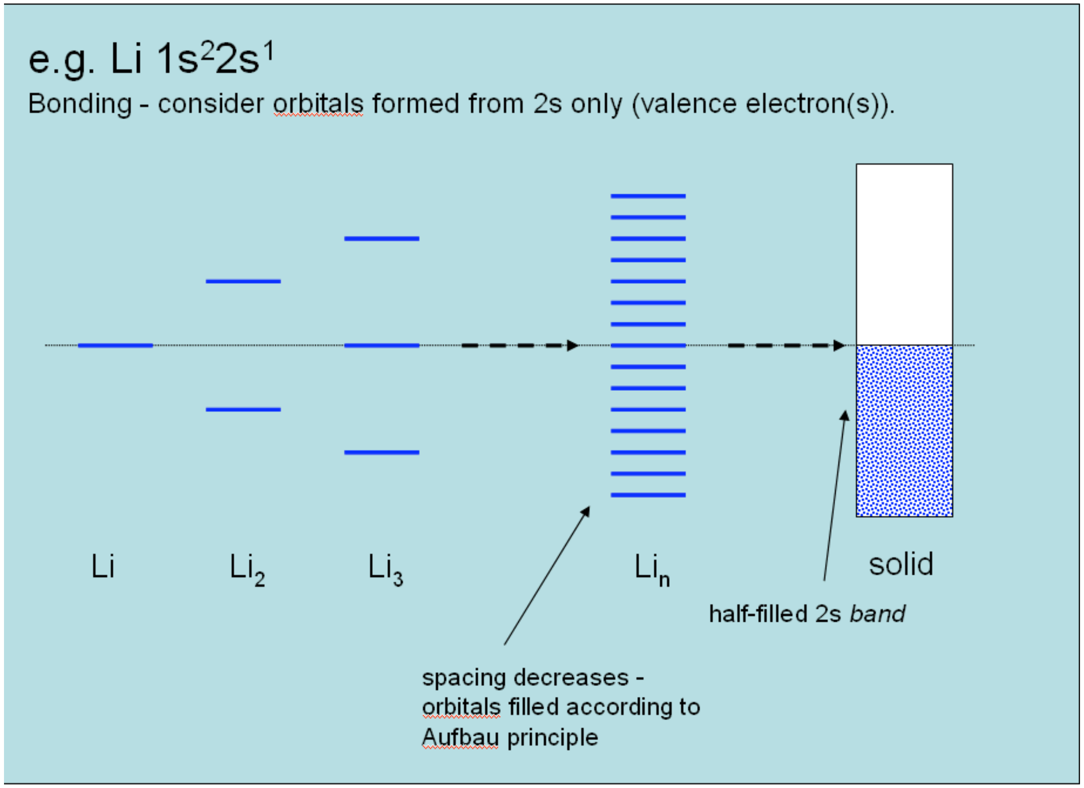
Semiconductors and p-n Junctions

- D. Chapin, C. Fuller, and G. Pearson at Bell Labs, 1954
- p-n junctions in single crystal Si with efficiencies of 5–6% (Chapin, Fuller, and Pearson 1954).

Physical Review, vol. 96, Issue 6, pp. 1708-1709

Band Theory

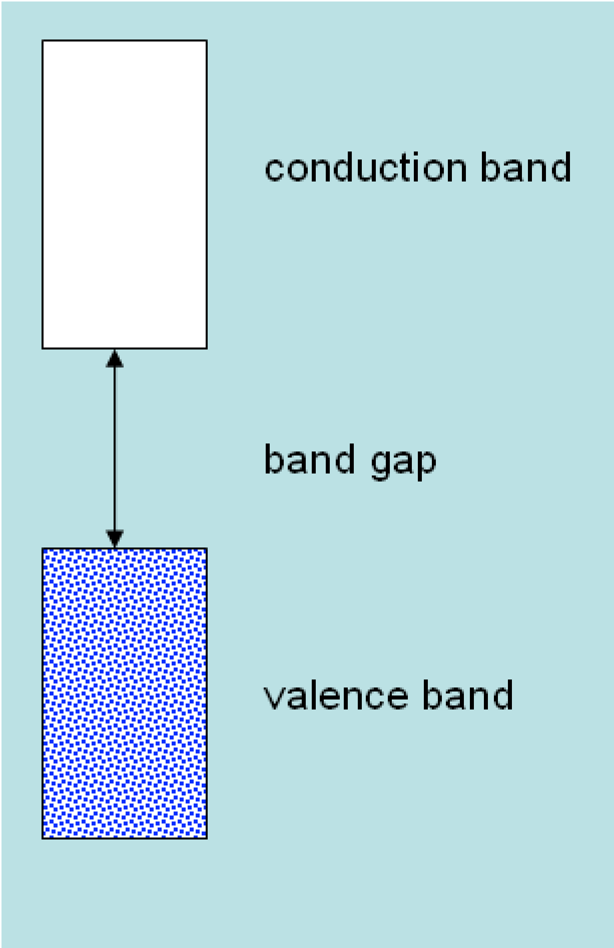
- Valence Band (VB)
- Conduction Band (CB)

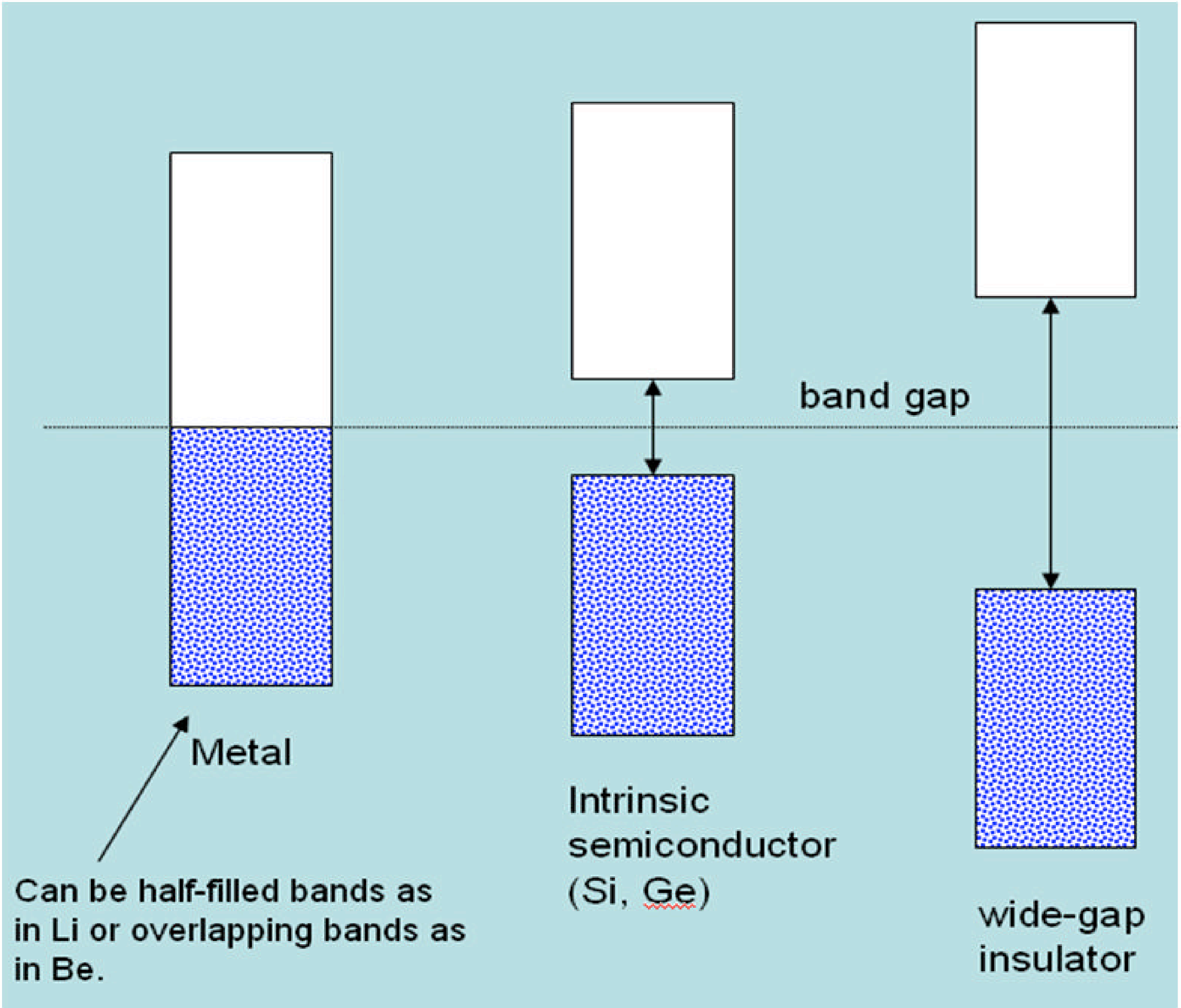


R.Macrae, lecture notes, 2009

Band Theory, cont.

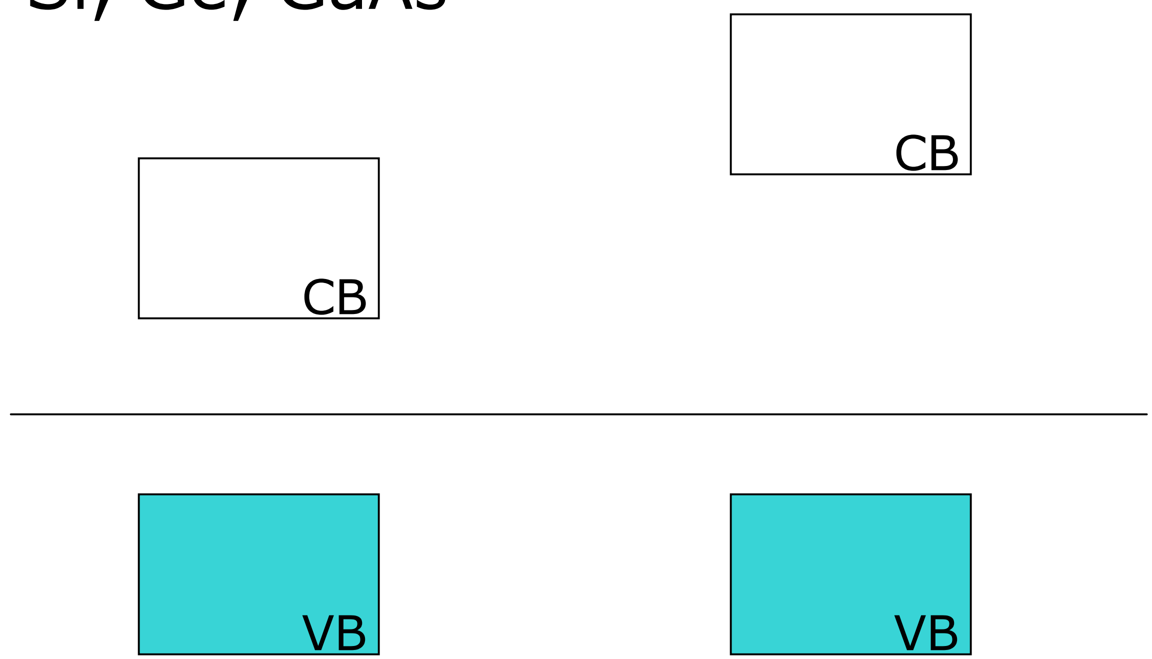
- General way to represent the different bands of a solid.
- Band gap distance associated with different materials.




band gap
Metal
Intrinsic
semiconductor
(Si, Ge)
wide-gap
insulator
Can be half-filled bands as
in Li or overlapping bands as
in Be.

Semiconductors

- Intrinsic- VB and CB are closely spaced
  - Si, Ge, GaAs



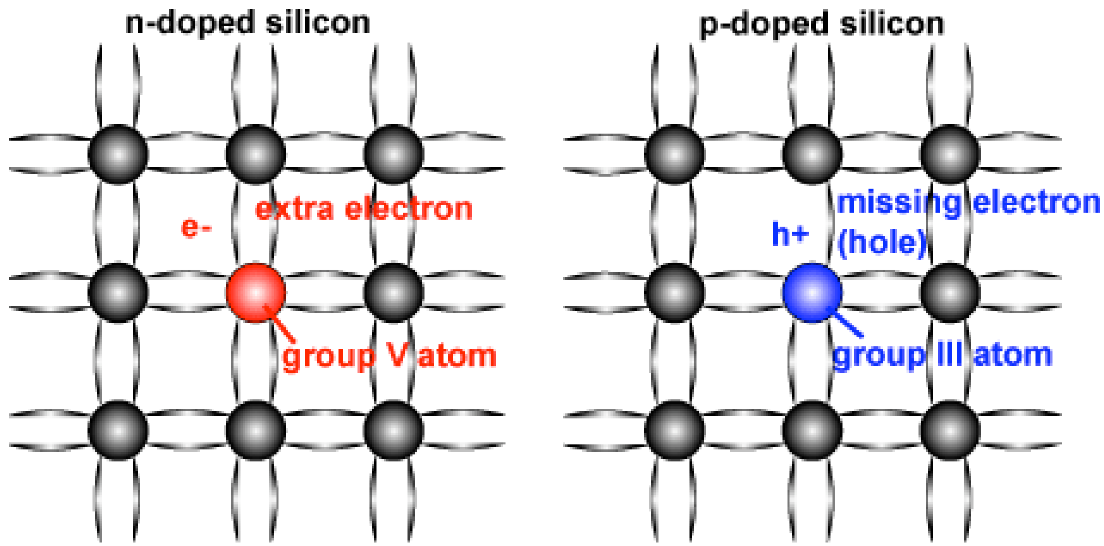
Intrinsic semiconductor

Insulator

Doped Semiconductors

- Add impurities in order to improve conductivity (via increased carriers).
- p-type v. n-type

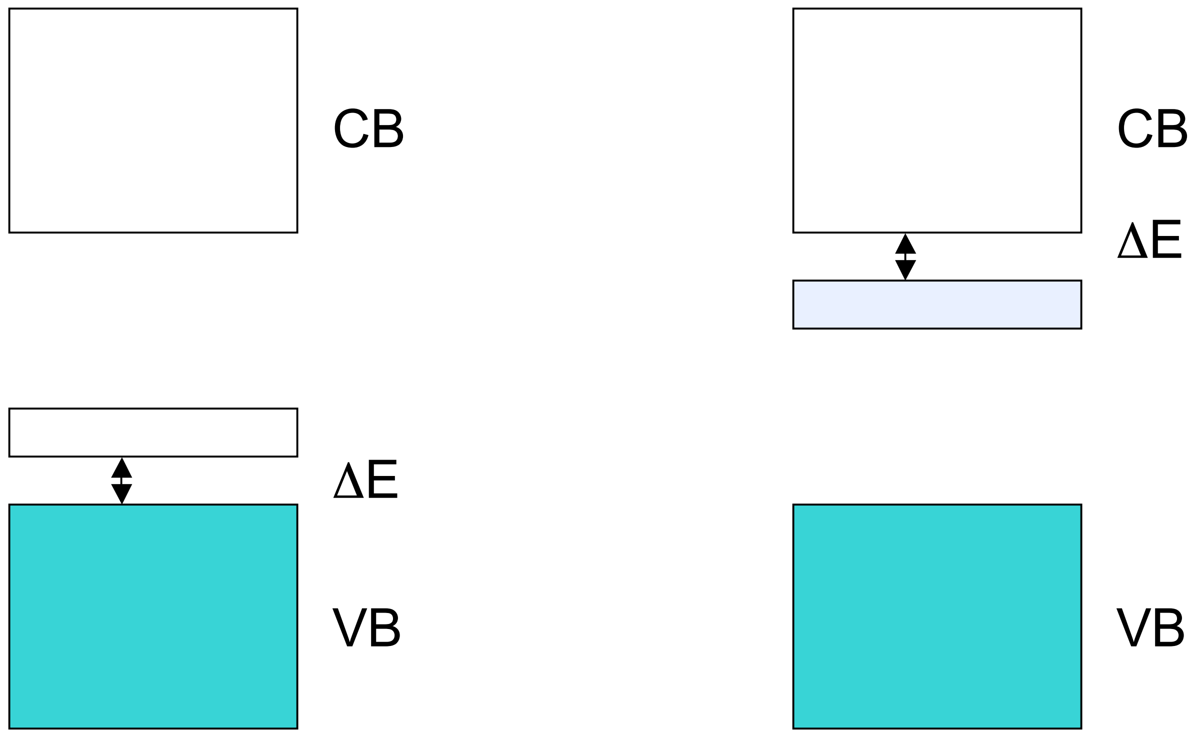
p-type v. n-type Semiconductors



	p-type	n-type
Dopant	Group III (B, In, Ga, etc…)	Group V (P, As, Sb, ect…)
Adds	Holes	Electrons

http://pvcdrom.pveducation.org/SEMICON/Images/DOPING.gif

Band Diagrams



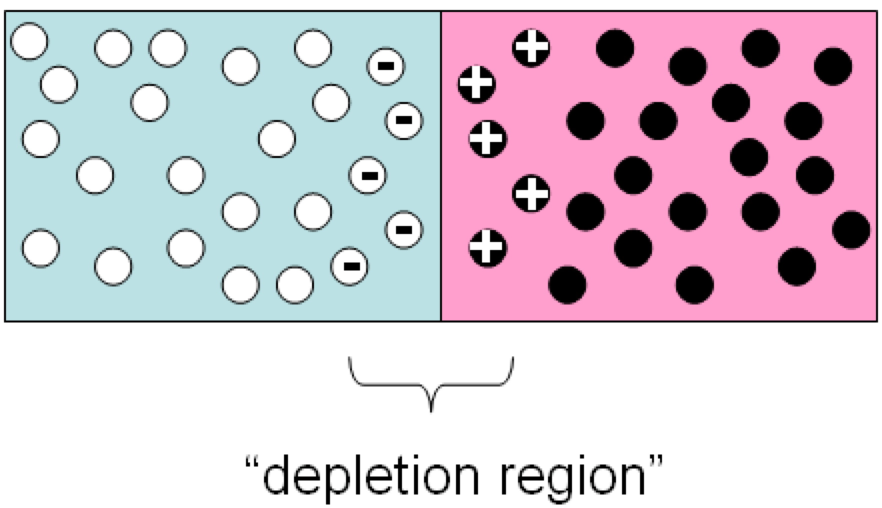
p-type semiconductor - empty acceptor band near VB

n-type semiconductor - filled donor band near CB

Electrons are more mobile than holes; so, n-type semiconductors are more conductive than p-type semiconductors.

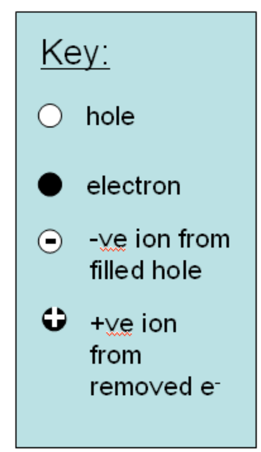
The p-n junction

- The essence of all semiconductor devices is the pn junction between p-doped and n-doped materials in contact with one another.



The holes and electrons combine at the junction; this leads to a loss of hole from the p-region and electrons from the n-region

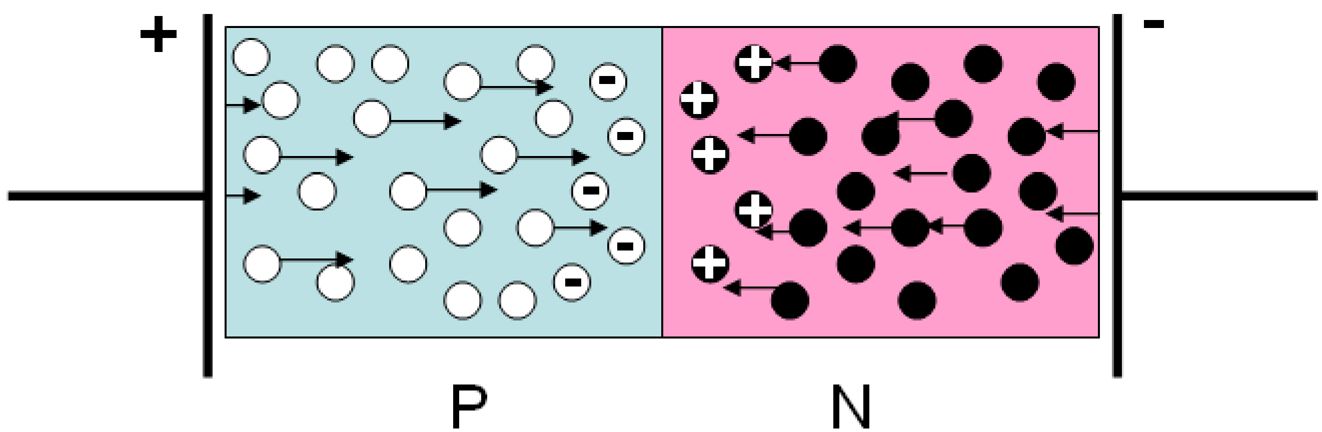
This junction potential acts as a barrier to current flow.



Creating a Current

- In order to overcome the potential, a positive bias must be applied.

Positive bias

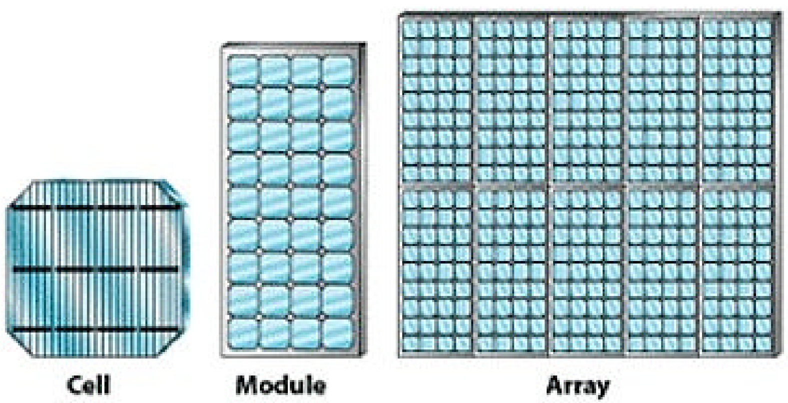


The holes and electrons are forced together and annihilate, but more are supplied by the source→ current flows!

This is cool, but why does it matter?

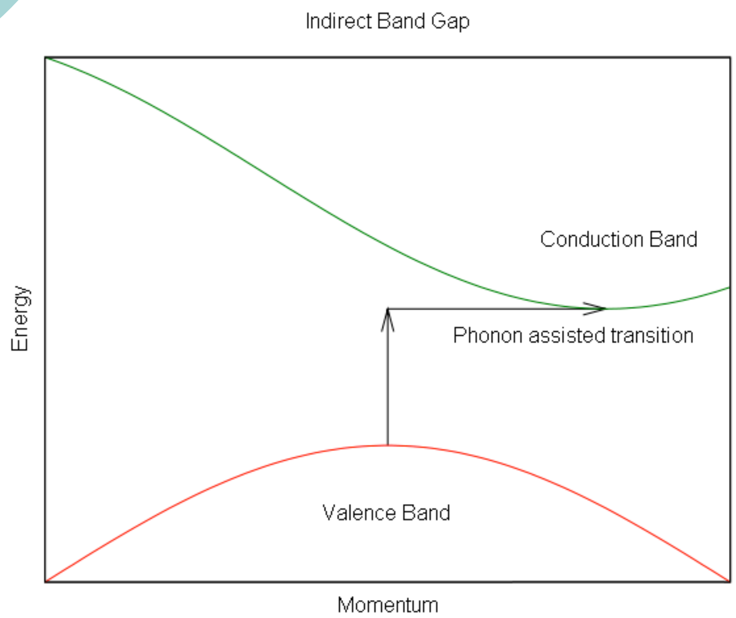
Photovoltaic Cells

- Produce electricity (DC) from light
- Photons knock electrons into a higher state of energy to create electricity
- Virtually all photovoltaic devices are some type of photodiode.

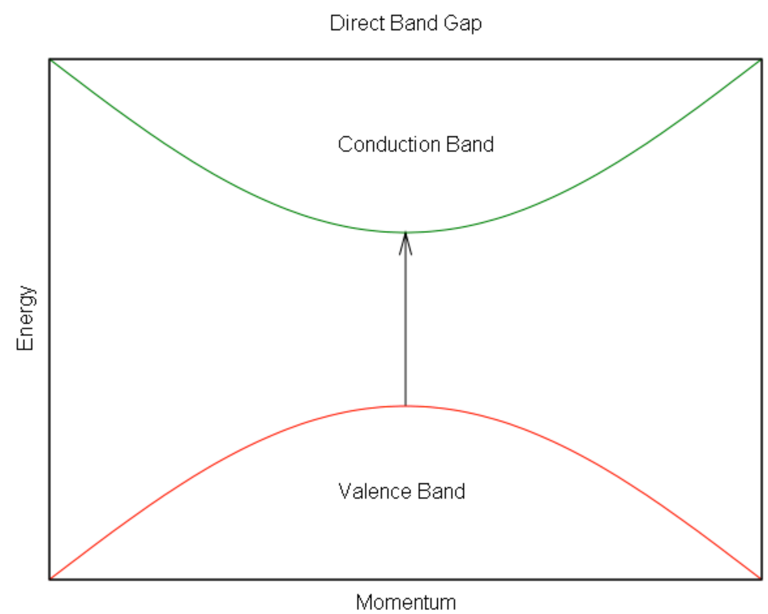


Photovoltaic Systems

- Make use of p-n junctions
- Direct gap (CdTe) v. Indirect gap (Si)



Sunlight and vibrations are needed to overcome the junction potential.



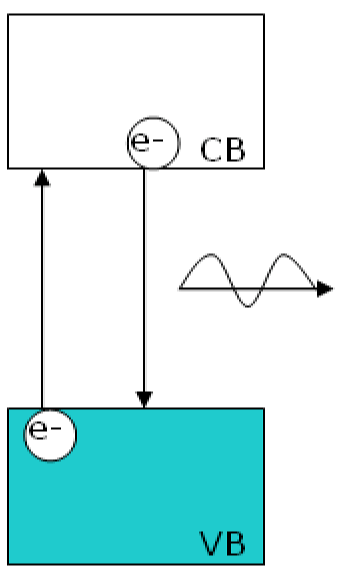
Sunlight is able to overcome the junction potential.

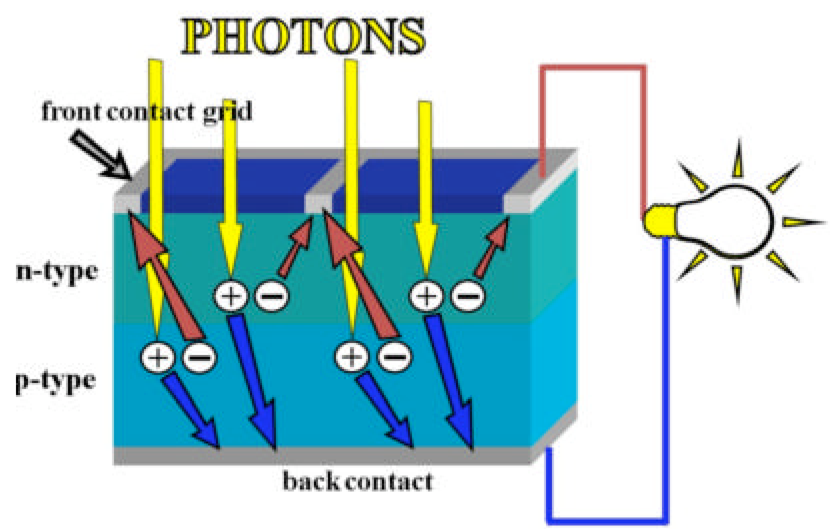
http://en.wikipedia.org/wiki/Direct_and_indirect_band_gaps

How PV systems work

- An electron in the conduction band annihilates a hole in the valence band, releasing the excess energy as a photon (radiative recombination).
- If the electron is near the bottom of the valence band and the hole is near the top of the conduction band, this process is possible in a direct gap semiconductor, but impossible in an indirect band gap system
- For radiative recombination to occur in an indirect band gap material, the process must also involve the emission of a phonon
    - Quantized mode of vibration occurring in a rigid crystal lattice

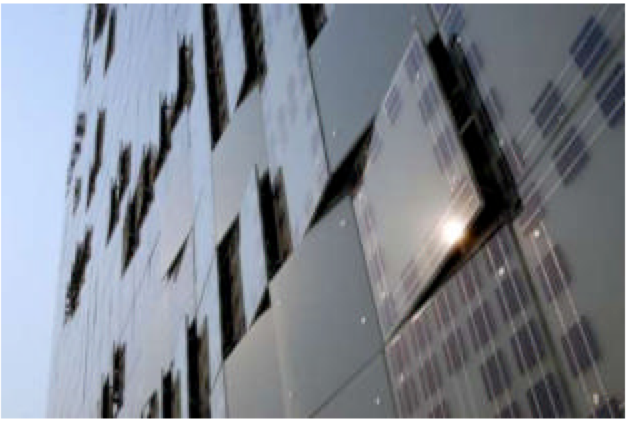
Radiative recombination





Applications

- Generation of electricity
  - Sustainable and economical



A building with photovoltaic walls (China)

Modern Photovoltaics

Cell Type	Efficiency	Band Gap Energy
a-Si	14%	?
mj-Si	40%	range
mc-Si	18%	?
CdTe	16%	1.5 eV
CIS	20%	1.9 eV

Max intensity sunlight(500nm): 2.3eV

a-Si: amorphous

mc-Si: multi-crystalline

mj-Si: multiple junction

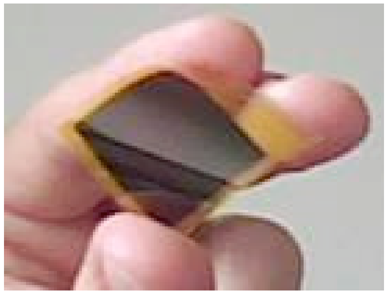
CIS: copper indium diselenide

CdTe: Cadmium telluride

Jardine, C; Conibeer, G.; Lane, K. *PV-COMPARE: Direct Comparison of Eleven PV Technologies at Two Locations in Northern and Southern Europe*

Improving Modern Cells

- Band gap energy of ~2eV
- Thin layers
  - CdTe, CIS
- Multi-junction
  - Different materials that with a range of band gap energies
  - Different combinations (n-i-p and p-i-n)



Limitations

- Cloudy, rainy days and nights
- Efficiency
- Operating temperature
- Power grid (SmartGrid) technology

maximum power point

$$\eta = \frac{P_m}{E \times A_c}$$

Irradiance (W/m^2)

Surface area of cell (m^2)

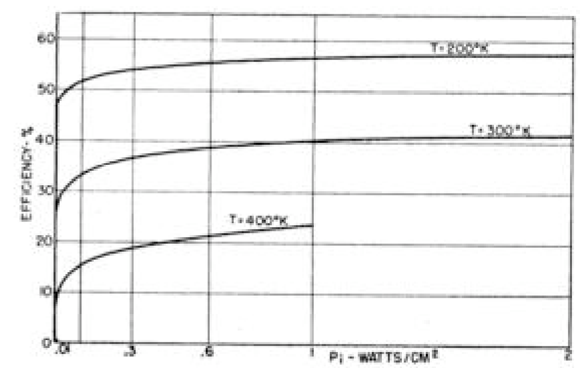


FIG. 5. Efficiency of power conversion as a function of power input for 0.01 ohm-cm germanium for three different temperatures, $d=3.5\times10^{-3}$ cm.

R.L. Cummerow, *Phys Rev*, 95, 16 (1954)

The Future

- More research on thin-films (CaTe)
- Improve efficiencies
- Improve cost
- Build grid
- Integrate into buildings, cars, etc…



Questions?