Electromechanical Systems
ASE 375

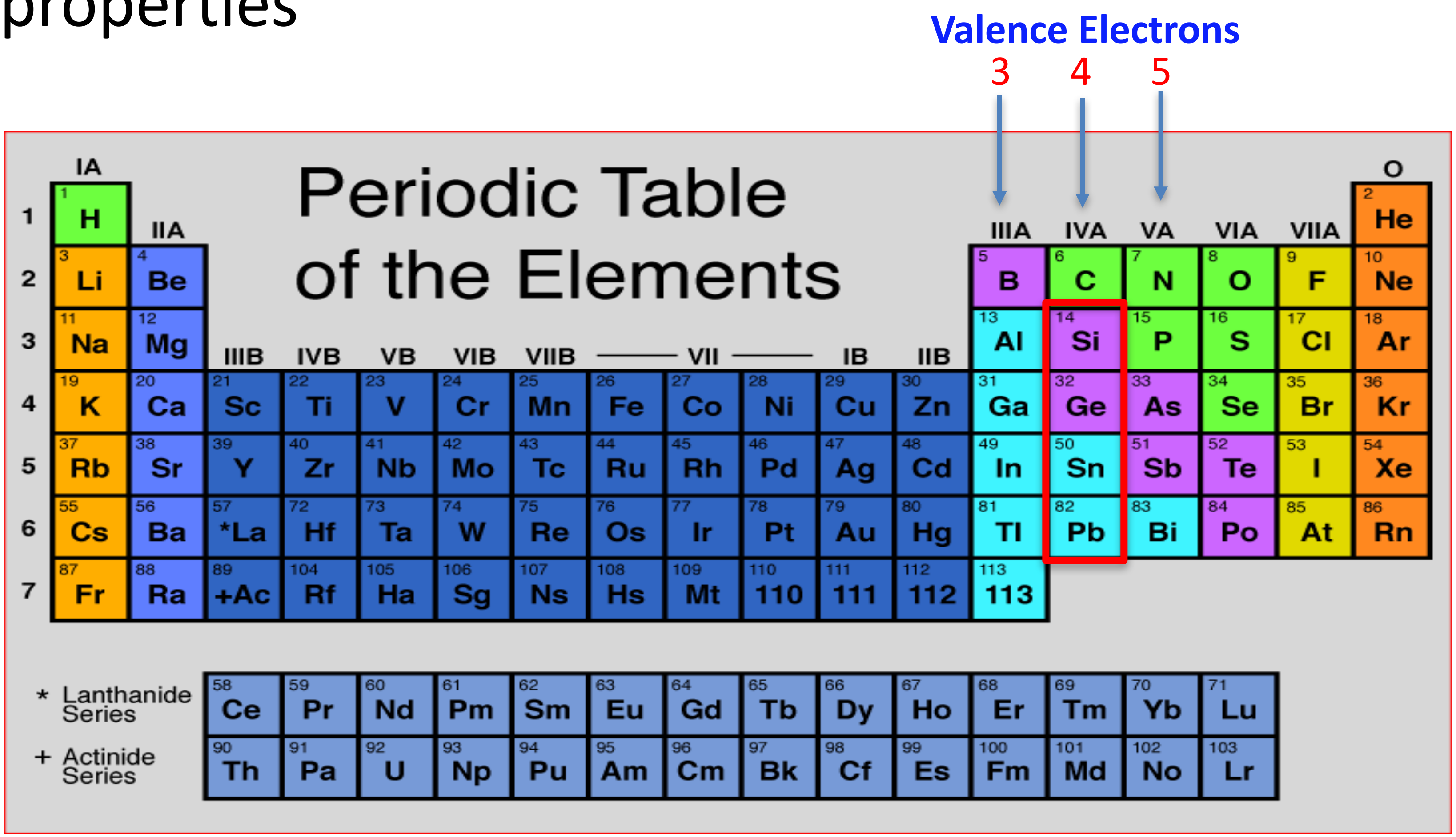
Lecture 18: Optical Measurement Techniques (PhotoDiodes)

Conductors vs Insulators

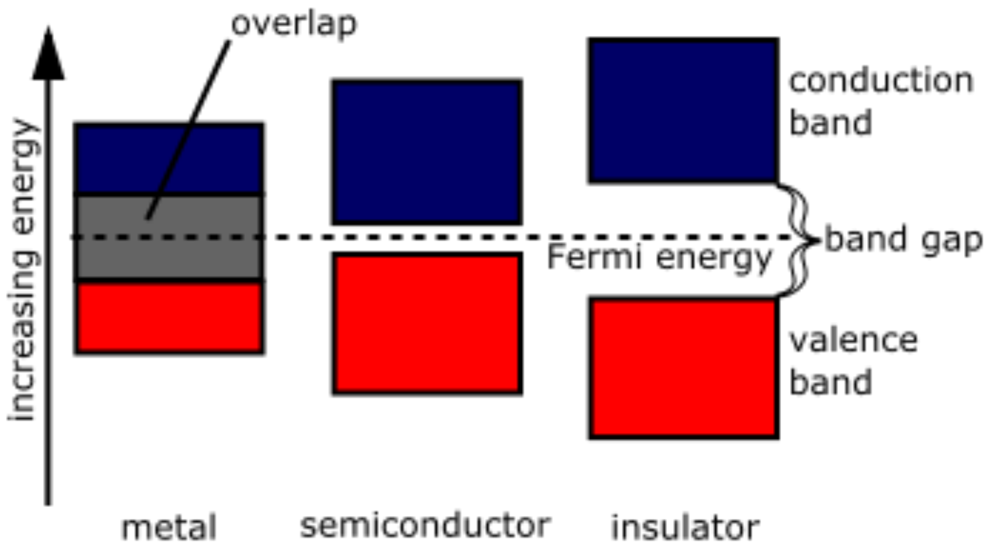
- Conductors
  - Ex: Metals
  - Flow of electricity governed by motion of free electrons
  - As temperature increases, conductivity decreases due to more lattice atom collisions of electrons
  - Idea of superconductivity at temperatures close to absolute zero
- Insulators
  - Ex: Plastics
  - Flow of electricity governed by motion of ions that break free
  - As temperature increases, conductivity increases due to lattice vibrations breaking free ions
  - Irrelevant because conductive temperature beyond melting point

Semiconductors

- Semiconductors are more like insulators in their pure form– most commonly, Si and Ge
- Adding dopants allows them to gain conductive properties



Band Gap Physics

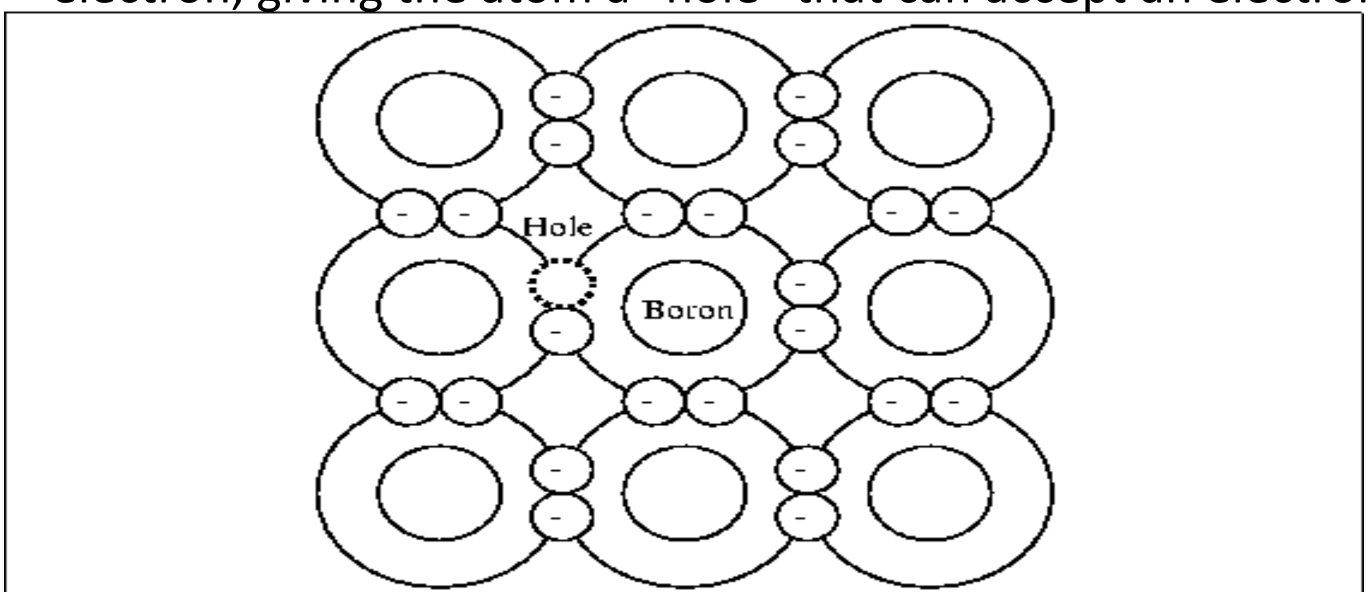


Material	Symbol	Band gap (eV) @ 302K
Diamond	C	5.5
Silicon	Si	1.11
Germanium	Ge	0.67
Gallium nitride	GaN	3.4
Gallium phosphide	GaP	2.26
Gallium arsenide	GaAs	1.43
Silicon nitride	Si_3N_4	5
Lead sulfide	PbS	0.37
Silicon dioxide	SiO_2	9
Copper oxide	Cu_2O	2.1

- Electrons can occupy only certain energy levels in any atom - called valence bands
- For a material to be conductive, it needs to have electrons with a higher energy level, called the conduction band
  - Metals typically see an overlap in the energy levels of the valence band and conduction band
  - Insulators have a large gap between the two bands, so it take a high temperature to cross that threshold
  - Semiconductors fall in between
- The gap between the valence band and the conduction band is called band gap
- Different semiconductors have different band gaps, but Si and Ge have the lowest, so tend to be the most commonly used semiconductors

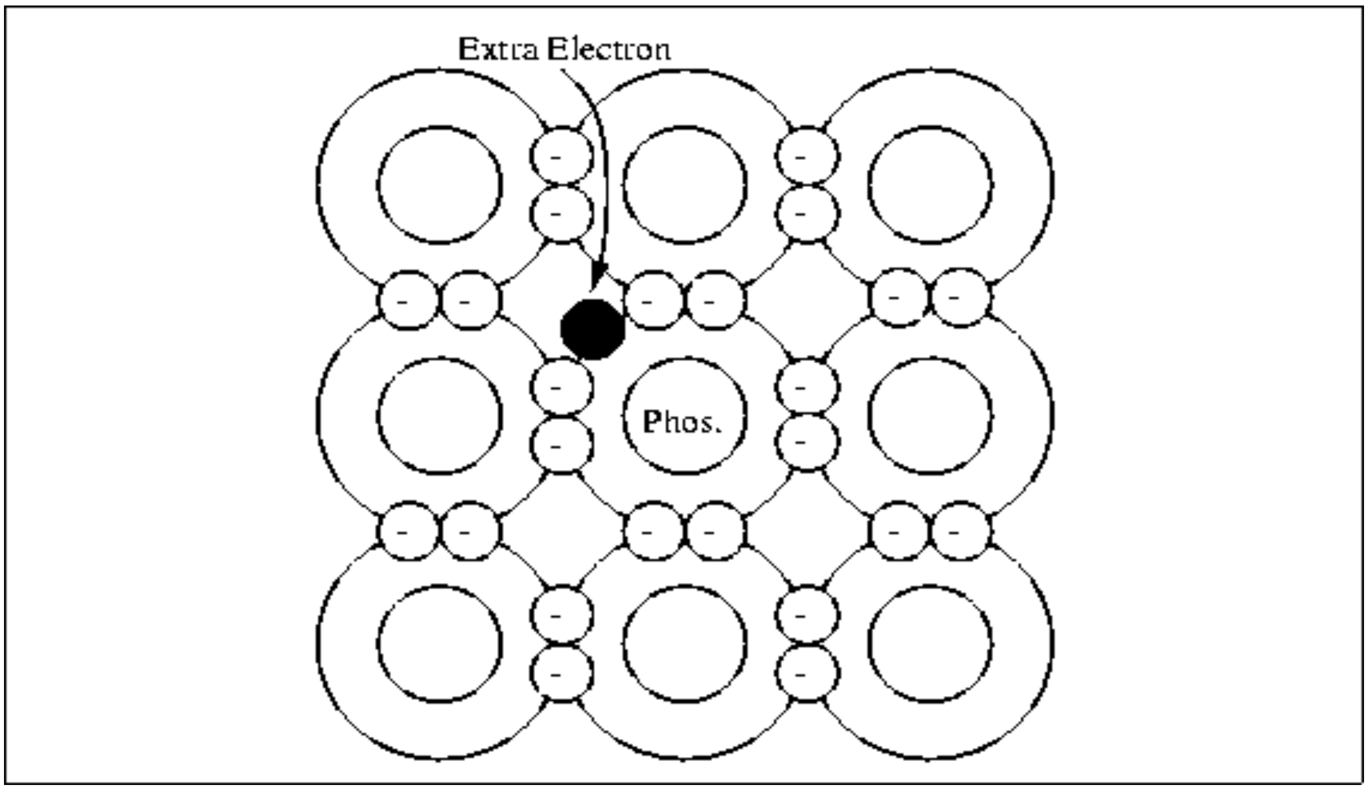
Doping – P-type

- Foreign elements are added to the semiconductor to make it have an excess of electrons or dearth of electrons
- P-type semiconductor
  - Dopants include Boron, Aluminum, Gallium, Indium, and Thallium
- Ex: Silicon doped with Boron
  - The boron atom will be involved in covalent bonds with three of the four neighboring Si atoms. The fourth bond will be missing and electron, giving the atom a “hole” that can accept an electron



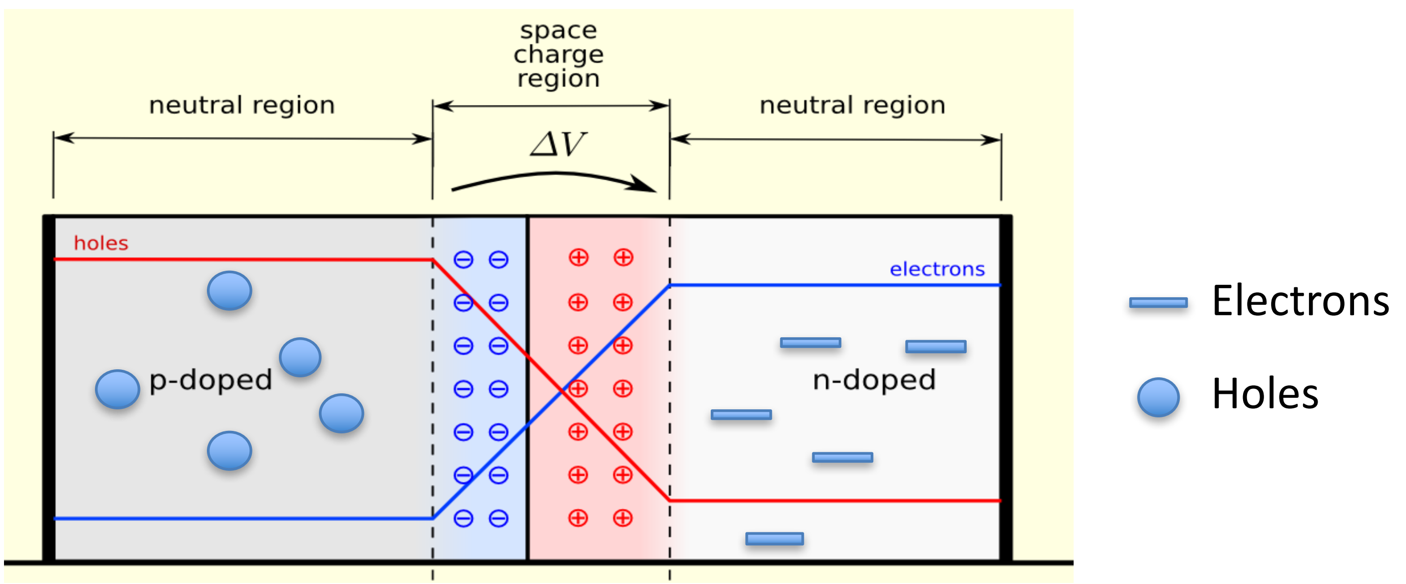
Doping – N-type

- N-type semiconductor
- Dopants include Nitrogen, Phosphorous, Arsenic, Antimony, and Bismuth
- Ex: Silicon doped with Phosphorous
  - The Phosphorous atom will contribute and additional electron to the Silicon giving it an excess negative charge



Unbiased p-n junction diode

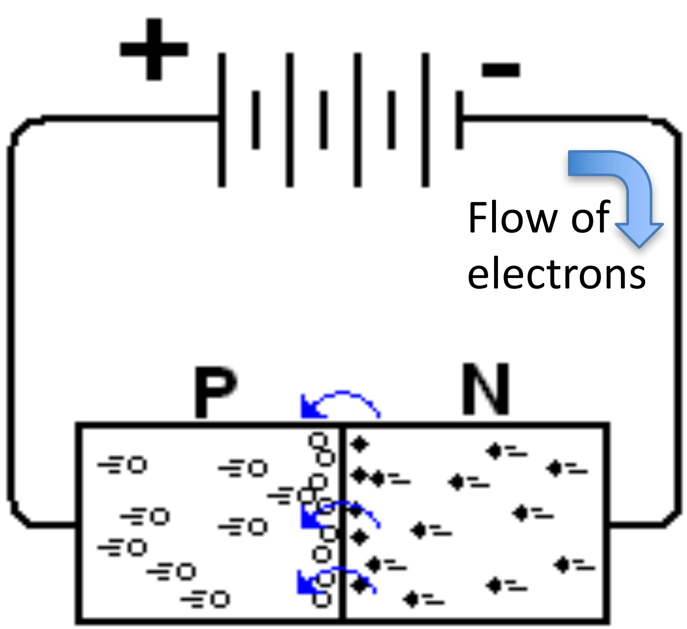
- A diode is formed by a p-type and n-type semiconductor are fused together
- The p-type and n-type are both electrically neutral by themselves
- Initially, at the junction electrons from the n-type recombine with holes from the p-type
- This creates a region (called the space charge region or depletion layer) with a potential difference created by the excess negative charge in the p-side and positive charge in the n-side
- Once the depletion layer is a certain width, no more electrons can jump over the potential barrier



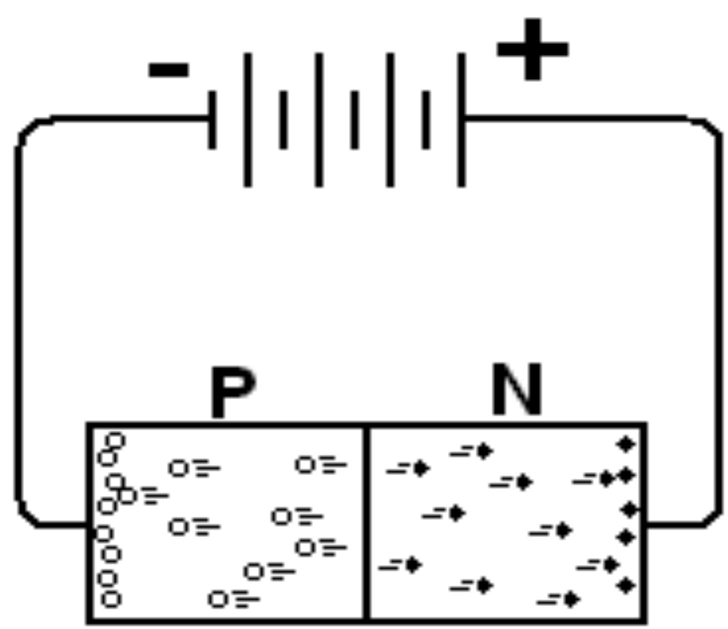
P-N Junction Diodes

- Since p-type and n-type are oppositely charged, a forward-bias encourages current flow from P to N
- A reverse bias causes no current flow, so a diode acts like an one-way valve (in terms of fluid flow)

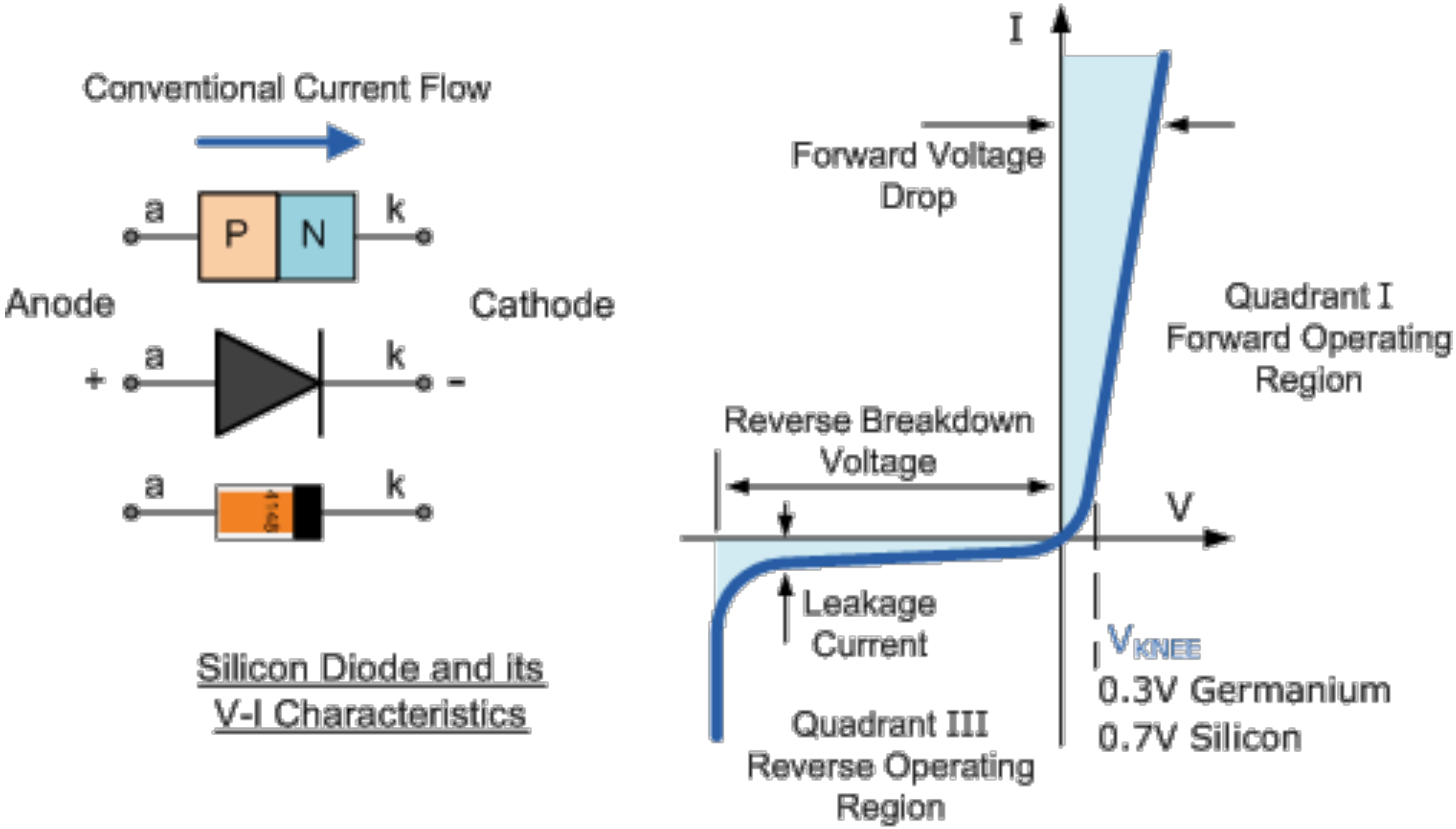
- Forward Bias
  - Current flows from P to N



- Reverse Bias
  - No Current flows

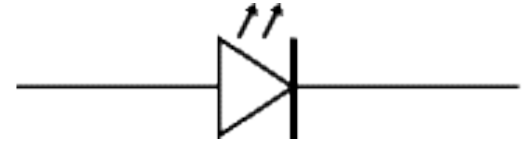


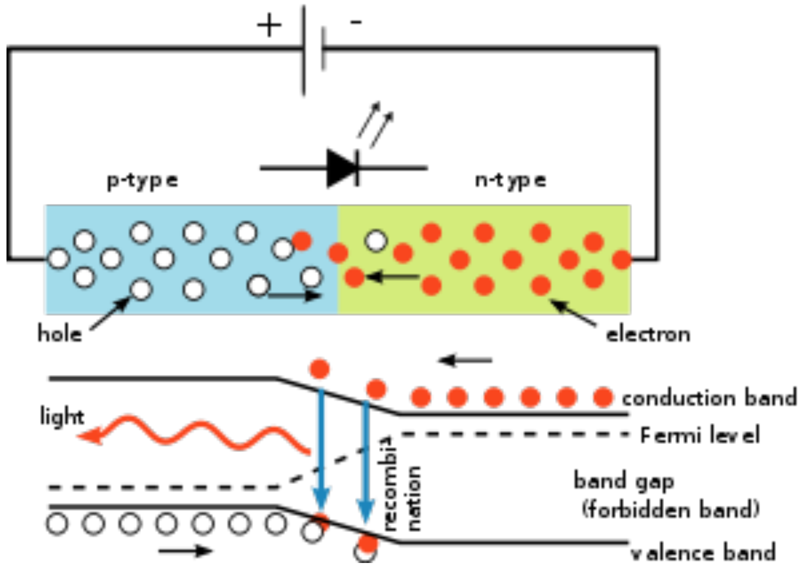
P-N Junction Diodes

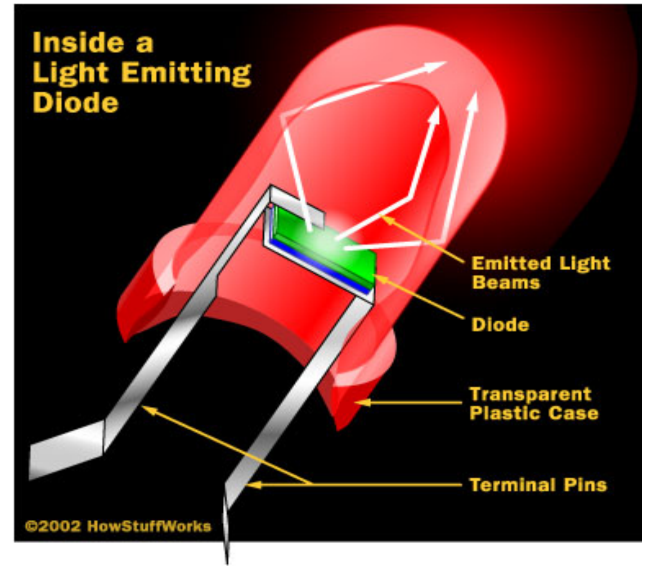


Silicon Diode and its
V-I Characteristics

LED: Light Emitting Diodes

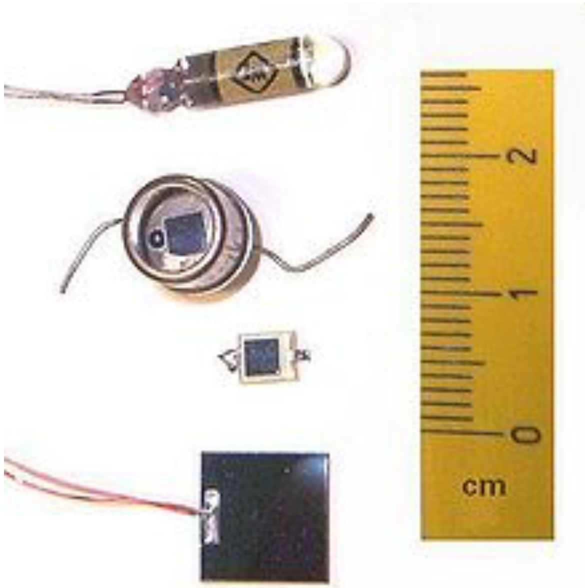


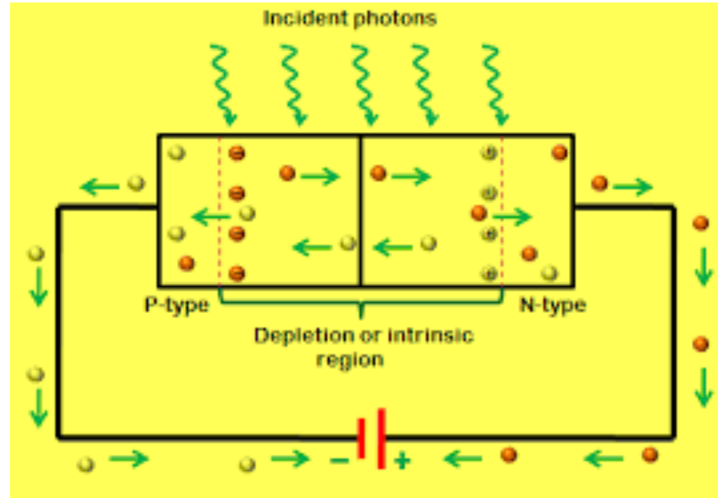




- Each time an electron recombines with a hole, electric potential energy is converted into electromagnetic energy.
- The electrons dissipate energy in the form of heat for silicon and germanium diodes but in gallium arsenide phosphide (GaAsP) and gallium phosphide (GaP) semiconductors, the electrons dissipate energy by emitting photons.
- A light emitting diode (LED) is essentially a PN junction opto-semiconductor that emits a monochromatic (single color) light (photons) when operated in a forward biased direction.
- If the semiconductor is translucent, the junction becomes the source of light as it is emitted, thus becoming a light-emitting diode

Photodiodes





- Photodiodes are semiconductor light sensors that generate a current or voltage when the P-N junction in the semiconductor is illuminated by light
- When a photon of sufficient energy strikes the diode, it creates an electron-hole pair. This mechanism is also known as the inner photoelectric effect.
- If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in electric field of the depletion region.
- Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.
- The common, traditional solar cell used to generate electric solar power is a large area photodiode.
- Properties of photodiodes
  - Excellent linearity with respect to incident light
  - Low noise
  - Wide spectral response
  - Mechanically rugged
  - Compact and lightweight
  - Long life