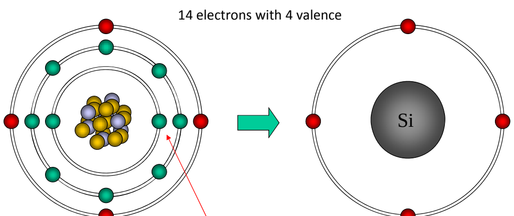
EELE408 Photovoltaics
Lecture 05: Semiconductor Basics

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

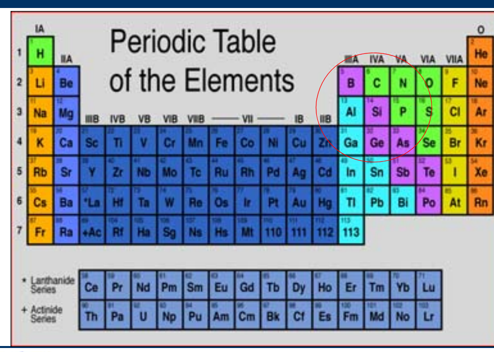
Department of Electrical and Computer Engineering
Montana State University - Bozeman

Bond Model

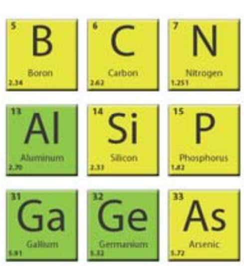
Silicon Atom

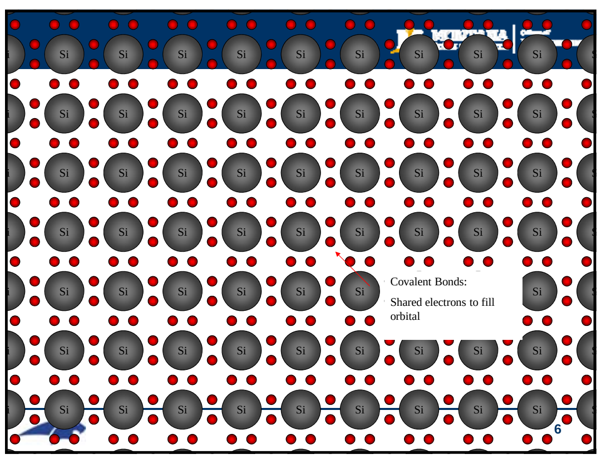


Semicconductors

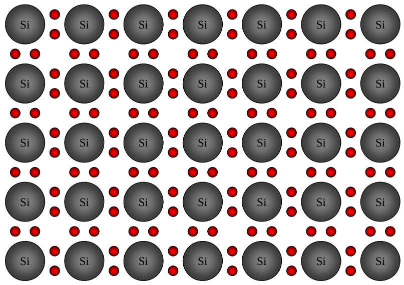


Elements around Silicon



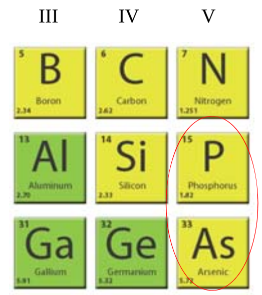


Intrinsic Silicon

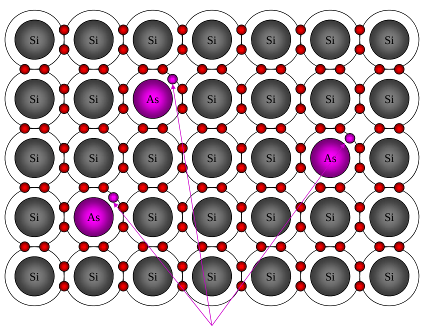


Poor conductor: No free electrons to carry current
Need to engineer electrical properties (conduction)

Valence V: n-type doping

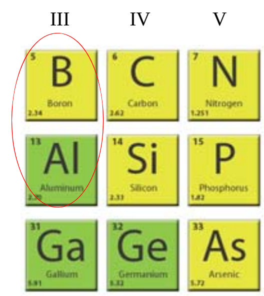


Extra Negative Electrons

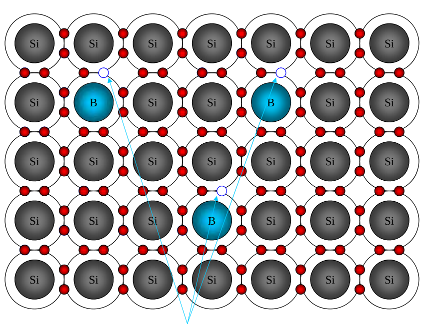


Each N-type dopant brings an extra electron to the lattice

Valence III: p-type doping



Extra Positive Holes



Each P-type dopant is short an electron, creating a hole in the lattice

Bond Model

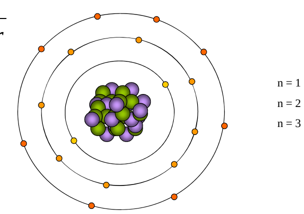
- Electrons from broken bonds are free to move
- Electrons from neighboring bonds can also move into the 'hole' created by a broken bond, allowing the broken bond or 'hole' to propagate as if had a positive charge
  - Bubble in a liquid

Band Model

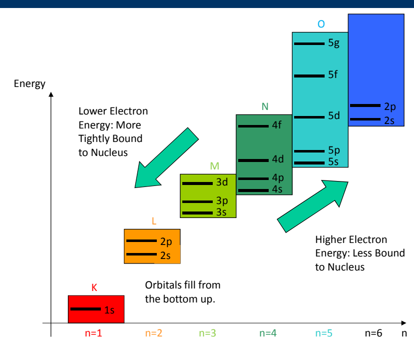
Orbital Shells

- The positions of the electrons around the nucleus are quantized to specific energy levels or Shells
- The orbital determines the energy of the electron

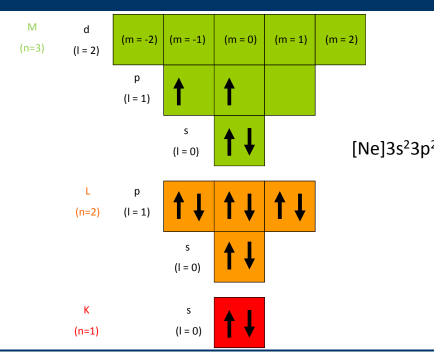
$$V = \frac{-q^2}{4\pi\varepsilon_0 r}$$



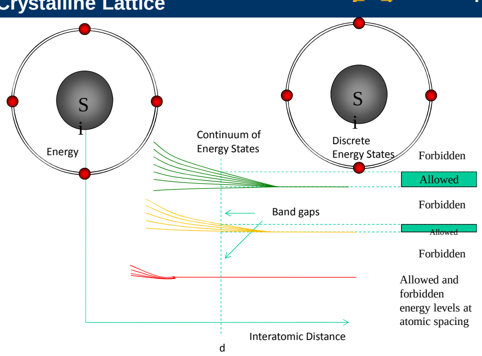
Energy of Electrons



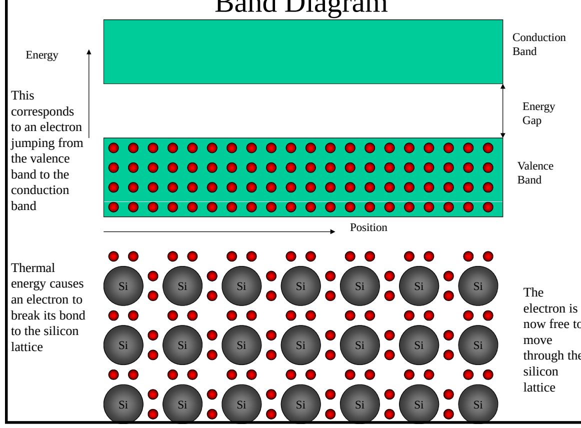
Silicon Electron Configuration



Splitting of Energy Levels in a Crystalline Lattice



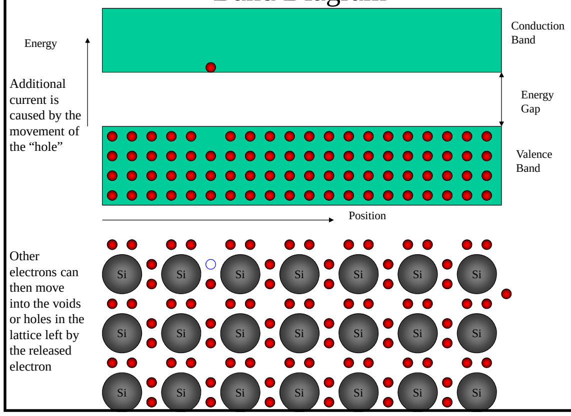
Band Diagram



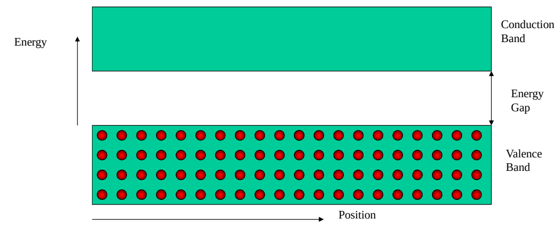
Band Diagram

Additional current is caused by the movement of the "hole"

Other electrons can then move into the voids or holes in the lattice left by the released electron



Band Diagram

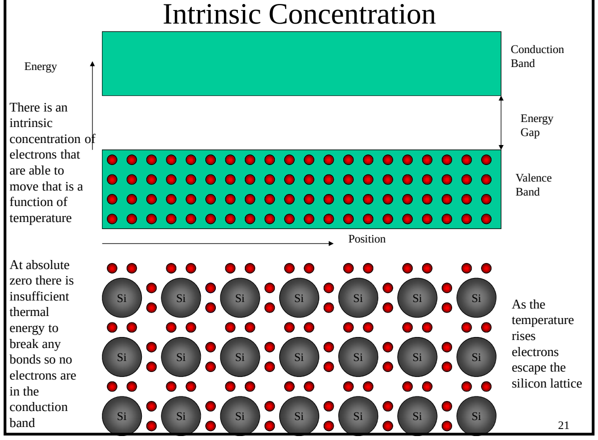


It is easier to think of a positive hole moving in the valence band

Intrinsic Concentration

There is an intrinsic concentration of electrons that are able to move that is a function of temperature

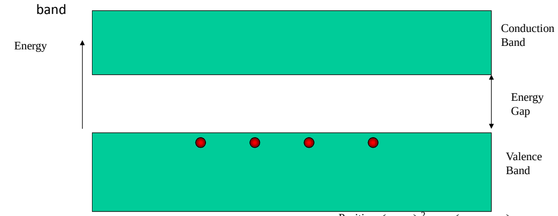
At absolute zero there is insufficient thermal energy to break any bonds so no electrons are in the conduction band



21

Intrinsic Concentration

As the temperature rises more and more electrons are excited into the conduction band and the silicon becomes more conductive with an equal concentration of electrons in the valence band and holes in the conduction band



Empirical equation for near room temperature

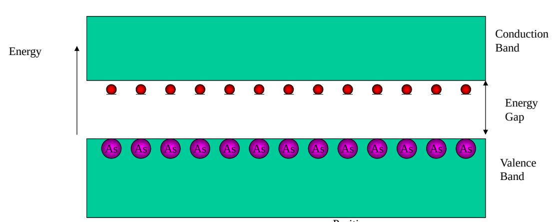
$$n_i(T = 275K - 375K) = 9.38\times10^{19}\left(\frac{T}{300}\right)^2 \exp\left(-\frac{6884}{T}\right)$$

$$n_i(T = 300K) = 1\times10^{10}\left(/cm^3\right)$$

22

N-Type Doping

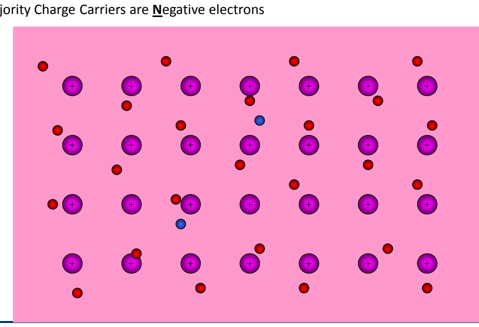
Doping the silicon lattice with atoms with 5 valence electrons (V) create sites in the band diagram that require little energy to break the bond to the dopant atom and become free to move in the lattice or in other words move into the conduction band.



23

N type Material

Majority Charge Carriers are Negative electrons

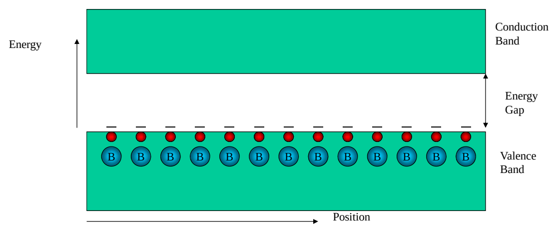


Few holes

24

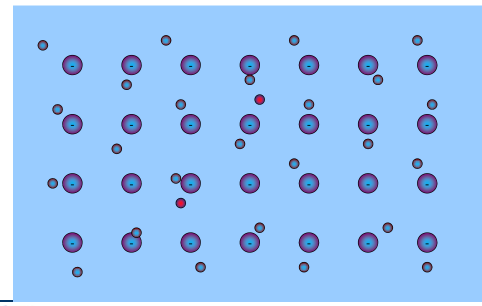
P-Type Doping

Doping the silicon lattice with atoms with 3 valence electrons (III) create sites in the band diagram that require little energy to trap an electron into the dopant atom. Holes are created in the valence band that are free to move.



P type Material

Majority Charge Carriers are Positive holes



Few electrons

Equilibrium Carrier Concentration

- Law of Mass Action
  - At equilibrium the product of the majority and minority carrier concentration is a constant

$$n_0 p_0 = n_i^2$$

  - n_0 is the equilibrium electron concentration
  - p_0 is the equilibrium hole concentration
  - n_i is the intrinsic concentration

N-Type Carrier Concentration

- At room temperature in an N-type material, the electron concentration is approximately the donor doping concentration

$$n_0 = N_D$$

$$p_0 = \frac{n_i^2}{N_D}$$

  - N_D is the donor doping concentration

P-Type Carrier Concentration

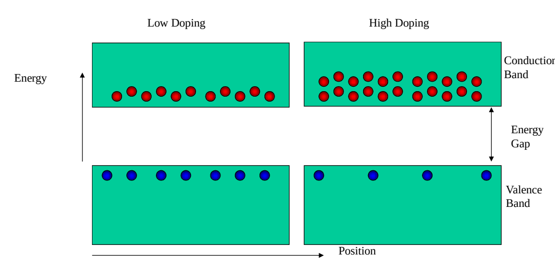
- At room temperature in a P-type material, the hole concentration is approximately the acceptor doping concentration

$$p_0 = N_A$$

$$n_0 = \frac{n_i^2}{N_A}$$

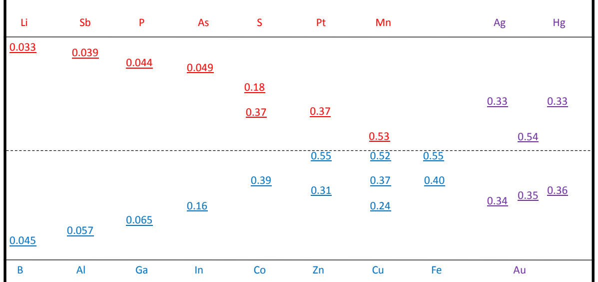
  - N_A is the acceptor doping concentration

Minority Concentration Dependence



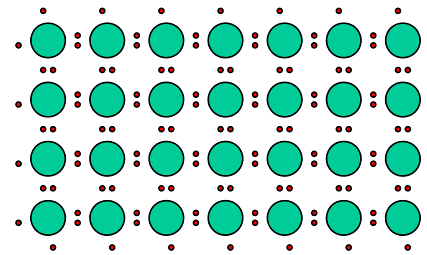
As the doping concentration increases the concentration of minority carriers decreases.

Energy Levels of Elements in the Band Gap of Silicon (Traps)



31

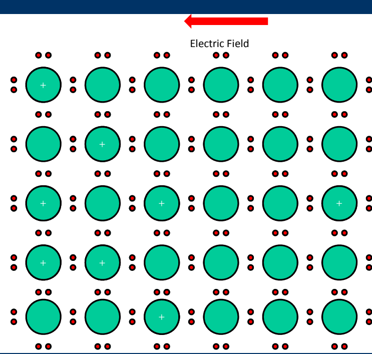
Electrical conductivity in nonmetals



32

Silicon

- Thermal energy breaks bond and creates a free electron and a hole
- The concentration of holes equals the concentration of free electrons
- An applied field causes electrons to contribute to electrical conduction
- Movement of electrons filling holes create net charge movement contributing to electrical conduction



33

Conductivity of Semiconductor

$$\sigma = ep\mu_h + en\mu_e \qquad \mu_h < \mu_e$$

- p: concentration of holes
- n: concentration of electrons
- μ_h: hole mobility
- μ_e: electron mobility

$$\sigma = \frac{1}{\rho} \Rightarrow \rho = \frac{1}{\sigma}$$

34