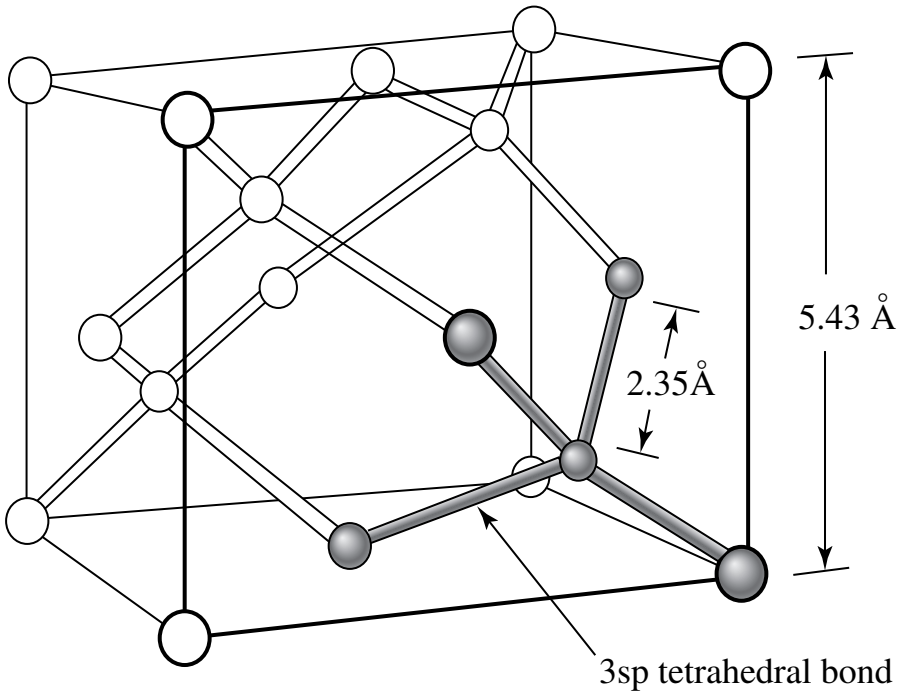
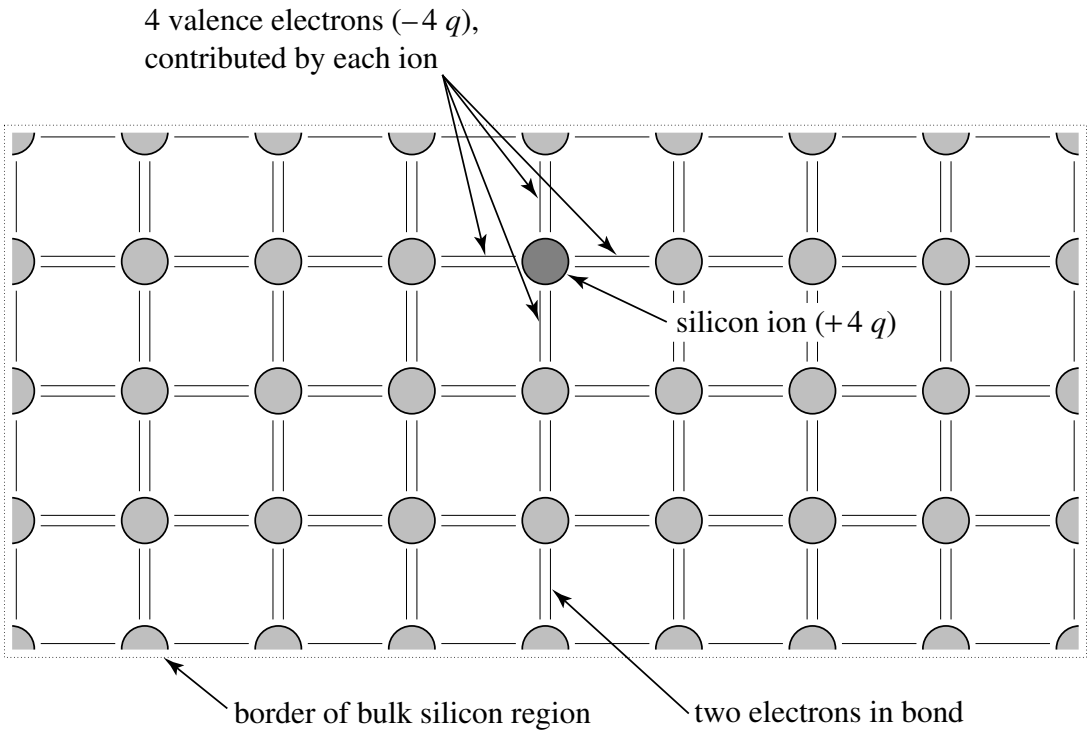
I. Intrinsic Semiconductors

A. Silicon Crystal Structure



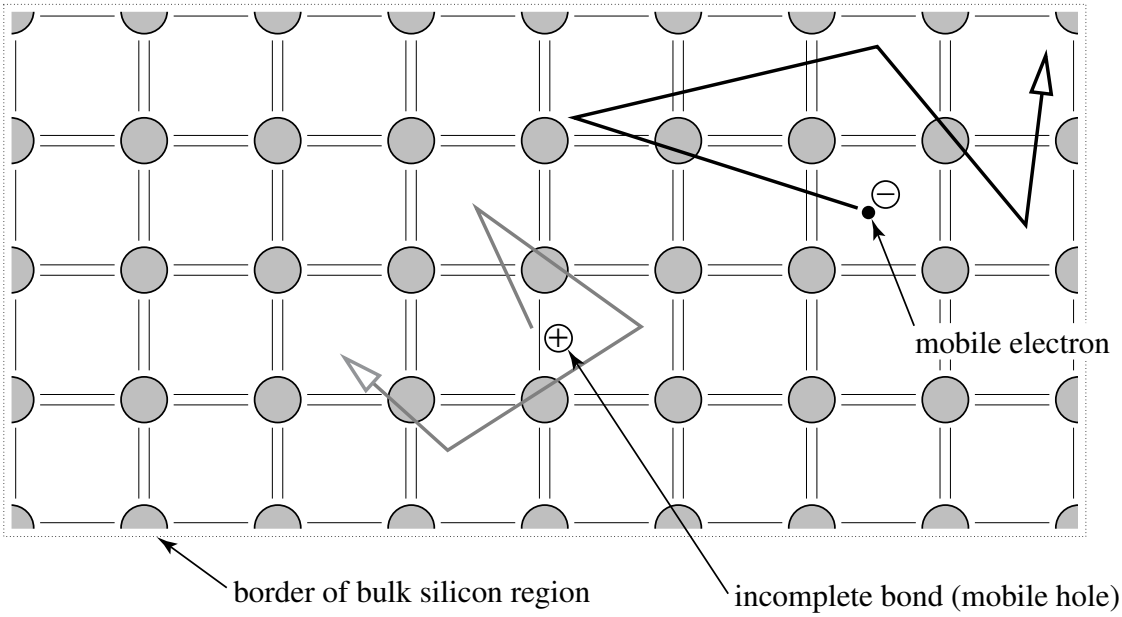
- #14 in Periodic Table: 10 Core Electrons 4 Outer Electrons
- diamond lattice
- atoms tetrahedrally bonded with covalent bonds-$5X10^{22}$ Atoms/cm^3

B. Intrinsic Silicon Bond Model: (T=0K)



- All Bonds Satisfied
- No Free Electrons

C. Intrinsic Silicon Bond Model (T > 0K)



- electron: mobile negative charge, concentration n (cm^{-3})
- hole: mobile positive charge, concentration p (cm^{-3})

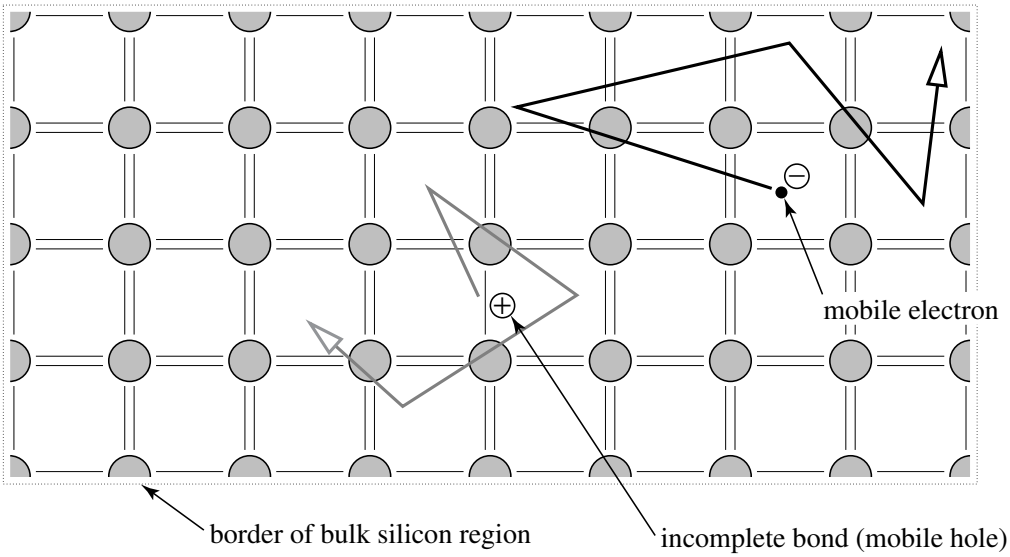
D. Limitations of Bond Model

- e and h are NOT localized in space
- Does not take into account Quantum Mechanics

E. Summary

- e & h classical particles with unit charge = $\pm 1.6X10^{-19}$ C

II. Generation and Recombination



Generation rate: G **units: cm^{-3} s^{-1}** **(thermal, optical processes)**

$$G = G_{th}(T) + G_{op}$$

- Independent of n & p since atomic density >> n,p

Recombination rate: $R \propto n \cdot p$

- n = electron concentration cm^{-3}
- p = hole concentration cm^{-3}

Steady State G=R

$$n \cdot p = \frac{G_{th}(T) + G_{op}}{k}$$

III. Thermal Equilibrium

Absense of External Energy Sources-Finite Temperature

PLUS Steady State

$G_o = R_o$ subscript "o" indicates thermal equilibrium

$$n_o \cdot p_o = \frac{G_{th}^{o}(T) + G_{op}^{o}(T)}{k_o}$$

$$n_o \cdot p_o = n_i^2(T)$$

$n_o\, p_o$ = constant = $n_i^2 = 10^{20}$ $(\text{cm}^{-3})^2$ at room temperature

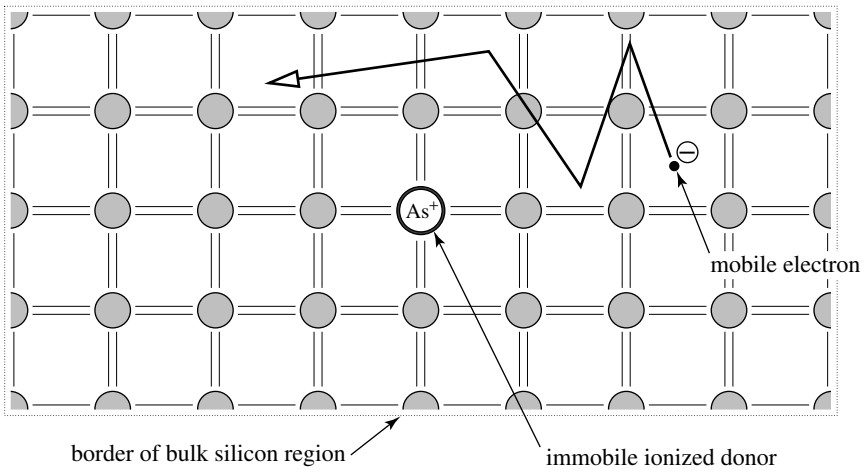
Since holes and electrons are created together in intrinsic silicon,

$n_o = p_o$ which implies that both are equal to $n_i = 10^{10}$ cm^{-3}

IV. Doping

A. Donors

- Donors (group V) *donate* their 5^{th} valence electron and become fixed positive charges in the lattice.
- Examples: Arsenic, Phosphorus.



- Donor concentration is N_d (cm^{-3})
- Assume $N_d >> n_i$ and all donors ionized- typical for room temp.
- One electron is added per donor:

$$n_o = N_d$$

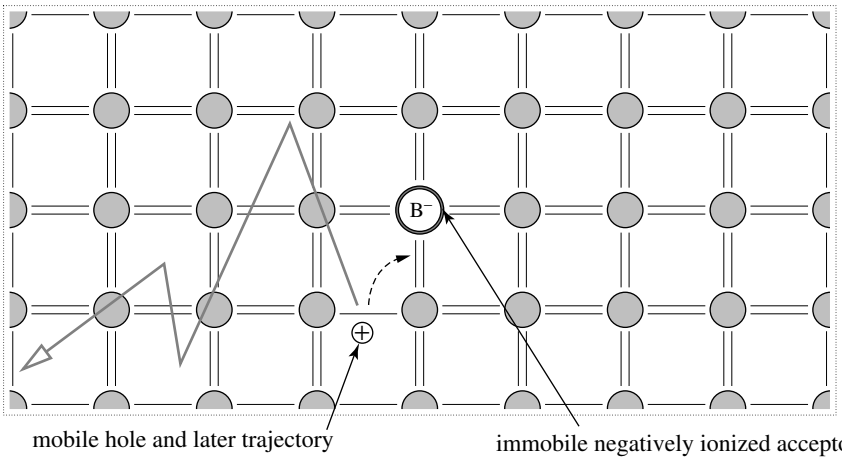
- Equilibrium hole concentration is:

$$p_o = n_i^2 / N_d$$

- If $N_d >> n_i$ ----> $n_o >> p_o$ ----> n-type semiconductor

B. Acceptors

- Acceptors (group III) *accept* an electron from the lattice to fill the incomplete fourth covalent bond
- a mobile hole and fixed negative charge results
- Example: Boron.



- Acceptor concentration is N_a (cm^{-3})
- Assume $N_a >> n_i$ and all acceptors ionized- typical for room temp.
- One hole is added per acceptor:

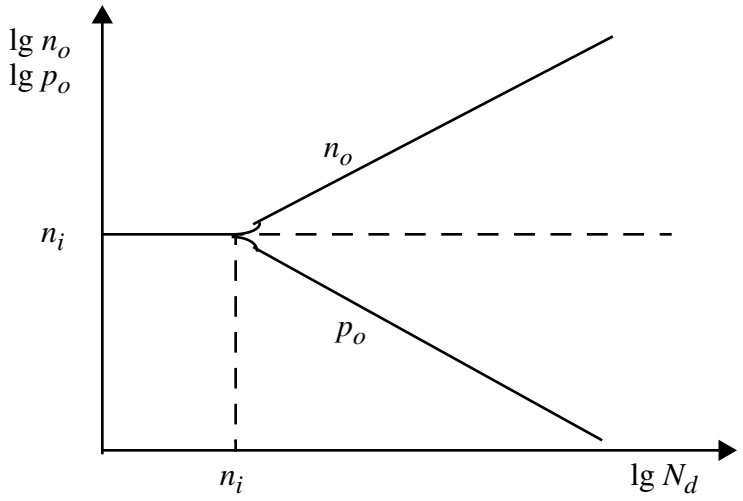
$$p_o = N_a$$

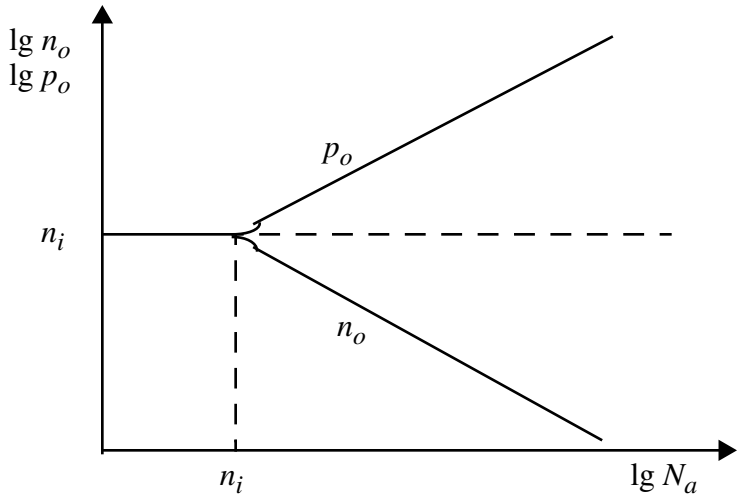
- Equilibrium electron concentration is:

$$n_o = n_i^2 / N_a$$

- If $N_a >> n_i$ ---> $p_o >> n_o$ ---> p-type semiconductor

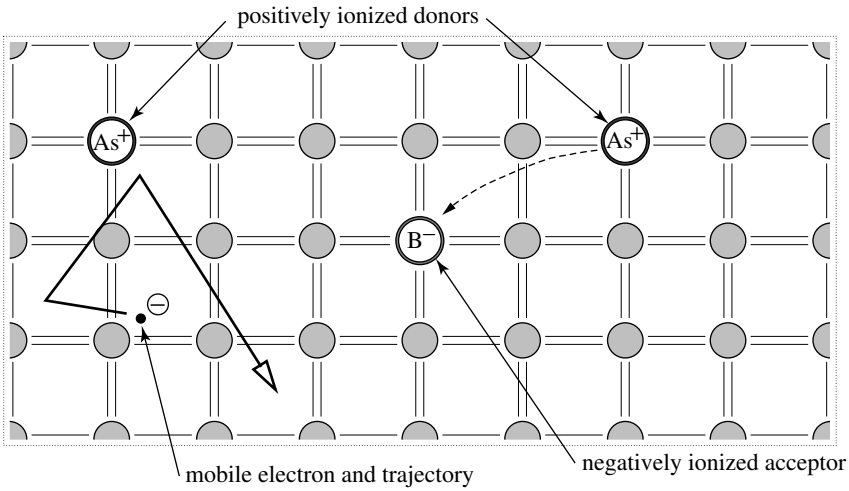
C. Graphical Viewpoint





D. Compensation

- Both Donors and Acceptors Present



- Larger Number Dominates
- N_d-N_a>>n_i

Example:

Given N_d=10^{16} cm^{-3}, N_a=10^{15} cm^{-3}

N_d-N_a = 9X10^{15} cm^{-3}

n_o ~ 9X10^{15} cm^{-3}

p_o ~ n_i^2/(N_d-N_a) = 1.1X10^4 cm^{-3}

E. Charge Neutrality

$$\rho = q(p_o - n_o + N_d - N_a) = 0$$

- If $N_d = 10^{15}$ cm^{-3} and $N_a = 0$
- $n_o \sim 10^{15}$ cm^{-3} and $p_o \sim 10^5$ cm^{-3} since $n_o p_o = n_i^2$
- **BUT** Charge Neutrality says $p_o = 0$??

This is only a problem when $N_d \sim n_i$