R. T. Howe

Lecture 7

- Last time:
  - Underdamped 2^{nd} order transfer functions
- Today :
  - Bode plots for general transfer functions
  - Start: semiconductor properties of Si

H&S Chapter 2

Electronic Properties of Silicon

- Silicon is in Group IV
  - Electronic structure: $1s^2 2s^2 2p^6 3(sp)^4$ C, Ge
  - Diamond lattice, with 0.235 nm bond length
- Very poor conductor at room temperature: why?

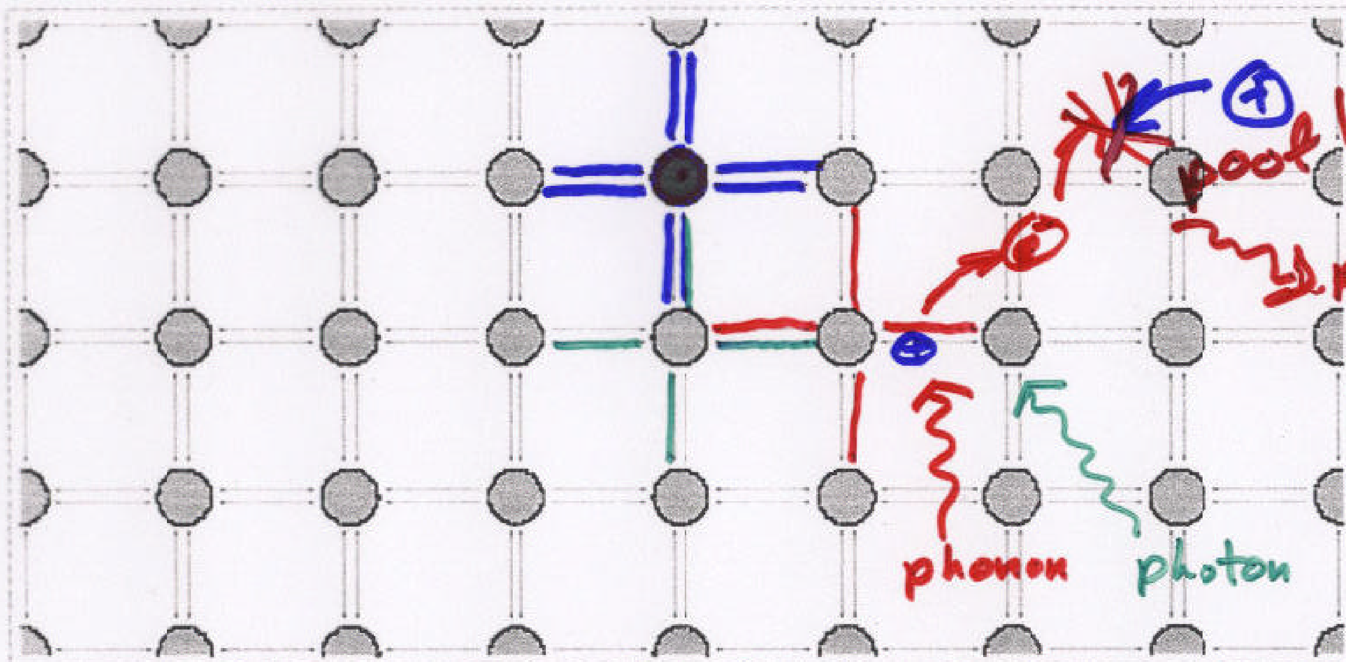
nm 10^{-9} m

Å 10^{-10} m

μm 10^{-6} m

Bond Model for Silicon

$0°K$ $\rho \to \infty$



At R.T. ~ 300°K very few free carriers

0° → 50 → 100°C

Thermal Equilibrium (Pure Si)

- Balance between generation and recombination determines $n_o = p_o$ ← TE

n = # elec/cm^3

p = # holes/cm^3

- Strong function of temperature: $T = 300$ K

$G(T)$ at a given temp G = const

$R = K(n \cdot p)$

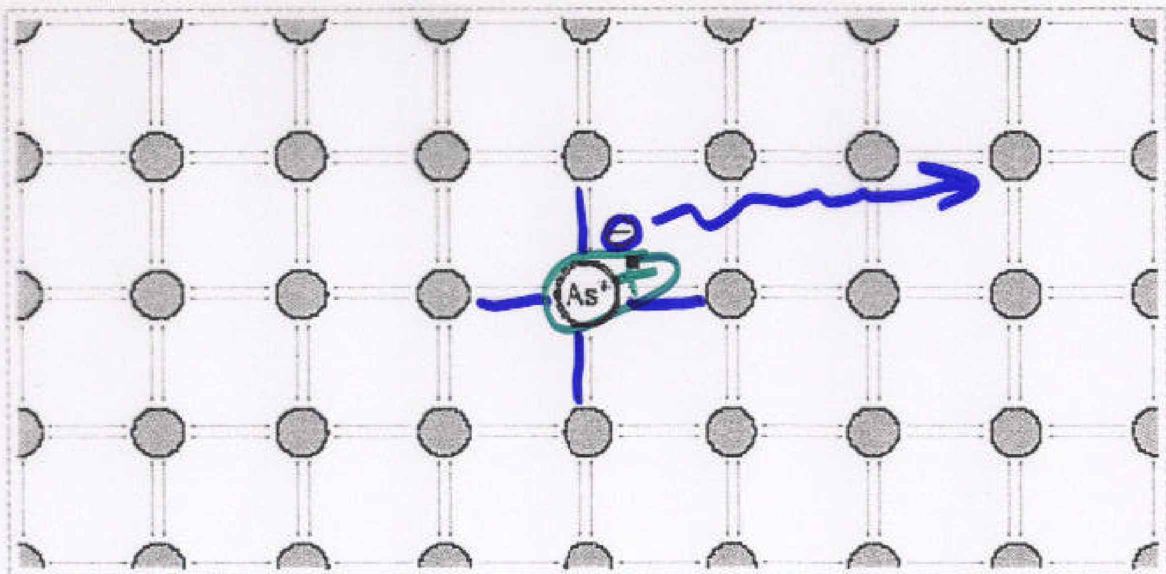
at T.E. $G = R$ = const

$\Rightarrow n_o \cdot p_o$ = const

Doping with Group V Elements

phosphorus – Arsenic; 5 valence electrons

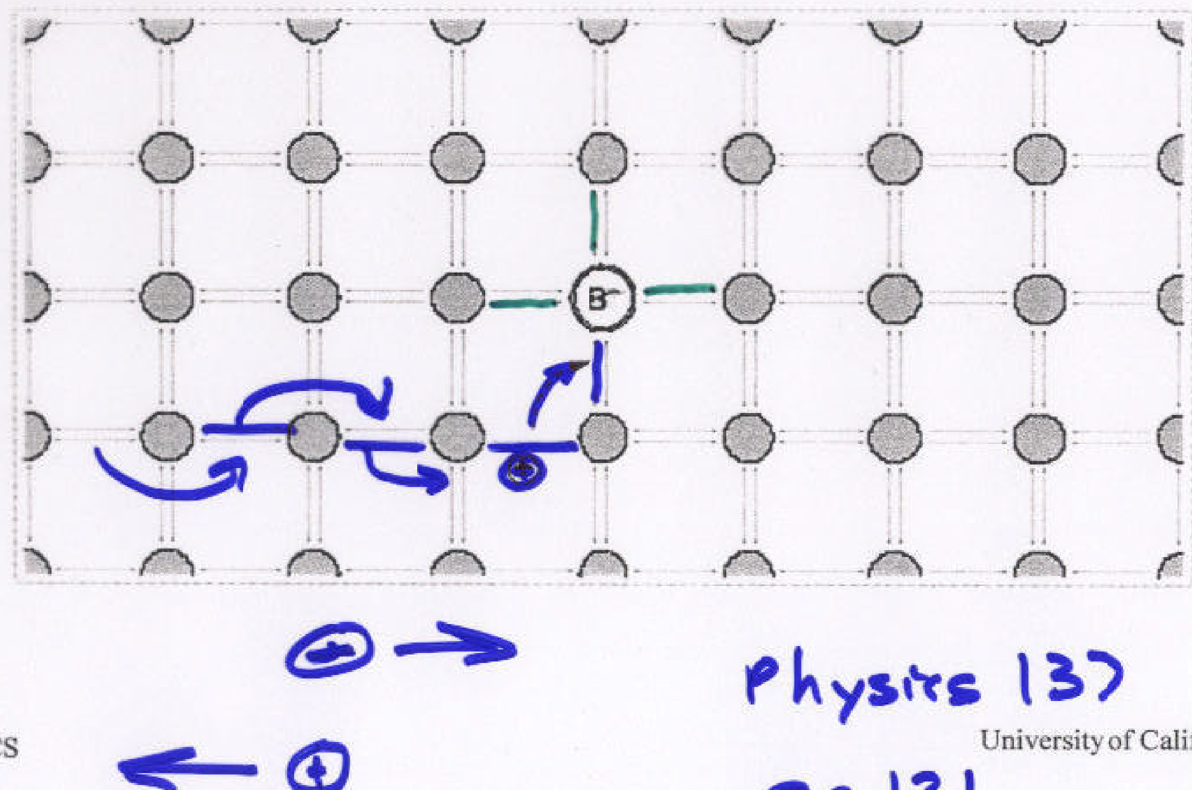
- P, As: extra bonding electron … lost to crystal at room temperature



Doping with Group III Elements

3 valence electrons

- Boron: 3 bonding electrons → one bond is unsaturated



Physics 137

ee 131

Mass Action Law

- Balance between generation and recombination:

$p_o \times n_o = \text{const}$

$$\boxed{p_o \cdot n_o = n_i^2} = 10^{+20}$$ intrinsic

$n_i = p_i \cong 10^{+10}\ \text{cm}^{-3}$

- N-type case: $n_o \simeq N_d$

$$p_o = \frac{n_i^2}{N_d}$$

N_d # donors/cm^3

N_d $10^{+14} \rightarrow 10^{19}\ \text{cm}^{-3}$

$N_d = 10^{16}$

$n_o = 10^{16}$

$$p_o = \frac{10^{20}}{10^{16}} = 10^{4}\ \text{cm}^{-3}$$

n-type

- P-type case:

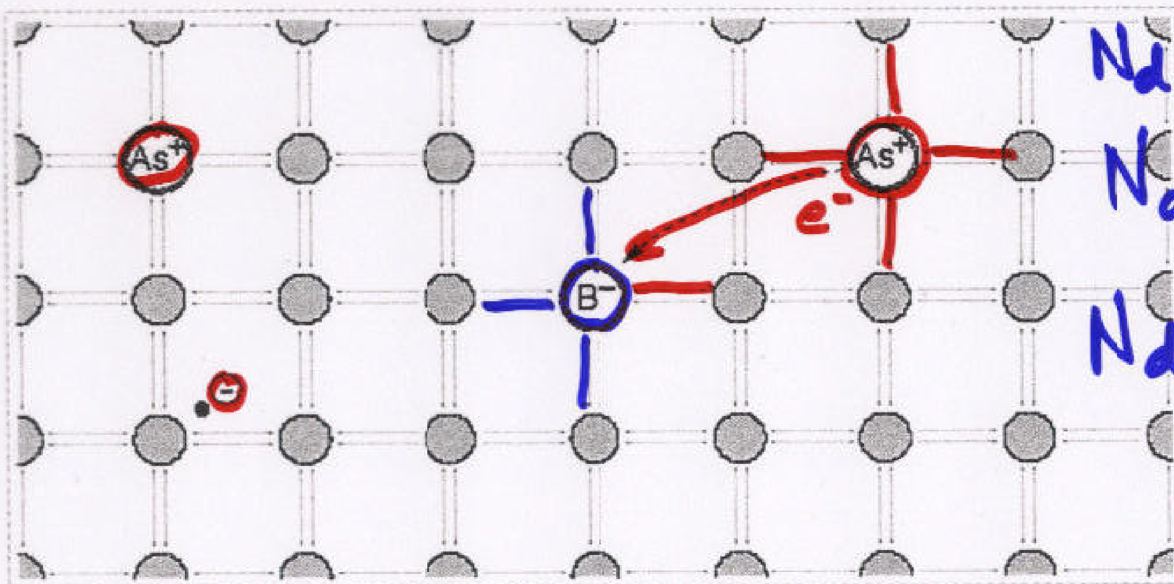
$p_o = N_a$

$$n_o = \frac{n_i^2}{N_a}$$

N_a = # acceptors per cm^3 ← acceptors

Compensation

- Dope with *both* donors and acceptors



$N_d \approx 10^{16}\ cm^{-3}$

$N_a \approx 10^{16}\ cm^{-3}$

$N_d = 1.001 \times 10^{16}$

$N_a = .999 \times 10^{16}$

$N_d - N_a = 2 \times 10^{13}\ cm^{-3}$

$\gg n_i = 10^{10}$

 Hard messy formula

Compensation (cont.)

$N_d - N_a \gg n_i$

$N_a - N_d \gg n_i$

- More donors than acceptors: $N_d > N_a$

$$n_o = N_d - N_a \qquad p_o = \frac{n_i^2}{N_d - N_a}$$

$p_o n_o = n_i^2$ Mass Action

- ~~Hole concentration:~~ More acceptors than donors $N_a > N_d$

$$p_o = N_a - N_d$$

$$n_o = \frac{n_i^2}{N_a - N_d}$$

$n_o \Rightarrow \rho \Rightarrow R$