Lecture 8

• Last time:
  – Bode plots for general transfer functions
  – Start: semiconductor properties of Si

• Today:
  – Compensation
  – Majority and minority carriers
  – Drift current density
Announcements:

12:00 noon TODAY MOMENT OF SILENCE
12:00 noon MONDAY MEMORIAL GLADE

CLASSES SUSPENDED 12-2 MONDAY

MY OH MONDAY 4 -> 5:30

*GREEN SPACE N.W. OF CAMPANILE?

(DOE LIBRARY)

MONDAY LATE 12-3 SECTION CANCELLED.
Doping with Group V Elements

- P, As: extra bonding electron ... "lost to crystal at room temperature"
Doping with Group III Elements

- **Boron** 3 bonding electrons → one bond is unsaturated

*Acceptors*

**MOBILE** "Hole"

**Bond-breaking origin** "The hole"

→ Few 2 Book
Mass Action Law

- Balance between generation and recombination:
  \[ p_0 \cdot n_0 = n_i^2 \]

- N-type case:
  \[ n_0 = N_d \approx \text{#}/\text{cm}^3 \text{ holes} \]
  \[ n_0 = N_a \Rightarrow n_0 = N_a \ldots \]

- P-type case:
  \[ N_a \Rightarrow 10^{13} - 10^{17} \]

\[ N_i^2 \approx (10^{10} \text{ cm}^{-3})^2 \]
\[ T = 300 \text{ K} \]
\[ n_0 = n_d \quad \text{"One mobile electron donated per donor"} \]

\[ p_0 = ? \]

\[ n_0 p_0 = n_i^2 \quad \Rightarrow \quad p_0 = \frac{n_i^2}{n_d} \]

\[ n_i = (10^8)^2 \quad \Rightarrow \quad n_d = 10^{17} \text{ cm}^{-3} \]

\[ p_0 = \frac{(10^8)^2}{10^{17}} = 10^3 \text{ cm}^{-3} \]

\[ n_0 = \text{N-type!} \]

\[ p_0 \ll n_d \quad \text{"Given"} \]

\[ n_0 = \frac{n_i^2}{n_d} \quad \text{"One hole per acceptor"} \]

\[ n_0 = \frac{n_i^2}{n_d} \quad \text{Small}. \]
Compensation

- Dope with both donors and acceptors

\[ N_d + p_0 = \text{constant} \]

\[ N_d = 2N_0 \]

\[ 1.01 \times 10^{16} - 9.99 \times 10^{15} = 0.02 \times 10^{16} = 2 \times 10^{14} \]

\[ N_0 f 10^{16} = 1.000000 \times 10^{16} \]

\[ N_d f 10^{16} = 1.000000 \times 10^{16} \]

\[ \text{SUBTRACT} \Rightarrow \text{MAJORITY TYPED AS} \Rightarrow \text{MINORITY} \]

\[ \text{WE NEVER HAVE } N_d = N_0 . \]
Compensation (cont.)

- More donors than acceptors: \( N_d > N_a \)
  \[ n_0 = \frac{N_d - N_a}{N_d - N_a} \]
  \[ p_0 = \frac{n_i}{N_d - N_a} \]

- Hole concentration:
  \[ p_0 = \]

\[ n_0 = \frac{N_a - N_i}{N_a - N_a} \] \( \text{(SMILE)} \)

\[ n_i = \frac{10^{10}}{\text{cm}^{-3}} \]

\[ N_a, N_d \approx n_i \ldots \]

\[ \text{NEED TO CONSIDER} \]

\[ N_d > N_i \ldots \]

\[ \text{SEE H&S 2.0} \]
**Pure Si:** $n_0 = p_0 = n_i$.

[Thermal Equilibrium]

Rapid, random motion of holes and electrons at "thermal velocity" $v_{th} = 10^7$ cm/s with collisions every $\tau_c = 10^{-13}$ s.

\[ \frac{1}{2}mv^2 = K.E. = \frac{1}{2} kT \]

Apply an electric field $E$ and charge carriers accelerated ... for $\tau_c$ seconds

**Holes**

*Zero $E$ field*

$V_i$

Positive $E$

$V_i$

(hole case)

\[ E = \frac{AV}{L} = \frac{5V}{L} \]

$E \Rightarrow E > 0$. $g = 9.5 \times 10^{-3}$
Drift Velocity and Mobility

\[ v_{dr} = a \cdot \tau_c = \left( \frac{F_e}{m_p} \right) \tau_c = \left( \frac{qE}{m_p} \right) \tau_c = \left( \frac{q\tau_c}{m_p} \right) E \]

For electrons:

\[ F_e = -qE \quad \text{MOBILITY} \]

\[ v_{dr} = -\mu_n E \quad \text{electrons} \]

\[ v_{dr} = \mu_p E \]

\[ f(T, N_d, N_a) \]

\[ m_p = (0.58) m_0 \quad \text{electron} \]