Lecture 2

• Last time:
  – Course introduction
  – Start: semiconductor properties of Si

• Today:
  – Drift velocity
  – Drift current density
  – Resistivity and resistance; the IC resistor
Thermal Equilibrium

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

Apply an electric field \( E \) and charge carriers accelerate … for \( \tau_c \) seconds

![Diagram of hole case](image)

zero \( E \) field

positive \( E \)

(hole case)
**Drift Velocity and Mobility**

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

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

For electrons:
Mobility vs. Doping in Silicon at 300 K

“default” values:
Velocity Saturation

![Graph showing velocity saturation with axes labeled as follows:]

- $V_{dn}$ and $V_{dp}$ in cm/s
- $E$ in V/cm

- Two curves: one for electrons and one for holes
Drift Current Density (Holes)

Hole case: drift velocity is in same direction as \( E \)

The hole drift current density is:

\[
J_p^{dr} = q_p \mu_p E
\]
Drift Current Density (Electrons)

Electron case: drift velocity is in \textit{opposite} direction as $E$

The electron drift current density is:

$$J_n^{dr} = (-q) \ n \ v_{dn}$$

units: Ccm$^{-2}$ s$^{-1}$ = Acm$^{-2}$
Resistivity

*Bulk silicon*: uniform doping concentration, away from surfaces

n-type example: in equilibrium, \( n_o = N_d \).

When we apply an electric field, \( n = N_d \).

\[
J_n = q\mu_n nE = q\mu_n N_d E
\]

Conductivity \( \sigma_n = \)

Resistivity \( \rho_n = \)
Ohm’s Law

- Current $I$ in terms of $J_n$
- Voltage $V$ in terms of electric field

– Result for $R$
Sheet Resistance

- IC resistors have a specified thickness – not under the control of the circuit designer
- Eliminate $t$ by absorbing it into a new parameter: the sheet resistance

\[ R = \frac{\rho L}{Wt} = \left( \frac{\rho}{t} \right) \left( \frac{L}{W} \right) = R_{sq} \left( \frac{L}{W} \right) \]
Using Sheet Resistance

- Ion-implanted (or “diffused”) IC resistor
Idealizations

• Why does current density $J_n$ “turn”?
• What is the thickness of the resistor?
• What is the effect of the contact regions?