EE 40

11/14 – Discussion – Semiconductor Physics

- Silicon (Intrinsic):
  - Bond Model – ok + increasing temperature
  - Electrons, holes

- Doping (Conductive):
  - n-type – majority carriers are electrons
  - p-type – majority carriers are holes

- Band Diagrams
  - Conduction band, valence band, bandgap
  - Conductors – $E_c + E_v$ overlap
  - Insulators – large bandgap ~ 8 eV
  - Semiconductors – small bandgap ~ 1 eV

- Fermi Level/Energy:
  - Fermi function – Probability function of finding electrons at a specified energy level
  - Fermi level – Energy level at which the probability of finding an electron is 1/2. So, when $E = E_f$, $f(E) = 1/2$ where $f(E)$ is Fermi function.

- Fermi Level + Band Diagram:
  - Is $E_f$ closer to $E_c$ or $E_v$ for n-type silicon?
    - Hint: There are more electrons in conduction band in n-type silicon.
    - Answer: $E_f$ is closer to $E_c$ for n-type Si.
    - $E_f$ is closer to $E_v$ for p-type Si.

- Drawing Band Diagrams for different dopants:
  - Light-doped with As
  - Heavy-doped with As
  - Light-doped with B
  - Heavy-doped with B
PN Junctions
- p-type Si placed next to n-type Si.

- What do the Band Diagrams look like?

- What does the above figure tell us about:
  Due to
  1. Currents - Types of currents
  2. Electric Fields
  3. Potential

Currents - Drift & Diffusion
- Drift - caused by $E$-field
  - holes move in the direction of $E$-field
  - electrons move in the direction opposite of $E$-field
  - $E$-field always points from high potential (+ charges) to low potential (- charges)
- Diffusion - caused by concentration gradients
  - particles like to move from areas of high concentration to those of low concentration

$J_p$ → current flow associated with hole movement is in the same direction as hole movement.

$J_{in}$ → current flow associated with electron movement is in the opposite direction as electron movement.
Electric Fields:
- Caused by the depletion region
- Depletion Region:
  - Assume the region near the interface is completely depleted of mobile carriers.
  - So: no holes or electrons near the junction.

- Which direction does the E-field point?
  - Hint: from positive to negative.

Band Diagrams Revisited:
- Electrons travel towards lower energy levels
- Holes travel towards higher energy levels

- Draw the drift + diffusion components for holes + electrons.

So Far \( V_A \), the applied bias, was 0 V.

What happens when you apply a bias, i.e. when \( V_A \neq 0 \)?
$V_A > 0$:
- Applying positive potential on the p-side.
- Applied $E$-field is against the built-in $E$-field.

$E_{F_0}$

$E_{F_1}$

$E_C$

$E_V$

$E_{diff}$

$E_{drift}$

$I_{n,diff}$

$I_{p,drift}$

$I_{p,diff}$

$E$-field decreases

Net current flow — large

$V_A < 0$:
- Applying positive potential on the n-side.
- Applied $E$-field is in the same direction as the built-in $E$-field.

$E_{F_0}$

$E_{F_1}$

$E_C$

$E_V$

$E_{diff}$

$E_{drift}$

$I_{n,drift}$

$I_{p,diff}$

$I_{p,drift}$

$E$-field increases

Net current flow — Small

Even though $E$-field increases, the drift component of the total current does not increase. Why?
- Hint: Drift, in a PN Junction, is associated with minority carriers. Because there are few of them, the current related to them is small.