P-N Junction Diodes

How do they work?
(postponing the math)

Chap. 5.2

Diode: Why we need to understand diode?

- The base emitter junction of the BJT behaves as a forward bias diode in amplifying applications.
- The behavior of the diode when reverse bias is the key to the fabrication of the integrated circuits.
- The diode is used in many important nonamplifier applications.

Chapter-2: Diode circuits

Creating a Diode

- One single semiconductor crystal, part n-type and part p-type material.

The p-n Junction

- Concentration gradients of holes and electrons near the junction plane.
- Holes diffuse from p-type to n-type.
- Electrons diffuse from n-type to p-type.
- Result — a separation of charge and a potential barrier.

p-n Junction Diode

p-Type Material

n-Type Material

p-n Junction
A p-n junction diode is made by forming a p-type region of material directly next to a n-type region.

**Built-in barrier potential**

Calculated as follows:

\[ V_{bi} = V_T \ln \frac{N_A N_D}{n_i^2} \]

where

\[ V_T = \frac{kT}{q} = \text{thermal voltage} \]
In regions far away from the “junction” the band diagram must be flat! We can then fill in the junction region of the band diagram as:

But when the device has no external applied forces, no current can flow. Thus, the Fermi-level must be flat!
p-n Junction Diode

- **Built-in-potential**

  - *p*-Type Material
    - $E_c$
  - *n*-Type Material
    - $E_v$

  - Electrostatic Potential
    - $V = \frac{1}{q}(E_c - E_v)$

  - Built-in-potential
    - $V_{bi}$

- **Electric Field**

  - $E = -\frac{dV}{dx}$

  - Charge Density
    - $\rho = qN_D - qN_A$

- **Poisson’s Equation**

  - $\nabla \cdot E = \frac{\rho}{K_S \cdot \varepsilon_0}$
  - $\frac{dE}{dx} = \frac{\rho}{K_S \cdot \varepsilon_0}$ in 1-dimension

- **Built-in-potential**

  - Electrostatic Potential
    - $V = \frac{1}{q}(E_c - E_v)$

  - Built-in-potential
    - $V_{bi}$
p-n Junction Diode

Energy
\[ \frac{1}{q} \]

Potential
\[ \frac{dV}{dx} \]

Electrical Field
\[ K_s \cdot \varepsilon_0 \frac{dE}{dx} \]

Charge Density

Electron Potential Energy \( PE(x) \)

Space charge region

Metallurgical Junction

Neutral p-region

Neutral n-region

Neutral n-region

Neutral p-region

Hole Potential Energy \( PE(x) \)

p-n Junction Principles