

EE Notes

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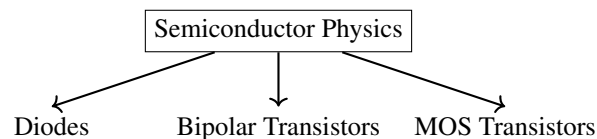
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1. ch1: finishing doping section and practice problems another time. skipped over donors/holes concept
2. Chapter 4 diodes
3. Chapter 5 mos
4. Chapter 6 bjts are optional header
5. Chapter 8 integrated circuit amplifiers
6. dead week planning
 - (a) monday: lec2-6
 - (b) tuesday: lec7-11, end of lec14-16
 - (c) Wednesday

1.1 Charge Carriers and Doping

1.1.1 Introduction

We start learning about resistors, capacitors, and inductors from earlier courses such as EECS 16A and 16B. With more components like transistors, diodes, and op-amps (which are all based on semiconductors), we are able to expand upon circuit design. We need to understand semiconductor physics in order to understand how these components operate.



We can also redefine Ohm's Law which we know as $(V = IR)$ as $J = \sigma \mathbf{E}$. We can also write resistance(R) and conductance(G) in terms of other variables

- J : current density, A/m^2 (Amperes per meter squared)
- σ : conductivity, S/m (Siemens per meter)
- \mathbf{E} : electric field, V/m (Volts per meter)

$$R = \frac{R}{L} = \rho \frac{L}{A} \text{ and } G = R^{-1} = \sigma \frac{A}{L}$$

- σ : conductivity
- ρ : resistivity

For collisions in gas, we focus on the idea that initial velocity and direction is lost/randomized after a few collisions. So, when we sum over the random velocities of the particles and average it, it comes out to zero. Average momentum gain is:

$$\bar{\mu} = \frac{\mathbf{E}q\tau}{M} = \mu\mathbf{E}, \quad \mu := \frac{q\tau}{M} = \frac{\bar{v}}{\mathbf{E}}$$

- μ : mobility, $m^2/(V \cdot s)$
- q : electric charge, 1.60×10^{-19} , Coulombs = Amperes/second
- τ : mean free time
- M : mass
- \bar{v} : average velocity

Different elements have a different number of outer shell electrons. For semiconductors like silicon, we can increase the temperature to increase its conductivity. Silicon atoms are arranged in a diamond structure and in general, the energy levels that an atom can occupy are discrete. The **valence band** electrons are at a lower energy state (bound to host atoms) while **conduction band** electrons are at a higher energy state and are "free" electrons. These electrons are free to move around the crystal and take part in conduction.

1.1.2 Conduction and Fermi Dirac Distribution

Thermal energy is on average about $\sim 26 \text{ eV}$ at room temperature. How large the **band-gap**, the gap between the conduction and valence band, determines how conductive a material is:

- Insulators: band gap $\sim 15 \text{ eV}$
 - Glass, rubber, oil, plastic, diamond
- Semiconductors: band gap $\sim 1 \text{ eV}$
 - Silicon = 1.12 eV
- Conductors: Not applicable due to overlapping conduction/valence bands

Because electrons are a type of particle called a **fermion**, we can say that

$$f(\epsilon) = \frac{1}{e^{\frac{E - E_F}{k_B T}} + 1}$$

- $f(\epsilon)$: occupational probability of a state energy ϵ
- E_F : fermi energy, eV
- k_B : Boltzmann's constant, $1.380649 \times 10^{-23} \text{ J/K}$ (Joules per Kelvin)
- T : temperature in Kelvin

1.1.3 Doping

Doping is defined as introducing impurities inside a silicon crystal to adjust the number of free electrons that we have. The following materials are commonly used:

- Group III elements: boron, aluminum, gallium \rightarrow acceptors
- Group IV elements: germanium and silicon
- Group V elements: phosphorus, arsenic, antimony \rightarrow donors

Sometimes we assume that the number of electrons we add is much greater than the original free electrons that pure silicon had (10^{10} per cubic centimeter). This leads to the simplification that the number of free electrons in our silicon crystal is N_D , where N_D is the number of donor atoms that we add per cubic centimeter.

1.1.4 Practice Problems

1.1.5 Sources

- [Razavi Electronics 1, Lec 1, Intro., Charge Carriers, Doping](#)
- EE105 Reader

- Sedra, Adel S., et al. Microelectronic Circuits. Oxford University Press, 2021
- Engineering LibreTexts: The Fermi-Dirac Distribution

1.2 Drift and Diffusion Current

1.2.1 Practice Problems

1.2.2 Sources

- [Razavi Electronics 1, Lec 2. Doping, Drift](#)
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- EE105 Reader

1.3 EE105 04/09/2024 Lecture: Back-gate effect

The source and drain in a MOSFET are symmetric. For the most part, we haven't worried about the body electrode up until this point