# EE Notes

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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
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5. Chapter 8 integrated circuit amplifiers
6. dead week planning
   (a) monday: lec2-6
   (b) tuesday: lec7-11, end of lec14-16
   (c) Wedesnday

## 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.

$$\begin{tikzcd} & \boxed{\text{Semiconductor Physics}} \arrow[dl] \arrow[d] \arrow[dr] & \\ \text{Diodes} & \text{Bipolar Transistors} & \text{MOS Transistors} \end{tikzcd}$$

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)
- $\sigma$: conductivity, $S/m$ (Siemens per meter)
- $\mathbf{E}$: electric field, $V/m$ (Volts per meter)

$R = \frac{R}{I} = \rho\frac{l}{A}$ and $G = R^{-1} = \sigma\frac{A}{l}$

- $\sigma$: conductivity
- $\rho$: 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:

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

- $\mu$: mobility, $m^2/(V \cdot s)$
- $q$: electric charge, $1.60 \times 10^{-19}$, Coulombs = Amperes/second
- $\tau$: 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 $eV$ 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 $eV$
  - Glass, rubber, oil, plastic, diamond
- Semiconductors: band gap $\sim 1eV$
  - 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 $\epsilon$
- $E_F$: fermi energy, $eV$
- $k_B$: Boltzmann's constant, $1.380649 \times 10^{-23} J/K$ (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
- 
- 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