Mobility and Scattering Lesson

Lesson Topic: Mobility and Scattering

Objective of Lesson: To learn about mobility and scattering, how they are related, and how they are important in semiconductors.

Reading Assignment: Section 3.1.3

Discussion Questions:

1. How does scattering impact mobility?
2. What is responsible for scattering?
3. How does a change in temperature impact scattering?
4. How does a change in temperature impact mobility?
5. How does a change in doping impact scattering?
6. How does a change in doping impact mobility?

Homework: None

What do you need to know for the exam?

1. Discussion questions

Summary
Mobility is a measure of the ability of an electron or a hole to get around inside a semiconductor. Scattering events lower mobility. This lesson explains this relationship further.

Mobility and Scattering
Mobility is a measure of the ability of an electron or a hole to get around inside a semiconductor. It is a “constant” for a particular situation—a “situation” meaning a particular temperature and doping concentration. We treat it as a constant because we cannot solve any problems on paper (without a computer simulator) unless the mobility and diffusion constants are constant in value.

Mobility was defined as a result of Figure 3.4—it was noted that the drift velocity could be replaced with a constant times the electric field. Given a particular electric field, an electron or hole moves faster with the field if it has a higher mobility than if it has a lower mobility. Mobility has units $cm^2/V*s$; those units come about from the need to balance the units on both sides of the defining mobility equations,

$v_d = \mu_n \mathcal{E}$ and $v_d = \mu_p \mathcal{E}$

Scattering is what determines how responsive carriers are in a semiconductor. A scattering event is when an electron (or a hole, but let's just mention the electrons for now and keep in mind that everything we say for electrons is valid for holes) bumps into something such that it changes its direction, momentum, and/or energy. An electron can bump into other electrons, holes, ionized impurities, and into phonons—lattice vibrations. Obviously, the more of those things there are around, the more frequent the scattering events.

Imagine an electron in a semiconductor without an electric field. That electron will move randomly about, hither and thither, continuously—and it will move very fast (the thermal velocity, the average velocity of the many electrons, is 10^7 cm/s at room temperature). If an electric field is applied, a small part of the total motion of the electron will be due to drift velocity. The drift velocity comes about because of the force on the electron. The electron is accelerated opposite the direction of the field, and the acceleration continues until a scattering event randomizes the motion of the electron. It then starts again, being accelerated by the field. Clearly the drift velocity, the average velocity of the electron due to the field, will be higher if the electron has more time to accelerate between collisions—scattering events. The greater the frequency of scattering events, therefore, the lower the mobility.

Dope a semiconductor and the dopants become ionized (except at the lowest temperatures). A free electron passing near to an ionized impurity will be either pushed away or drawn nearer. This deflection is considered a scattering event so the greater the number of ionized impurities, the greater the scattering frequency—and the greater the scattering frequency, the lower the mobility.

As the temperature of a semiconductor increases, there will be more and more lattice vibrations. Lattice vibrations create localized, microscopic potentials that can change the direction of an electron. They create scattering events. They lower mobility. Raising the temperature of a semiconductor decreases the mobility.

There is one more subtle point to make about mobility dependencies. At very low temperatures there can be an increase in the scattering frequency for ionized impurities because the thermal velocity is reduced so they are more likely to be captured.

Definitions:

Mobility: Capable of moving or of being moved from place to place, moving quickly from one place to another; flowing freely.

Scattering: The act or process of separation or dispersing, the dispersal of a beam of particles or of radiation into a range of directions resulting from physical interactions.