ECE 30
Day 23 Notes

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Agenda

- Energy Bands
  - Insulators
  - Conductors
  - Semiconductors
- P and N Doped Silicon
  - The MOSFET

Energy Bands

Conductors are when the outer electron energy level is not empty. This allows electrons to move between atoms in a lattice when electric field is provided.

1. For electrons to move in a field, must have empty avalible states and allowed avalible states.

   When a band is full, electrons need sufficient energy to jump to next allowed band, otherwise they cannot move.
2. Each band has a limit on the number of electrons. For a structure with N atoms, s bands can hold 2N electrons, and p bands can hold 6N electrons.

Conductor:

Avalible states in partially filled bands.

When a voltage is applied electrons are accelerated resulting in a current.

For Sodium metal (11 electrons).

We have a 1S layer with two electrons, a 2S band with two electrons, 2P band with six electrons, 3S band with a single electron.

There is space in the outer band and there are electrons in the outer band, the material must be a conductor.

Insulator:

No avalible spaces in the upper band, if a voltage is applied no electrons can move.

If the voltage is high enough the electrons can be stripped off.

ex: Helium. (2 electrons)

First band 1S has two electrons which is full, the next band 2S is completely empty.

The first layer has no free states, and the outer band has no free electrons, therefore Helium is an insulator.

Semiconductor:

In some ways a midpoint between Conductors and Insulators. All semiconductors are group four elements.

Known semiconductors are Silicon, Germainium, Carbon, etc.

If we graph Energy levels against Inter atomic distance we find something interesting. When they are far apart they have normal energy levels. As they form a crystal the 1S level becomes a band, like normal, but the 2S and 2P levels merge before separating around the table crystal lattice. This means that the energy bands are extremely close. We end up with four electrons in a new valence band, and no electrons in the conduction band.

Since the valence and conduction band are so close we can use a normal voltage to force electrons from the valence to the conduction band without completely ionizing the material.

The energy gap between the valence and conduction bands is known as E_g.

Here are the values for various semiconductors.

Silicon 1.1eV

Carbon 6eV

Germainium 0.7eV

This fact was used by Brattain, Bardeen, and Shockley to create the first Field Effect Transistors with Germainium.

Shockley was involved in the creation of Intel and Fairchild semiconductors which shaped computing for decades.

All three were working on semiconductors at Bell labs which was the R&D department of AT&T.

Minor Notes:

Holes: Normally we show the flow of positive current, however in real life only electrons exist which are negative. However mathematically the states where electrons could be, but aren't move just like electrons and can be treated as "positive" particles.

These missing electrons are positively charged, and disappear when meeting an electron.

Electron holes move in the opposite direction as electrons.

Holes behave exactly the same as electrons but with opposite charge. Which is extremely helpful for calculation.

Doped Silicon

All the group three atoms have one less electrons in their outer shell, and all the group five atoms have one additional electron in their outer shell.

By inserting group three or group four electrons in the semiconductor lattice, we can change the charge of the structure.

N-type silicon is created with Phosphorus usually and adds a free electron which hovers just below the conduction band meaning it is really easy to conduct.

Around 10^{-2}eV below conduction band.

When electrons move because they are free no holes move. These are called majority carriers. N-type semiconductors are easily excited into conducting electrons.

When doping with a group three element we get P-type semiconductors which have opposite properties. Usually Boron or Arsenic is used.

To create these doped semiconductors gaseous group 3 or 4 elements are diffused into Silicon at extremely high temperature, using photo lithography to control which portions are doped using which element. Alternate method is ion implantation where you ionize the gas first.

MOSFET (Metal Oxide Semiconductor Field Effect Transistor)

Using a P type substrate with two N type portions embedded on the surface. One is the drain and on is the source.

We then cover the surface with Silicon dioxide which is a dielectric, and on top of the Dielectric layer we put some metal which is usually doped polysilicon, this is called the Gate.

The Gate is connected to a variable voltage source, which we can control. The substrate is connected to ground.

The drain is connected to a resistor and then ground. The source is connected to ground.

If the gate is at zero nothing conducts, if we apply a voltage to the gate, a negative charge is created between the source and drain creating a channel allowing for the source and drain to conduce electrically.

If we reverse the n and p silicon we get the opposite behavior.