Unit 1: Introduction to Electronics

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Text: *Electronic Devices* by Floyd

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Introduction

- **"*Electronics*" is a field of study of physical mechanisms involving electrons**
- **The "*electron*" was discovered in the 1890's by separate researchers performing experiments with the current in a vacuum tube.**

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Topics of Discussion

- **Brief history and need for amplification**
- **Silicon and Germanium: intrinsic, doping, N & P type**
- **The Diode: characteristics, forward and reverse bias, depletion region, temperature effects, specifications, and testing**

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History

- **Up until 1947, the electronic devices invented were primarily vacuum tubes of one kind or another**
  - → **1904 vacuum tube - used to detect electromagnetic**
  - → **1907 audion - a triode vacuum tube capable of**
- **Cartoon on vacuum tubes at www.pbs.org .**

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Solid State Electronics

- In 1947, the era of solid state electronics began with the invention of the transistor made from semiconductor material at Bell Labs
- Several advantages of solid state electronics over vacuum tube electronics
  - » smaller size
  - » lower power requirements
  - » integration

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Development of Solid State Electronics

- Brought about tremendous improvement in amplification and rectification circuitry
  - ➔amplification circuitry
    - » able to amplify small ac signals
  - ➔rectification circuitry
    - » convert standard ac signal (110V, 60 Hz) to a dc power supply

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Solid State Electronic Devices

- made of "*semiconductor*" material
- to understand "*semiconductor*" , need a basic knowledge of atomic structure and interaction

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Review of Atomic Terms

- atom - smallest particle of an element
- nucleus - in the center of the atom, contains the positively charged particles (protons) and uncharged particles (neutrons)
- electrons - negatively charged particles which orbit the nucleus

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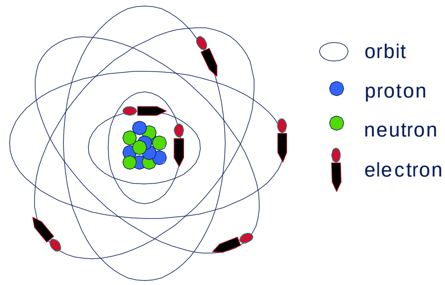
Review of Atomic Terms

- **neutral state - equal number of protons and electrons such that the net charge of the atom is zero**
- **atomic number - number of electrons in a neutral atom (same element, same atomic number)**
- **atomic weight - slightly greater than the sum of the number of protons and neutrons**

Bohr Model of an Atom



Energy Levels

- **Energy bands**
  - ➔**the electrons which orbit around the nucleus have specific and discrete allowable orbits**
  - ➔**the orbits are grouped into energy bands known as shells**
  - ➔**the number of electrons in each shell is set by physics and studied in chemistry**
- **Each electron has a unique energy level**
  - ➔**energy increases with increasing distance from the nucleus**

Valence Shell

- **Valence electrons**
  - ➔**orbit in the valence shell (the energy band furthest away from the nucleus).**
  - ➔**most loosely bound to the atom**
  - ➔**have the highest energy among bound electrons**
  - ➔**contribute to chemical reactions and bonding in materials**
- **The periodic table column an element is in indicates the number of electrons in its valence shell. (see periodic table)**
- **Atoms/molecules with 8 electrons in its valence shell are not interested in any interaction.**

Free Electrons

- **When atoms absorb energy (i.e.. from heat or light), the energy levels of the electrons are raised ... the atom is "*excited* ".**
- **A really "*excited* " valence electron may acquire enough energy to free itself from the atom, becoming a *free electron in the conduction band.***
  - **➔Conduction band electrons have more energy than bound electrons.**

Chemical Interactions

- **Atoms have chemical interactions in order to fill the outer valence shell.**
- **There are two basic kinds of chemical interactions (or bonds):**
  - **➔Ionic**
    - **» involves acquiring or releasing free electrons**
  - **➔Covalent**
    - **» involves sharing of valence electrons**

Ionization

- **Ionization is the process of either gaining or losing valence electrons**
  - **➔losing electron --> produces net positive charge**
    --> positive ion
  - **➔gaining electron --> produces net negative charge**
    --> negative ion

Materials

- **Materials can be distinguished by the types of chemical bonds they make.**
- **Materials can be classified by their ability to conduct electricity.**
  - **➔Since conducting electricity requires free electrons then conductors, semiconductors, and insulators can be identified by their ability to generate free electrons.**

Material Comparison

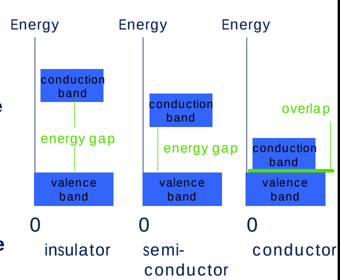
Conductors	Insulators	Semiconductors
easily conducts electrical current	does not conduct electrical current	between conductors and insulators in its ability to conduct electrical current
best conductors are single element materials with only 1 or 2 very loosely bound valence electrons	generally compounds with tightly bound valence electrons	most common are single element semiconductors having 4 valence electrons
doesn't take much to generate many free electrons	takes break down of material to produce free elctrons	
ex/ copper, silver, gold, aluminum		ex/silicon, germanium, carbon

Energy Gap

- **A distinguishing atomic *difference* between materials is the size of the energy gap.**
- **The energy difference between the valence and conduction bands is the Energy Gap …**
  "*The gap to cross into freedom*".

Distinguishing Energy Gaps

- **So what's the *difference* ?**
  - **➔insulators - insurmountable energy gap, NO free electrons**
  - **➔semiconductors - narrow energy gap, some free electrons**
  - **➔conductors - overlapping valence and conduction bands, no gap, MANY free electrons**



More on the Energy Gap

- **The energy gap is a physical characteristic of a material and varies from one material to the next.**
- **Within the classification of semiconductors, the size of the energy gap is one of the deciding factors as to which material is to be used for a given application.**
- **Compare Silicon and Germanium**
  - **➔See figure 1-7, Floyd**
  - **➔Which would have the larger energy gap?**

More Terms

- crystalline structure - a structure of at... which are arr... in a fixed pa...
- covalent bo... bond between ... the "s... valen... crystals ... together by covalent bonds
- int... rial ... no atom... s

How would the atoms be arranged in a silicon crystal? [See figures 1-8 and 1-9]

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Conduction electrons and holes

- **At absolute zero (0ºK or -273ºC), the electrons all occupy their assigned energy levels.**
- **At room temperature (25 ºC), some valence electrons gain enough energy to jump the gap into the conduction band, leaving behind a "hole" in the valence band and producing an *electron-hole pair*.**
- ***Recombination* occurs when a conduction band electron loses energy and falls back into a hole in the valence band.**

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Electron and Hole Current

- **When applying a voltage to a semiconductor material, what would happen? Let's draw a picture!**
  - → the generated free electrons in the conduction band are easily attracted and free to move to the positive end, producing an *electron current*
  - → the valence electrons can move to nearby holes in the valence band, thus producing a *hole current* in the opposite direction from the electron current
- **Are conduction and valence band electrons equally free to move?**

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Intrinsic(pure) vs. Extrinsic(impure)

- **Intrinsic semiconductor materials have too small a supply of current carriers (free electrons and valence holes) to be useful in electronic devices.**
- **Extrinsic semiconductor materials provide a significant yet controlled increase in the number of current carriers.**
  - → controlled addition of impurities is accomplished in a process called doping
  - → depending on the additive material, a significant number of electrons or holes is generated in the extrinsic product

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N -type Semiconductor

- ***N*** **stands for negative**
- **This type semiconductor is created by addition of *donor atoms* with 5 valence electrons. Thus, after bonding with the intrinsic material, the extra electron is *donated* to the conduction band.**

P -type Semiconductor

- ***P*** **stands for positive**
- **This type semiconductor is created by addition of *acceptor atoms* with 3 valence electrons. Thus, after bonding with the intrinsic material, a hole is produced in the valence band.**

Majority/Minority Carriers

- **majority carriers (electrons or holes) are responsible for the majority of the current flow**
- **minority carriers (holes or electrons) are thermally generated rather than generated by the doping process and carry only a small minority of the current**

	majority carriers	minority carriers
N-Type	conduction band electrons generated by doping with donor atoms	thermally generated valence band holes
P-Type	valence band holes generated by doping with acceptor atoms	thermally generated conduction band electrons

The PN Junction

Let's diagram it!

- **At junction formation, free electrons in the *n-region* near the pn junction begin to diffuse [illegible] and [illegible] holes [illegible] the [illegible]**
- **[illegible]**
- **This action co[illegible] the voltage [illegible] barrier repels further diffusion.**

Important Terms

- **depletion region**
  - ➔ refers to the fact that the region near the pn junction is depleted of charge carriers (electrons and holes) due to the diffusion across the junction
- **barrier potential**
  - ➔ amount of energy required to move electrons "against their will" across the depletion region
  - ➔ typical values are 0.7V for silicon and 0.3V for germanium (at room temperature)

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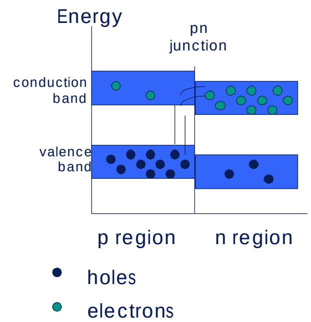
Energy Diagram at the Instant of Formation

- valence and conduction bands in an n-type material are slightly lower than those in a p-type material
- free electrons in the n-type material move to the conduction band in the p-type material and then fall into the holes



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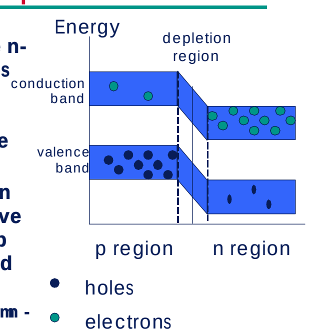
Energy Diagram of the PN Junction at Equilibrium

- the energy level of the conduction band in the n-type material decreases due to the loss of high energy electrons that have diffused across the junction
- equilibrium occurs when the electrons do not have enough energy to climb the energy "hill" created by the initial diffusion
  - ➔ electrons cannot go from n-region to p-region



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Biasing the PN Junction

- **The term bias refers to the use of a dc voltage to establish certain operating conditions for an electronic device.**
- **There are two bias conditions for the pn junction:**
  - ➔ forward bias
    - » apply a dc voltage … p region and negative terminal to …
  - ➔ reverse bias
    - » apply a dc voltage, negative terminal to p region and positive terminal to n region

Diagram it!

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Forward Biasing the PN Junction

- **condition which allows current through a pn junction**
- **causes the depletion region to narrow**
- **electrons still require the energy equal to the barrier potential to climb the energy hill**
  - ➔ **the electrons must give up the amount of energy equal to the barrier potential when they cross the depletion region**
  - ➔ **this energy loss results in a *voltage drop across the pn junction equal to the barrier potential***

Reverse Biasing the PN Junction

- **condition which prevents current through a pn junction**
- **causes the depletion region to widen**
- **the *voltage across the depletion region eventually equals the bias voltage***
- **reverse current**
  - ➔ **caused by the minority carriers in the p-region "rolling down the energy hill" to the n-region resulting in a very small reverse current**

Reverse Breakdown

- **a high enough reverse-bias voltage may impart enough energy to the free minority electrons in the p-region that in their race to get to the n-region they may collide hard enough with atoms to free valence electrons!**
- **a chain reaction effect called avalanche occurs**
- **the electrons which have crossed the depletion region still have enough energy to flow and not recombine with holes**

Summary of PN Junction Bias

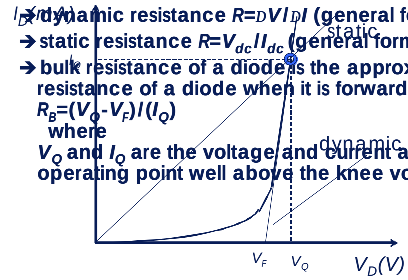
	bias voltage	bias voltage range	majority carriers	current	depletion region
Forward Bias: permit current	positive to p-region, negative to n-region	greater than the barrier potential	flow toward the pn junction	majority carriers provide forward current	narrows
Reverse Bias: prevent current	positive to n-region, negative to p-region	less than the break-down voltage	flow away from the pn junction	minority carriers provide small reverse current	widens

I-V Characteristic of a PN Junction

- **Forward Bias**
  - ➔ initially, small changes in current flow with increasing forward voltage
  - ➔ once the applied bias is greater than the barrier potential, the current flow increases rapidly with small increases in the applied voltage
  - ➔ the “knee” in the curve occurs around the barrier potential, V_F
  - ➔ sketch expected characteristic

I-V Characteristic of a PN Junction

- **Diode Resistance**
  - ➔ dynamic resistance $R=\Delta V/\Delta I$ (general formula)
  - ➔ static resistance $R=V_{dc}/I_{dc}$ (general formula)
  - ➔ bulk resistance of a diode is the approximate resistance of a diode when it is forward biased $R_B=(V_Q-V_F)/(I_Q)$
    where
    V_Q and I_Q are the voltage and current at an operating point well above the knee voltage V_P



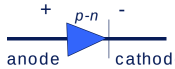
I-V Characteristic of a PN Junction

- **reverse bias**
  - ➔ very small reverse current until breakdown voltage is reached
  - ➔ past the breakdown voltage, the reverse current increases very rapidly while the voltage across the pn junction increases only slightly
  - ➔ in general, breakdown is not a normal operation for most pn junction devices and often will cause the device to no longer function properly
  - ➔ sketch expected characteristic

Some Real Numbers

- for a typical silicon pn junction:
  - » V_F = 0 7V
  - » I_R = 5 0nA
  - » V_{BR} >5 0V
- What would you expect to happen to the barrier potential as temperature increases?
- What would you expect to happen to the reverse current as temperature increases?

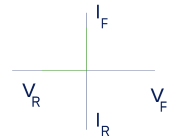
The Diode!



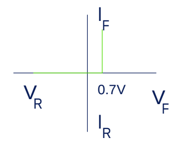
- a single pn junction with conductive contacts and wire leads connected to each region
- the schematic symbol for the diode is shown here
  - ➔ the "arrow" in the symbol points in the direction of conventional current (opposite to electron flow)

Ideal and Practical Diode Models

- ideal model (first approximation)
  - ➔ diode looks like a short circuit when forward biased and like an open circuit when reverse biased



- (second approximation)
  - ➔ diode looks like a dc source with a potential drop of the source equal to the barrier potential when forward biased and like an open circuit when reverse biased



So What Now?

- try to absorb the material
- be assured that although this material is abstract, it is important to understand in order to appreciate how electronics work
- do a lab to help digestion
  - ➔ Diode I-V Characteristic

Related Assignments

Floyd: Read Chapter 1

HW#1:chapter 1 - Self-Test #1-34

Problems #16, 18