The Chemistry of Semiconductor Integrated Circuit

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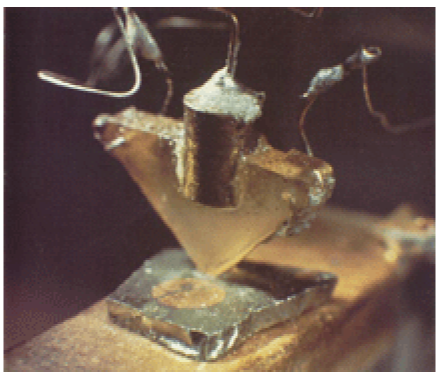
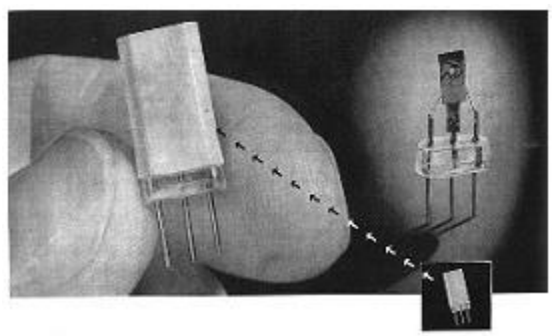


The Point Contact Transistor



Transistors circa 1960

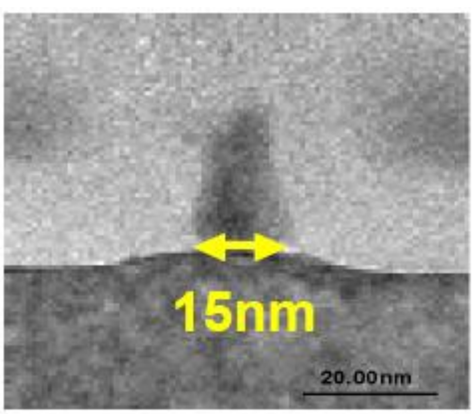
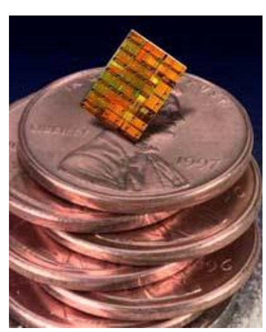


Figure 5: TeraHertz transistor with 15nm gate

Goal of this Unit



The goal of this unit is to introduce students to the chemistry of the semiconducting materials used in the fabrication of diodes and transistors. The unit is meant to give students a conceptual and practical understanding of these devices through classroom instruction and laboratory activities. The unit will also explore the lives of the scientists, and engineers who discovered and perfected semiconducting technologies. The historical perspective on the development of these devices is meant to highlight the manner in which science, engineering, and mathematics converge in the creation of the technological advances.
Although this unit will take place in my chemistry class, it is part of a larger school wide effort to increase student interest in science and engineering as post secondary fields of study and/or in STEM related careers. Our school is an all female, urban high school and few of our students pursue science or engineering related careers. Data on our graduating students is similar to national statistics (National Science Foundation , 2014), that documents the underrepresentation of women and minorities in STEM related fields. This unit will therefore be a part of our effort to offer activities that will encourage our students to pursue science and engineering as post secondary courses of study. Recent research has shown that increasing interest in STEM requires a combination of extra curricular activities, mentoring, and research opportunities that augment in class activities. As such, this unit will be supported by an after school robotics team and an engineering club. Our school has an established robotics club that will provide students experiences with the electronics, programming and assembling of robots. Working with robots in an informal after school setting has been shown to increase student's awareness and understanding of science, engineering, and technology concepts ((Barker & Ansorge, 2007). An Engineering club will supplement our robotics club as students will experience a wider range of activities and interactions with engineering students, working engineers, and other professionals in STEM related fields. It is our hope that these combined opportunities will increase awareness and interest in engineering and science as post secondary opportunities.

Problem Statement

Women have been historically underrepresented in the scientific research, engineering and technological fields in our society (Muller, 2003). This disparity is more pronounced among women of color from low-income urban populations who often fail to receive the rigorous science instruction that would prepare them to compete in today's technological society (Landgraf, 2003). As a result, there is a lack of minority students who undertake science or engineering concentrations in their post secondary institutions (Hurtado, Newman, Tran, & Chang, 2010), or pursue careers in STEM related disciplines (National Science Foundation , 2014). This is an unfortunate reality for our society as many of these young women have the skills and intellectual ability to make significant contributions to our society.

Rationale

Our society is ever more dependent on the use of electronic devices. Computers and "smart" cellular devices are indispensible components of every aspect of our lives. Young adults are increasingly able to use smart technologies in their everyday interactions, their studies, and their interconnection with their peers. Few however are aware of the science that has informed the creation of the electronic devices that are central to their lives. Neither are many aware of the areas of study that could lead to rewarding occupations in the many technological industries in our society. This unit study on the science and technology of semiconducting devices is meant to provide students a historical perspective on the development of the transistor and diode, as these devices are the essential components of the technology that is central to their lives.

Background

SEMICONDUCTING DEVICES

The great eras in human history are often characterized by the dominant economic technology of the time (The Iron Age, The Stone Age), the nature of social political thought (The Enlightenment, The Renaissance, The Victorian Era), or in terms of shifts in fundamental economic or industrial modes of production (The Agricultural, Scientific, or Industrial Revolutions). It is difficult however, to characterize contemporary human history in such broadly general terms, as modern life is too complex and emergent for any reductive description. Although our global reality defies simple description, the reliance on digital electronic devices is a reality that pervades the daily life of almost every individual on planet earth. Digital electronics devices have so affected every aspect of our industrial, educational, and personal endeavors that we speak of contemporary history as the time of the Digital Revolution. The revolution's affects are widespread because digital electronic devices are powerful, economical, and readily adapted to countless societal and personal uses. Digital devices are powered by astonishingly small, reliable integrated circuits fabricated on and in the surface of semiconducting substances. The fabrication processes that can place millions of electronic devices on circuits the size of an American penny are largely responsible for the dominance of digital electronics. Digital devices are especially suited to applications that store, retrieve, and process vast amounts of information. The information industry (corporations that process data, the hardware / software they use, and the technologies that fabricate informational devices) is quickly becoming the dominant industrial activity in postindustrial society. The role of the information technology is so central to modern society that we refer to our time as the Information Age.

Contemporary society is characterized by electronic devices: Smartphone technology, computers, and an ever-expanding array of electronic devices are central to all aspects of modern society. The principal components for these devices are semiconducting materials as they can be manufactured so that they can selectively conduct current. The most important device is the transistor as it has revolutionized all electronic devices making them smaller, more powerful, and more accessible to people in every corner of the world.

The history of the semiconductor integrated circuit is a combination of technological and scientific discoveries in a wide variety of disciplines. Two developments in electronic circuitry (the invention of the point contact and junction transistors, and the development of the semiconductor integrated circuit) are credited as the pivotal events of the past century (Sze, 2002; Riordan & Hoddeson 1997). The inventions are so important that their inventors have all received Nobel Prizes their work: John Bardeen, Walter Brattain, and William Shockley received the 1956 Nobel in physics for their work on the point contact and junction transistor. Before the invention of the transistor, electronic devices were filled with vacuum tubes that functioned as resistors, diodes, and capacitors. The required vacuum, the glass enclosure, and the heat generated by the fragile tubes meant that electronic devices were large, inefficient, and costly. Bardeen and Brattain's 1947 point- contact transistor (a piece of gold foil, a plastic triangle and a slice of germanium, ~ 0.5 inches long) functioned as a semiconducting amplifier. Ralph Bown of Bell Labs announced the invention:

> We have called it the Transistor because it is a resistor or semiconducting Device, which can amplify electrical signal as they are transferred through it from input to output terminals." Ralph Bown, June 30, 1948 Press Conference announcing the Transistor (Riordan & Hoddeson 1997, p.164)

William Shockley refined the design of the point contact transistor and created the Junction Transistor in early 1948. The Schockley transistor was a "sandwich" of p and n type germanium. The junction transistor eliminated wires and points of point contact device. Gordon Teale and Morgan Sparks perfected the junction transistor technology in 1950 by selectively doping areas of a germanium crystal with gallium (p doping) and antimony (n doping). Once doped, contact points were etched into the n regions and contact wires were attached. The technology of selectively doping and exposing areas on the surface of a semiconducting material remains to this day. By 1957, the transistor production had risen to ~ 30 million per year, the cost of all semiconducting devices (diodes, capacitors, resistors,) plummeted and annual revenues of the semiconducting industry grew beyond 100 million. Semiconducting devices displaced vacuum tubes and made new generations of electronic devices possible, however their size (immense by today's standards) and the complexity of wiring larger more intricately connected circuits limited the further growth of the electronics industry (Riordan & Hoddeson, 1997).

The problems posed by the wiring of discrete electronic devices were solved by Jack Kilby's 1959 invention of the semiconductor integrated circuit. Mr. Kilby's invention (patented on February 6,1959 as "Miniaturized Integrated Circuits") was revolutionary because it fashioned all of the components of an integrated circuit (the original circuit was an oscillating circuit) from the semiconductor germanium. "Extreme Miniaturization" and the use of only one substrate material were the stated goals of the invention. The oscillating circuit that Mr. Kilby and Texas Instruments (Mr. Kilby's employer) presented to the public later that year was about the size of a pencil point, however it performed better than circuits many times it's size. While Kilby and Texas Instruments were developing their integrated circuit, Robert Noyce and seven other scientists (one of which was Gordon Moore) at Fairchild Semiconducting Corporation were perfecting a similar semiconductor integrated circuit. Mr. Noyce (the head of research) and Gordon Moore (head of production engineering) would leave in 1968 to establish Intel Corporation. Noyce and Jean Hoerni (a physicist at Fairchild) developed a manufacturing process that began by growing a layer of silicon dioxide onto the surface of crystalline silicon (planar manufacturing). Photolithography was used to imprint the desired pattern onto the silicon. Once patterned, the selected areas were exposed using a chemical etchant. These areas were selectively doped, and then re oxidized. Fairchild's use of an oxide layer as an insulator between sectors of the devices effectively ended the use of germanium in semiconducting electronic devices because germanium has no naturally occurring oxide. Noyce also perfected the method of layering metal through openings in the SiO_2 insulation to interconnect all of the devices at one time. These modifications made it possible to fabricate large numbers of transistors and other electronic devices upon a silicon substrate at the same time. The Noyce planar manufacturing process was patented in 1959 as a means to

> "provide improved device and lead structures for making electrical connections to the various semiconductor regions, and make unitary circuit structures more compact and more easily fabricated in small sizes" (Riordan & Hoddeson p. 265)

The MOSFET (Metal Oxide Semiconductor Field-Effect Transistor) is the most important device in modern integrated "circuits such as memories and microprocessors because of its low fabrication cost, small size, and low power consumption" (Shimura, 106). They are ideally suited to the logic requirements of digital electronics as they can be easily programmed to be on (logic state =1) or off (logic state=0). There are currently 200 plus quadrillion transistors in use today.

LIGHT EMITTING DIODES

Current technological advances in LED technology have increased the use of diodes, as these new sources of light will eventually displace conventional light bulbs, sources given their efficiency and limited environmental impact. LED use electroluminescence rather than incandescence to emit visible light as a result there is no loss from thermal energy. LED are already used predominantly as emitters of IR waves in electronic devices however recent improvements in design permit the use in a wide array of colors and as white light LED. Thus, their range of uses has expanded: now in stoplights, automobile lighting systems, and in a wide range of digital displays (LED high density displays). This increasing impact on our society makes LED's an obvious choice for a unit that seeks to show students how Science Technology and Engineering combine to create useful products in society.

SEMICONDUCTORS

Semiconductors are elements or combination of elements whose resistivity and hence conductance is between that of conductors and insulators. The resistivity of conductors is between ~10^{-8} and 10^{-12} Ω cm: insulators ~10^{9} and 10^{19} Ω cm, while that of semiconductors varies between 10^{-5} and 10^{2} Ω cm (silicon has a resistivity between 0.1 and 60 Ωcm) (Giancoli, 2002). Semiconductors are intermediate between insulators and conductors because their band gap (the energy difference between the highest level of their valence band and the lowest level of their conductance band) is relatively small.

Molecular orbital theory states that as atoms bond, each type of atomic orbital forms a bonding and non-bonding molecular orbital. Thus whenever n atoms bond, n-bonding and n-non-bonding molecular orbitals are formed.

The Band theory of solids, suggests that as these large numbers of atoms come together (as in a lattice structure), the discrete energy levels of the two types of molecular orbitals merge together to form bands. In solids, the highest occupied energy levels are referred to as the valence band (highest occupied molecular orbitals), while the conduction band (is the lowest unoccupied molecular orbitals (Miesler, 1999).

The difference in energy between the two bands is referred to as the band gap, and the energy required for an electron to move between the two bands is referred to as the band gap energy. The conductive properties of insulators, conductors, and semiconductors can be understood from the difference in their band gaps. Table 1 compares the band gaps and band gap energies of conductors, insulators, and semiconductors.

Table 1: Band Gap and Band Gap Energy of Conductors, Insulators, and Semiconductors

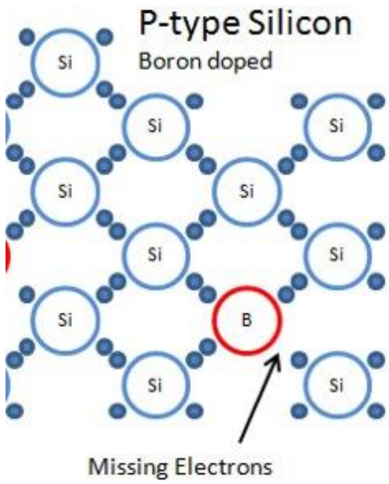
Material	Band Gap eV	Band Gap Joules	Population in Conduction Band (300K)
Carbon	5.5	8.8 E –19 Joules	5.11E-19
Silicon	1.11	1.76 E –19 Joules	206,723
Germanium	0.66	1.0 E –19 Joules	1.9E13
□ Tin	0.11	1.76 E –20 Joules	8.54 e21

Source: http://www.owlnet.rice.edu/~chem152/lecture/Reading/semibands.html

As one can note from this data, the band gap (and band gap energy) for conductors is much smaller (0.11 eV), than that for insulators (5.5 eV). This value makes it nearly impossible for electrons to move from the valence band to the conduction band. The corresponding values for semiconductors (silicon & germanium) are between the two extremes, which permit these elements to function as conductors or insulators. It is also important to note that the population of electrons in the conduction band of insulators is negligible when compared to that of a conducting metal. Note the relatively large populations of electrons in the semiconducting elements (germanium and silicon). The combination of these factors helps explain the differential conductivity of these three types of elements. Semiconductors are well suited for semiconductor electronics because their resistivity can be altered by the addition of impurities (either pentavalent or trivalent atoms) to their lattice. The process of adding impurities to an intrinsic (pure) semiconductor (silicon or germanium) is referred to as doping (the impurities are called dopants).

Each element has a characteristic number of valence electrons used in the creation of molecular bonds. Bonding occurs as atoms “share” their valence electrons in bonding.

A typical semiconductor such as silicon requires four electrons to complete its valence shell. If silicon is bonded with an atom with less than four valence electrons (such as Boron) , a “hole” will be created as it only has seven of its required eight valence electrons. This missing electron is referred to as a postive “hole.” This material given its deficiency in negative charge is referred to as “p” (positive) substrate. If the silicon is configured with an atom that has five valence electrons (such as Phosphorous), the material will have an excess (one extra electron) negative charge and will be referred to an a “n” (negative) substrate. Figures 1 and 2 illustrate how dopants affect the resistivity / conductance of a semiconductor. In figure 1, the dopant (Boron) has created a hole as it is missing one of four electrons required to bond with the tetravalent silicon. The hole is a positive charge carrier as it is the site of electron depletion. The addition of phosphorous contributes an extra electron (charge carriers) to the lattice. Silicon is thus ideally suited for integrated circuits as it is quite easy to create areas of differential electrical properties by bonding it with other group 13 or group 15 elements.



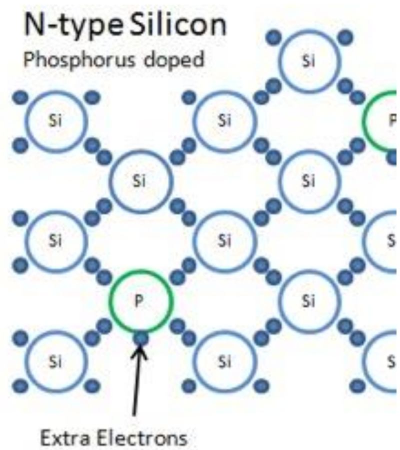


Figure 1: P- type Silicon

Figure 2: N-type Silicon

Source for images: West Florida Components, 2013

TRANSISTORS

Transistors are combinations of n-type and p-type semiconductors. They are essentially a sandwich of a p type region between two n semiconductors (PNP) or a p type semiconductor between two n regions (NPN). The two outer regions are termed the collector and emitter, while the central region is designated the base. It is the interaction between these three regions that give the transistor its ability to control current through a circuit. Thus, the transistor can serve to turn current on or off: or (in most instances) to amplify electrical signals.

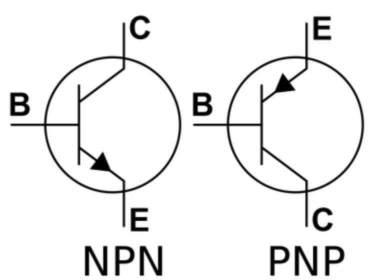


Figure 3: NPN and PNP Transistors
Source: http://daniel-joel.blogspot.com/2013/06/transistor.html

The diagram shows three components: the Base, Emitter and the Collector. Transistors work as an amplifier by using a small base current I_b to increase the current flowing from the Collector to the Base (in an NPN transistor) or from Emitter to Base to Collector as in a PNP transistor. The base current controls the current flow through the transistor. Amplification occurs because a small base current will allow a large current (Ic) to flow from the collector to the emitter. Similarly when no base current is present, no current flows through and the transistor functions as a switch. The transistor's Gain is defined as the amount of amplification that it provides to the circuit. The gain is calculated by the equation Ic = □□□or H_{FE}) * I_B. The specific transistor to use is determined by a variety of factors, principally the amount of current that will pass through the circuit. Once the amount of current is determined (by the requirements of the load device), the base current can be calculated using the transistor's gain as a ratio. Controlling the amount of base current can be accomplished by using an appropriate resistor between the base current voltage source and the transistor. A typical setup is shown in figure 3a.

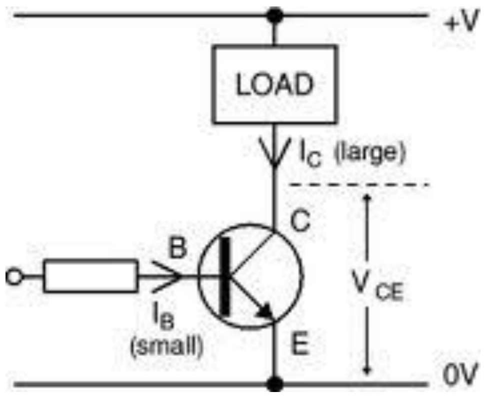


Figure 3a: Transistor Amplifier Circuit:
Source: http://electronicsclub.info/transistorcircuits.htm

LIGHT EMITTING DIODES

Figure 4 illustrates a P-N junction between a P and an N type semiconductor. When the conductors are joined there is an initial "movement of positive holes towards the N conductor and free electrons towards the P material. These charge carriers meet in the junction where they recombine until all charges are effectively cancelled.

Once completed this area is termed the depletion zone, as no other charge carriers are available.

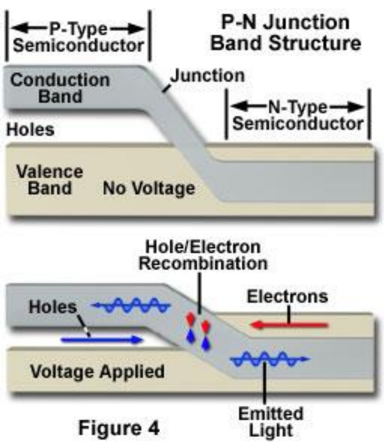


Figure 4

When a voltage is applied, (anode negative lead attached to the n side of the diode and the positive cathode lead attached to the positive side: (known as forward bias)) electrons in the depletion zone are energized and move into the conduction band, which allows more electrons and holes to migrate to the junction where they will once again recombine. As long as a voltage is applied, this process will continue and a current will flow across the semiconductor. As the electrons in the conduction band return to their ground state, a photon of light is emitted. The color of the light corresponds to the size of the band gap that corresponds to the paired materials. Small band gaps produce emissions from the IR through the reds; larger gaps emit light of shorter wavelength and higher energy. Thus, the color of an LED is a function of the band gap resulting from the various materials and impurities used in their manufacturing.

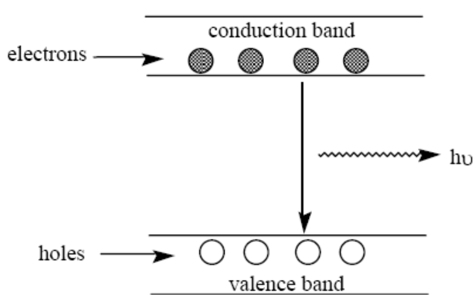


Figure 1: Electron passing from conduction band to the valence band releases energy. If the photon of light has a wavelength in the visible range, "colored" light is observed.

Table 1: Relationship between LED Color, Wavelength and Energy of Light.

Color of Light	Wavelength (nm)	Energy (eV & kJ/mol)
Violet	410	3.0 (290)
Blue	480	2.6 (250)
Green	530	2.3 (225)
Yellow	580	2.1 (205)
Orange	610	2.0 (195)
Red	680	1.8 (175)

Figure 5: Relationship between LED Color and Wavelength / Energy of Emitted Light: Source: University of California 2005)

THE TECHNOLOGY OFSEMICONDUCTORS AND LIGHT EMITTING DIODES

UNIT OVERVIEW

The investigation of diodes and semiconductors must begin after basic concepts of atomic structure, bonding, and periodicity have been covered. Students will need to know atomic structure: electrons protons, neutrons, models of the atom (especially Bohr's model), valence electrons, the octet rule and how atom share electrons to form covalent bonds. Once understood these concepts may be applied to periodic patterns, group number and how atoms share electrons to complete their octet. The following unit can commence once these concepts are covered. In my year's progression, this occurs in late October Early November. Thus, I plan to begin this exploration in the first week of November. The unit on LED's will first explore the chemistry of semiconducting materials as part of the larger chemistry unit on periodic table and properties of elements. Students will be able to understand the difference between conductors, insulators, and semiconductors. The second unit will explore the chemistry of transistors, their application in society, and their history.

Standards Used in the Unit

HIGH SCHOOL STANDARDS FROM THE NEXT GENERATION SCIENCE STANDARDS

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

HS-PS4-2. Evaluate questions about the advantages of using a digital transmission and storage of information.

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

COMMON CORE LITERACY STANDARDS

CCSS.ELA-LITERACY.RST.11-12.8 EVALUATE THE HYPOTHESES, DATA, ANALYSIS, AND CONCLUSIONS IN A SCIENCE OR TECHNICAL TEXT, VERIFYING THE DATA WHEN POSSIBLE AND CORROBORATING OR CHALLENGING CONCLUSIONS WITH OTHER SOURCES OF INFORMATION.

CCSS.ELA-Literacy.RST.11-12.9 Synthesize information from a range of sources into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Lesson Plans

WEEK ONE LESSON PLANS

DAY ONE: THE CHEMISTRY OF SEMICONDUCTORS, INSULATORS, AND CONDUCTORS

OBJECTIVES: TO ANALYZE THE ATOMIC STRUCTURE AND PROPERTIES OF CONDUCTORS, INSULATORS, AND SEMICONDUCTORS. TO DIFFERENTIATE THE DIFFERENCES IN CONDUCTIVITY

SKILLS: Compare Conduction and Insulation Using Band Gap Theory
Differentiate the Conductivity of Insulators, Conductors, and Semiconductors
Analyze the Relationship between Band Gap and Conductivity

ESSENTIAL QUESTION: HOW DOES THE BAND GAP (AND BAND GAP ENERGY) EXPLAIN THE DIFFERENCE IN CONDUCTIVITY OF CONDUCTORS, INSULATORS AND SEMICONDUCTORS?

ANTICIPATORY SET: Why Do We Have A Plastic Material Surrounding Electrical Cords? Which Of These Materials Will Conduct An Electric Current?

DIRECT INSTRUCTION: The band gap theory of solids helps to explain the differences in conductivity between conductors, insulators and semiconductors. Conductors readily allow the flow of electrons through their valence and conduction bands, Insulators do not permit the flow of electrons. Semiconductors are in between these two extreme as they can (under give conditions) permit the flow of electrons. When large numbers of atoms bond, two distinct areas knows as the Valence and Conduction Bands are created. When boding occurs, electrons populate the lowest available energy state, which is the Valence Band, and some will populate the higher energy Conduction band. The difference in between the two bands is known as the Band Gap, while the energy needed to traverse the band gap is known as the band gap energy. In conductors the band gap (and the band gap energy) between the two bands is very small (in some cases they overlap), while Insulators have a very large band gap / energy. Semiconductors have intermediate band gap / energy. In order conduct a current; electrons must be able to move from the valence band to the higher energy conduction band. Electrons in conductors are able to move freely into the conduction band, electrons in insulating materials cannot traverse the gap. Semiconductors are unique because they can function as either a conductor or an insulator. The minimal band gap energy for conductance will be calculated with the class: (~ 5- 8 eV for insulators - ~ 1 eV for semiconductors): See Table 3 for Band Gap Energy of conductors, insulators, and semiconductors.

GUIDED / INDEPENDENT PRACTICE: Students will use their periodic tables to identify elements that are classified as metals, non-metals and semiconductors. Students will also then be given a set of elements with their band at with their band gap energies (in Joules): students will be asked to calculate the band gap energy (IN eV) for the given elements and thence to determine which will be a conductor, insulator or semiconductor.

ASSESSMENT: Students should be able to differentiate between insulators, conductors and semiconductors based on their band gap energies. Students should also be able to describe conductivity in terms of electron flow in the conduction band.

EXIT QUESTION: What is the difference (in terms of band gap energy) between conductors and insulators?

EXTENSION ASSIGNMENT: Determine which elements are most commonly used in semiconducting technology. Explain why these elements are considered to be semiconductors (in terms of band gap energy).
MATERIALS NEEEDED: Periodic tables, conversion data, images of valence / conduction band: Table of selected band gap energy.

DAY TWO: THE CHEMISTRY OF SEMICONDUCTORS AND DIODES

OBJECTIVES: TO DESCRIBE METHODS OF DOPING SEMICONDUCTORS. TO ANALYZE THE PROCESS OF LIGHT EMISSIONS IN LIGHT EMITTING DIODES

SKILLS: To describe the process of creating p and n type semiconductors
To describe the structure of diodes
To analyze the process of light emission in LED
To calculate the wavelength of emitted light in LED's

ESSENTIAL QUESTION: How are semiconductors used to create diodes? What are Light Emitting Diodes?

ANTICIPATORY SET: What is the difference between a conductor an insulator and a semiconductor?

DIRECT INSTRUCTION: Silicon is a tetravalent atom, which needs four electrons to complete its valence shell. If Silicon is selectively treated with a trivalent atom (such as Boron) then Silicon will have a one-electron deficiency in its lattice (known as a positive hole). If Silicon is treated with a pentavalent atom (such as Phosphorous) then there is an excess of electrons in its lattice. The electron deficient Silicon lattice is characterized as a p (positive) semiconductor, while the lattice with excess electron is characterized as an n (negative) semiconductor. When the two substrates (p-type and n-type) are joined together, a Diode is created. When the two semiconductors are initially joined, electrons from the n- region and "holes" from the p region will migrate towards each other until all charges are equalized. At this point, there is no net movement of charge. If an external current is applied (anode to n region, cathode to p region: known as forward bias), electrons will move into the conduction band and a current will flow in the diode. As the electrons drop from a higher potential energy to their ground state (in the valence band) a photon of energy is released. Light is seen if the energy of the emitted photon falls within the visible range of the electromagnetic spectrum.

GUIDED / INDEPENDENT PRACTICE - Narrative Writing: Students will be given models of silicon atoms, boron and phosphorous atoms so as to analyze the creation of n and p type semiconductors. Students should make diagrams of the two types of semiconductors.

Students will then asked to draw a diode, and to diagram the process of light emission. Students will use the drawings to write a brief narrative summary of how semiconductors are used to create light emitting diodes. The completed drawings will be used to analyze the emission of light. On this day students will be given a list of the colors of light emitting diodes and the wavelength of the emitted light. Students will be asked to calculate the band gap energy of the diode using the equation: $E = h /$□

ASSESSMENT: Students will be able to describe the process of creating n and p-type semiconductors and how they function in diodes. Students will be able to explain how light emission occurs and be able to calculate the band gap energy given the wavelength of emitted light.

EXIT QUESTION: How are n and p type semiconductors created? How is the light generated in LED's?

EXTENSION ASSIGNMENT: Research the different materials used in LED's of different colors. Explain which is the n and which is the p semiconductor: include an explanation of what materials were used to create the semiconductor.

MATERIALS NEEEDED: Sufficient atomic model kits for 8 groups of 4 students; Sufficient drawing materials for diagrams of diodes. Table of representative colored LED's (see Table 4)

DAY THREE and FOUR: DETERMING ENERGY OF EMITTED LIGHT:
WIRING A DIODE:

OBJECTIVES: TO INTERCONNECT THE COMPONENTS OF A DIODE. TO MEASURE THE WAVELEGHT OF EMITTED LIGHT AND CALCULATE THE BAND GAP OF THE LED

SKILLS: Using electronic components to create a diode on a breadboard
To analyze light emissions using a spectroscope
To use wavelength of emitted light to determine the band gap of a diode.

ESSENTIAL QUESTION: How can we determine the chemical composition of distant stars? How can we use emitted light to analyze the structure of matter?

ANTICIPATORY SET: Stars and the analysis of the spectra of emission spectra of gases.

DIRECT INSTRUCTION: Students will be shown how to use spectroscopes to view the light from a white light source. Students will be instructed on the use of the instruments and how to use the diffraction grating to approximate the wavelength of emitted light. Students will then view a group of spectrum tubes and determine the wavelength of the emitted light.

GUIDED / INDEPENDENT PRACTICE: Introduction to Wiring a Breadboard: Once students have completed their exploration of the spectrum tubes, they will begin to wire their diode. Students will be show a breadboard, and shown how to use the rows and columns in wiring diagrams. Students will then be given a wiring diagram of a diode circuit. Students will learn what the symbols mean and how to use it to guide their wiring activity. Students will then be given LEDs of differing colors, resistors, and a small 9V battery, and sufficient wires for their wiring. In order to address the role of resistors, students will be introduced to Ohms Law. The class will practice calculating resistance, current given voltage. Students will learn that the current across the diode must not exceed the recommended voltage / current for the given diode.

Students will be given data for their diode and asked to calculate the necessary resistance. The class will end once calculations are completed.

ASSESSMENT: Students will be able to describe the components of their wiring diagram, and explain how they should be wired into the breadboard. Students should also be able to explain why a resistor is necessary in a diode circuit. Students should also explain how they determine the wavelength of emitted light using their spectroscope.

EXIT QUESTION: What is the resistance of a circuit with a voltage of 5.6V and a current of 0.12A? Why must we limit the current flow across a diode?

MATERIALS NEEEDED: Spectroscopes for 32 students, Spectrum tubes of differing gases, a darkened room, wiring diagrams for diode circuits, and sufficient materials for wiring: (one breadboard, 9Vbattery, battery clips, wires, diodes (of varying colors), resistors, wires and alligator clips) for 33 students, and data sheets for each diode.

DAY FOUR:
WIRING A DIODE: DETERMINING BAND GAP OF DIODE

OBJECTIVES: TO WIRE THE COMPONENTS OF A DIODE. TO MEASURE THE WAVELEGHT OF EMITTED LIGHT AND CALCULATE THE BAND GAP OF THE LED

SKILLS: Using electronic components to create a diode on a breadboard
To analyze light emissions using a spectroscope
To use wavelength of emitted light to determine the band gap of a diode.

ESSENTIAL QUESTION: WHAT IS THE RELATIOSHIP BETWEEN THE ENERGY AND WAVELEGHT OF THE LIGHT EMITTED FROM DIODES?

ANTICIPATORY SET: WHAT IS THE MINIMAL CURRENT FOR YOUR DIODE? HOW DO YOU DETERMINE THE RESISTANCE IN A CIRCUIT?

GUIDED / INDEPENDENT PRACTICE: Wiring a Diode Circuit Students will review their circuit diagrams; then assemble their materials for setting up their circuit. Students will be shown the proper method of setting their diode into the circuit. Students will then be given a chart explaining how resistors are coded. Student will then select the appropriate resistor for their circuit. Once completed students will build their diode circuit. Once completed students will view their emitted light through a spectroscope in order to determine the light's wavelength. Once students have determined their wavelength they will calculate the band gap energy. Students and teacher will review their circuit, data, and calculated band gaps. Students will compare their findings to the given wavelengths of their diodes. Students will then write a narrative summary of their wiring activity. The narrative will be used in their assessment of their diode project.

ASSESSMENT: Students will be able to describe the components of their wiring diagram, and explain how they should be wired into the breadboard. Students should also be able to explain why a resistor is necessary in a diode circuit. Students should also explain how they determine the wavelength of emitted light using their spectroscope.

EXIT QUESTION: What is the resistance of a circuit with a voltage of 5.6V and a current of 0.12A? Why must we limit the current flow across a diode?

MATERIALS NEEEDED: Spectroscopes for 32 students, Spectrum tubes of differing gases, a darkened room, wiring diagrams for diode circuits, and sufficient materials for wiring: (one breadboard, 9Vbattery, battery clips, wires, diodes (of varying colors), resistors, wires and alligator clips) for 33 students, and data sheets for each diode.

DAY FIVE:
ANALYZING THE ENVIROMENTAL IMPACT OF LED TECHNOLOGY

OBJECTIVES: TO COMPARE THE EFFICIENCY OF LED'S AND CONVENTIONAL LIGHT SOURCES.

SKILLS: Analyze the energy efficiency LED and Incandescent lights
Determine the environmental impact of each technology
Create a Persuasive Argument in favor of the "green" light source

ESSENTIAL QUESTION: WHY IS IT IMPORTANT TO CONSIDER "GREEN" TECHNOLOGIES IN OUR DAILY LIVES? WHAT SHOULD WE DO IF ENVIRONMENTAL CONSIDERATIONS IMPACT OUR ECONOMY?

ANTICIPATORY SET: WHICH TYPE OF LIGHT BULB DO YOU USE AT HOME? ARE THOSE BULBS ENERGY EFFICIENT? IS IT IMPORTANT TO CONSIDER WHICH TYPE OF BULB IS BETTER FOR OUR ENVIRONMENT?

GUIDED / INDEPENDENT PRACTICE: Green Technology Debate: Students will be given data comparing the energy efficiency of incandescent, compact fluorescent, fluorescent and LED lights for comparison. Students will also be given data on the economics of each light source. Students will be asked to determine which light source they deem more beneficial to the environment and which is more economically feasible. Students will need to consider short range and long-range economic impacts in their analysis. Students will be asked to decide which light source is better for our their households and for our society. Students will be asked to write a persuasive argument that explains their position.

ASSESSMENT: Students will be able to write a position statement on the use of green technologies as light sources. Students will need to support their position with at least three opinions and three data facts.

EXIT QUESTION: Which light source do you consider more "eco-friendly? Is it more or less economical?

MATERIALS NEEEDED: Comparative data on the efficiency of the three light sources. Data is available at: Comparison Chart LED vs. Incandescent vs. CFL at:
http://www.designrecycleinc.com/led%20comp%20chart.html

UNIT TWO: HISTORY AND SCIENCE OF TRANSISTORS:
DAY ONE: THE HISTORY OF THE DEVELOPMENT OF THE TRANSISTOR

OBJECTIVES: TO CRITIQUE THE INTERACTION BETWEEN SCIENTISTS AND ENGINEERS. TO ANALYZE HOW SCIENCETIFIC KNOWLEDGE, SOCIAL-POLITICAL

ENVIRONMENT AND PERSONALITY AFFECTED THE INVENTION OF THE TRANSISTOR.

ESSENTIAL QUESTION: HOW DO SCIENTIFIC PRINCIPLES, ENGINEERING, AND INTUITION HELP TO CREATE TECHNOLOGY.

ANTICIPATORY SET: WHAT DO YOU THINK IS THE GREATEST INVENTION OF THE 20^{TH} CENTURY? WHAT IS THE GREATEST INVENTION IN YOUR LIFETIME? HOW DO YOU THINK THAT GREAT INVENTIONS CAME ABOUT?

DIRECT INSTRUCTION: The transistor is considered the most important invention of the last century. Its discovery is credited to William Schockley, Walter Brattain and John Bardeen. Although the three are renowned for their scientific work, the story of the discovery of the transistor is a one of difficult personal interactions and failed aspirations. Today we will view a short video on the discovery of this great device. You will complete a video viewing guide that you will use in your critique of the lives of these three great scientists.

GUIDED / INDEPENDENT PRACTICE: VIDEO VIEWING GUIDE.

ASSESSMENT: Students should develop an essay that analyzes (critiques) the manner in which Shockley, Brattain, and Bardeen interacted during the time they worked at Bell Labs.

EXIT QUESTION: What was the most positive facet of the their interactions? How did it contribute to the development of the transistor? What was the more negative aspect of their personalities? How did that influence the development of the transistor?

EXTENSION ASSIGNMENT: What happened to each scientist after the invention?
MATERIALS NEEEDED: Access to the "Transistorized" Video from PBS. Video is available from PBS. org or on line at YouTube Education.

DAY TWO / DAY THREE: THE TRANSISTOR AS AMPLIFIER CIRCUIT:

OBJECTIVES: TO ANALYZE THE COMPONENTS OF A BIPOLAR TRANSISTOR. TO DESCRIBE HOW BASE CURRENT AFFECTS EMITTER-COLLECTOR CURRENT FLOW

SKILLS: To Differentiate the Parts of a Bipolar Transistor
To Calculate the Gain of a Transistor
To Explain How a Transistor Amplifies Current in a Circuit

ESSENTIAL QUESTION: HOW DOES A TRANSISTOR AMPLIFY CURRENT FLOW

ANTICIPATORY SET: Reassemble your Diode Circuit: Today we are going to amplify the current through your circuit. Make sure the LED lights up. Once it does try the following experiment: Disconnect the one of the leads from the battery terminal. Hold the lead in your hand and place your other hand on the battery terminal. What happens to the LED? This happens because your body's resistance has lowered the current across the circuit. Today we are going to use a transistor to amplify that current.

DIRECT INSTRUCTION: The Transistor amplifies current flow by passing a small current from the base to the emitter. This allows a larger current to pass from the collector to the emitter. The transistor you will use today will be placed in your diode circuit along with two other devices (a base current resistor) and a second external power supply (the base current). Before we begin, you will need to determine which resistor to use across the base current. To determine this you will need to remember the current needed for you diode and divide by the gain of the transistor: (we are using a PN222A) which has a gain of 100. This will give you approximate base current. You will then use Ohm's law to determine the resistor needed for a 4.3 V voltage source at the base. (Note: 4.3 V is a reduction of 0.7 V, which occurs because of a voltage drop at the base-emitter NP junction). Once you have determined the correct resistor for you base current you will be ready to assemble your circuit. Make sure to position the transistor so that the collector and emitter prongs are correctly inserted into your breadboard.

GUIDED / INDEPENDENT PRACTICE: Students will determine the correct resistor to use in their circuit. Once done they will wire the circuit and test the amplification of the transistor: Students will wire the circuit (as shown in figure) and hold the leads in their hands. Initially this setup failed to light the LED. Now with the use of a transistor, the gain should increase the current so that the LED will light.

ASSESSMENT: Students will be able to wire the transistor circuit and prove that it amplifies the current sufficiently to light the LED.

EXIT QUESTION: Why did the LED light once the transistor was placed in the circuit?

MATERIALS NEEEDED: For a class of 32 students: (a breadboard, a PN2222A transistor, wire leads, 9V batteries, a 5V power source). ACTIVITY ADAPTED FROM: (Hare, 2004)

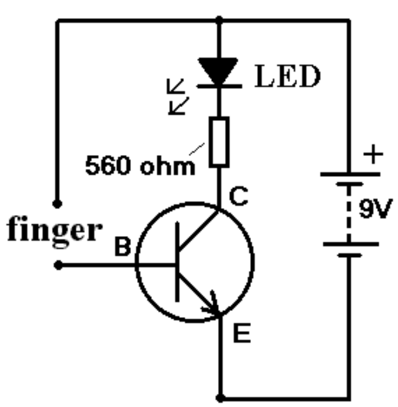


Figure 6 : Transistor Amplifier Circuit:
Source: http://www.creative-science.org.uk/transistor.html

DAY FOUR / FIVE: THE TRANSISTOR AS AMPLIFIER: Note: This day's Activity will start once students have completed the LED amplification. It is likely that many students may need more time to complete their work. As a result, this day's activity may continue onto a sixth day.

OBJECTIVES: TO USE A BIPOLAR TRANSISTOR TO AMPLIFY CURRENT FLOW IN A CIRCUIT. TO USE KNOWLEDGE OF WIRING CIRCUITS TO ASSEMBLE A SOUND AMPLIFICATION CIRCUIT

SKILLS: Wiring a sound amplification circuit on a breadboard

Identifying resistors based on color-coding
Calculating current and resistance in a circuit using Ohm's law

ANTICIPATORY SET: Why did Bell Labs begin to look for a transistor in the early 1920's? Remember the video we saw. What were they trying to amplify? Today we are going to use transistors to do the same.

DIRECT INSTRUCTION: Before you wire your amplifier, you will build a "10 minute" radio. Once you assemble it you will tune it by listening to the sound throught the earpiece: the sound will be very low. To improve this situation you will build an amplifier using a transistor circuit. Follow the circuit diagram and connect your radio to the Students will be given sufficient materials to wire a circuit that will amplify sound. Students will work independently with little assistance from the teacher.

INDEPENDENT PRACTICE: Students will first build a "10 minute radio" as adapted from the SCI TOYS. Once completed students will build an amplification circuit and test its ability to amplify the sound of their ten minute radio.

ASSESSMENT: This day's activity is a formative assessment of the skills gained in the first two weeks of this unit. Students should have a modicum of dexterity wiring components of the radio and the amplifier.

EXIT QUESTION: How did your radio sound with the earpiece? How did it sound with the transistorized amplifier?

MATERIALS NEEEDED:

For the radio:

- A ferrite loop antenna coil
- A variable capacitor (30 to 160 picofarads)
- A Germanium diode (1N34A)
- A piezoelectric earphone
- Two alligator jumper wires
- About 50 to 100 feet of stranded insulated wire for an antenna.
- A block of wood or something similar for a base

Instructions for Ten Minute Radio: Adapted from: Sci Toys: located at:http://sci-toys.com/scitoys/scitoys/radio/ten_minute_radio.html

For the amplifier:

• wire
• 10K-ohm resistor
• 100K-ohm resistor
• switch
• capacitors (0.1 microfarad and 0.01 microfarad)
• 1K CT: 8-ohm transformer (Radio Shack Cat # 273-1380)
• 8 ohm speaker
9-V battery and clip with leads
• breadboard
• hook-up wire
• LED

• 220-ohm resistor
• 100K-ohm resistor
• Transistor, 2N2222A (Si type, NPN, Radio Shack part number 276-2009)
• Microammeter (0–50 000 µA range)
Activity and Instructions Adapted from “Transistorized” web site: located at:
http://www.pbs.org/transistor/teach/teacherguide_html/lesson4.html

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