POLITEKNIK MALAYSIA

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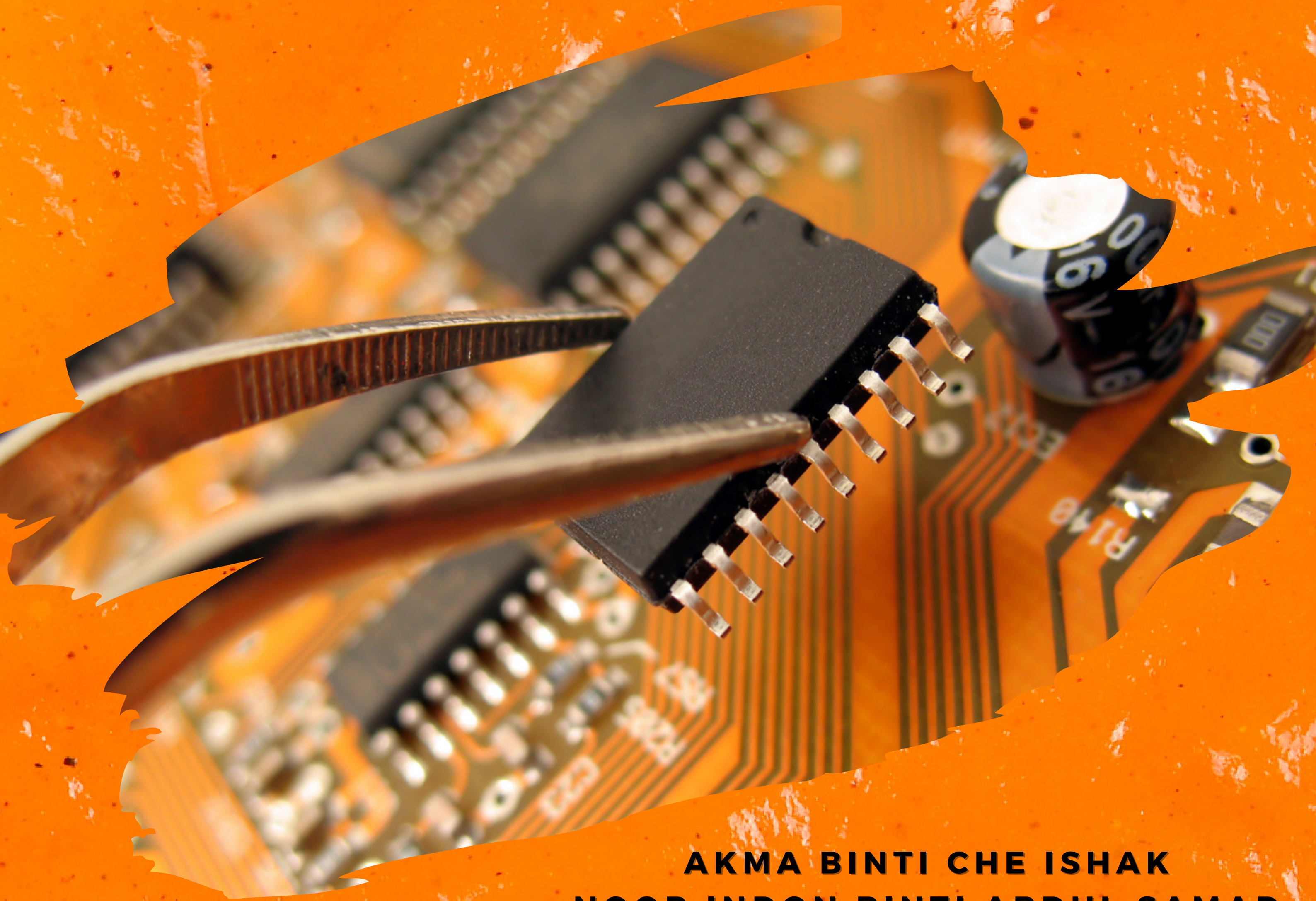
INTRODUCTION TO SEMICONDUCTOR



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ELECTRICAL ENGINEERING

INTRODUCTION TO SEMICONDUCTOR

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The editor would like to give highest regards and appreciation to all who have been involved either directly or indirectly in making this pro ject eBook work. Any positive feedback from lecturers and students are mostly welcomed and appreciated. It is hoped that this eBook will be one of the tiny steps that we have made to start the long journey of road to excellent.

ABSTRACT

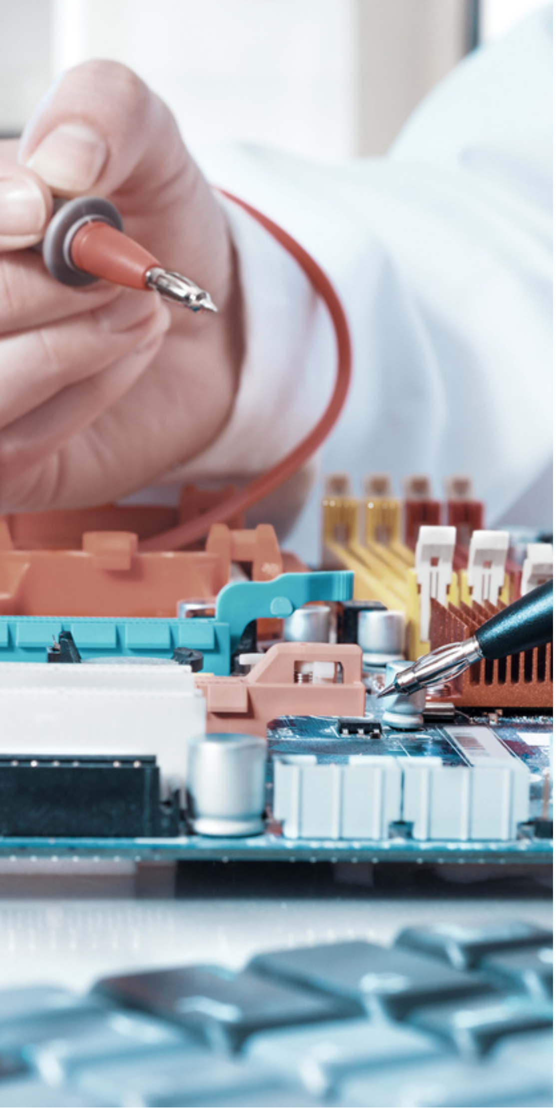
The world would be a very various place if without semiconductors like no electronic hand calculators, cellphones, electronically controlled transmission or personal computer. The eBook Semiconductor Devices is a comprehensive guide for student and lecturers as references. Student can easily read the eBook even they are not in a place that has internet coverage. It required memory in a device such as a smartphone or laptop as storage space.

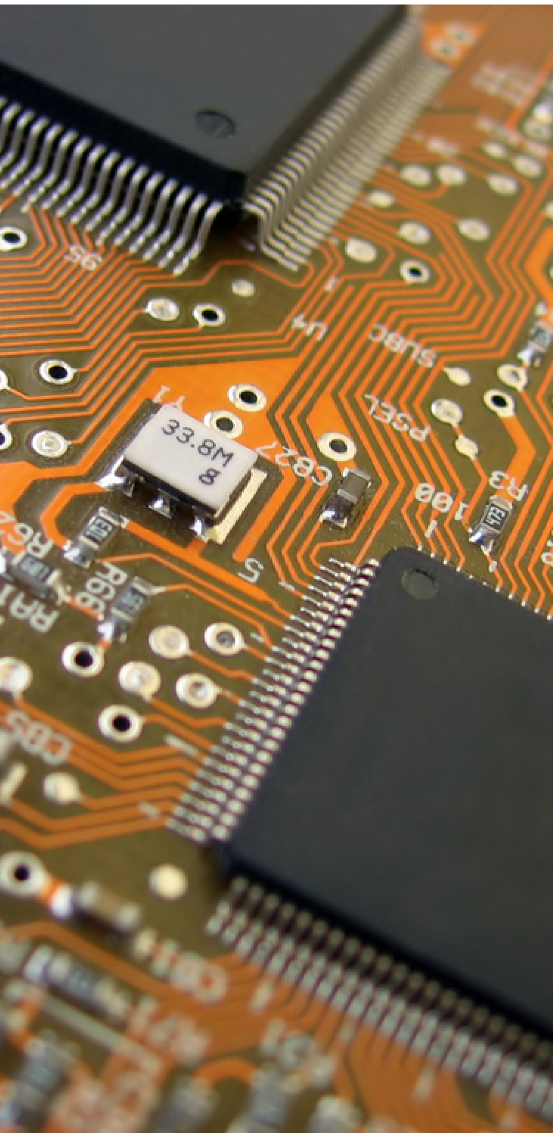
The biggest advantage of this eBook is the ability to own the book in a short period of time. The content of this eBook Semiconductor Devices has been designed to cater the Polytechnic's syllabus requirement. It consists of notes, review question and tutorial questions that can assist the students in the learning processes. This eBook Semiconductor Devices will be useful to assist student in understanding electronic device and circuits.

Key term: Semiconductor Devices, Polytechnic, eBook

TABLE OF CONTENTS

TABLE OF CONTENTS



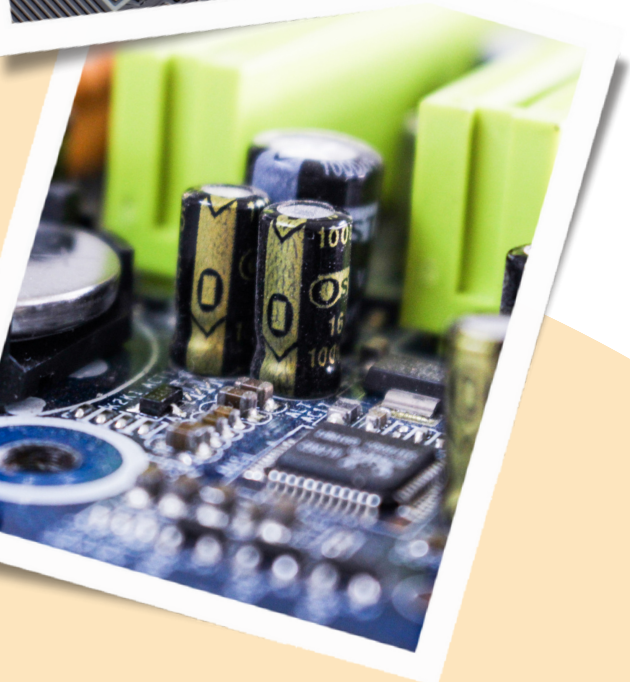


INTRODUCTION TO SEMICONDUCTORS

LEARNING OUTCOMES

At the end of this chapter, you should be able to:

- Describe semiconductor of silicon and germanium
- Describe the characteristics of n-type and p-type semiconductors
- Explain the formation of p-n junction
- Explain meaning of forward biased voltage and reverse biased voltage supplied across a P-N junction.
- Discuss effects when a P-N junction is supplied with forward biased voltage and reverse biased voltage



INTRODUCTION

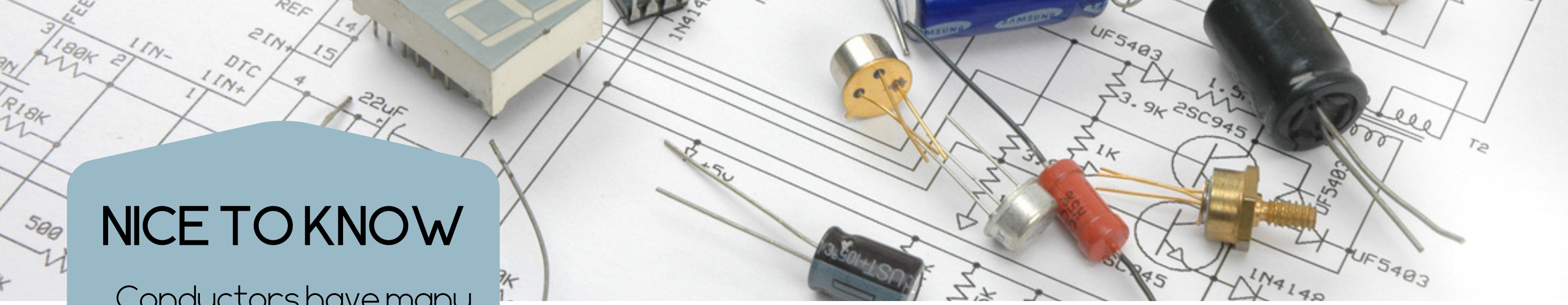
Atoms are the main core of all materials. It is the smallest units that make up a substance. Atomic structure can be used to determine the electrical properties of substance.

Electronic component and device are made of semiconductor as electrical materials. To understand more about the use of semiconductors, the importance things to know is the characteristic and electrical properties of it. In this chapter, it will be more focused on the atomic structure of semiconductor materials, the p-n junction reactive towards voltage biasing and their properties.

As you know, there is prescribed energy band, that the electrons of an atom can exist within it. Each shell around the nucleus corresponds to a certain energy band and is separated from adjacent shells by band gaps, in which no electrons can exist.

An insulator is functioned to not allow the electrical current flow through it. The material itself does not conduct electrical current when working in normal condition.

For the high-performance insulators, it is compounds rather than single-element materials and it also will have a very higher resistivities.



NICE TO KNOW

Conductors have many free electrons whereas insulators have very few or none at all.

The valence atom in the material have a tight bound to the atoms and will result a very few free electrons that can flow across the insulator. For example, such as rubber, plastics, glass, mica, and quartz.

SILICON

A conductor is functioned to allow current flow through it. The materials itself is good conductor such as metal. The best conductors are single-element materials, such as copper (Cu), silver (Ag), gold (Au), and aluminum (Al), which are characterized by atoms with only one valence electron very loosely bound to the atom. The free electron inside conductor is the loosely bound valence electrons. This may result in a conductive material the free electrons are valence electrons.

GERMANIUM

A semiconductor is a material that can conduct electrical current through it. The condition of the materials is between conductors and insulators. A semiconductor in its pure (intrinsic) state is neither a good conductor nor a good insulator.

A commonly used of single-element semiconductor such as antimony (Sb), arsenic (As), astatine (At), boron (B), polonium (Po), tellurium (Te), silicon (Si), and germanium (Ge). For compound semiconductors that usually being used such as gallium arsenide, indium phosphide, gallium nitride, silicon carbide, and silicon germanium. The characteristic of the single-element semiconductors is the atom with for valence electrons. The most commonly semiconductor that being used use in the industry nowadays is Silicon.

1.0 CHARACTERISTICS AND ELECTRICAL PROPERTIES OF SEMICONDUCTORS

The materials can be divided into conductors, insulators and semiconductors by determine their electrical conductivity. The material that allows current to flow through it easily are called conductor.

The reason because valence electron can easily become free electron that can flow throughout the material due to its atoms that have valence electrons that is not strong enough to be held by nucleus. However, for the insulator materials, its valence electrons are tightly bound and because of this, it does not conduct electricity.

A material with electrical conductivity that lies between those of insulators and conductors are called semiconductor. Semiconductor materials can conduct electricity better than insulators but not as good as conductors. The semiconductor atoms have four valence electrons. The total of free electron numbers is not fix depend on external condition such as increasing and decreasing temperature of the materials or by adding the voltage to the semiconductors. The best and commonly use semiconductors is silicon.

Insulators have tightly bound electrons in their outer shell. These electrons require a very large amount of energy to free them for conduction. The force on each electron is not enough to free it from its orbit and the insulator does not conduct. Insulators are said to have a high resistivity or resistance.

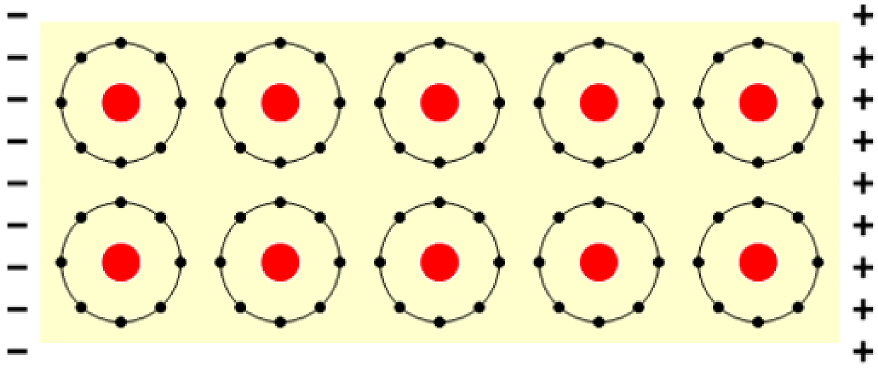


Figure 1.1 : Insulator

Conductors have loosely bound electrons in their outer shell. These electrons require a small amount of energy to free them for conduction. The force on each electron is enough to free it from its orbit and it can jump from atom to atom. Conductors are said to have a low resistivity or resistance.

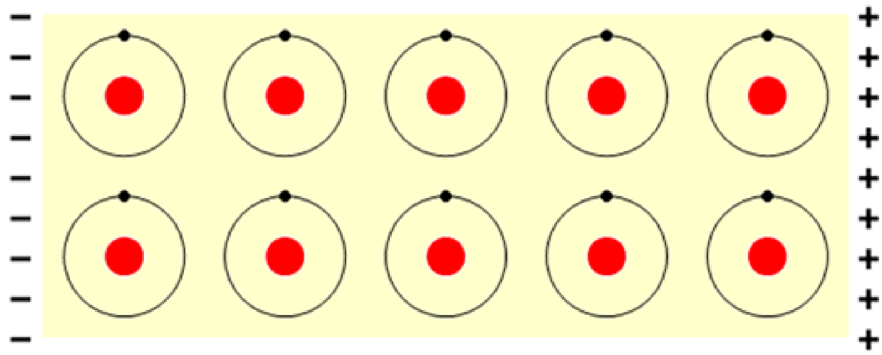


Figure 1. 2 : Conductor

The total atomic number of silicon is 14. This means that inside its nucleus it has 12 protons that balanced by 14 orbiting electrons. The very outermost of the ring of an atom is called the valence ring and the electrons in this ring are called valence electrons. There are four valence electrons for all semiconductors. In order to determines its electrical conductivity, it depend on number of valence electron possessed by any atom.

In order to determines how it will combine with other atoms it depends on the number of valence electron also. In order to determine whether the conductor is the best or not, by checking the number of valence electron. If there is only one valence electron that's means it is the best conductor. It also to determine whether the insulator is the best or not, by checking the number of valence electron. If there are complete shells, that's means it is the best insulator. The characteristics of conductors, insulators and semiconductors are summarized in Table 1.

Table 1 : Characteristics of conductors, insulators and semiconductors

CHARACTERISTICS	CONDUCTOR	INSULATOR	SEMICONDUCTOR
Conductivity	Conducts electricity	Does not conduct electricity	Electrical conductivity intermediate between insulator and conductor
Valence electrons	1-3 valence electrons	5-8 valence electrons	4 valence electrons
Resistivity	Low resistivity. Atoms tend to release valence electrons	High resistivity. Atoms tend accept electrons	Does not easily release or accept electrons
Valence and conduction	Valence and conduction bands are overlapped	Valence and conduction bands are separated by forbidden energy gap of 6 to 10eV	Valence and conduction band are separated by forbidden energy gap of 1.1eV
Temperature	It has positive temperature	It has negative temperature coefficient	It has negative temperature coefficient
Forbidden gap	It has no forbidden gap	It has large forbidden gap	It has small forbidden gap
Zero Kelvin behavior	Acts like a superconductor	Acts like an insulator	Acts like an insulator
Examples	Examples: copper, silver, aluminum	Examples: glass, plastics, ceramics	Examples: silicon, germanium, carbon

2.0 Atomic Structure

The atomic structure model was introduced by Niels Bohr in 1913. Atoms is built of nucleus and electrons. The nucleus are combination of protons and neutrons. Positive charged are called protons while negative charged are called electrons.

For the neutrons it is unchanged. An atom's structure is consisting of a nucleus in the center and electron will move around it layer by layer. For this layer it is called shells. The first shell (n=1) is called K, the second shell L (n=2), followed by M, N, O, P, and Q.

The valence electron stays at the outermost of the shell. The valence electron is used to determine the electrical properties of the materials.

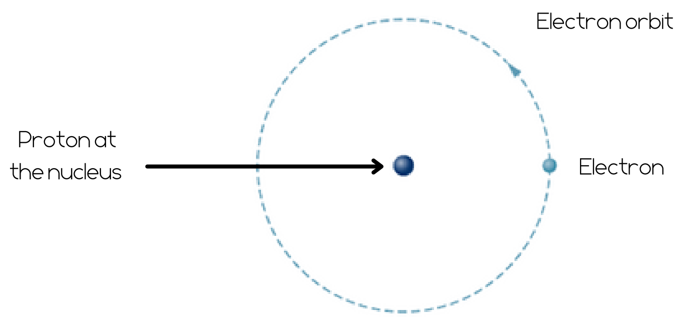


Figure 2.1 : Bohr's atomic model

The maximum number of electrons in each shell is given by the following formula:

$$2 \times n^2$$

From the formula given, the maximum number of electrons for each shell are as depicted in Table 2.

N	Shell	Maximum number of electrons
1	K	2
2	L	8
3	M	18
4	N	32
5	O	50
6	P	72
7	Q	98

Table 2.1 : Maximum number of electrons for each shell

Figure 2.2 shown the sample of atomic structures of silicon and germanium which is the silicon atom has 14 electrons and a germanium atom has 32 electrons. The electrons that are in the outermost shell of an atom called valence electrons. In other words, these are the electrons that can be gained or lost during a chemical reaction.

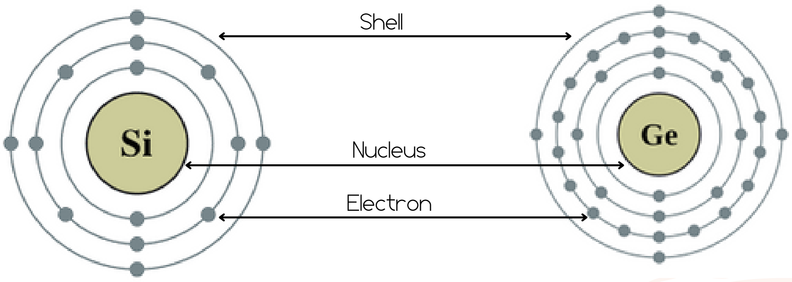
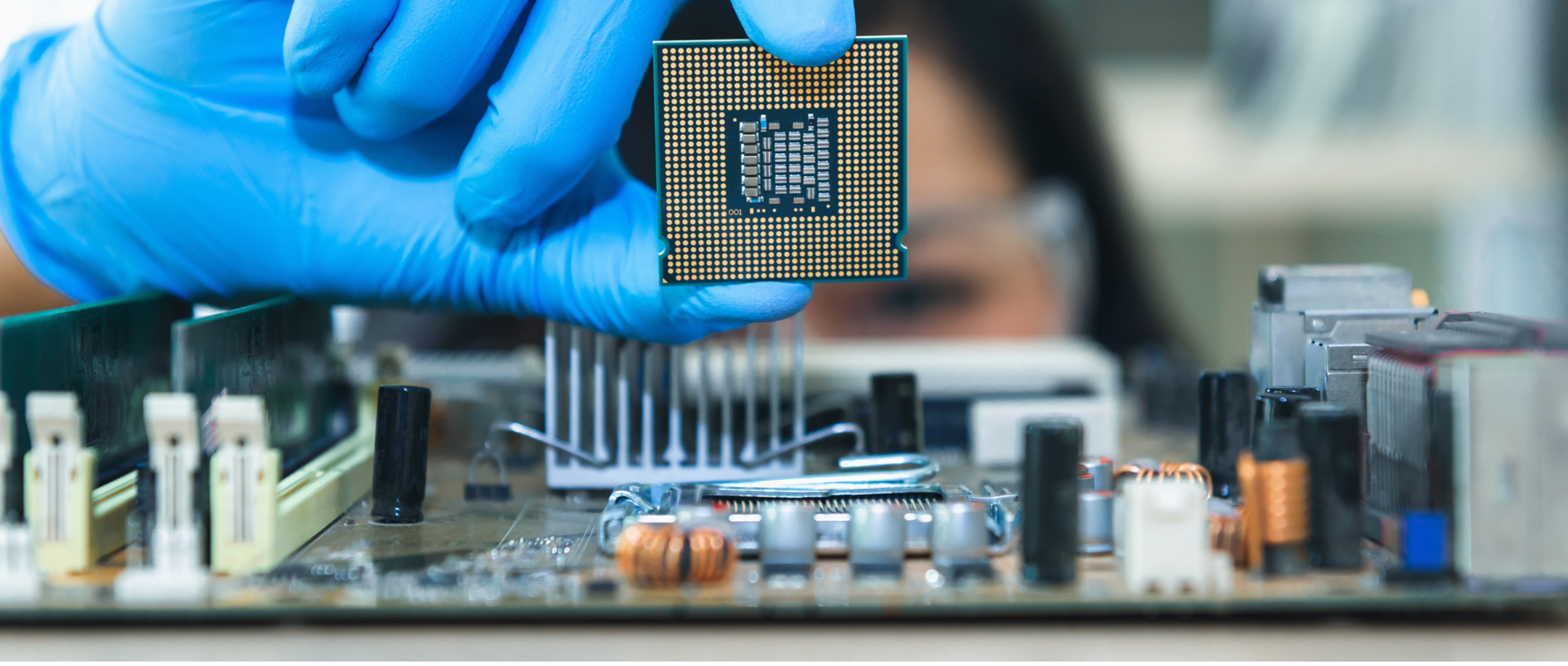


Figure 2.2 : Atomic Structure of silicon and germanium



TUTORIAL QUESTION

(Answer at end of chapter)

Using the atomic number from the periodic table in Table 2.2 .show a silicon (Si) atom using an electron configuration table and draw simple diagram to show the atomic structures.

Helium
Atomic number = 2

Silicon
Atomic number = 14

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cp	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

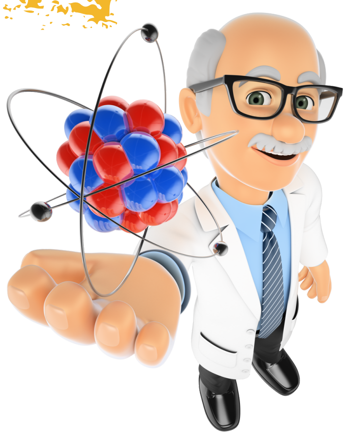
Table 2.2 : Periodic Table

3.0 COVALENT BONDS IN SEMICONDUCTORS

Atoms will always try to fill the maximum number of electrons for their valence bands. A semiconductor has four valence electrons. I order to complete the maximum number of electrons, an atom in semiconductor will take or share valence electron from nearby atoms, to forming a covalent bond.

A bond formed between two atoms are called covalent bond. I happened between two atoms when they try to share one or more pairs of valence electrons.

Semiconductor will behave like insulator at room temperature, due to strong and stable covalent bonds between their atoms.



There are some aspects that interrupt covalent bonds such as heat, temperature, potential different and the doping process.

The covalent bonds will break due to this factor and some electrons are freed to become free electrons. A small amount of current will flow because a small number of free electrons are produced if small voltage is applied to the semiconductors.

More valence electrons will be freed from their bonds to become free electrons if the temperature keep increase. The semiconductor will become as conductor if the voltage is kept continues to be supply and the current will keep increase.

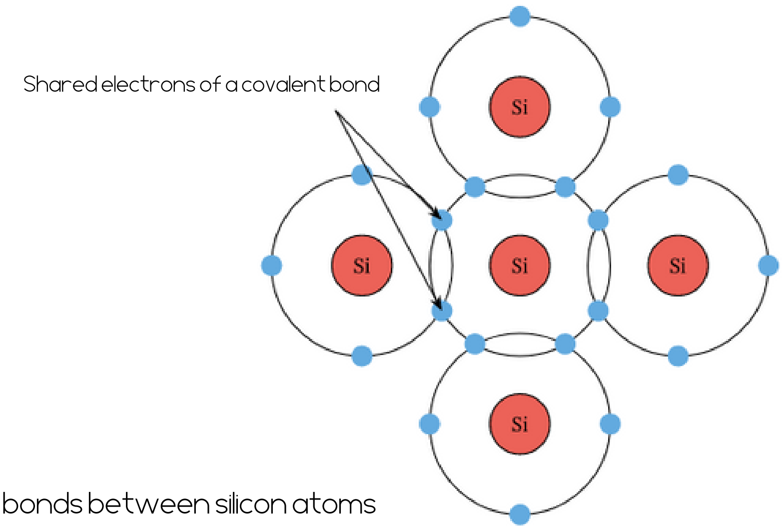


Figure 3.1 : Covalent bonds between silicon atoms

TUTORIAL QUESTION

(Answer at end of chapter)

a) What is the basic difference between conductors and insulators?

b) How do semiconductors differ from conductors and insulators?

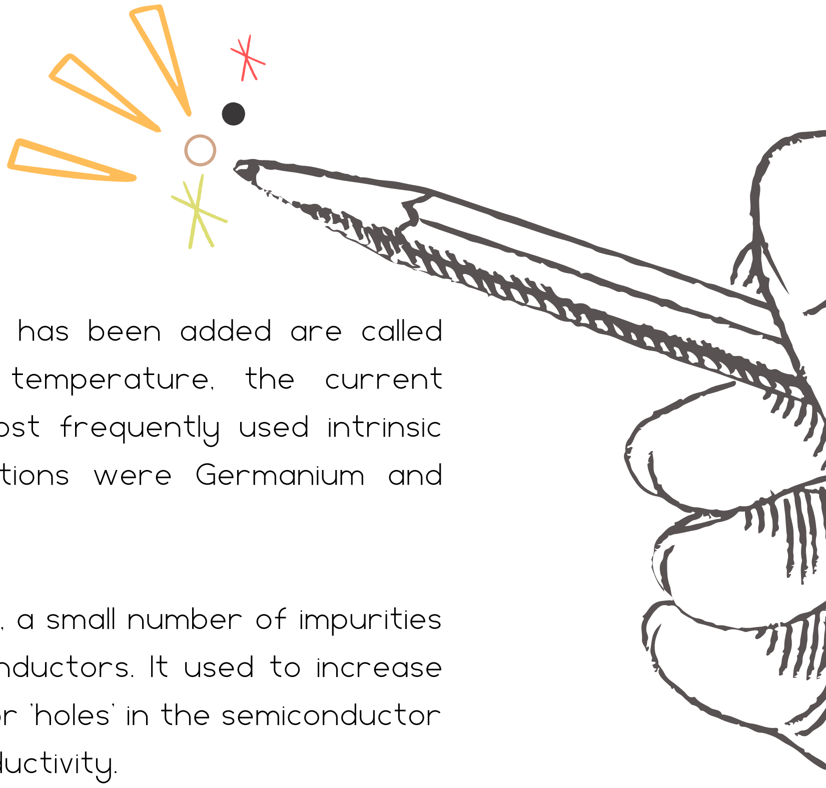
c) How many valence electrons does a conductor such as copper have?

d) How many valence electrons does a semiconductor have?

e) Name three of the best conductive materials.

4.0 CHARACTERISTICS AND ELECTRICAL PROPERTIES OF SEMICONDUCTORS

4.1 INTRINSIC AND EXTRINSIC SEMICONDUCTORS



A pure substance to which impurity has been added are called intrinsic semiconductors. At room temperature, the current conductivity capability is low. The most frequently used intrinsic semiconductors in electronic applications were Germanium and Silicon.

To produced extrinsic semiconductors, a small number of impurities need to be added to intrinsic semiconductors. It used to increase either the number of free electrons or 'holes' in the semiconductor crystal. I also increase the current conductivity.

The impurities added to semiconductors have two category which is trivalent and pentavalent. Trivalent impurities consist of three valence electrons while pentavalent impurities consist of five valence electrons. Doping is the process to adding impurities to the semiconductors.

4.2 DIFFERENCE BETWEEN INTRINSIC AND EXTRINSIC SEMICONDUCTOR

An intrinsic semiconductor is the one which is made of the extremely pure semiconductor material. They have the equal number of holes and electrons so do not conduct the current. Extrinsic semiconductors are made out of intrinsic semiconductors by adding some suitable impurity (P-Type or N-Type) in an extremely small amount.

Table 4.1 : Difference between Intrinsic and Extrinsic Semiconductor

CHARACTERISTICS	INTRINSIC SEMICONDUCTOR	EXTRINSIC SEMICONDUCTOR
Purity	Pure semiconductor (with an impurity) is considered to have an intrinsic nature.	Such semiconductors are made by adding impurities to pure semiconductors.
Conductivity	Low	High
Use	They are not practically used	They are practically used in various applications.
Energy gap	Energy gap is small.	The energy gap is more than that in an intrinsic semiconductor.
Electrons vs Holes	Number of electrons and holes are equal.	In N-type, electrons are in ma jority whereas in P-Type, holes are in ma jority.
Examples	Silicon, Germanium	For P-Type: Gallium, Aluminum, Boron. For N-Type: Phosphorous, Antimony, Arsenic.
Elements table	Group IV elements lie in this category.	Group III and V elements (as an impurity) are introduced in Group IV elements.
Conductivity Vs Temperature	Conductivity increases as temperature rises.	Conductivity mainly depends on the impurity added.

5.0 THE DOPING PROCESS

To produce an extrinsic semiconductor, the doping process is needed. The doping process is the process of adding impurities to an intrinsic semiconductor.

It will increase the number of free electron or 'holes'. To generate a p-type semiconductor, a semiconductor will need to be doped with trivalent impurity.

Indium, gallium, boron and aluminum were example of trivalent impurities. While phosphorus, arsenic and antimony were example of pentavalent impurities.

An intrinsic semiconductor will be like insulator rather than a conductor when the surrounding temperature is at room temperature which is approximately 25°C.

The conductivity of an intrinsic semiconductor is lower than an extrinsic semiconductor. The higher number of impurity atoms will increase the level of conductivity that have been added while doping process activity.

5.1 P-Type Semiconductors

By adding trivalent impurities to intrinsic semiconductors, it will be produced p-type of semiconductors. It will create excess holes which can accept electrons.

Any impurities which can produce p-type semiconductors are known as acceptor impurities. Figure 5.1 shows an example of a p-type semiconductor formed by adding indium to silicon.

The atom that has only three valence electrons is called trivalent atom. There is some examples of material such as aluminum (Al), boron (B), and gallium (Ga). Atom that doped with large number of trivalent impurities such as silicon crystal, may results in many holes, or vacancies

in the covalent bond structure of the material. At the vacancy area, one more valence electron is needed for each trivalent atom for the crystal to gain the maximum stability of electric charge with eight electrons.

Indium has 3 valence electrons while silicon has four valence electrons. Referring to Figure 5.1, notice that indium contributes all three of its valence electrons to form three covalent bonds with three silicon atoms.

Due to Indium atom has no more valence electron left, one of the valence electrons consist of four silicon atoms does not form a covalence bond. A hole was created due to missing electron that left an empty space which has a positive electric charge.

Majority current carriers are holes that is p-type semiconductors while free electrons are the minority current carriers. Due to the predominance of holes, it has positive charge compare to free electron. It is p-type semiconductor material where p is stands for 'positive'.

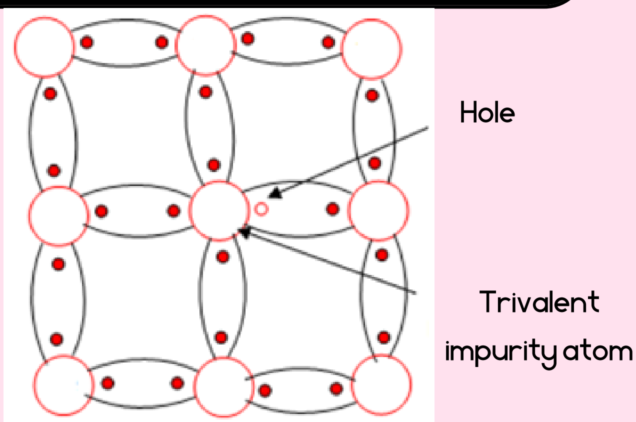


Figure 5.1 : Formation of p-type material

5.2 N-Type Semiconductors

By adding pentavalent impurities to intrinsic semiconductors, the n-type semiconductor can be produced.

Donor impurities is impurities which can produce n-type semiconductors because they able to donate free electron to the semiconductor.

Arsenic has five valence electron and for silicon it has four valence electrons. As shown in Figure 5.2, arsenic contributes four valence electrons to form four covalent bonds with four silicon atoms. Due to this, the arsenic atom leaves with one excess valence electron will not bonding. It will become a free electron.

The free electron will be negative current carrier. In n-type semiconductors, the majority of current carrier is free electrons. While in minority of current carriers, it is holes.Due to the predominance of free electrons, that are negative compared to holes, the semiconductor is called an n-type semiconductor, where n stands for 'negative'. Table 5.1 show comparison of p-type and n-type semiconductors.

The atom that has five valence electrons is called pentavalent atom. There is some examples of materials such as antimony (Sb), arsenic (As), and phosphorous (P).

Large number of pentavalent impurity atom when doped with a silicon crystal may results in produce more free electrons in the material. At the location of each pentavalent atom, there will have one electron there and it is not used in the covalent bond structure. Bear in mind, that there will be only eight electron that can be exist in the outer ring on every atom.

This may result one of the valent electrons is the pentavalent impurity is not needed in the structure of the covalent bond and will be free electron that will floating across the material.

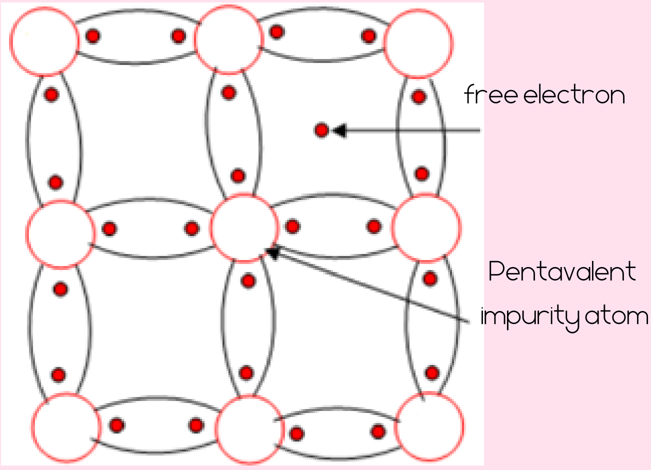
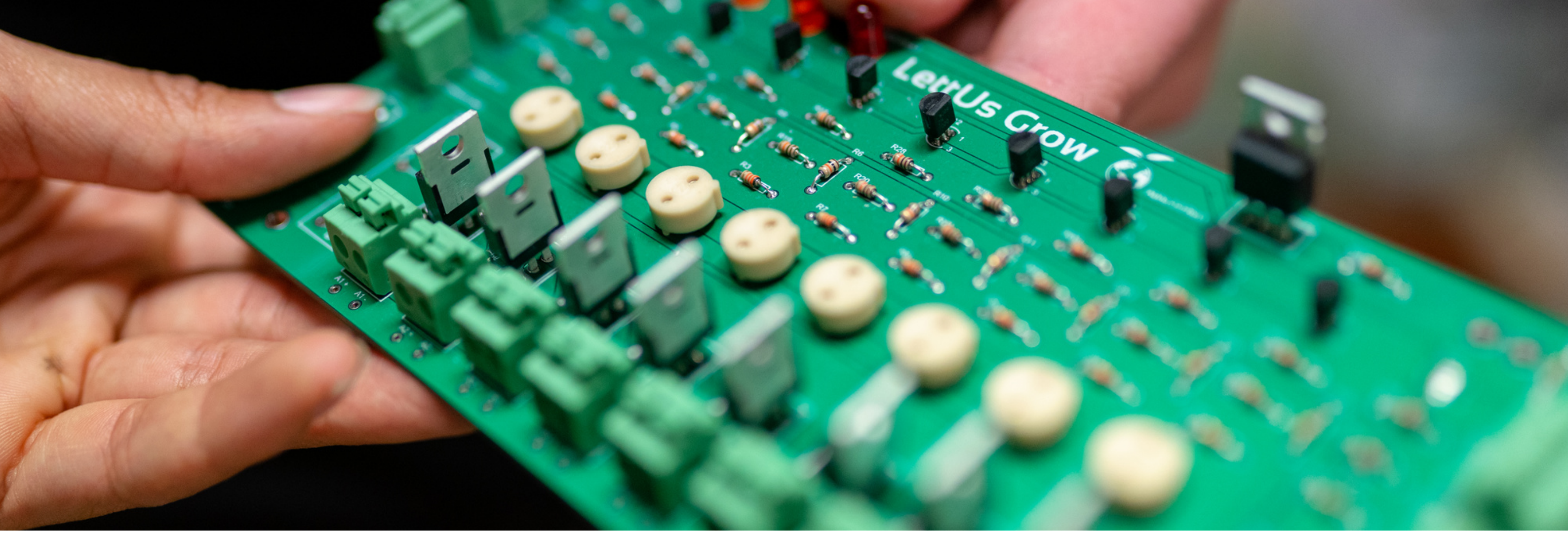


Figure 5.2 : Formation of n-type material

Table 5.1 : Comparison between p-type and n-type semiconductors

PARAMETER	P - TYPE SEMICONDUCTOR	N- TYPE SEMICONDUCTOR
Nature of doping element	Donor type	Acceptor type
Impurity added in doping process	Trivalent	Pentavalent
Ma jority current carrier	Holes	Electrons
Minority current carrier	Electrons	Holes
Conductivity	Due to presence of holes	Due to presence of electrons
Concentration of electrons	Low	Very high as compares to p type semiconductor
Concentration of holes	High	Comparatively less than p type semiconductor



TUTORIAL QUESTION

(Answer at end of chapter)

a) What is the purpose of doping process?

b) What type of semiconductor material is created when a silicon crystal is doped with pentavalent impurity atoms?

c) Identify how many electrons are presented at valence layer of the trivalence atoms for doping process.

d) What are the minority current carriers in a p-type semiconductor material?

e) Does a hole exhibit a positive, negative, or neutral charge?

6.0 Formation of p-n Junctions

6.1 Free Electrons mobility

When there is no voltage or electric field applied across the semiconductor, the free electrons moves randomly.

However, when the voltage or electric field is applied across the semiconductor, each free electron starts to move more quickly in particular direction. Electrons move very fast in vacuum.

According to conventional current theory, current flows from the positive terminal to the negative terminal because current flows from a higher potential to a lower potential.

The positive terminal has higher potential than the negative terminal. According to electron current theory, electrons flow from the negatives terminal to the positive terminal.

Free electrons are electrons freed from covalent bonding. An electron is a current carrier and since it is negatively charged it is called a negatives current carrier. When an electron moves, it leaves a space called a hole.

Holes are considered to be positively charged. They attract electrons to fill the empty spaces. The movement of electrons causes current flow in semiconductors.

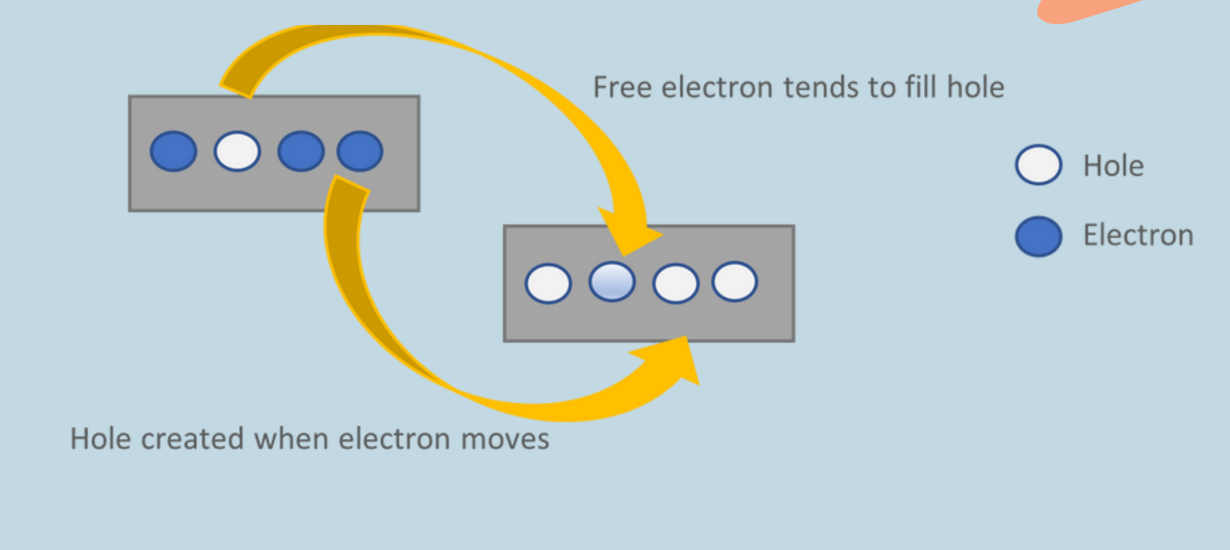


Figure 6.1 : Electron and hole pair

6.2 Formation of a Depletion Region

When p-type and n-type materials are combined together, they form a p-n junction. p-Type materials contain holes as majority carriers while n-type materials contain electrons as majority carriers. When these two materials are combined, the free electrons in the n-type material are pulled to replace the holes in the p-type material.

Diffusion of electrons occurs across the junction until it stops when the barrier voltage is reached. The area around the p-n junction is called a depletion region and it is electrically neutral.

The barrier voltage depends on the type of semiconductor, temperature, and doping densities. The barrier voltage for silicon is 0.7 V and 0.3 V for germanium.

At the moment of p-n junction formation, the free electrons of the n-type semiconductor begin to diffuse across the junction to combine with holes in the p-type semiconductor.

This process will create a layer of positive charge between the n-type semiconductor and the junction since the n-type semiconductor loses its free electrons.

As the electrons and holes combine, a layer of negative charge will form between the p-type semiconductor and the junction since the p-type semiconductor loses its holes. The positive and negative layer near the junction form a depletion region as illustrated in Figure 6.2.

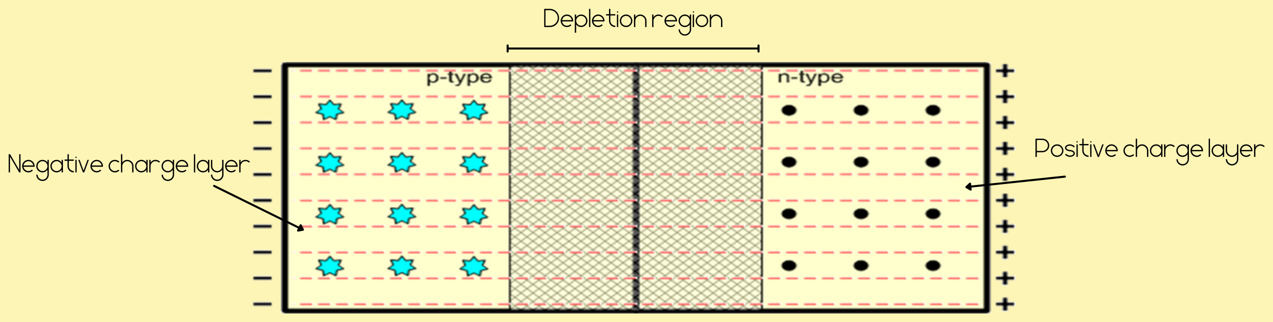


Figure 6.2 : Formation of p-n junction

7.0 PN Junction Reactions towards Voltage-Biasing

Voltage supplied to a p-n junction is known as bias voltage. Bias voltage will determine whether current can flow across the p-n junction or not.

There are two types of bias voltage, namely forward bias and reverse bias. Current can flow in a forward biased condition but cannot flow in a reverse biased condition.

7.1 Bias

The term bias is defined as a control voltage or current. The term bias refers to the application of DC voltage to set up certain operating conditions. Or when an external source of energy is applied to a P-N junction it is called a bias voltage or simply biasing.

This method either increases or decreases the barrier potential of the junction. As a result, the reduction of the barrier potential causes current carriers to return to the depletion region.

Following two bias conditions are applied in PN junctions:

Forward Biasing

An external voltage is added of the same polarity to the barrier potential, which causes an increase in the width of the depletion region.

Reverse Biasing

A PN junction is biased in such a way that the application of external voltage action prevents current carriers from entering the depletion region.

7.2 Forward Bias

Forward-biasing a diode allows current to flow easily through the diode. Figure 7.1 illustrates a p – n junction that is forward-biased. In Figure 7.1 , notice that the n material is connected to the negative terminal of the voltage source, V and the p material is connected to the positive terminal of the voltage source, V.

The voltage source, V must be large enough to overcome the internal barrier potential VB. The voltage source repels free electrons in the n side across the depletion zone and into the p side.

Once on the p side, the free electron falls into a hole. The electron will then travel from hole to hole as it is attracted to the positive terminal of the voltage source, V.

For every free electron entering the n side, one electron leaves the p side. Notice in Figure 7.1 that if the p – n junction is made from silicon, the external voltage source must be 0.7 V or more to neutralize the effect of the internal barrier potential,

VB and in turn produce current flow. (It should be noted that in a practical circuit, a resistance would be added in series with the diode to limit the current flow.)

Figure 7.2 shows the schematic symbol of a diode with the voltage source, V connected to provide forward bias. Notice that forward bias exists when the anode,

A is positive with respect to the cathode, K. Notice that electrons flow to the n side, against the arrow on the diode symbol. The arrow on the diode symbol points in the direction of conventional current flow.

Either current direction works well when analyzing diode circuits. However, we will use electron flow when analyzing circuits containing diodes.

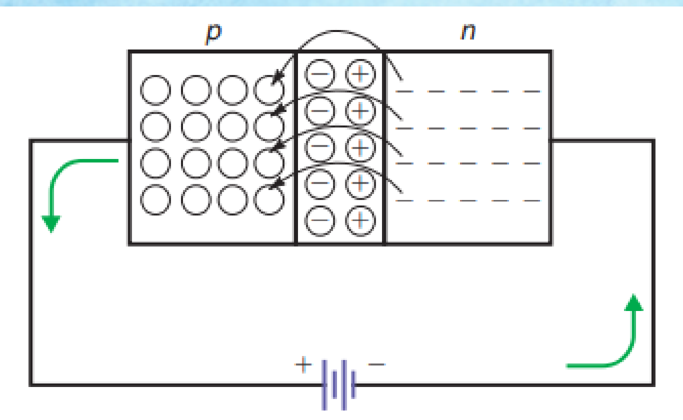


Figure 7.1 : Depletion region when supplied with forward bias

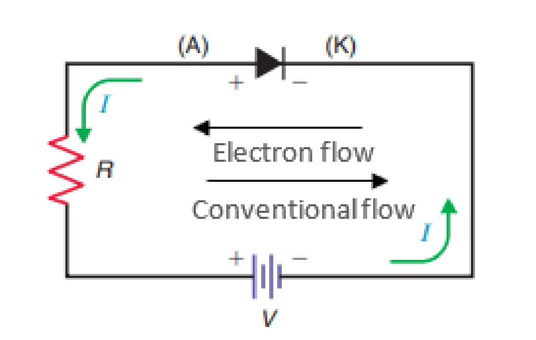


Figure 7.2 : Electron flow is against the arrow.

7.3 Reverse Bias

The p- n Junction Figure 7.3 show how to reverse-bias a p - n junction. Notice that the negative terminal of the voltage source, V, is connected to the p -type semiconductor material and that the positive terminal of the voltage source, V, is connected to the n -type semiconductor material.

The effect is that charge carriers in both sections are pulled away from the junction. This increases the width of the depletion zone, as shown. Free electrons on the n side are attracted away from the junction because of the attraction of the positive terminal of the voltage source, V. Likewise, holes in the p side are attracted away from the junction because of the attraction by the negative terminal of the voltage source, V.

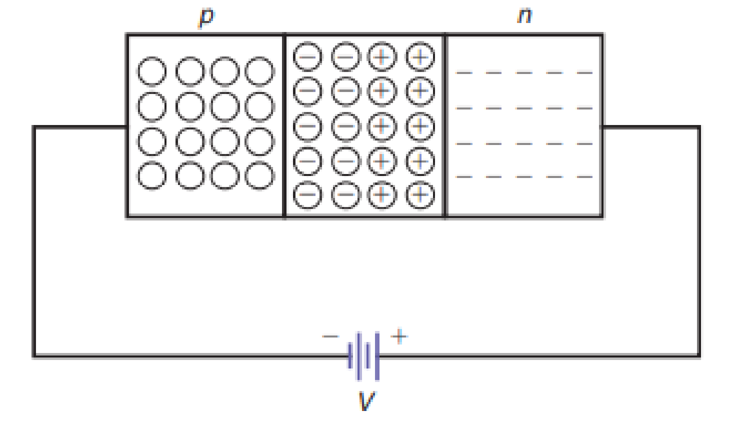


Figure 7.3 : Depletion region when supplied with reverse bias

In Figure 7.4 shows the schematic symbol of a diode with the voltage source V , connected to provide reverse bias.

The result of reverse bias is that the diode is in a nonconducting state and acts like an open switch, ideally with infinite resistance.

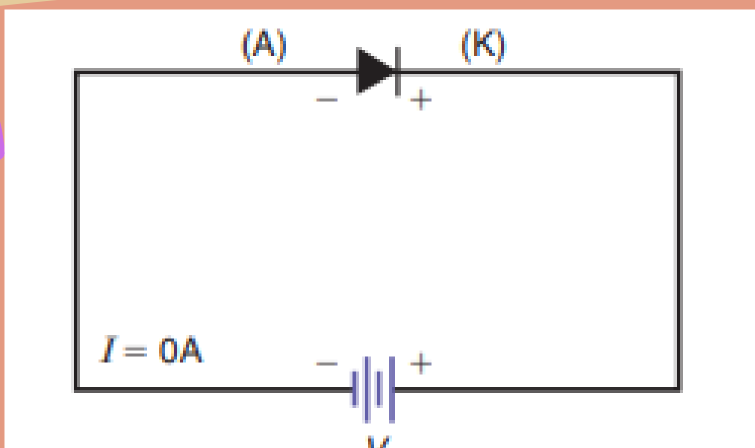


Figure 7.4 : Schematic symbol

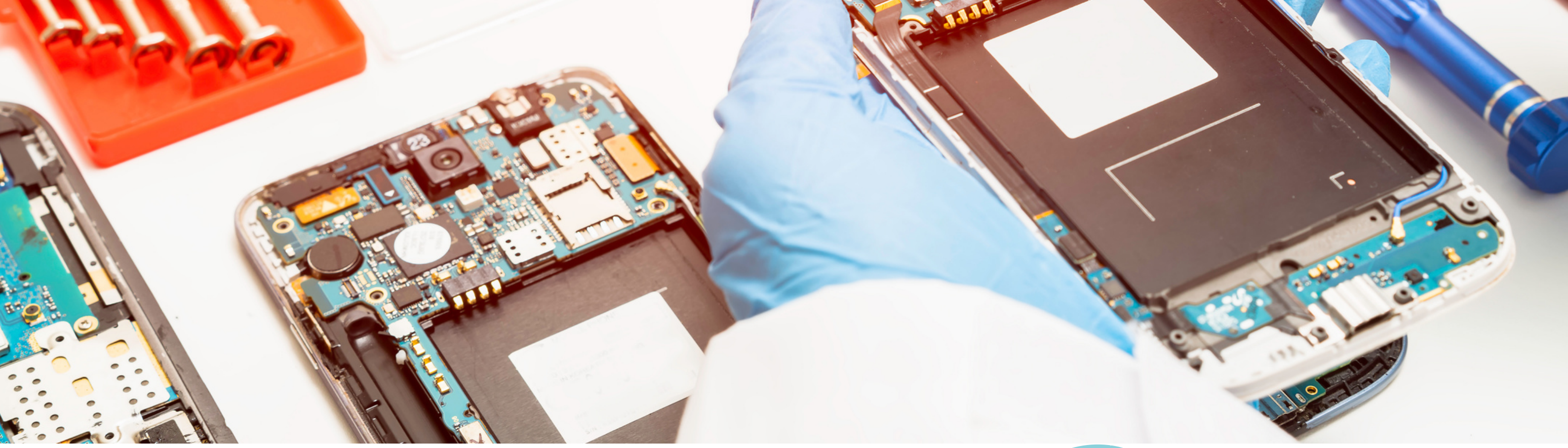
7.4 Leakage Current

Even a reverse-biased diode conducts a small amount of current, called leakage current. The leakage current is mainly due to the minority current carriers in both sections of the diode.

The minority current carriers are holes in the n side and free electrons in the p side. The minority current carriers exist as a result of thermal energy producing a few electron-hole pairs.

Since temperature determines the number of electron-hole pairs generated, leakage current is mainly affected by temperature.

Any increase in the temperature of the diode increases the leakage current in the diode. These minority current carriers move in a direction that is opposite to the direction provided with forward bias



Reminders
Tutorial Question

1. The p side of a diode is called the (**anode**/cathode) and the n side is called the (anode/**cathode**).

2. To forward-bias a diode, the anode must be (**positive**/negative) with respect to its cathode.

3. A reverse-biased diode acts like an (**open**/closed) switch.

SUMMARY

RECAP 1

Materials can be classified as conductors, semiconductors and insulators based on their electrical conductivity.

RECAP 2

- The properties of materials are determined by their atomic structure especially their valence electrons.
- Semiconductors are materials with electrical conductivity between those of conductors and insulators.

RECAP 3

- Silicon and germanium are commonly used semiconductors.
- P-Type or N-type material can be produced by adding impurities to pure semiconductors through the doping process.

RECAP 4

- A p n junction is formed when p-type and n-type materials are combined together
- P-n junctions are more useful when bias voltage is applied.

RECAP 5

- There are two types of bias voltage, namely forward bias and reverse bias.
- Now that we understand the basic characteristics of semiconductors and the effect of voltage biasing on p n junctions.

Notes

Materials can be classified into three categories.i.e. conductors, insulators and semiconductors

Semiconductors are materials with electrical conductivity between those of conductors and insulators. They conduct electricity better than insulators but more poorly than conductors.

The maximum number of electrons in each shell of an atom is given by the formula $2xn^2$. A covalent bond is a sharing of valence electrons between two atoms.

Intrinsic semiconductors are pure semiconductors while extrinsic semiconductors are created by adding impurities to pure semiconductors.

P-Type semiconductors are produced by adding trivalent impurities to intrinsic semiconductors.

N-Type semiconductors are produced by adding pentavalent impurities to intrinsic semiconductors.

Electrons are negatively charged while holes are positively charged. The movement of an electron leaves behind an empty space called a hole. Other electrons are attracted to fill up these empty spaces.

Increasing the reverse voltage past a particular point will cause breakdown which destroys the p-n junction permanently.

Current can flow easily when a semiconductor is supplied with a voltage in forward bias but cannot flow when the semiconductor is supplied with a voltage in reverse bias. However, a small leakage current still flows in the reverse bias condition.

TUTORIAL QUESTIONS

Multiple-Choice Questions

1. The most widely used semiconductive material in electronic devices is
   - A. germanium
   - B. carbon
   - C. copper
   - D. silicon

2. Select the statement which explains the term semiconductor. A valence electrons which are weakly attracted to the nucleus of atoms
   - A. Valence electrons which are weakly attracted to the nucleus of atoms
   - B. A material with electrical conductivity in between those and insulators
   - C. A substance that resists the flow of electric current
   - D. A large amount of free mobile electrons

3. What is the atomic number of silicon?
   - A. 10
   - B. 14
   - C. 16
   - D. 32

4. The valence shell in a silicon atom has the number designation of
   - A. 0
   - B. 1
   - C. 2
   - D. 3

5. What will happen to the depletion region when the terminals are connected as shown in Figure 1?

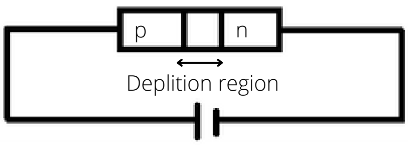
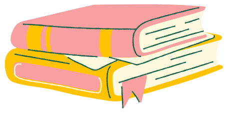


Figure 1

   - A. The depletion region is destroyed.
   - B. The width of the depletion region increases.
   - C. The width of the depletion region decreases.
   - D. The width of the depletion region remains the same.

TUTORIAL QUESTIONS

Multiple-Choice Questions



6. The process of adding impurities to a pure semiconductor material in order to increase its electrical conductivity is called

   A. Velocity
   B. Conductivity
   C. doping.
   D. Permeability

7. The purpose of adding a pentavalent impurity to a semiconductor is to

   A. increase the number of free electrons
   B. increase the number of holes
   C. reduce its electrical conductivity
   D. create minority carriers

8. Holes in an n-type semiconductor are

   A. minority carriers that are thermally produced
   B. minority carriers that are produced by doping
   C. majority carriers that are thermally produced
   D. majority carriers that are produced by doping

9. A pn junction is formed by

   A. the recombination of electrons and holes
   B. ionization
   C. the boundary of a p-type and an n-type material
   D. the collision of a proton and a neutron

10. The depletion region is created by

    A. Ionization
    B. diffusion
    C. recombination
    D. answers (A), (B), and (C)

TUTORIAL QUESTIONS

Short-Answer Questions

- When a p-n junction is formed, a ___________ region is created on either side of the junction.
- What is meant by the term intrinsic semiconductor?
- Explain how a barrier voltage is produced at a p-n junction.
- Figure 2 shows the structure for an ___________ atom. The electrons are ___________ charged and the protons are ___________ charged.

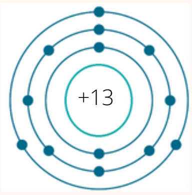


Figure 2

- When a p-n junction is supplied with a forward biased voltage, what will happen to
  a) the width of the depletion region?
  b) the junction resistance?
  c) the current flow?
- When a diode is forward-biased, the current is produced __________holes and electrons.
- Although current is blocked in reverse bias, there is a very ___________ current due to minority carriers.
- A diode is normally operated in the __________________ the ___________________.
- For a silicon diode, the value of the forward-bias voltage typically must be greater than __________________.
- When forward biased, a diode __________________.

TUTORIAL QUESTIONS

True/False Questions

1. An atom is the smallest particle in an element.	TRUE	FALSE
2. An electron is a negatively charged particle	TRUE	FALSE
3. An atom is made up of electrons, protons, and neutrons.	TRUE	FALSE
4. Electrons are part of the nucleus of an atom.	TRUE	FALSE
5. Valence electrons exist in the outer shell of an atom.	TRUE	FALSE
6.Crystals are formed by the bonding of atoms.	TRUE	FALSE
7. Silicon is a conductive material.	TRUE	FALSE
8. Silicon doped with p and n impurities has one pn junction.	TRUE	FALSE
9. The p and n regions are formed by a process called ionization.	TRUE	FALSE
10. The absence of an electron in the valence band of an atom is called hole.	TRUE	FALSE

TUTORIAL QUESTIONS
Essay Questions

Question 1

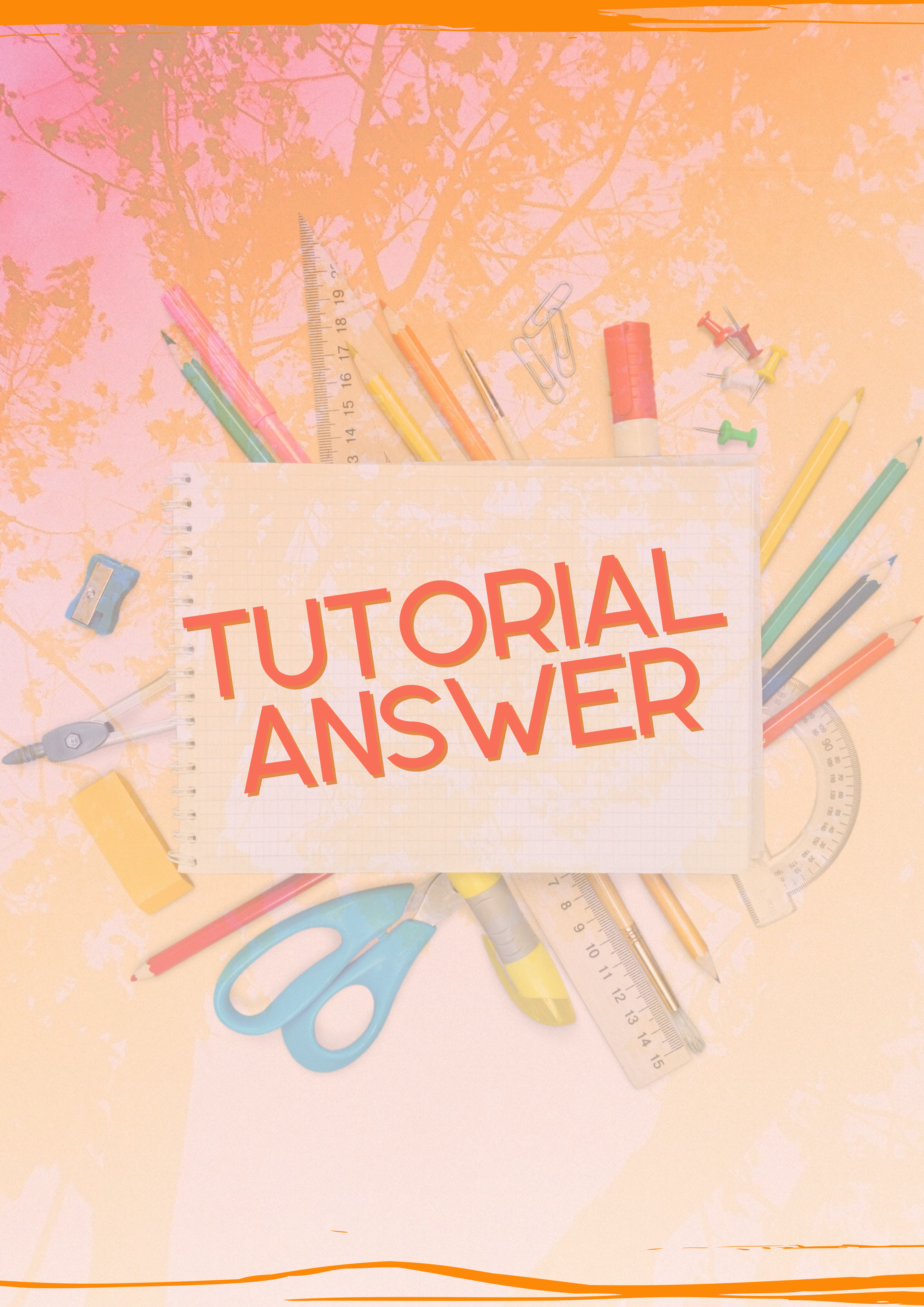
SUPER

a)Define semiconductor.
b)List FIVE (5) types material in semiconductor's family.
c)State the three categories into which materials can be classified based on electrical conductivity. Explain how atomic structure determines the electrical conductivity of these materials.
d) Explain Forward Bias condition when VD>0V which related to the P-N junction and internal distribution of charge under forward-bias conditions.
e)State the factors that can free electrons from covalent bonds.

Question 2

COOL

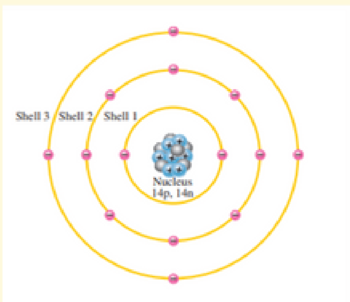
a)List all the importance parameter for the atomic structure.
b)Draw and label a p-n junction.
c)By using a suitable diagram, explain how an n-type semiconductor can be produced.
d)With the aid of diagrams, illustrate the meaning of forward biased and reverse biased p-n junctions.
e)Illustrate the formation of a P-N junction in terms of:
i.Free electrons mobility
ii.Formation of depletion region and its properties
iii.Existence of threshold voltage and its values for silicon and germanium.


TUTORIAL
ANSWER

Tutorial answer pg :10

- The atomic number of silicon is 14. This means that there are 14 protons in the nucleus. Since there is always the same number of electrons as protons in a neutral atom, there are also 14 electrons.
- As you know, there can be up to two electrons in shell 1, eight in shell 2, and eighteen in shell 3.
- Therefore, in silicon there are two electrons in shell 1, eight electrons in shell 2, and four electrons in shell 3 for a total of 14 electrons. The electron configuration table for silicon is shown in Table 1.

Notation	Explanation
1st shell	2 electron in 1 shell
2nd shell	8 electron in 2 shell
3rd shell	4 electron in 3rd shell



Silicon

Tutorial answer
pg :13

BRILLIANT

Answer

a)What is the basic difference between conductors and insulators?

Conductor	Insulator
Conducts electricity	Does not conduct electricity
1-3 valence electrons	5-8 valence electrons
Low resistivity. Atoms tend to release valence electrons	High resistivity. Atoms tend accept electrons
Examples: copper, silver, aluminum	Examples: glass, plastics, ceramics

b)

- Electrical conductivity intermediate between insulator and conductor
- 4 valence electrons
- Does not easily release or accept electrons
- It has negative temperature coefficient
- It has small forbidden gap
- Examples: silicon, germanium, carbon

c) A conductor such as copper have 1-3 valence electrons.

d) A semiconductor has 4 valence electrons.

e) Three of the best conductive materials is copper, silver and aluminum

Tutorial answer pg :22

a)The purpose of doping process is to produce an extrinsic semiconductor.

b) n-type semiconductor is created when a silicon crystal is doped with pentavalent impurity atoms.

c) It has only three valence electrons of the trivalence atoms for doping process.

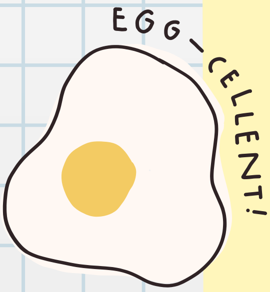
d) The minority current carriers in a p-type semiconductor material is the electrons.

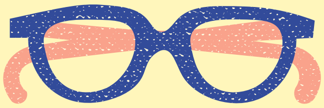
e) A hole exhibits a positive charge.

TUTORIAL ANSWER

Multiple-choice Question

1. D
2. B
3. B
4. D
5. C
6. C
7. A
8. A
9. C
10. D





TUTORIAL ANSWER

Short-Answer Questions

1. depletion

2. Intrinsic semiconductor is a pure semiconductor material which does not contain impurities.

3. The transfer of electrons from the n side of the junction to holes on the p side of the junction produces a barrier voltage. The barrier voltage value for silicon is 0.6 to 0.7 V and 0.2 to 0.3 V for germanium.

4. aluminium, negative, positive

5. Area of depletion region: Becomes smaller or thinner
Junction resistance: Decreases
Current flow: Increases

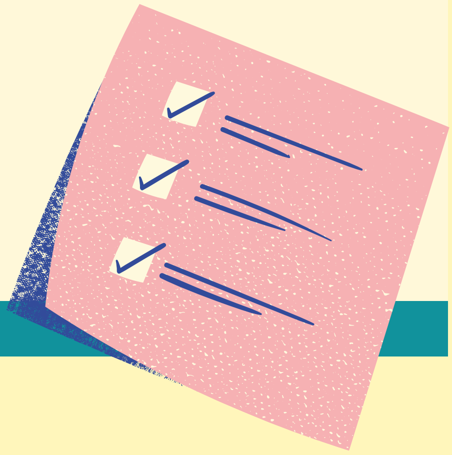
6. Both

7. Small

8. forward-bias region, reverse-bias region

9. 0.7V

10. conducts currents



TUTORIAL ANSWER

True/False Questions

1. TRUE

2. TRUE

3. TRUE

4. TRUE

5. TRUE

6. TRUE

7. FALSE

8. TRUE

9. FALSE

10. TRUE

Well Done!

TUTORIAL ANSWER

Essay Questions

IMPRESSIVE

Question 1

a) Semiconductor is a matter between the insulator and conductor. It conducts electricity better than insulator but poorer than conductors.

b) Five (5) types material in semiconductor's family.

- Silicon,si
- Germanium,Ge
- Stanum,Sn
- Plumbum,Pb
- Carbon,C

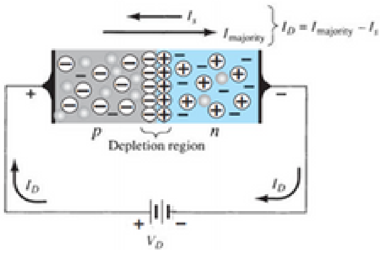
c) Electrical materials can be classified as conductor, insulator and semiconductor. The differences between these materials are the number of valence electrons in their atomic structure. Conductor has one to three valence electrons so atoms tend to release valence electron. Insulator has five to eight valence electrons. The insulator atom tend to receive valence electron while semiconductor only has 4 valence electrons. It's not easy to release or receive valence electron.

d)

i.VD will "pressure" electrons in the n-type material and holes in the p-type material to recombine with the ions near the boundary and reduce the width of the depletion region.

ii.The resulting minority-carrier flow of electrons from the p -type material to the n-type material has not changed in but the reduction in the width of the depletion region has resulted in a heavy ma jority flow across the junction.

iii.An electron of the n -type material now "sees" a reduced barrier at the junction due to the reduced depletion region and a strong attraction for the positive potential applied to the p -type material.



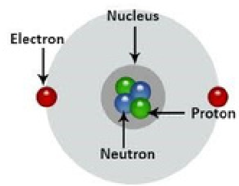
e) Factors that allow electron to become free from covalent bonds are heat, temperature, potential difference and doping process.

TUTORIAL ANSWER

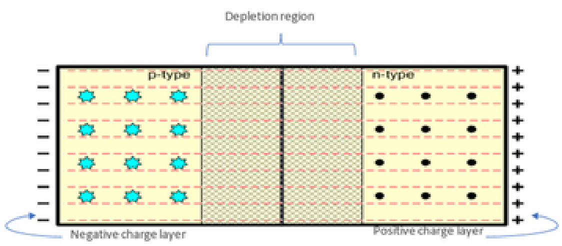
Essay Questions

Question 2

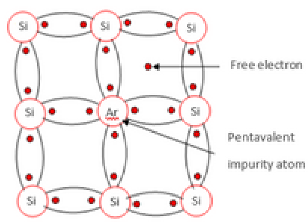
a) Atoms consist of three basic particles: protons, electrons, and neutrons. The nucleus (center) of the atom contains the protons (positively charged) and the neutrons (no charge).



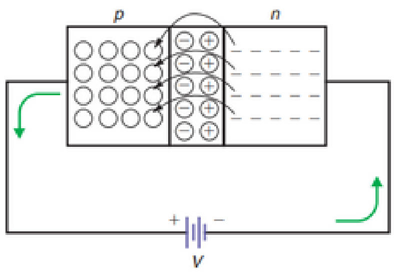
b) p-n junction



c) n-Type semiconductors can be constructed by adding pentavalent impurity atom to the intrinsic semiconductor. This process is called doping. Pentavalent atoms such as arsenic and phosphorus have five valence electrons which will provide an extra free electron. So electrons are majority carrier in n-type material.



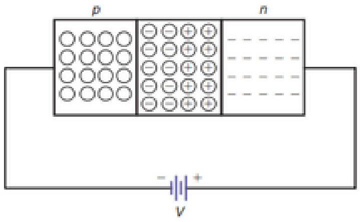
d) Forward biased: p-type connected to the positive terminal of supply voltage while n type connected to the negative terminal.



TUTORIAL ANSWER

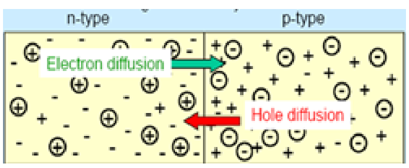
Essay Questions

Reverse biased: p-type connected to the negative terminal of supply voltage while n type connected to the positive terminal.



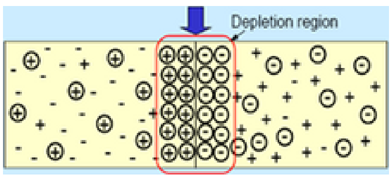
e)

i. Free electrons mobility



With the formation of the p and n materials, holes from p-type will diffuse into the n-type, and electrons from n-type will diffuse into the p-type. Combination of electrons and holes at the junction takes place.

ii. Formation of depletion region and its properties



When equilibrium is reached, no further diffusion of electrons and holes across the junction. This creates the depletion region and has a barrier potential.
The depletion region is a region depleted of any charge carriers.

iii. Existence of threshold voltage and its values for silicon and germanium.
An electric field oriented in the direction from the (+) charge to the (-) charge will be created. Potential difference across the depletion region occurs and it is called threshold/ knee voltage (Vk).
Value of Vk for silicon = 0.7 V and germanium = 0.3 V.

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