Lesson 08

Title of the Experiment: Identification of active components in electronic circuits and characteristics of a Diode, Zener diode and LED

(Activity number of the GCE Advanced Level practical Guide - 21)

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Introduction:

All the components in the electronic circuits can be divided into two categories namely active and passive components.

Active components

Components which required an external source to their operation are called Active Components. Examples for the active components are Diodes, Transistors, Operational Amplifiers etc…..

Passive components

Components which do not required an external source to their operation are called Passive Components. Examples for the passive components are Resistors, Capacitors, Inductors, etc….

Semiconductors

A semiconductor is a material which has property of conduction of electric current in between conductors and insulators. Semiconductors can be divided into two main categories namely Intrinsic and Extrinsic semiconductors.

Intrinsic semiconductors

Intrinsic semiconductors compose of one kind of materials which belong to the group IV of the periodic table. The most common intrinsic semiconductors (single-element semiconductors) are Silicon, Germanium and Carbon (pure form of the materials).

As shown in Figure 1(a), Si crystal forms combining each Si atom with four adjacent Si atoms. A Si atom with its four valance electrons shares an electron with each of its four neighbors. This effectively creates eight valance electrons for each atom and produce a state of chemical stability. Si crystal at room temperature has sufficient heat energy for some valance electrons in the crystal to become free electrons. These free electrons are called conduction electrons. When valance electron becomes a free electron, a vacancy is left in the crystal. This vacancy is called a hole. In the intrinsic semiconductor at room temperature creates equal number of conduction electrons and holes.

When a voltage is applied across a piece of intrinsic semiconductor, thermally generated conduction electron, which are free to move randomly in the crystal structure, are easily attracted towards the positive end. This movement of free electrons is one type of current in a semiconductor material and is called electron current. Valance electrons are attached to their atoms and are not free to move randomly in the crystal structure as free electrons. However, a valance electron can move into a nearby hole leaving another hole where it came from. Effectively the hole has moved from one place to another in the crystal structure. This is called hole current.

Conductivity of Intrinsic semiconductors are very low and temperature dependent due to the limited number of conduction electrons (holes) and number of conduction electron depends on temperature therefore intrinsic semiconductors are not suitable for practical devices. Intrinsic semiconductors (Si) can be modified by increasing the number of free electrons or holes to increase

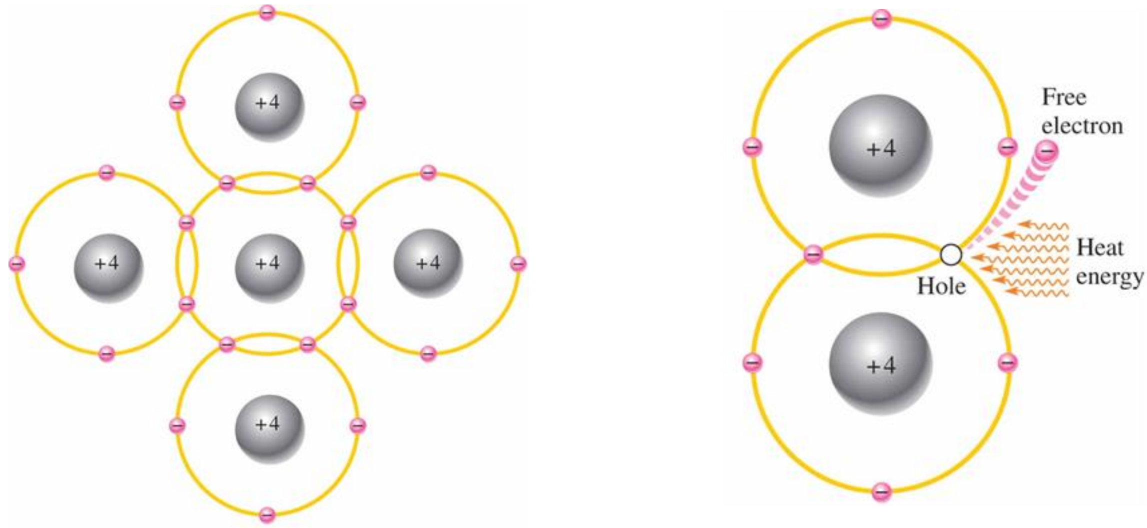


Figure 1: Atomic arrangement of Si crystals and generation of the electron-hole pairs

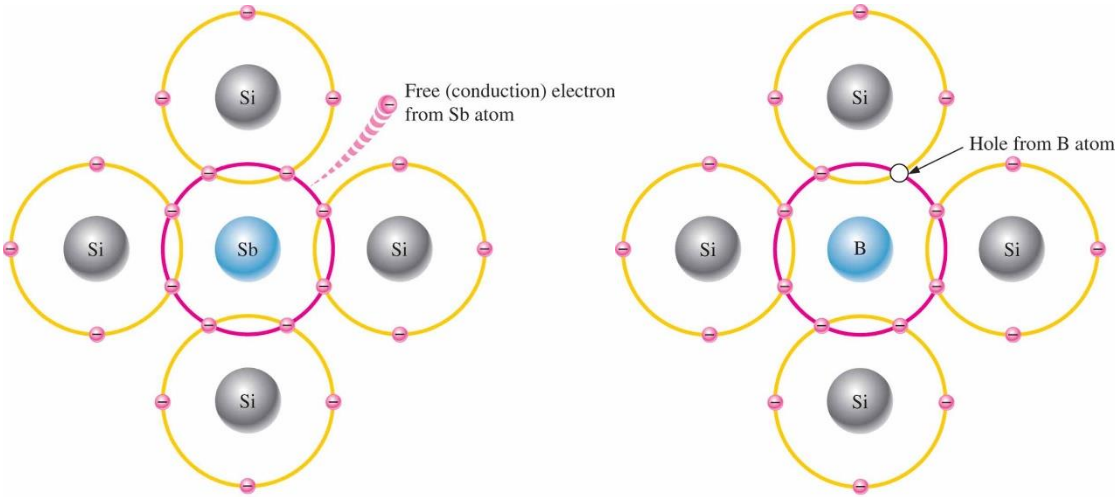
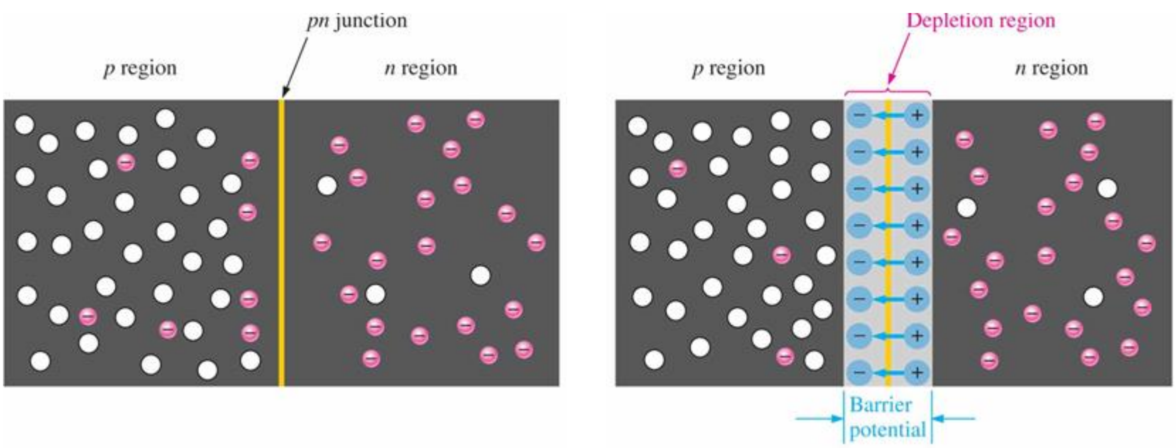


Figure 2: Crystal structure of (a) n-type Si and (b) p-type Si



(a) (b)

Figure 3: (a) before and (b) after formation of p-n junction diode

its conductivity for making it useful in electronic devices. This can be done by adding impurities to the intrinsic material and the process is called doping. After doping the intrinsic semiconductors, materials are called as extrinsic semiconductors. There are two types of extrinsic semiconductors, n-type and p-type, which are the key building blocks for most types of electronic devices.

Extrinsic semiconductors

The conductivity of the intrinsic semiconductors can be drastically increased by the controlled addition of impurities to the intrinsic semiconductor material. This process is called doping, increases the number of current carriers (electrons or holes). Since there are two categories of impurities, extrinsic semiconductors attribute n-type conductivity (conduction due to electrons) and p-type conductivity (conduction due to holes) depending of the type of the impurity.

n-type Semiconductors

To increase the number of conduction electrons in the intrinsic semiconductor (Si), pentavalent impurity atoms (Sb) are added. Each pentavalent atom forms covalent bonds with four adjacent Si atoms as shown in Figure 2(a). Four of Sb atom's valance electrons are used to form the covalent bonds with Si atoms, leaving one extra electron. This extra electron becomes a conduction electron because it is not attached to any atom at room temperature. The number of conduction electrons can be carefully controlled by the number of impurity atoms added to the Si. These conduction electrons do not produce holes in the valance band as thermally generated electrons. The conduction electrons are much higher than the holes in the material and therefore the electrons are called the majority carriers while holes are called minority carriers in the material. Since most of the current carriers are electrons, extrinsic semiconductors doped with pentavalent atoms are n-type semiconductors.

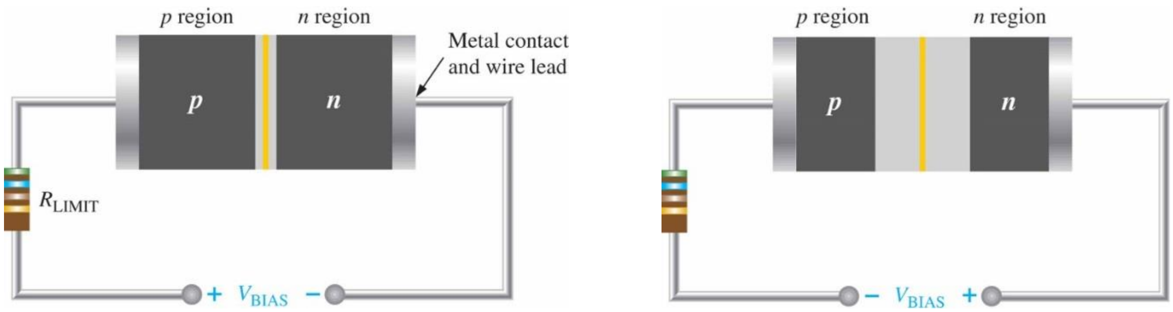
p-type Semiconductors

To increase the number of holes in the intrinsic semiconductor (Si), trivalent impurity atoms (B) are added. Each trivalent atom forms covalent bonds with four adjacent Si atoms as shown in Figure 2(b). Three of B atom's valance electrons are used to form the covalent bonds with Si atoms, creating a hole since four electrons required. This trivalent atom due to the hole can accept an electron. The number of holes can be carefully controlled by the number of impurity atoms added to the Si. The holes are much higher than the thermally generated conduction electron in the material and therefore the holes are called the majority carriers while conduction electrons are called minority carriers in the material. Since most of the current carriers are holes, extrinsic semiconductors doped with trivalent atoms are p-type semiconductors.

p-n junction diode

The *pn* junction is basically a diode, which is a device that allows current in only one direction. The p-n junction diode can be fabricated by combining p-type and n-type semiconductors. Before making junction n-type semiconductor has more electrons (majority carriers) and few thermally generated holes (minority carriers) on the other hand p-type semiconductor has more holes (majority carriers) and few thermally generated electrons (minority carriers) as shown in Figure 3(a). When a p-n junction is formed, electrons in the n-material diffuse across the junction and recombine with holes in the p-material. However, electrons leaving the n-type side will create a charge imbalance in this side by exposing ionized donors (positive charge). Similarly, holes leaving the p-type side will expose negative charge. Those expose charges will set up an electric field that will oppose the natural diffusion tendency of the electrons and holes and an equilibrium situation will be obtained as shown in Figure 3(b). Interfacial region between n-type and p-type materials is very narrow. Since this electric field is a barrier to move the electrons across the junction, external energy must be applied to get the electrons to move across the barrier of electric field.

Generally the term bias refers to the use of a dc voltage to establish certain operating conditions for an electronics devices. There are two bias conditions in relation to a diode.



(a) (b)

Figure 4: Diode is under forward bias (a) and reverse bias (b)

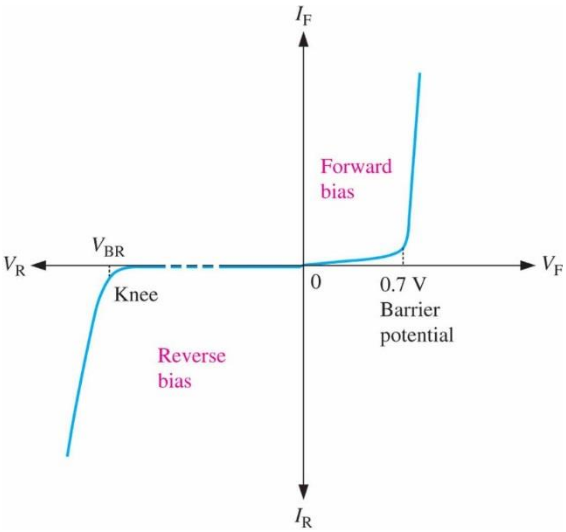


Figure 5: Diode characteristics

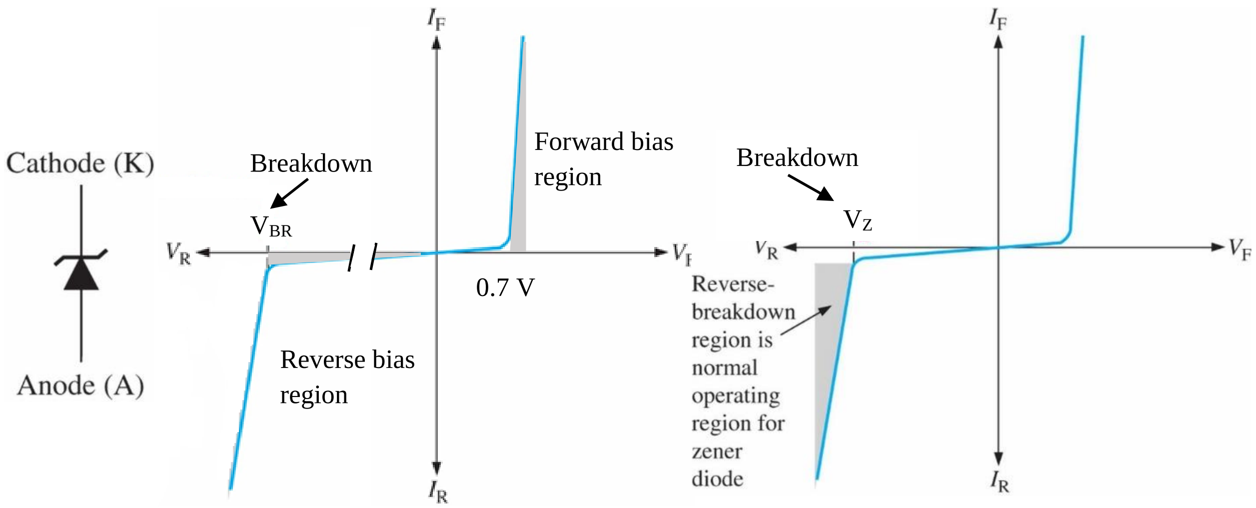


Figure 6: (a) Symbol of zener diode (b) operating regions of rectifier dilde and (c) operating region of zener diode

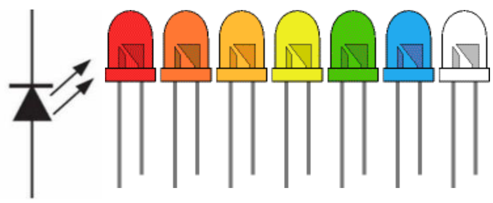


Figure 7: Symbol of LED and typical packagers of LEDs

Forward bias

To bias a diode, a dc voltage should be applied across it. Forward bias is the condition that allows current through the p-n junction. External bias voltage (V_{bias}) is connected to the diode through a resistor (R) as shown in Figure 4(a). Positive terminal of the V_{BIAS} should be connected to the p side of the diode and the negative terminal should be connected to the n-side of the diode. This is one requirement for forward bias. Second requirement is that the magnitude of V_{BIAS} must be greater than the barrier potential. For a silicon diode, this is about 0.7 V.

Reverse bias

Reverse bias is the condition that prevents the current trough the diode. In reverse bias, positive terminal of the V_{BIAS} are connected to the n-side of the diode and the negative terminal are connected to the p-side of the diode as shown in Figure 4(b). Positive side of the bias voltage pulls the free electrons, which are majority carriers in the n-side, away from the p-n junction. As electron flow towards the positive terminal of the voltage source, additional positive ions are created and hence widening of the depletion region. This results that the current generated by the majority carriers ceases except very small reverse current due to the minority carriers.

Diode Characteristic

Diode characteristic is current variation trough the diode in response to the bias voltage. Complete diode characteristic is shown in Figure 5. Note that scale of the current is in mA and μA under forward and reverse bias conditions respectively.

Zener diode

The zener diode is another p-n junction device that differs from diodes (rectifier diodes) because it is designed for operation in the reverse breakdown region. Two types of reverse breakdown in a zener diode are avalanche (breakdown at normal diode) and zener. In a zener diode zener breakdown occurs at low reverse voltage because it is heavily doped to reduce the breakdown voltage. Figure 6 shows the symbol of a zener diode and operating regions of a rectifier diode and zener diode. Zener diodes are operated in reverse breakdown region where its voltage remains almost constant even though the current changes drastically. This is the key feature of a zener diode. Therefore it can be used as voltage regulator because it maintains a nearly constant voltage across its terminals over a specified range of reverse current values.

Light emitting diode (LED)

LED is a p-n junction device which emits light unlike rectifier diodes which produce heat. LEDs are made of gallium (Ga) compound materials unlike Si or Ge. LEDs are operated under forward bias. Electrons cross the p-n junction from n-type material and recombine with holes in the p-type material. The recombining electrons release energy in the form of heat and light. LEDs which dope with various impurities, emit different wavelengths which determine the colour of the light. Figure 7 shows the symbol and typical LEDs. The cathode is the short lead and there may be a slight flat region on the body of round LEDs. Most LEDs are limited to a maximum current of 30 mA, with typical voltage values across the LED varying from 1.7 V for red to 4.5 V for blue.

Theory:

Symbol **Appearance**

The arrow indicates the direction of conventional current flow.

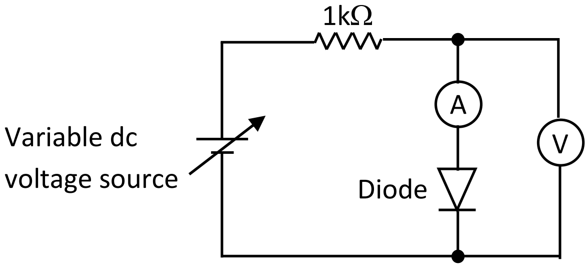


Figure 8: Circuit diagram of the forward bias diode

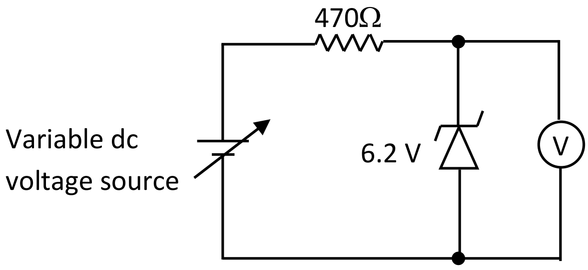


Figure 9: Circuit diagram of the reverse bias zener diode

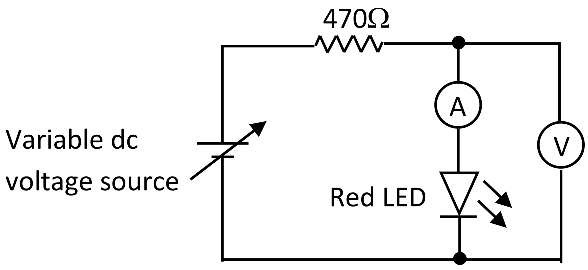


Figure 10: Circuit diagram of the forward bias LED

Learning outcomes:
In this experiment you will study the characteristics of rectifier diode, Zener diode and LED. At the end of this experiment you should be able to explain operation of rectifier diodes, zener diodes and LEDs in electronic circuits.

Materials/Equipment:
Rectifier diode, 6.2 Zener diode, Red and Blue LEDs, 9 V dc power supply, breadboard, voltmeter, Ammeter, 1 kΩ and 470 Ω resistors, connecting wires

Methodology/Procedure:

1. Examine each diode and determine the anode and cathode; the cathode is marked by a band of contrasting colour.
2. Connect the circuit shown in Figure 8. Show the circuit to your demonstrator before turning on the power to the circuit.
3. Increase the supply voltage from 0·00 V by 0·05 V intervals and measure the corresponding current using the ammeter until the ammeter reach 1mA.
4. Now change the current through the diode by 1mA and obtain the corresponding voltmeter readings. Do not exceed a current of 10 mA.
5. Tabulate the voltage and current in the sample data sheet.
6. Change the polarity of the diode in Figure 8.

7. Increase the supply voltage from 0·0 V by 0·5 V intervals and measure the corresponding current using the ammeter. Tabulate the voltage and current in the sample data sheet.
8. Plot Current versus Voltage for the diode.
9. Connect the circuit shown in Figure 9.
10. Set the supply voltage equals to 1 V. Measure the voltmeter reading.
11. Repeat step 10 for the input voltages given in the sample data sheet.
12. Tabulate the input and output voltages in the sample data sheet.
13. Connect the circuit shown in Figure 10 using Red LED.
14. Adjust the supply voltage until 10 mA current passing through the LED. Measure the voltage across the LED and record in the sample data sheet.
15. Change the Red LED from Blue LED and repeat the step 14.

Readings/Observations:

For rectifier diode

Forward bias		Reverse bias	
Voltage (V)	Current (mA)	Voltage (V)	Current (μA)
		0.0	
		1.0	
		2.0	
		3.0	
		4.0	
		5.0	
		6.0	
		7.0	
		8.0	
		9.0	

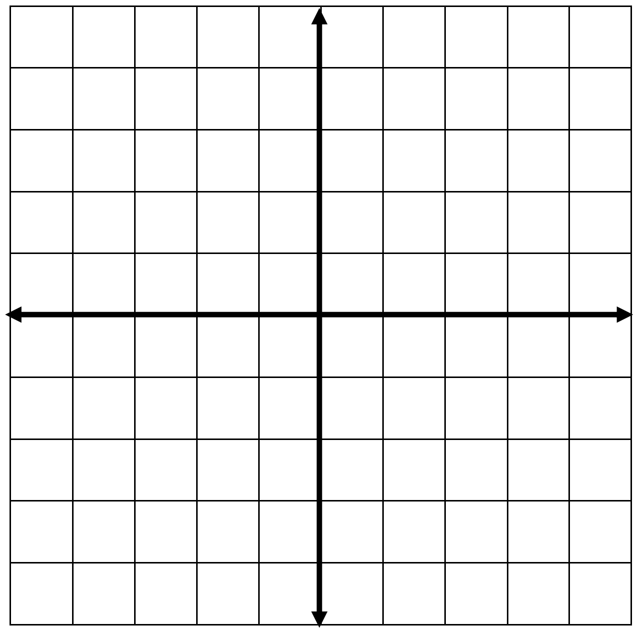
For zener diode

Reverse bias	
Input voltage (V)	Output voltage (V)
0.0	
1.0	
2.0	
3.0	
4.0	
5.0	
6.0	
6.1	
6.2	
6.3	
6.4	
7.0	
8.0	
9.0	

For the LED

LED	Current (mA)	Output voltage (V)	Light On/Off
Red	10		
Blue	10		

Graphs:



Discussions:

Conclusions:

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