1 DIODE CHARACTERISTICS

1.1 **Objectives**

- Understanding the characteristics of each type of diode device.
- Recognizing the specification of each type of these devices.
- Learning how to test the characteristics of each type of diode by using various instruments.

1.2 **Basic Description**

The semiconductor diode is formed simply by combining two main materials, ***n-*** type and ***p-*** type. There exist many electrons in ***n-*** type material whereas ***p-*** type material has many holes. When these two materials are combined, electrons of ***n-***type material that are close to the junction fill the holes of ***p-***type material that are also close to the junction as shown in **Fig. 1.1(a)**. Consequently, the region of ***n-***type material close to the junction is turned into positive ions and the region of ***p-*** type material close to the junction is turned into negative ions as shown in **Fig. 1.1(b)**.

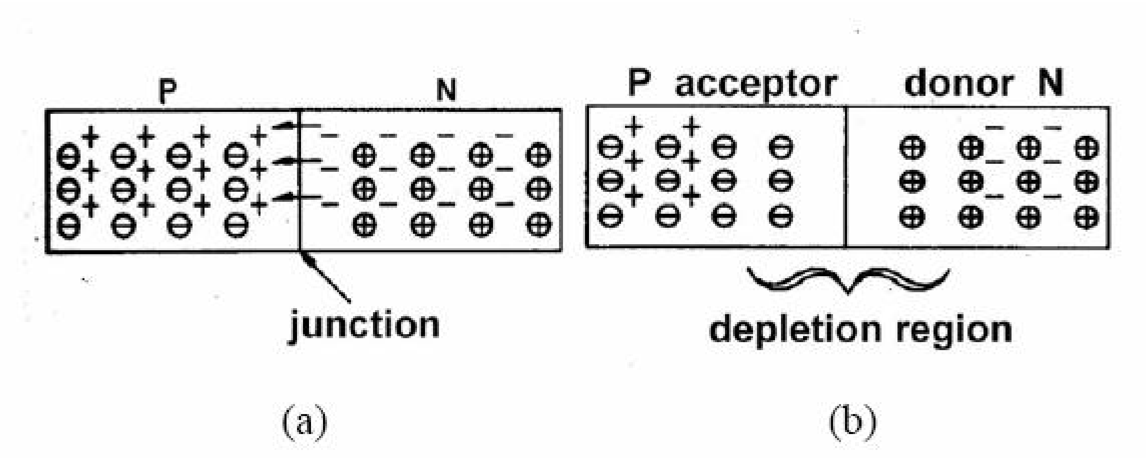

Fig. 1.1

Thus in the region close to the junction, the carriers (electrons & holes) are depleted, whereas only positive and negative ions can exist. This region is referred to as “**Depletion Region**”.

The force that prohibits the electrons and holes from passing the junction due to the effect of ions in the depletion region is referred to as “**barrier voltage**”. The typical barrier voltage in the p-n junction of germanium (Ge) is around 0.2 ~ 0.3 V, whereas it is around 0.6 V for silicon (Si).

Forward Bias:

As shown in **Fig. 1.2**, if the positive and negative terminals of the power supply are respectively connected to **p** and **n**, this connection is called "**forward bias**".

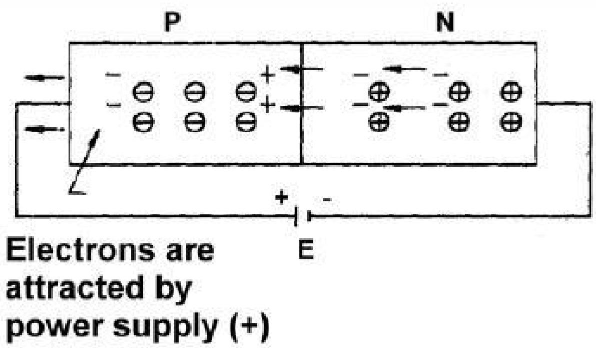

Fig. 1.2

If the voltage applied by forward bias is enough to overcome the barrier voltage, the positive terminal of the power supply will attract electrons, whereas the negative terminal will repel electrons. The electrons in the **n**-type semiconductor will thus cross the p-n junction and enter the p-type semiconductor to combine with the holes. Many holes are generated in the **n**-type semiconductor due to the ionization of electrons, together with the electrons provided by external power supply (E). The electrons continuously move through the driving of power supply (E) to form an electron stream with the direction from the negative terminal E to positive terminal, wherein this direction is contrary to that of conventional electric currents.

The forward bias applied to the diode generates a "**forward current"** denoted as I_F . The value of I_F is directly proportional to the external power supply (E) and is inversely proportional to the internal resistance (r) of the diode.

There exists a rate between the flow of injected rate and applied voltage called "**Diffusion Capacitance**". This capacitance is directly proportional to the current I_F .

Reverse Bias:

As shown in **Fig 1.3,** if the positive terminal and negative terminal of the power supply are respectively connected to **n** and **p**, both the electrons and holes will be attracted by E and will be away form the junction to enlarge the depletion region, and no electron or hole can cross the junction for combination. This method, to apply the external voltage, is called "**reverse bias".**

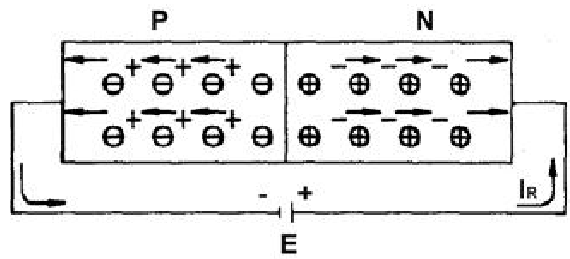

Fig 1.3

While the reverse bias is applied to the p-n junction, there shall be no reverse current in the ideal case. However, due to the effect of temperature, thermal energy will generate minority electron - hole pairs in the semiconductor. When the reverse bias is applied, the minority electrons in the **p**-type semiconductor can just cross the **p-n** junction to combine with the holes in the **n** terminal since the minority carriers exist in the semiconductor.When the reverse bias is applied to the p-n junction in practical operation, a very low current will exist. This current is referred to as "**leakage current**" or "**reverse saturation current**" denoted to be $\mathbf{I_R}$ or $\mathbf{I_S}$.

$\mathbf{I_R}$ is independent of the value of reverse bias, but is in relation to temperature. Regardless of germanium or silicon, the $\mathbf{I_R}$ is doubled for every 10^0C of temperature rise. Under same temperature, $\mathbf{I_R}$ of silicon diode is only 1 % ~ 0.1 % of that of germanium diodes. While $\mathbf{I_R}$ of germanium diode is 1~2 A, the diode applied with reverse bias is <u>deem to be open – circuit at room temperature</u> (25^0C).

Breakdown:

While the reverse bias is applied to the ideal **p-n** diode, $\mathbf{I_R}$ is very low. However, if the applied revere bias is too high (higher than rated value), the minority carriers will acquire enough energy to impact and disintegrate the covalent bonds to generate signifivant amount of electron - hole pairs. These newly generated electrons and holes will acquire energy from higher reverse bias to disintegrate other covalent bonds. The movement of free electrons will be accelerated and the reverse current will thus be signifacantly increased. This phenomenon is referred to as "**breakdown**".

When the breakdown is found in the diode due to the increased reverse bias, the diode <u>will burn down</u> if the current is not limited. The maximum reverse voltage applied to the diode before its breakdown is called **"peak reverse voltage (PRV)"** or **"peak inverse voltage (PIV)".**

Assembly and symbol of a diode:

After combination of **n** and **p** type materials, the diode is completed by adding two lead wires to the terminals, then sealing the body with <u>ceramics or glass</u> (iron housing is supplemented for high-power diodes to facilitate heat dissipation).

The internal structure of the diode is shown in **Fig 1.4 (a)**, its symbol in **Fig 1.4 (b)** and perspective view is shown in **Fig 1.4 (c).**

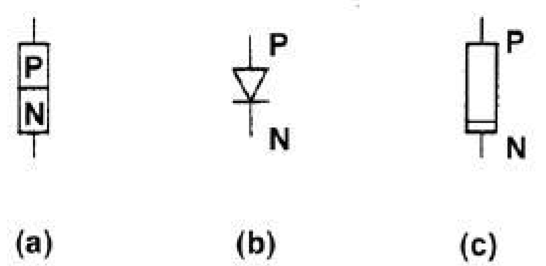

Fig 1.4

Characteristic Curve (V-I Curve) of Diode:

The forward characteristic curve is shown in first quadrant of **Fig. 1.5 (c).**

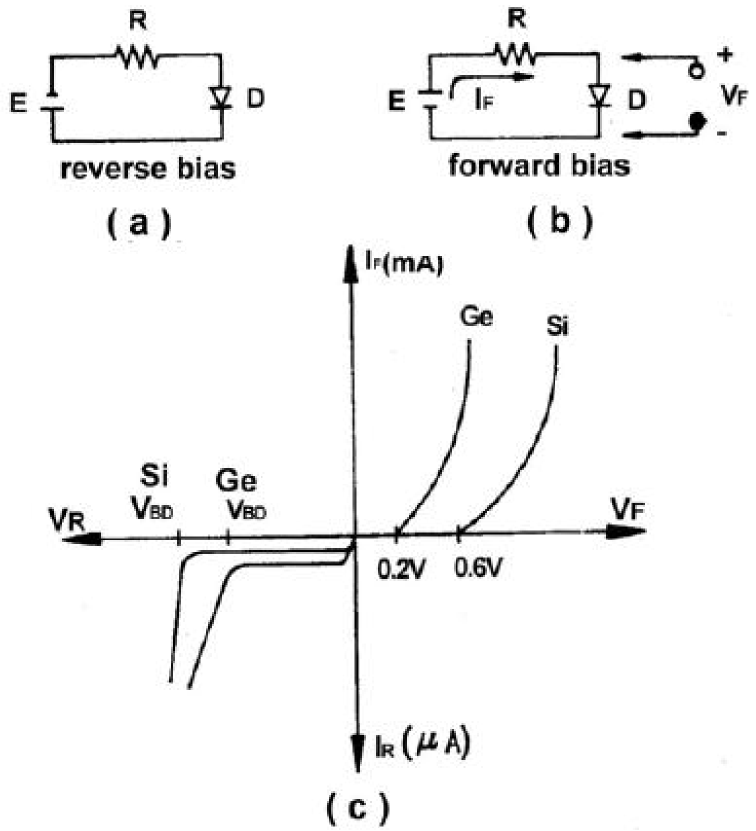

Fig. 1.5

From the characteristic curve we can see that the current is very low if the forward bias applied to the diode is lower than the cutin voltage (**V_r**). Once the forward biases exceed the cutin voltage (0.2 V for germanium diode, 0.6 V for silicon diode), the current (**I_F**) will be dramatically increased, in the manner that the diode will function as short-circuit (with **V_F** being around 0.7 V). The equivalent circuit is shown **in Fig 1.6.**

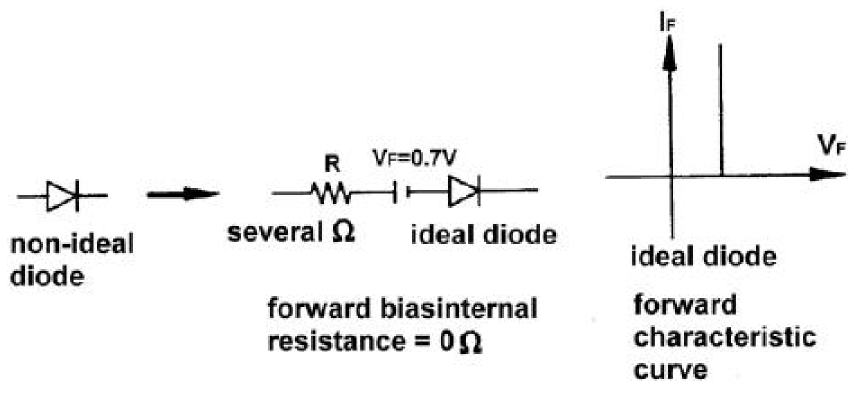

Fig. 1.6

Turning now to **Fig. 1.5**,the reverse characteristic curve of diode is shown in the fourth quadrant of **Fig 1.5 (c).** The reverse current before breakdown is very low, which can be treated as an open-circuit. When the reverse bias has reached the breakdown voltage, $\mathbf{I_R}$ will be dramatically increased.

As **Fig 1.5 (c)** reveals, silicon and germanium type diodes have different parameters, which are compared in the following table.

Items / Type	**PIV**	**Temperature Range**	**Cutin Voltage (Vr)**	**Leakage Current (Ir)**
Silicon	High	200^0C	0.7 V (0.6)	1/100~1/1000 of germanium
Germanium	Low	100^0C	0.3 V (0.2)	Several A

Table 1.1

1.3 **Other Two-terminal Devices with p-n Junction**

1.3.a **Zener Diode (ZD)**

Zener diode (also referred as regulated diode) is a two terminal device that is widely used in voltage regulators. As shown in the characteristic curve of diode (**Fig 1.5 (b)**), when the reverse bias, applied to the semiconductor, has reached to V_z , the current will be dramatically increased while the voltage keeps constant. The value of V_z can be controlled by changing the doping concentration. If the doping concentration is increased, the increased amount of impurity will decrease the value of $V_{z.}$ The regulated values of the zener diode are thus distributed in the range from 3V to several hundreds of volts, whereas the power range is distributed from 200mW to 100W.

While applied reverse current I_z is lower than a specific I_{zmin} , the zener diode can not be used for regulating voltage. Moreover, as ZD will burn down if $\mathbf{I_z}$ is , this time, higher than a specific $\mathbf{I_{zmax}}$, an adequate resistance should be connected to ZD in series. Typical regulating circuit is shown in **Fig 1.7.**

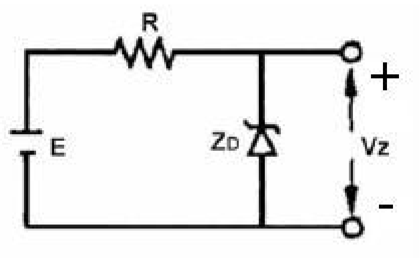

Fig. 1.7

The voltage that a ZD can regulate is called the zener voltage (V_z). The product of V_z and I_{zmax} gives the maximum consuming power of each zener. That is;

$$P_{Z\,max} = V_Z . I_{Z\,max}$$

By these judgements, operating current range must be kept below $\mathbf{I_{zmax}}$ and above $\mathbf{I_{zmin}}$. These boundaries are specific for each type of zener diode and are given in specification sheets of corresponding manufacturers. Symbol and appearance of Zener diode is given below.

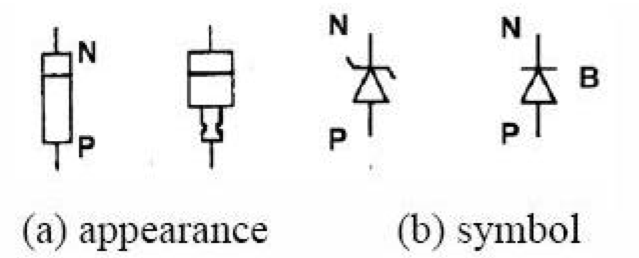

Fig. 1.8

1.3.b **Light Emitting Diode (LED)**

LED is one kind of p-n junction device made of gallium arsenic phosphide or gallium phosphide. When the electrons and holes of LED are combined under the forward bias, the energy carried by free electrons will be transformed into light energy that is within the spectrum of visible light. If the silicon or germanium is used as material, the energy will be transformed into heat energy, but no visible light will be generated.

Typically, the operating voltage of LED is around 1.7 V ~ 3.3 V, the power consumption is around 10 ~ 50 mW and the operating life is more than 100 thousand hours. The LEDs can generate visible lights with colors red, yellow, green..etc. depending on the selected materials.

The LED will be illuminated if minimum 1.5V forward voltage is applied. The highr the current, the brighter the LED. However when the current exceeds 10 mA, the increase of brightness will not be significant. If more than 1.5 V is continuously applied to LED, it will burn down. Moreover, as the breakdown voltage of LED is very low, the applied reverse voltage of LED should not exceed 3 V.

Appearance (a and b) and symbol (c) of LED is given below.

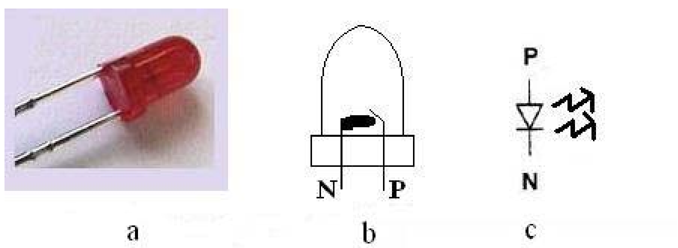

Fig. 1.9