3. Theory

1) V-I characteristics

Applying a DC current to a component, measuring the voltage across the component with a voltmeter and measuring the current through the component with an ammeter, the relationship curve between the current and voltage of the component is plotted with voltage as the abscissa and current as the ordinate, which is called the V-I (volt-ampere) characteristic curve of the component. Components with a linear V-I characteristic curve are called linear components, such as resistors. Components with a non-linear V-I characteristic curve are called non-linear components, such as diodes and transistors.

In addition to the voltage and current, the V-I characteristics of some components also change regularly with the change of certain physical quantities, such as temperature, light intensity, magnetic field strength, etc. These are the sensing elements for various physical quantities. .

According to Ohm's law, the relationship among resistance R, voltage U, and current I is follows:

$$R = U/I \, . \tag{1}$$

The resistance value of the element R_x can be calculated by measuring values U and I using a voltmeter and an ammeter. However, the R value of a non-linear element is a variable, so its resistance value is related to its specific operating voltage (or current).

There are two ways to express the resistance of nonlinear components. One is called static resistance (or DC resistance), expressed by R_D; the other is called dynamic resistance, expressed by r_D, which is equal to the ratio between the amounts of voltage change and current change near the operating point. The dynamic resistance can be obtained b

y the V-I curve, as shown in Figure 1, where the static resistance $R_D = U_Q/I_Q$ and the dynamic resistance $r_D = \Delta U_Q/\Delta I_Q$ at point Q.

When measuring the V-I characteristics, a certain system error will be introduced due to the internal resistance of the voltmeter and ammeter. Because of high internal resistance of the digital voltmeter and small internal resistance of the digital ammeter, the system error is small and it is ignored in this experiment.

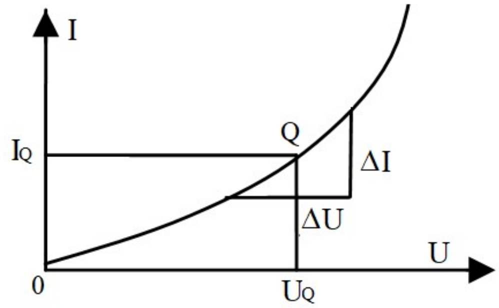
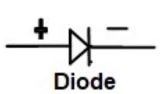


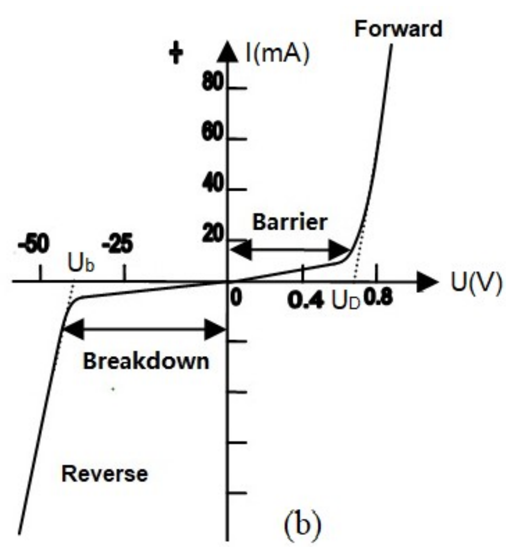
Figure 1 Schematic of dynamic resistance at point Q

2) Characteristics of semiconductor diode

The semiconductor diode is a commonly used non-linear element. Figure 2(a) is the circuit symbol. The main characteristic of the diode is unidirectional conductivity. Its V-I characteristic curve is shown in Figure 2 (b). When the forward voltage is small, the current is small. When the forward voltage increases to a certain value, the forward current increases significantly and thereafter approximately increases in linear. Extend this straight line in the opposite direction to the horizontal axis, the intersection point U_D is called the forward threshold voltage. After forward conduction, the forward voltage drop is about 0.2-0.3 V for a germanium diode, and about 0.6-0.8 V for a silicon diode. When the reverse voltage exceeds a certain value $-U_b$, the current increases sharply. This situation is called breakdown, and U_b is the breakdown voltage.



(a)



(b)

Figure 2 (a) Symbol of a diode and (b) its V-I characteristic curve

The main parameters of a diode include (1) the maximum rectified current I_f, that is, the maximum average forward current allowed to pass through the diode during normal operation and (2) the maximum reverse voltage U_R, which is generally limited to half of the reverse breakdown voltage U_b.

Because diodes have the property of unidirectional conductivity, they are widely used in electronic circuits, and are often used in rectification, detection, amplitude limiting, device protection, and as switching components in digital circuits.

3) Characteristics of Zener diode

The zener diode is a special silicon diode. Its symbol is shown in Figure 3(a); its V-I characteristic curve is shown in Figure 3(b). It has a wide current range in the reverse breakdown region and the V-I curve is cliffy straight line. This straight line intersects the horizontal axis at U_w.

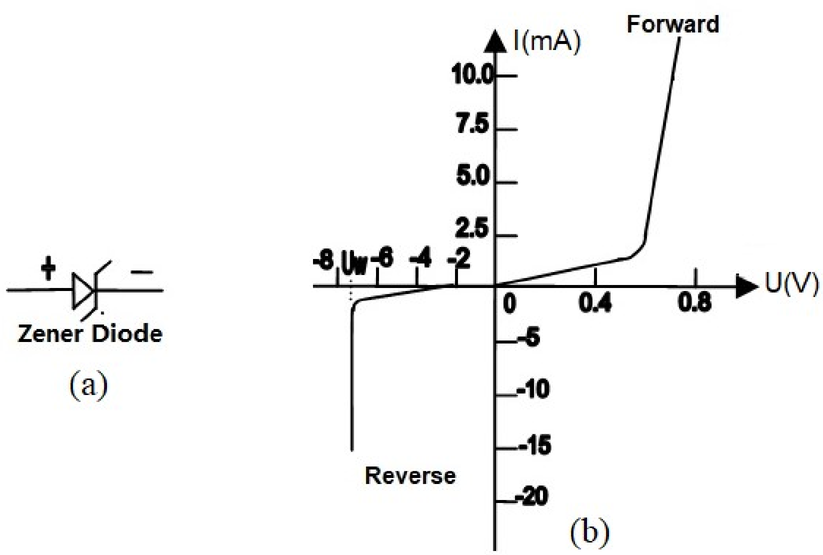


Figure 3 (a) Symbol of Zener diode and (b) V-I characteristic curve

For ordinary diodes, the current increases sharply after the breakdown voltage and when the current exceeds the limit value *-Is*, the diode will be burned. For Zener diode, the reverse breakdown is reversible, i.e. after removing the reverse voltage, the Zener diode returns to normal state (but if the reverse current exceeds the allowable range, the Zener diode will also be burned due to thermal breakdown). Therefore, the working current of the Zener diode should be set according to the allowable working current for normal operation.

The main parameters of a Zener diode include regulation voltage U_w, dynamic resistance r_D (the smaller r_D, the better the voltage regulation performance), the minimum regulated current I_{min}, the maximum regulated current I_{max}, and the maximum dissipated power Pmax. Zener diodes are commonly used in circuits such as voltage regulation and constant current.

4) Characteristics of light emitting diode

The core of light emitting diodes (LED) is a PN junction, which is made of III and V compounds such as GaAs (gallium arsenide), GaP (gallium phosphide), GaASP (gallium arsenide phosphide) or other semiconductor materials. Therefore, it has the V-I characteristics of a general PN junction, namely forward conduction, reverse cut-off, and breakdown characteristics. The symbol of LED is shown in Figure 4(a), which is mainly because it has light-emitting characteristic. Under the impact of a forward voltage, electrons migrate into the P region from the N region, and holes migrate into the N region from the P region. The minority carrier enters the opposite region, at this time, the electrons have entered the P region recombine with the holes in the P region, and the holes have entered the N region recombine with the electrons in the N region, and radiate excess energy in the form of light, which is the basic working principle of LED, as shown in Figure 4 (b).

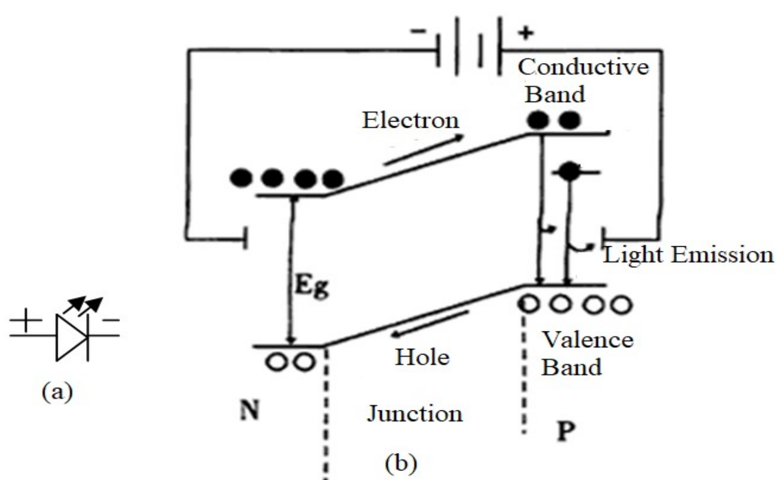


Figure 4 (a) LED symbol and (b) LED basic working principle

Theory and practice have proved that the peak wavelength λ of light emission is related to the width Eg of the semiconductor forbidden band in the light-emitting region, $\lambda \approx 1240 / Eg(nm)$, the unit of Eg is electron volt (eV). In order to emit visible light of wavelength between 380 nm (purple light) and 780 nm (red light), the Eg of the semiconductor material should be between 3.26 and 1.63 eV.

The main parameters of a LED are follows:

a) Maximum forward current I_{Fm}: The maximum forward DC current allowed. The LED will be damaged if it exceeds this value.

b) Forward working current I_F: refers to the forward current value when the LED normally emits light. In actual use, the I_F should be selected below $0.6*I_{Fm}$ according to the brightness needs.

c) Forward working voltage V_F: The forward working voltage is measured at a given forward current. Generally at $I_F = 20$ mA, V_F is 1.4 ~ 3 V.

d) Maximum reverse voltage V_{Rm}: The maximum reverse voltage allowed to be applied, and the LED may be damaged by breakdown if it exceeds this value.

e) Allowable power consumption P_m: The maximum value of the product of the forward DC voltage applied to both ends of the LED and the current flowing through it. Beyond this value, the LED may be damaged by heat.

f) V-I characteristic: The relationship between LED voltage and current, as shown in Figure 5.

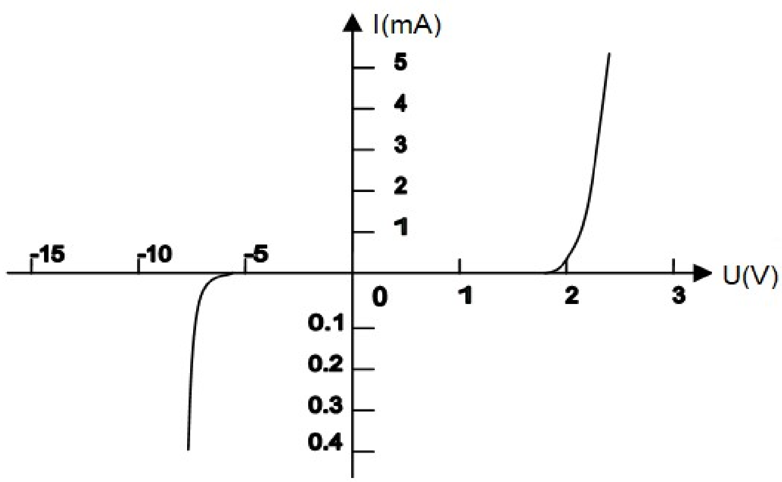


Figure 5 Relationship between voltage and current of LED

g) Spectral distribution and peak wavelength: The light emitted by a certain LED is not a single wavelength, and its wavelength spectrum is generally shown in Figure 6 (for example).

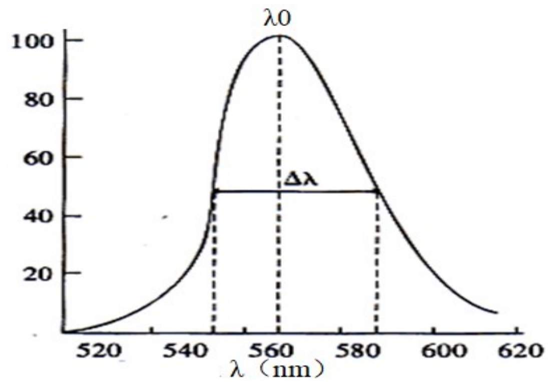


Figure 6 Example of spectral distribution and peak wavelength of LED

h) Spectral half-width $\Delta\lambda$: It represents the spectral purity of the LED, which refers to the interval between two wavelengths corresponding to 1/2 peak light intensity.

* Parameters such as luminous intensity, divergence angle and viewing angle are also important, but not studied in this experiment.