Experiment No 1: I/V characteristics PN junction diode

Theory

A semiconductor PN junction diode is a two terminal electronic device that allows current in only one direction. The diode is firmed by doping a semiconductor (like silicon or germanium) with trivalent impurity (e.g. Boron or Aluminium) from one end to form *p-type* region and with pentavalent impurity like Phosphorous from the other end to form *n-type* region on the other end. The metal contacts taken out from *p-region* and *n-region* are called ***anode*** and ***cathode*** respectively. Please refer the applet to know the fabrication process of the diode.

Unbiased *pn* Junction:

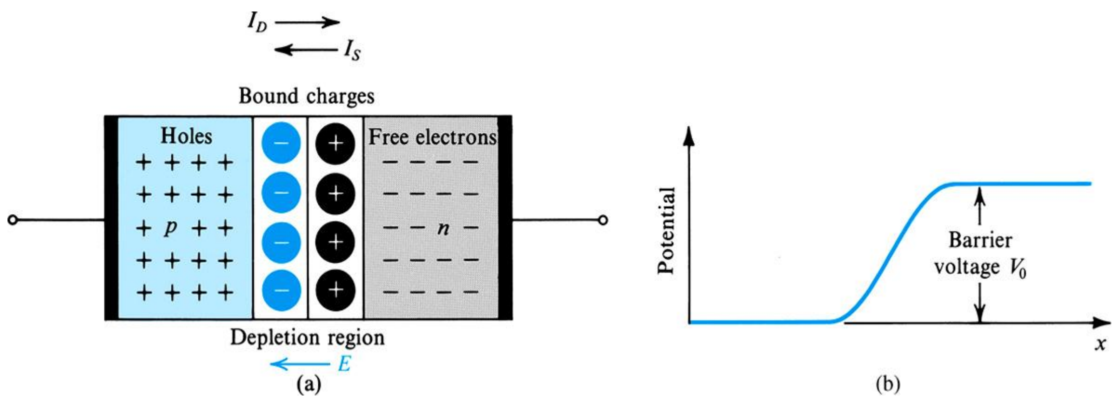
As the *pn* junction is formed, holes from *p-region* diffuse across the junction and recombine with the electrons in the *n-region* near the junction resulting in formation of positive ions in the *n-region* near the junction. Similarly, electrons from *n-region* diffuse across the junction and recombine with the holes in *p-region* near the junction to form negative ions. Thus there exists a narrow region extended in both the regions, that does not have any mobile charge carriers (neither holes nor electrons) is called depletion region, the region depleted of charge carriers. This region has negative ions on one side and positive ions on the other, resulting in an electric field across the junction. The resulting electric field opposes further diffusion of hole and electrons across the junction as the voltage drop across the junction acts as a barrier for any charge carrier to cross the junction. The more the barrier, fewer charge carriers will be able to overcome it and result in lower magnitude of diffusion current I_D. This electric field also causes the minority carriers from respective junctions to drift across the junction and constitute drift current I_S which flows in the direction opposite to that of diffusion current. This component of current is due to minority carriers which are thermally generated and hence this current strongly depends upon temperature.

At equilibrium, these two currents are equal and opposite i. e. $I_D = I_S$. This condition is maintained by barrier potential. The built-in potential across the junction is given by,

$$V_0 = V_T \; ln\left(\frac{N_A N_D}{n_i^2}\right) \qquad (1.1)$$

where, $V_T = \frac{k\,T}{q}$, called thermal voltage, N_A, N_D are doping concentrations of p side and n side.

Typically the value of V_0 at room temperature ranges between 0.6 to 0.8V



Forward biasing a pn junction

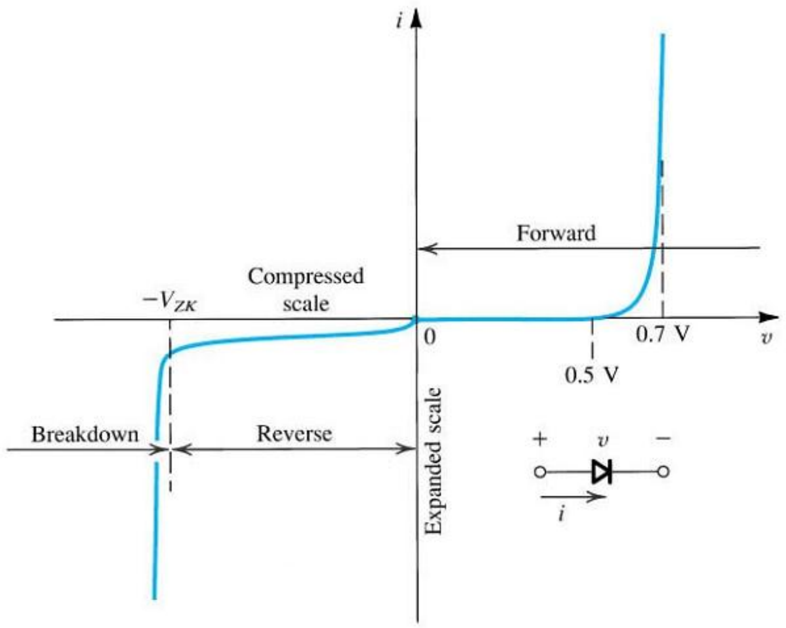
The diode is said to be forward biased when the positive terminal of the battery is connected to anode and negative terminal to cathode. Under these conditions, the holes in p-region are repelled by the positive terminal of the battery and electrons are repelled by the negative terminal. These charge carriers are then pushed across the junction. The applied voltage supplies majority charge carriers to both the regions. These charge carriers neutralise some of the uncovered bound charges causing the space charge region to store less charge reducing the depletion region barrier voltage. This helps the electrons from n-region and holes from p-region to cross the junction easily. As the applied voltage increased, the diode current increases exponentially once the potential barrier is overcome and is given by,

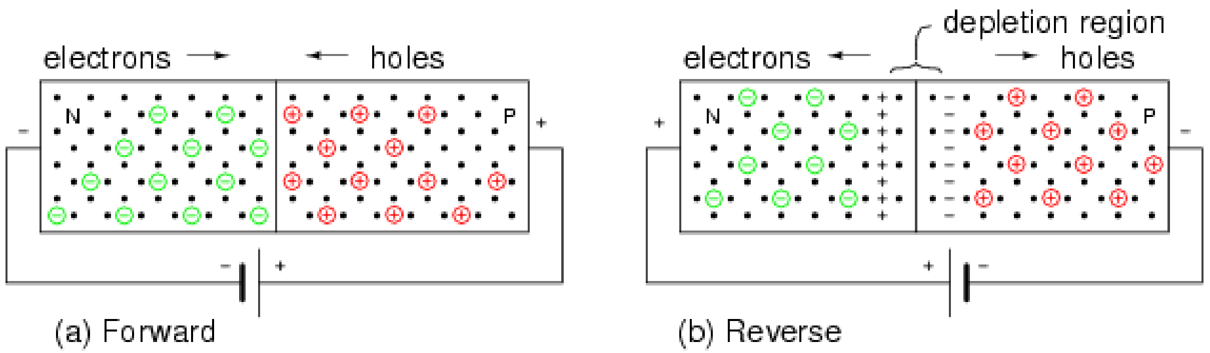
$$I_D = I_S(e^{\frac{V_D}{\eta V_T}} - 1) \tag{1.2}$$

where, *Is* is the saturation current which is given by,

$$I_S = Aqn_i^2\left(\frac{D_p}{L_P N_D} + \frac{D_n}{L_n N_A}\right) \tag{1.3}$$

Is is directly proportional to junction area A *and* n_i^2 which is a strong function of temperature. η is called ideality factor 1 for Ge and 2 for Si. Fig 3 shows the I-V characteristics od pn junction diode. The characeristic in first quadrant (positive voltage and current) shows the exponential relationship between diode current and diode voltage.





Reverse biasing a PN junction

When the polarity of the battery is reversed, the cathode is connected to positive end of the battery and anode to negative. This causes electrons from n-region to get attracted to positive terminal of the battery and holes by the negative terminal. This causes uncovered positive bound charge to increase in n-region and negative bound charge to increase in p-region resulting in wider depletion region and higher barrier potential reducing the diffusion current I_D. The small reverse current flows through the diode which is due to thermally degenerated charge carriers (minority carriers) in respective regions. The reverse current is nearly equal to I_S and is of the order of a few nanoamperes. This current is independent of the barrier voltage but strongly depends on the temperature.

Zener Diode

For the reverse voltages the electric field intensity increases beyond a critical level, the junction breaks down and a reverse large current starts flowing due to either zener breakdown or avalanche breakdown. This is shown in the third quadrant I-V characteristic in Fig 3. Under a high electric field, high energy carriers can cause the generation of more electron hole pairs, and the subsequent collisions quickly become an avalanche. When this process is taking place, very small changes in voltage can cause very large changes in current. Zener diodes can be made which break down at precise voltages from about 3 volts to few volts. Avalanche breakdown takes place at higher reverse voltages. Both the breakdowns are non-destructive provided the excessive reverse current does not overheat and damage the device.