Experiment 1: Diode Characteristics

A **diode** is a terminal device in which current flows easily in one direction but not in other. A *pn-*junction shows diode characteristic. Through a theoretical analysis the I-V characteristics of a *pn-*junction diode is given by **Shokley Equation** as follows

ID = IO (eV/ηVt − 1)

Where,

**ID** is the current flowing through diode. The positive sense of **ID** is from p-type to n-type region.

**V** is the voltage applied across diode terminals. **V** is positive for forward biased *pn-*junction.

**η** is ideality factor or emission coefficient. Value of η is in the range 1 ≤ η ≤ 2. This takes into account any recombination of electrons and holes in the space charge region. At very low current levels the recombination is a significant factor and η is close to 2. At higher current levels the recombination are not significant factor and η is 1. Unless otherwise stated we assume η = 1.

**IO** is reverse saturation current. For Silicon *pn* junction diode typical values of IO are in range of 10-15 to 10-13 Ampere. Actual values depend on doping concentration and cross sectional area of junction.

**Vt**  is thermal voltage which is approximately 0.026 V at room temperature of T = 300K. Vt is given by

Vt = kT/q

Where k is the Boltzmann’s constant, T is absolute temperature, and q is the magnitude of electronic charge.

The exponential part of the diode current equation is due to diffusion and the non-exponential part is due to drift phenomenon.

**Figure1**. Diode I-V characteristics

Vγ

γ

Vbr

γ

V in Vots

I in mA

Forward Bias Region

Reverse Bias Region

I in μA

Forward Bias Condition

When *pn-*junction diode is forward bias, that is when V several times higher than Vt which makes eV/ηVt >> 1. Thus,

ID = IO eV/ηVt  Ampere

This is expected as decrease is potential barrier permits carriers to diffuse more readily across the junction.

Reverse Bias Condition

When *pn-*junction diode is reverse bias, that is when VD << Vt then eV/ηVt << 1. Thus,

ID = − IO Ampere

Negative sign indicate current from n to p region. Due to increase in potential barrier the flow of majority carrier decreases but the minority carriers which fall down the hill are unaffected. Thus a small constant current flows from n to p region.

Cut-in or Turn-On voltage Vγ

The voltage below which current is small (less than 1 percent of rated of rated current) is called cut-in voltage. When the voltage V > Vγ the current increases rapidly.

Breakdown Voltage

If the reverse bias voltage is increased beyond the breakdown voltage Vbr a large reverse current may flow through diode and Shokley’s equation is no longer followed.

*Avalanche Breakdown*

When a thermally generated carrier falls down the junction barrier it acquires energy from the applied potential. This carrier collides with a crystal ion and imparts sufficient energy to disrupt a covalent bond. Thus a new hole-electron pair is generated which also gains sufficient energy to create new hole-electron pairs. This cumulative process is called *Avalanche Breakdown* which increases reverse current through diode.

*Zener Breakdown*

Thisbreakdown is initiated through a direct rupture of bonds by applying a very high electric field. The electric field at the reversed biased junction rips out the electron from the covalent bond. These newly generated hole-electron pair increases the reverse current through diode.

Temperature Dependence of Diode Characteristic

The thermal voltage Vt and reverse saturation current IO in the Shokley Equation are temperature dependent. Thus current through diode at a particular voltage is a function of temperature also. Typically the reverse saturation current doubles for every 10o C rise in temperature. Thus if IO1 is reverse saturation current at temperature T1, then reverse saturation current at temperature T2 is given by

IO2 = IO1 × 2(T2−T1)/10 Ampere

Thus at a fixed voltage the diode current ID increases with increase in temperature

The temperature dependence of Thermal voltage is given by

Vt = kT/q

Here k is the Boltzmann’s constant, T is absolute temperature, and q is the magnitude of electronic charge.

Points to ponder

* At low current levels why the slope of *ln*(I) vs. V characteristics has a slope of q/2kT at low current levels. (Hint: η = 2 at low current levels)