Characterization of pn Junction Diode.

→ The pn junction of a Semiconductor material forms part of many Commercially important devices Such as bipolar junction transistors (BJT), junction field effect transistors (JFET). and various kind of diodes (eg: Zener, rectifying, lasers, light emitting)

→ Semiconductor engineers routinely use the Current-voltage measurement technique both for the design of Semiconductor devices and for yield or process checks during manufacture.

Principle

→ The ideal diode equation has been derived by Shockley (1949, 1950) with following assumptions:

1. there is an abrupt junction where the depletion approximation is valid, i.e, the built-in potential and applied voltages are modeled by a dipole layer with abrupt boundaries and the semiconductor is neutral outside of the boundaries.

2. No generation or recombination takes place in the depletion region.

3. Injection Currents are low such that injected minority-Carrier densities are small compared with the majority-Carrier densities

4. The Boltzmann approximation applies (used for deriving equations to calculate free Carriers in each of the regions).

→ The equations of state are solved for the current density

$$J = \left(q \frac{D_N}{L_N} n_{po} + \frac{D_P}{L_P} P_{no}\right) \left[\exp\left(\frac{qV_j}{nKT}\right) - 1\right]$$

where, D_N & D_P → electron & hole diffusion Constants

n_{po} & P_{no} → the equilibrium electron and hole Concentrations in the n & p regions

L_N & L_p are the Debye lengths for electrons & holes.

V_j → is the junction voltage.

q → magnitude of electron charge

k → is the Boltzmann Constant.

T → Temperature.

→ More generally,

$$J = J_0\left[\exp\left(\frac{qV_j}{nkT}\right)-1\right] = J_0\left[\exp\left(\frac{q(V_a-IR)}{nkT}\right)-1\right]$$

where, $V_a = V_j + IR \approx V_j$ for low currents

R → extrinsic diode resistance.

Experiment

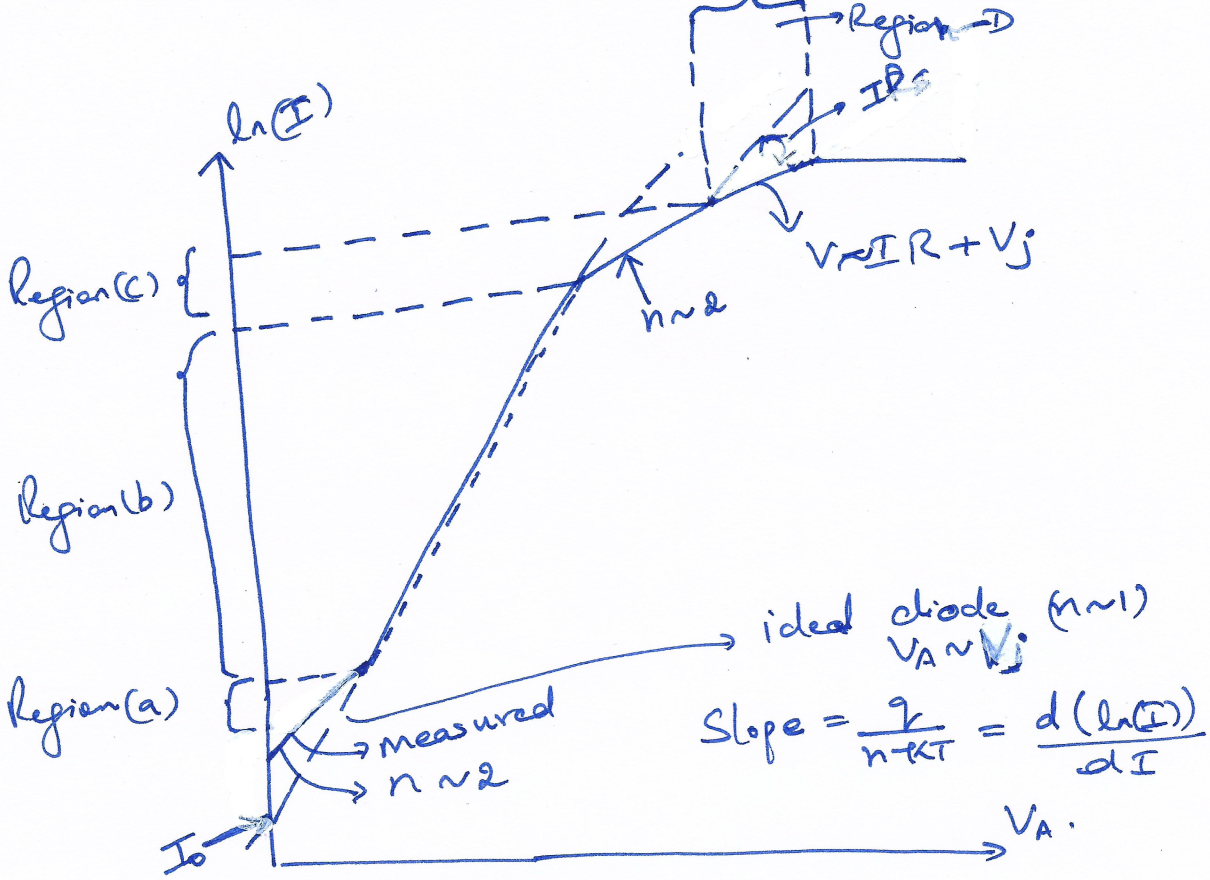
→ In current density equation, the first term dominates for positive applied voltages (forward biased junction) several times greater than kT and current increases exponentially.

→ In current density equation, the second term dominates for negative applied voltages (reverse biased junction) several times greater than kT and the reverse current approaches a constant value $-J_0$.

→ In practice, this equation applies well to Ge but less to Si and GaAs semiconductors.

→ The deviation from ideality are mainly due to:

1. Surface related currents.
2. The generation and recombination of carriers between the states in the bandgap.
3. tunneling of carriers between states in the bandgap.
4. high injection condition
5. Series resistance in the diode.



Deviations from the Ideal forward biased p-n junction I-V characteristic.

→ In forward bias conditions, the exponential terms dominate

→ At very low positive V_j, J_0 is proportional to $(n_i)^2$.

→ (a) In this region, an inverse logarithmic slope of $\frac{2kT}{q}$ is obtained.

(b) At higher values of V_j, the inverse slope approaches the ideal kT/q value in this region.

(c) The curve deviates again at higher applied bias voltages in this region. Here, the current is attributed to effect of high injection (conditions where the injected minority carriers approach the same concentration as the majority carriers). The net result is an increase in recombination with an exponential slope of $2kT/q$.

(d) The exponential increase in current stops as the diode current becomes limited by the resistances of the undepleted regions of the diode. This increase follows equation $V_a = V_j + IR$, with IR component becoming dominant term.