Capacitance-Voltage Measurements

→ Hillibrand and Gold (1960) first described the use of Capacitance-voltage (C-V) methods to determine the majority carrier concentration in semiconductors.

→ C-V measurements are capable of yielding quantitative information about the diffusion potential and doping concentration in semiconductor materials.

→ The technique employs pn-junctions, metal-semiconductor junctions (Schottky barriers), electrolyte-semiconductor junction metal-insulator-semiconductor junctions capacitors, and MIS field effect transistors.

→ C-V measurements yield accurate information about the doping concentrations of majority carriers as a function of distance (depth) from the junction.

Principle

→ The capacitance at an p-n or metal-semiconductor junction depends on the properties of the charge-depletion layer formed at the junction.

→ The depletion region is in the viscinity of the pn junction and is "depleted" of free carriers due to the drift field required to maintain charge neutrality.

Experiment.

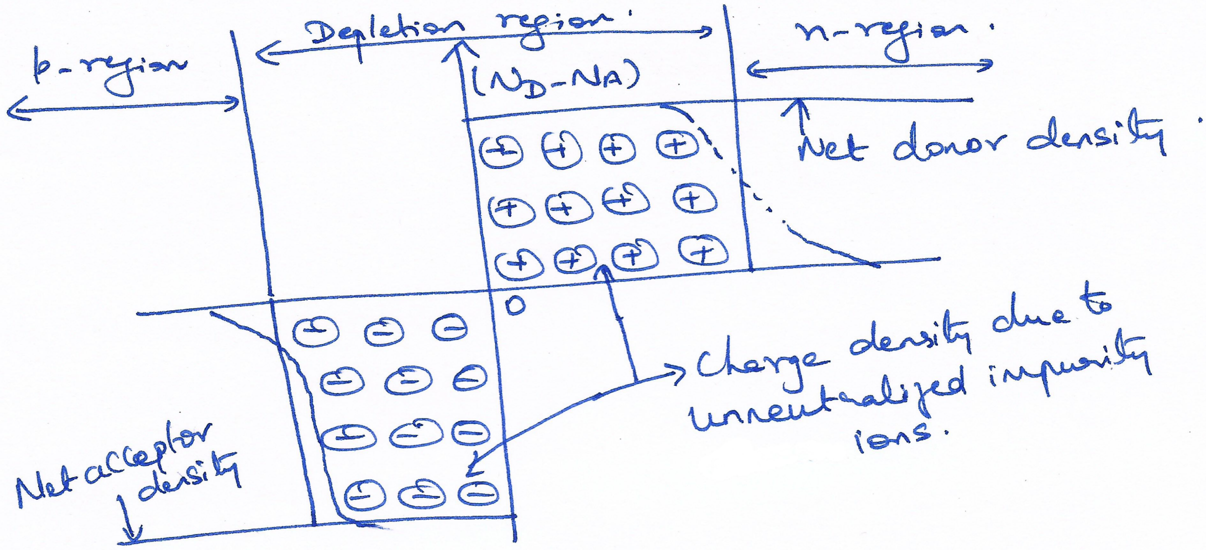
→ As shown in figure, an abrupt pn junction is considered.

→ The bandgap of the semiconductor $E_G = E_C - E_V$ is defined by the difference between the conduction band energy E_C and the valence band energy, E_V

→ The fermi energy E_F defines the equilibrium condition for charge neutrality.

→ The difference in energy between the conduction band as one crosses the pn junction is called the diffusion potential, V_{bi} (built-in potential).

A



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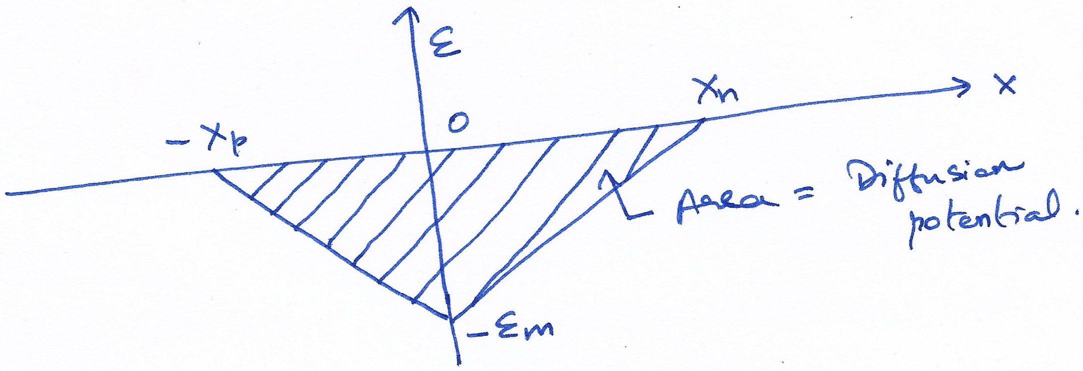

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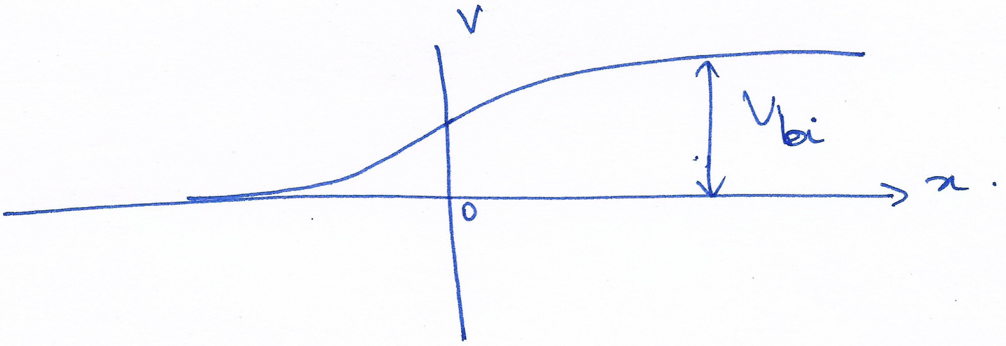

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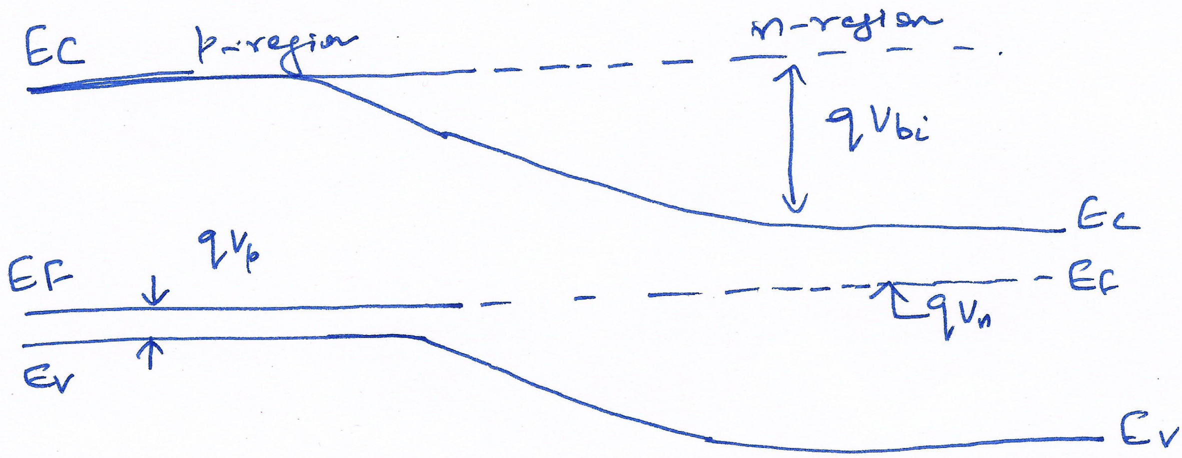

Diagram Explanation:

Abrupt pn junction in thermal equilibrium (no bias).

A. Space charge distribution in the depletion approximation. The dashed lines indicate the majority carrier distribution tails.

B. Electric field accross the depletion region.

C. Potential distribution due to the electric field where V_{bi} is the (built-in) diffusion potential.

D. Energy band diagram.

→ Consider the pn junction, where the regions denoted by ⊕ and ⊖ indicate the junction region depleted of free carriers, leaving behind ionized donors and acceptors.

→ In this region, from Poisson's equation

$$-\frac{\partial^2 V}{\partial x^2} = \frac{\partial E}{\partial x} = \frac{\rho(x)}{\varepsilon} = \frac{q}{\varepsilon}\left[p(x) - n(x) + N_D^+(x) - N_A^-(x)\right]$$

→ For predominantly doped p-type

$$-\frac{\partial^2 V}{\partial x^2} \approx \frac{q}{\varepsilon} N_D^+ \quad \text{for } 0 < x \leq x_n$$

→ and for n-type

$$-\frac{\partial^2 V}{\partial x^2} \approx \frac{q}{\varepsilon} N_A^- \quad \text{for } (-x_p \leq x < 0)$$

where, $V \to$ voltage, $E \to$ electric field.

$q \to$ electronic charge,

$p(x)$ & $n(x) \to$ the hole and electron concentrations (electric potential) comprising the mobile carriers.

$N_D(x)$ & $N_A(x)$ → the donor and acceptor doping concentrations

$\varepsilon = K_s \varepsilon_0$ → the permittivity with dielectric coefficient K_s

→ The spatial dependence, x, is measured relative to the physical location of the p-n junction.

→ The solution of these equations in a form useful for C–V measurement is

$$V(x) = V_{bi}\left[2\left(\frac{x}{W}\right) - \left(\frac{x}{W}\right)^2\right]$$

where, $$V_{bi} = \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right)$$