

DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

Module –IV ; LECTURE - 7

HOT PROBE METHOD FOR SEMICONDUCTOR THIN FILM

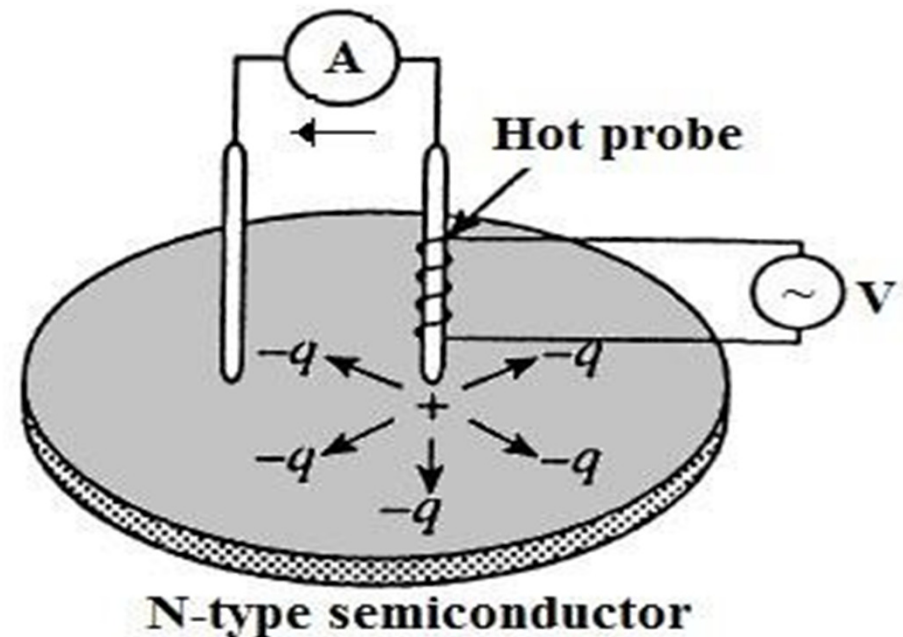
- Physical properties of thin films significantly differ from those of bulk material
- There are various parameters such as a thickness, crystal structure, composition and other, which characterize a semiconductor film
- The parameters of charge carriers are
 - (a) Type of semiconductor,
 - (b) Impurities concentration,
 - (c) Mobility of charged carriers,
 - (d) Diffusion coefficient.

Define the possibility to apply material for various electronic devices

Principle:

- A conventional Hot-Probe experiment enables a simple and efficient way to distinguish between n-type and p-type semiconductors using a hot probe and a standard multi- meter.

- While applying the cold and hot probes to an n-type semiconductor, positive voltage readout is obtained in the meter, whereas for a p- type semiconductor, negative voltage is obtained.



Experiment:

- A couple of a cold probe and a hot probe are attached to the semiconductor film surface.
- The hot probe is connected to the positive terminal of the multimeter while the cold probe is connected to the negative terminal.
- The thermally excited majority free charged carriers are translated within the semiconductor from the hot probe to the cold probe.
- Mechanism for this motion within the semiconductor is of a diffusion type since the material is uniformly doped due to the constant heating in the hot probe contact.
- These translated majority carriers define the electrical potential sign of the measured current in the multimeter

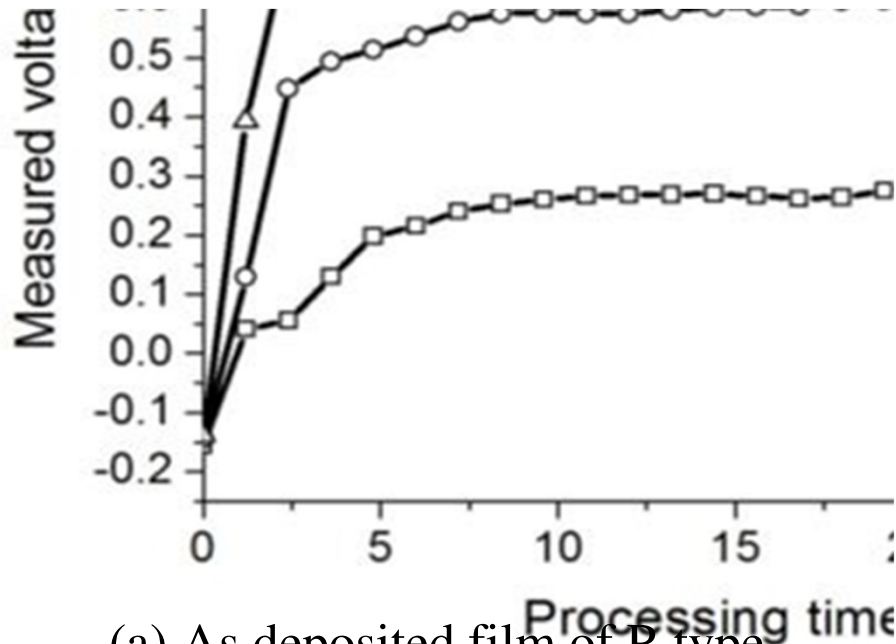
- The Hot-Probe measurement may be described as a three-step process:
 - (1) the heated probe excites additional free charged carriers of two types
 - (2) The hot majority carriers begin to leave the heated part of the semiconductor surface by a diffusion mechanism. Simultaneously, a built-in electrical field is created between the electrodes and the second (cold) electrode is warmed as well. This warming and the built-in electrical field tend to prevent the diffusion process up to a halt at a steady state. This steady state condition exists until the heated source is switched off.
 - (3) The third process is actually a recombination of the excited additional charged carriers.

- This three-step process may be described, in general, by the continuity and Poisson's equations

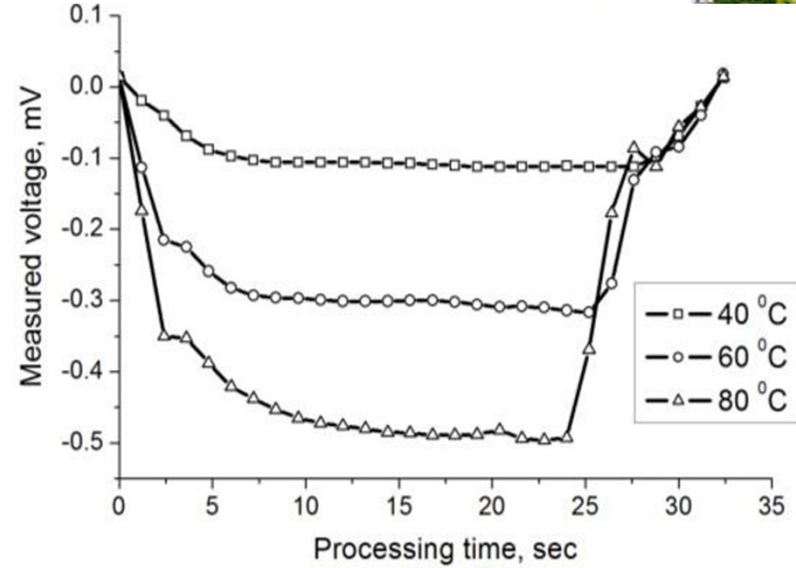
$$\nabla J + \frac{\partial Q}{\partial t} = 0$$

$$\nabla E = \frac{Q}{\epsilon_0 \epsilon_r}$$

- Here Q is the uncompensated charge density excited by the heated electrode, J is the current density, ϵ_0 and ϵ_r are the absolute and relative permittivity, and E is the built-in electrical field.



(a) As deposited film of P-type



(b) thermally treated film of N-type

Hot-probe characteristics for vanadium oxide thin films deposited on the oxidized silicon surface by thermal evaporation.

Capacitance-Voltage measurements

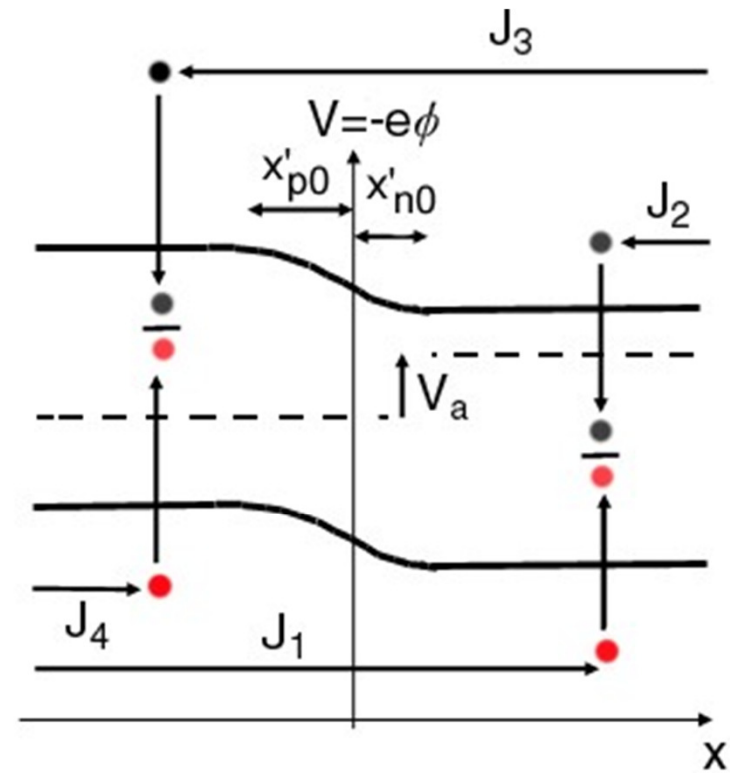
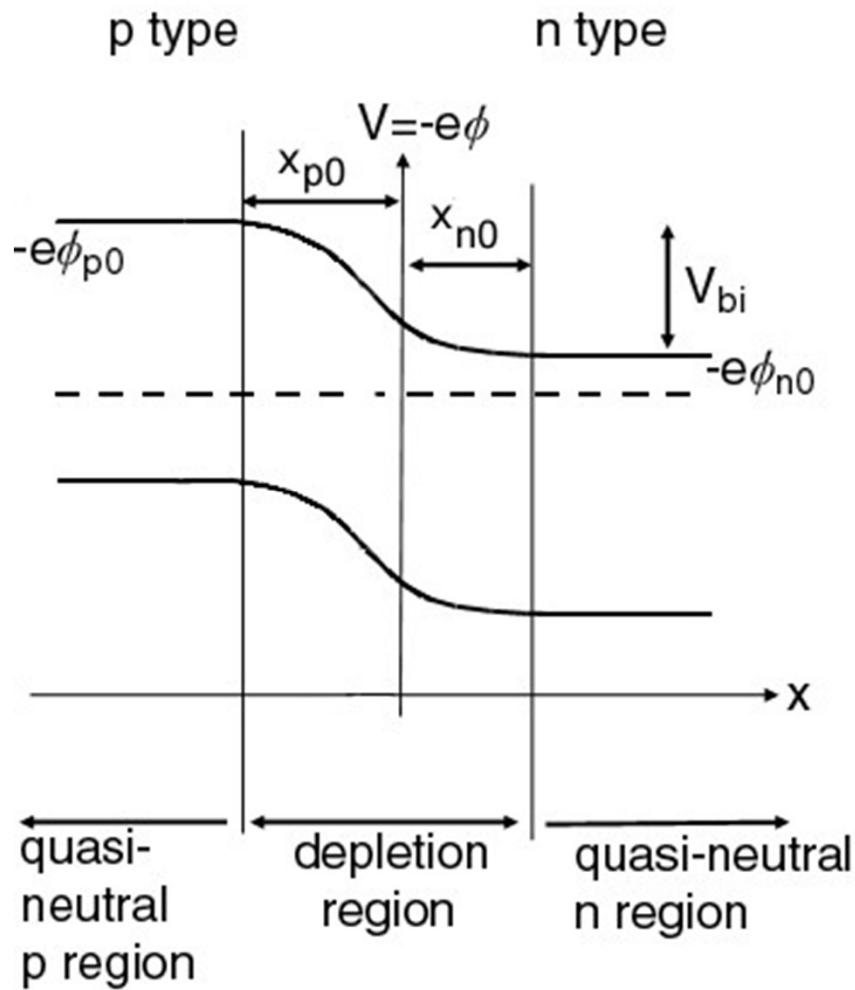
- Hillibrand and Gold (1960) first described the use of capacitance –voltage (C-V) methods to determine the majority carrier concentration in semiconductors.
- C-V measurements are capable of yielding quantitative information about the diffusion potential and doping concentration in semiconductor materials.
- The technique employs PN-junctions, metal- semiconductor junctions (Schottky barriers), electrolyte –semiconductor junction MIS field effect semiconductors.
- C-V measurements yield accurate information about the doping concentrations of majority carriers as a function of distance (depth) from the junction.

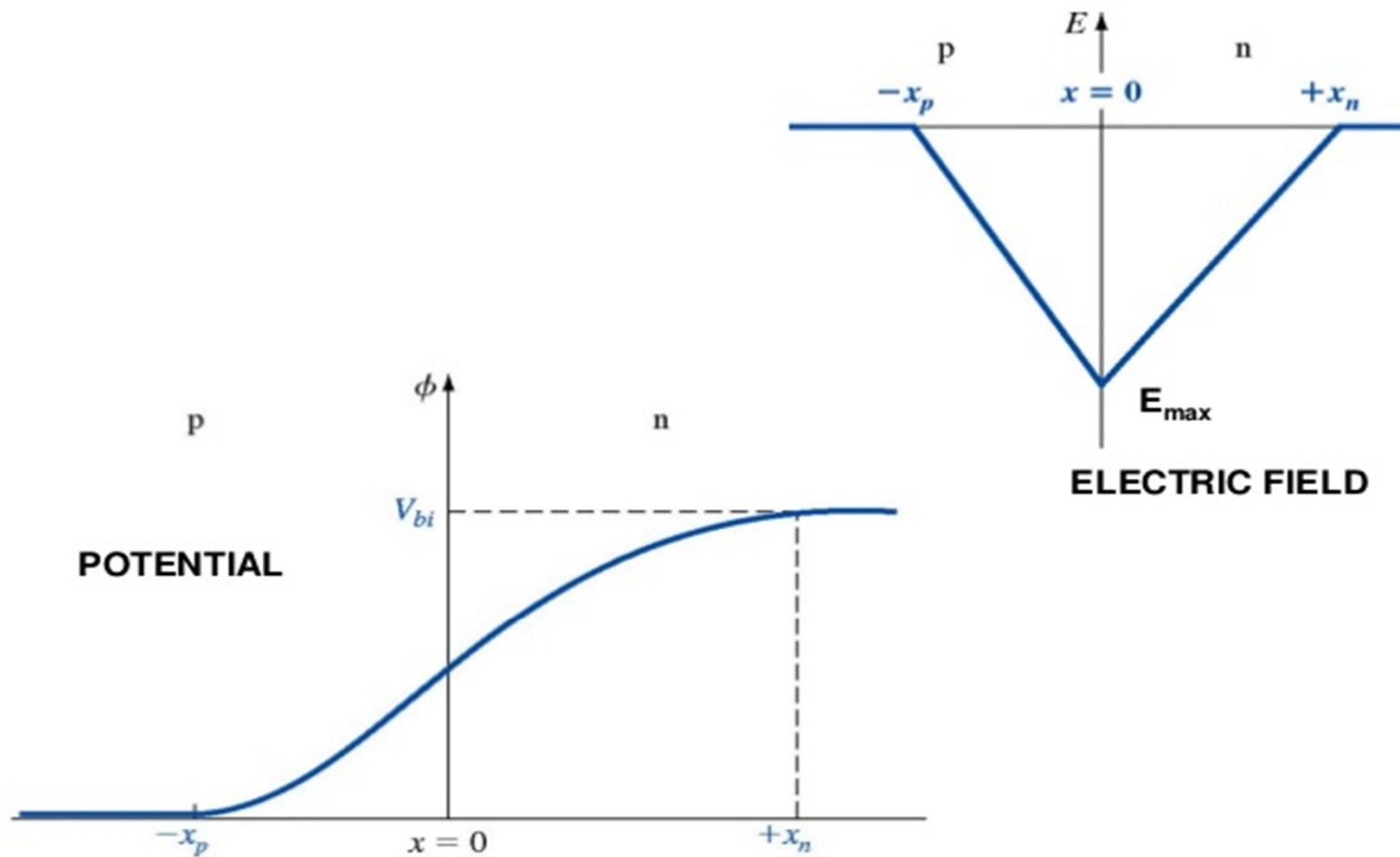
Principle:

- The capacitance at an p-n or metal –semiconductor junctions depends on the properties of the charge- depletion layer formed at the junction
- The depletion regions is the vicinity 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 valance band energy E_v .
- The fermi energy E_F defines the equilibrium condition for the 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).





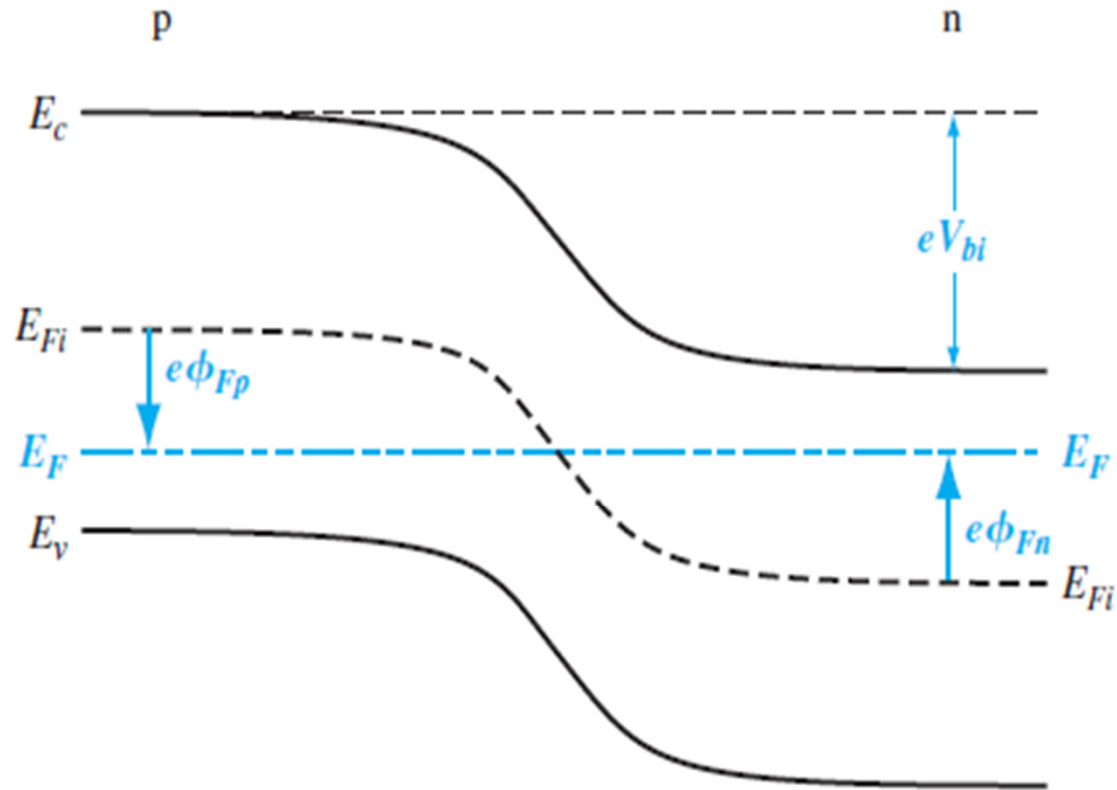


Figure 7.3 | Energy-band diagram of a pn junction in thermal equilibrium.

- 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 across 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 – indicates the junction region depleted of free carriers, leaving behind ionized donors and acceptors.
- In this region from Poisson's equations

- $$\frac{\partial^2 v}{\partial x^2} = \frac{\partial E}{\partial x} = \frac{\rho(x)}{\varepsilon} = \frac{e}{\varepsilon} [p(x) - n(x) + N_D^+(x) - N_A^-(x)]$$

For predominantly doped p-type

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

And for n-type

- $$-\frac{\partial^2 v}{\partial x^2} \approx \frac{e}{\varepsilon} N_A^- \quad \text{for } -x_p \leq x < 0$$

- Where v - Voltage, ε – Electric field, e - charge, $p(x)$ and $n(x)$ –the hole and electron concentration(electric potential) comprising the mobile carriers.
- N_D^+ and N_A^- - the donor and acceptor doping concentrations
- $\varepsilon = K_s \varepsilon_0$ – The permittivity with dielectric coefficients
- *The* spatial dependence, x is measured relative to the physical location of the p-n junction. The solution of three equations is a form useful for C-V measurements is
- $$V(x) = V_{bi} \left[2 \left(\frac{x}{w} \right) - \left(\frac{x}{w} \right)^2 \right]$$
- *where*
$$V_{bi} = \frac{KT}{e} \ln \left(\frac{N_d N_a}{n_i^2} \right)$$