DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB103J –Semiconductor Physics

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

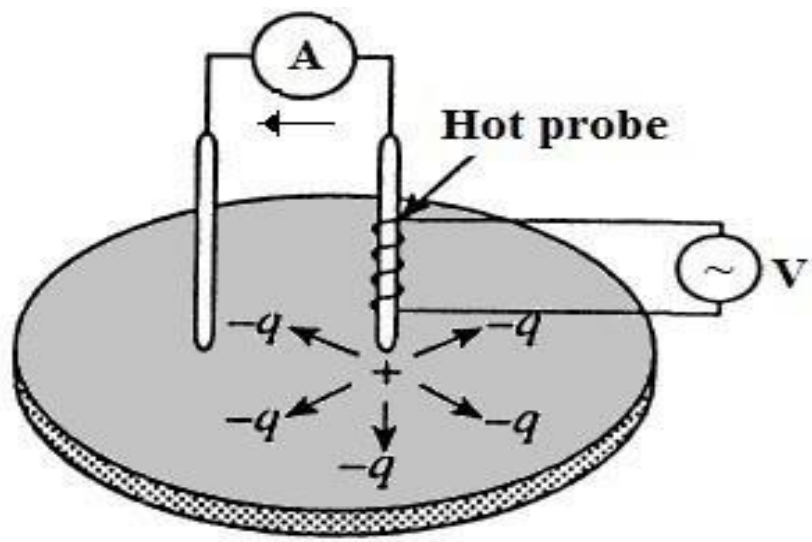
(a) Type of semiconductor,
(b) Impurities concentration,
(c) Mobility of charged carriers,
(d) Diffusion coefficient.

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 con- stant heating in the hot probe contact.
- These translated majority carriers define the electri- cal 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.

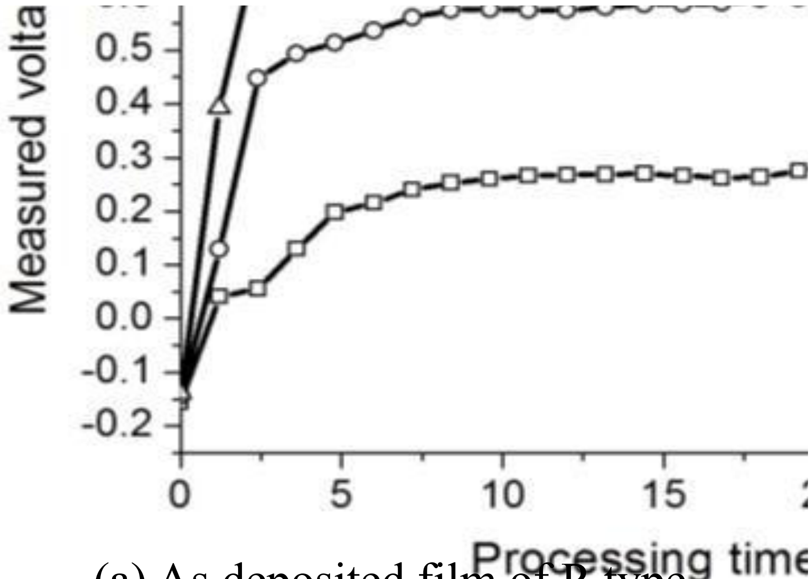
(3) The third process is actually a recombination of the excited additional charged carriers.

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

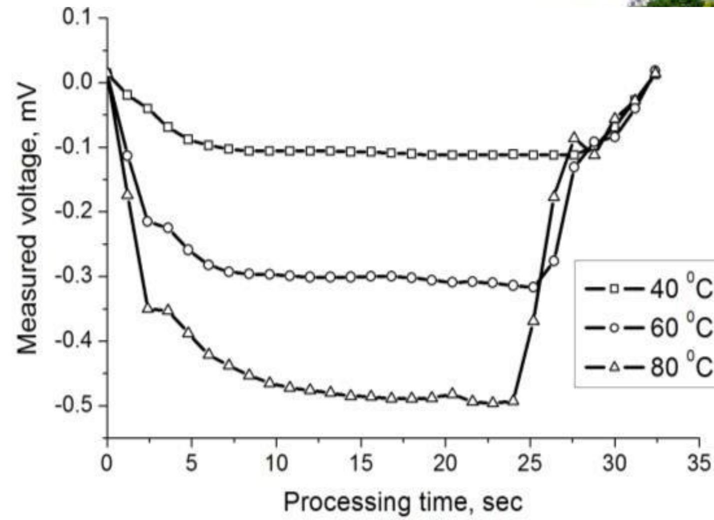
$$\nabla J + \frac{\partial Q}{\partial t} = 0$$

$$\nabla E = \frac{Q}{\varepsilon_0 \varepsilon_r}$$

- 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

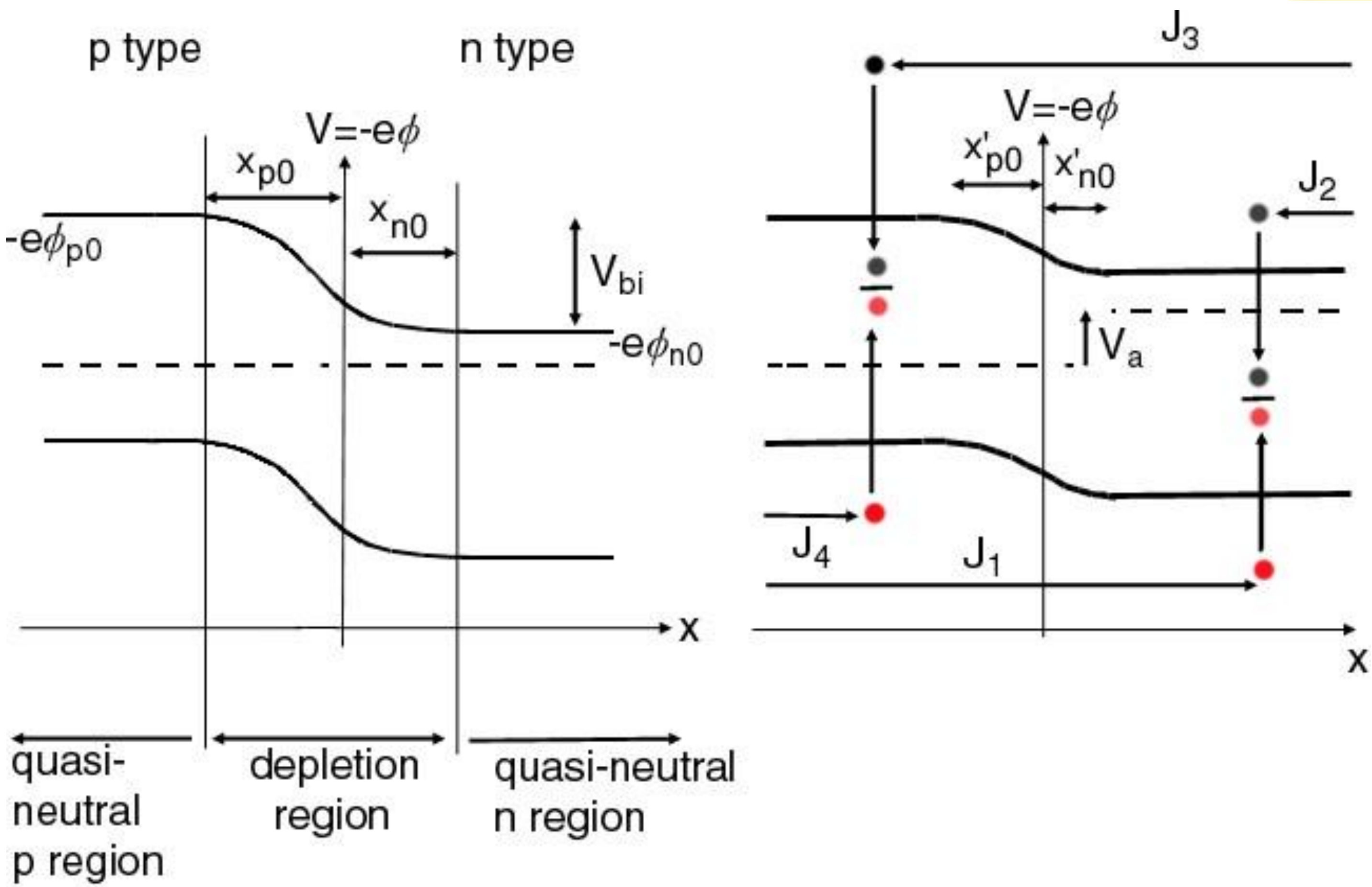
- Hillibrand and Gold (1960) first described the use of capacitance –voltage (C-V) methods to determine the majority carrier concentration in semiconductors.
- C-V measurements are capable of yielding quantitative information about the diffusion potential and doping concentration in semiconductor materials.
- 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:

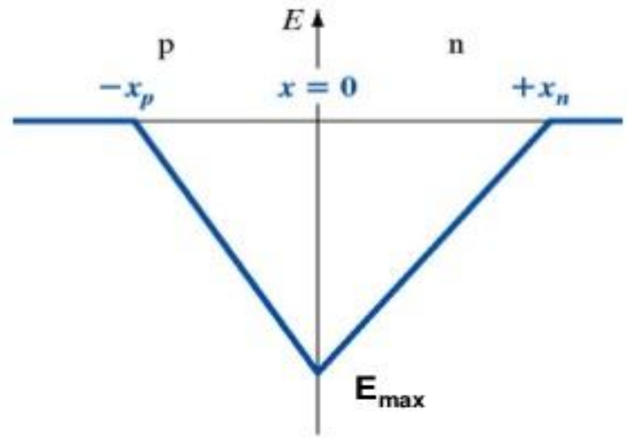
- The capacitance at an p-n or metal –semiconductor junctions depends on the properties of the charge- depletion layer formed at the junction
- The depletion regions is the vicinity of the PN junction and is " depleted" of free carriers due to the drift field required to maintain charge neutrality.

Experiment

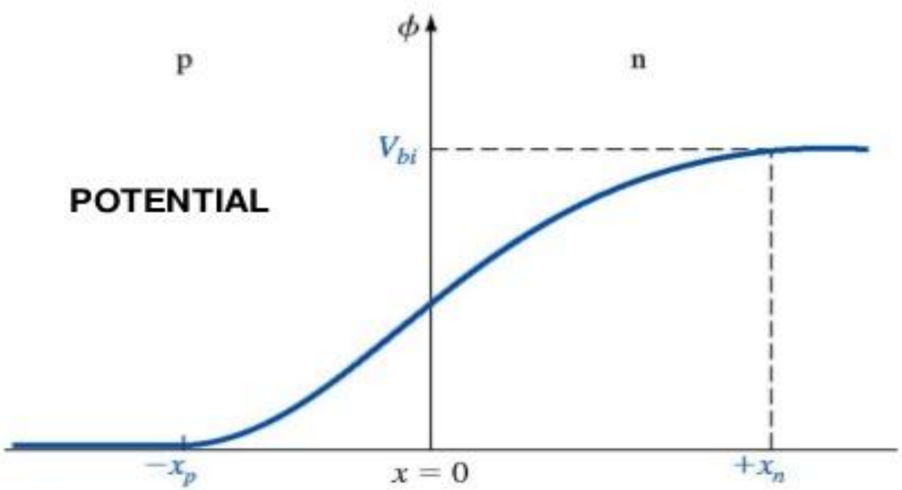
- As shown in figure an abrupt pn junction is considered.
- The bandgap of the semiconductor $E_G = E_c – E_V$ is defined by the difference between the conduction band energy E_c and the valance band energy E_V .
- The fermi energy E_F defines the equilibrium condition for the charge neutrality.
- The difference in energy between the conduction band as one crosses the PN junction is called the diffusion potential, V_{bi} (built-in- potential).



p type
n type
V=-eϕ
x_{p0}
x_{n0}
$-e\phi_{p0}$
V_{bi}
$-e\phi_{n0}$
x
quasi-neutral p region
depletion region
quasi-neutral n region
J_3
V=-eϕ
x'_{p0}
x'_{n0}
J_2
V_a
J_4
J_1
x



ELECTRIC FIELD



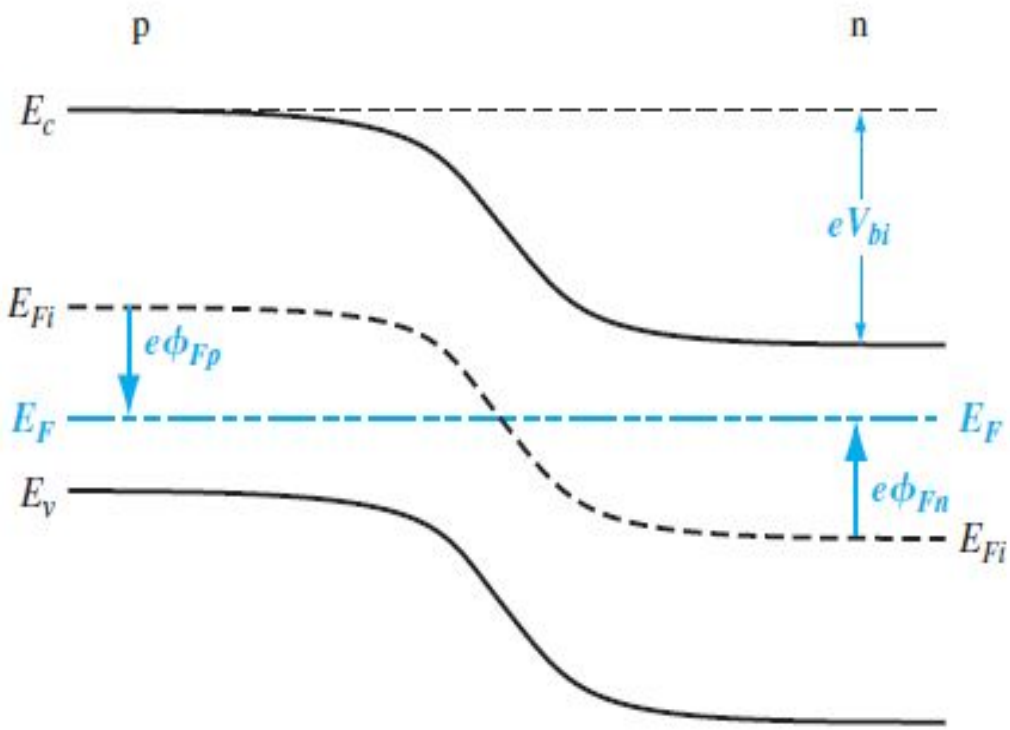


Figure 7.3 | Energy-band diagram of a pn junction in thermal equilibrium.

- 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

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

And for n-type

- $-\frac{\partial^2 v}{\partial x^2} \approx \frac{e}{\varepsilon} N_A^- \quad$ 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
- $V(x) = V_{bi}\,[\,2\,(\frac{x}{w}) - (\frac{x}{w})^2\,]$
- *where* $V_{bi} = \frac{KT}{e} \ln\left(\frac{N_d N_a}{n_i^2}\right)$