DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB103J –Semiconductor Physics

Module-IV Lecture-9

Deep Level Transient Spectroscopy(DLTS)

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Deep-level transient spectroscopy(DLTS)

DLTS Principle:

- Emission of trapped charge carriers change the depletion capacitance of a pn-junction or Schottky diode. The transient measurement provides information on the defect levels in the band gap.

- Deep-level transient spectroscopy is a method of determining the concentration and thermal emission rate of semiconductor deep levels by measuring capacitance transients as a function of temperature.

- A Schottky or p-n diode is first forward biased to fill the traps, then the capacitance transient caused by carrier emission from filled traps in the depletion region is measured at the quiescent reverse bias.

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- A DLTS peak is generated when the thermal emission rate of the trap is the same as that of the rate window. Because of the strong temperature dependence of the trap emission rates, it is possible to resolve the emission from different traps using an appropriate emission rate window.

- When voltage across a p-n junction is changed, there is a corresponding change in the depletion region width. This change in width causes a change in the number of free charge carriers on both sides of the junction, resulting in a change in the capacitance.

- This change has two contributions; a) the contribution due to change in depletion width known as the junction capacitance and b) the contribution due to change in minority carrier concentration called the diffusion capacitance.

- Junction capacitance is dominant under reverse biased conditions while diffusion capacitance is dominant under forward biased conditions.

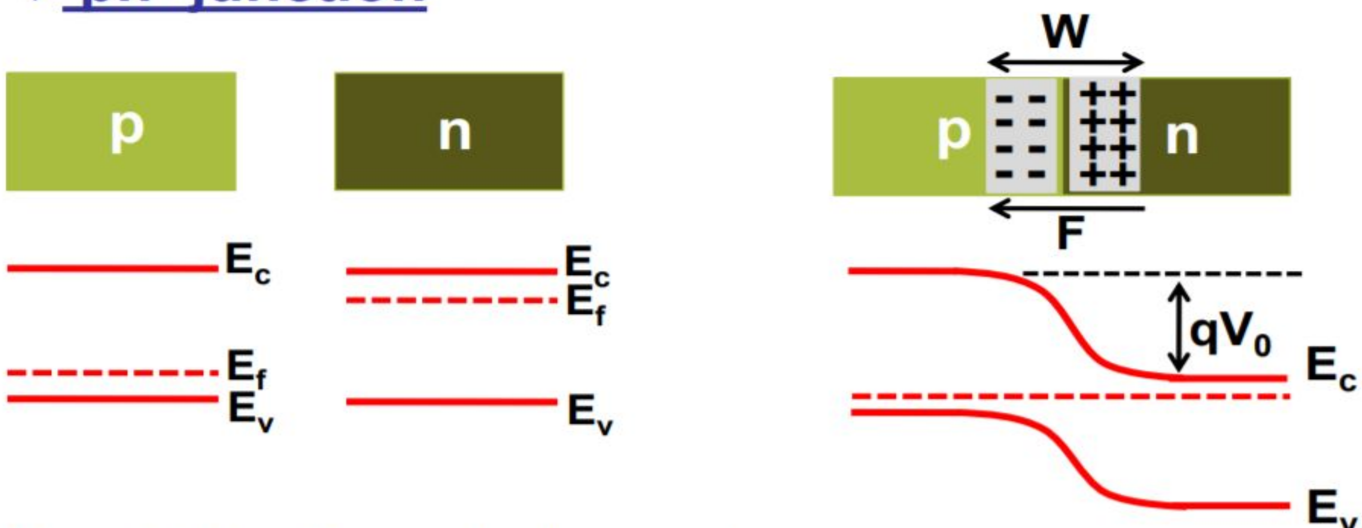
- Consider a p-n junction with a deep level present having its energy as E_T. In steady state there is no net flow of charge carriers across the trap. Also the electron and hole densities within the depletion region are negligible. Thus from **Shockley and Reed & Hall** the relationship between the total density of deep sates N_T and density of filled traps is given by

$$e_p n_T = (en+ep)N_T$$

where e_p is the hole emission rate, e_n is the electron emission rate, n_T is the density of filled traps, and N_T is the total density of deep sates.

Semiconductor Basics

❖ pn- junction



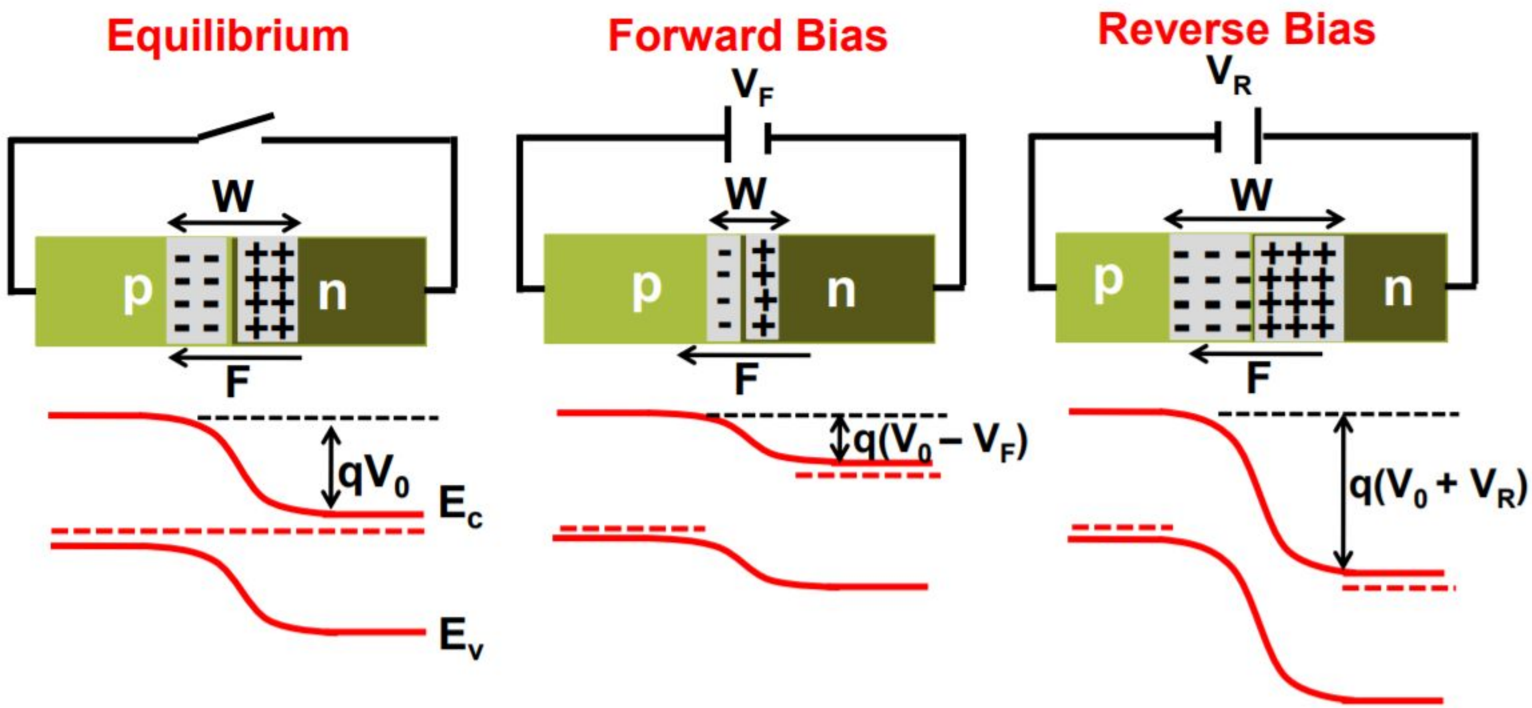
$$C = \frac{\varepsilon A}{W}$$

- Connection of p- and n-type regions:

– Diffusion of charge carriers into the opposite regions.

–This will give rise to an electric field across the depletion region (W), with a capacitance C

– No free charge carriers in W as the field will sweep them across the junction



- The SCR width (W) Changes with applied voltage and doping concentration

–High doping ⇨ small W

–Low doping ⇨ large W

- The depletion region width (W) will extend mostly into low-doped material in order to keep charge balance

Point Defects

- **Substitution impurity:** extra impurity atom in an origin position
- **Vacancy:** missing atom at a certain crystal lattice position
- **Interstitial impurity atom:** extra impurity atom in an interstitial position
- **Self-interstitial atom:** extra atom in an interstitial position;

Introduce energy level in the band structure

•Shallow level

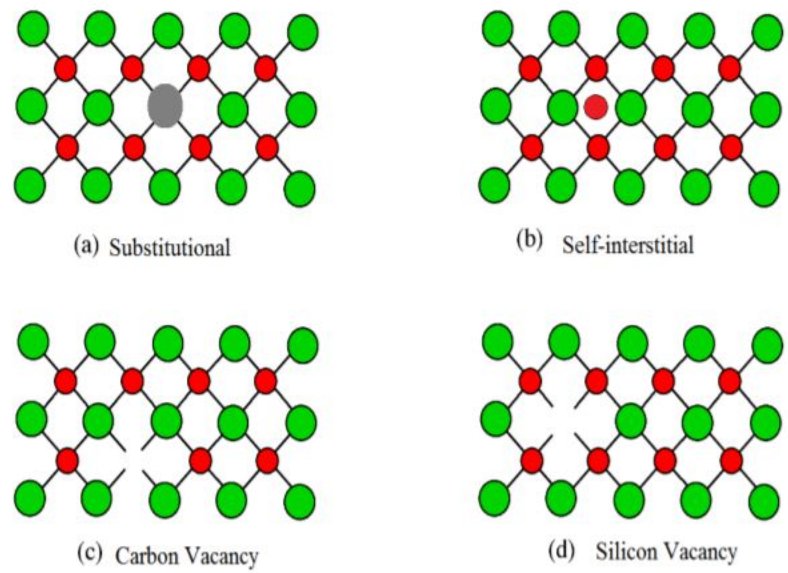
–Close to the edges of the bandgap

–Use mainly as a dopant

•Deep level

–Close to the middle of the bandgap

–Act as generation/recombination or trap center.



(a) Substitutional (b) Self-interstitial (c) Carbon Vacancy (d) Silicon Vacancy

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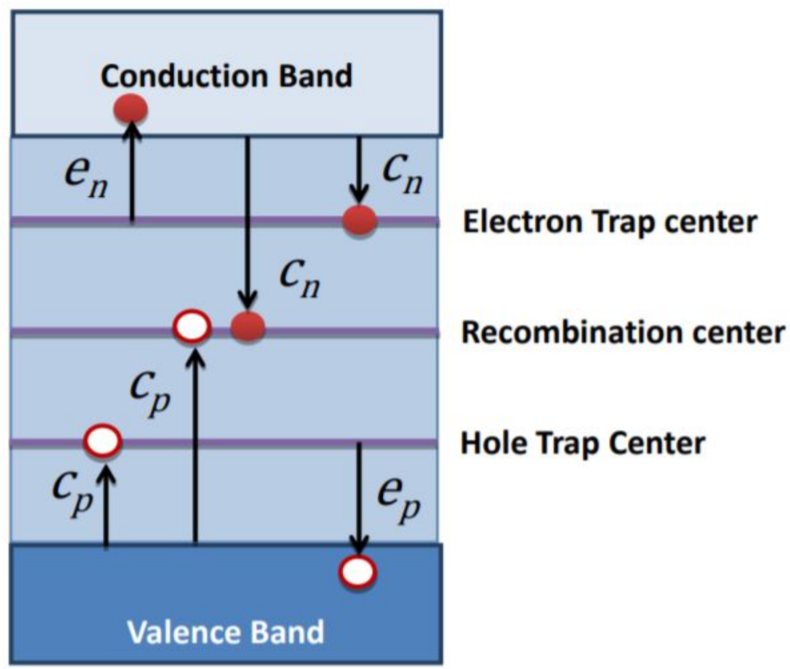
Capture & Emission Processes

Deep levels in the band gap act as

- **Recombination centers:** can interact with both edges of bandgap $c_n = c_p$.
- **Electron traps:** If they mostly interact with the conduction band $c_n \gg c_p$.
- **Hole traps:** If they mostly interact with the valence band $c_n \ll c_p$.



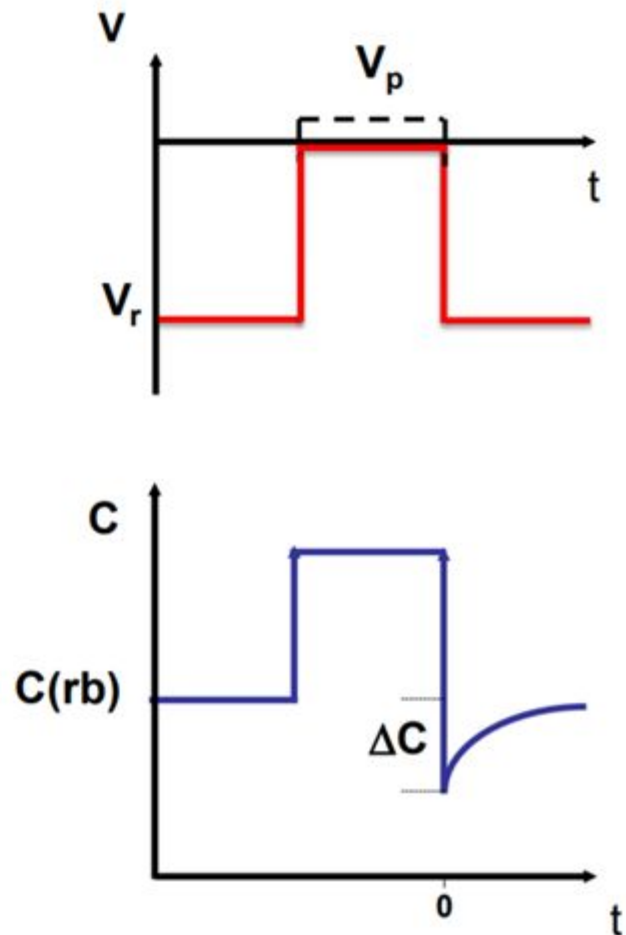
DLTS Theory

Principle of measurement

- Diode kept at fixed reverse bias.
- Filling Pulse to fill the traps.
- Return to the reverse bias:
  - Change of the W
  - Emission of charge carriers changes the capacitance of the depletion region as a function of time

$$C(t) = C_{rb} - \Delta C_o \, exp(-e_n t)$$

- Repeated through a temperature scan



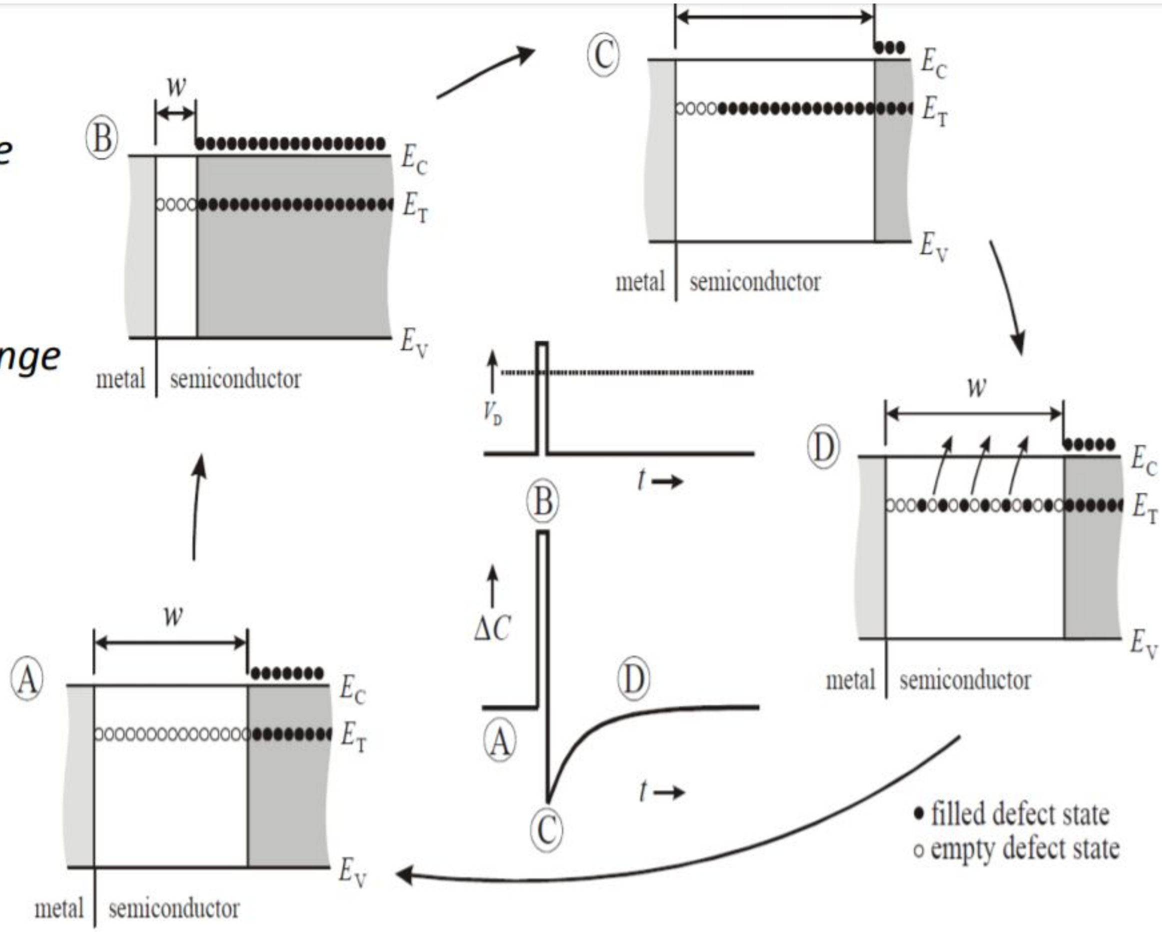
DLTS Measurement:

(A) Equilibrium state

(B) Filling pulse

(C) Return to the reverse bias with change in the capacitance

(D) Emission case.



-The carrier concentration of the traps is changed exponentially

$$n_T(t) = N_T \exp(-e_n t)$$

- The trap concentration can be deduced from the maximum amplitude of the transient

$$\Delta C_o = \frac{N_T}{2N_d} C_{rb}$$