Deep-Level Transient Spectroscopy. (DLTS)

→ Defects are responsible for many characteristic properties of a SemiConductor. They play a Crucial role in determining the viability of a given material for device applications.

→ The performance and reliability of devices can be significantly affected by only minute concentrations of undersirable defects.

→ Deep-level transient Spectroscopy (DLTS) probes the temperature dependance of the charge carriers escaping from trapping centers formed by the point defects in the material.

Principle.

→ Deep-level transient Spectroscopy was first introduced in 1974, by Lang.

→ The basis of this method is the dependence of the capacitance of a Space-charge region on the occupancy of the traps within the space-charge region in a Semiconductor.

→ Under a non-equilibrium Condition such as that existing in a Space-charge region, a trapped carrier can escape from a trapping center by thermal excitation to the nearest energy band.

Experiment.

→ To characterize a Semiconductor, it is neccessary to fabricate a junction diode such as p-n- or Schottky barrier diode on material of interest.

→ A Space-Charge region is formed by reverse biasing the p-n or schottky diode. The diode is initially reverse biased to empty the traps.

→ when the bias across the junction is reduced (or even forward biased), the width of the space-charge region is reduced.

→ An equilibrium condition is established in the neutralized region with the majority carriers populating the traps.

→ When the reverse bias is restored, the space-charge region is again created as before, with only difference being that there are trapped carriers now residing in the defect centers within the space-charge region.

→ The non-equilibrium condition thus created causes the trapped carriers to be thermally re-emitted to the relevant energy band.

→ The rate of thermal emission, or "detrapping", of a carrier is temperature dependent.

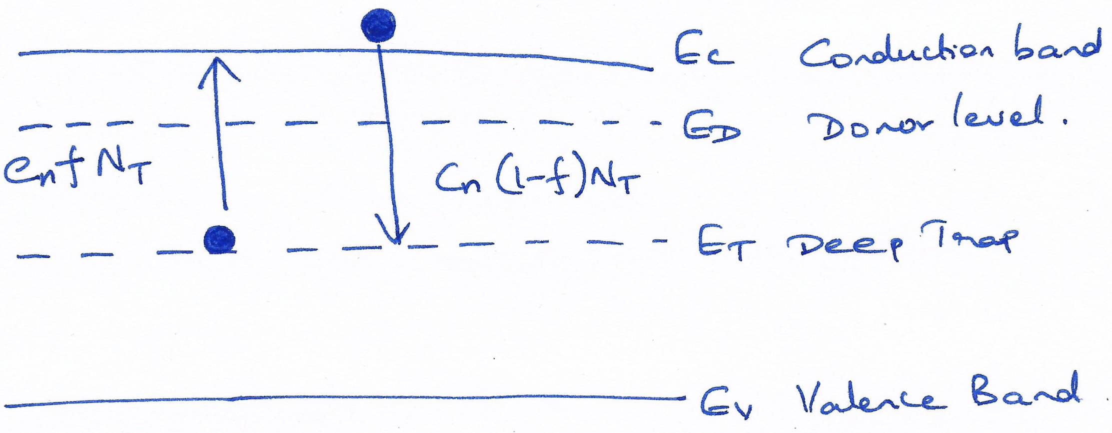
→ The change of occupancy of these trapping centers is reflected in the capacitance of the junction producing a capacitance transient.

→ Minority-carrier injection can also occur when the junction is forward biased during the bias pulse.

→ Since both the majority and minority charge carriers are involved, which makes this method all more effective because emission of each type of carrier can be detected by monitoring the capacitance transients.

→ The activation energy of the trap, or the depth of the trapping level from the nearest energy band edge, and the capture cross-section can be determined from the temperature dependance of emission rate.

→ The trap concentration can be determined from the intensity of the capacitance peak, and the polarity of the carriers can be found from the sign of the capacitance change.



Electron transitions between the trapping level and the Conduction band.

→ The rate of electron Capture

$$\frac{dC_n}{dt} = n\, V_{th}\, \sigma_n\, (1-f)\, N_T$$

Where, C_n → Capture probability.
σ_n → electron Capture Cross-section
V_{th} → thermal Velocity.
n → electron Concentration.
$(1-f)$ → probability that a trap is vacant.
f → fermi-Dirac probability factor (a fraction of total Concentration of traps N_T is filled)

→ The electron detrapping rate

$$\frac{de_n}{dt} = e_n N_T^- = e_n f N_T$$

where, e_n → electron emission rate
N_T^- → Concentration of occupied traps N_T^-

Instrumentation:

→ As the trapped electrons are emitted into the conduction band following the termination of the bias pulse, the capacitance of the junction will decay exponentially with a time constant τ_n according to the equation

$$C(t) = C(0)\, e^{-t/\tau_n}$$

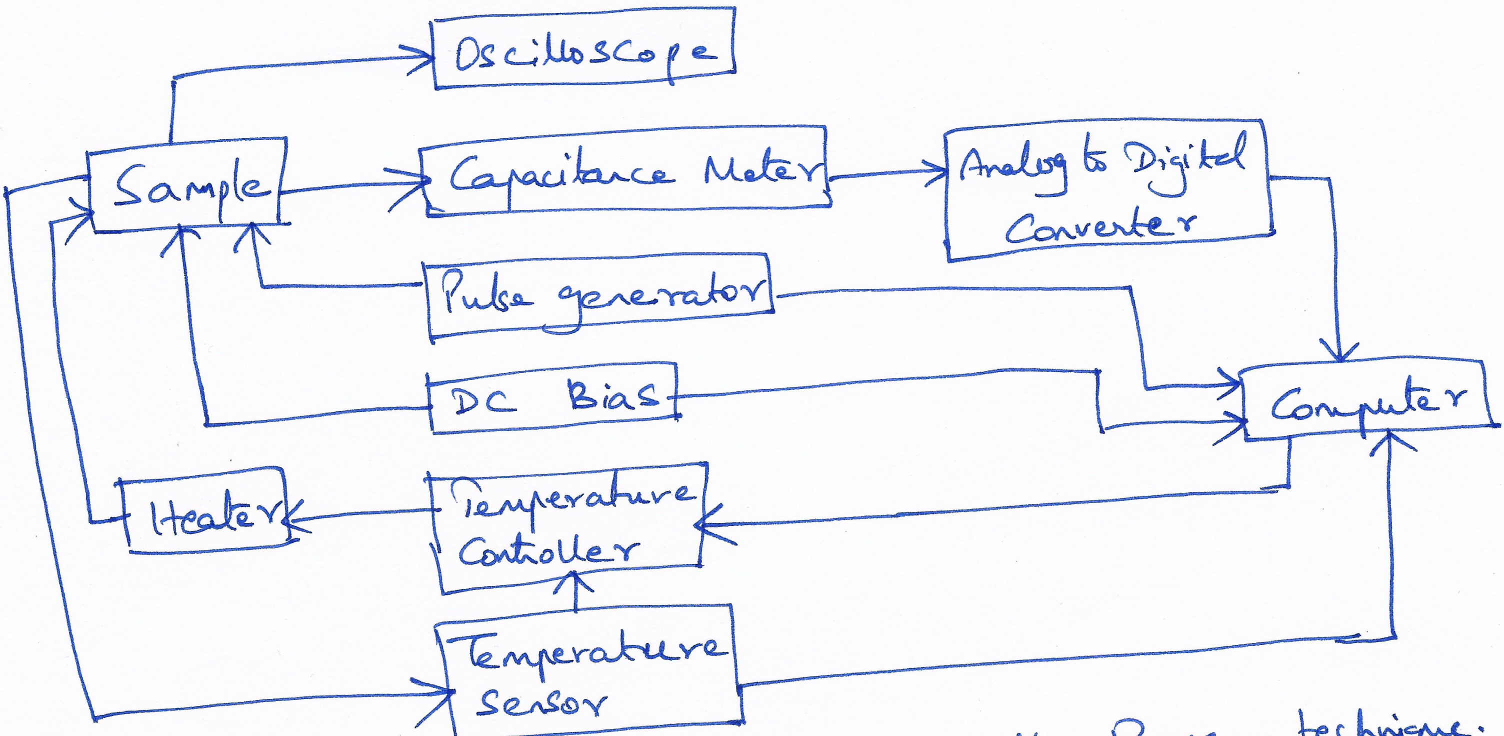
→ But $e_n = \dfrac{1}{\tau_n}$

then, $$C(t) = C(0)\, e^{-e_n t}$$

→ If the decaying capacitance transient is measured at two different time delays t_1 and t_2 from the termination of the bias pulse, then the difference in the capacitances will be given by

$$S = \Delta C = C(t_1) - C(t_2) = C(0)\left(e^{-e_n t_1} - e^{e_n t_2}\right)$$

→ The capacitance difference S is the DLTS signal.



A DLTS Spectrometer using the Boxcar technique.

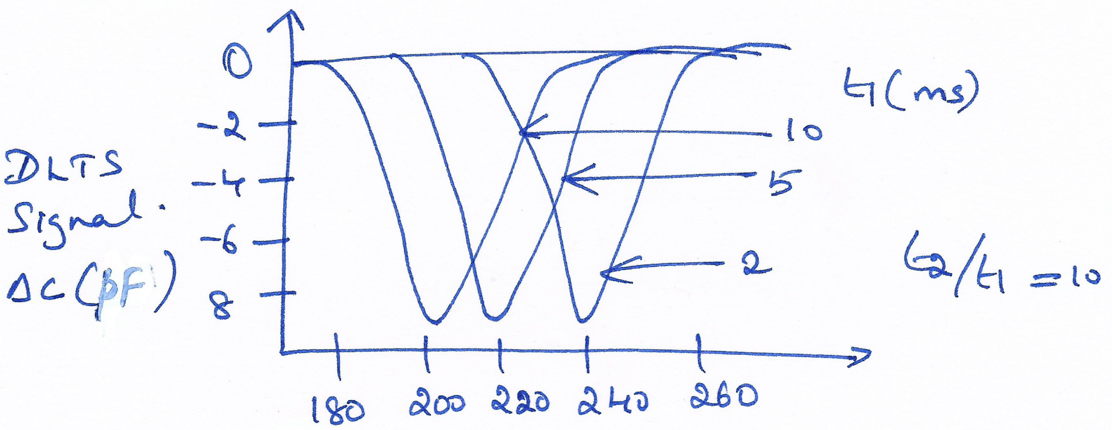
→ By monitoring the DLTS Signal s, as a function of temperature, it is observed that at low temperatures ($T \ll T_m$) and at high temperatures ($T \gg T_m$), the signal is very small.

→ However, at an intermediate temperature T_m, the signal will go through a maximum value. At this temperature,

$$\frac{ds}{dT} = \frac{ds}{de_n} \times \frac{de_n}{dT} = 0$$

Therefore, $$\frac{ds}{de_n} = -t_1 e^{-e_n t_1} + t_2 e^{-e_n t_2} = 0$$

which gives, $$e_n = \frac{\ln(t_2/t_1)}{t_2 - t_1}$$



→ By varying t_2 and t_1, but keeping the ratio t_2/t_1 constant (thus changing to different value of e_n) and repeating the temperature scan, a different curve will be obtained, with signal S peaking at different temperatures T_m.