ShanghaiTech GaNology Lab
氮化镓电子器件实验室

Identification of deep-level types by DLTS

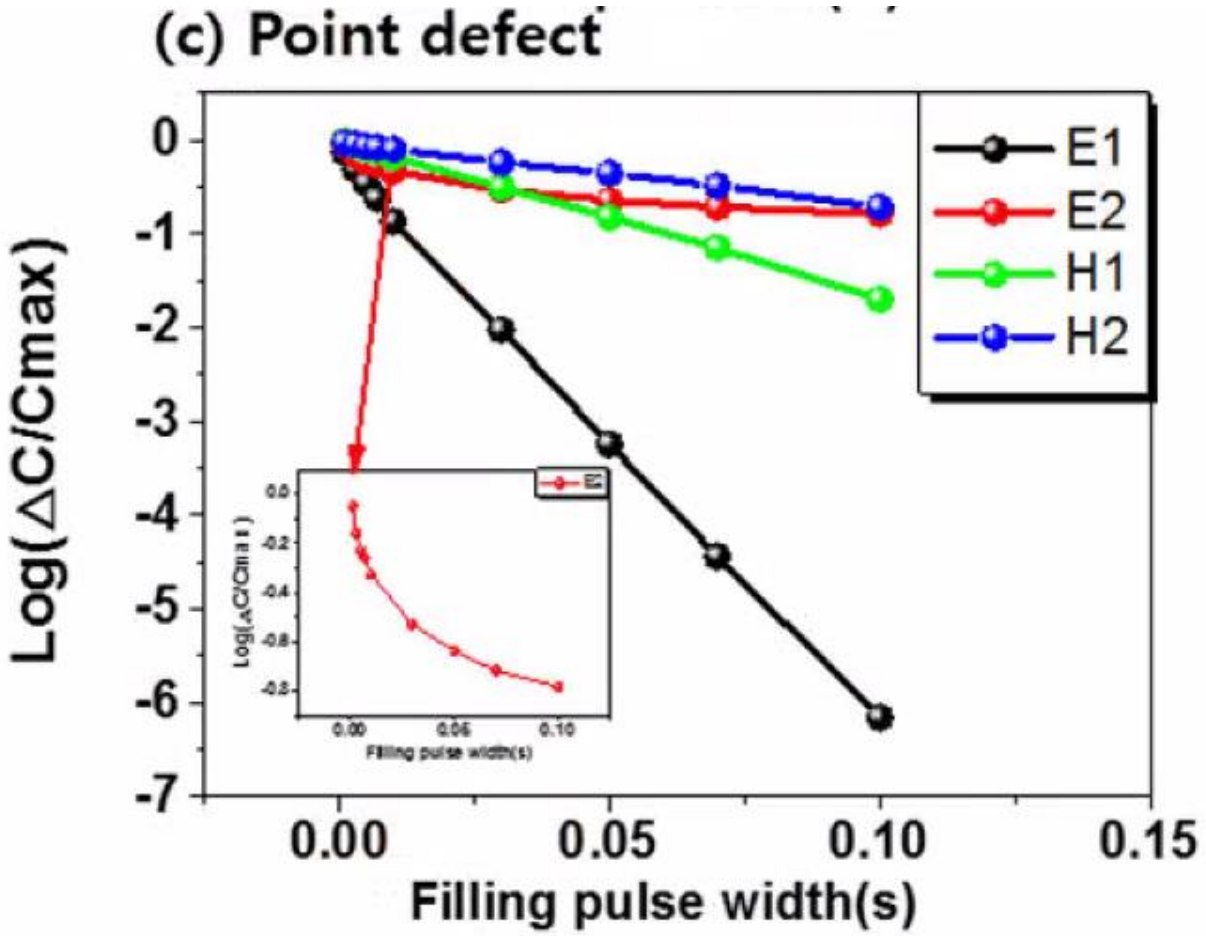
Jiaxiang Chen

Different types of trap

- Point or extended defect
- Electron or hole trap

1. Point and extended defect

Point defect



Cu(InGa)$(SeS)_2$ thin films solar cells

- For point defect, the majority capture cross-section should demonstrate a linear dependence on the logarithm of a combination of the capacitance terms as a function of pulse length.

$$\ln\left(\frac{\Delta C_\infty - \Delta C_t}{\Delta C_\infty}\right) = \sigma_p \cdot \nu_{th} \cdot p(n) \cdot tp$$

- where ΔC_∞ is the equilibrium capacitance value

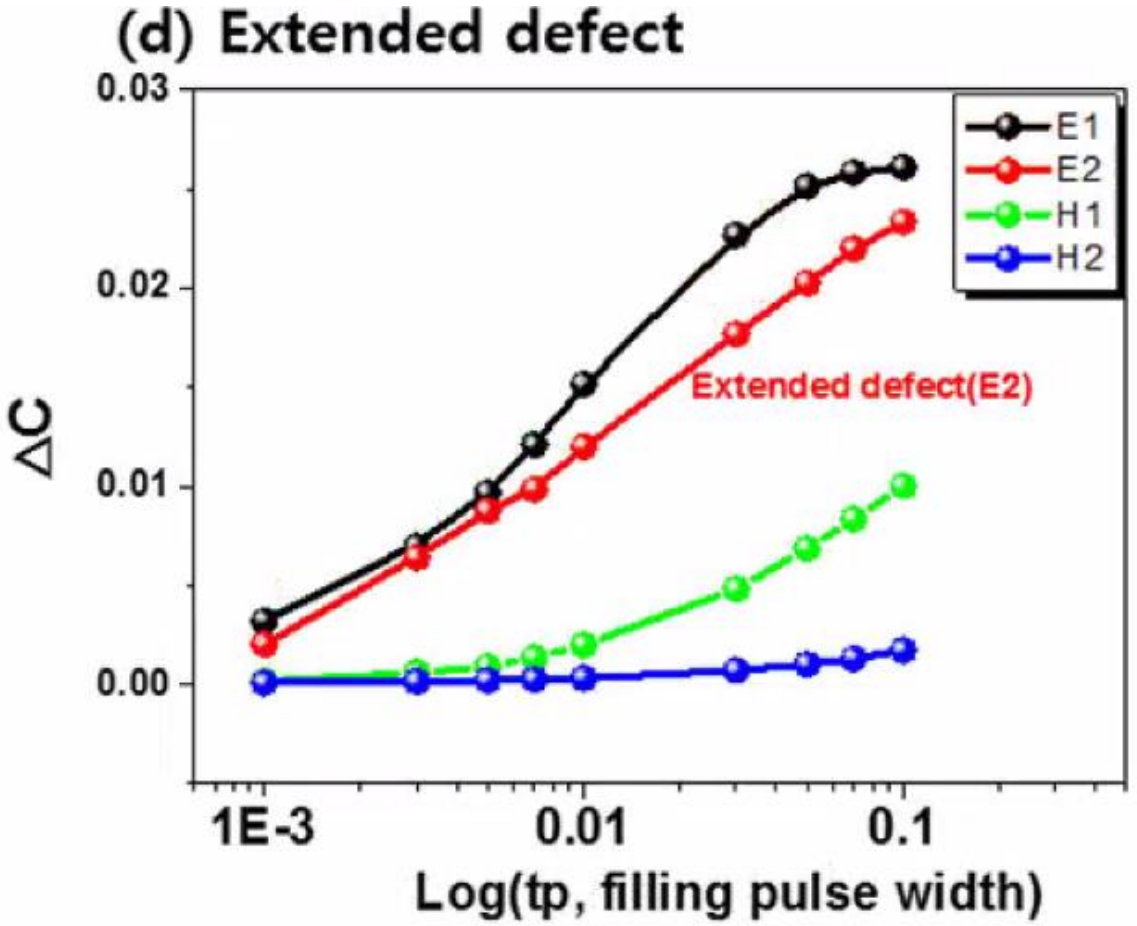
ΔC_t is the capacitance at time t

σ_p is the trap capture cross-section

p(n) is the majority (minority) carrier concentration

[1] Heo, et al **6.** 30554, Sci.Rep.(2016)

Extended defect (dislocation)



Cu(InGa)$(SeS)_2$ thin films solar cells

- For deep level is due to a dislocation:
- the defects can be closely spaced along a dislocation line.
- when an electron (or hole) is trapped, it generates a time-dependent coulombic potential Φ (t) that repels other electrons (or holes) from neighboring defects.
- DLTS signal should be dependent on the logarithm of the filling pulse width

$$\Delta Cm \propto \ln(tp)$$

where Δ Cm denotes the amplitude of the DLTS signal[1].

[1] Heo, 6. 30554, S. Sci.Rep.(2016)

Extraction of extended defect by carrier capture

- In this model, the dislocation has a coulombic barrier height, the number of which is increased as the number of electrons gets trapped.
- When an electron is trapped, it generates a time-dependent coulombic potential $\phi(t)$ that repels other electrons from neighboring defects.
- In this case, the capture process is regulated by the following rate equation[2]:

$$\frac{dn_{T(t_p)}}{dt} = v_{th}\sigma_n n\left(N_T - n_T(t_p)\right)e^{-\frac{q\phi(t_p)}{kT}}$$

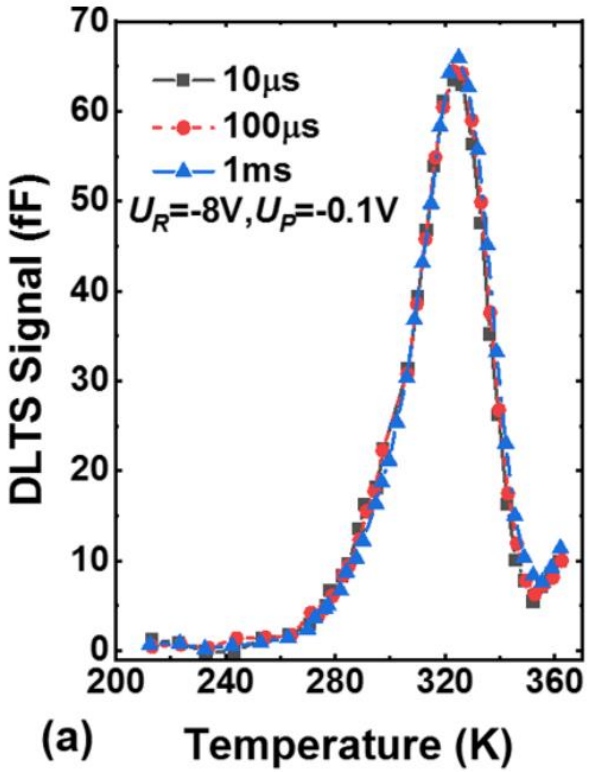
- The solution shows that the number of trapped electrons n_T (proportional to the DLTS signal (ΔC_m) depends logarithmically on the filling time.

$$n_T(t_{po}) = A\,log(t_p) \quad \Rightarrow \quad \Delta C_m \propto ln(t_p)$$

$\Rightarrow$ DLTS signal (ΔC_m) should be dependent on the logarithm of the t_p

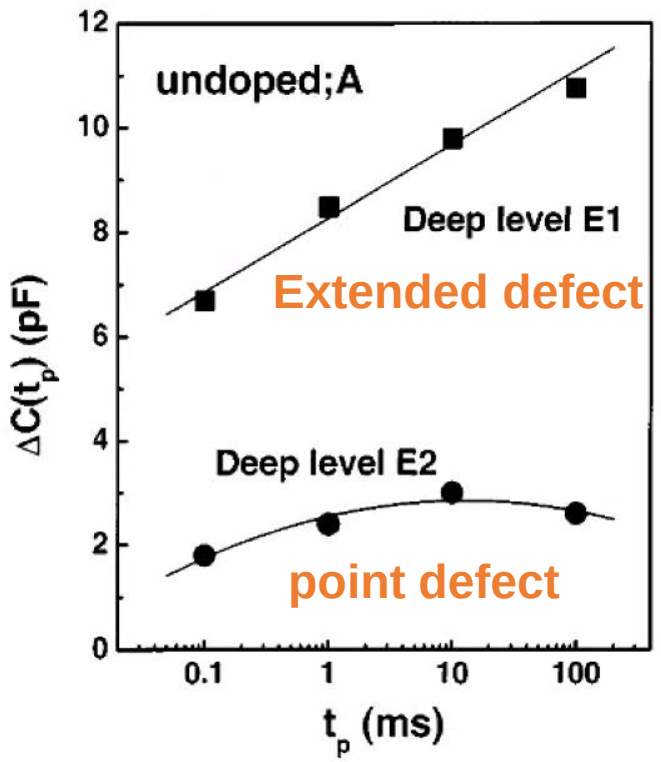
[2] Manuel Fregolent et al 2021 J. Phys. D: Appl. Phys. 54 345109

Distinguish the extended/point defect by DLTS



Ga2O3 SBD

[3] 2021 Semicond. Sci. Technol. 36 055015 by GaNology Lab



[4] J. Appl. Phys., Vol. 94, No. 3, 1 August 2003

Isolated point defects:

- filling time in the shorter range.
- DLTS signal depends exponentially on tp

$$\ln\left(\frac{\Delta C_\infty - \Delta C_t}{\Delta C_\infty}\right) = \sigma_p \cdot \nu_{th} \cdot p(n) \cdot tp$$

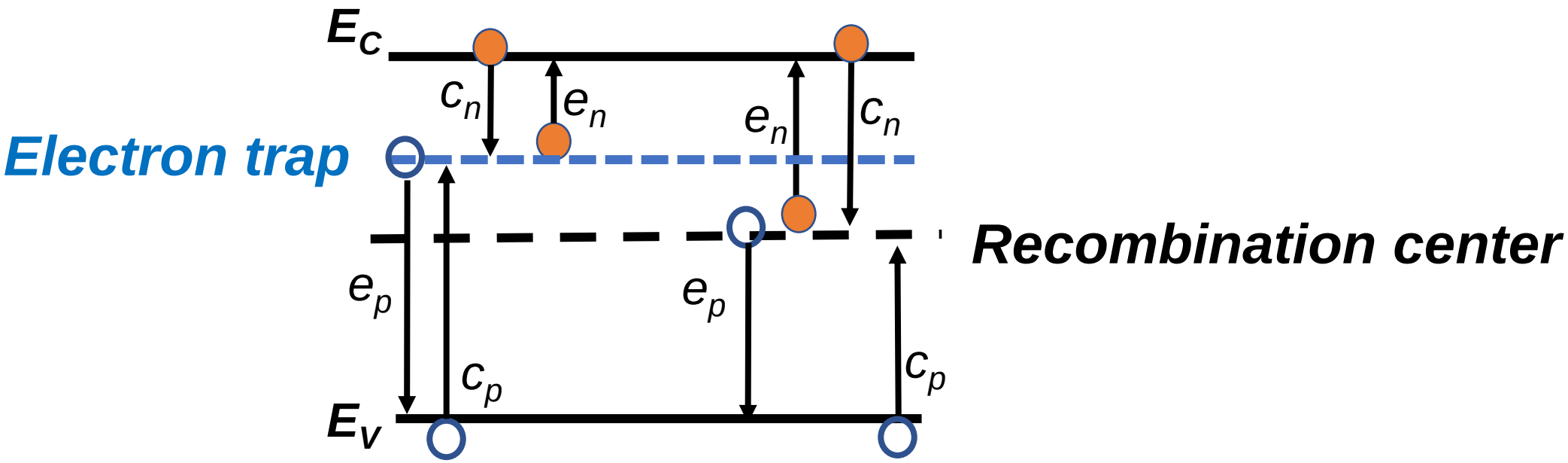
Extended defect (dislocation):

- DLTS signal are proportional to ln(tp)
- The dislocation-related defects show the slower capture kinetics

$$\Delta Cm \propto \ln(tp)$$

2. Electron and hole traps (majority and minority carrier traps)

Capture and emission processes of deep level



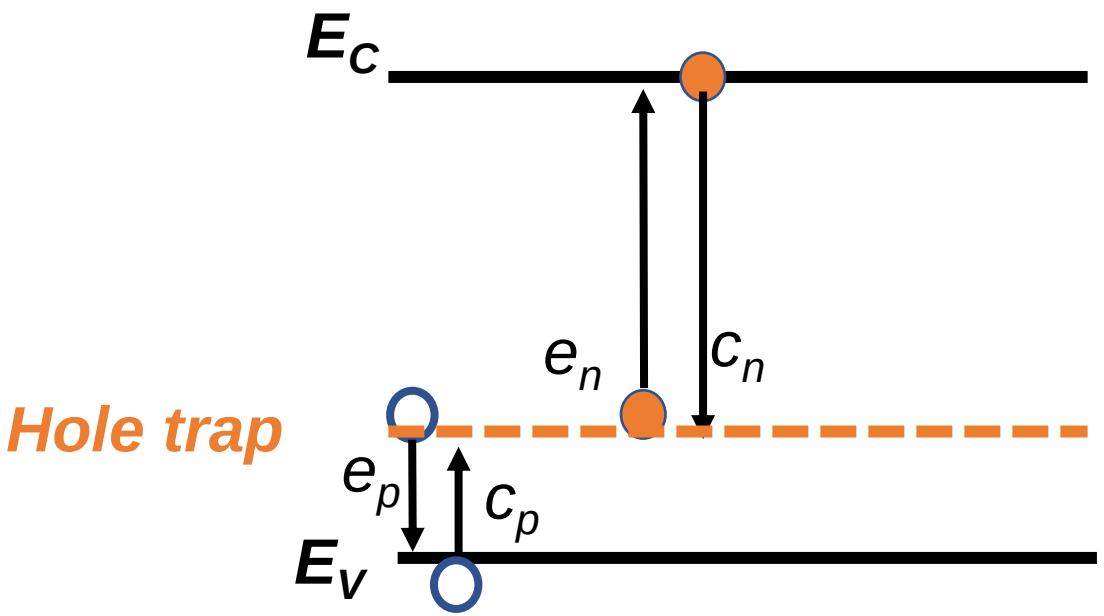
Deep levels in the band gap act as

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

Notes:

- The recombination rate of electrons (c_n) and holes (c_p)
- The generation rate of electrons (e_n) and holes (e_p)

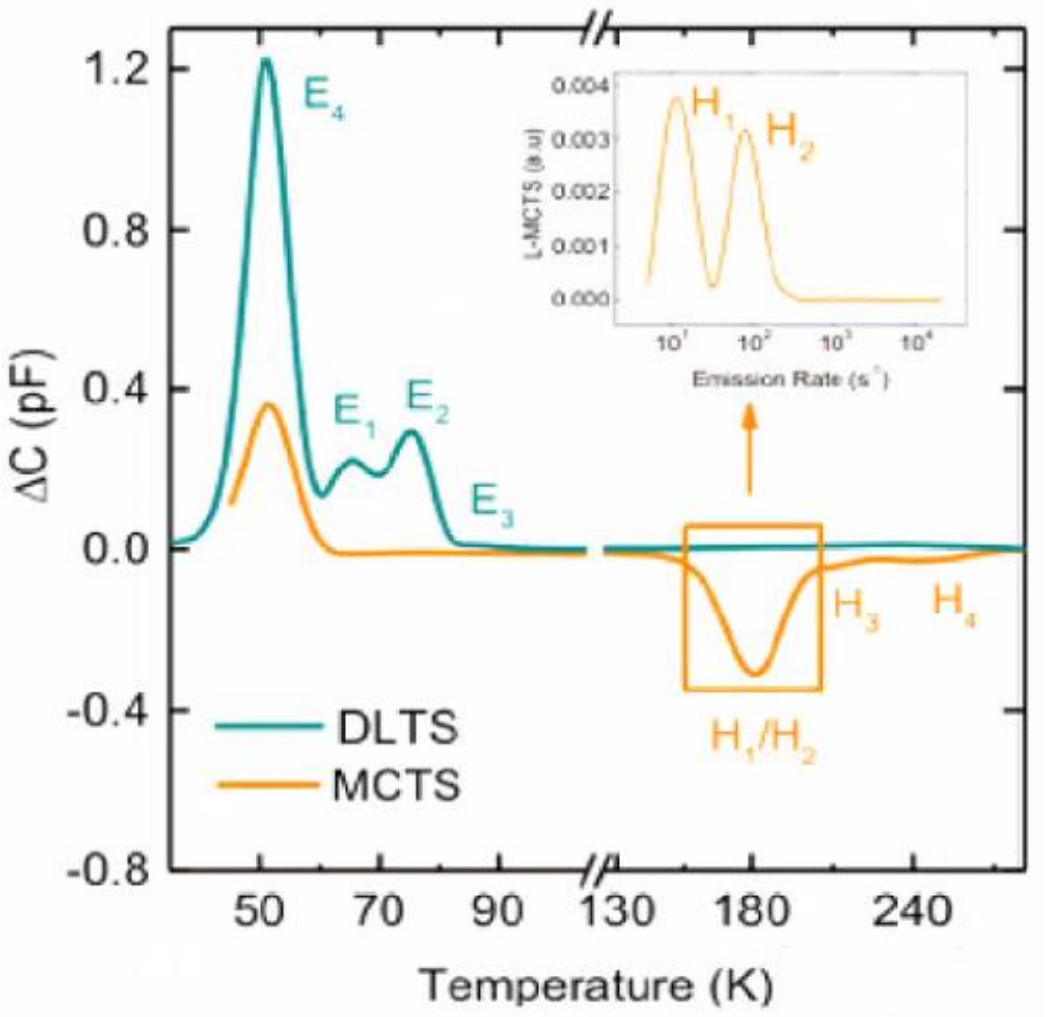
Capture and emission processes of deep level



Deep levels in the band gap act as

- **Hole traps**: If they mostly interact with the conduction band $c_p >> c_n$.

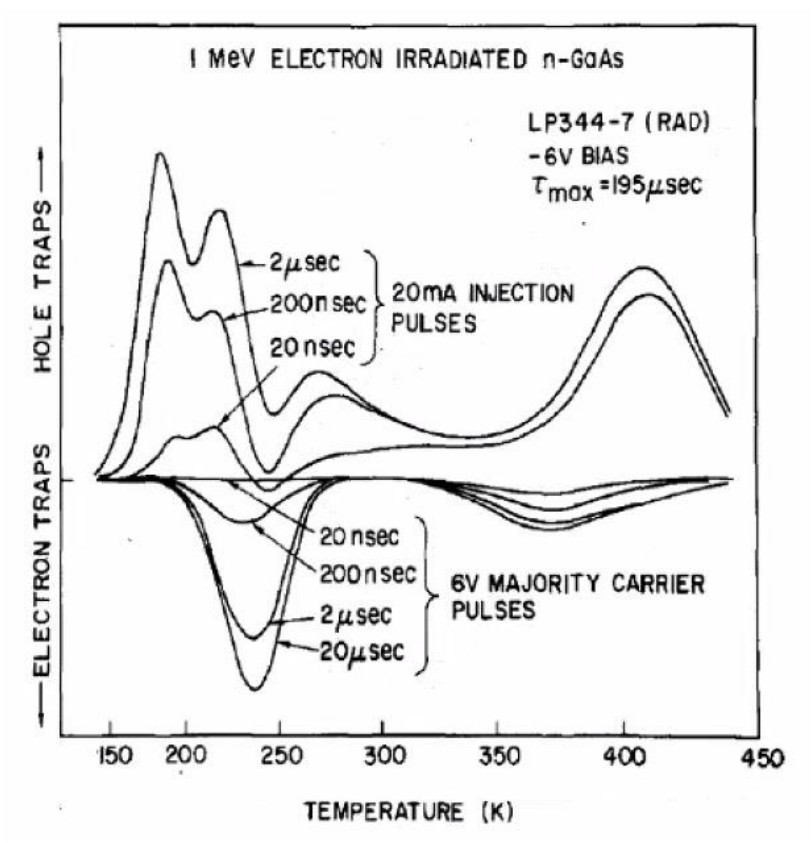
Majority and minority carrier traps



- It is usual to use positive peaks to show majority carrier emission, while minority carrier traps are negative signals.[5]
- Light can be applied through a sample to generate the ephs.
- Trap with close emission time could be separated by Laplace DLTS.

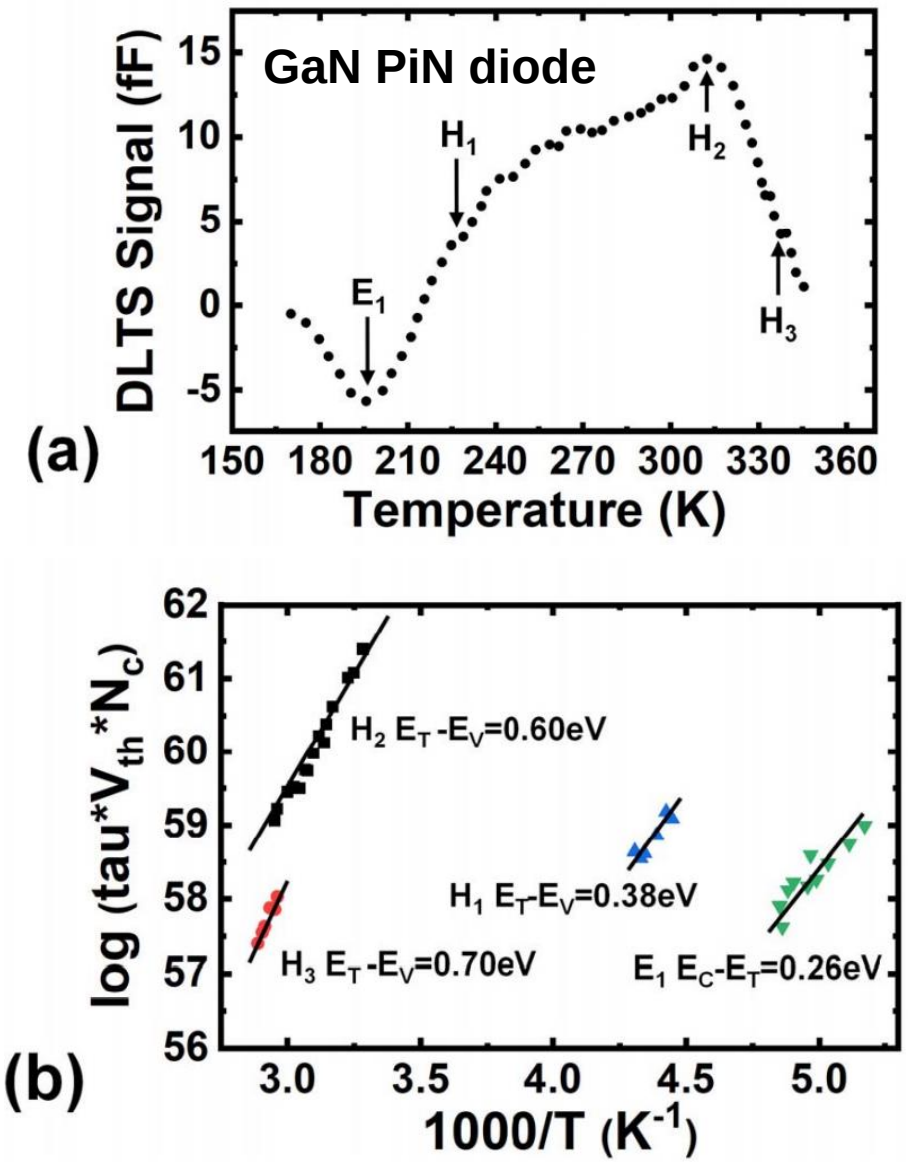
[5] Peaker, J. Appl. Phys. 123, 161559 (2018)

Identification of electron and hole traps by DLTS



[5] Peaker, A. R. , 123, 161559, JAP, (2018)

In some publications, majority carrier transitions are depicted as negative signals while minority carrier transitions are positive peaks.



[6] ZHANG et al. IEEE TED,(2019)

Conclusion

- In general, the amplitude of the capacitive transient induced by the filling pulse is proportional to the number of filled defects: the higher the ΔC value, the higher is the number of defects filled.
- Point and extended defect could be identified by investigating the DLTS signals as a function of the filling pulse width (tp).
- The dislocation-related defects show the slower capture kinetics due to a time-dependent coulombic potential barrier built up by trapped charges at dislocations. And, DLTS signals are proportional to ln(tp)
- For point defect, DLTS signal depends exponentially on tp.
- Majority and minority carrier traps could be identified by DLTS signal.