Deep electron trapping level in ^{60}Co gamma irradiated silicon detectors-possible V_2O defect – investigated by C-DLTS method

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Material

- FZ and DOFZ (72 h) p^+nn^+ Si diodes
- Wacker Si <111> , high resistivity (3-4 kΩcm)
- processed by CiS

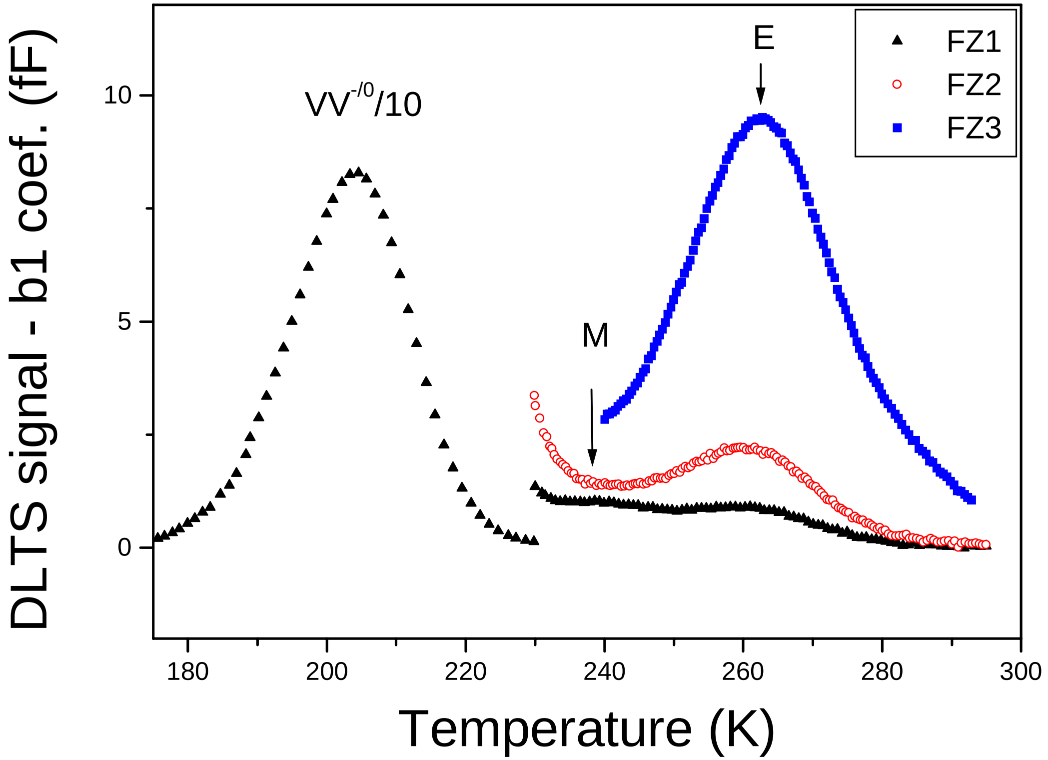
^{60}Co gamma irradiation doses:

- 4 Mrad → FZ1, DOFZ1
- 10 M rad → FZ2, DOFZ2
- 42.5 Mrad →FZ3, DOFZ3

Methods

- Capacitance Deep Level Transient Spectroscopy – DLTS

Standard FZ detectors - DLTS spectra recorded after electron injection



U = -16 V

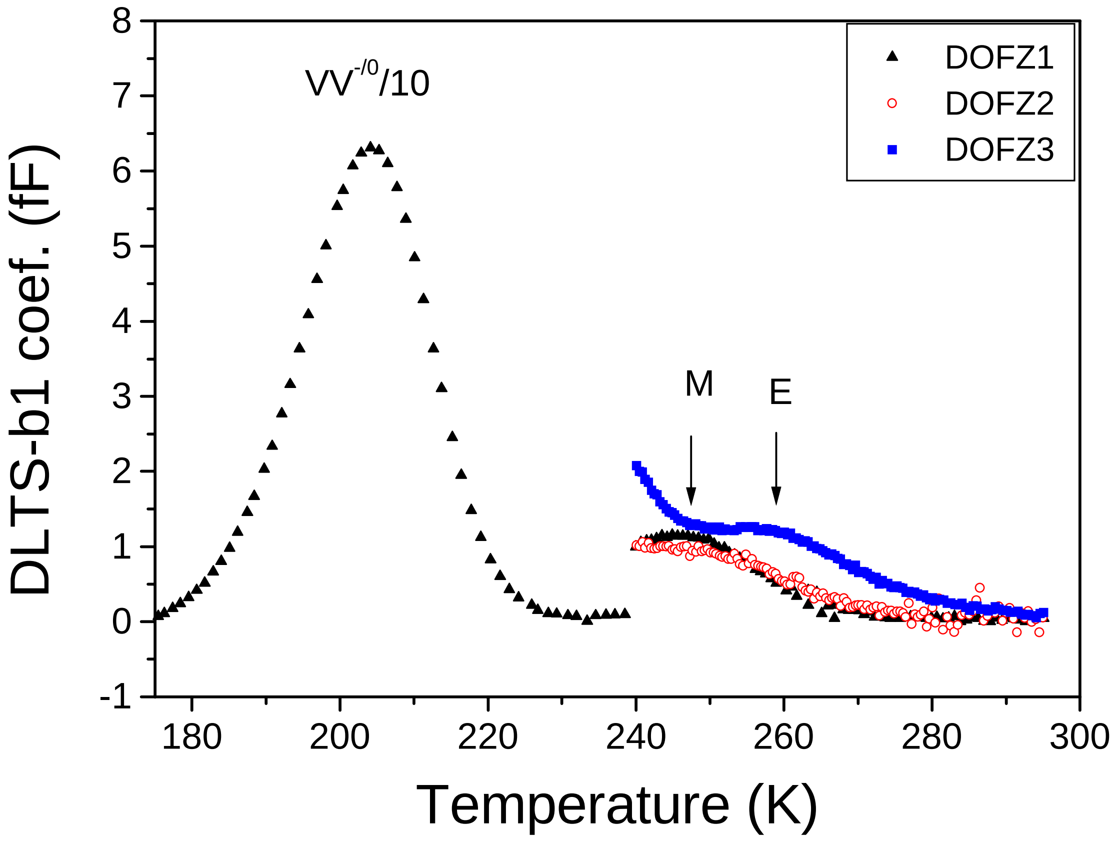
V_p = - 2 V

t_p =1 ms

T_W = 200 ms

- E defect can be detected starting with 4 Mrad Co^{60} gamma irradiation dose in standard FZ silicon detectors

DOFZ detectors - DLTS spectra recorded after electron injection



U = -16 V

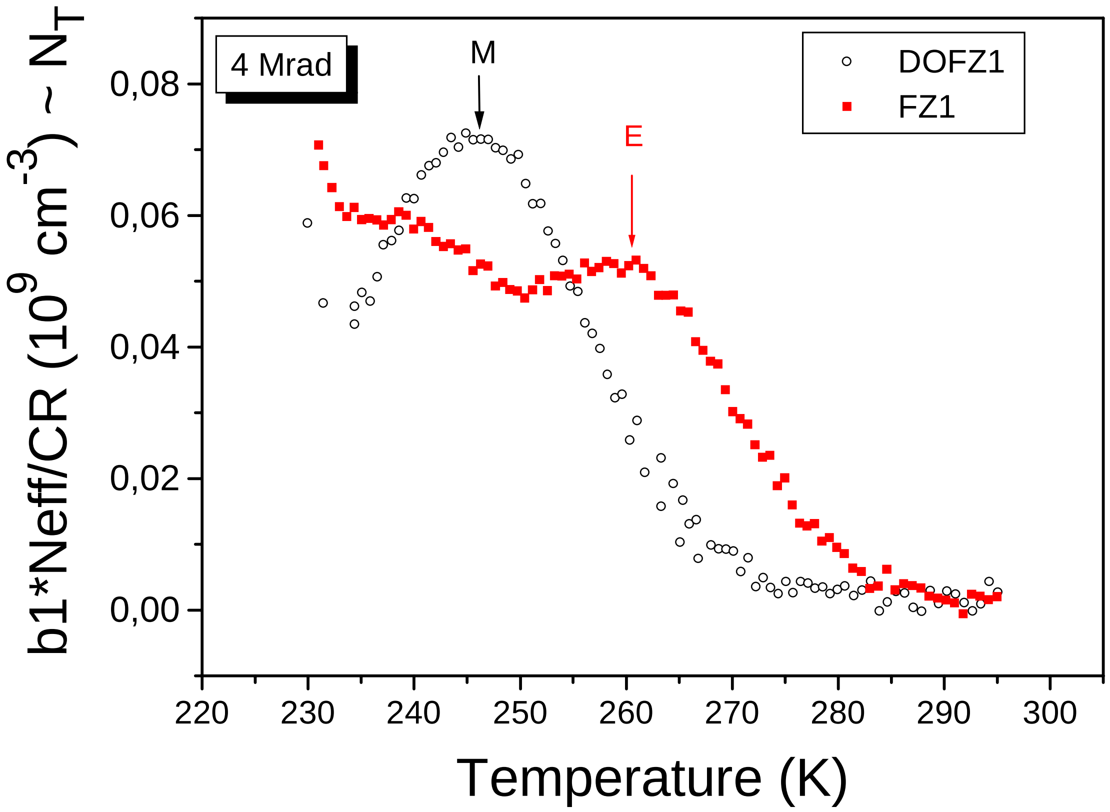
V_p = - 2 V

t_p =1 ms

T_W = 200 ms

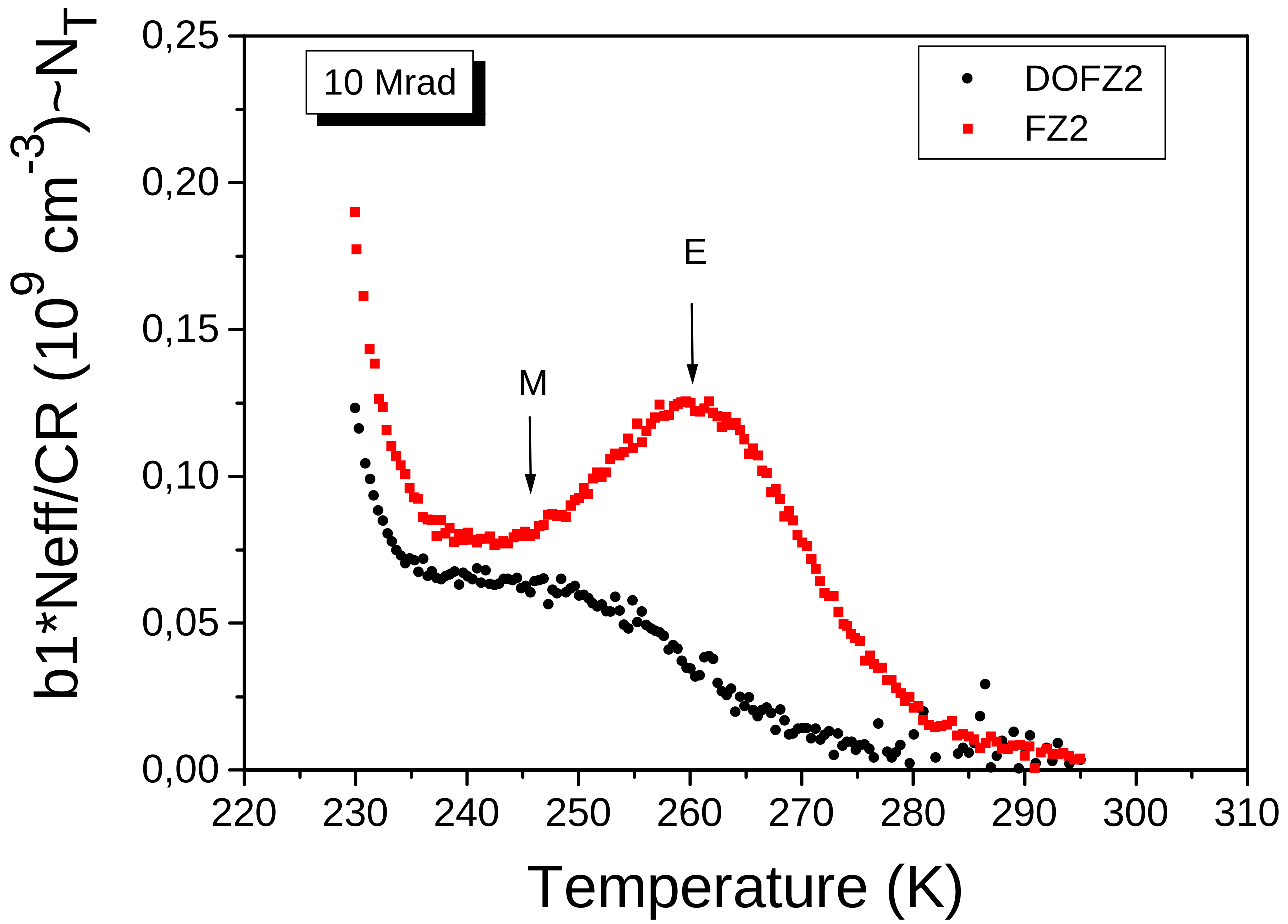
- In DOFZ detectors the E defect can be detected only for 42.5 Mrad gamma irradiation dose !!

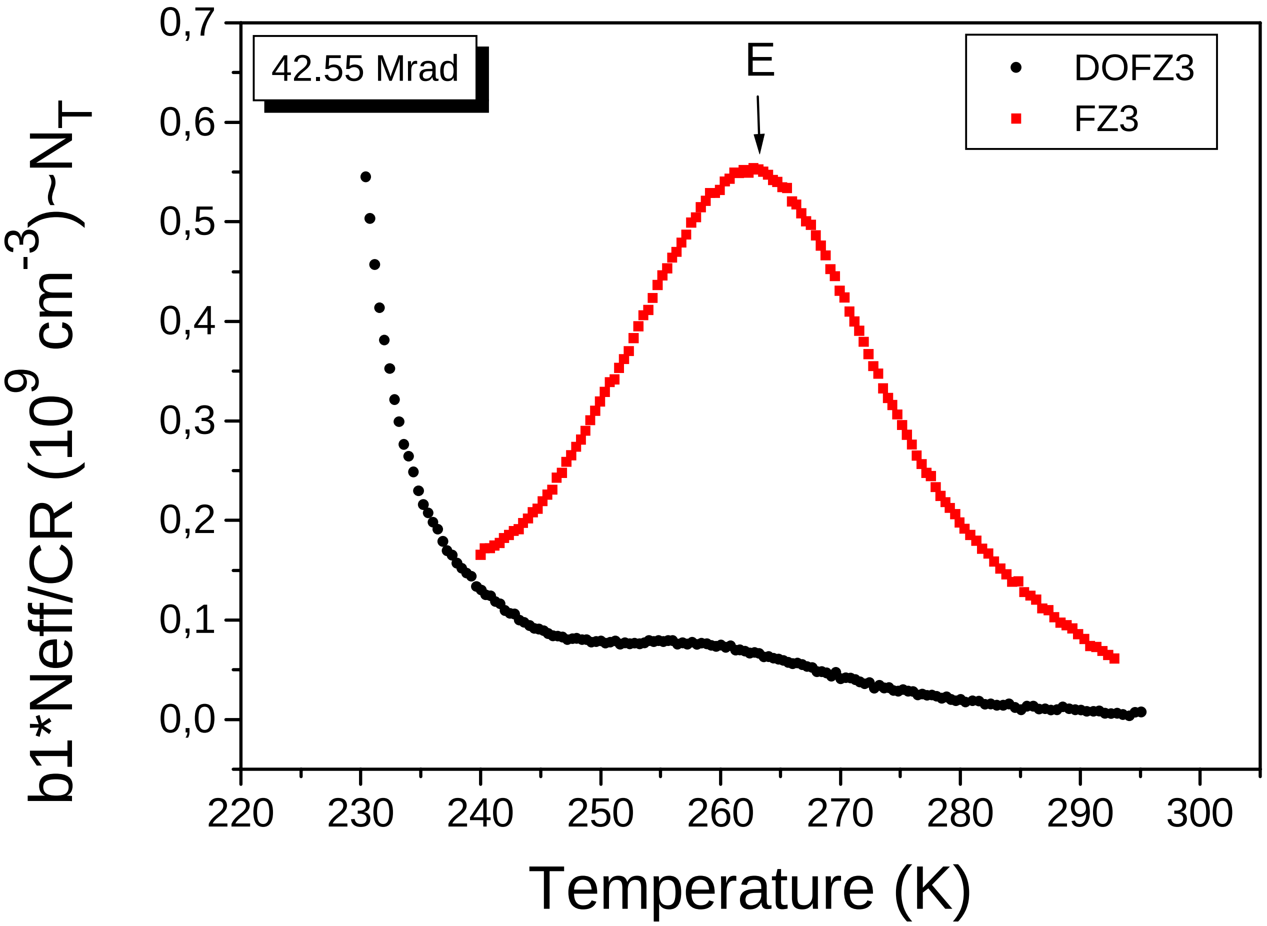
Comparison between FZ and DOFZ irradiated detectors



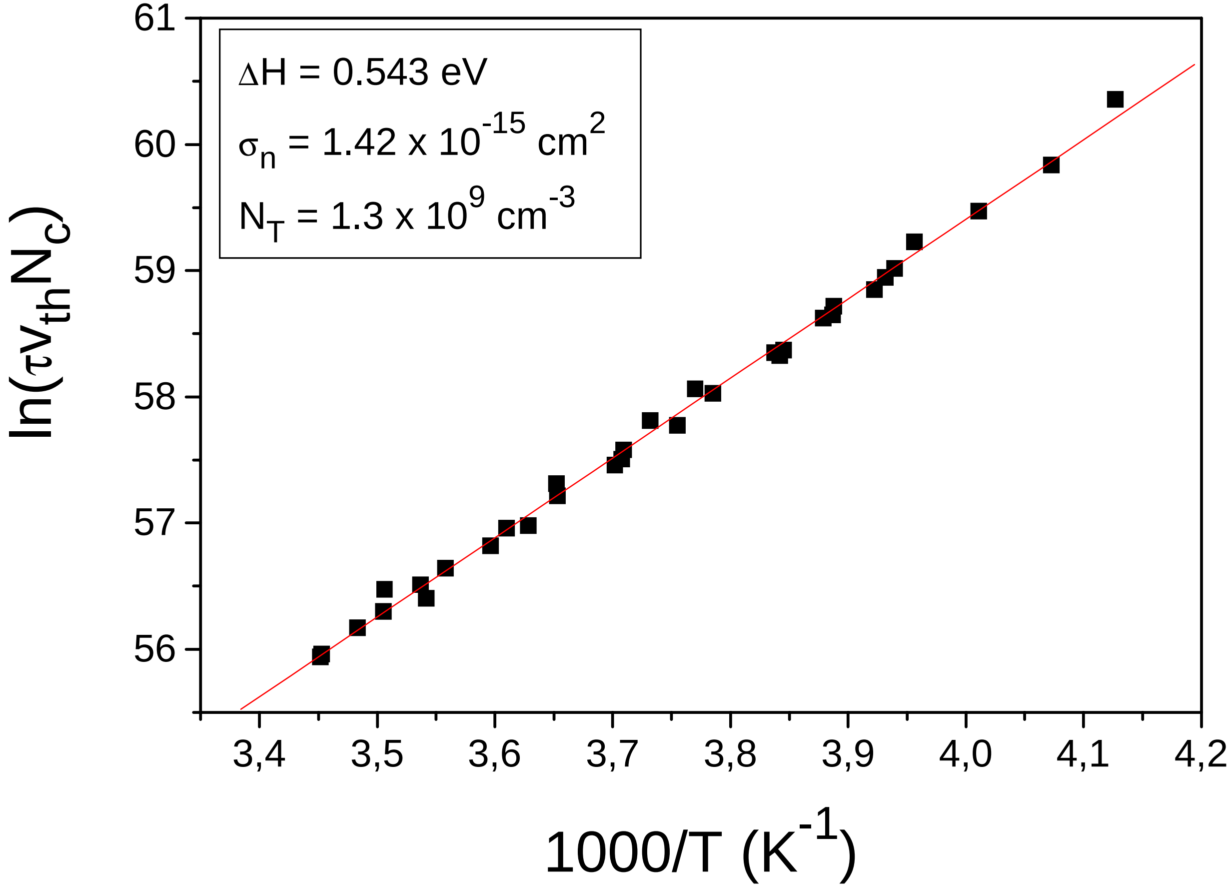
M defect – present in both FZ and DOFZ unirradiated detectors

[M]= (3÷9)x10^8 cm^{-3}

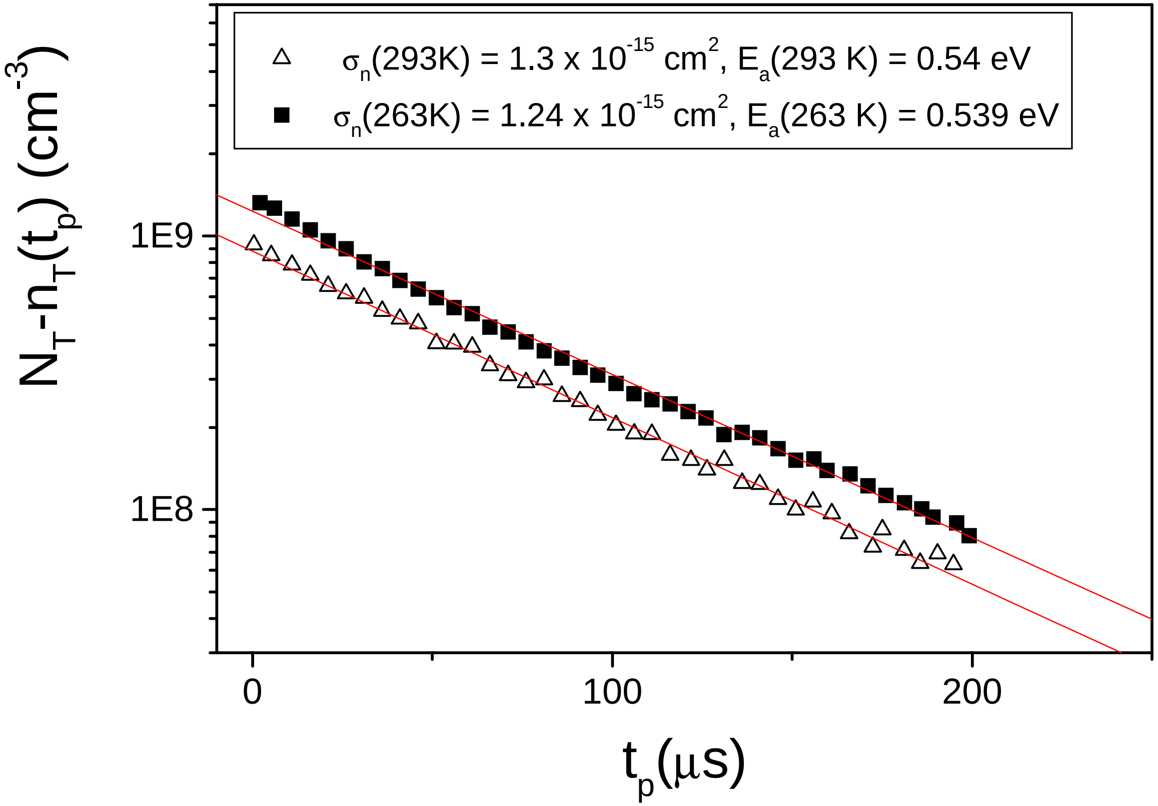

10 Mrad
DOFZ2
FZ2
E
M
b1*Neff/CR (10^9 cm^{-3})~N_T
0,25
0,20
0,15
0,10
0,05
0,00
220
230
240
250
260
270
280
290
300
310
Temperature (K)


42.55 Mrad
E
● DOFZ3
▪ FZ3
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
220
230
240
250
260
270
280
290
300
Temperature (K)
b1*Neff/CR (10^9 cm^{-3})~N_T

FZ2 detector - Enthalpy and capture cross section evaluation for the E level from Arrhenius plot



FZ2 detector (10 Mrad) - Electron capture cross section and activation energy of the E level at 263 K and 293 K.



What influence might have E level on detector performances ?

E level parameters: $E_C - E_a = 0.54$ eV; $\sigma_n = 1.4\text{x}10^{-15}$ cm^2
$E_V + E_a = 0.58$ eV; σ_p = ?

The general relation which gives the steady state occupation of E level is:

$$n_E^{RB}(T) = N_{TE} \frac{c_n(T) * n^{RB} + e_p(T)}{e_n(T) + e_p(T) + c_n(T) * n^{RB} + c_p(T) * p^{RB}}$$

$$e_{n,p}(T) = \sigma_{n,p}(T) * v_{th,n,p}(T) * N_{C,V}(T) * \exp\left(\pm \frac{E_a(T) - E_{C,V}}{k_b T} \right)$$

$$c_{n,p}(T) = \sigma_{n,p}(T) * v_{th,n,p}(T)$$

n^{RB}, p^{RB} = concentration of free carriers in the space charge region (SCR)

Parameters for fit: n^{RB}, p^{RB}, N_{TE} and σ_p ⇒ 4 constraints are needed to be fulfilled for unique solution !

Requirements for fitting:

1) $\mu_n n^{RB} = \mu_p p^{RB}$ *(neglecting the diffusion current)*

2) $N_T^{DLTS}(T)$*: recovered 100 % (electron injection)*

$$N_T^{DLTS}(T) = N_{TE} - n_E^{RB}(T)$$

3) $p_T^{DLTS}(T)$ *recovered 100 % (forward injection*

$$p_T^{DLTS}(T) = \left(N_{TE} - n_E^{RB}(T)\right) * \frac{c_p(T)}{c_p(T) + c_n(T)}$$

4) $\Delta N_{eff}(293K)$ recovered nearly 100 %

$$\Delta N_{eff}(293K) \approx n_E^{RB}(293K)$$

5) LC contribution – about half of the measured leakage current

$$\alpha_E(T) = V * q_0 * e_n(T) * n_T(T)$$

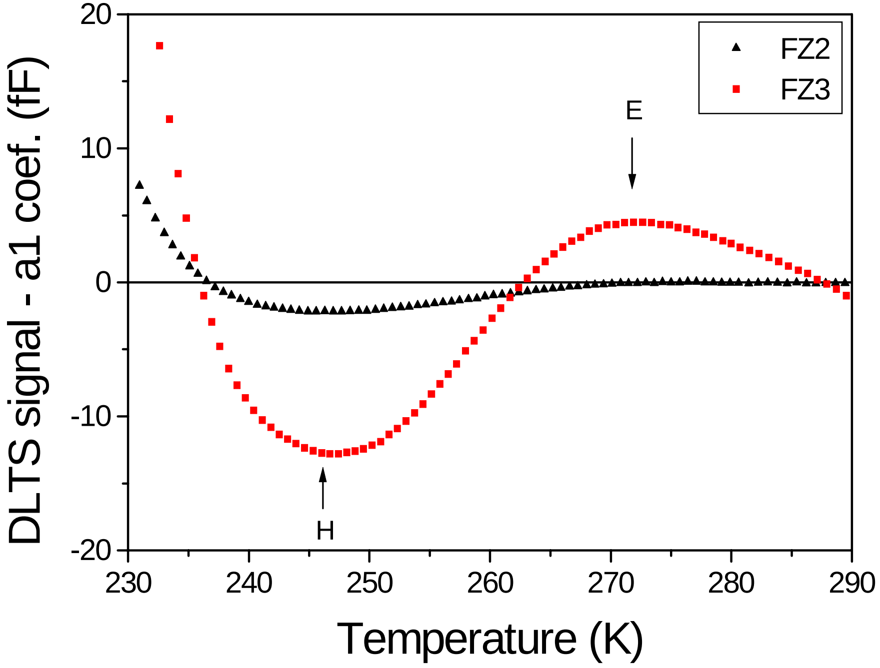
Parameters to fulfill best the experimental data: $N_{TE} \approx 10 * N_T^{DLTS}$; $\sigma_p \approx 50\sigma_n \approx 7.4x10^{-14} cm^2$; p ~ 3n

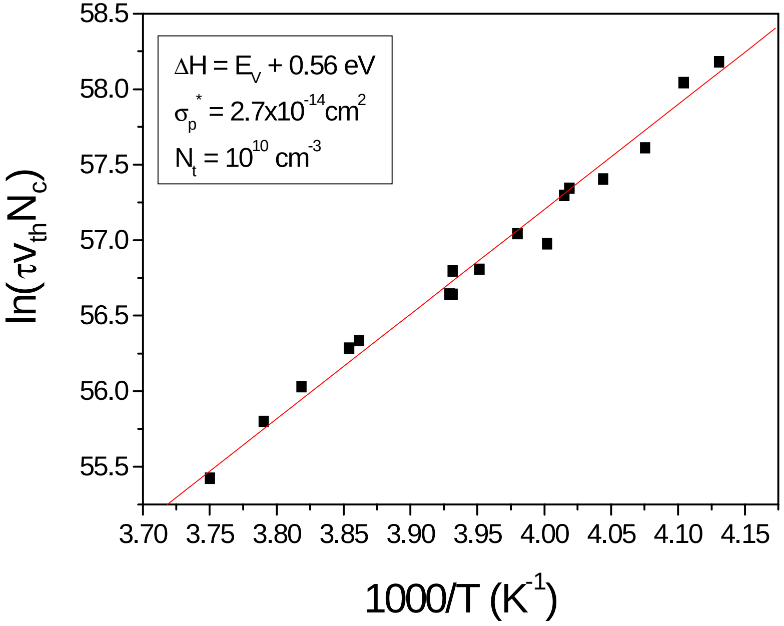
Dose	4 Mrad	10 Mrad	42.5 Mrad
n (cm^{-3})	10^{5}	2.35x10^{5}	10^{6}

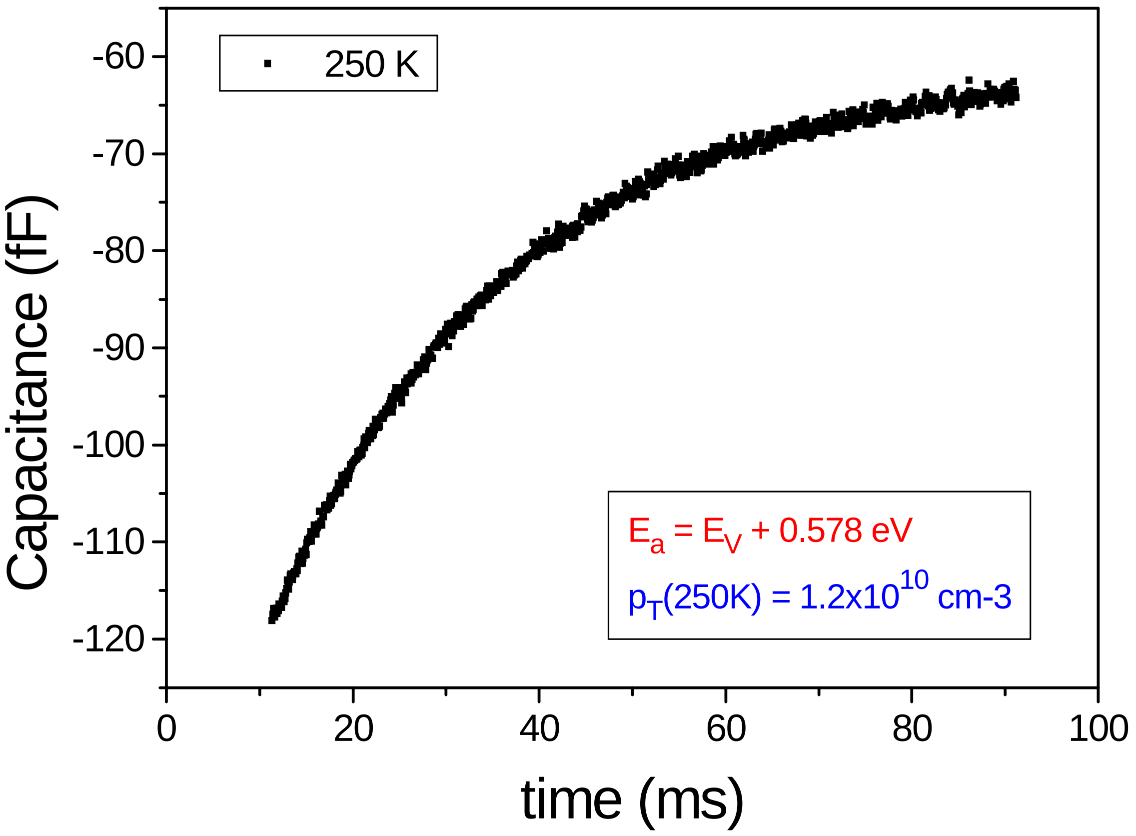
293 K		exp.	calc.	exp.	calc.	exp.	calc.
Detector	Dose Mrad	N_T^{DLTS} (cm^{-3})	N_{TE} (cm^{-3})	ΔN_{eff} (cm^{-3}) from C-V	n_T(cm^{-3}) =ΔN_{eff}	LC_{exp} (nA) from I-V	α_E (nA)
FZ1	4	5x10^{8}	7x10^{9}	8.x10^{9}	6.5x10^{9}	2.6	1.48
DOFZ1	4	<10^{8}				2.38	
FZ2	10	1.32x10^{9}	1.45x10^{10}	1.62x10^{10}	1.34x10^{10}	4.46	3
DOFZ2	10	<10^{8}				4.42	
FZ3	42.5	6.6x10^{9}	8.8x10^{10}	8.58x10^{10}	8.15x10^{10}	25.84	18.68
DOFZ3	42.5	8.75x10^{8}	8x10^{9}	1.62x10^{10}	1.11x10^{10}	18.89	2.55

The same contribution to LC and N_{eff} happen for $\sigma_p = 3\sigma_n = 5.2x10^{-15}$ cm^2 and *$N_{TE}^{*} = 2$ x N_{TE} but then the signal predicted to be measured by DLTS is ~ 15 times higher than measured!!*

DLTS spectra obtained by forward injection (V_p = +3V) – H level







H level

- Transient recorded at 250 K for $T_W = 80$ ms after forward injection
- analysed considering

$\sigma_p = 7.4x10^{-14}$ cm^2

Summary

- We have detected by C-DLTS a close to midgap trapping level with following parameters:
  - $E_C - E_a = 0.54$ eV; $\sigma_n = 1.4\text{x}10^{-15}$ cm^2
  - $E_V + E_a = 0.58$ eV; $\sigma_p = 7.4\text{x}10^{-14}$ cm^2 – should be checked doing only holes injection (optical filling under reverse bias from the rear electrode side)

- Being more abundant in standard FZ detectors than in DOFZ ones, the E level can explain the beneficial effect of oxygenation in case of Co^{60}-gamma irradiation (ΔLC, ΔN_{eff}).

- Taking into account that:
  - the present defect models attribute the oxygenation effect to lower probability of V_2O formation in DOFZ than in FZ – gamma irradiated silicon;
  - the activation energy of V_2O defect is 0.5 ± 0.05 eV, as determined from Photo-EPR

⇒ the E defect, detected by DLTS technique in this work, is up to now, the best candidate to be associated with V_2O complex

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