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Deep levels induced by very high dose neutron irradiation in 4H-SiC

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Research objectives

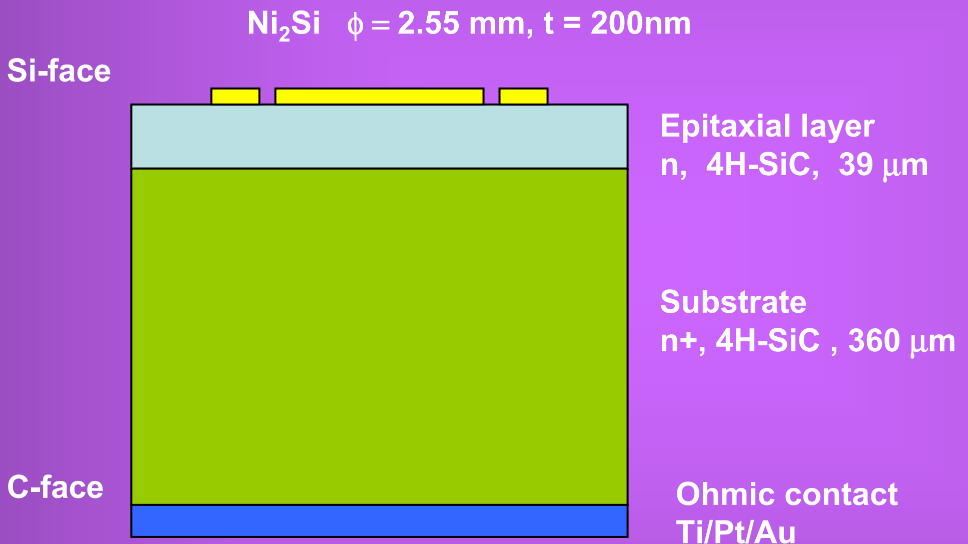
- to contribute to the characterization and understanding of defects in 4H SiC by their controlled generation
- to straightforwardly relate them to device performance, specifically the efficiency of high energy radiation detectors

Outline

- ✓ device structure and irradiation conditions
- ✓ EBIC mapping
- ✓ detailed characterization as a function of dose by:
    - I-V
    - junction spectroscopy
    - charge collection efficiency
- ✓ correlation to charge collection efficiency, CCE
- ✓ summary and conclusions

4H SiC device structure

schematic



epilayer n = 6 x 10^{14} cm^{-3}

substrate 4H-SiC (0001)
CREE Res. Inc. R&D
medium quality

epitaxial grown
silane (2% in H_2)
propane (5% in H_2)
C/Si ratio of 2

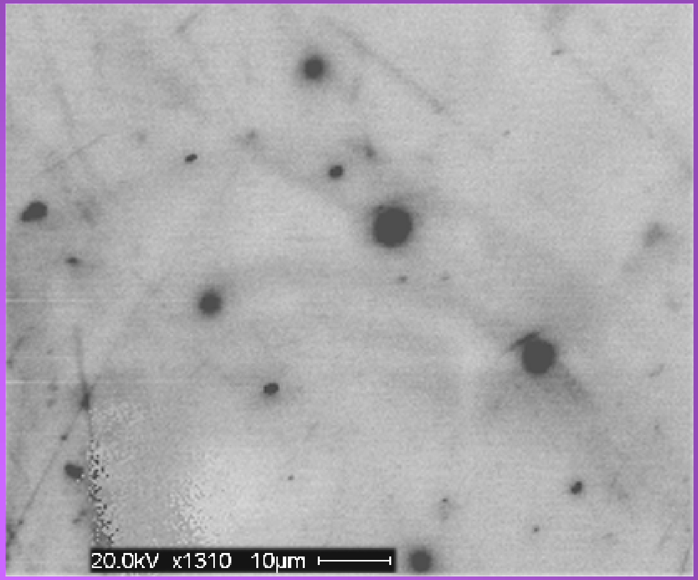
ohmic contact
Ti/Pl/Au (30/30/50 nm)
at 1000 ^{0}C

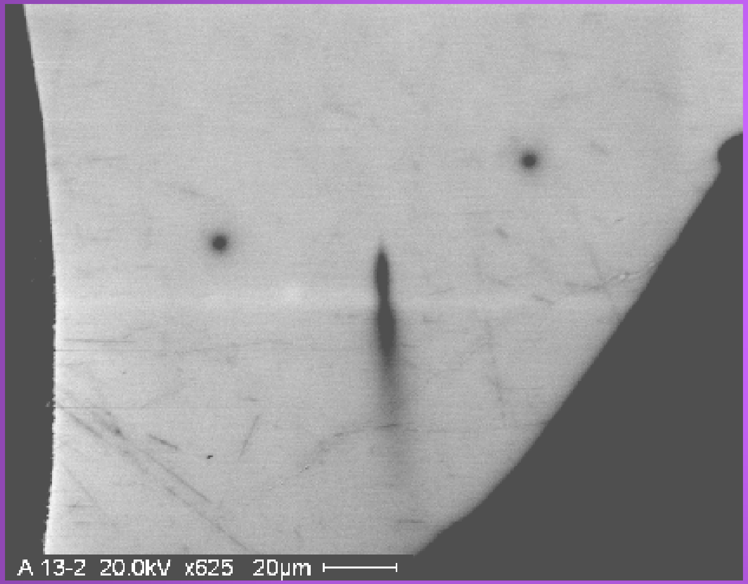
neutron irradiation: E = 1 MeV (Niel equivalent in Si), fluence $\Phi \leq 8 \times 10^{15}$ cm^{-2}

EBIC micrographs

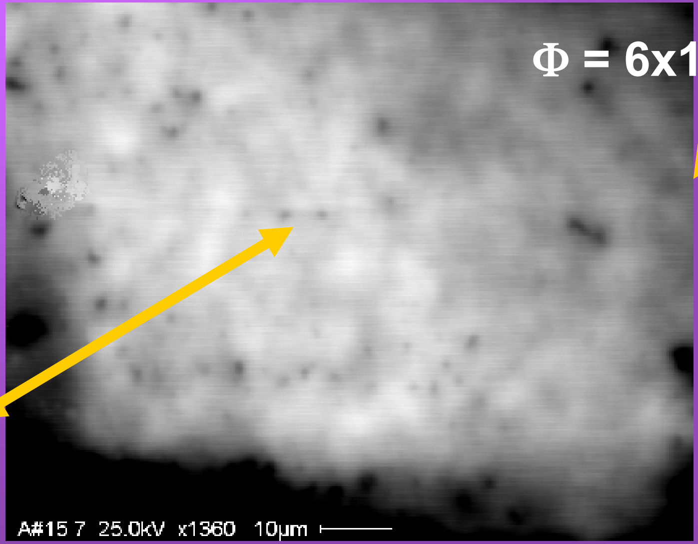
electrically active defects in as-prepared and irradiated diodes

as-prepared

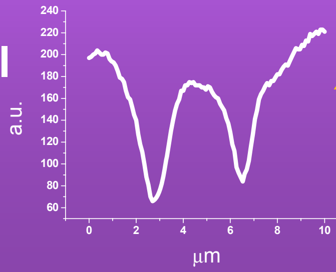




$\Phi = 6\text{x}10^{13}\ \text{n/cm}^2$



emergency points of the partial dislocation at the SF, c=14%



inhomogeneity of the bulk

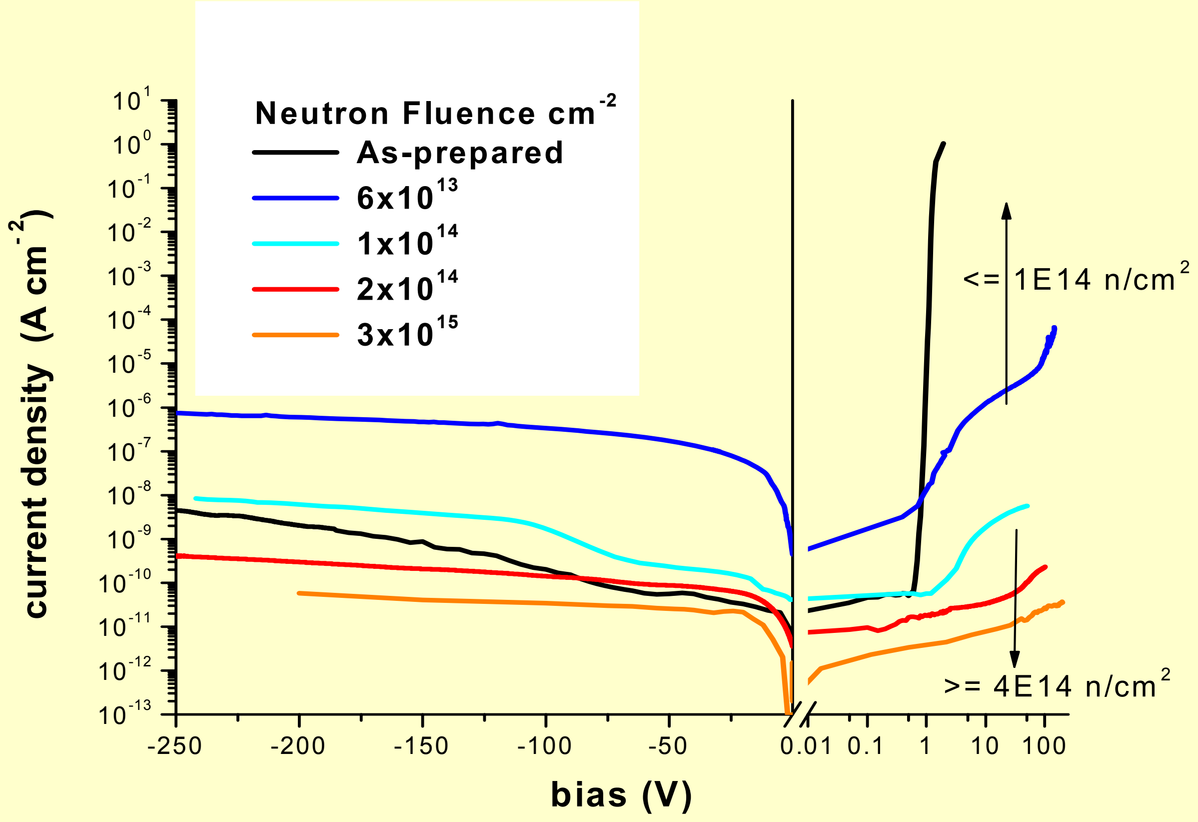
and

recombination activity enhanced at the SFs

⬇

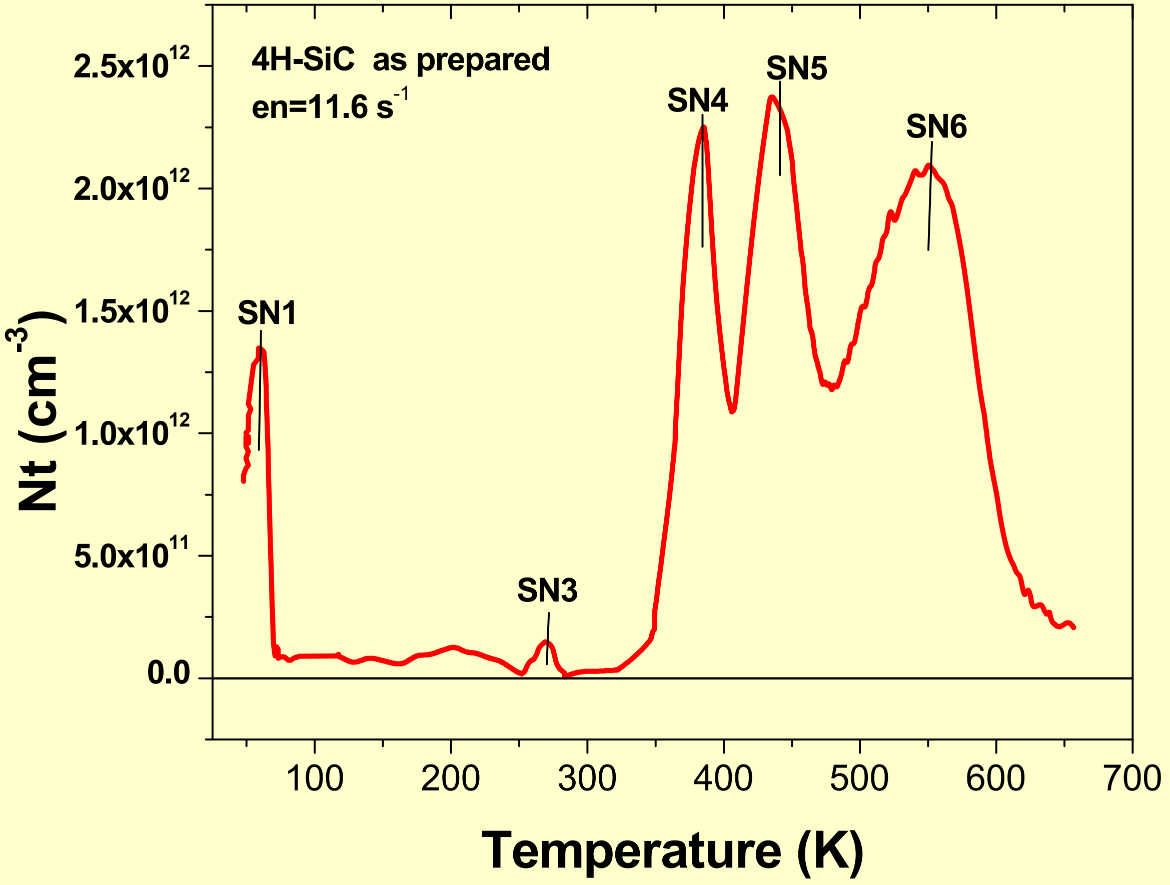
generation of electrically active defects in the strain field of stacking faults

Current-voltage characteristics at RT



forward current after 1×10^{14} n/cm^2 is the same as reverse current due to high series resistance, like in semi-insulating material

DLTS spectra of as-prepared diodes



un-irradiated diode

bias -10, 0, -10 V
pulse of 10ms
$t_1 = 5.2\text{x}10^{-2}$ s
$t_2 = 1.3\text{x}10^{-1}$ s

DLTS spectra
neutron irradiation $\Phi \leq 10^{14}$ cm^{-2}

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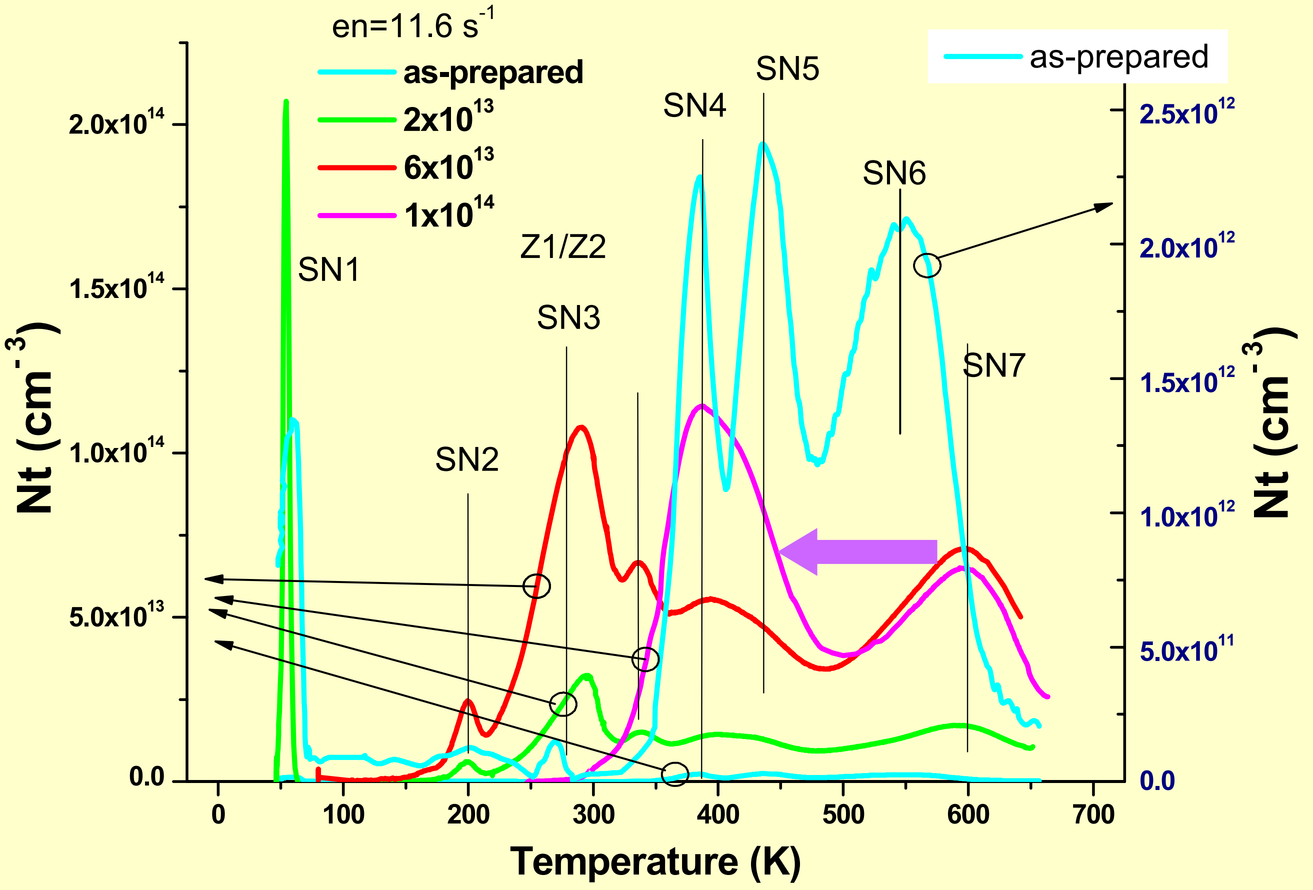

Capture kinetics of traps SN5 and SN7

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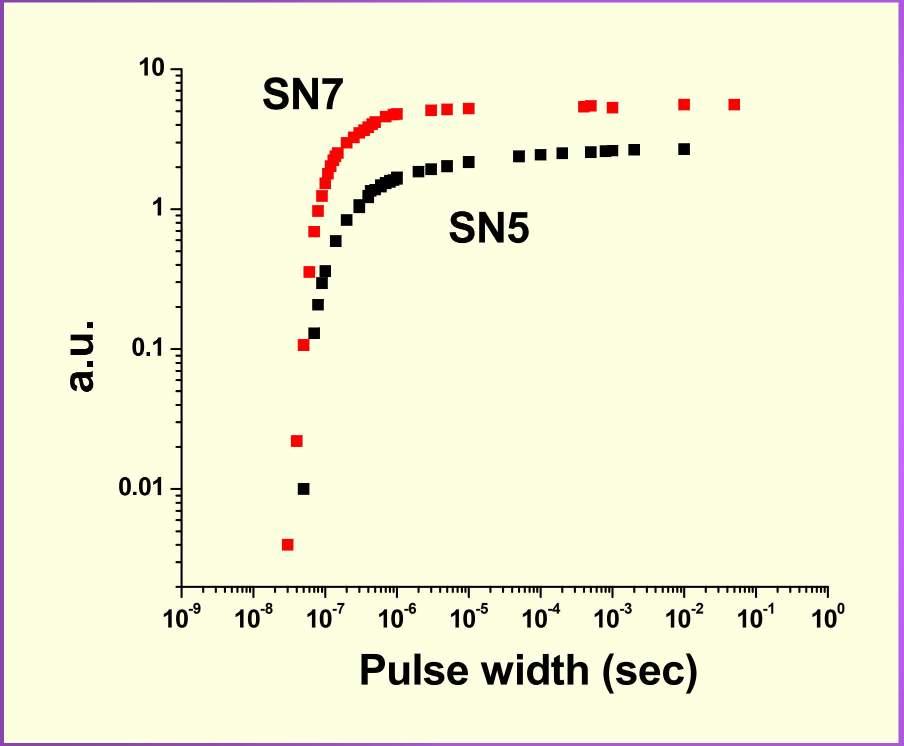
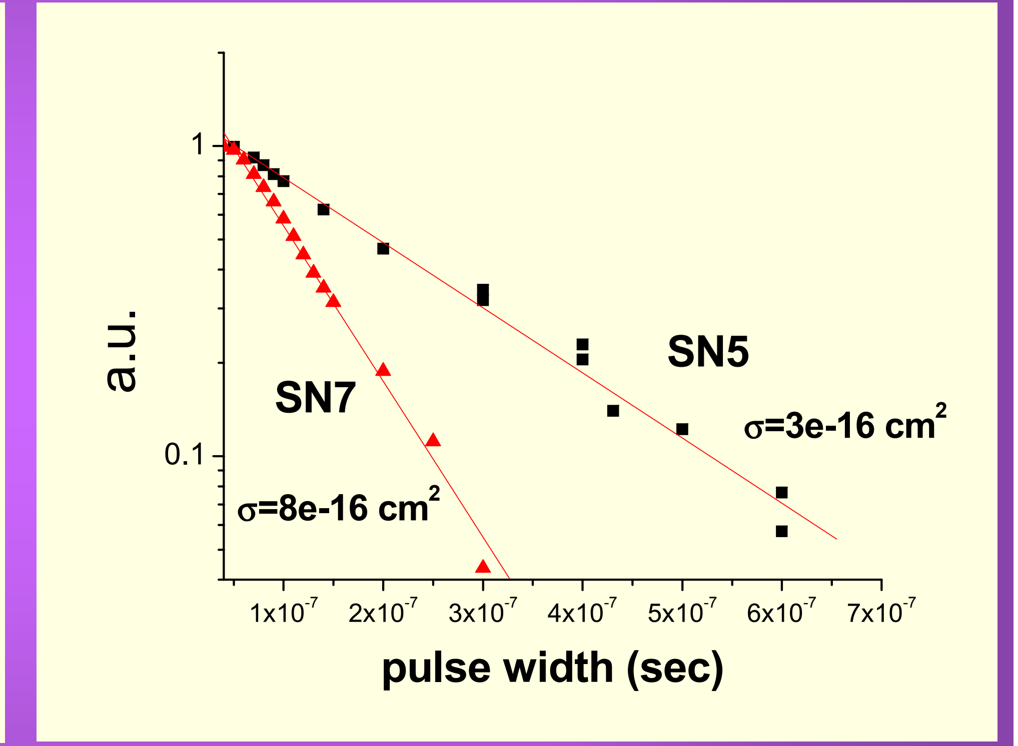
neutron fluence $\Phi = 1\text{x}10^{14}$ cm^{-2}





$$\frac{\Delta C_{(\infty)} - \Delta C_{(t)}}{\Delta C_{(\infty)}} = \exp - \left[\left(\sigma_n v_{th} n \right) t \right]$$

From DLTS to PICTS

DLTS:

transients of capacitance, ΔC

↓

majority carrier traps

PICTS, Photo-Induced Current Transient Spectroscopy:

transients of photocurrent, ΔI

↓

majority and minority carrier traps

PICTS spectra
of diodes neutron-irradiated up to 8x10^{15} cm^{-2}

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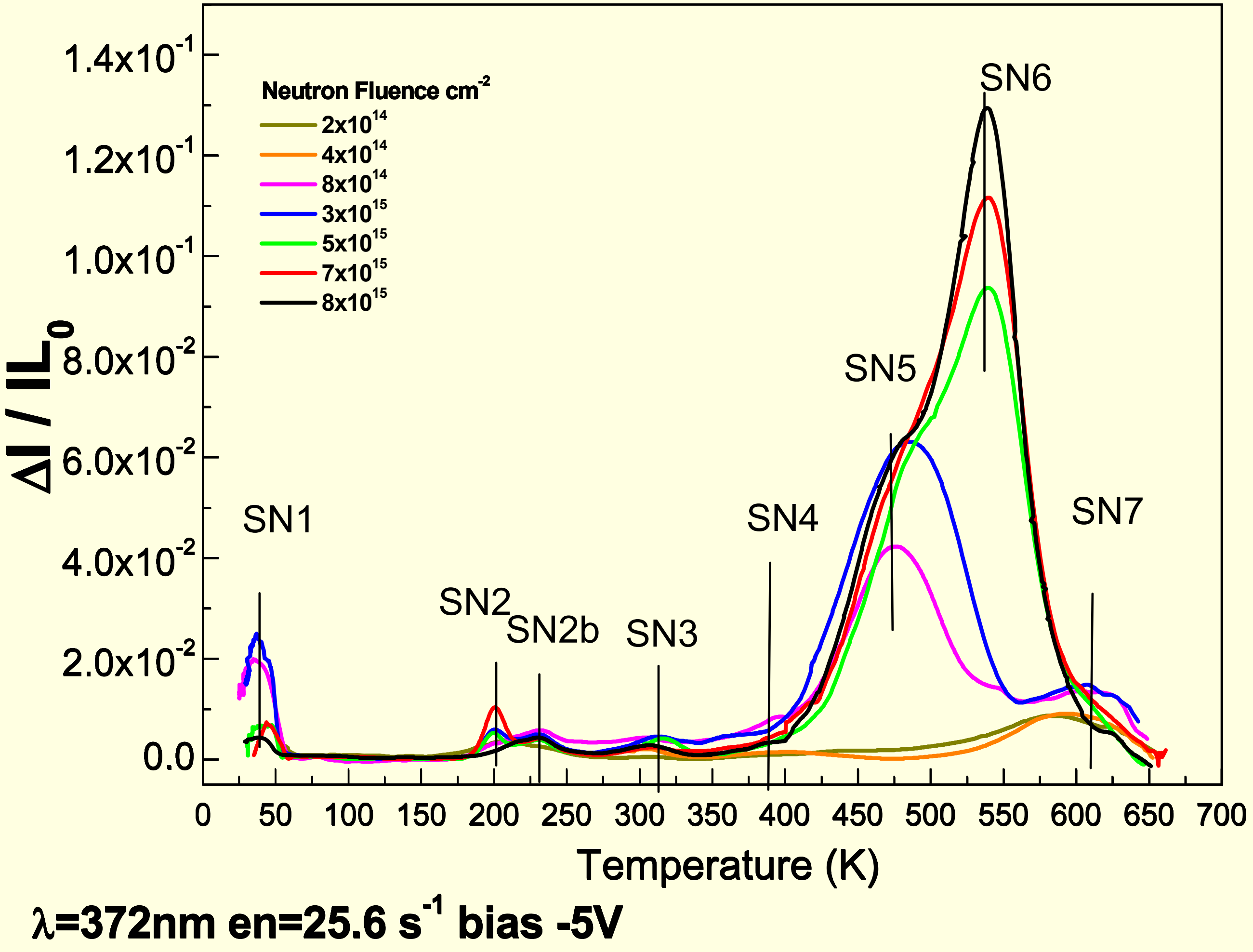

neutron fluence increasing from 2x10^{14} to 8x10^{15} cm^{-2}

PICTS peak amplitude vs neutron fluence Φ

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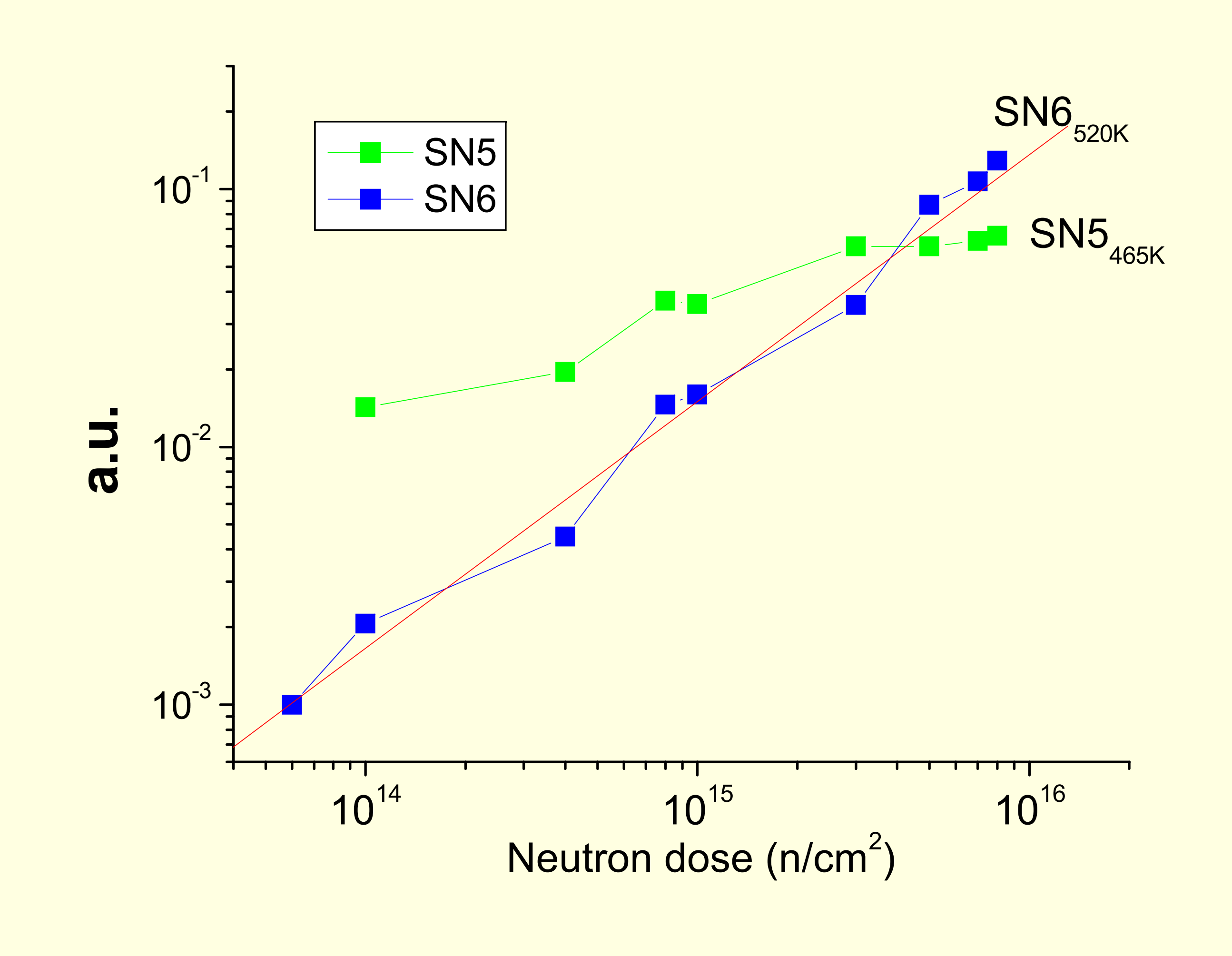

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Evaluation of trap concentration from PICTS

$$N_t = \frac{2.718 t_1 \beta(\lambda) I_a \lambda}{d \times hc} \frac{\mu_0 \tau_0}{\mu_1 \tau_1} i_N(t_1, T_m)$$

where $i_N(t_1, T_m) = \dfrac{\Delta i(t_1)}{i_L(0)}$

$I_a = I_0 - I_r - I_T$

$I_0 = incident\ light,\ I_r = reflected\ light,\ I_T = transmitted\ light$

$\beta(\lambda) = quantum\quad efficiency$

$$\beta(\lambda) = \frac{(1-R)\times\alpha\times d}{1 - R\times(1-\alpha\times d)}$$

$R = Reflectivity = 2.95$

$\alpha = absorption$

$d = thickness = 38\mu m$

$\lambda = wavelength = 372nm \Rightarrow 3.314eV$

with

$$\alpha(T) = A\left[\frac{(h\nu\text{-}E_g(T)\text{-}k\theta)^2}{1\text{-}\exp(\text{-}\theta/T)} + \frac{(h\nu\text{-}E_g(T)+k\theta)^2}{\exp(\theta/T)\text{-}1}\right]$$

$E_g(T) = E_g(0K) - 3.5\times10^{-4} \times T^2/(T + 1.1\times10^3)$

$k\theta = 0.07eV \quad phonon \quad energy$

$A = 6200 cm^{-1} eV^{-2}$

$E_g(0K) = 3.285eV$

A.Galeckas, Phis.Stat.Sol, (a), 191, n2, 613-620, (2002)

$$\frac{\mu_0\tau_0}{\mu_1\tau_1} = \left(\frac{I_t}{I_0}\right)^{1-\gamma} \approx \frac{i_L(0, T_m)}{i(t_1, T_m)}$$

$from \quad transient \quad at\ Tm$ with $0.5 < \gamma < 1$

M.Tapiero et al, "Photoinduced current transient spectroscopy in high-resistivity bulk materials: instrumentation and methodology" J.Appl.Phys. 64(8) (1988).

DLTS, PICTS, P-DLTS

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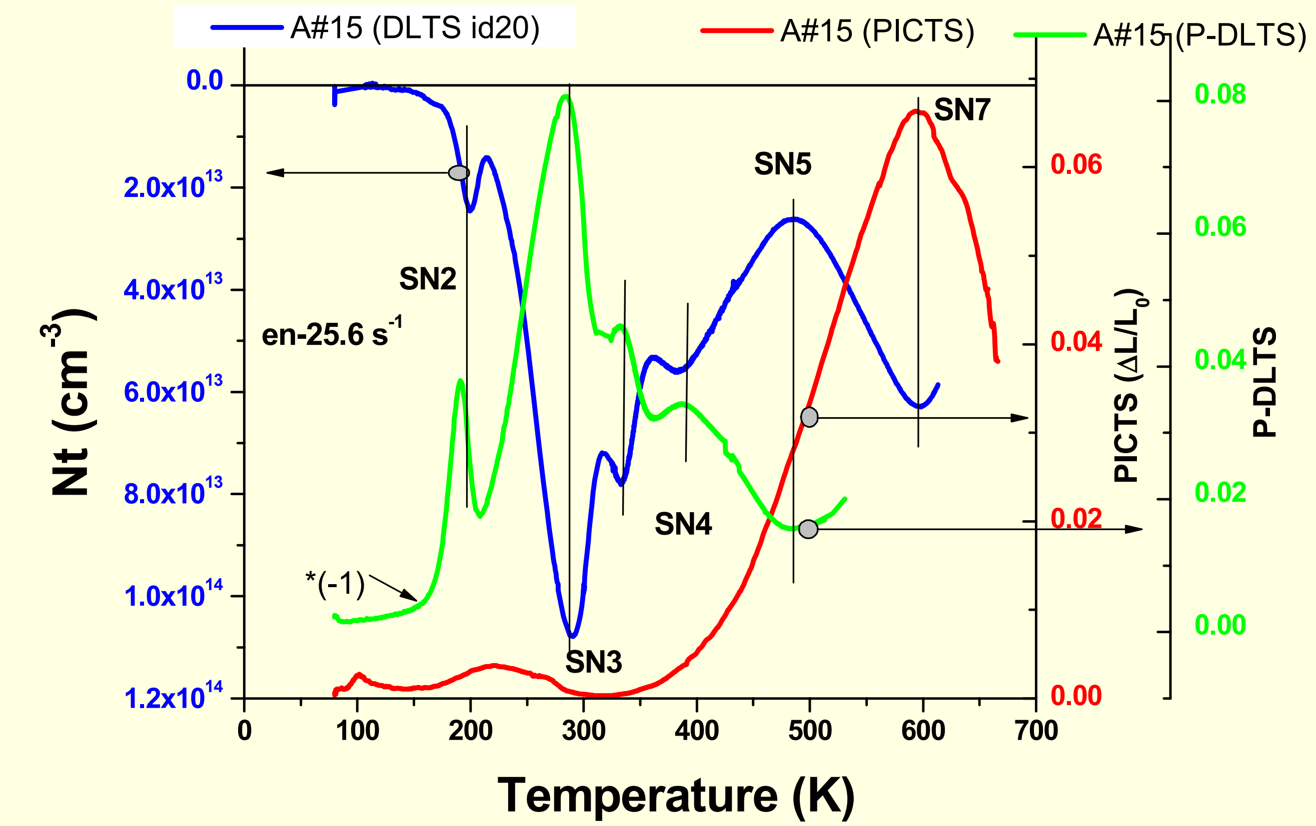
Neutron fluence 6x10^{13} cm^{-2}



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Arrhenius plot

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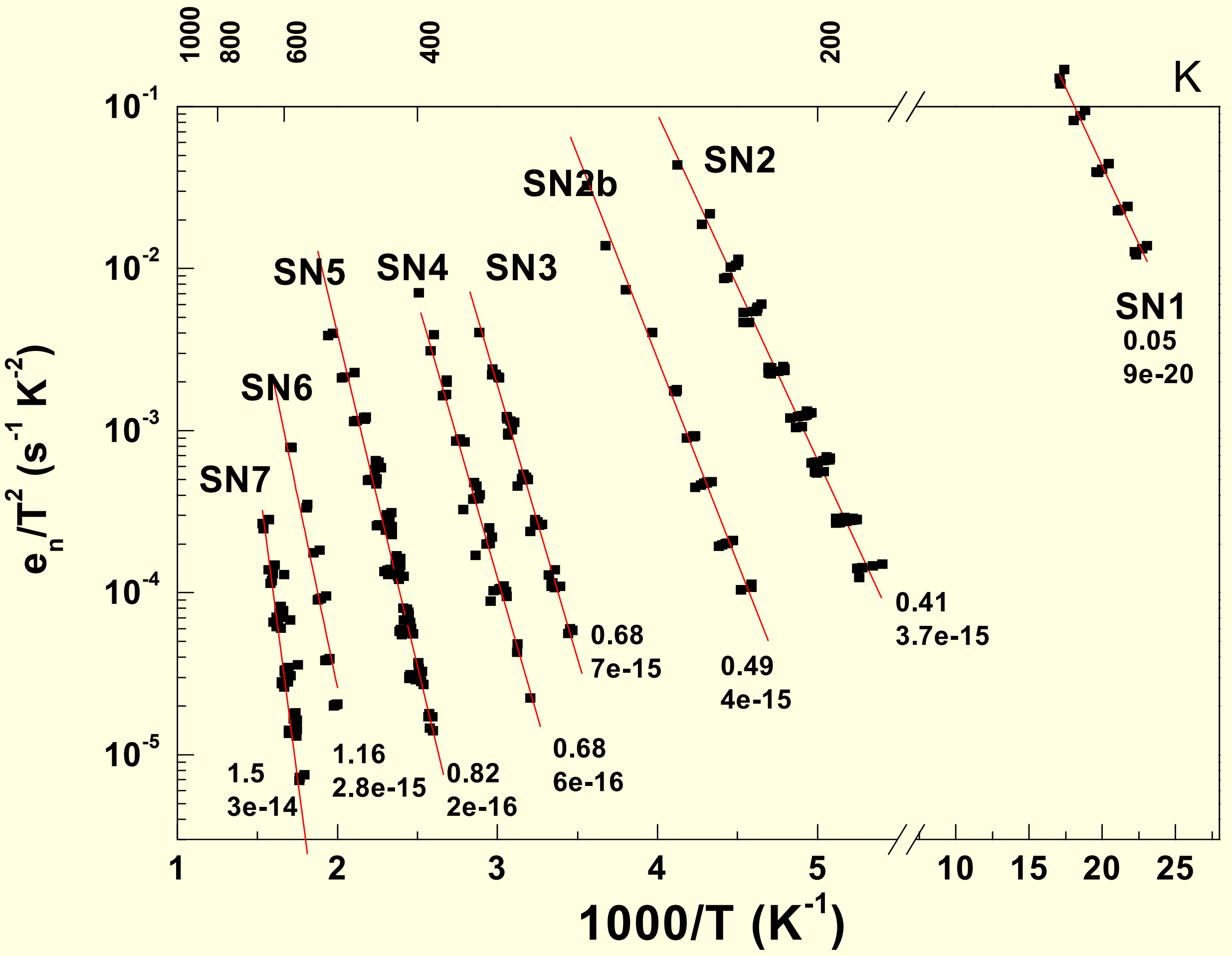

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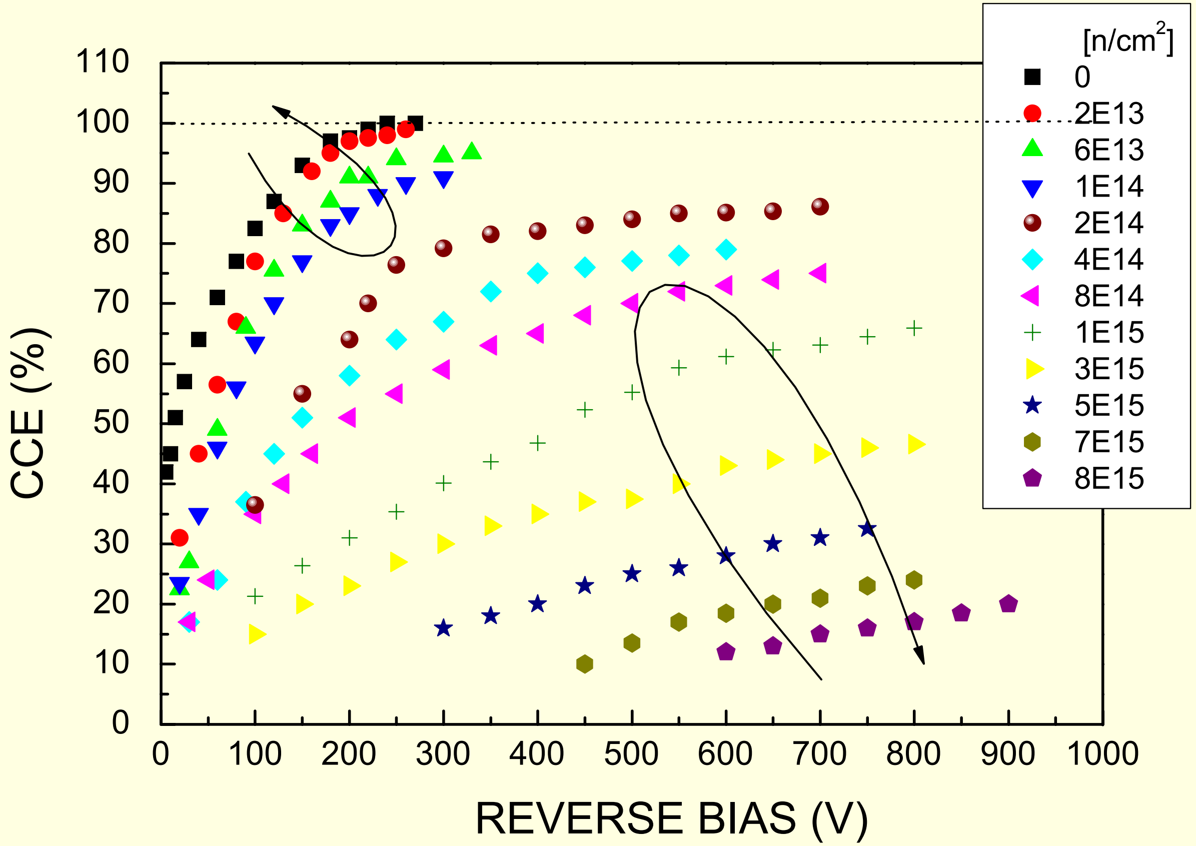
CCE vs bias voltage



CCE by 5.486 MeV α-particle from ^{241}Am source in vacuum (1 Pa)

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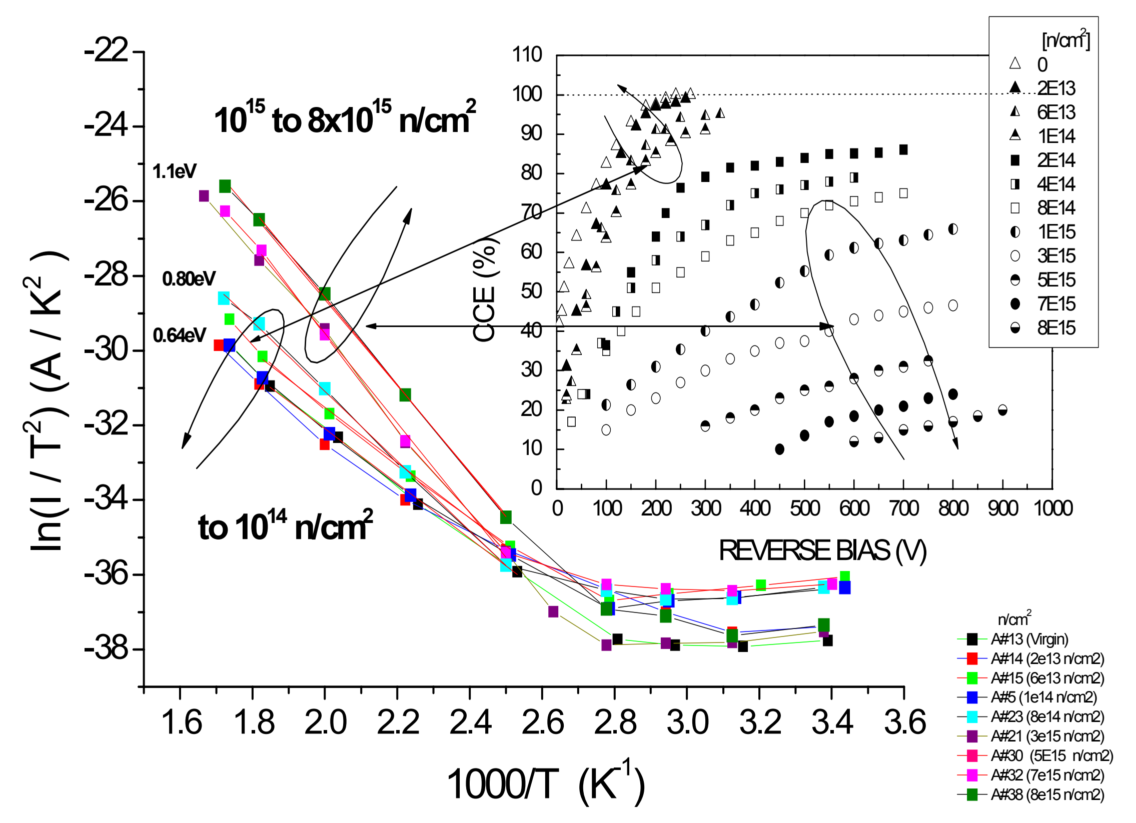
Thermal activation plot

$$I/T^2 = \left(AA^*\right) \times exp\left(-qE/kT\right)$$

$$A = area \qquad A^* = 100 \quad A\,cm^{-2}K^{-2}$$



Activation plot shows two ranges of activation energy, at ≈ 0.64 and ≈ 1.1 eV

in the inset the CCE vs bias

role of trap SN6 at E_T =1.16eV !?

Trap density NT vs CCE$_{max}$

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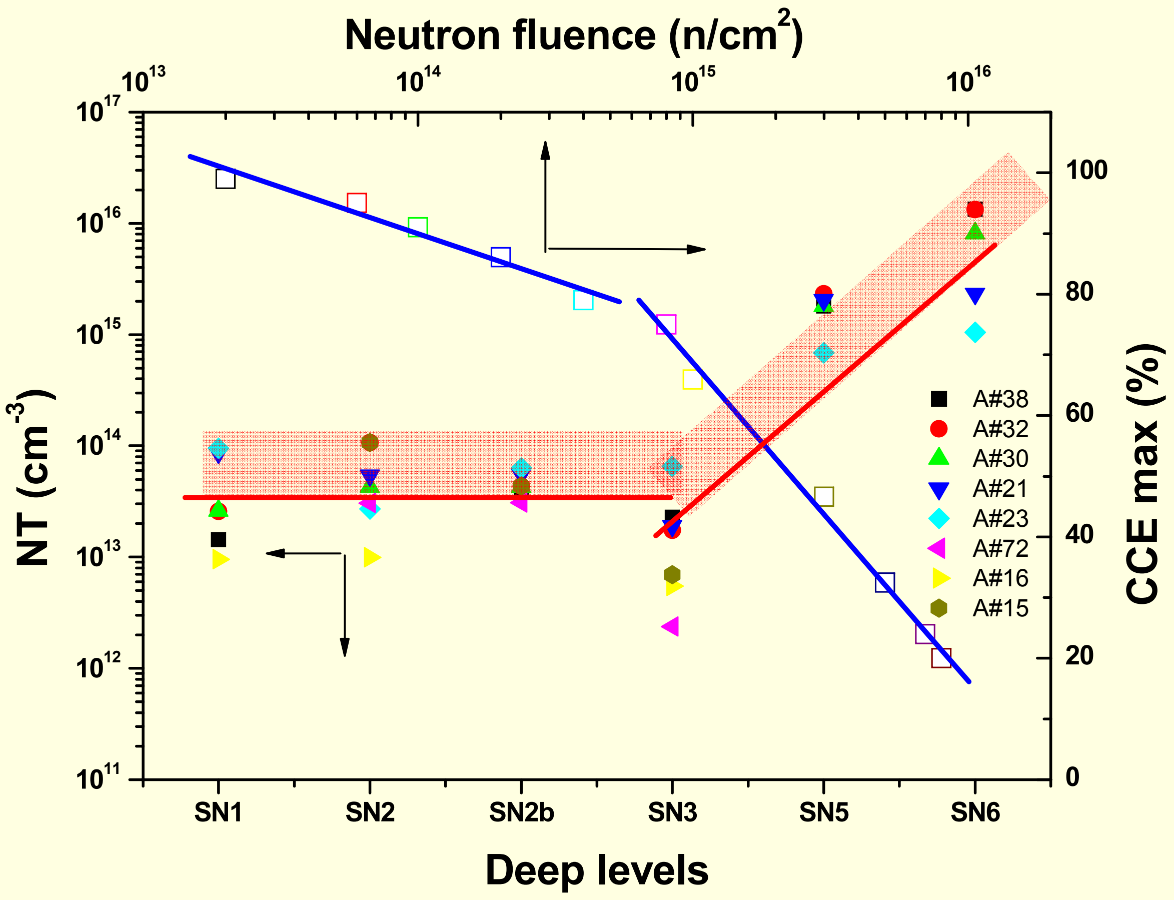

Trap label	**Et** (eV)	**Nt** (cm^{-3})	σ(cm^2)	**Label**	**Attribution**
SN1	0.05	10^{14}	8.8×10^{-20}	**N_{hs}** [a]	$N_{\text{hexag site}}$
SN2	0.41	10^{14}	3.7×10^{-15}	**EH1** [b], **$Z_2^{0/+}$** [c]	$V_{Si}^{-/--}$
SN2b	0.49	10^{13}	4.0×10^{-15}	**RD5, ID_8** [d], **$Z_1^{0/+}$** [c]	-
SN3	0.68	10^{13}	7.0×10^{-15}	**Z1/Z2** [e, c, l]	$V_{Si}+V_C$
SN4	0.68	-	6.0×10^{-16}	**M2** [f], **EH3** [h]	-
SN5	0.82	10^{15}	2.0×10^{-16}	**$RD_{1/2}$** [d], **SI5** [g]	V_{Si}^{+}
SN6	1.16	10^{15}-10^{16}	2.8×10^{-15}	**EH5** [b], **$IL_{4/5}$** [h]	$Vc+V_{Si}$
SN7	1.50	10^{13} -10^{16}	3.0×10^{-14}	**EH6/EH7** [b, i]	Vc^{+}, Vc^{+}complex

Summary and Conclusions (1)

- ✓ irradiation modifies the defect electrical activity
- ✓ at $\Phi \geq 4x10^{14}$ cm^{-2} the material becomes semi-insulating
- ✓ irradiation dramatically affects the concentration of deep levels
- ✓ at $\Phi > 3 \times 10^{15}$ cm^{-2} SN6, E_T=1.16 eV, becomes dominant (what about SN7, E_T = 1.50 eV ?)
- ✓ estimate of the trap concentration at high fluences
- ✓ charge collection efficiency is mostly affected by SN5 and SN6

Conclusions (2)

✓capture kinetics evidences point-like defects

✓some of them are located in the strain field of the dislocations (electrical activity of partial dislocations at SFs)

but

✓they are not at the dislocation core, i.e. inside the potential barrier, as demonstrated by their capture kinetics

future plans:

MCTS measurements

annealing treatments

⇩

nature of the traps

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