The X defect in Epi/Cz silicon diodes after high doses of Co^{60}-γ irradiation

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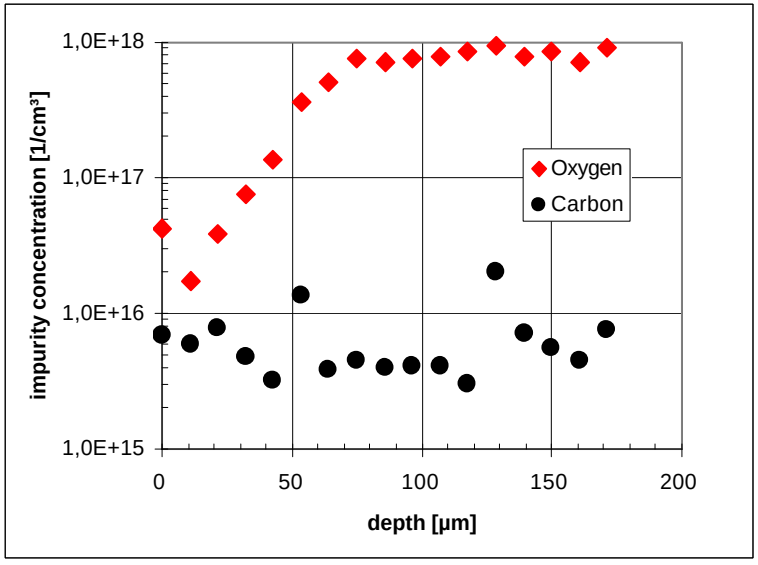
Material

EPI-Silicon wafers: <111>, n/P, 50 Ocm, 50 µm on 300 µm Cz-substrate, CiS process

Irradiation source: Brookhaven National Laboratory for ^{60}Co-γ-photons

Sample	STFZ	DOFZ	EPI/Cz	Cz
SIMS [O]	$<5*10^{16}$	$1.2*10^{17}$	» $9*10^{16}$	$8.1*10^{17}$

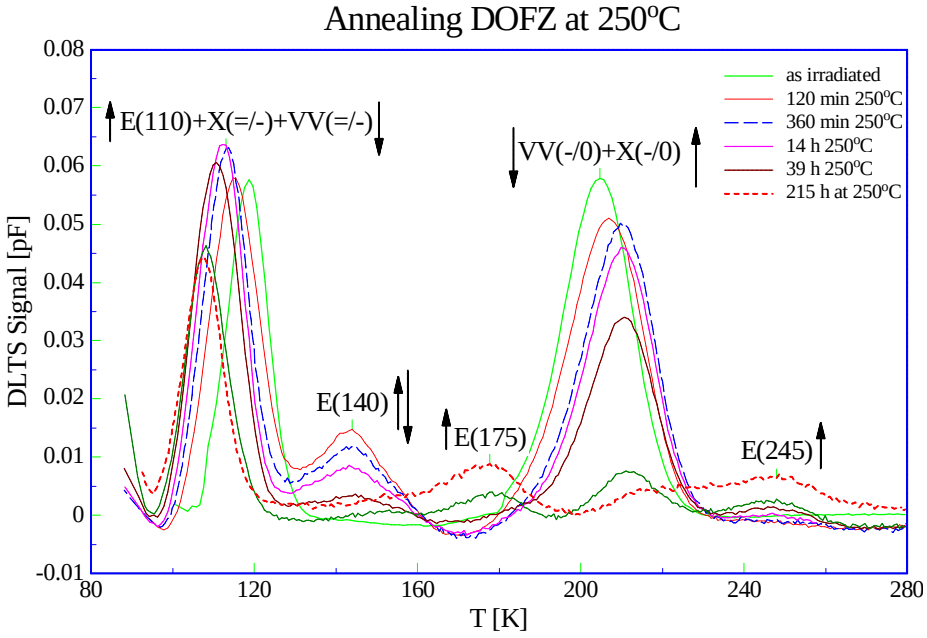
Carbon concentration for all materials at detection limit [C] » $5.7´10^{15}$ cm^{-3}

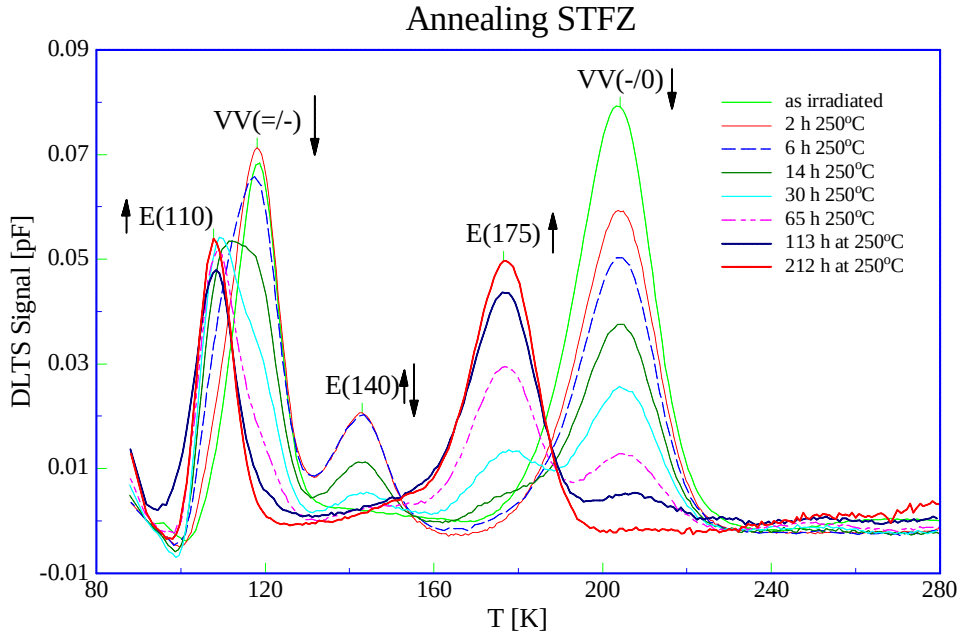


Oxygen depth profile of EPI with SIMS (ITME+SIMS lab. Warsaw)

Short history of the X defect

• ***low irradiation doses*** (4 Mrad) – the X defect is formed in oxygen enriched material via the annealing of divacancy for T> 250^{0}C





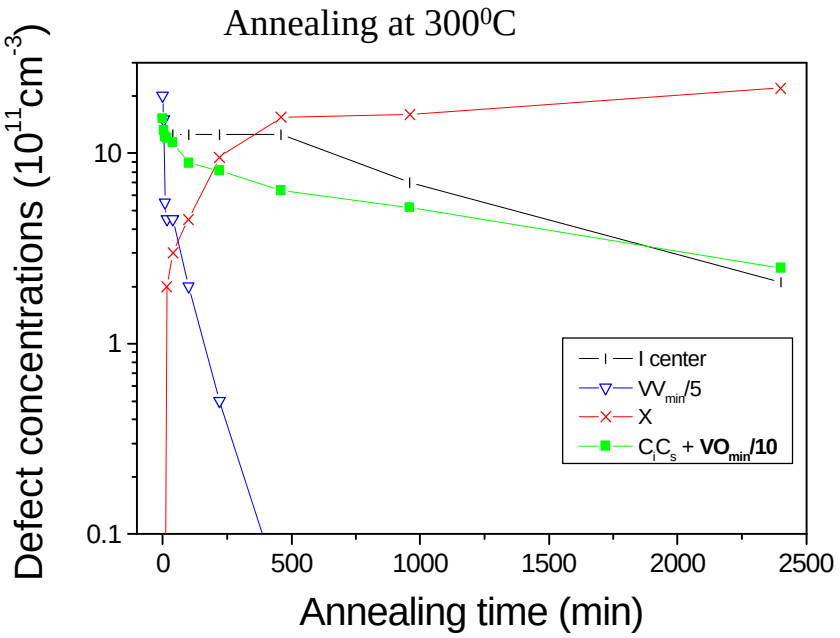
X defect – two acceptor states

Proposed formation mechanism[1)]: $V_2 + O_i \Rightarrow V_2O$

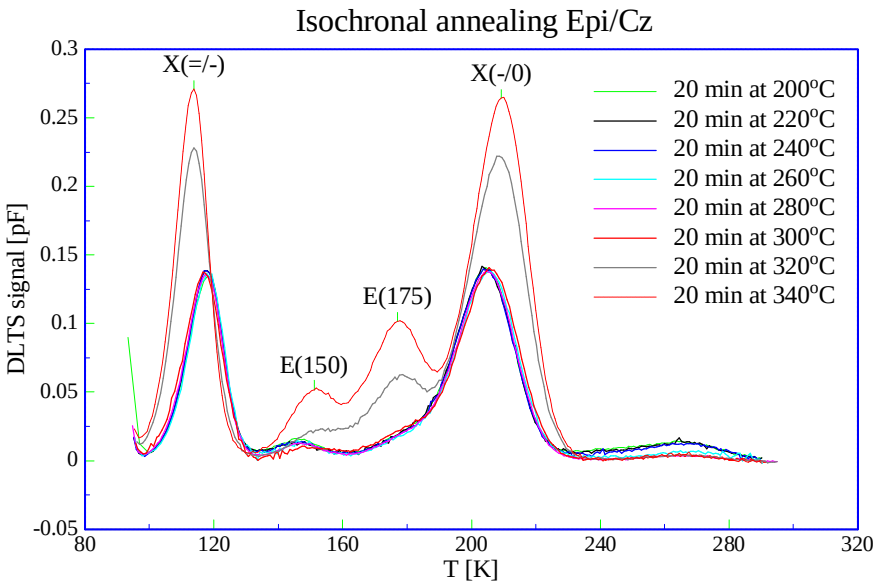
[1)] Monakov et al, Phys Rev B, Volume 65, 233207 (2002)

- ***High irradiation doses***

360 Mrad STFZ*



Epi/Cz – 105 Mrad**



The X-level is also generated in STFZ material, ***but*** after annealing out of V_2

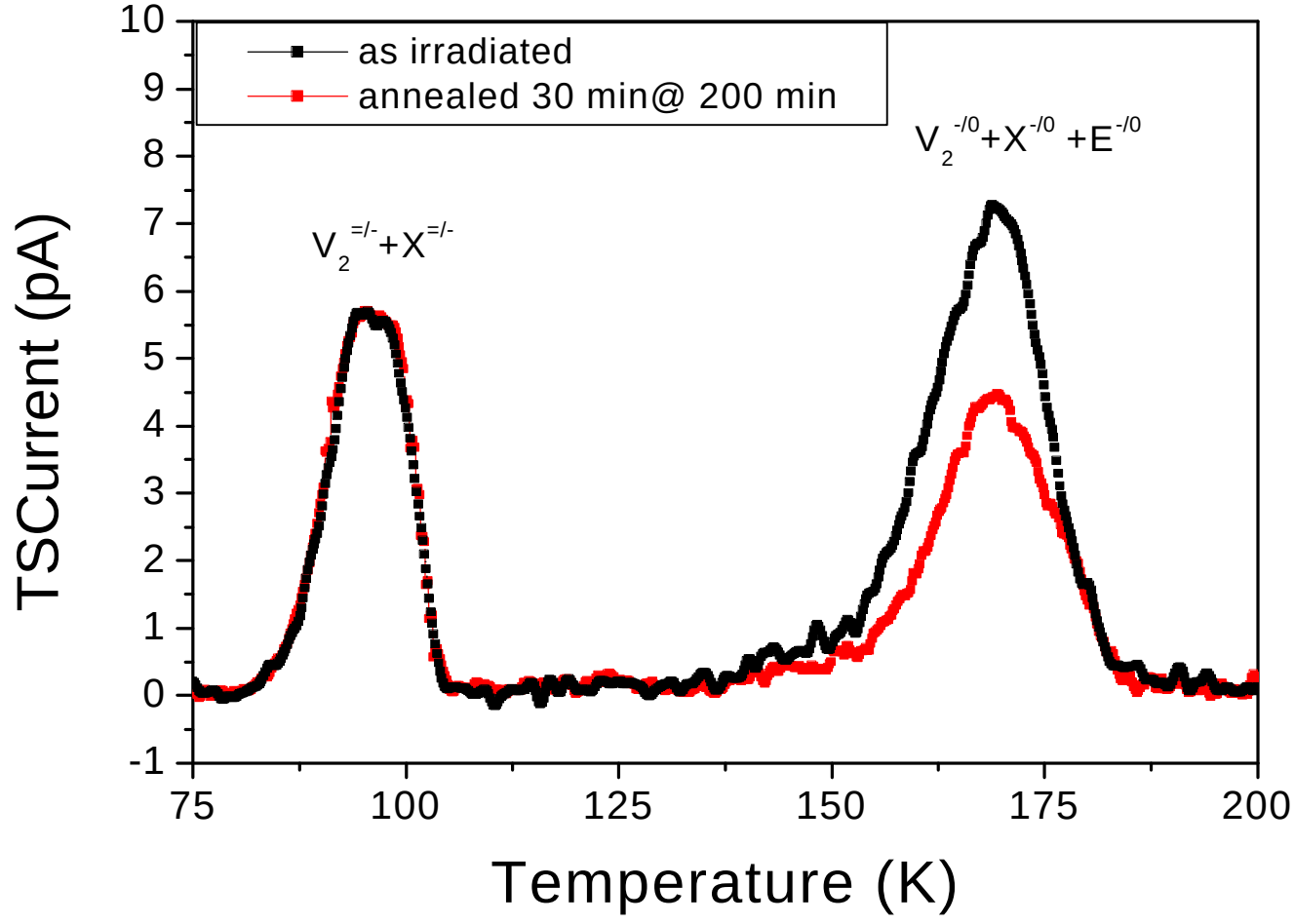
At 320°C the X-level appears, ***but*** in larger concentration than V_2!

Þ For the high dose the annealing relation between the X-level and the divacancy is not given any more !!

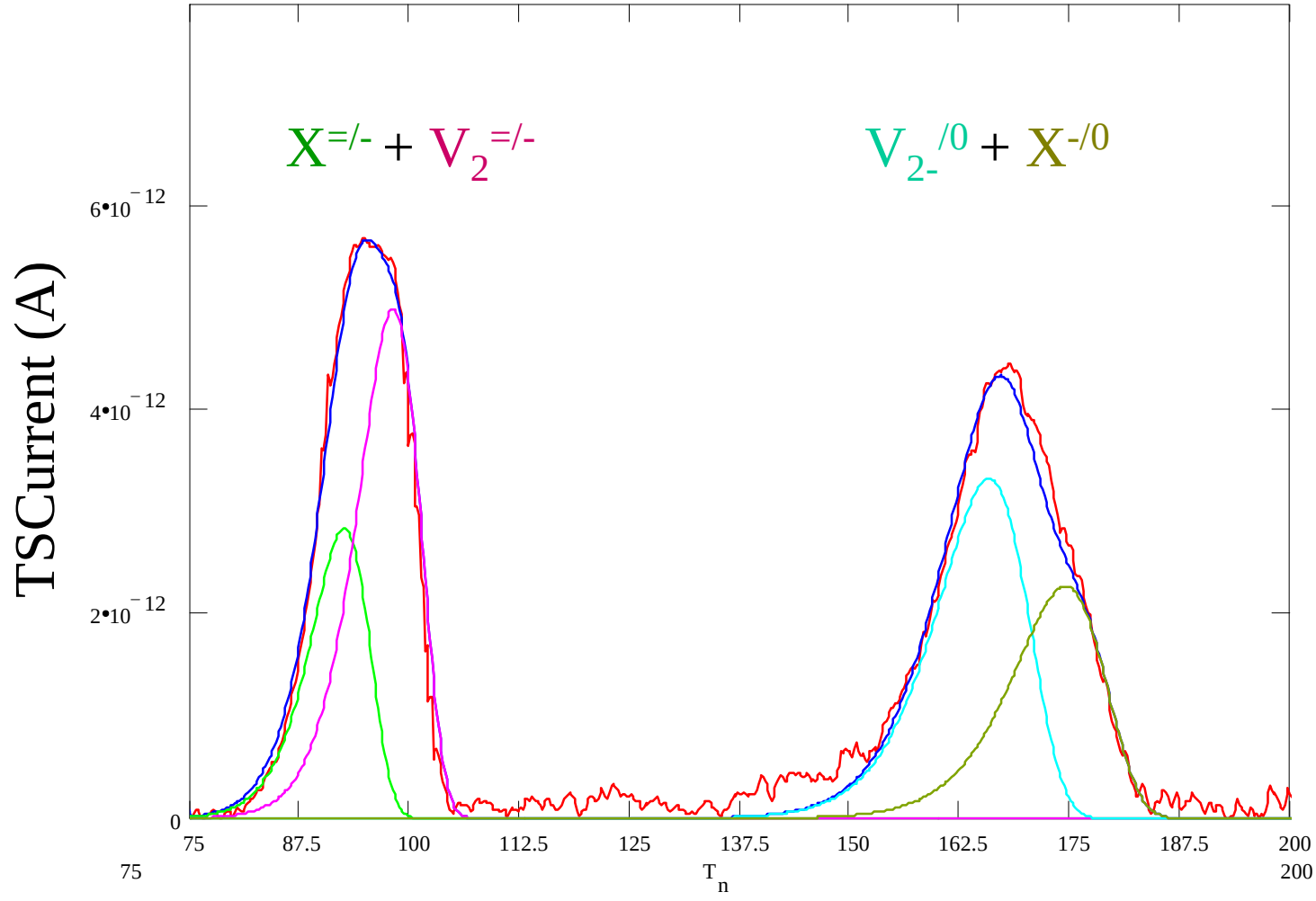
*I. Pintilie, E. Fretwurst, G. Kramberger, G. Lindstroem, Z. Li and J. Stahl, ***Physica B: Condensed Matter***, 340-342, 578, (2003)

**J.Stahl, *Reaction kinetics in different silicon materials,* 3rd RD50 workshop, CERN- Geneve

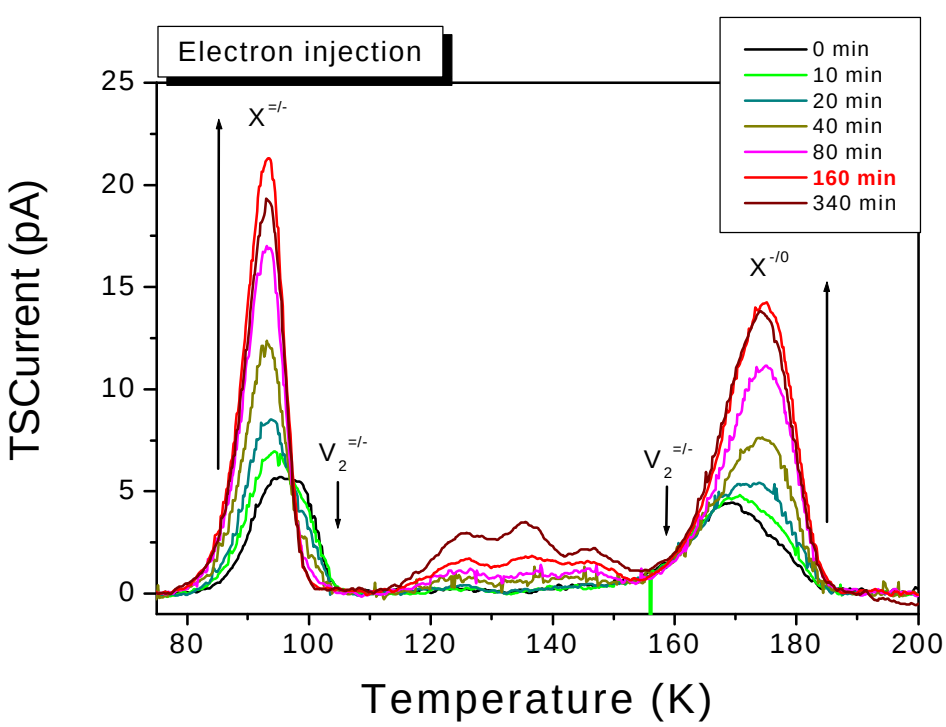
X center in Epi/Cz after 520 Mrad dose

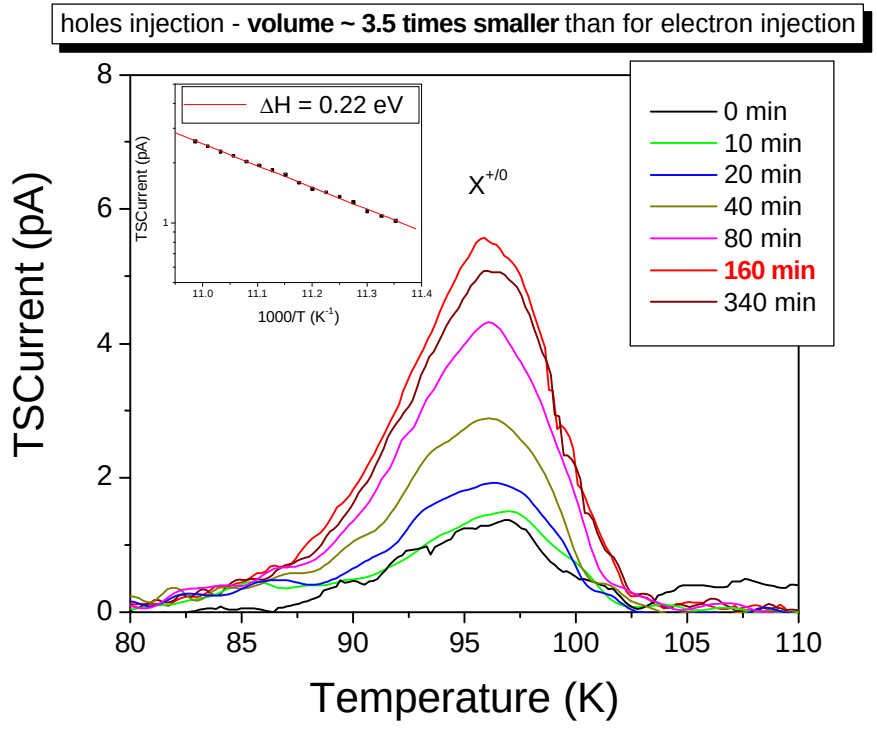


X center in Epi/Cz after 520 Mrad dose



Annealing at 320 ^{0}C



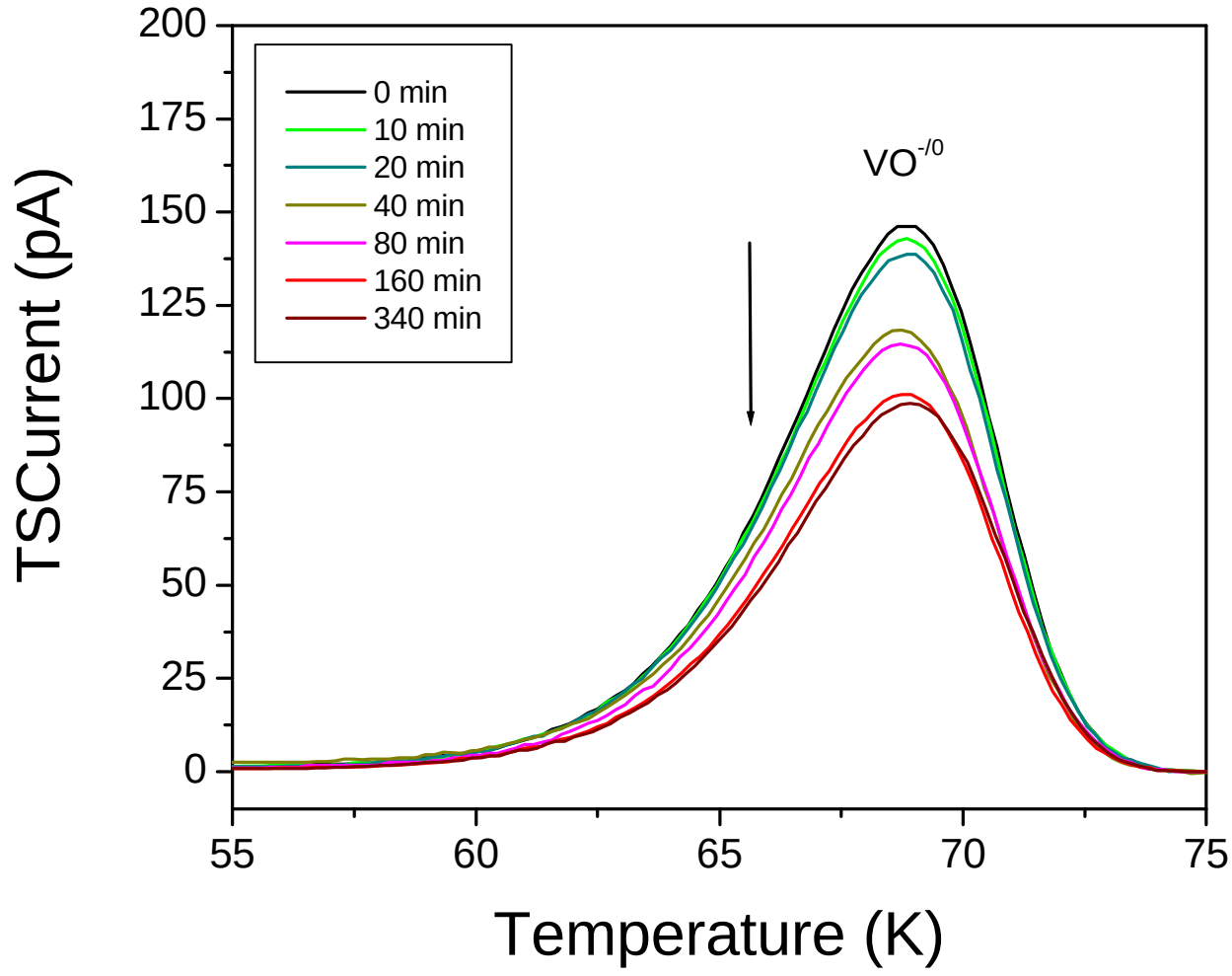


After 160 min@ 320^{0}C
[X] ~ 5x[V_2]

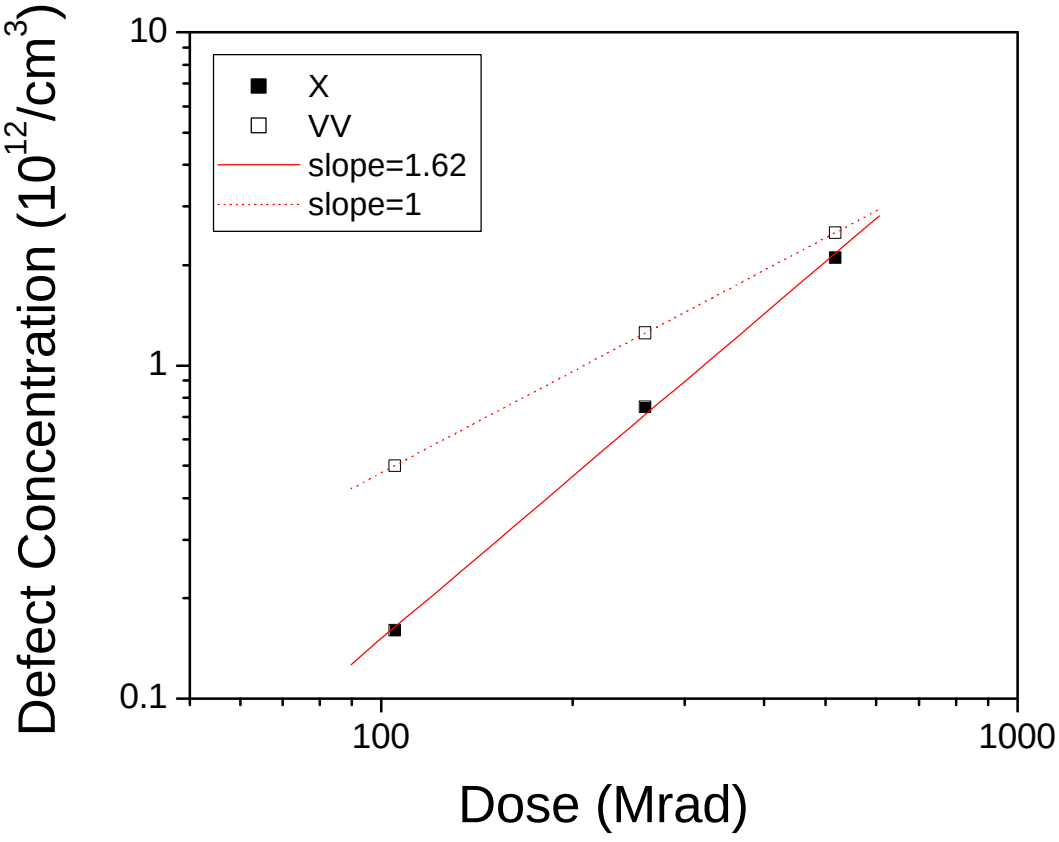
X$^{+/0}$ state – detected!
ΔH ~ 0.22 eV
σ_p ~ 7x10^{-16}cm^2

Annealing of VO center

Initial [VO]~$4.4 \times 10^{14} cm^{-3}$



Introduction rate of X defect



Most likely – the X center is formed via a second order process !

X defect - Formation mechanism

Can be V_2O ?

for low irradiation doses when [X] ≤ [VV]

Reactions for V_2O

$V_2+O \Rightarrow V_2O$

Possible, since

$[O]_{DOFZ} > [O]_{STFZ} \approx [O]_{EPI}$

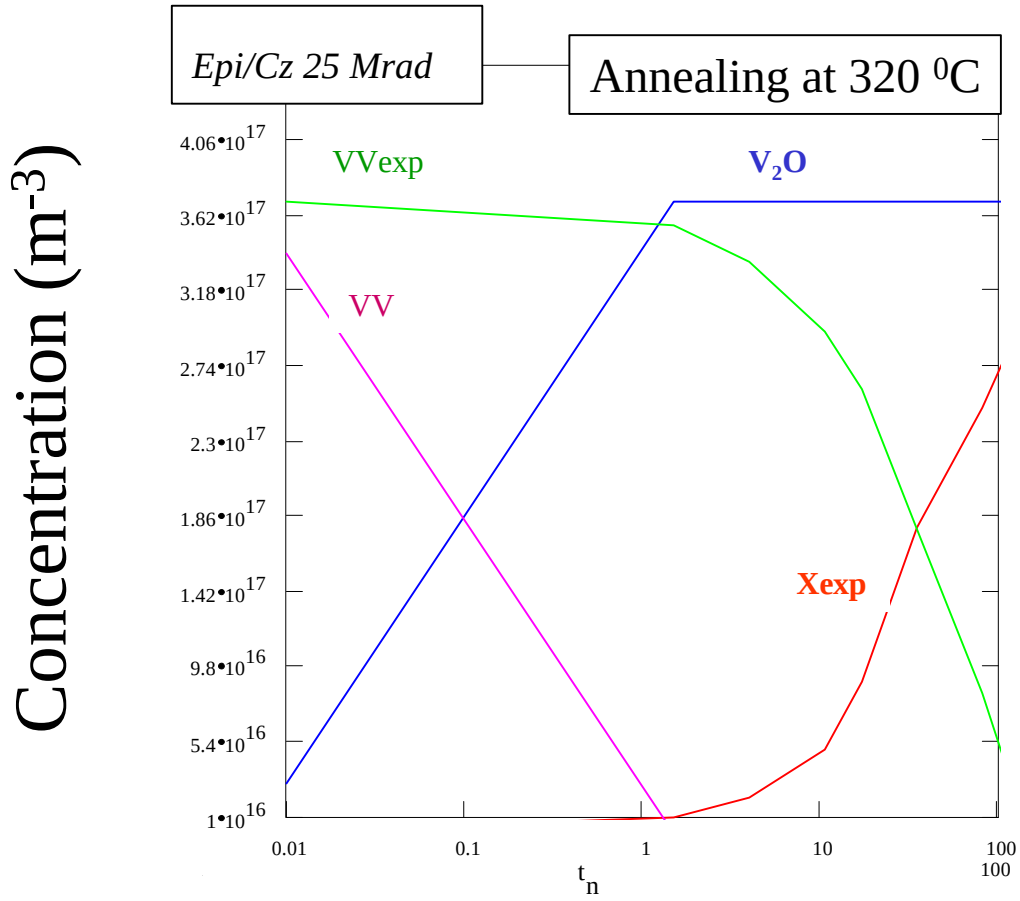
$[X] > [V_2]$

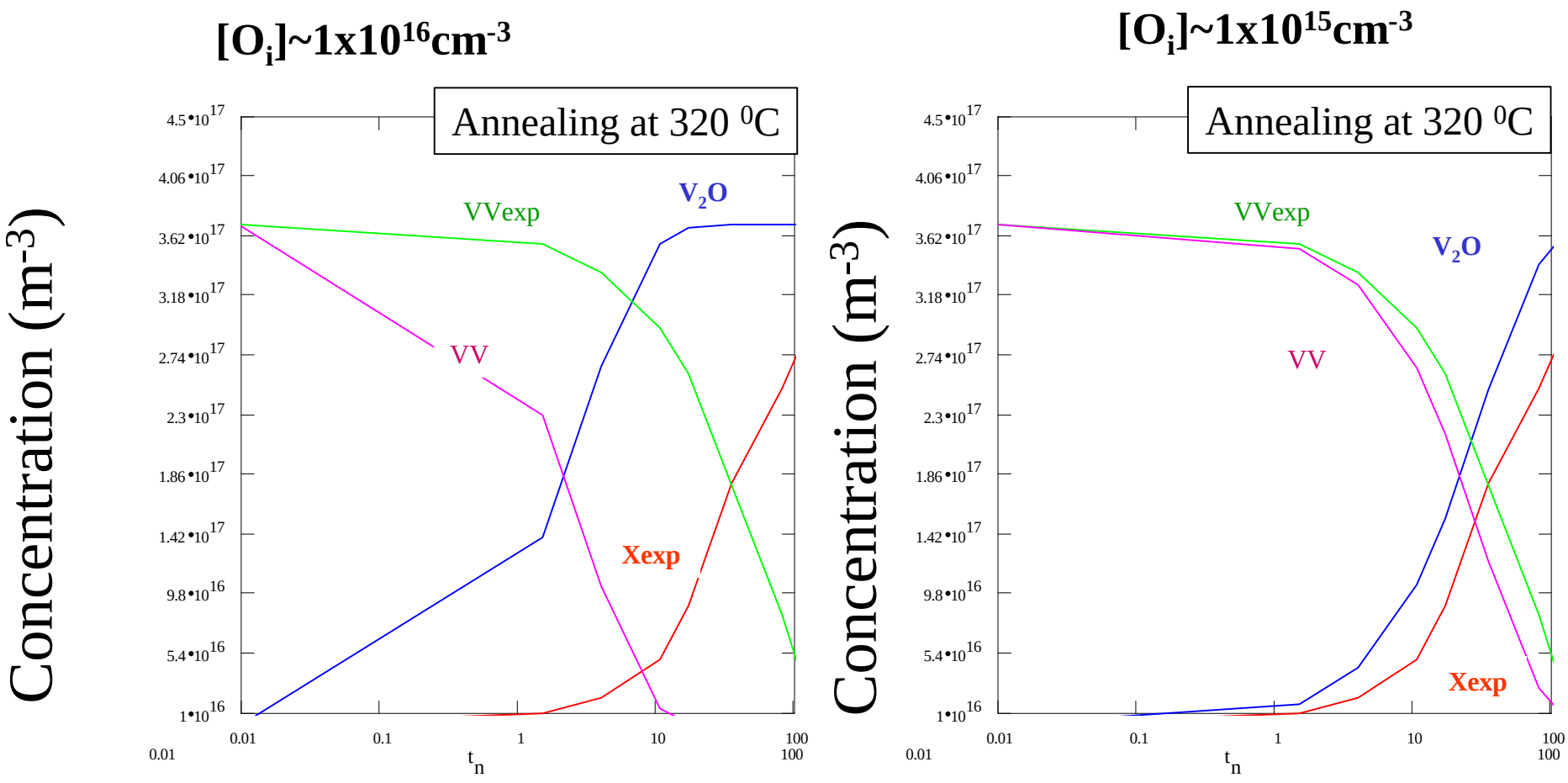
$VO+V \Rightarrow V_2O$

Unlikely for high irradiated doses where [X] > [VV], because no free vacancies are available at T>250°C!

$$DVV(y) := 1 \cdot 10^{-5} \cdot \exp\left(\frac{-1.3 \cdot q}{k \cdot y}\right)$$

$[O_i]$~9x10^{17}cm^{-3}





The impurity which forms the X center via VV migration should be in a much smaller concentration than that of oxygen interstitial

Can be V_2O_2 ?

From theoretical calculations V_2O_2 has basically the same properties as V_2O [1)]

Reaction for V_2O_2

$V_2+O_2 \Rightarrow V_2O_2$

Probable, because
$[O_2]_{EPI}$ and $[O_2]_{DOFZ} >> [O_2]_{STFZ}$

$VO+VO \Rightarrow V_2O_2$

Probable, because from exp. data the additional formation of X is related to annealing of VO

$[O_{2i}]$~1x10^{15}cm^{-3}

[2)]

$$DVV(y) := 1\cdot10^{-5}\cdot\exp\left(\frac{-1.3\cdot q}{k\cdot y}\right)$$

$$DVO(y) := 6\cdot10^{-4}\cdot\exp\left(\frac{-1.8\cdot q}{k\cdot y}\right)$$

During irradiation: $V+O_{2i} \Rightarrow VO_2$ and $V+ VO_2 \Rightarrow V_2O_2$

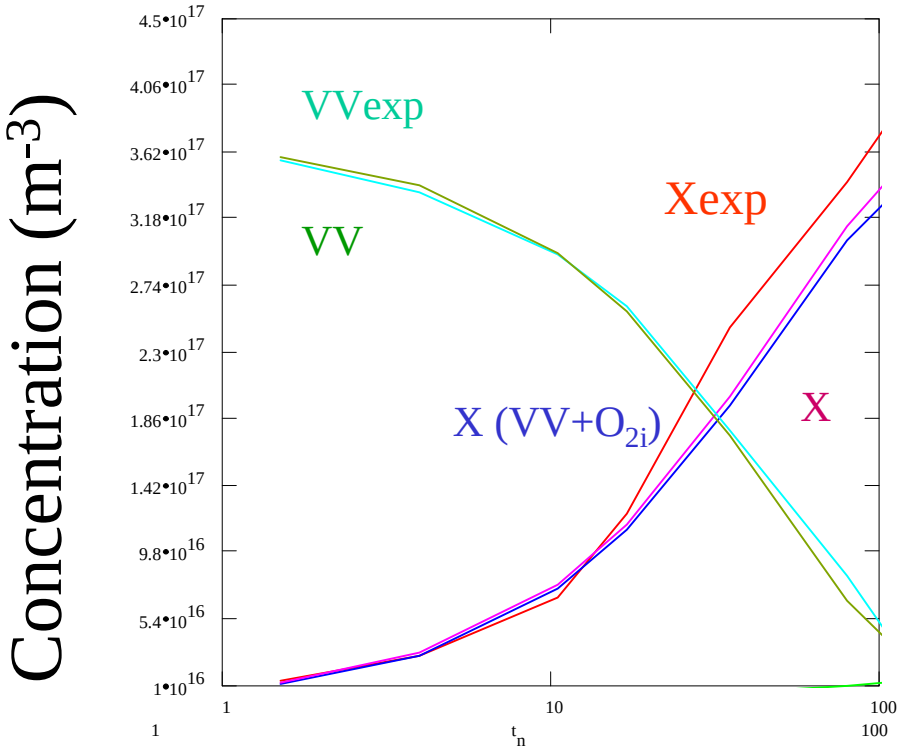
[1)] J. Coutinho et al, „The formation dissociation and electrical activity of divacancy oxygen complexes in Si“, PHYSICA B, in press

[2)] B. G. Svensson et al, PRB 34 (12) 1986

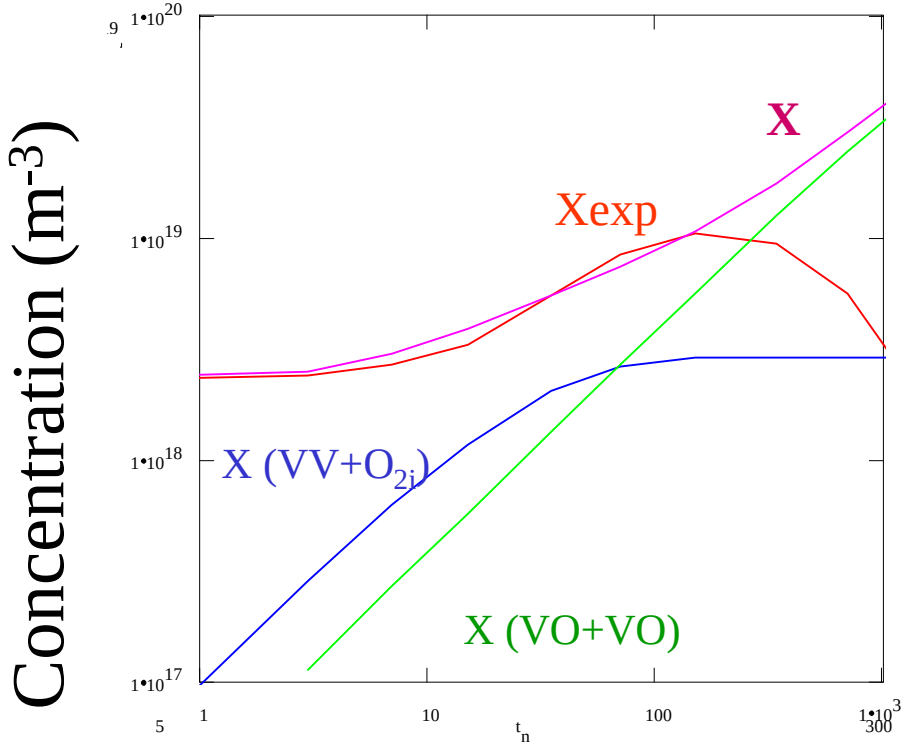
$$DVV(y) := 1\cdot10^{-5}\cdot\exp\left(\frac{-1.3\cdot q}{k\cdot y}\right)$$

$$DVO(y) := 6\cdot10^{-4}\cdot\exp\left(\frac{-1.8\cdot q}{k\cdot y}\right)$$

Low doses
25 Mrad



High doses
520 Mrad



Conclusions

X defect

- induced by irradiation in Epi material for doses ≥ 100 Mrad
- generated via a second order process
- has a donor state at $\Delta H \sim E_V + 0.22$ eV and a capture cross section of $\sigma_p \sim 7x10^{-16} cm^2$
- in the light of the experiments, its dentification with V_2O is doubtfull
- a better candidate to be associated with, is the V_2O_2 complex