Defect kinetics in Epi/Cz silicon after Co^{60}-γ irradiation

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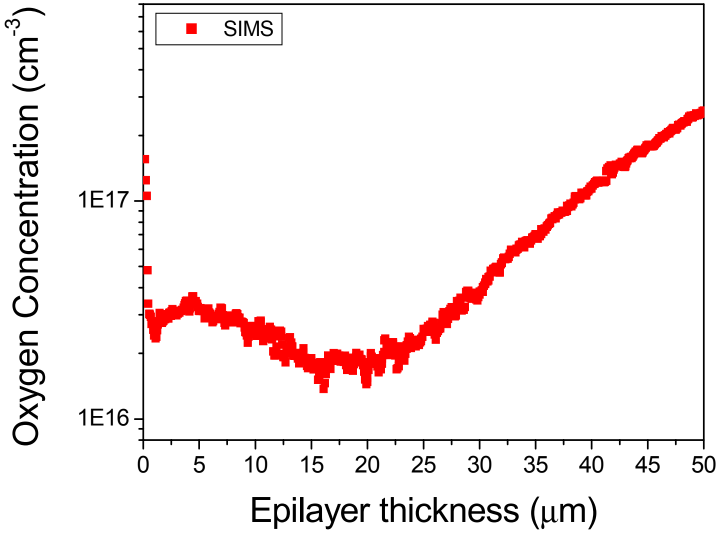
Motivation- The divacancy annealing mechanisms proposed for STFZ after low irradiation doses cannot explain the results obtained in Epi/Cz diodes after high doses of irradiation

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

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

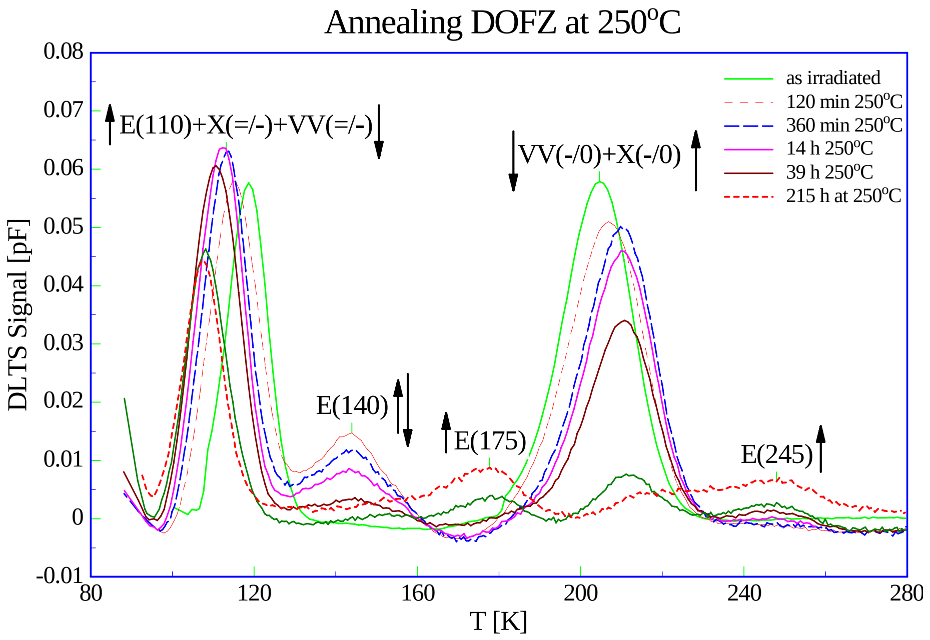
Sample	STFZ	DOFZ	EPI/Cz
SIMS [O]	**<5*10^{16}**	**1.2*10^{17}**	**(1.5- 30)*10^{16}**

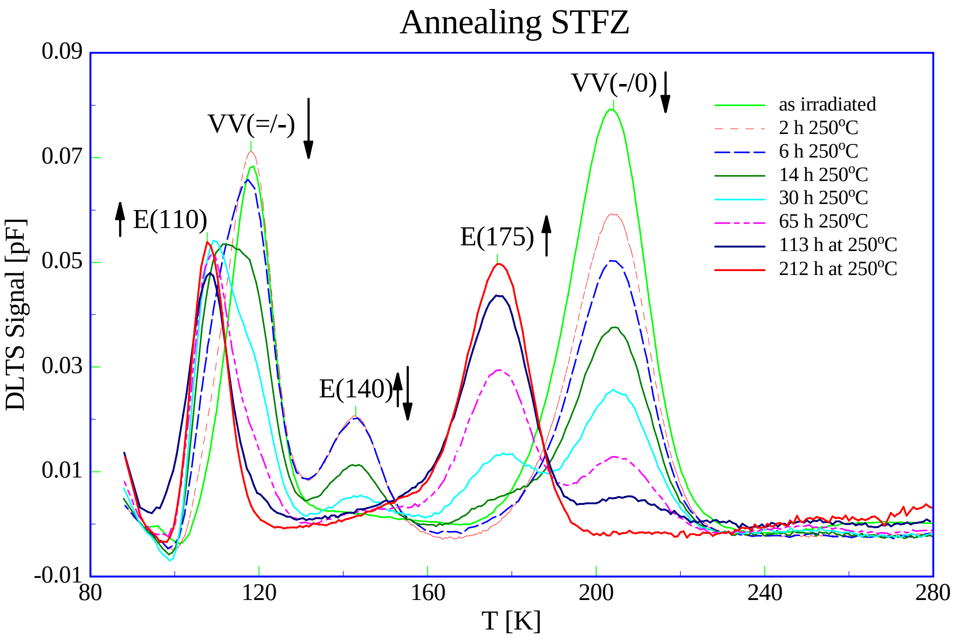
Carbon concentration for all materials at detection limit [C] ≈ 5.7×10^{15} cm^{-3}



Annealing experiments

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





X defect – two acceptor states - Identified as V_2O 1)

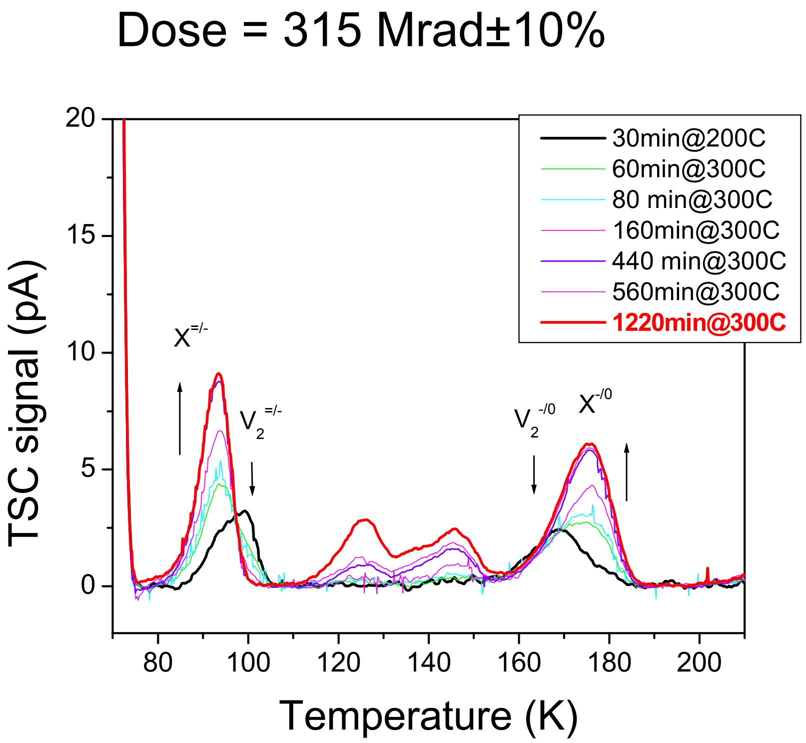
Proposed formation mechanism1): $V_2 + O_i \Rightarrow V_2O$

(with $D_{V2} = 3 \times 10^{-3} \exp(-1.3eV)$) instead of the former $D_{V2} = 0.1 \exp(-1.3eV)$)

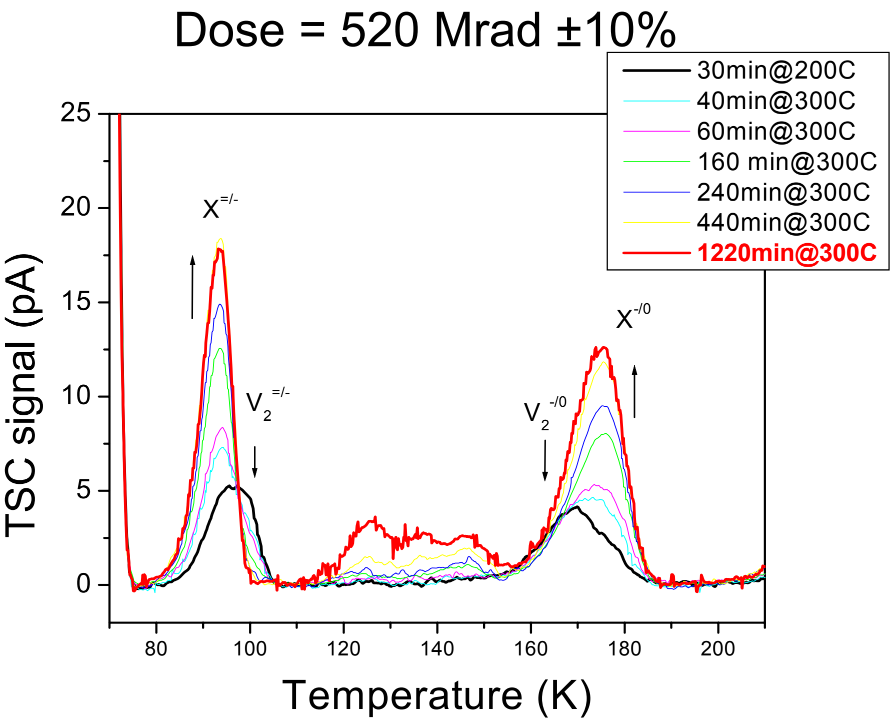
1) Monakov et al, Phys Rev B, Volume 65, 233207 (2002)

- ***high irradiation doses*** (>100 Mrad) – ***X center formed in concentration higher than of V_2 for $T> 250^0C$***

Epi/Cz material – T = 300 ^{0}C



$[X]\sim3x[V_2]$



$[X]\sim5x[V_2]$

X defect – Identified as V_2O_2 [2] via: $V_2 + O_2 \Rightarrow V_2O_2$ and VO+VO

(with $D_{V2} = 0.1 \exp(-1.3eV)$ and $D_{VO}(T)=6Exp(-1.8eV/KT)$ cm^2/s)

[2] I.Pintilie et al- 6th and 7th RD50 workshops

Which defect reactions at T>250 C can produce more V_2O ?

- $V_2 + O \rightarrow V_2O$
- $V + VO \rightarrow V_2O$

⇒ **Should exists a source of V**

- Most probable VO can be the V source – it dissociates during annealing at T >250 C
- **$VO \rightarrow V + O$**

Defect reactions

Vacancy-Oxygen related defect reactions

Diffusion reactions

- $V + O \rightarrow VO$
- $V+VO \rightarrow V_2O$
- $V+V \rightarrow V_2$
- $V_2 + O \rightarrow V_2O$
- $V_2 + O_2 \rightarrow V_2O_2$
- $V+O_2 \rightarrow VO_2$
- $VO+O \rightarrow VO_2$
- $V + VO_2 \rightarrow V_2O_2$
- $VO+VO \rightarrow V_2O_2$

Dissociation reactions

- $VO \rightarrow V + O$
- $V_2O \rightarrow V + VO$
- $V_2O_2 \rightarrow VO+VO$
- $V_2 \rightarrow V + V$

Defect reactions with other impurities*

Diffusion reactions

- $VO+H \rightarrow VOH$
- $V_2 + H \rightarrow V_2H$
- $V + H \rightarrow VH$
- $CiOi+H \rightarrow COH$
- $V+CiOi \rightarrow CsOi$
- $Ci+V \rightarrow Cs$
- $Ci+Oi \rightarrow CiOi$
- $V+ CiCs \rightarrow CsCs$

Dissociation reactions

- $VOH \rightarrow VO + H$
- $V_2H \rightarrow V + VH$
- $VH \rightarrow V+H$
- $CiCs \rightarrow Ci+Cs$

*Do not affect the V-O defect reactions as long as $[H]<10^{15}$ cm^{-3}

Parameters used for simulations

- $[O_i]$ = profile from SIMS
- $[VO] = 1.1 \times 10^{12}$ x Dose (Mrad) x cm^{-3}
- $r = 5 \times 10^{-10} m$

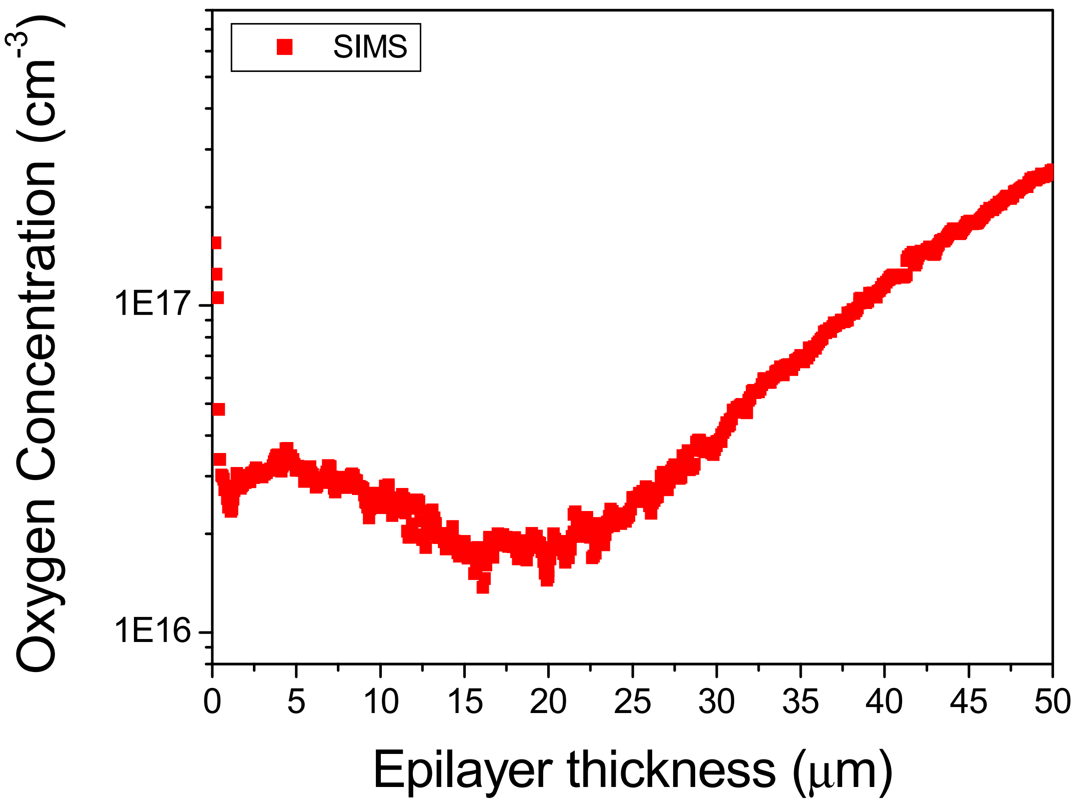
Diffusion parameters
(updated to nowdays literature)

- $D_{VO}(T)=6Exp(-1.8eV/KT)\ cm^2/s$;
- $D_{VV}(T)= 3 \times 10^{-3}exp(-1.3eV/KT)\ cm^2/s$;
- $D_{Od}(T)=3 \times 10^{-4}exp(-1.3eV/KT)\ cm^2/s$;
- $D_{oi}(T)=0.17exp(-2.54eV/KT)\ cm^2/s$
- $D_V(T)= 4.5 \times 10^{-4}exp(-0.3eV/KT)\ cm^2/s$;
- $D_{Ci}(T)= 4.4 \times 10^{-1}exp(-0.87eV/KT)\ cm^2/s$;

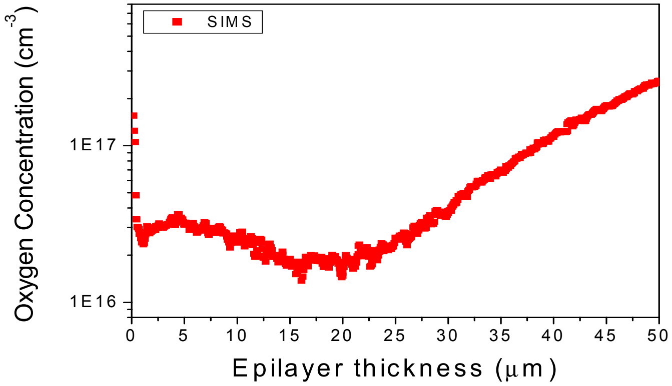
Dissociation

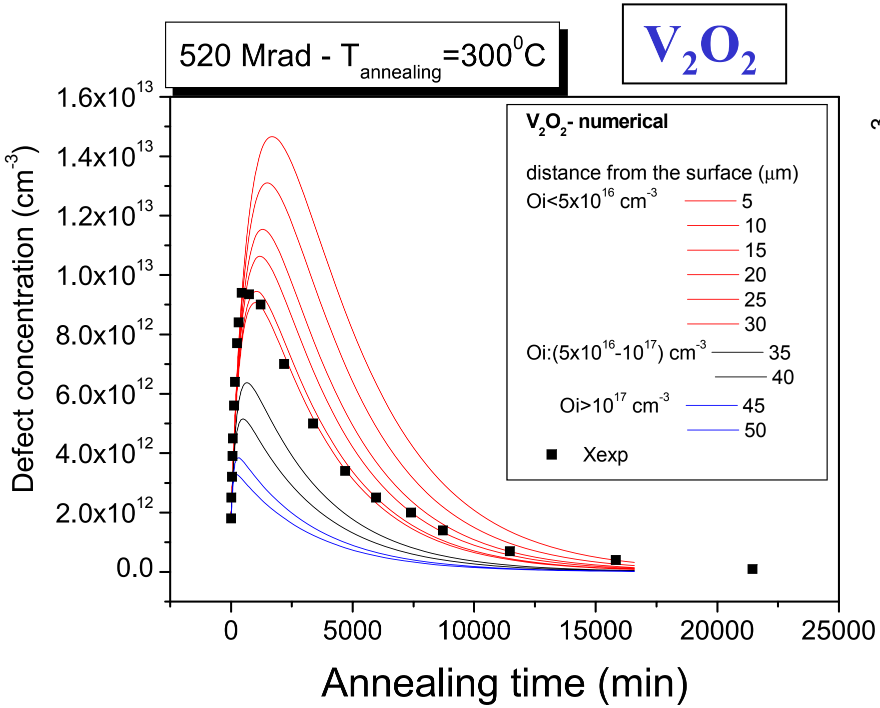
- $K^{VO} = 1 \times 10^{13}exp(-2.1eV/KT)\ s^{-1}$;
- $K^{V2O2} = 1.5 \times 10^{13}exp(-2.1eV/KT)\ s^{-1}$
- $K^{V2O} = 2 \times 10^{13}exp(-2.1eV/KT)\ s^{-1}$

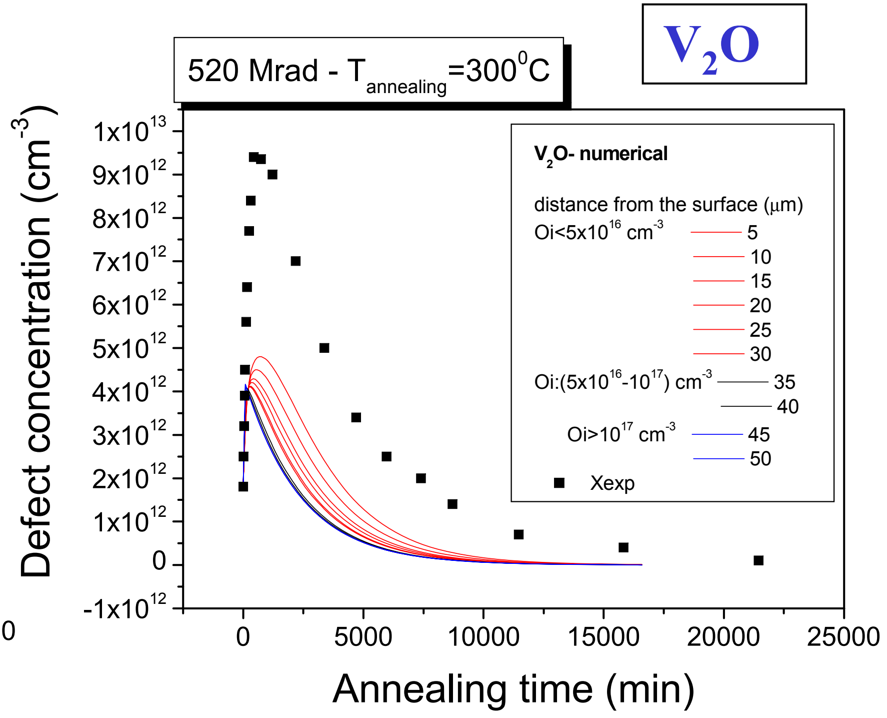
O_i profile - from SIMS measurements



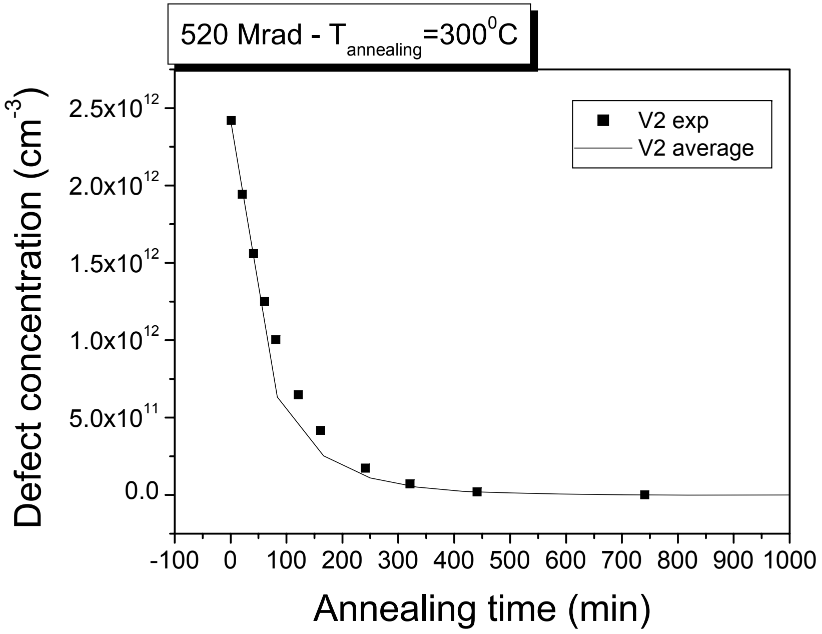
520 Mrad - T=300^0C

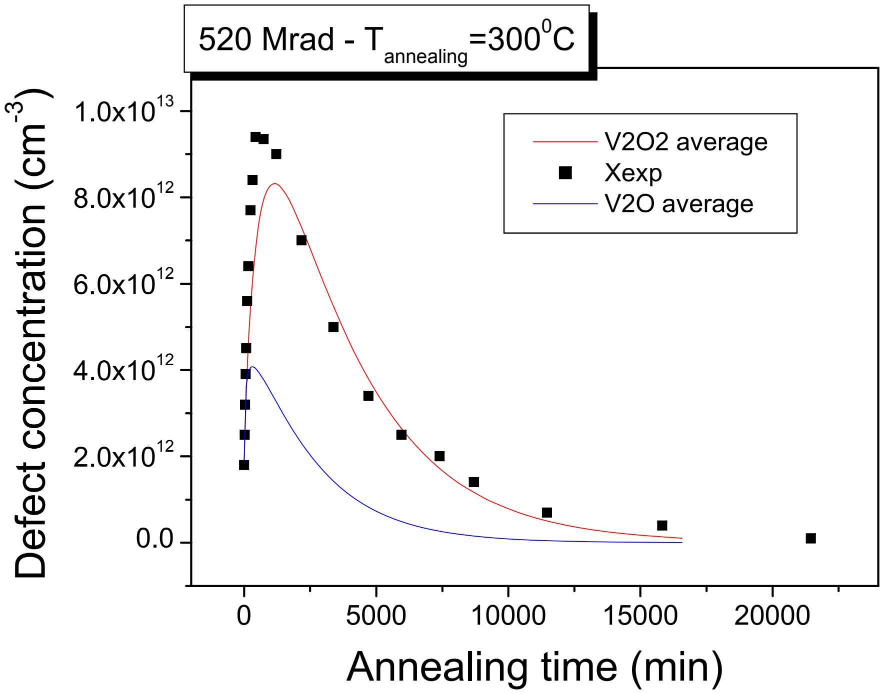




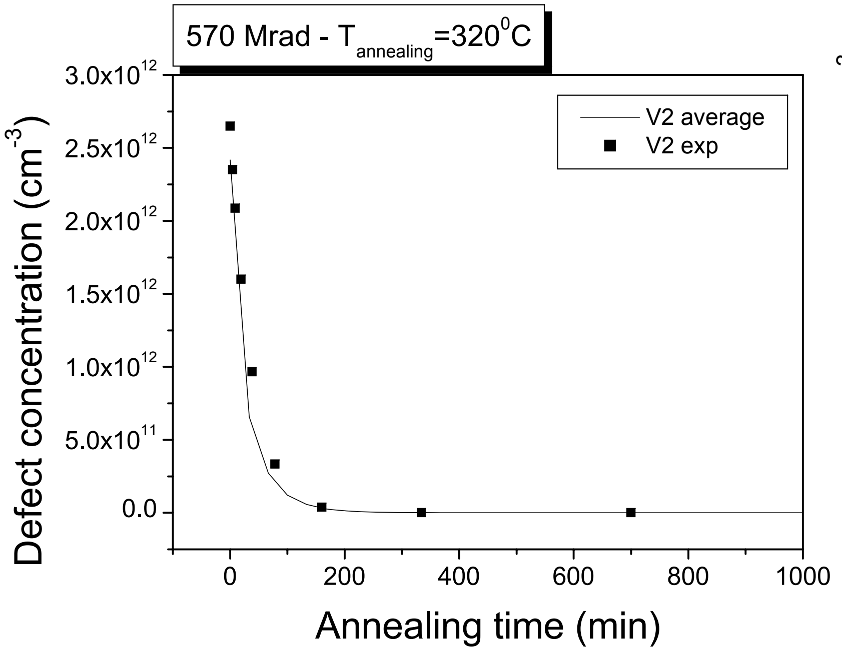


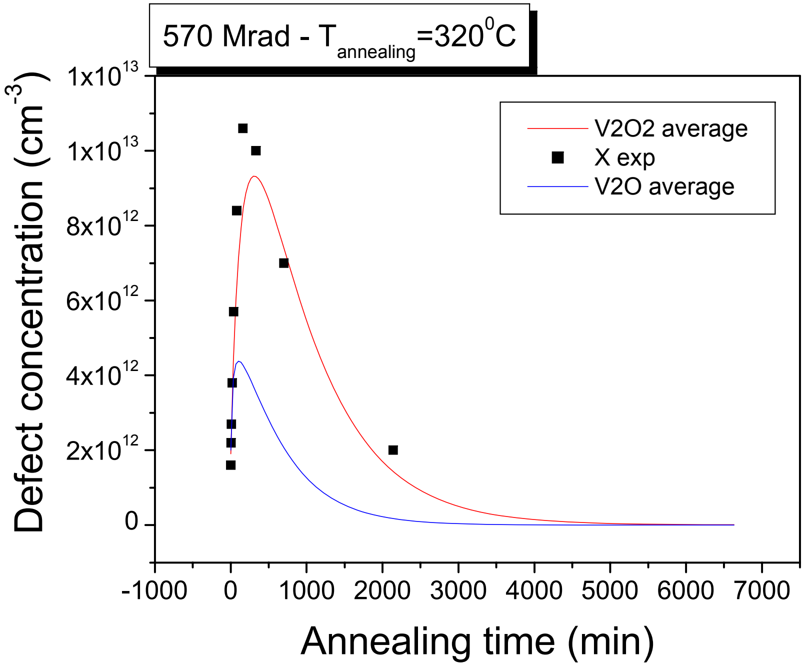
520 Mrad - T=300^{0}C





570 Mrad - T=320^{0}C





Conclusions

- Simulations based on a more complex system of defect reactions show that both **V_2O** and **V_2O_2** defects should form at elevated temperature.

- With VO as single initial source for vacancies and for the irradiation dose range investigated here:
  ⇒ **V_2O_2** can be produced in a similar concentration with X center
  ⇒ **V_2O** can be produced in a concentration higher than **V_2** but in a much smaller concentration than of the X center

- Further studies are under discussion regarding the existence of additional single V migrating from Cz substrate.