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Annealing behavior of defects in irradiated MCZ- and DOFZ-Si detector materials

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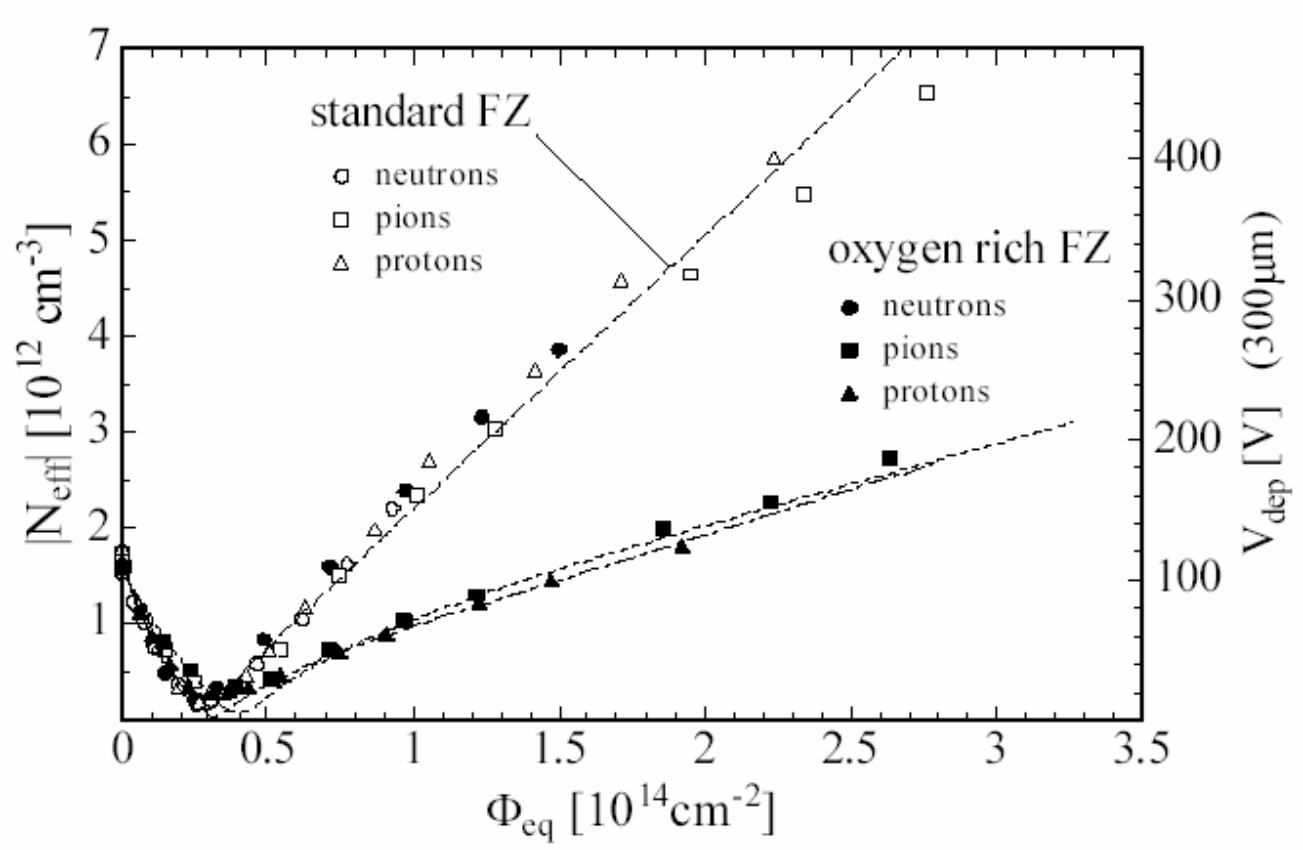
Background and motivation

- DOFZ-Si has showed considerably improved radiation-tolerance compared to more oxygen lean FZ-Si, as demonstrated by the RD48 collaboration.



Background and motivation

- CZ-Si has a higher oxygen concentration than oxygen enriched DOFZ-Si. It is expected that such a high concentration of oxygen will influence the radiation induced formation of oxygen related defects, in particular for high radiation doses where oxygen depletion can occur in O enriched FZ materials.

- High resistivity CZ-Si suited for detector application has only become available in the last years after recent developments in the crystal growth technique.

- For detector CZ-Si there is a lack of data on irradiation induced defects and their thermal behavior.

Experimental details

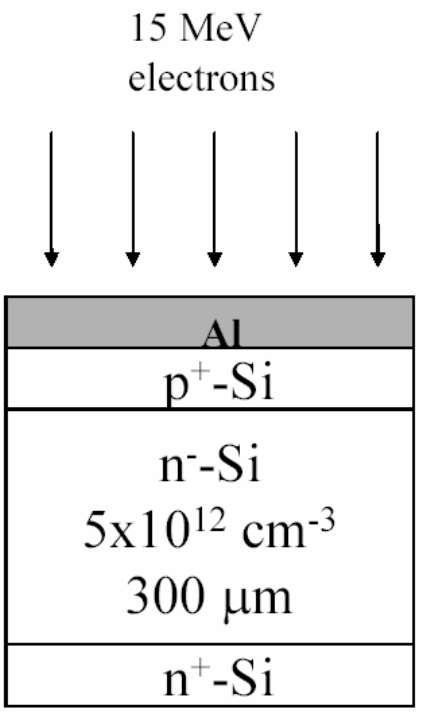


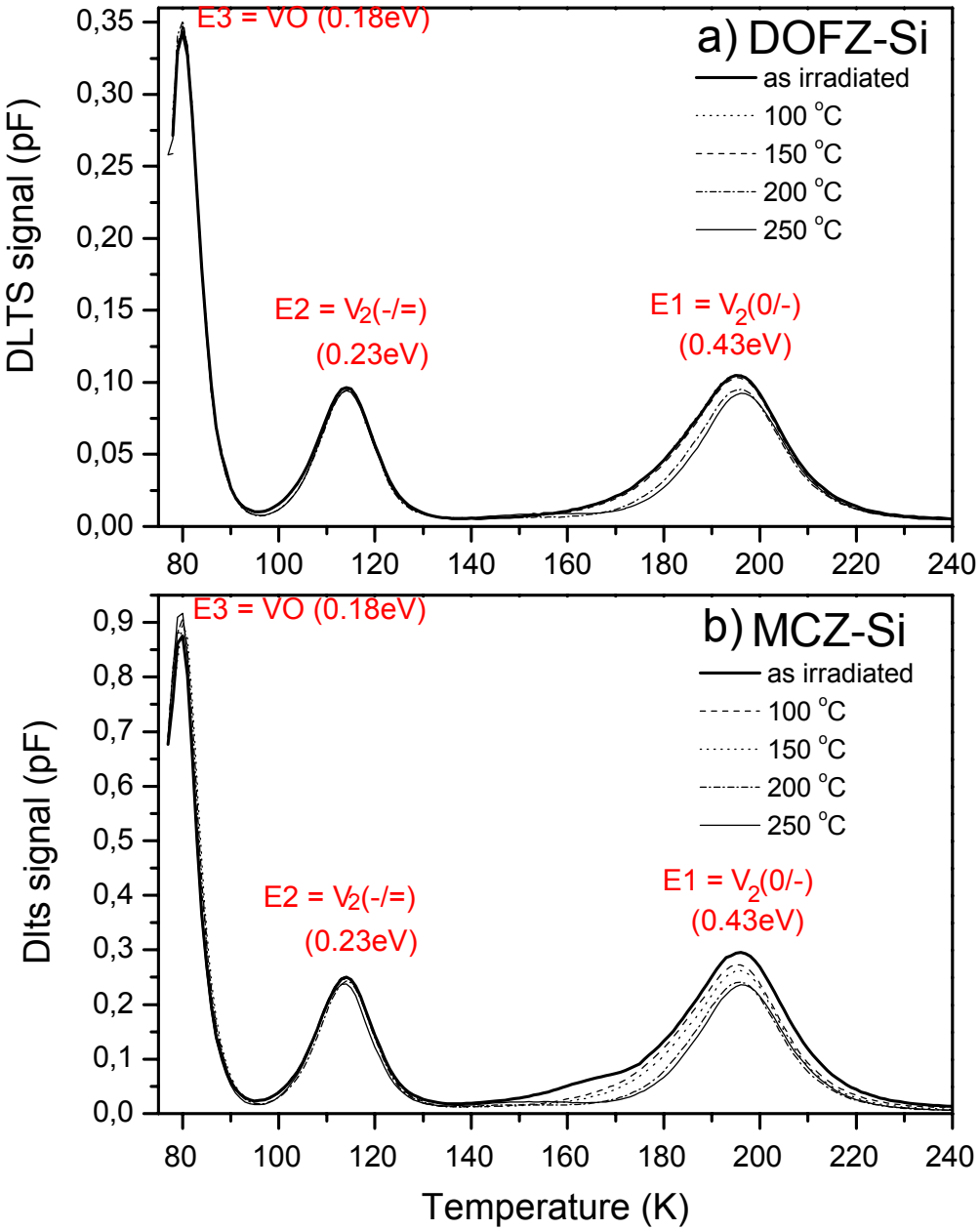
TABLE 1. Survey of the samples used in the study.

Sample	Doping (P/cm^3)	Carbon (cm^{-3})	Oxygen (cm^{-3})
MCZ-Si	5.5×10^{12}	$\leq 10^{15}$	$(5–10)\times10^{17}$
DOFZ-Si	5.0×10^{12}	$(2–4)\times10^{16}$	$(2–3)\times10^{17}$

- Electron dose:
  2 and 4 $\times10^{12}$ cm^{-2} for FZ and CZ-Si

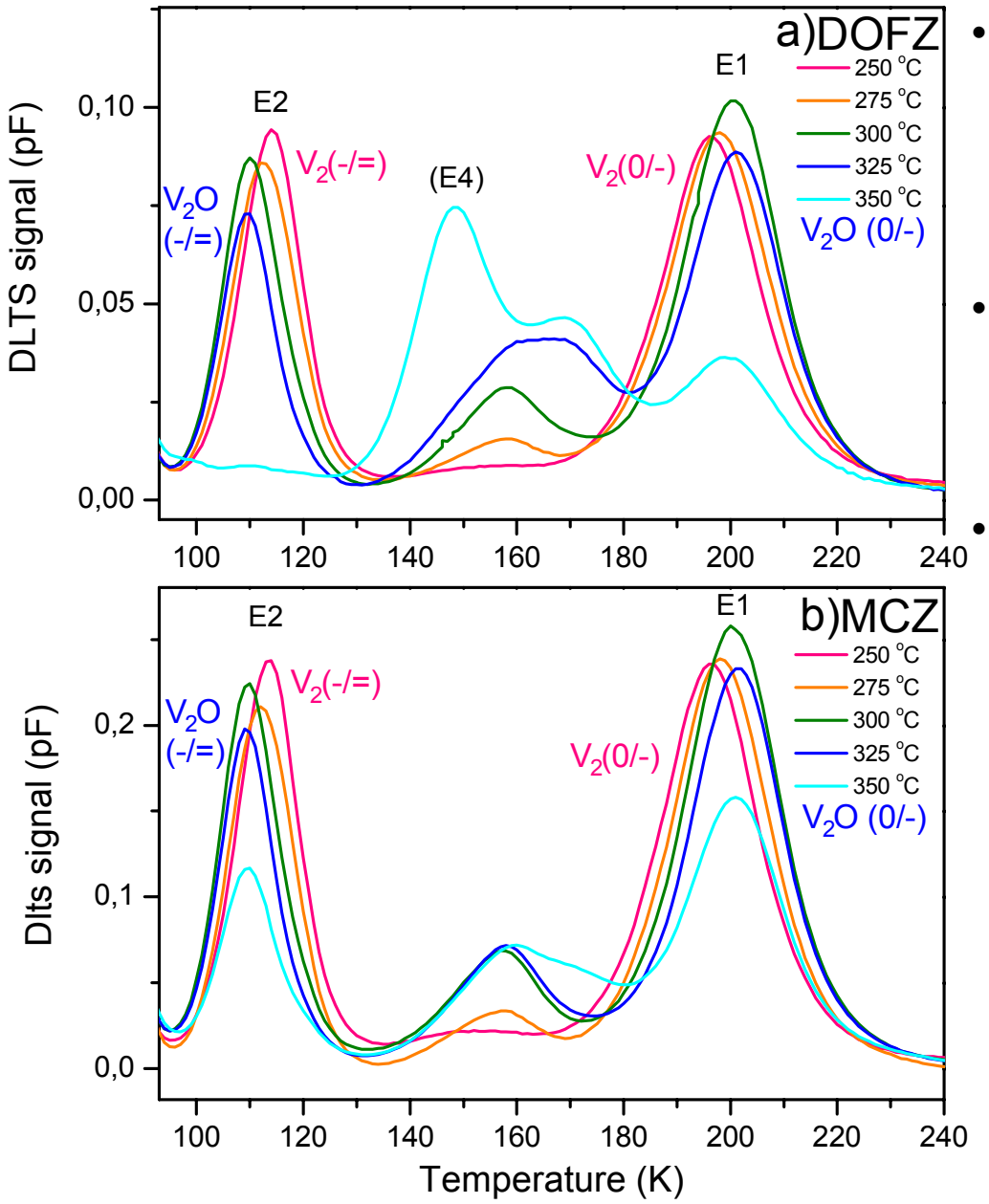
- Experimental method: 15 min isochronal annealing in the range 50-400°C, followed by DLTS scans.

Results



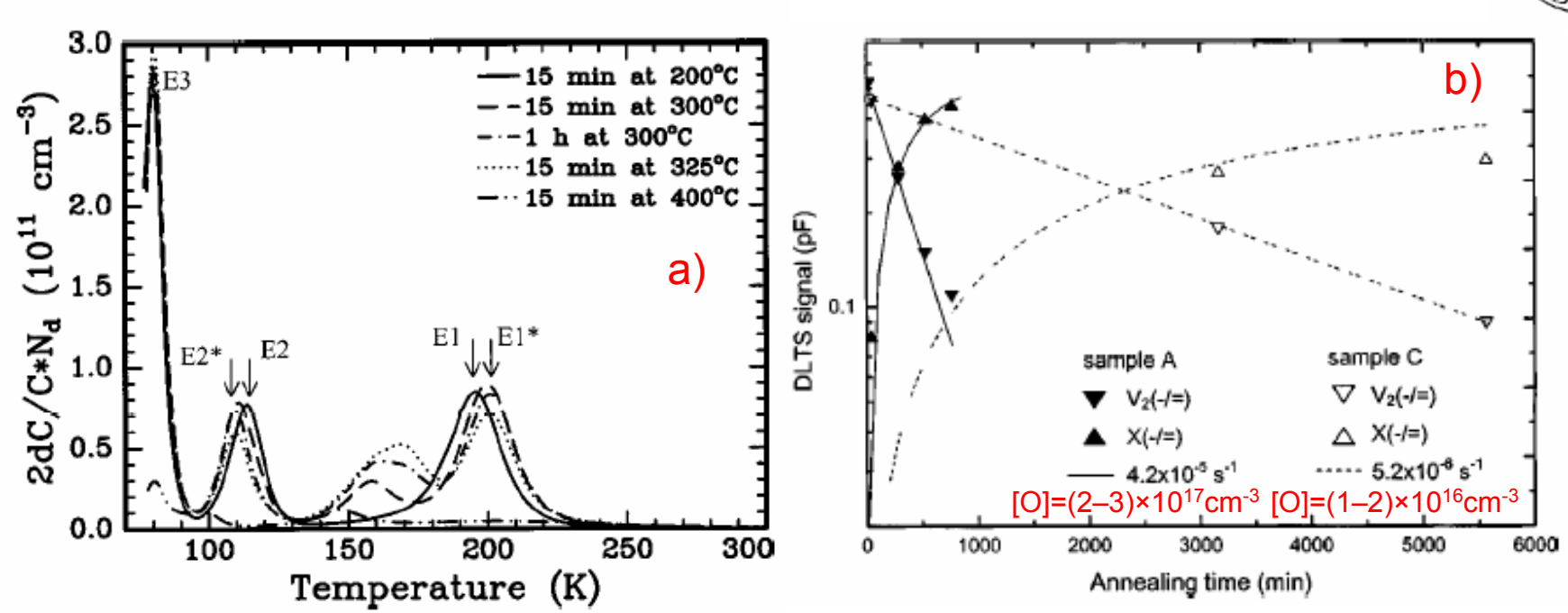
- E1 is a composite peak before any annealing. The other constituents to E1 anneal at ≤150°C.
- At 200°C we assume that E1 and E2 are purely V_2 peaks.

Results



- We observe the earlier reported shift in the V_2 related peaks. We *interpret* this as a transition from V_2 to V_2O.
- The peaks stabilize at 325°C where we assume the peaks are purely V_2O related.
- The activation enthalpies of $V_2O(0/-)$ and $V_2O(-/=)$ are 0.46eV and 0.20eV, respectively.

V_2O evidence



- One can observe a shift in V_2 related peaks during annealing of irradiated DOFZ-Si. (Figure a).) This is interpreted as a transition from V_2 to V_2O.

- The annealing rate of V_2 and formation rate of V_2O is proportional, within experimental errors, to the oxygen content. (Figure b).)

Figure references:

G. Alfieri, E. V. Monakhov, B. S. Avset, and B. G. Svensson Phys. Rev. B **68**, 233202 (2003)

E. V. Monakhov, B. S. Avset, A. Hallén, and B. G. Svensson, Phys. Rev. B **65**, 233207 (2002)

V_2O evidence

Laplace DLTS measurement (et Monakhov et al.):

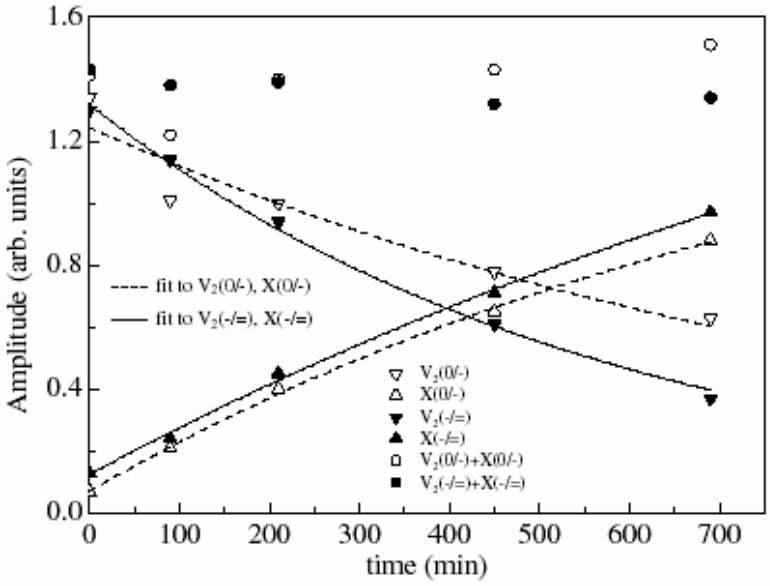


Figure 4. The amplitudes of the peaks as a function of time during isothermal annealing at 250 °C.

Laplace DLTS measurement (et Markevich et al.):

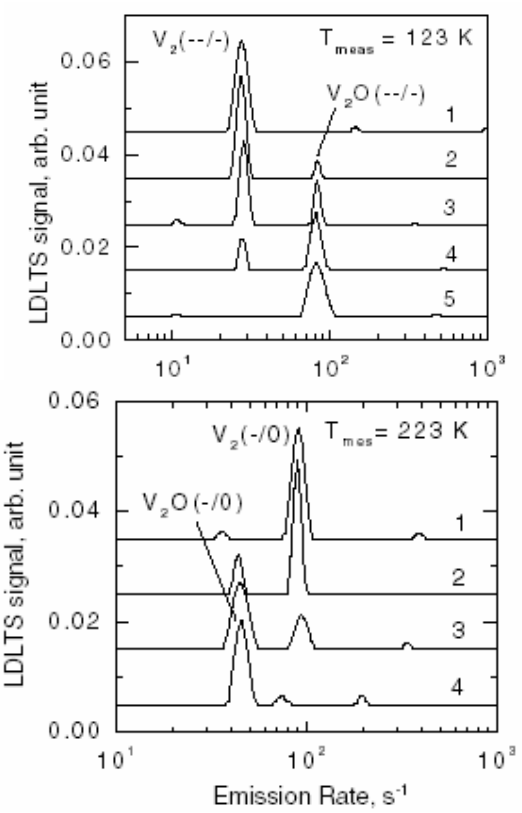
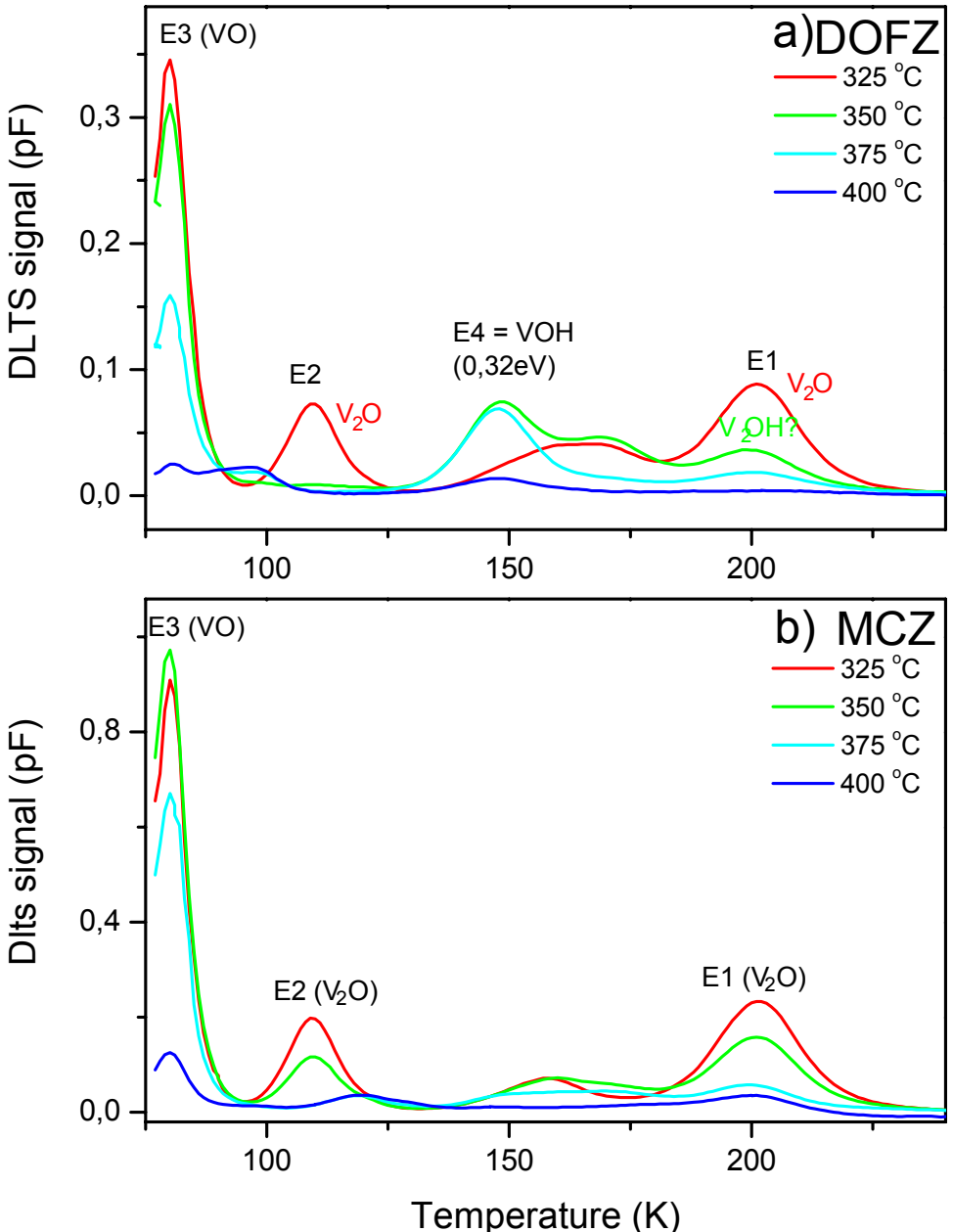


Figure references:

V. P. Markevich, A. R. Peaker, S. B. Lastovskii, L. I. Murin and J. L. Lindstom, J. Phys.: Condens. Matter **15**, S2779 (2003)

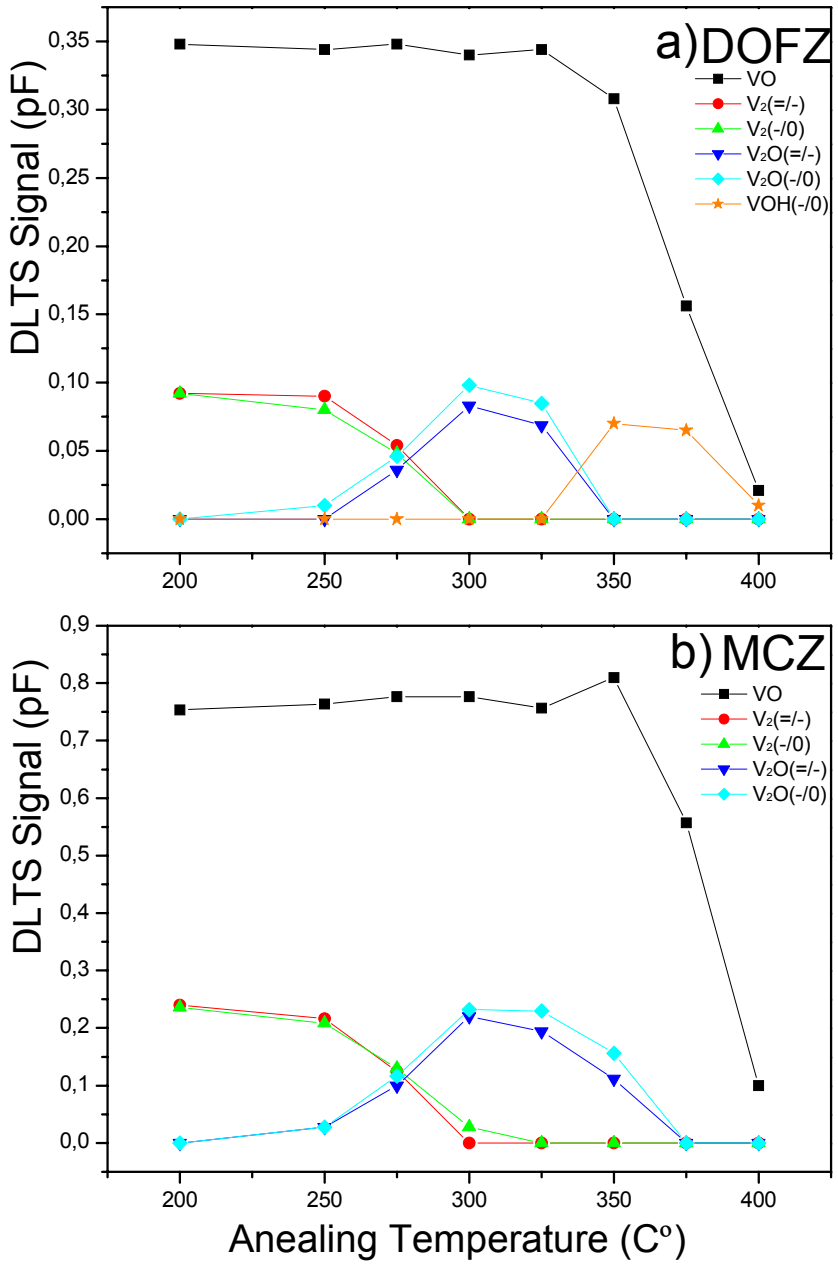
E V Monakhov, G Alfieri, B S Avset, A Hallén and B G Svensson , J. Phys.: Condens. Matter **15**, S2771 (2003)

Results



- E4 is identified as VOH. This strongly suggests a small presence of H in DOFZ but not in MCZ-Si.
- In DOFZ-Si V_2O anneals at 350°C, at the same time as VOH appears. In MCZ-Si V_2O is still present at 350°C.
- We observe a level at the E1 position in the DOFZ-Si. This is not V_2O, since E2 has annealed and V_2O is a double acceptor centre.

Results



- At 350ºC there is a small increase in VO amplitude in MCZ-Si. In contrast there is a small decrease in DOFZ-Si.
- The relative drop in VO and V^2O concentration after annealing at 350 and at 375ºC is greater in DOFZ compared with MCZ-Si.

Summary and discussion

- We have a strong indication that H is present in the DOFZ-Si. H is known to be mobile at elevated temperatures and interact with other defects. The reaction VO + H $\rightarrow$ VOH is known to occur. The interaction with H can therefore explain what looks to be a faster annealing of VO in DOFZ compared to MCZ-Si

- We suggest that the annealing of V_2O in DOFZ-Si is H-assisted similarly to that of VO: $V_2O + H \rightarrow V_2OH$. This explains the faster annealing rate of V_2O in DOFZ compared with MCZ-Si.

- Since this the electrical properties of V_2O are similar to those of V_2, it is not unreasonable to assume that the properties of V_2OH are similar to V_2H. It is known that V_2H has a level at ~0.4eV which overlaps with $V_2(0/-)$. We therefore *tentatively* identify the level observed in DOFZ-Si at 350^{o}C in the $V_2O(0/-)$ position as $V_2OH(0/-)$.

Summary and discussion

- In MCZ-Si we observe that the increase in E3 (VO) amplitude is the same (within 10%) as the decrease in E1 and E2 (V_2O) amplitude at 350°C. This may suggest that the annealing behavior of these to defects is connected. If dissociation is the annealing mechanism for V_2O, one would expect a similar behavior; $V_2O \rightarrow VO + V$.

We have observed H in DOFZ and not in MCZ.

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Our findings suggest two possible channels of V_2O annealing:

1. Interaction with H, as in the DOFZ.
2. Dissociation as in the MCZ.