



Microscopic Study of Proton Irradiated Epitaxial Silicon Detectors

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Motivation

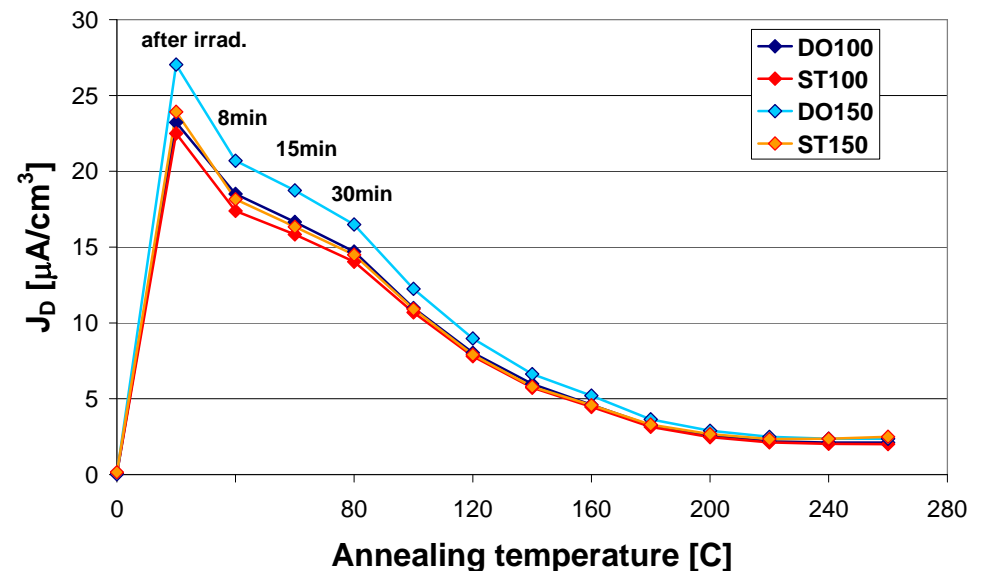
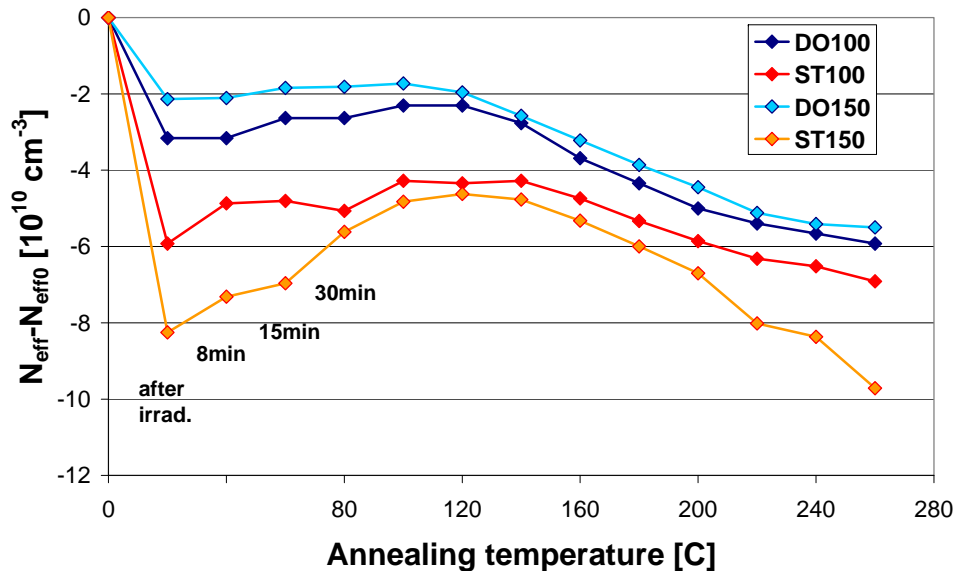
- Why **Epi**? Because this material (especially oxygen enriched) demonstrates better than **FZ** and **MCz** stable damage introduction rate, which means moderate necessary operation voltage:

Material	n-FZ		n-MCz		p-MCz	n-Epi-ST				n-Epi-DO			p-Epi-ST
Thickness [μm]	100	300	100	300	300	50	75	100	150	75	100	150	150
Resistivity [$\Omega\cdot\text{cm}$]	300	6000	1000	>500	>2000	50	150	300	500	150	300	500	1000
β_{protons} [10^{-3} cm^{-1}]	8	6	-12	-17	-7	-23	-12	-6	-6	-14	-10	-12	-10
β_{neutrons} [10^{-3} cm^{-1}]	4-5	12	9	>10	16	-5	4-6		5-6	5-6		5-6	6

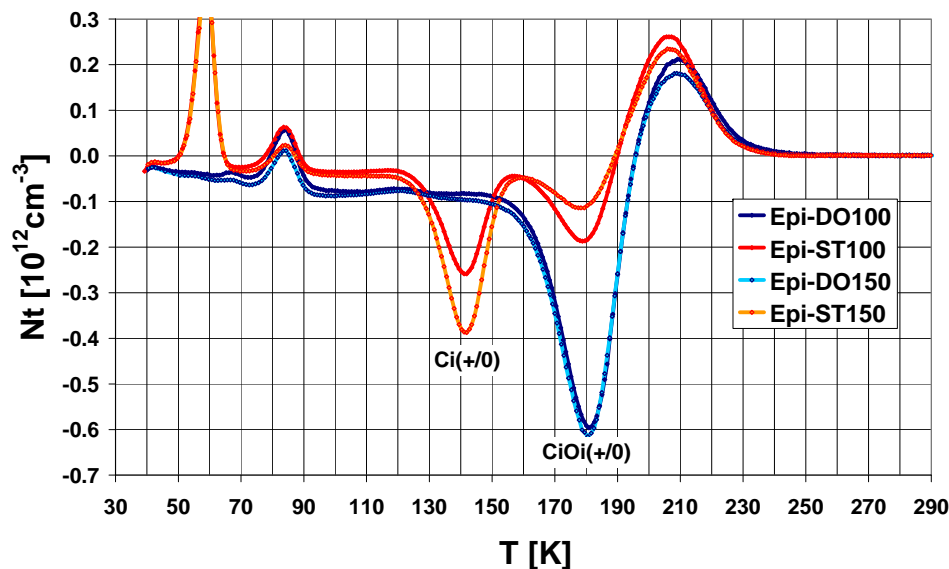
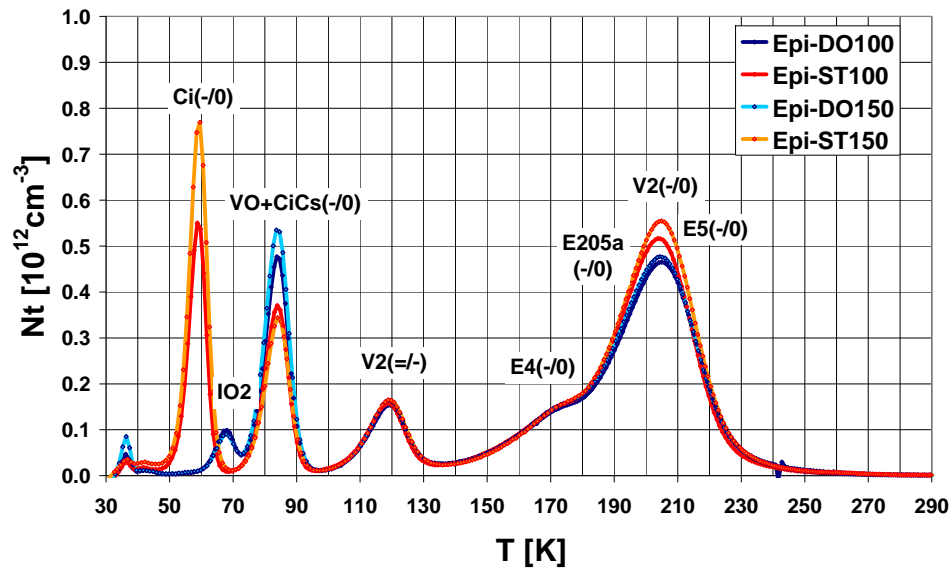
- Recently, correlation was established between defects concentration, obtained from **microscopic** study, and depletion voltage and leakage current values from **macroscopic** CV/IV measurements for **75 μm** thick Epi-diodes;
- Here we present preliminary results of similar study for Epi-diodes with thickness up to **150 μm** , which can already be considered as an option for S-LHC

Devices under test and measurement procedures

- 4 n-Epi pad diodes, ST and DO, 100 and 150 μm thick (one of each type and thickness) were irradiated with 23 GeV protons in the same batch to $\sim 7 \times 10^{11}$ p/cm²;
- After irradiation they were annealed:
isothermally at 80°C to 8, 15 and 30 min, and then
isochronally during 30 min at 100, 120, 140, ... up to 260°C
- Between each annealing steps CV/IV (at RT) and DLTS measurements were performed to obtain effective doping concentration N_{eff} , leakage current density J_D and defects parameters – concentration N_T , capture cross-section σ and activation energy ΔH .

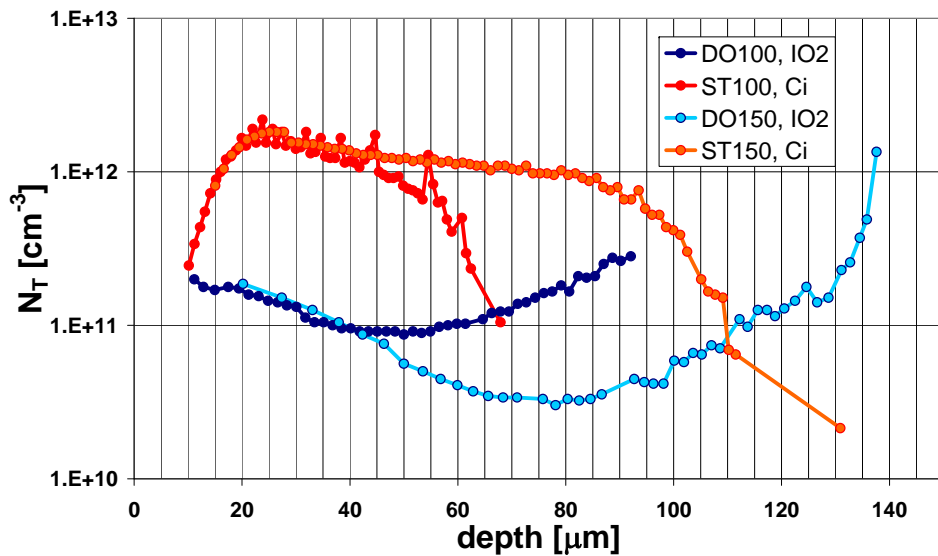
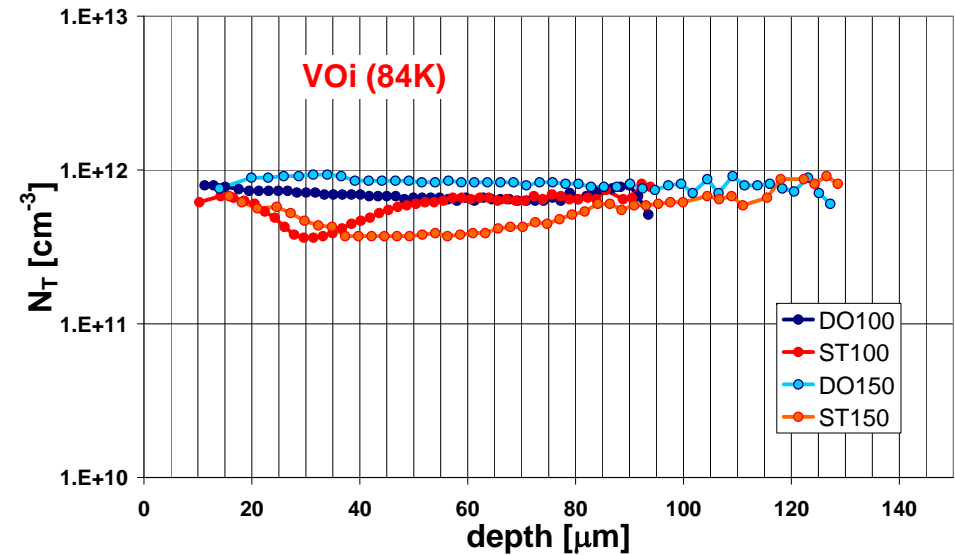
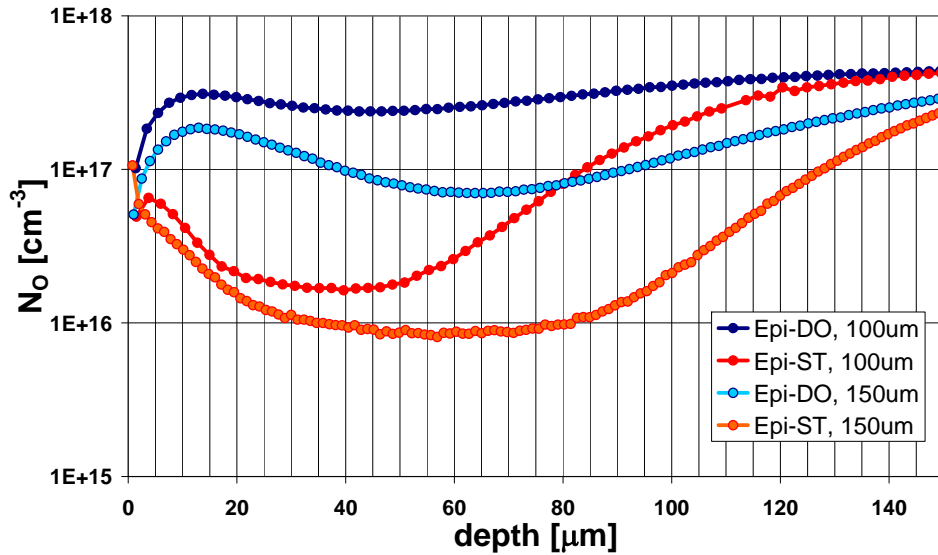


DLTS spectra after irradiation



- Oxygen enriched material shows presence of IO2 and higher concentration of VO defects, while Carbon immediately went to CiOi
- In standard samples Carbon concentration evidently depends on the Oxygen content (which is higher in 100 μ m)
- Above 100K electron injection spectra are practically equal, but higher 205K peak in standard material, which might be due to E-centers

Depth profile of Oxygen and related defects concentration

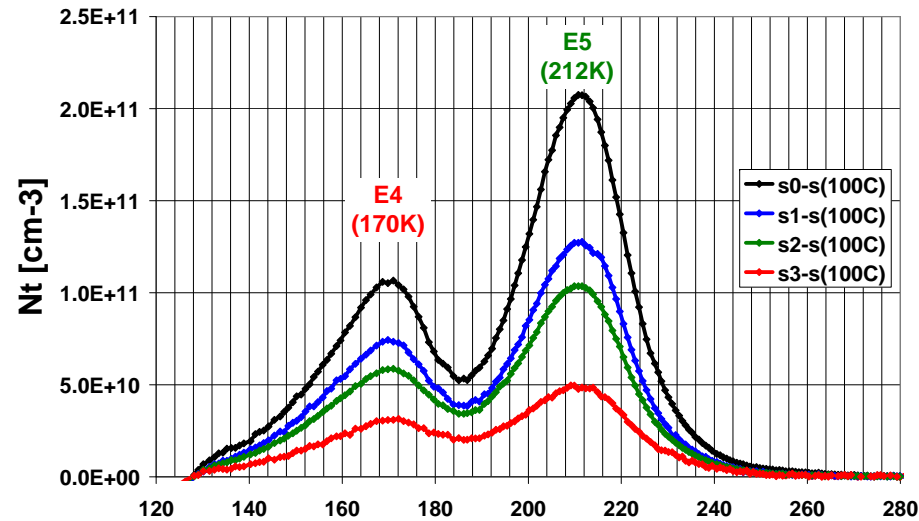


As expected:

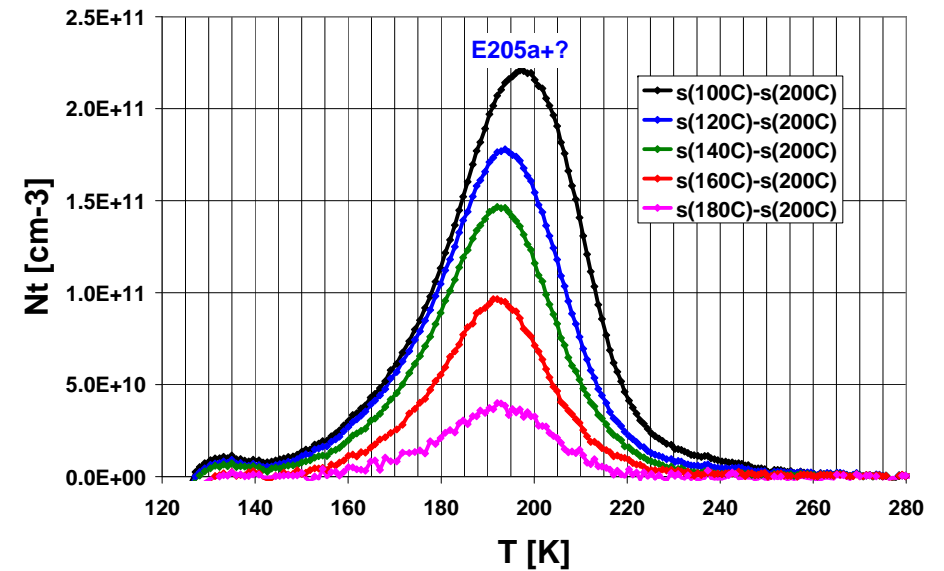
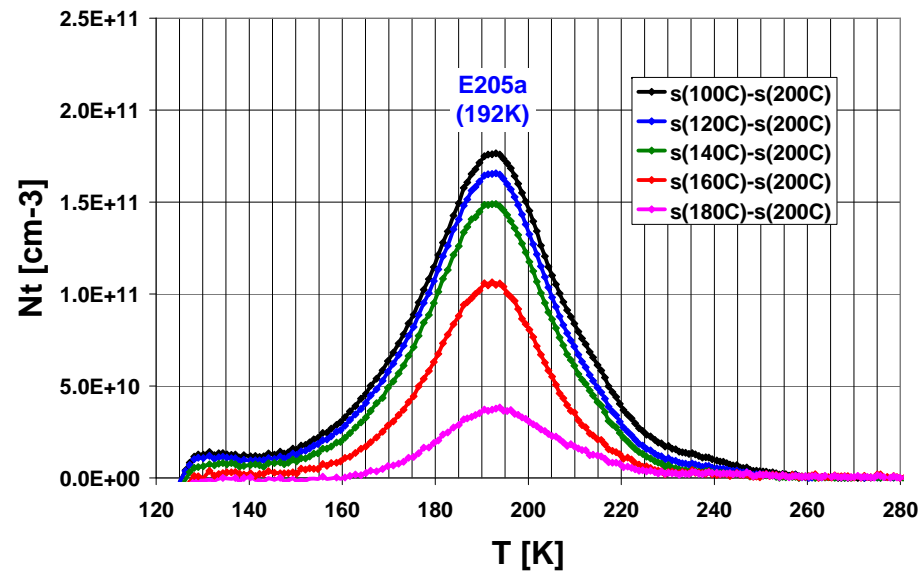
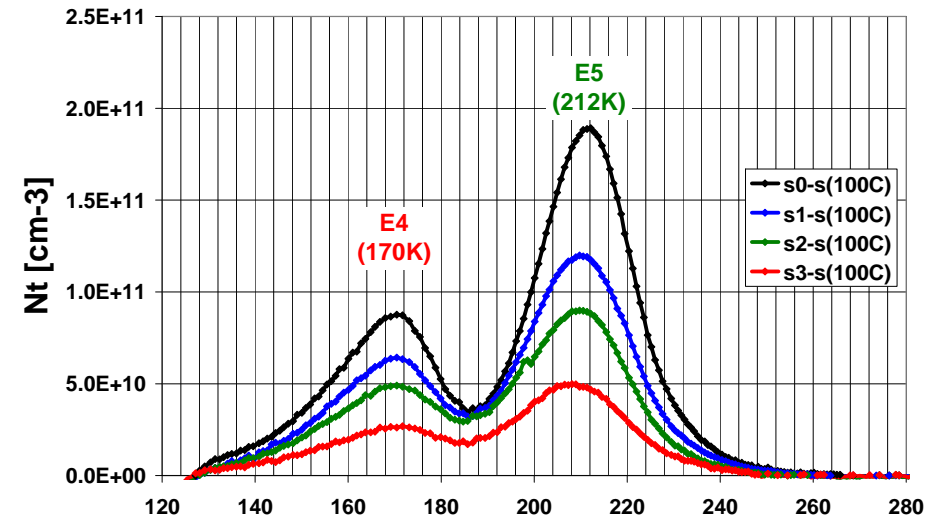
- IO_2 and VO distribution correlates with Oxygen;
- C_i anticorrelates due to C_iO_i formation

Annealing of current related defects

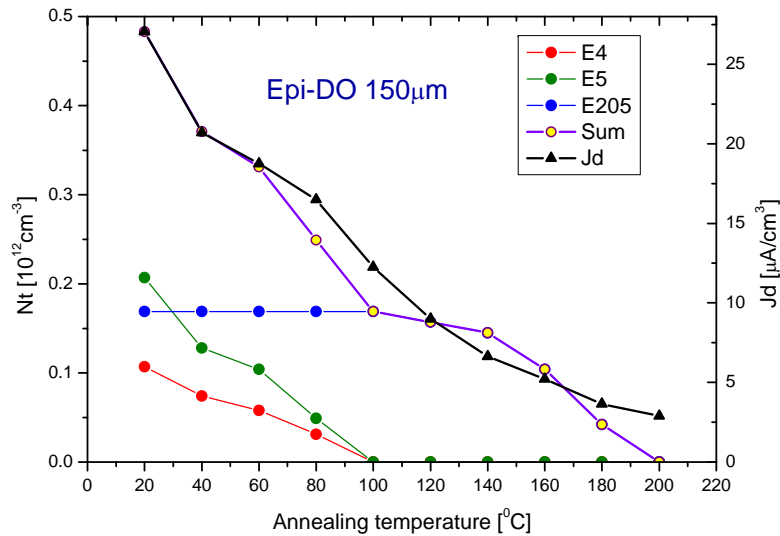
Epi-DO 150 μ m



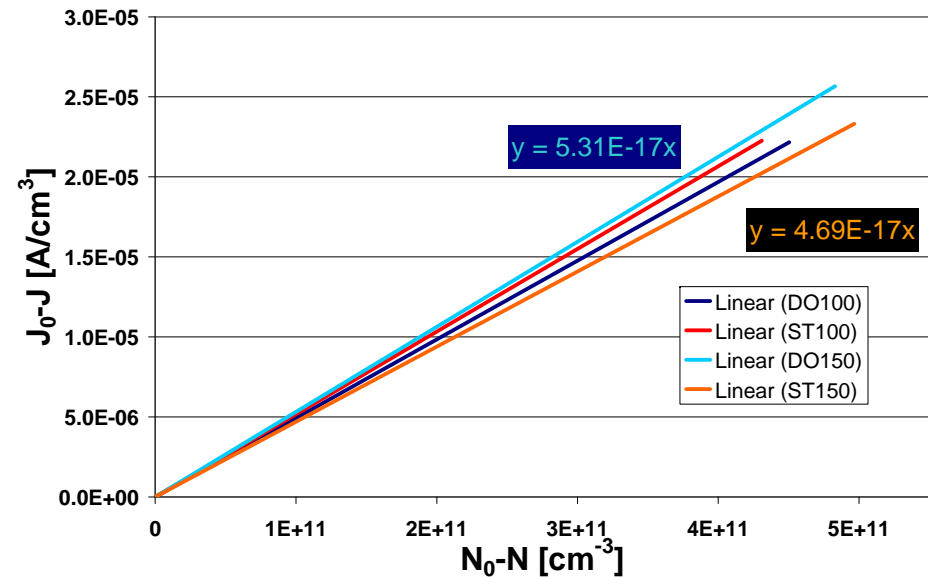
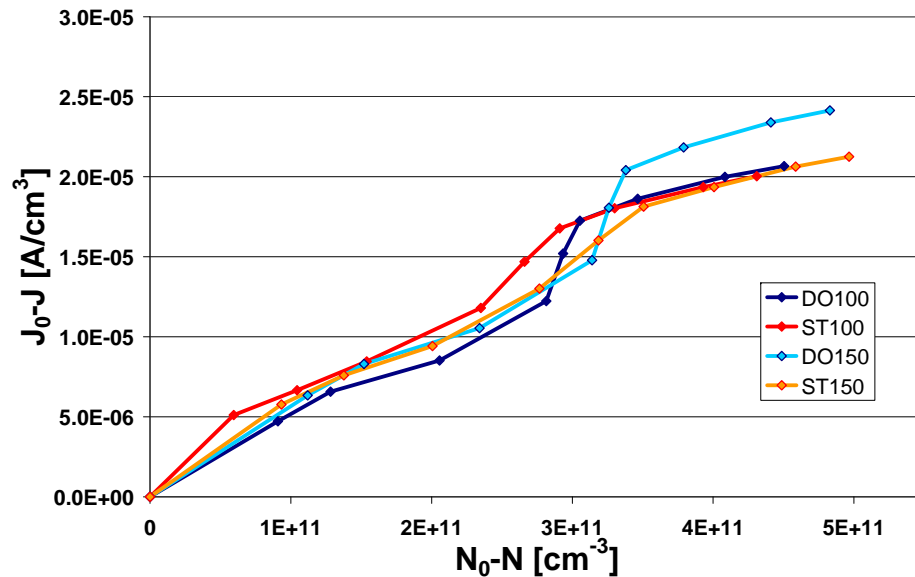
Epi-ST 150 μ m



Correlation between leakage current and defects concentration

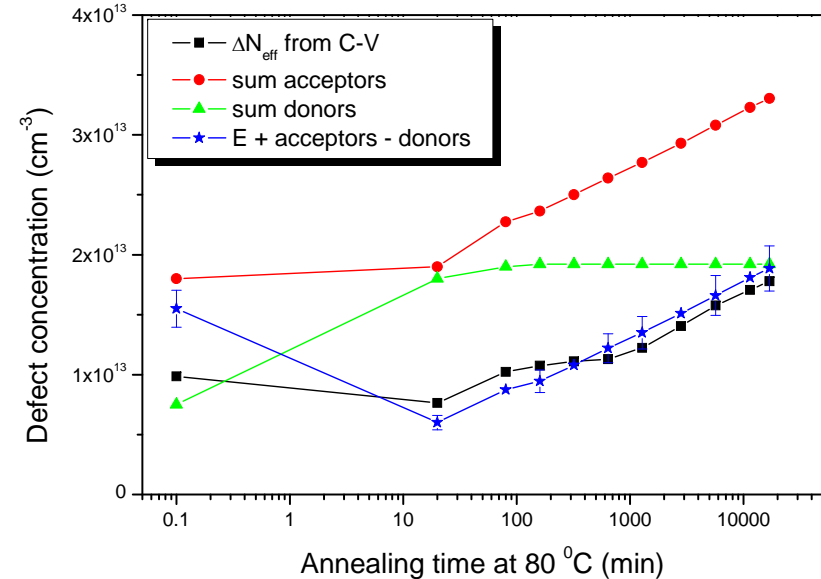
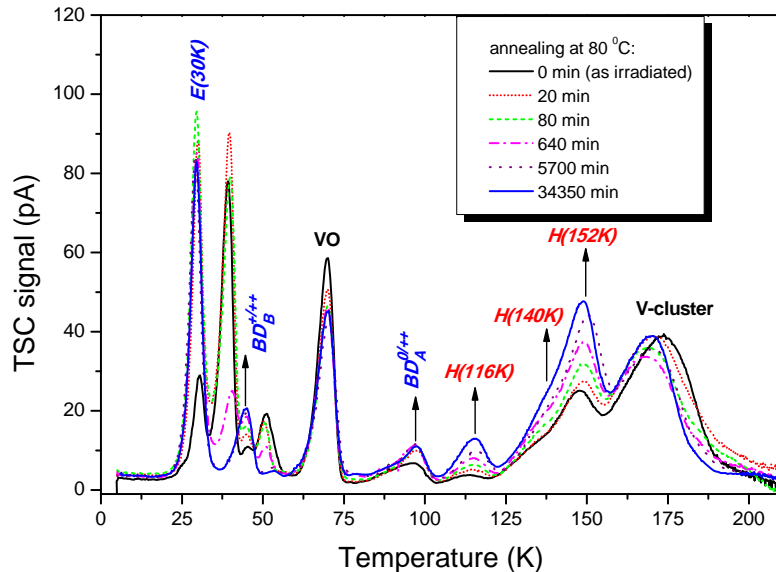


- Correlation exists, but not perfect
- Perhaps, defect concentrations should be calculated more accurate and/or additional defects should be taken into consideration

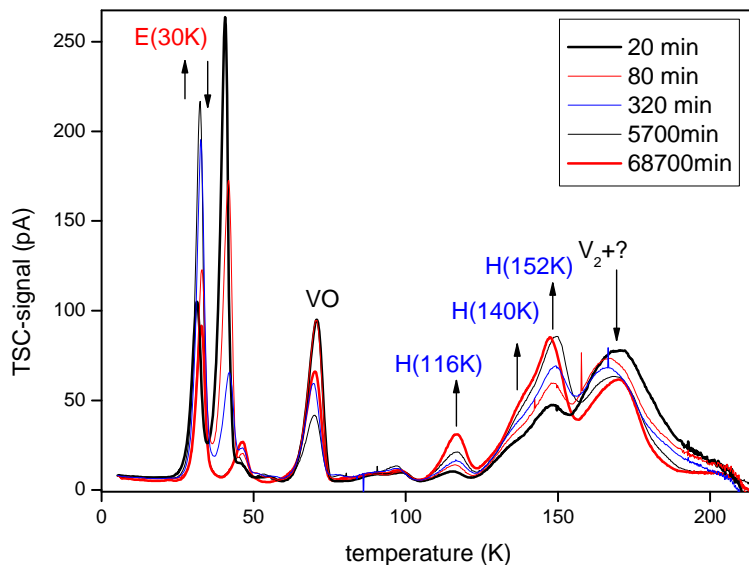


TSC: correlation between defects concentration and N_{eff} from C-V

Epi-DO 75 μm , p 23GeV, $\Phi_{\text{eq}} = 2.33 \times 10^{14} \text{ cm}^{-2}$



Epi-DO 150 μm , p 23GeV, $\Phi_{\text{eq}} = 2.1 \times 10^{14} \text{ cm}^{-2}$



75 μm : good agreement between microscopic and macroscopic measurements;

150 μm : TSC behaviour with annealing look similar to 75 μm , analysis is in progress

Summary:

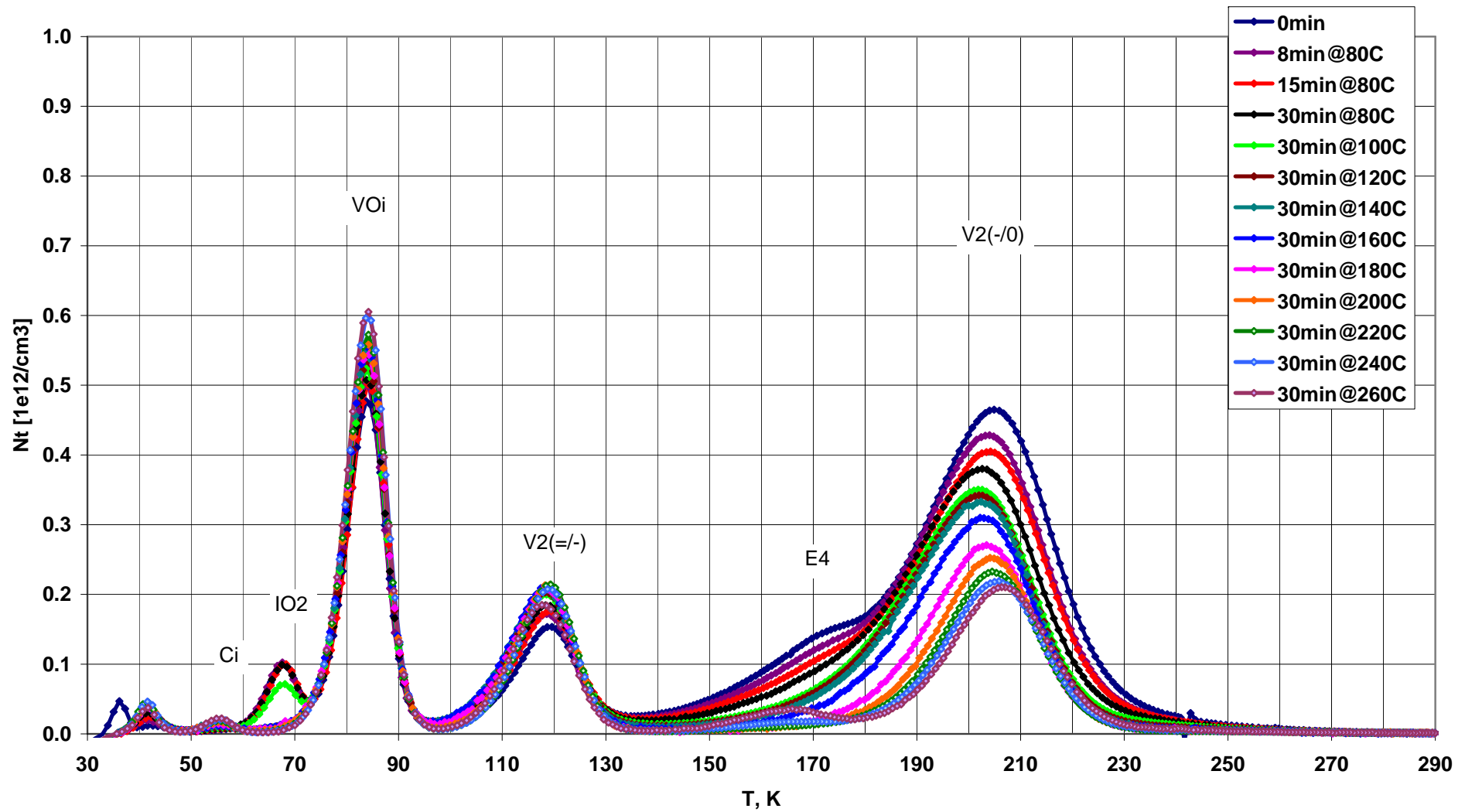
- Thick Epi-diodes (ST & DO) showed similar microscopic behaviour as earlier studied thin ones;
- Clear dependence on Oxygen content is observed;
- Correlation between leakage current and concentration of related defects exists evidently, but needs better evaluation;

Outlook:

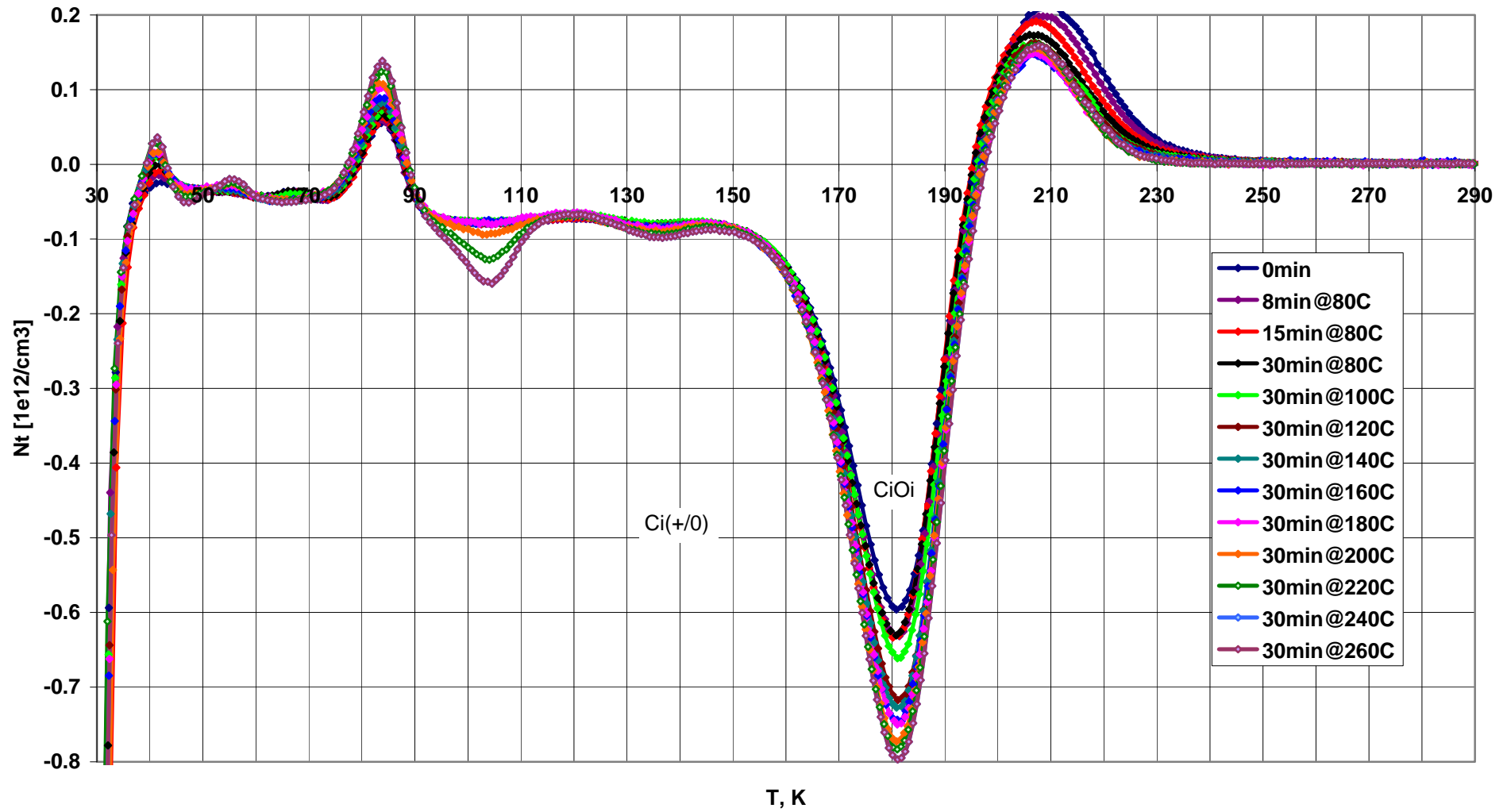
- Continue isochronal annealing study up to ~350C;
- Improve analysis of DLTS spectra, in particular, on group of defects around 200K;
- Analyze TSC spectra obtained for 150 μm Epi-diodes

Spare slides:

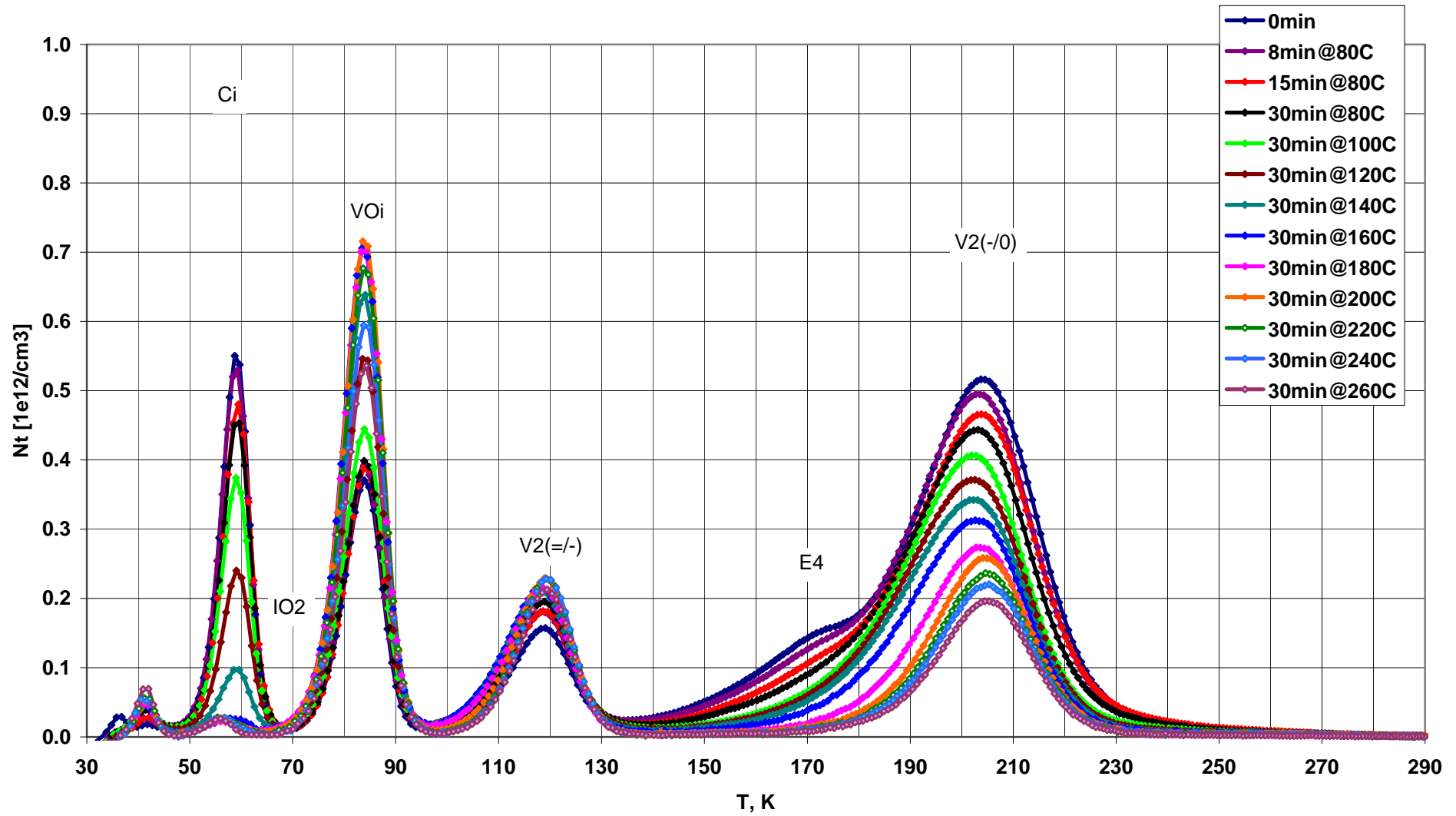
Epi-DO, 100 um, electron injection



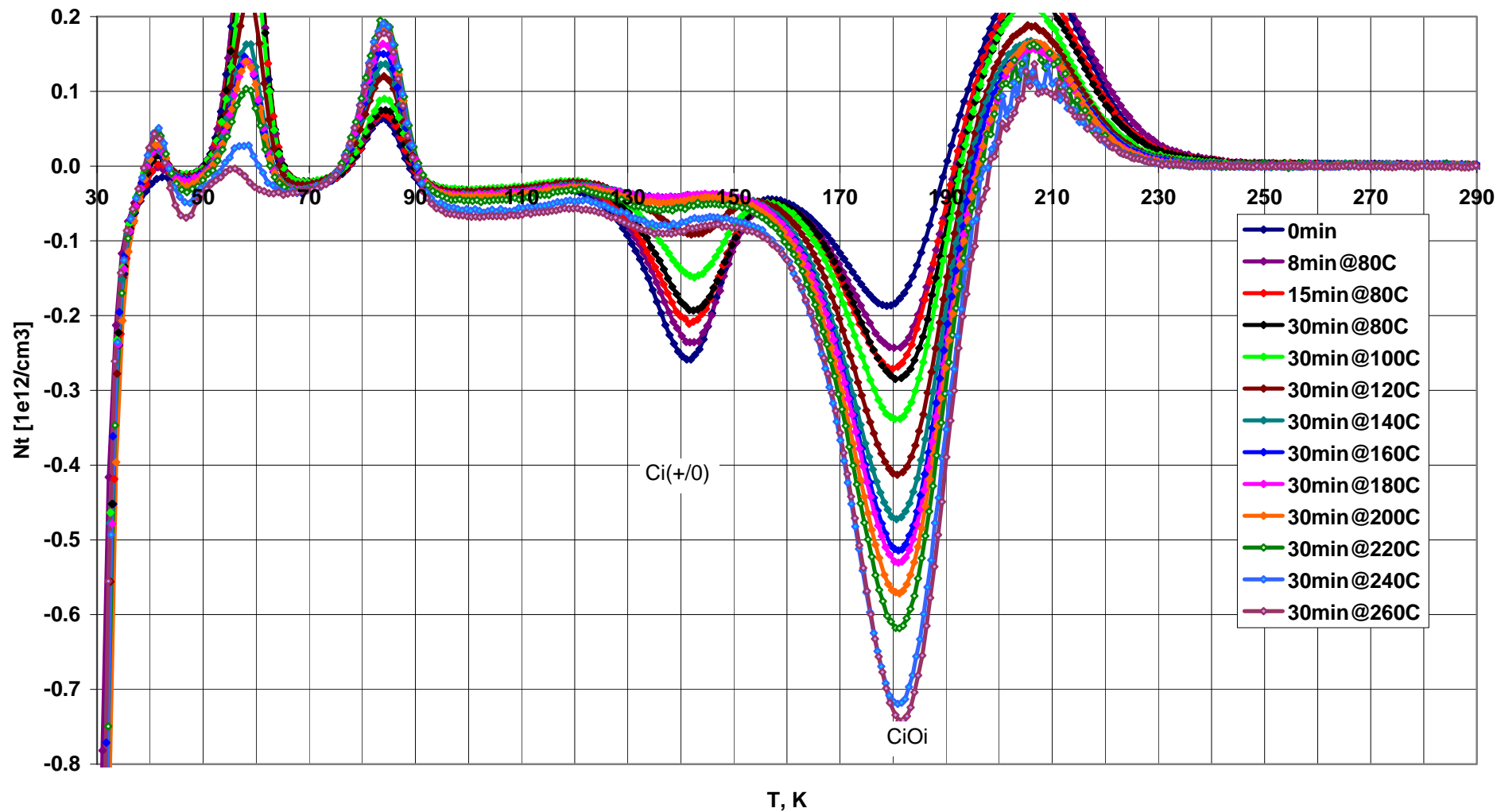
Epi-DO, 100 um, hole injection



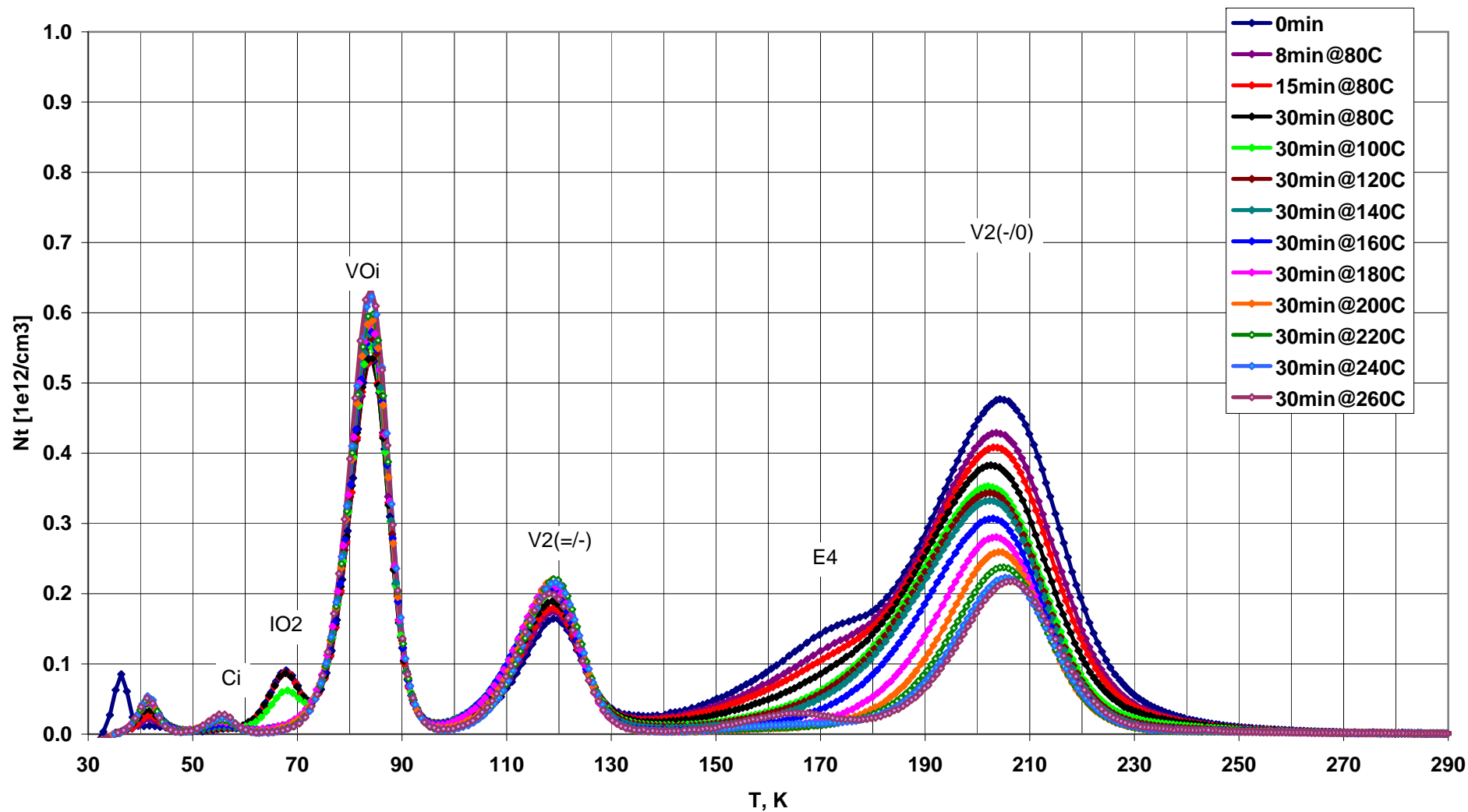
Epi-ST, 100 um, electron injection



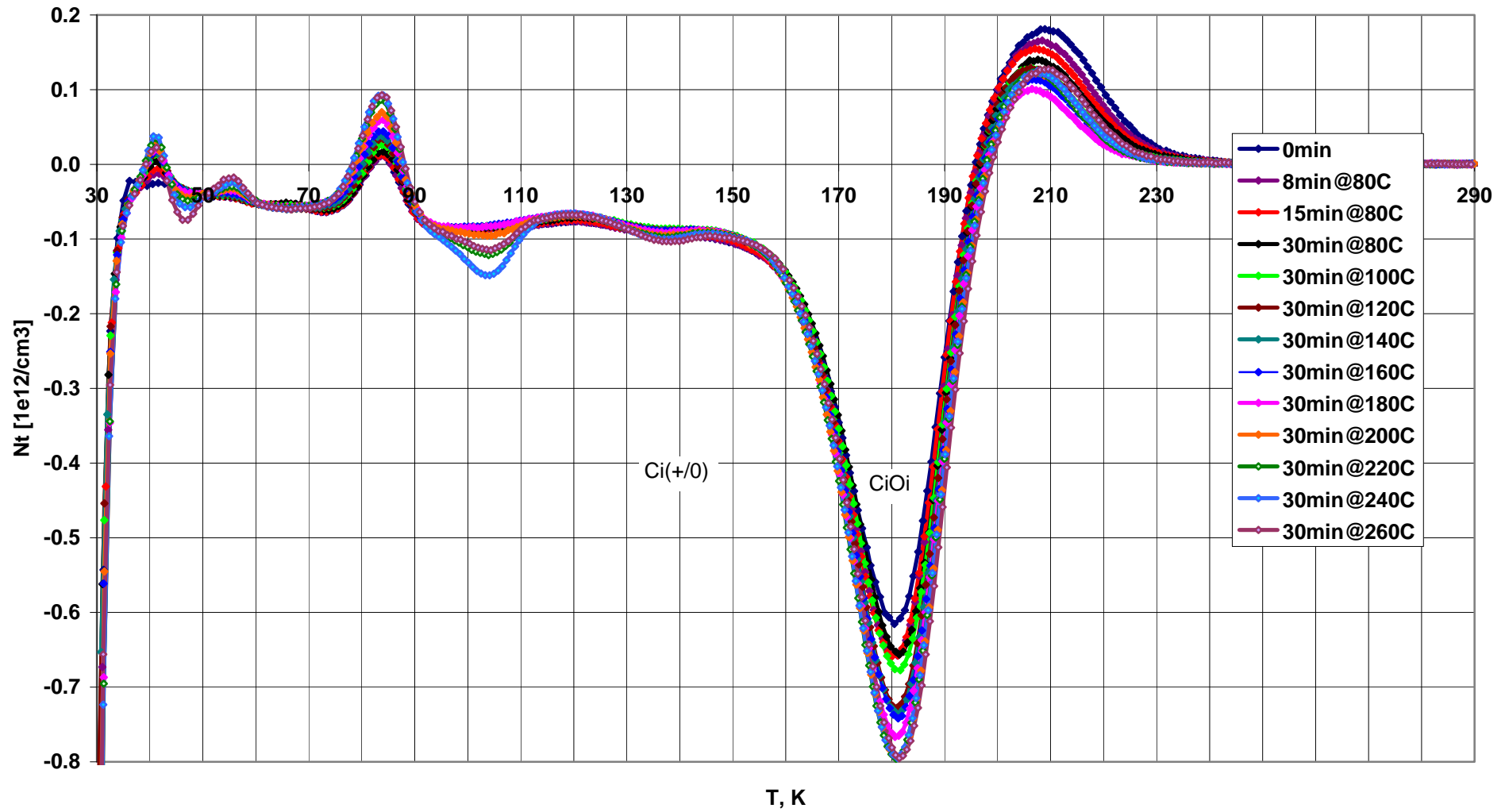
Epi-ST, 100 um, hole injection



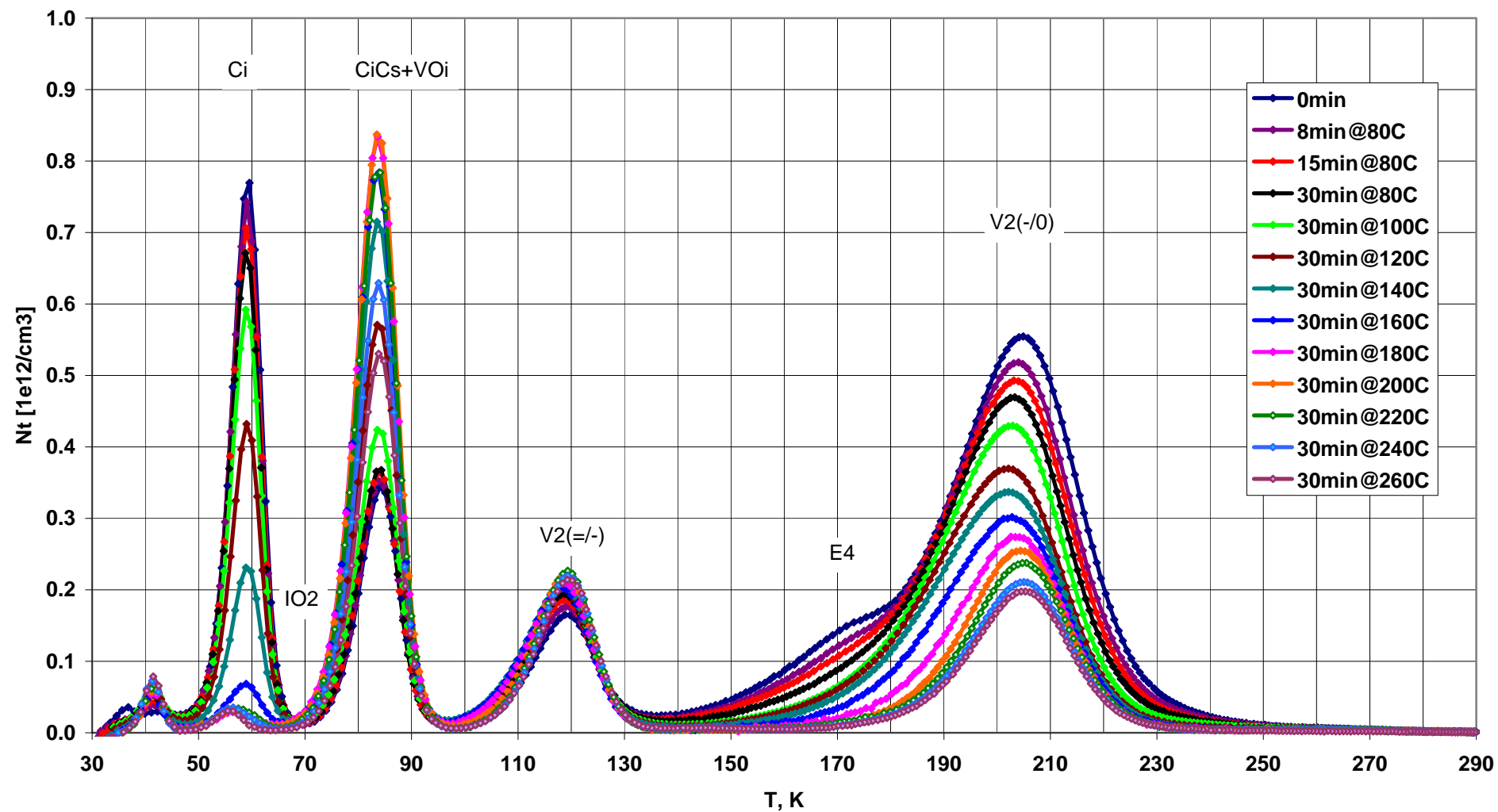
Epi-DO, 150 um, electron injection



Epi-DO, 150 um, hole injection



Epi-ST, 150 um, electron injection



Epi-ST, 150 um, hole injection

