Institute of Electronic Materials Technology

Joint Laboratory for Characterisation
of Defect Centres in Semi-Insulating Materials

Annealing induced evolution of defect centers in epitaxial silicon irradiated with high proton fluences

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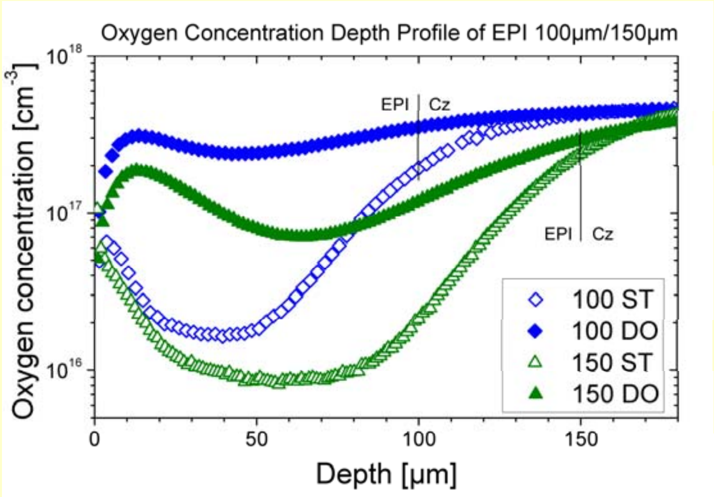
Outline

- Samples – pad detectors based on epitaxial silicon irradiated with high proton fluence
- Details of HRPITS measurements
- HRPITS images of spectral fringes for radiation defects in standard (ST) and oxygenated (DO) epitaxial layers before and after 1-h isochronal annealing
- Comparison of defect levels in ST and DO epitaxial silicon
- Comparison of defects concentrations in ST and DO epitaxial silicon
- Conclusions

Samples

- Epitaxial n-Si pad-detectors on Cz-substrate produced by ITME/CiS
- Resistivity : 500 Ωcm, Thickness: ~ 150 µm, Size: 5 x 5 mm^2
- Standard (ST) and oxygen enriched (DO, diffusion for 24 h at 1100°C) material
- 24 GeV/c-proton-irradiation (CERN PS), $\Phi_{eq} = 1.71 \times 10^{16}\ cm^{-2}$

Material	d [µm]	Wafer	Orientation	$N_{eff,0}$ [P] [10^{12} cm^{-3}]	[O] [10^{16} cm^{-3}]
EPI-ST 150	147	261636-13	<100>	8.8	4.5
EPI-DO 150	152	261636-09	<100>	8	14.0



From:

Charge collection and trapping effects in 75 µm, 100 µm and 150 µm thick n-type epitaxial silicon diodes after proton irradiation

Julian Becker, Eckhart Fretwurst, Jörn Lange, Gunnar Lindström, Hamburg University ,13th RD50 Workshop, CERN, November 2008

Imaging of defect levels for as-irradiated samples and after following annealing stages:

HT1: 1h, 80 ^{o}C + 24 h, RT

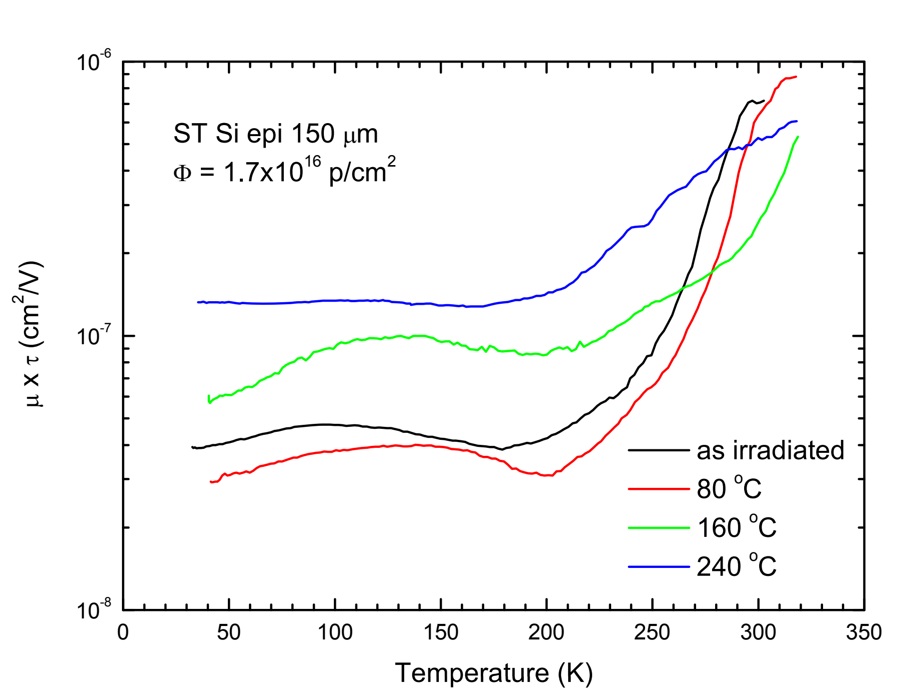
HT2: (1h, 80 ^{o}C + 24 h, RT) + 1h, 160 ^{o}C + 24 h, RT

HT3: (1h, 80 ^{o}C + 24 h, RT + 1h, 160 ^{o}C + 24 h, RT) + 1h, 240 ^{o}C + 24 h, RT

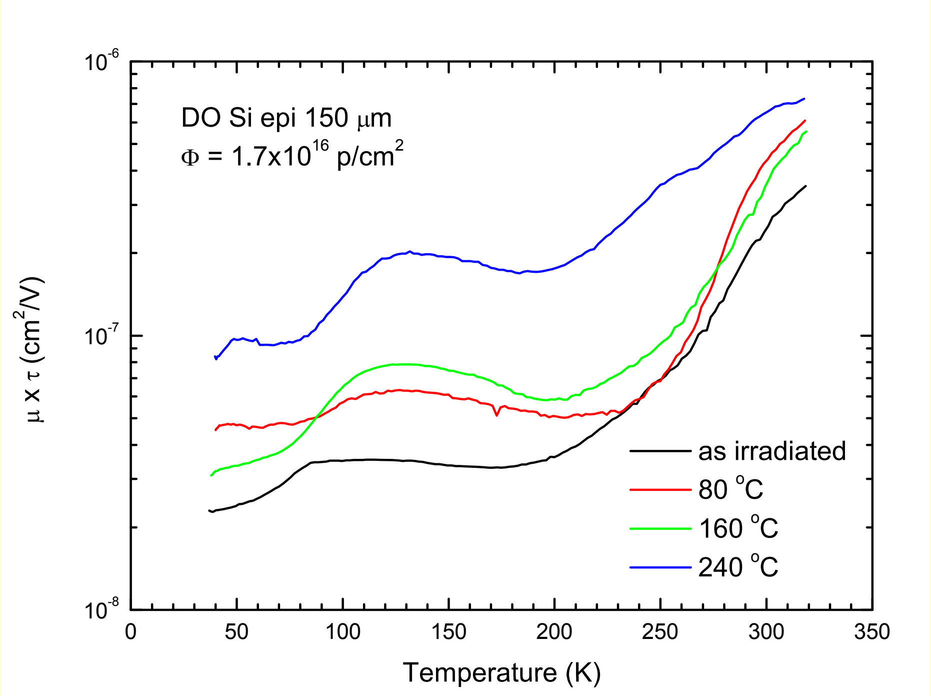
Details of HRPITS measurements

- Temperature range: 30 – 300 K, $\Delta T = 2$ K
- Excitation source: 1 mW, 650 nm laser diode (hν = 1.908 eV)
- Excitation pulse parameters: Period – 250 ms, Width – 50 ms
- Photon flux: 1.3×10^{17} $cm^{-2}s^{-1}$
- BIAS: 20 V
- Gain: 1×10^{6} – 1×10^{8} V/A
- AVG: 250 waveforms
- Analysis of photocurrent relaxation waveforms:
  - 2D correlation procedure (multi-window approach) → images of correlation spectral fringes for radiation defect centres
  - 2D inverse Laplace transformation algorithm → images of Laplace fringes for radiation defect centres

Effect of annealing on mobility lifetime product fluence $1.7x10^{16}$ p/cm^2

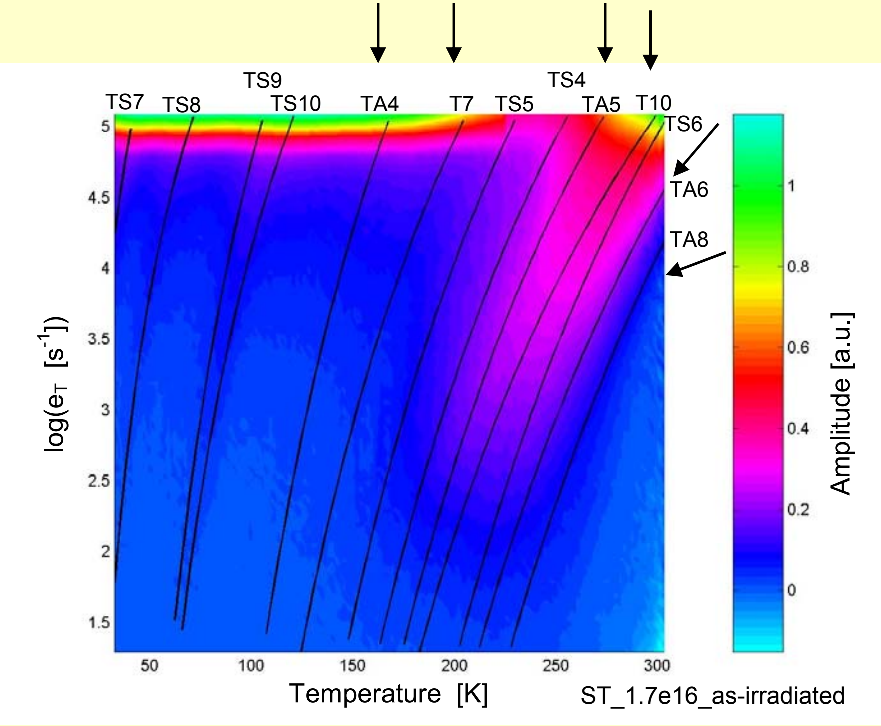


standard epilayer

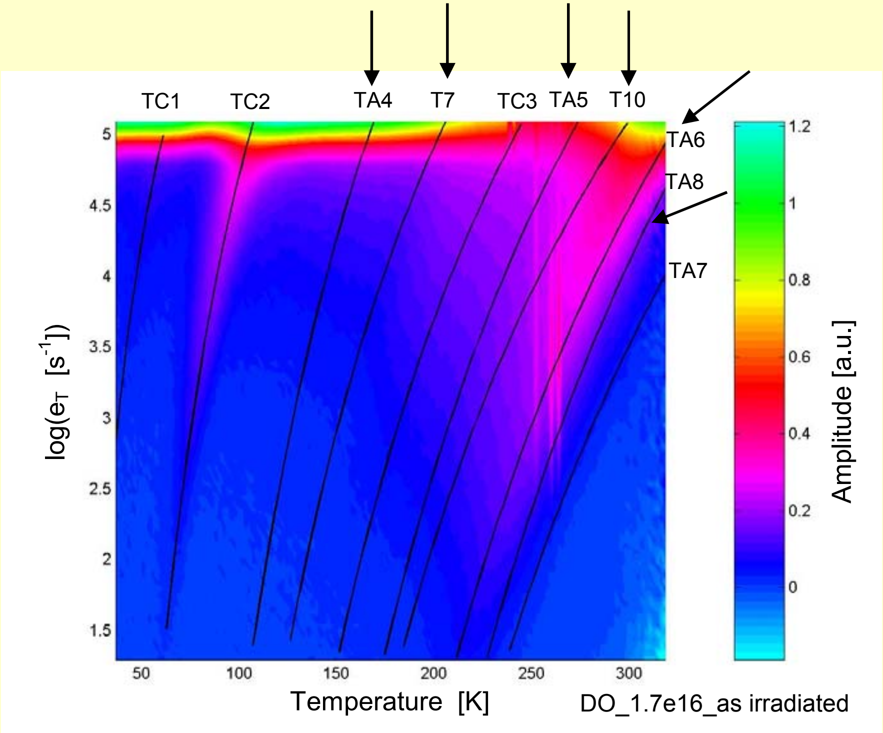


oxygenated epilayer

HRPITS images – fluence 1.7x10^{16} p/cm^2 – as-irradiated

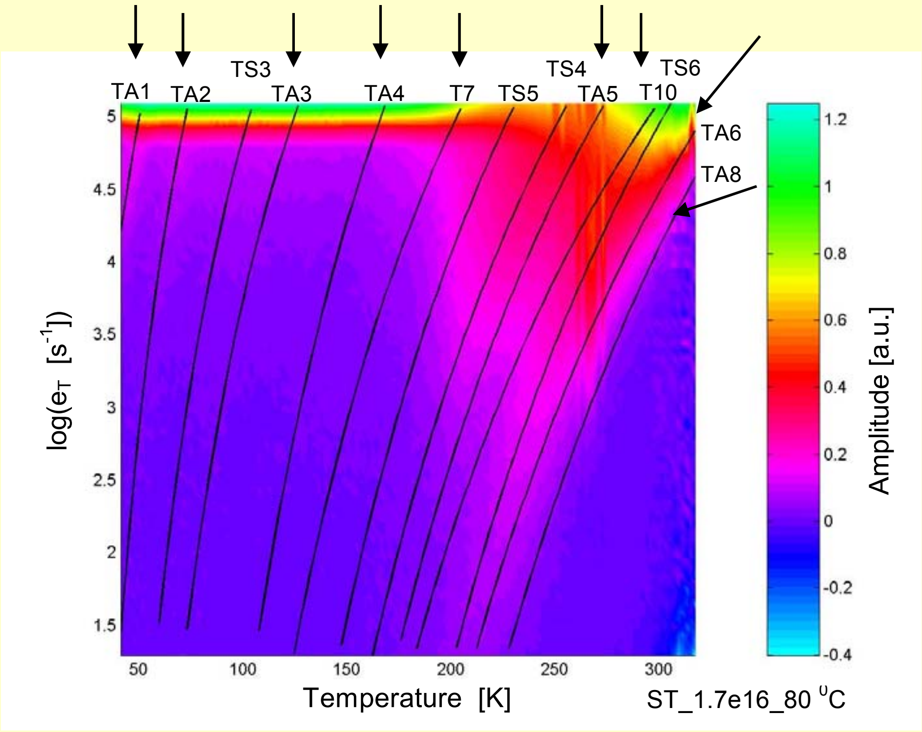


standard epilayer

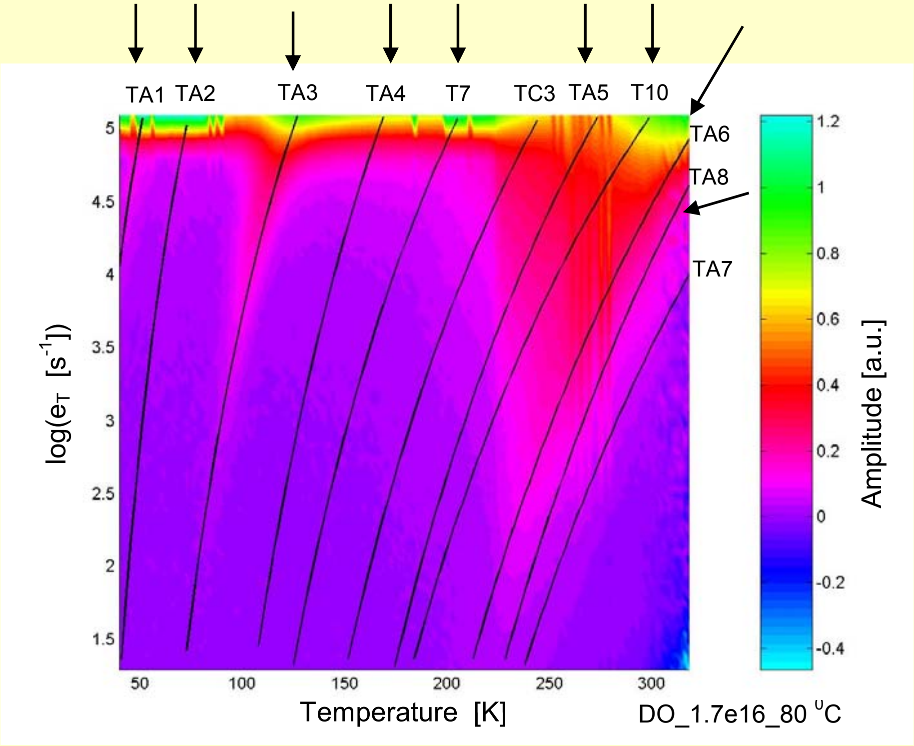


oxygenated epilayer

HRPITS images – fluence $1.7x10^{16}$ p/cm^2 – 80 ^{o}C

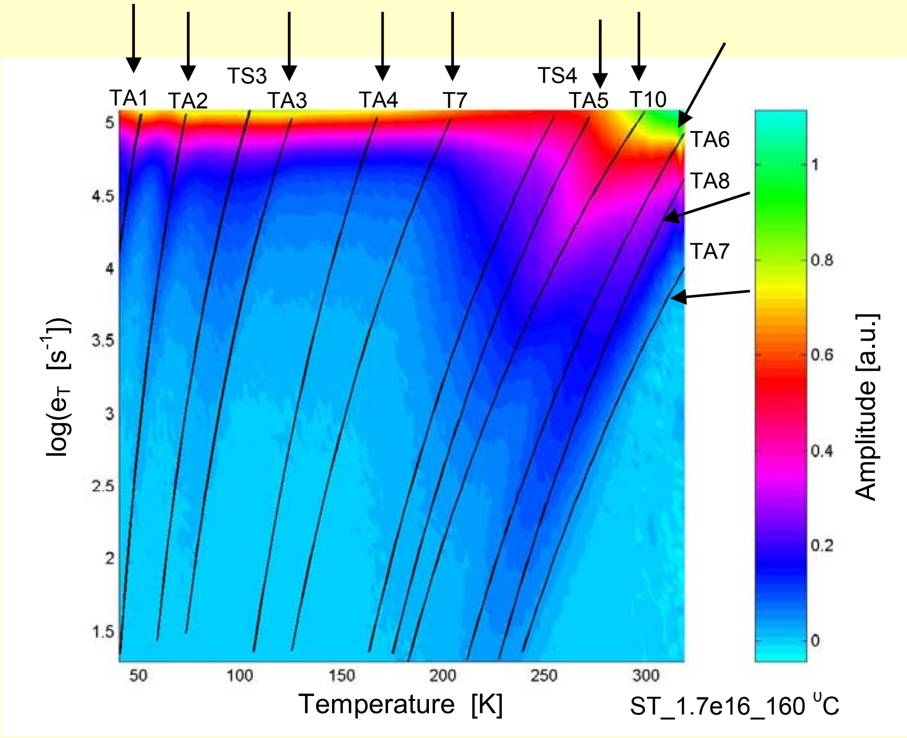


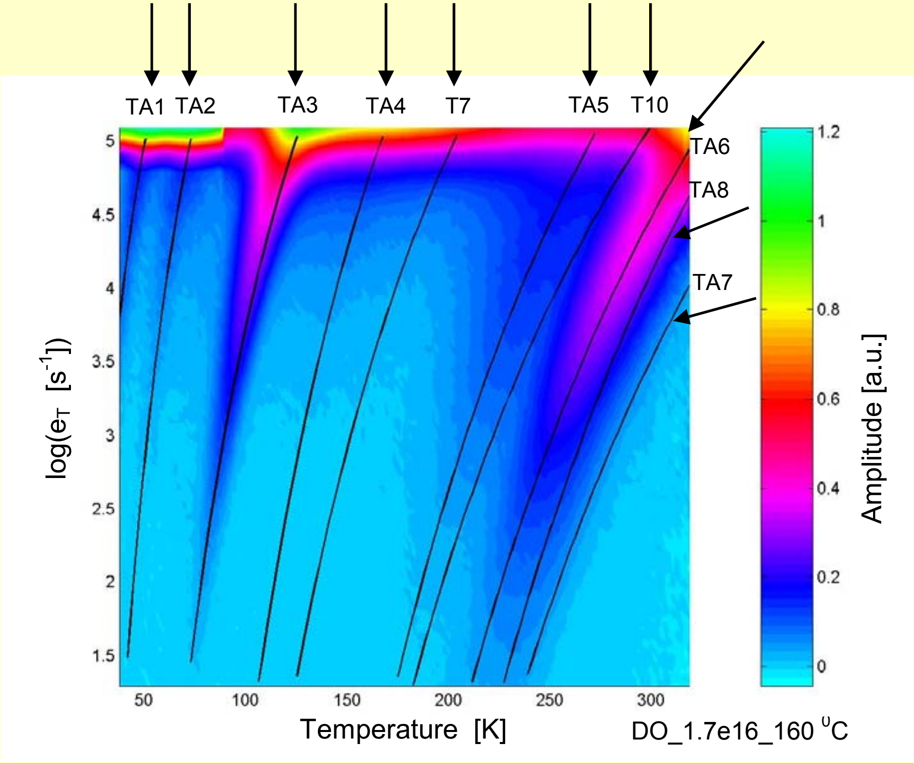
standard epilayer



oxygenated epilayer

HRPITS images – fluence $1.7x10^{16}$ p/cm^2 – 160 ^oC

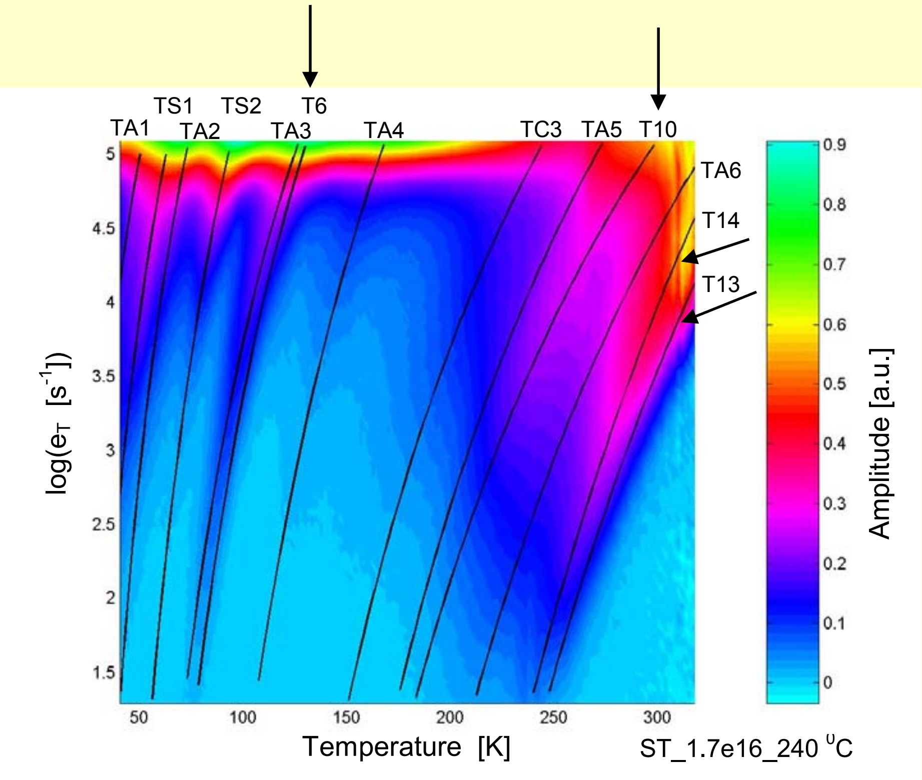


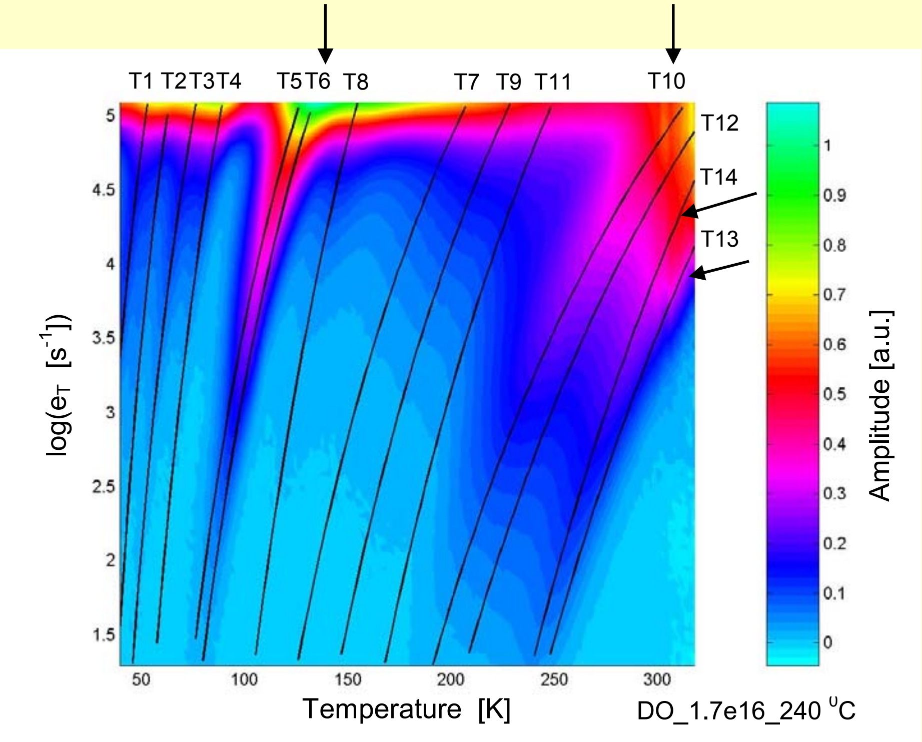


standard epilayer

oxygenated epilayer

HRPITS images – fluence $1.7x10^{16}$ p/cm^2 – 240 ^oC





standard epilayer

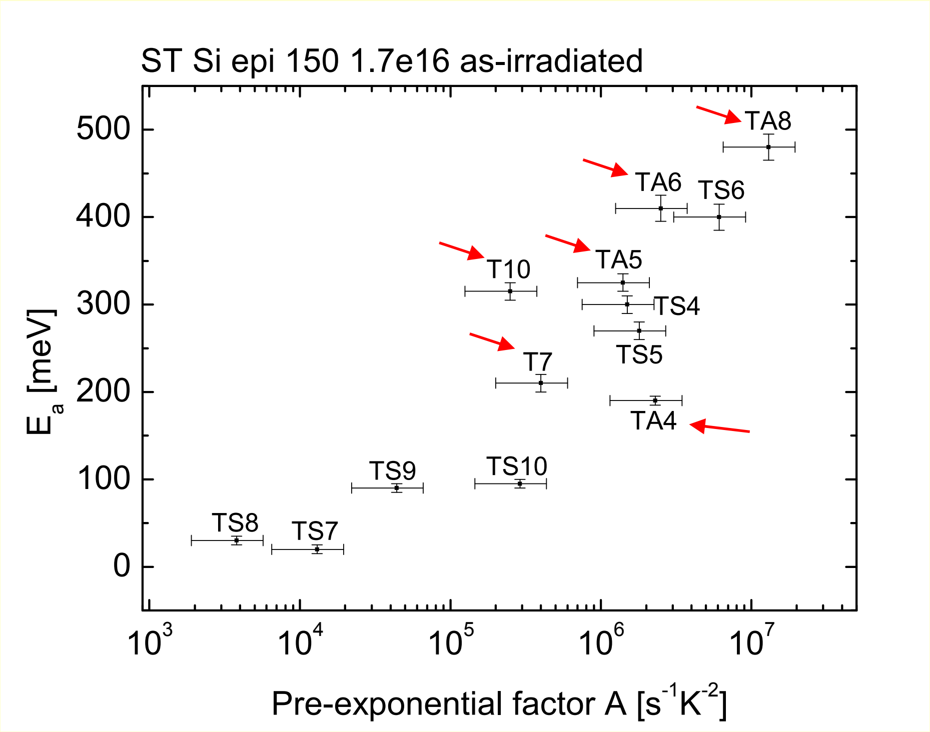
oxygenated epilayer

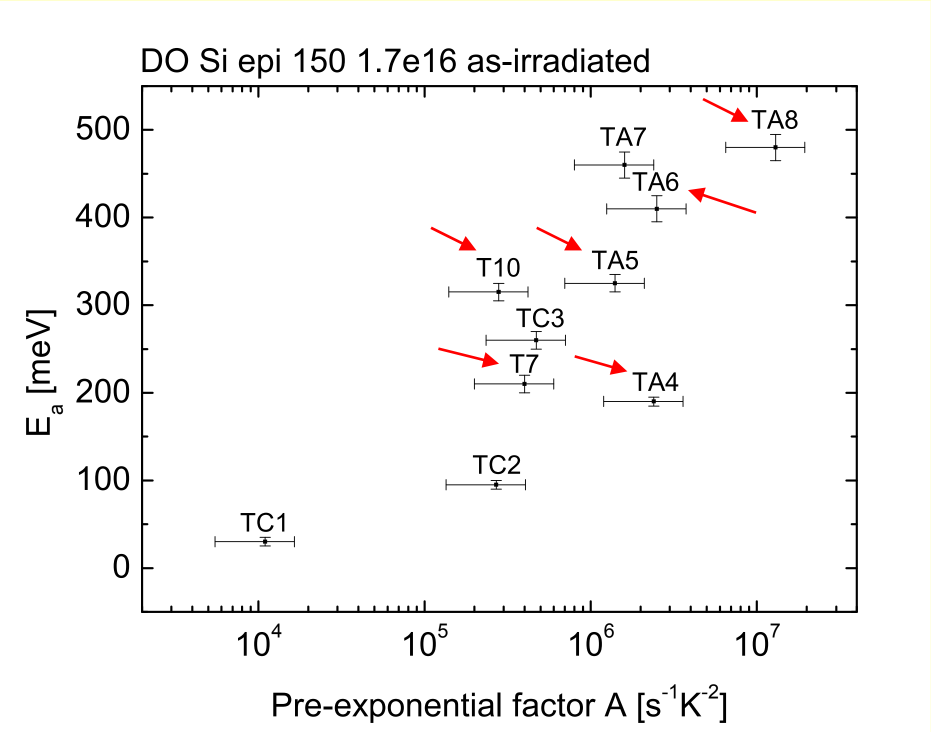
Comparison of defect levels in standard and oxygenated epitaxial silicon; 1.7x10^{16} p/cm^2; as-irradiated

$$e_{Tm} = A_m T^2 \exp(-E_{am} / k_B T);\ \ A_{mn} = \gamma_n \sigma_{mn}\ ;\ A_{mp} = \gamma_p \sigma_{mp}$$

TS8, TS7, TC1 : shallow donors-STD(H); TS9, TS10, TC2: I aggregates; T7: V_2(+/0); TA4: VO(-/0);

TA6: V_2(-/0); TA7: V_4V_5; TA8: complex of O with V aggregates (V_4,V_5); TS5: IO_2 (?)





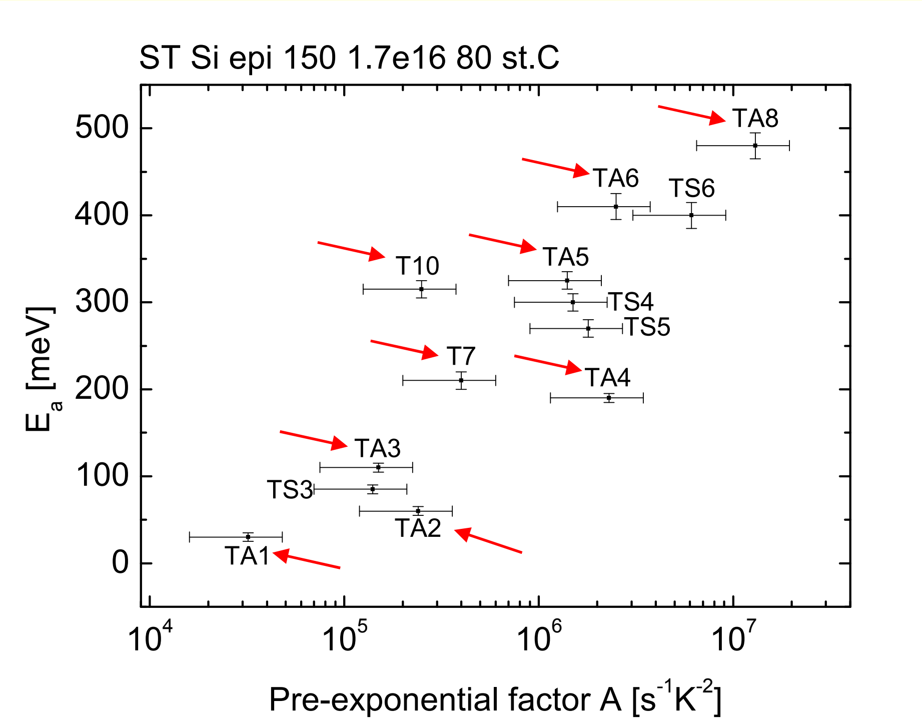
standard, *m = 1,2…13*

oxygenated, *m = 1,2…10*

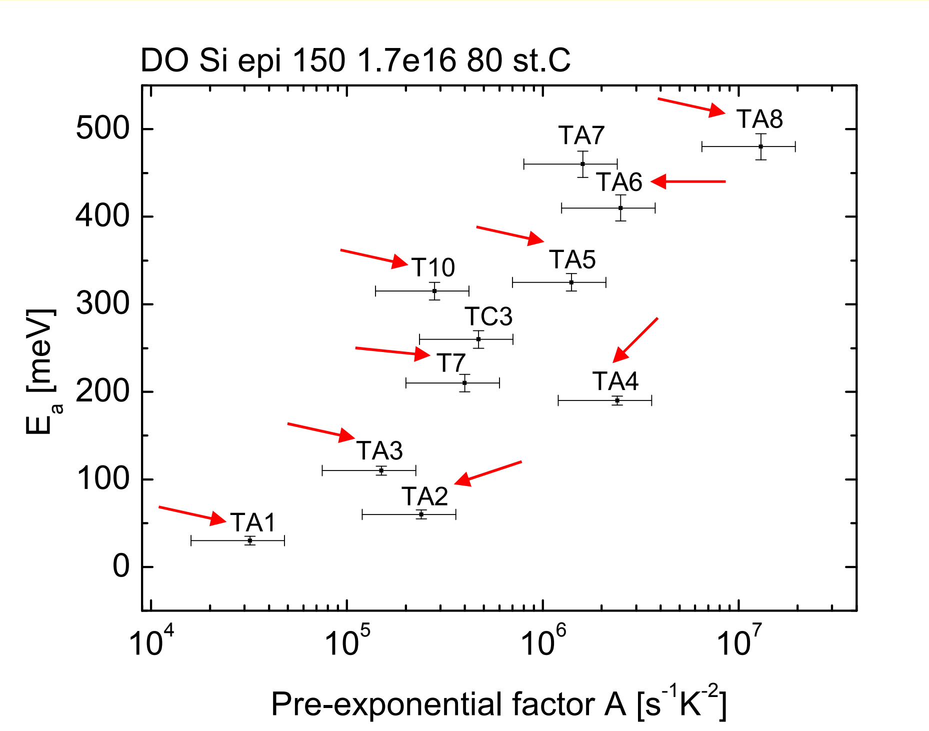
Comparison of defect levels in standard and oxygenated epitaxial silicon; $1.7x10^{16}$ p/cm^2; annealing at 80 ^{o}C

TA1: shallow donors; TA2: I aggregates; TA4: VO(-/0); TS5: IO_2 (?)

TA6: V_2(-/0); T7: V_2(+/0); TA7: V_4V_5; TA8: complex of O with V aggregates (V_4,V_5);



standard, *m=1,2…13*

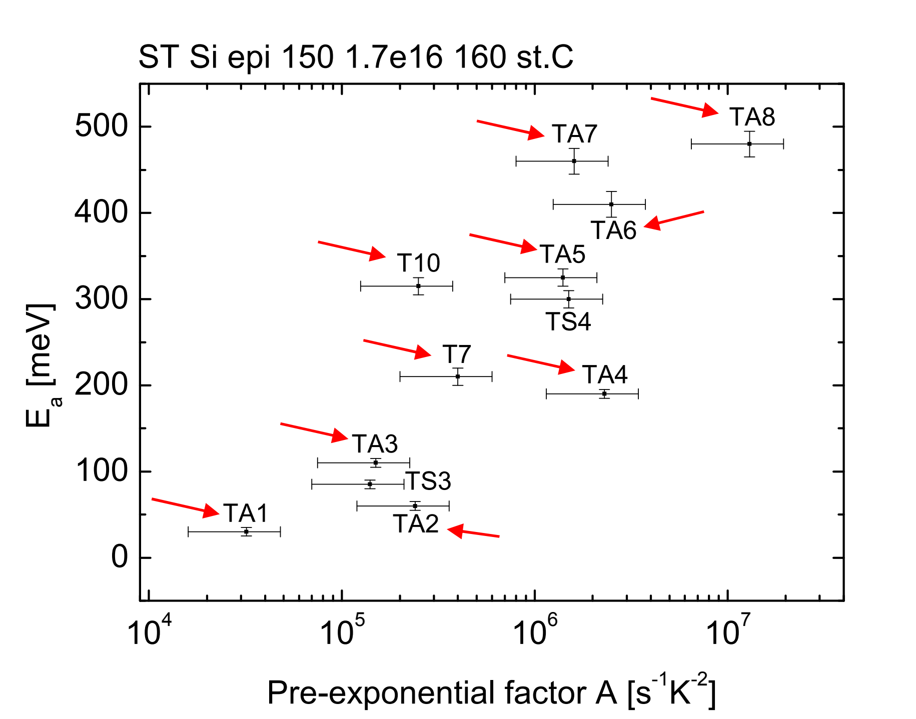


oxygenated, *m =1,2…11*

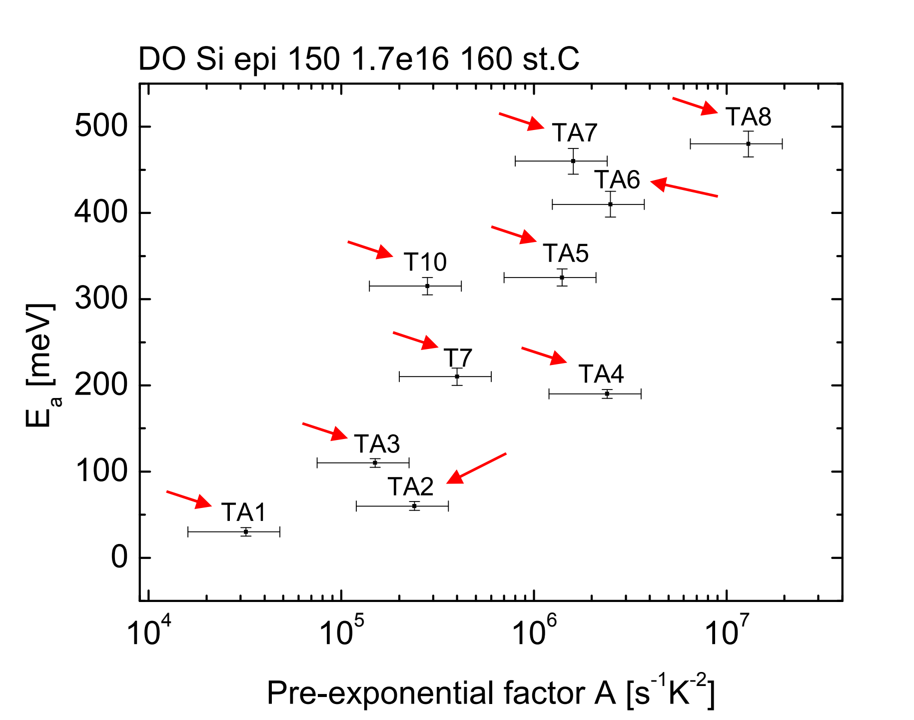
Comparison of defect levels in standard and oxygenated epitaxial silicon;1.7x10^{16} p/cm^2; annealing at 160 ^{o}C

TA1: shallow donors; TA2, TS3: I aggregates; TA4: VO(-/0);

TA6:V_2(-/0); T7: V_2(+/0); TA7: V_4V_5; TA8: complex of O with V aggregates (V_4,V_5)



standard, *m=1,2…12*

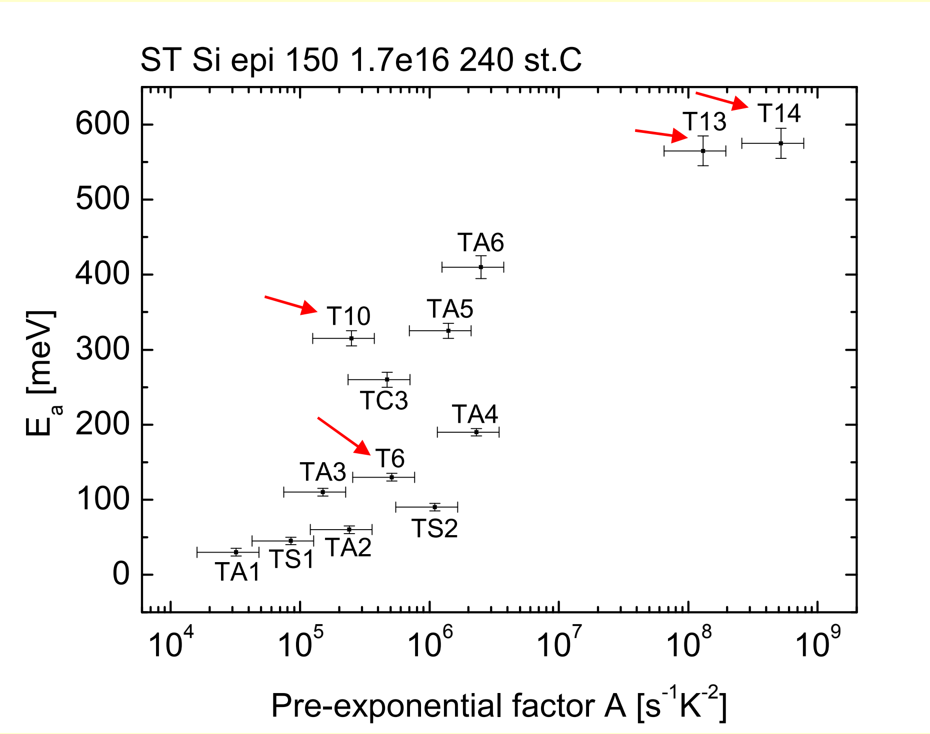


oxygenated, *m=1,2…10*

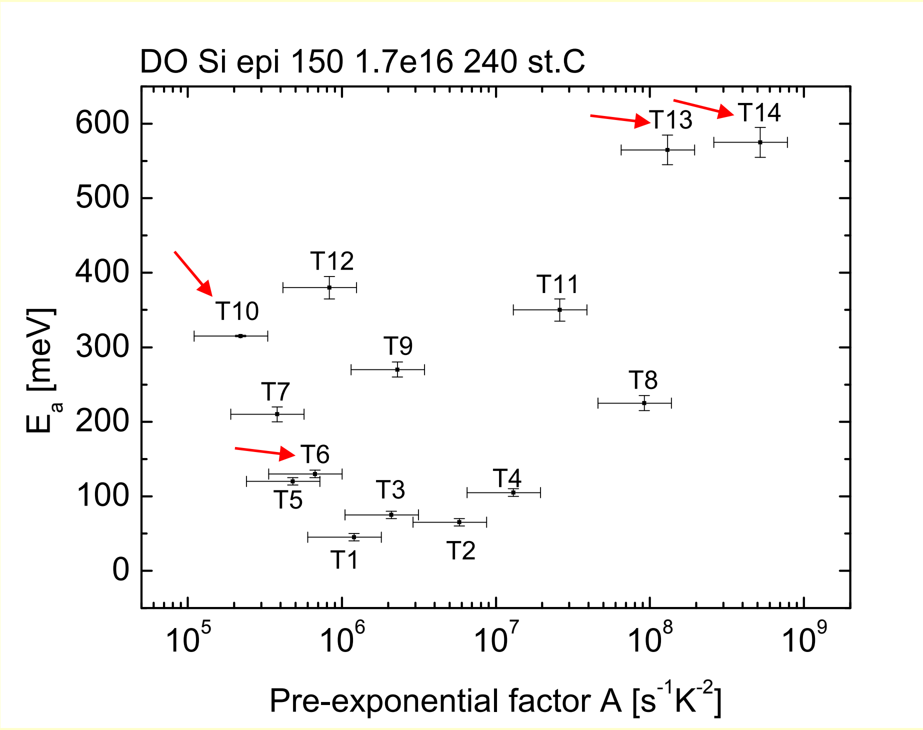
Comparison of defect levels in standard and oxygenated epitaxial silicon; 1.7x10^{16} p/cm^2; annealing at 240 ^{o}C

TA1: shallow donor; TS1, TA2, TS2, T1, T2, T3, T4: I aggregates; T7: V_2(+/0); TA4: VO(-/0);

TA6: V_2(-/0); T8: V_2O (2-/-); T13: I center (V_3); T14: V aggregate (V_5)



standard, *m=1,2…13*

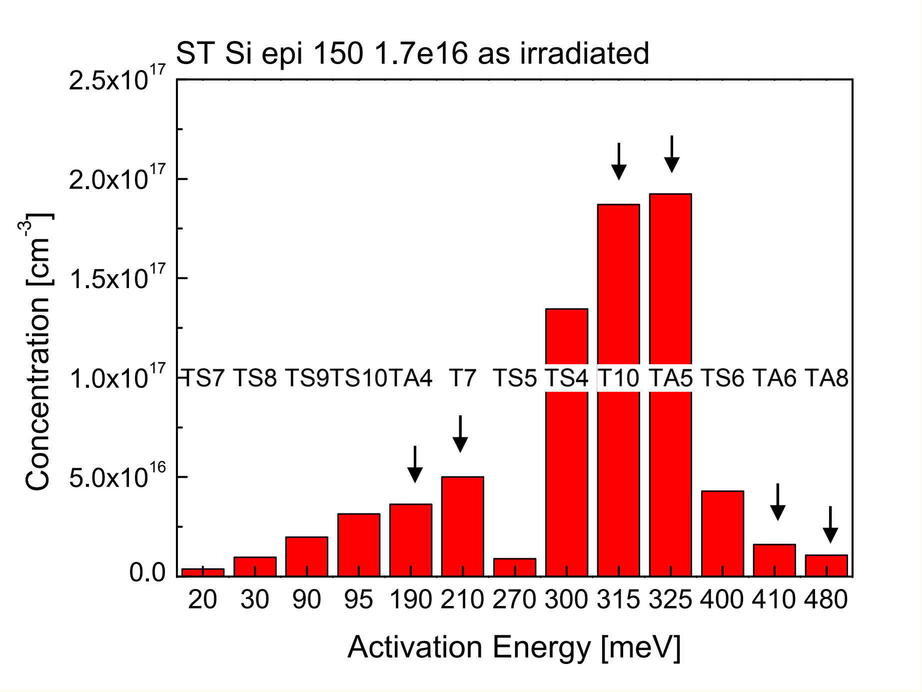


oxygenated, *m=1,2…14*

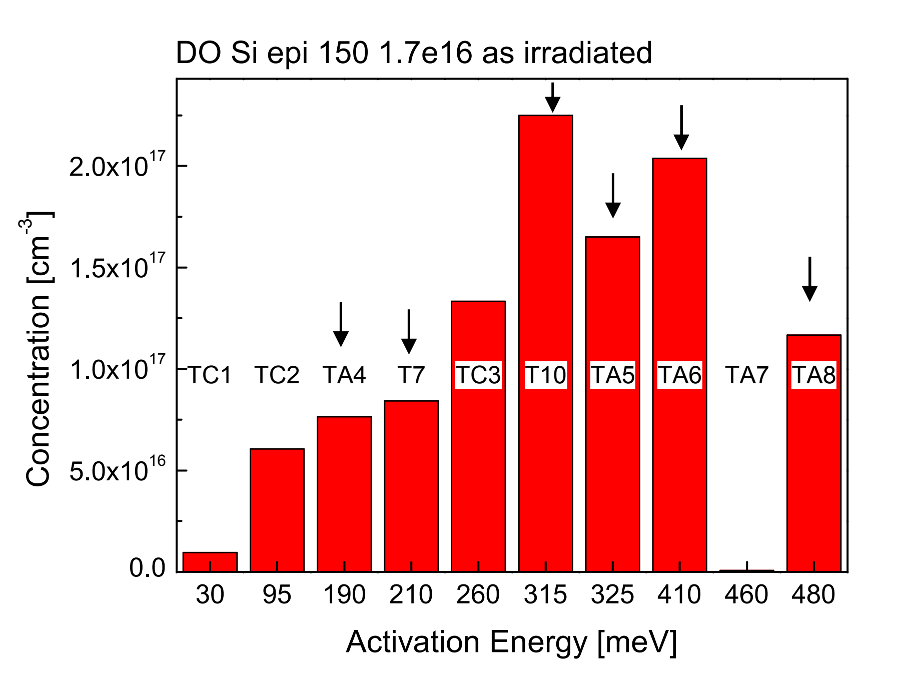
Comparison of defects concentrations in standard and oxygenated epitaxial silicon; $1.7x10^{16}$ p/cm^2 ; as-irradiated

TS7, TS8, TC1 : shallow donors; TS9, TS10, TC2: I aggregates; T7: V_2(+/0); TA4: VO(-/0);

TA6: V_2(-/0); TA7: V_4V_5; TA8: complex of O with V aggregates (V_4,V_5); TS5: IO_2 (?)



standard

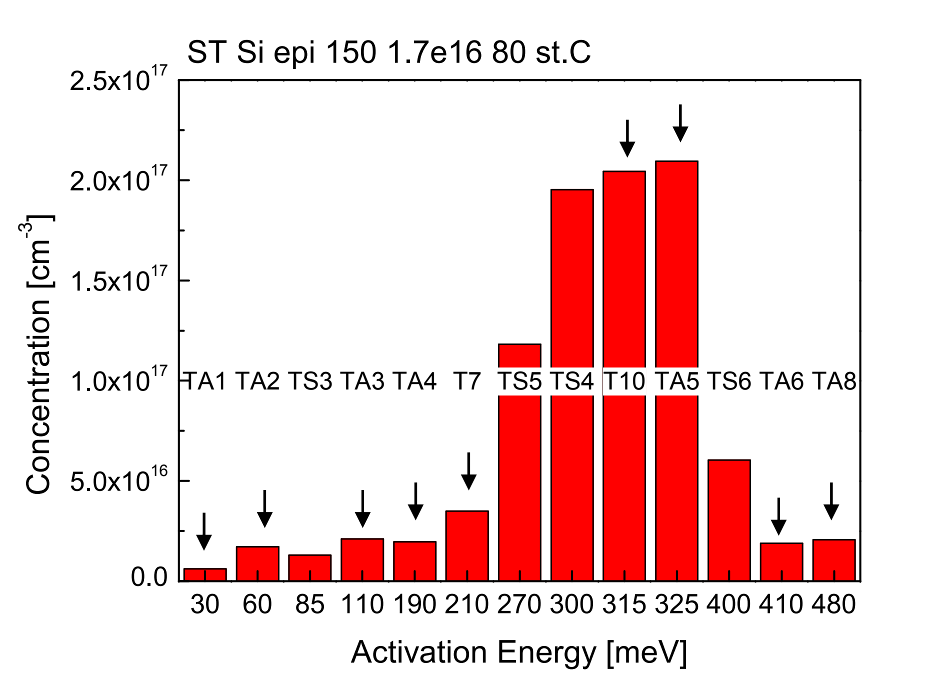


oxygenated

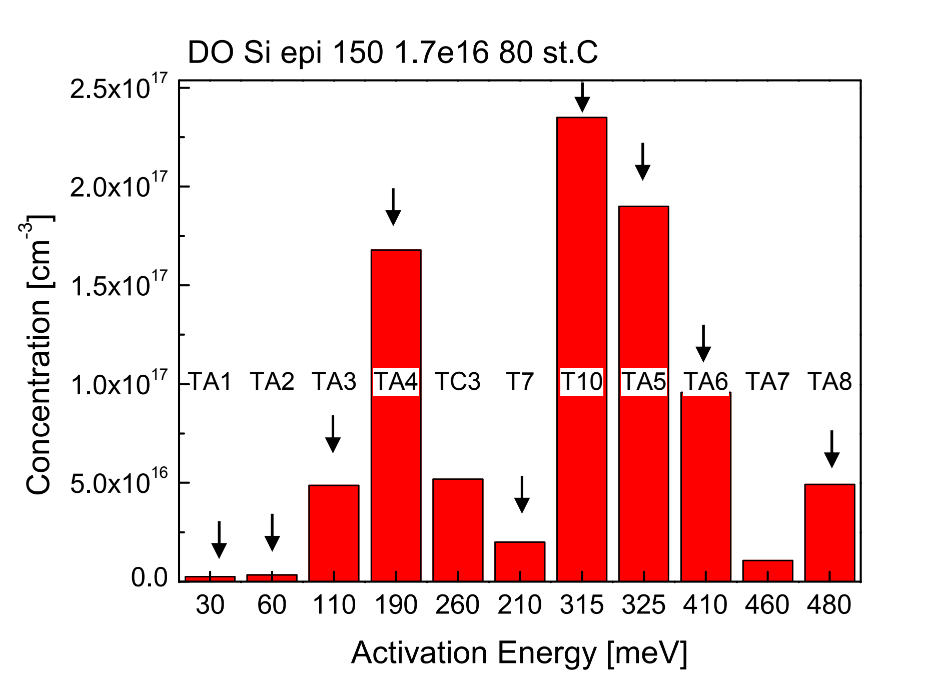
Comparison of defects concentrations in standard and oxygenated epitaxial silicon; 1.7×10^{16} p/cm^2 ; annealing at 80 ^{o}C

TA1: shallow donors; TA2: I aggregates; TA4: VO(-/0); TS5: IO_2 (?)

TA6: V_2(-/0); TA7: V_4V_5; T7: V_2(+/0); TA8: complex of O with V aggregates (V_4,V_5);



standard

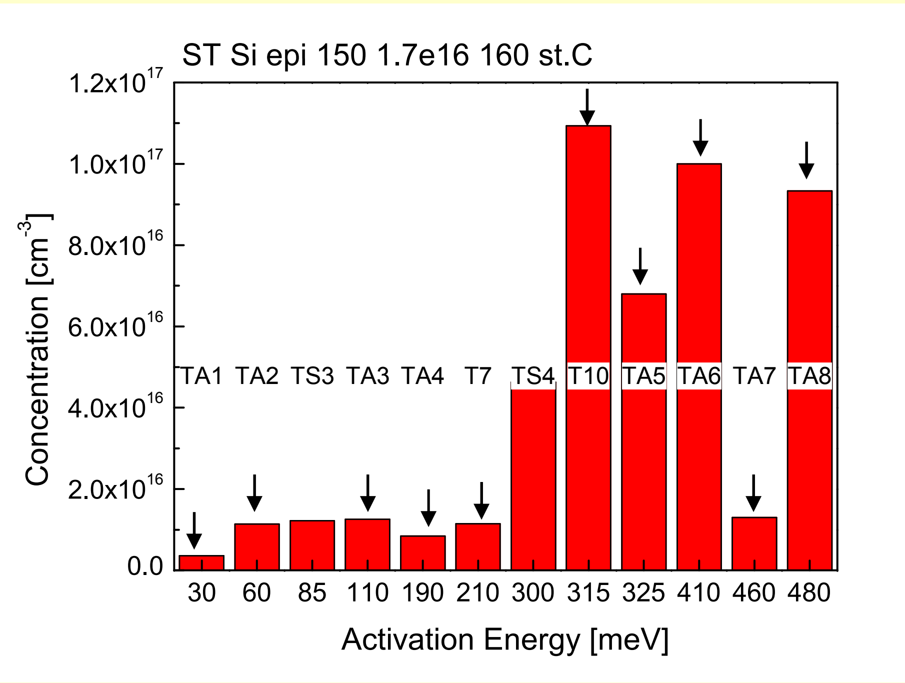


oxygenated

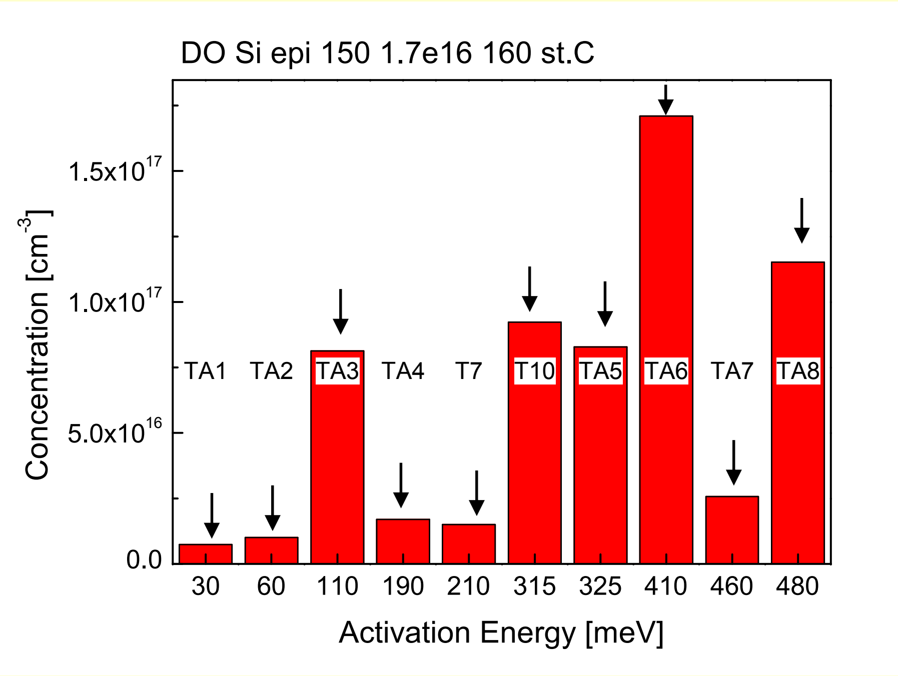
Comparison of defects concentrations in standard and oxygenated epitaxial silicon; 1.7×10^{16} p/cm^2 ; annealing at 160 ^{o}C

TA1: shallow donors; TA2, TS3: I aggregates; TA4: VO(-/0); TA6:V_2(-/0);

T7: V_2(+/0); TA7: V_4V_5; TA8: complex of O with V aggregates (V_4, V_5)



standard

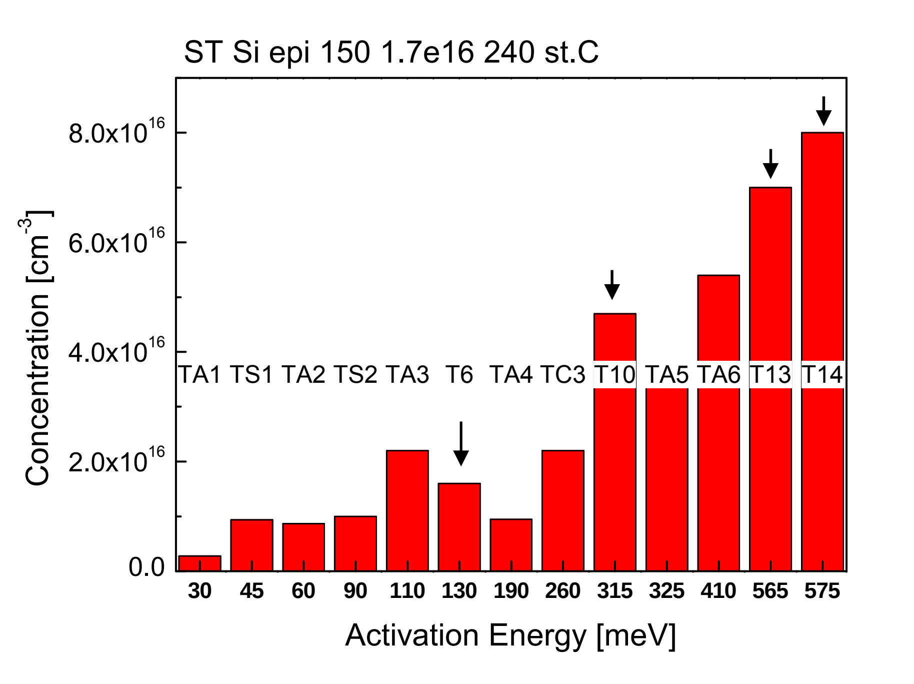


oxygenated

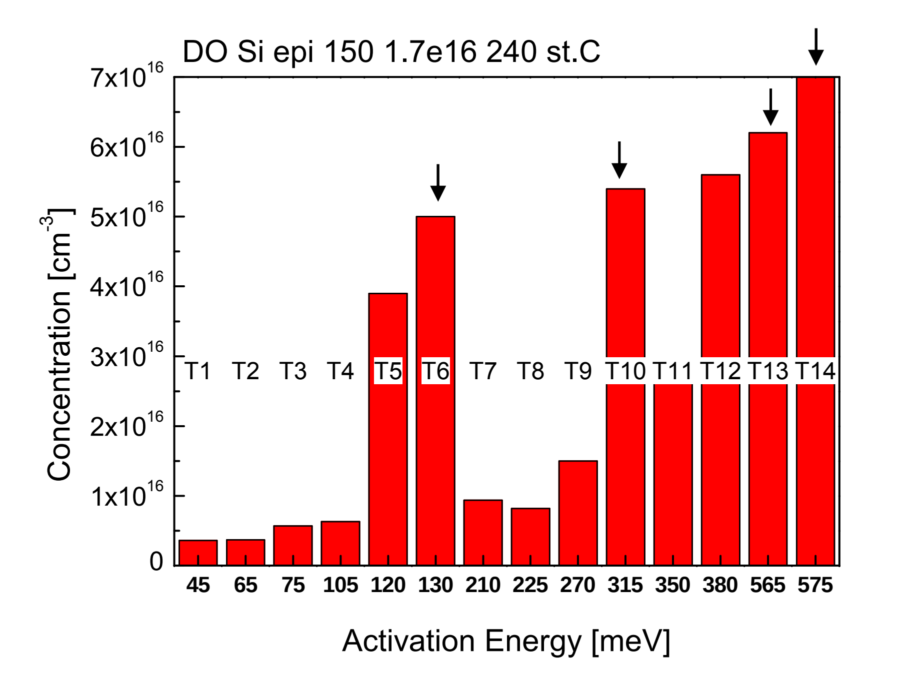
Comparison of defects concentrations in standard and oxygenated epitaxial silicon; $1.7x10^{16}$ p/cm^2; annealing at 240 ^oC

TA1: shallow donor; TS1, TA2, TS2, T1, T2, T3, T4: I aggregates; T7: $V_2(+/0)$;

TA4: VO(-/0); TA6: $V_2(-/0)$; T8: V_2O (2-/-); T13: I center (V_3); T14: V aggregate (V_5)



standard



oxygenated

Conclusions

- For the first time we have shown the results of both qualitative and quantitative analysis of defect levels for epitaxial silicon after 24 GeV/*c* protons irradiation with a fluence of 1.7x1016 cm-3. The radiation defect levels have been scanned by High-Resolution Photoinduced Transient Spectroscopy with implementation of the imaging procedure.

- The effect of the oxygen concentration in the epitaxial layers on the traps properties and concentrations was studied. It was found that the higher oxygen concentration affects mainly the properties of shallow traps related to interstitial aggregates. After annealing at 240 ^{o}C, the high concentrations of midgap traps with activation energies of 565 and 575 meV are observed independently on the oxygen concentration.

- After annealing at 80 and 160 ^{o}C, the greatest number of the same traps was observed both for standard and oxygenated epitaxial layers.

- Further studies aimed at verifying the values of traps concentrations are in progress.

Acknowledgments

We thank Prof. Gunnar Lindstroem for initiating the WODEAN collaboration and stimulating discussions.

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Model of Photocurrent Relaxation Waveforms

$$\boldsymbol{i_m(t, T) = I_m(\lambda, T)\,\exp(-e_{Tm}t);}$$

$$I_m(\lambda, T) = n_{tom}(T)\, e_{Tm}(T)\, \mu_T(T)\, \tau_T(T)\, C(\lambda, T)qE$$

$$i(t, T) = \sum_{m=1}^{M} I_k(\lambda, T)\exp(-e_{Tm}t);$$

$$\boldsymbol{e_{Tm} = A_m T^2 \exp(-E_{am} / k_B T)}$$

$$A_{mn} = \gamma_n \sigma_{mn}\,;\, A_{mp} = \gamma_p \sigma_{mp}$$

For Si: $\gamma_n = 1.07 \text{ x } 10^{21}\ cm^{-2}K^{-2}s^{-1}$; $\gamma_p = 2.64 \text{ x } 10^{21}\ cm^{-2}K^{-2}s^{-1}$