Electronic properties of vacancy aggregates in n-type silicon for particle detectors

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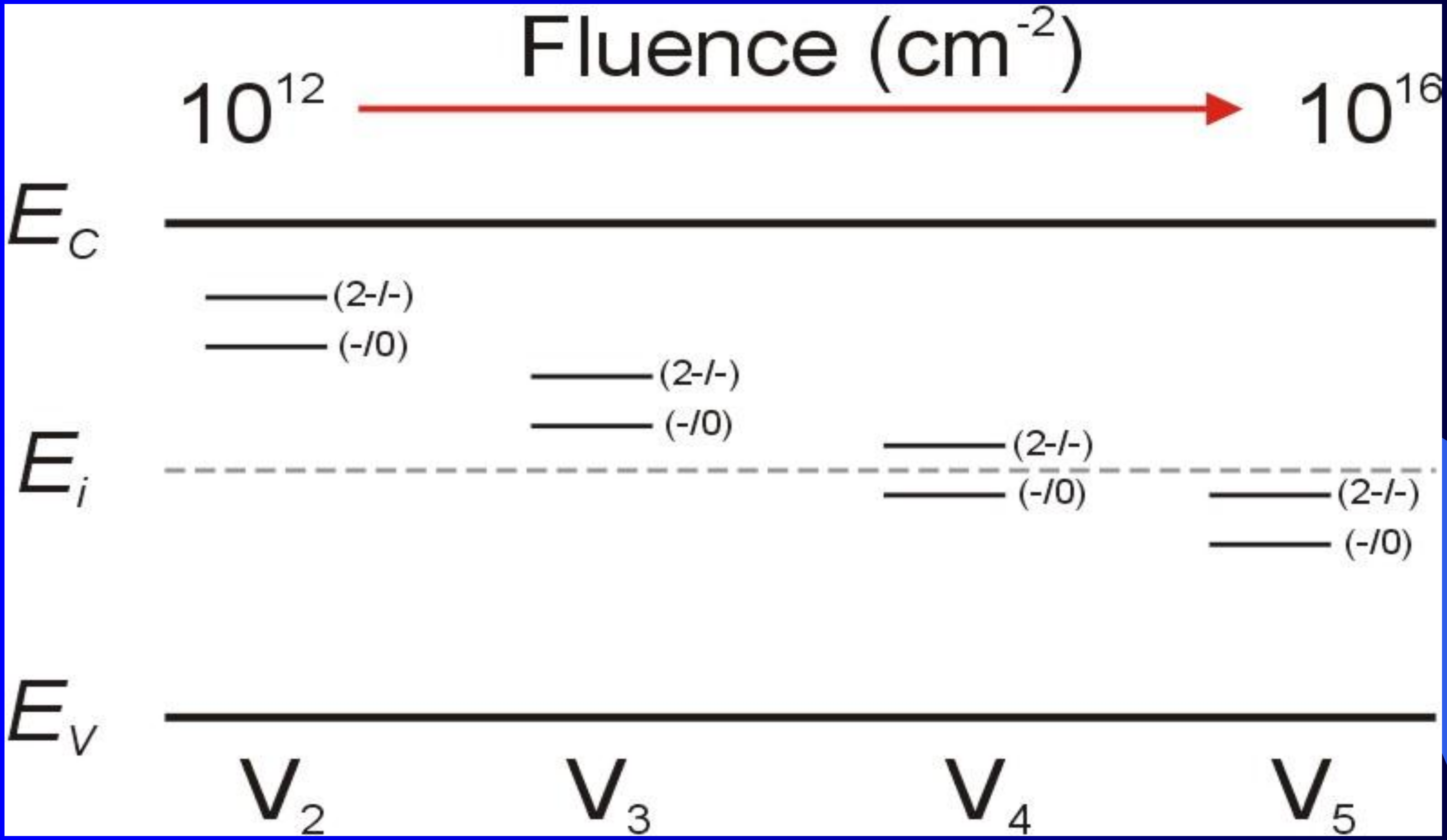
Do vacancy aggregates really exist ?

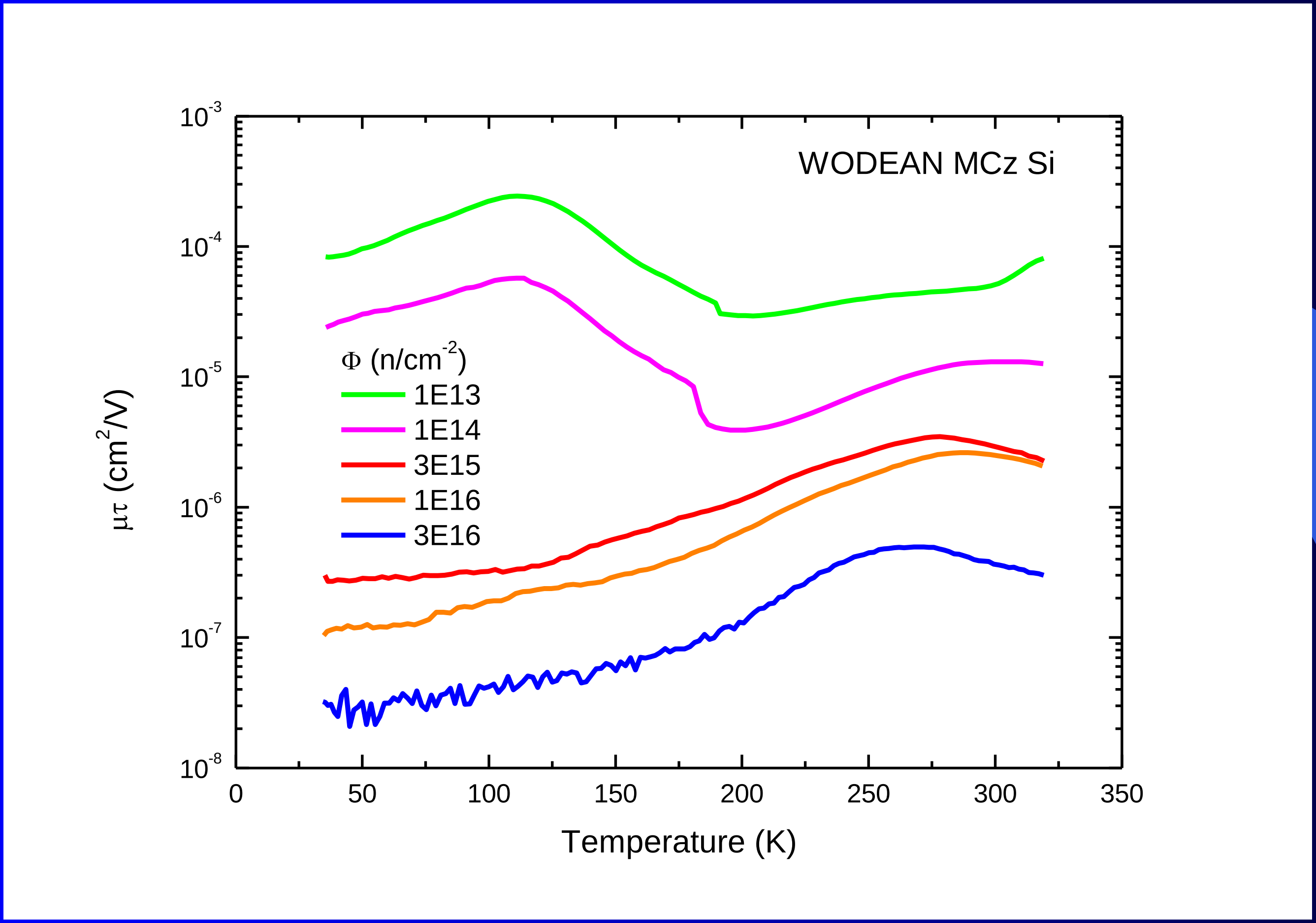
Defect	Irradiation	Fluence/Dose	Method	Reference
Divacancy (V_2)	(1-3)- MeV electrons 7-MeV protons	~1E17 cm^{-2} 5E9 – 1.2E11 cm^{-2}	EPR DLTS	Corbett and Watkins, Phys. Rev. Lett. 7, 314 (**1961**) Monakhov *et al.* Phys. Rev. B 65, 233207 (**2002**)
Trivacancy (V_3)	2-MeV electrons 24-GeV protons 6-MeV electrons	1E18 – 1E19 cm^{-2} 1E11 cm^{-2} 1E12 – 8E13 cm^{-2}	EPR (A4) DLTS LDLTS	Lee and Corbett, Phys. Rev. B 13, 2653 (**1976**) Ahmed *et al.* Nucl. Instr. and Meth. A, 457, 588 (**2001**) Markevich *et al.* Phys. Rev. B 80, 235207 (**2009**)
Tetravacancy (V_4)	Reactor neutrons O^{6+} ions 140 MeV	1E18 cm^{-2} 5E15 cm^{-2}	EPR (P3) EPR PAS	Lee and Corbett, Phys. Rev. B 9, 4351 (**1974**) Watkins, Mat. Sci. Sem. Proc. 3, 227 (**2000**) Chaudhuri *et al.* Physica B 406, 693 (**2011**)
Pentavacancy (V_5)	Reactor neutrons O^{6+} ions 140 MeV	1E18 cm^{-2} 5E15 cm^{-2}	EPR (P1) PAS	Lee and Corbett, Phys. Rev. B 8, 2810 (**1973**) Chaudhuri *et al.* Physica B 362, 249 (**2011**)
Hexavacancy (V_6)	There is no direct experimental evidence for existence of V_6, although theory predicts that it must exist			

Electronic properties



Hastings *et al*. Phys. Rev. B 56, 10215 (1997)
Ermolov *et al*. Semiconductors, 36, 1114 (2002)
Markevich *et al*. Phys. Rev. B 80, 235207 (2009)

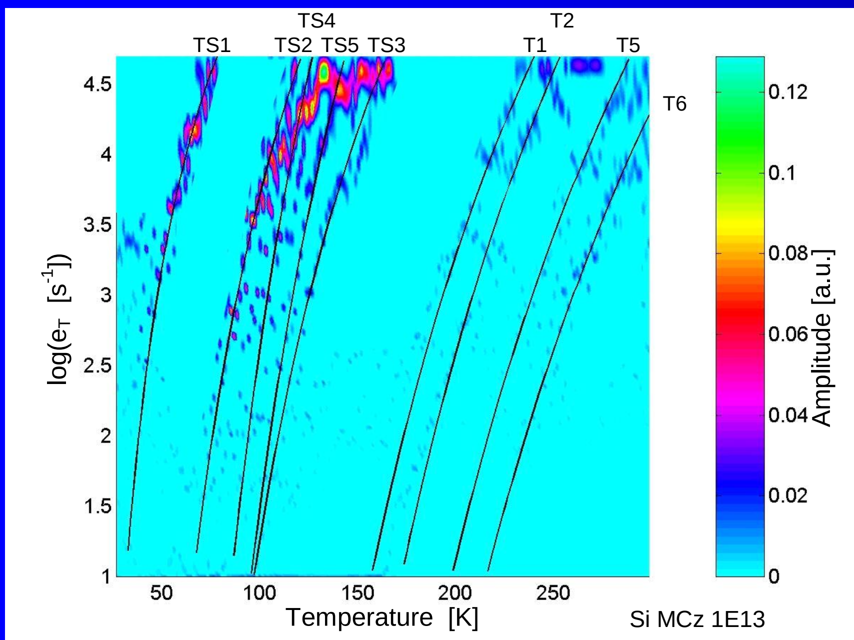
1-MeV Neutron Irradiated MCz-Si
Mobility lifetime product



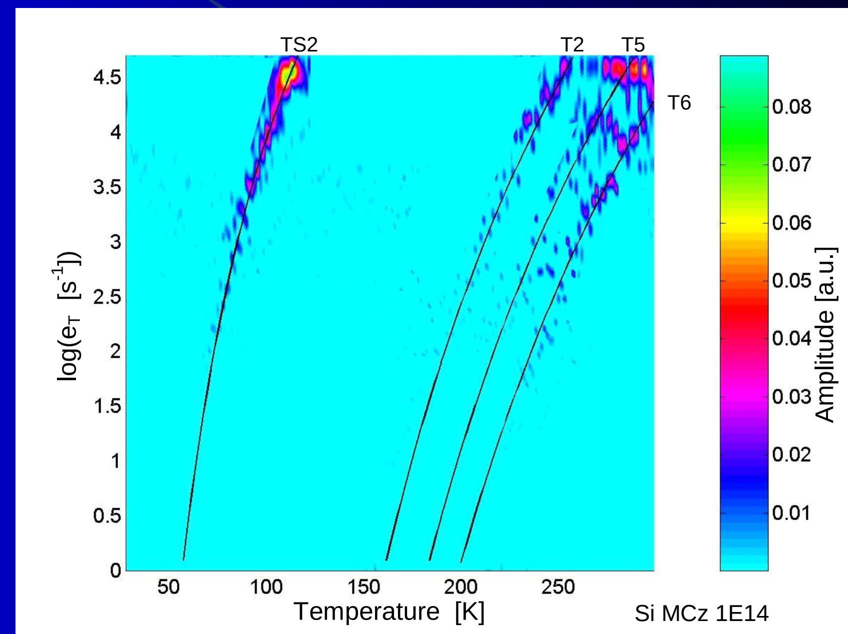
High-Resolution Photoinduced Transient Spectroscopy

Laplace spectral fringes for trivacancies

$\Phi = 1\times10^{13}\ \mathrm{cm}^{-2}$



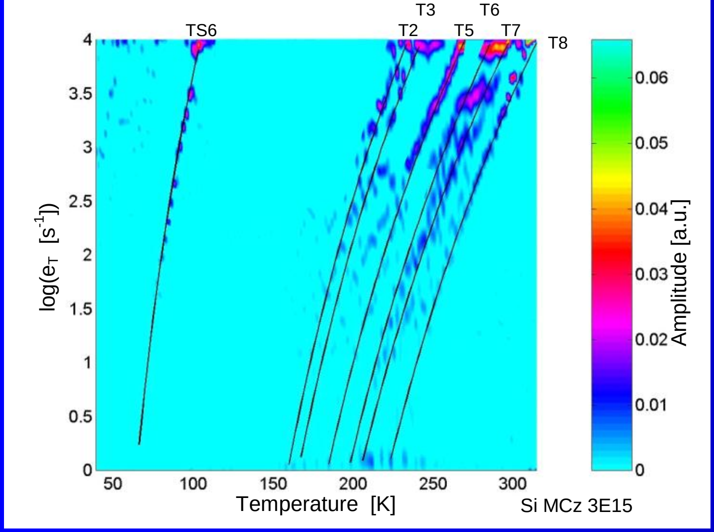
$\Phi = 1\times10^{14}\ \mathrm{cm}^{-2}$

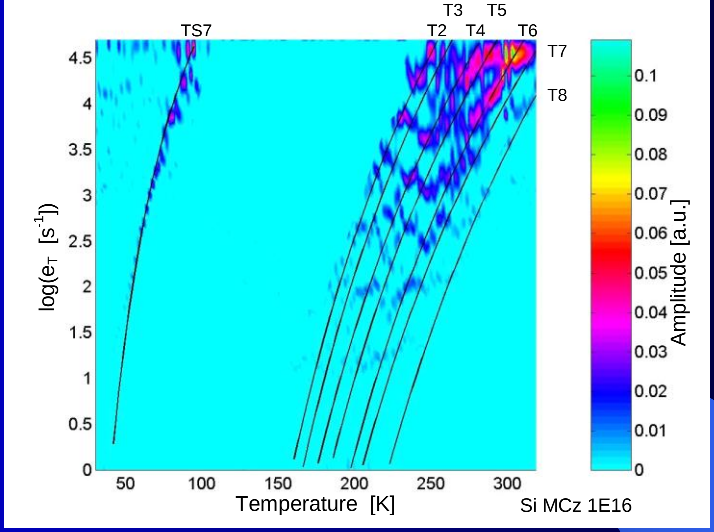


Trap	E_a (meV)	A ($K^{-2}s^{-1}$)	σ_n (cm^2)	Defect charge state
T2	360±10	$(1.0\pm0.1)\times10^{7}$	2.8×10^{-15}	V_3 (2-/-)
T5	420±10	$(9.6\pm2.0)\times10^{6}$	2.7×10^{-15}	V_2 (-/0)
T6	460±20	$(1.5\pm0.2)\times10^{7}$	4.3×10^{-15}	V_3 (-/0)

High-Resolution Photoinduced Transient Spectroscopy
Higher neutron fluence

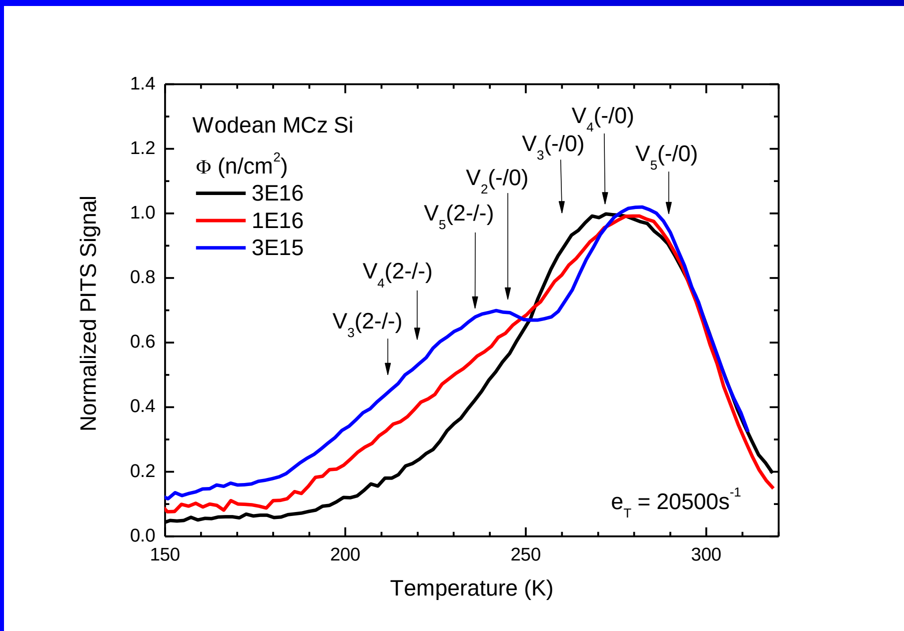
$\Phi = 3\times10^{15}$ cm^{-2} | $\Phi = 1\times10^{16}$ cm^{-2}

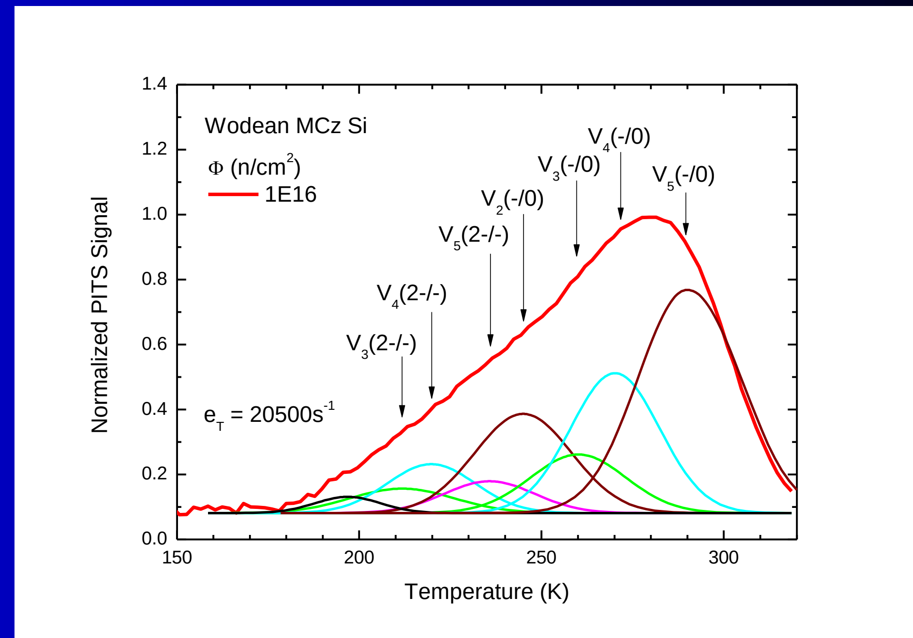




Trap	E_a (meV)	A (K^{-2}s^{-1})	σ_n (cm^2)	Defect charge state
T2	360±10	(1.0±0.1)x10^7	2.8×10^{-15}	V_3 (2-/-)
T3	380±10	(1.3±0.1)x10^7	3.7×10^{-15}	V_4 (2-/-)
T4	390±10	(5.7±0.5)x10^6	1.6×10^{-15}	V_5 (2-/-)
T5	420±10	(9.6±2.0)x10^6	2.7×10^{-15}	V_2 (-/0)
T6	460±20	(1.5±0.2)x10^7	4.3×10^{-15}	V_3 (-/0)
T7	475±20	(1.2±0.2)x10^7	3.4×10^{-15}	V_4 (-/0)
T8	545±20	(5.3±0.5)x10^7	1.5×10^{-14}	V_5 (-/0)

High-Resolution Photoinduced Transient Spectroscopy
1D Correlation spectra





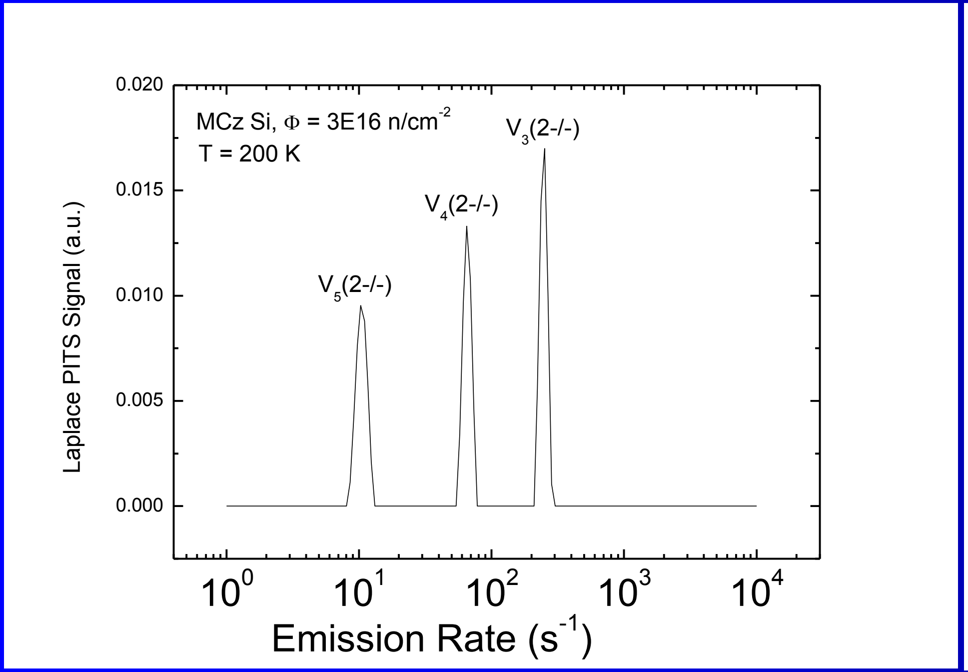
Activation energy for electron emission [meV]

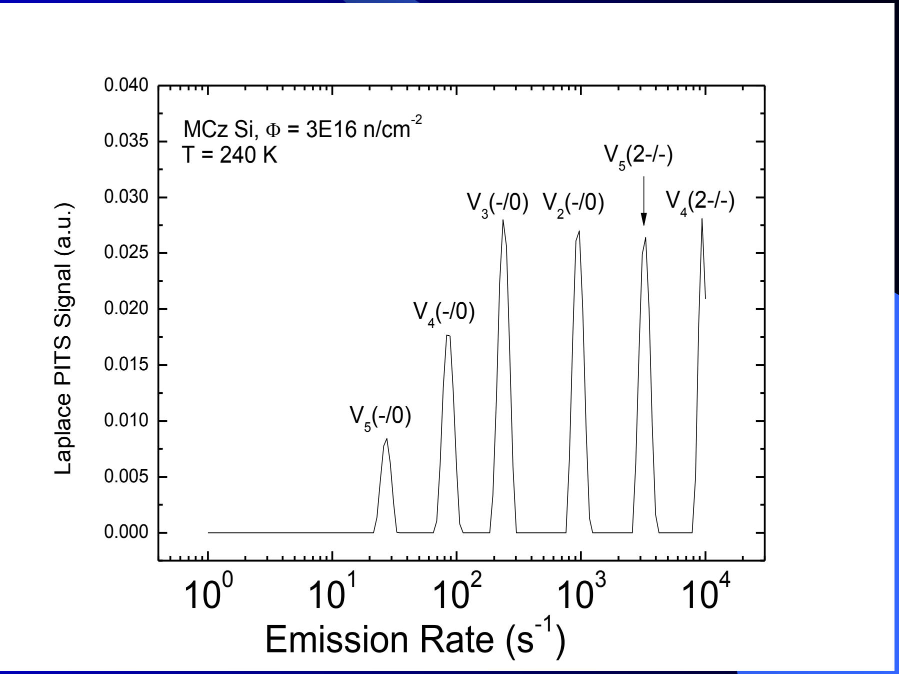
V_2 (2-/-)	V_2 (-/0)	V_3 (2-/-)	V_3 (-/0)	V_4 (2-/-)	V_4 (-/0)	V_5 (2-/-)	V_5 (-/0)
235	420	360	460	380	475	390	545

High-Resolution Photoinduced Transient Spectroscopy
1D Laplace spectra

T= 200 K

T= 240 K

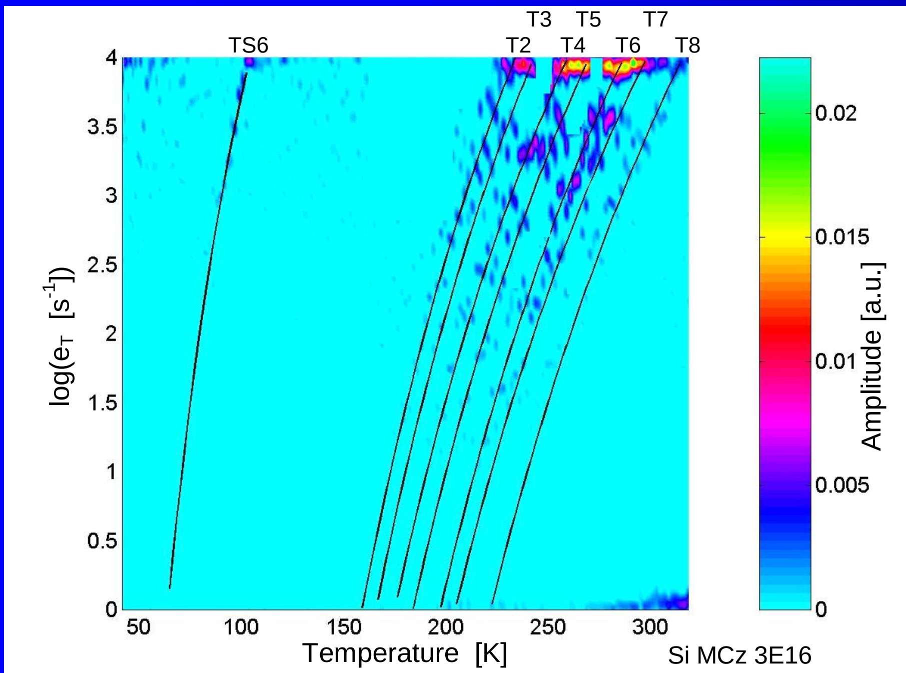




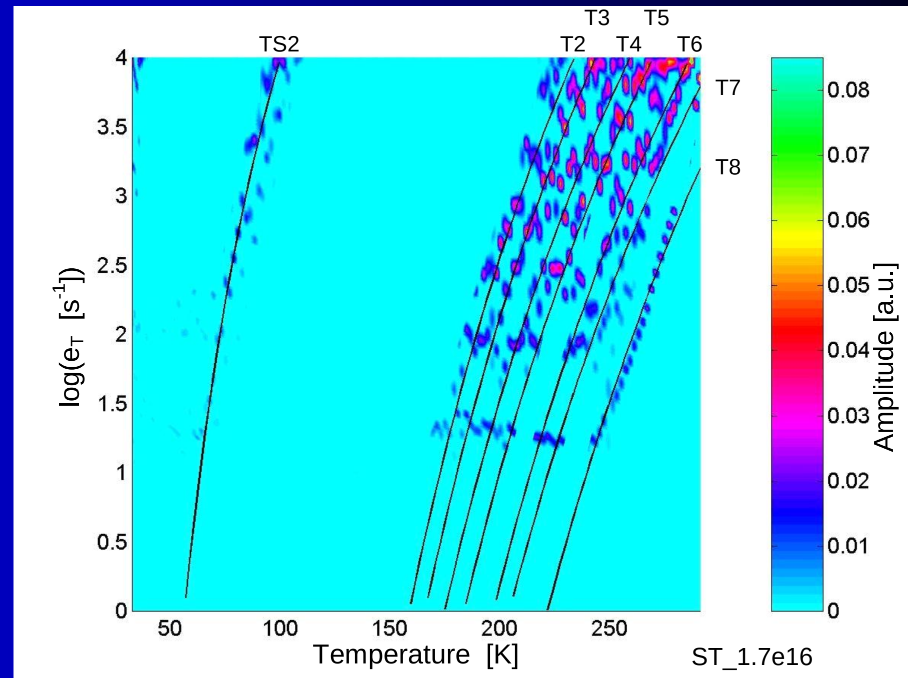
High-Resolution Photoinduced Transient Spectroscopy

Laplace spectral fringes for vacancy aggregates

MCz Si



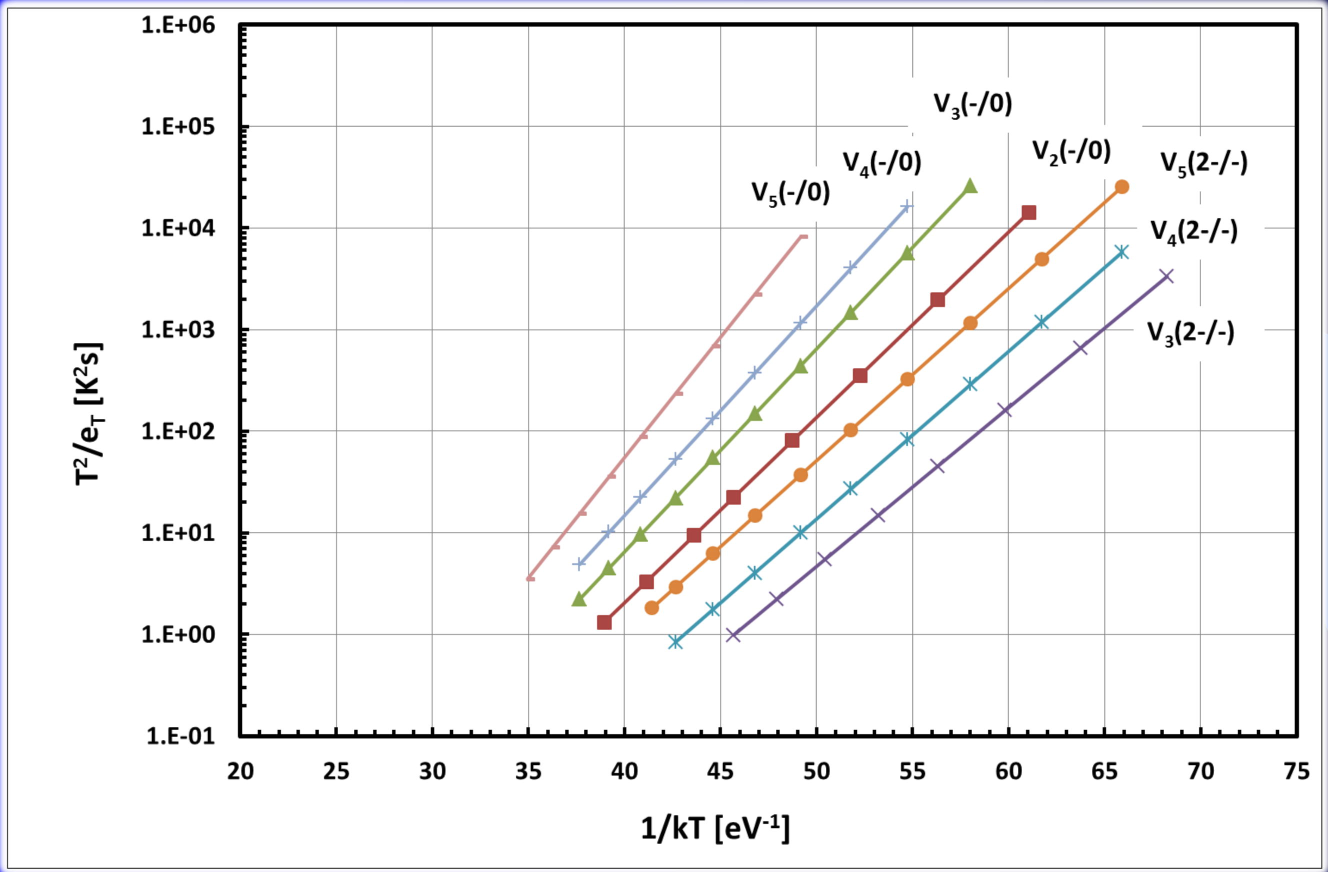
Standard epitaxial Si



T5	T2	T6	T3	T7	T4	T8
V_2 (-/0)	V_3 (2-/-)	V_3 (-/0)	V_4 (2-/-)	V_4 (-/0)	V_5 (2-/-)	V_5 (-/0)
420 meV	360 meV	460 meV	380 meV	475 meV	390 meV	545 meV

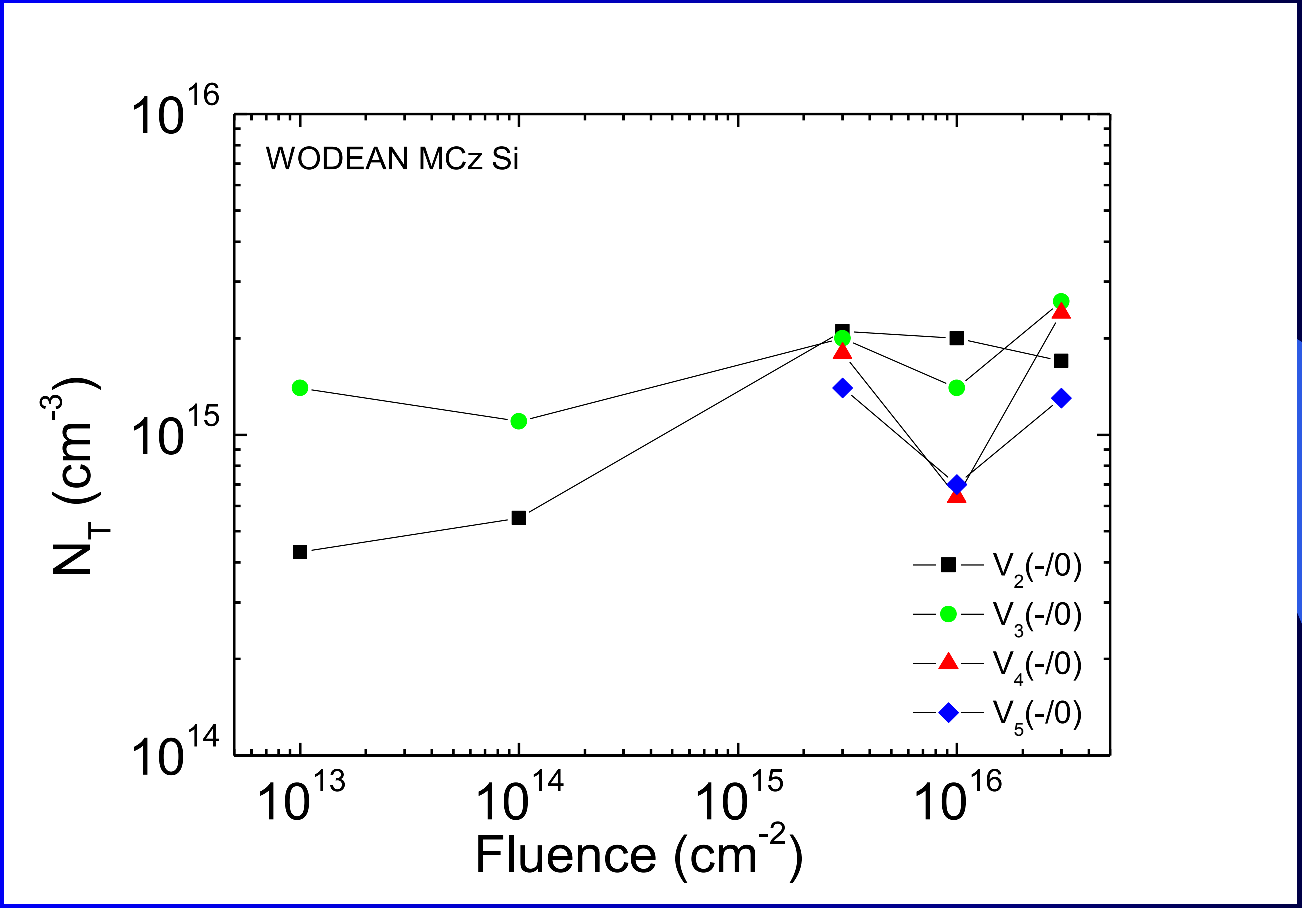
High-Resolution Photoinduced Transient Spectroscopy

Arrhenius plots



High-Resolution Photoinduced Transient Spectroscopy

Concentration of vacancy aggregates versus neutron fluence



Summary

- Using the HRPITS technique, we have determined the activation energies and apparent capture cross-sections for electron emission from negatively ionized vacancy aggregates: V_3, V_4, and V_5,formed in neutron and proton irradiated silicon.

- The effect of 1-MeV neutron fluence on the concentrations of vacancy aggregates has been found. For the fluence of 3E16 n/cm^2 , the concentrations of V_2 (-/0) , V_3 (-/0) , V_4 (-/0), and V_5 (-/0) are in the range of 1E15 – 3E15 cm^{-3}.

- The results are important for further studies aimed at suppressing of the vacancy aggregates formation by nitrogen doping.

Thank you for your attention.

Acknowledgements

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