The WODEAN project – outline and present status

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for the WODEAN collaboration

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WODEAN (WOrkshop on DEfect ANalysis),
1st meeting in Hamburg, 23-25 August 2006
idea triggered by Gordon Davies‘ talk at RD50, CERN, Nov. 2005
we need all available tools (not only DLTS, TSC)
for thorough defect analysis and possible defect engineering

WODEAN (WOrkshop on DEfect ANalysis),
2nd meeting in Vilnius, 2-3 June 2007

Methods-Institutes-Persons

C-DLTS:
NIMP Bucharest and Hamburg University: I. Pintilie, E. Fretwurst, G. Lindstroem
Minsk University: L. Makarenko
Oslo University: B. Svensson

I-DLTS:
INFN and Florence University: D. Menichelli

TSC:
NIMP Bucharest and Hamburg University: I. Pintilie, E. Fretwurst, G. Lindstroem

PITS:
ITME Warsaw: P. Kaminski, R. Kozlowski

PL:
Kings College London: G. Davies
ITME Warsaw: B. Surma

Recombination lifetime:
Vilnius University: E. Gaubas, J. Vaitkus

FTIR:
Oslo University and Minsk Joint Institute of Solid State and Semicond. Pysics: L. Murin, B. Svensson

PC:
Vilnius University: J. Vaitkus, E. Gaubas

EPR:
NIMP Bucharest: S. Nistor
ITME Warsaw: M. Pawlowski

Diode characteristics (C/V, I/V, TCT):
CERN-PH, Hamburg University, JSI Ljubljana: M. Moll, E. Fretwurst, G. Lindstroem, G. Kramberger

AND VERY IMPORTAN TOO:

Irraditions:
JSI Ljubljana: G. Kramberger

Outline of Correlated Project

- **Main issue:**

Φ_{eq} to be tolerated in S-LHC: 1.5E16 n/cm².
charge trapping: ultimate limitation for detector applications
responsible trapping source: so far unknown!

- **Charge trapping:**

independent of material type (FZ, CZ, epi) and properties (std, DO, resistivity, doping type).
independent of irradiating particle type and energy (23 GeV protons, reactor neutrons), if Φ normalised to 1 MeV neutron equivalent values (NIEL).
In contrast to I_{FD} and N_{eff} there are only small annealing effects (as studied up to T = 80°C)

- **Correlated project:**

use all available methods:
DLTS, TSC, PITS, PL, τ_{recomb}, FTIR, PC, EPR, diode C/V, I/V and TCT
concentrate on single material only: MCz chosen with extension to std. FZ for checking of unexpected results (FZ supposed to be cleaner, MCz has larger O concentration)
Use only one type of irradiation, most readily available (TRIGA reactor at Ljubljana) and do limited number of Φ steps between 3E11 and 3E16 n/cm² (same for all methods!)
Use same isothermal annealing steps for all methods
Reach first results within one year

1st WODEAN batch sample list

Φ (1MeV n)	C-DLTS	I-DLTS	TSC	PITS	PL	τ_{recomb}	FTIR	PC	EPR
3E11	HH,Oslo, Minsk								
6E11	HH,Oslo, Minsk								
1E12				ITME	KC, ITME	Vilnius		Vilnius	
1E13		Florence	HH, NIMP	ITME	KC, ITME	Vilnius		Vilnius	
3E13			HH, NIMP	ITME	KC, ITME	Vilnius		Vilnius	
1E14		Florence	HH, NIMP	ITME	KC, ITME	Vilnius		Vilnius	
3E14		Florence	HH, NIMP	ITME	KC, ITME	Vilnius		Vilnius	
1E15		Florence		ITME	KC, ITME	Vilnius	Oslo	Vilnius	NIMP ITME
3E15				ITME	KC, ITME	Vilnius	Oslo	Vilnius	NIMP ITME
1E16				ITME	KC, ITME	Vilnius	Oslo	Vilnius	NIMP ITME
3E16				ITME	KC, ITME	Vilnius	Oslo	Vilnius	NIMP ITME

150 samples n-MCz <100>1 kΩcm (OKMETIC, CiS): **84 diodes**, **48 nude standard**, **16 nude thick**

2nd WODEAN batch sample list

Φ (1MeV n)	C-DLTS	I-DLTS	TSC	PITS	PL	τ_{recomb}	FTIR	PC	EPR
3E11	HH,Oslo, Minsk								
6E11	HH,Oslo, Minsk								
1E12									
1E13		Florence	HH, NIMP	ITME	KC, ITME	Vilnius		Vilnius	
3E13			HH, NIMP						
1E14		Florence	HH, NIMP	ITME	KC, ITME	Vilnius		Vilnius	
3E14			HH, NIMP						
1E15		Florence		ITME	KC, ITME	Vilnius	Oslo	Vilnius	NIMP ITME
3E15				ITME	KC, ITME		Oslo		NIMP ITME
1E16		Florence		ITME	KC, ITME	Vilnius	Oslo	Vilnius	NIMP ITME
3E16				ITME	KC, ITME		Oslo		NIMP ITME

90 samples n-FZ <111>, 2 kΩcm (Wacker, STM): **67 diodes**, **24 nude thick samples;**

Irradiations

1st batch, MCz samples:
Irradiation: November 2006
Delivery to Hamburg: 8 January 2007
Distribution to WODEAN members: 9 February 2007

2nd batch, FZ samples:
Irradiation: April 2007
Delivery to Hamburg: 11 June (foreseen)✓
Distribution to WODEAN members: end June 2007 ✓

Important Info about irradiations:

$\Phi \leq$ 1E+15 n/cm²: T ≈ 20°C, duration ≤ 10 min

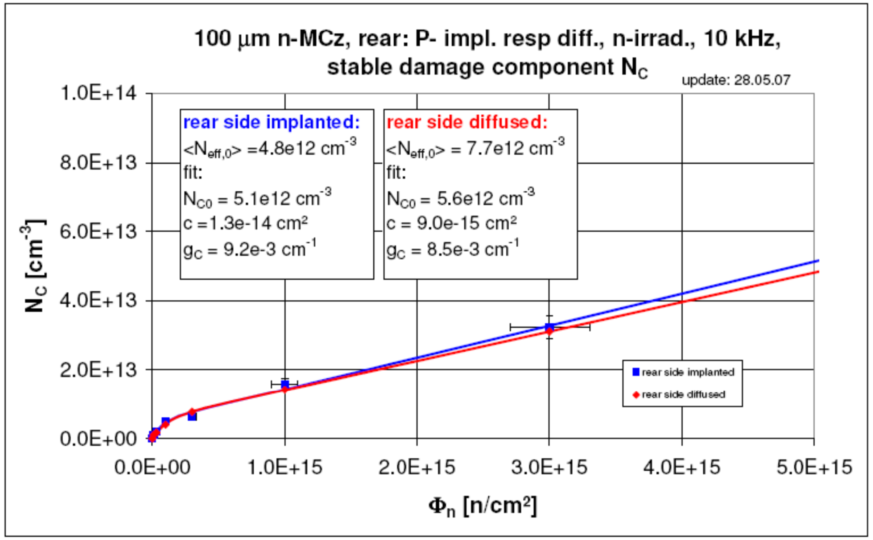
$\Phi \geq$ 2E+15 n/cm²: high flux: dΦ/dt = 2E12 n/cm²s

Temperature increase during irradiation
3E+15: t ≈ 25 min, temp. rising to 70-80°C within 15 min (then saturating)
1E+16: t ≈ 80 min, temp. 70-80°C as meas. with PT100
3E+16: t ≈ 4h, 10min, severe self annealing expected ?

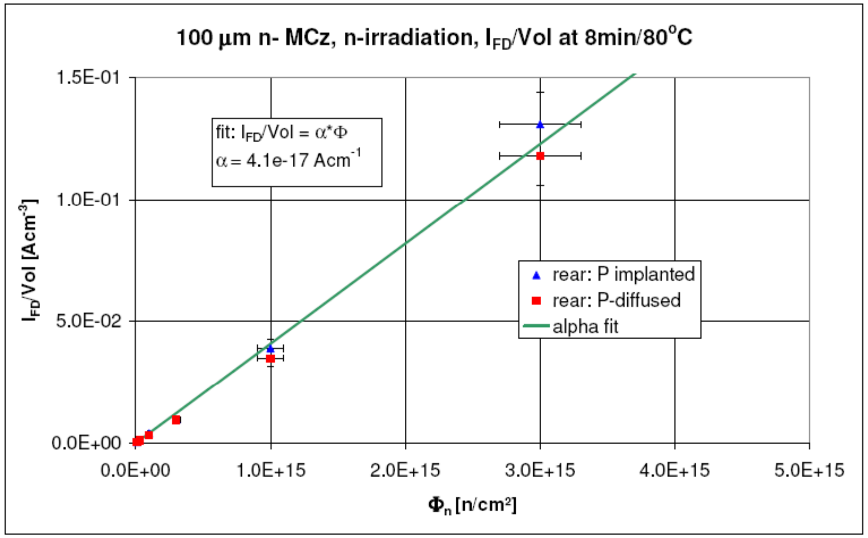
Present Status

Macroscopic results

1. C/V and I/V diode characteristics



Stable damage

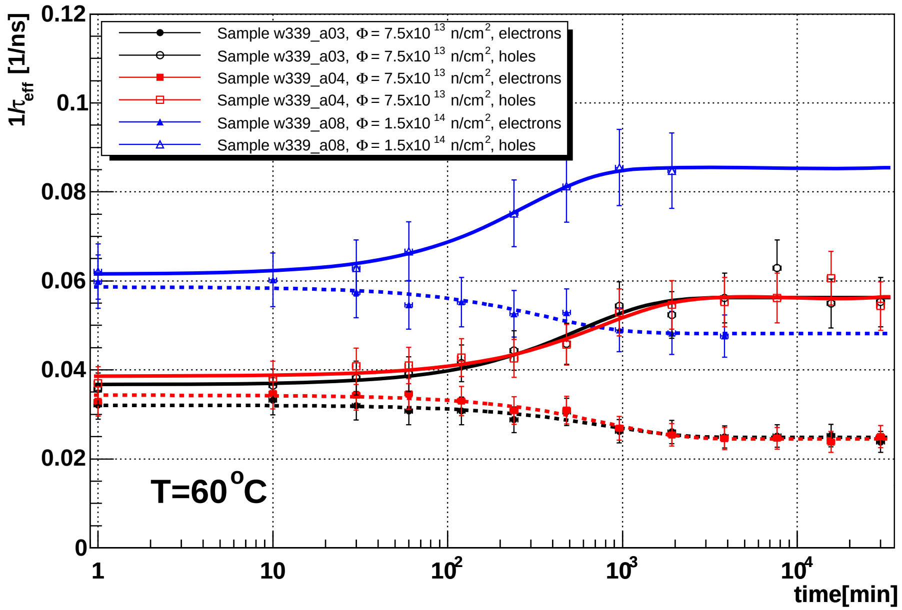


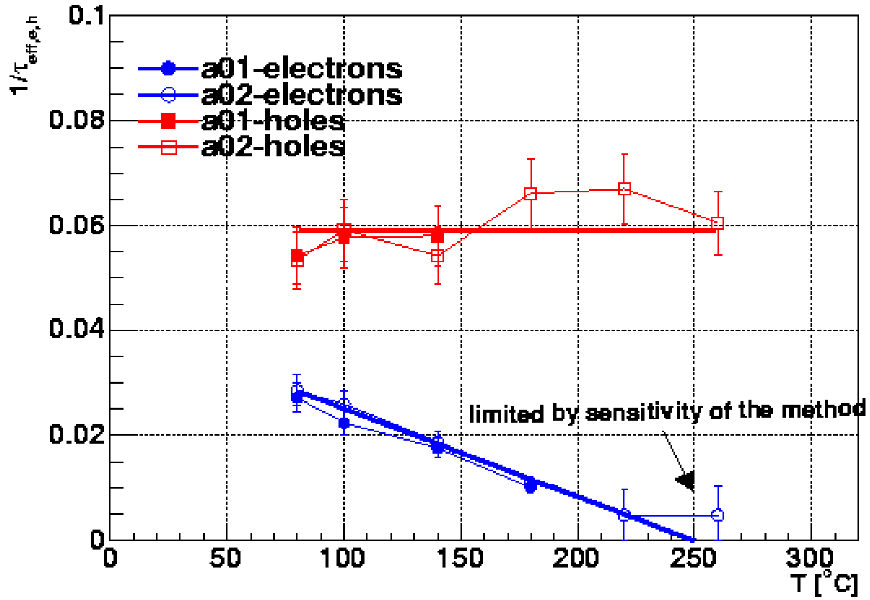
$I/V = \alpha\Phi$, $\alpha = 4.1E\text{-}17$ A/cm

As expected, no surprises for reverse annealing

Macroscopic results

2. TCT: trapping times, surprise in isochronal annealing!



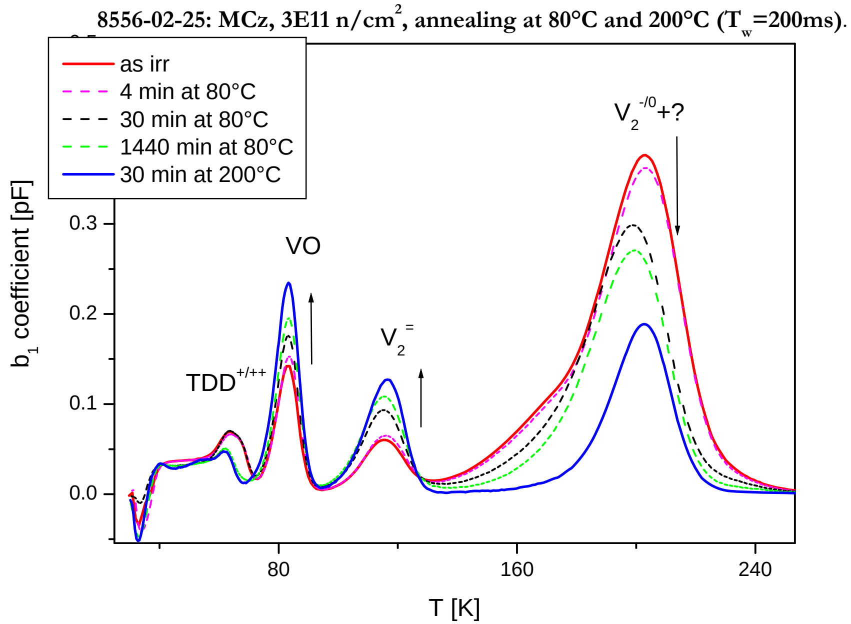


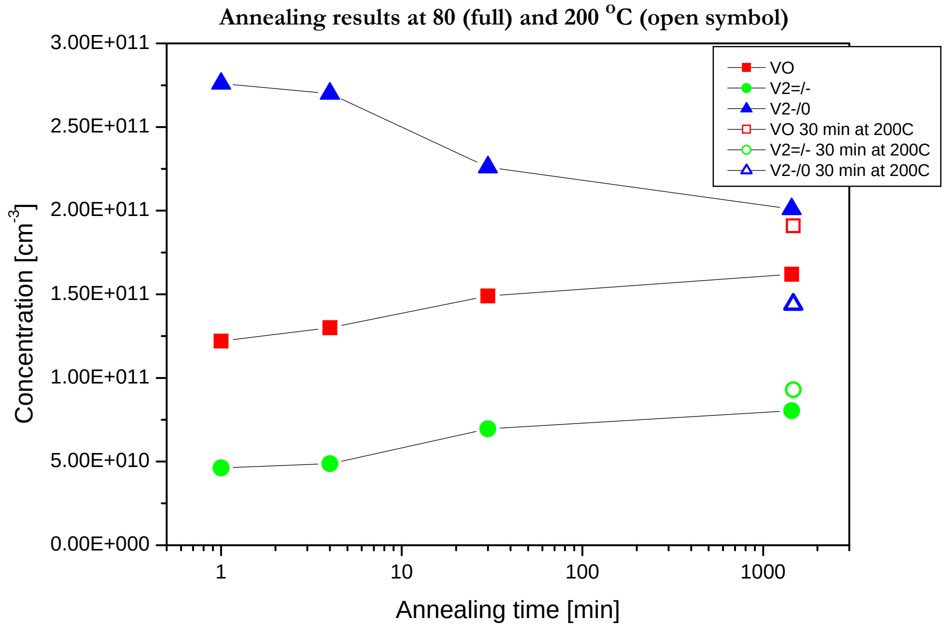
Isothermal annealing at 60°C
max: 30% effect

Isochronal anneal 80-260°C
stable h-trapping
e-trapping reduced by factor 5

Microscopic results

1. DLTS isothermal anneal at 80°C and 200°C

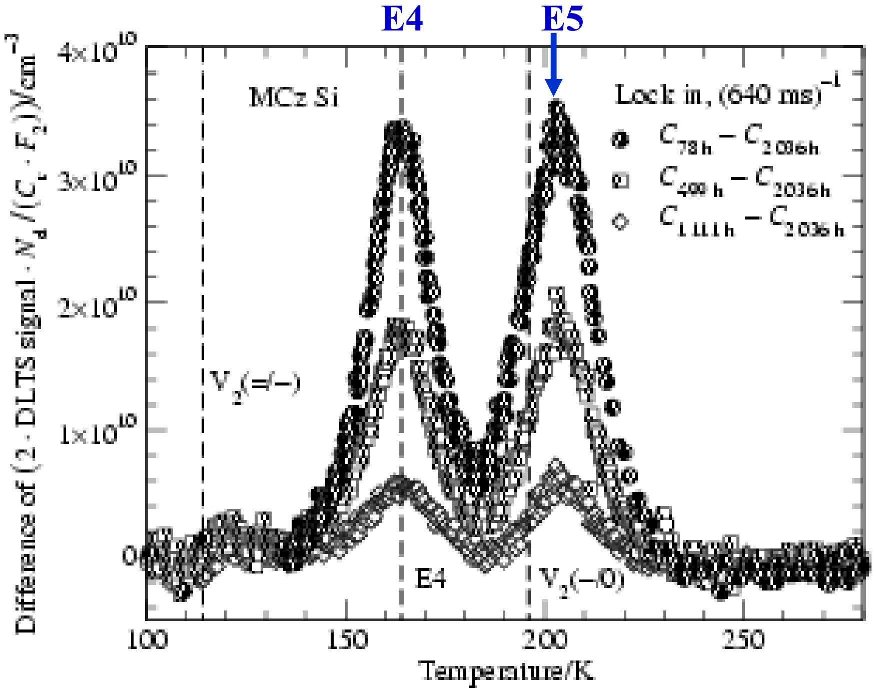




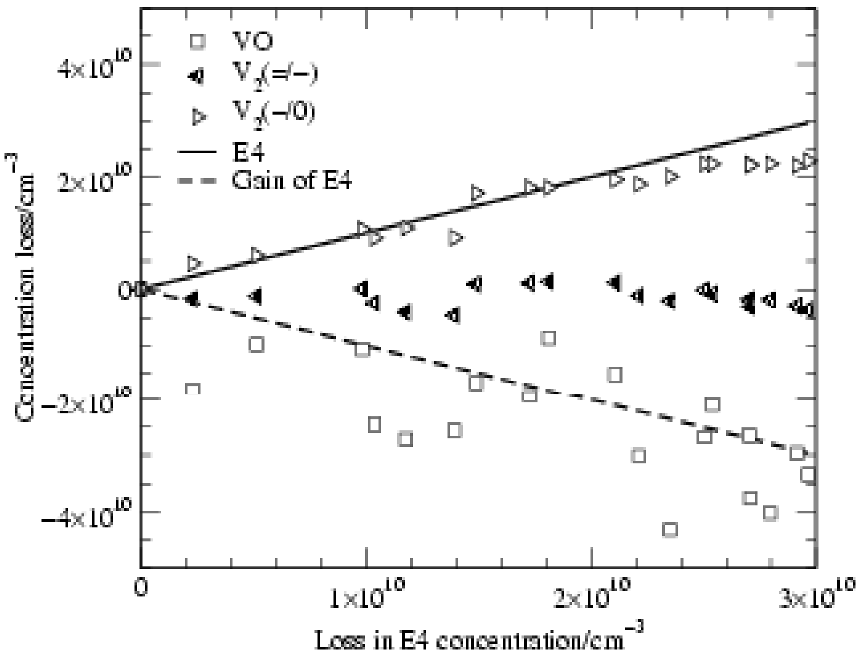
Annealing of vacancy cluster, increase of VO and signal for $V_2^{=/-}$

Measurements after 6 MeV electron irradiation:

Difference of DLTS spectra

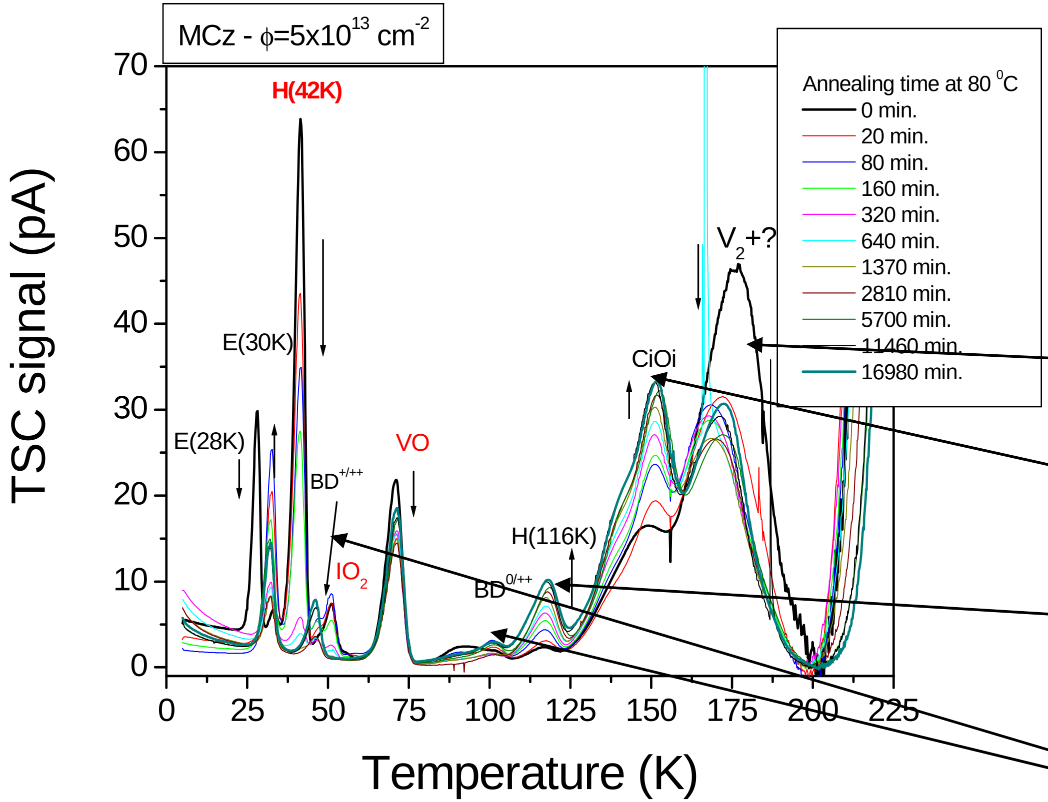


Loss of VO, $V_2^{=/-}$ and E5 vs loss of E4



E4 and E5 vacancy cluster related, 1:1 correlation
liberation of V leads to increase of VO

2. TSC isothermal anneal at 80°C



Annealing of vacancy cluster

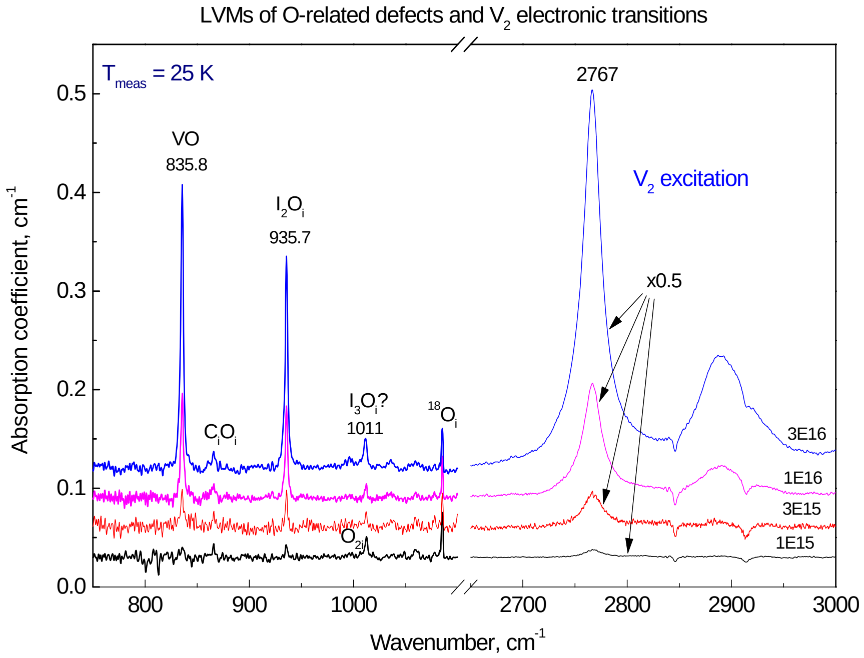
Increase of H(152K), not CiOi

Generation of H116K (reverse annealing related?)

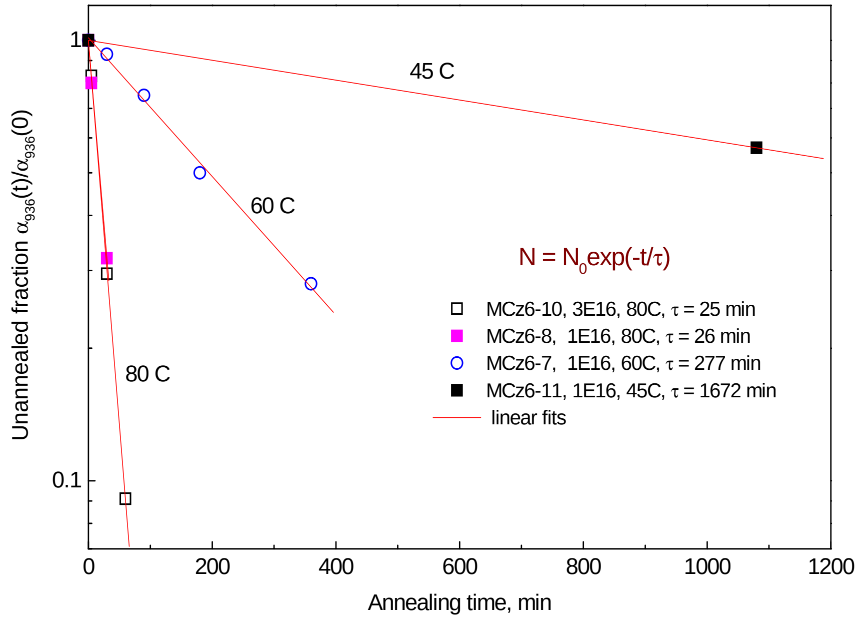
Shallow bistable donor BD(+/++) and BD(0/++)

3. InfraRed Absorption FTIR

Fluence dependence



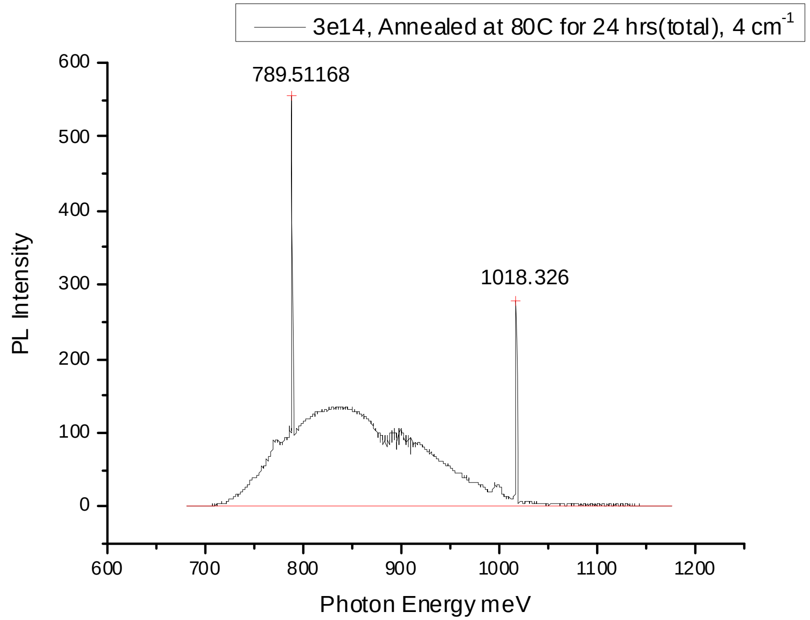
Isothermal annealing of I_2O



Increase of defect concentration with fluence

1st order process activation energy 1.16 eV

4. Photo-Luminescence PL



Summary of annealing

As received: low PL intensity, C_iO_i plus broad band

At 80 C, no change in bandshapes after 4 mins.

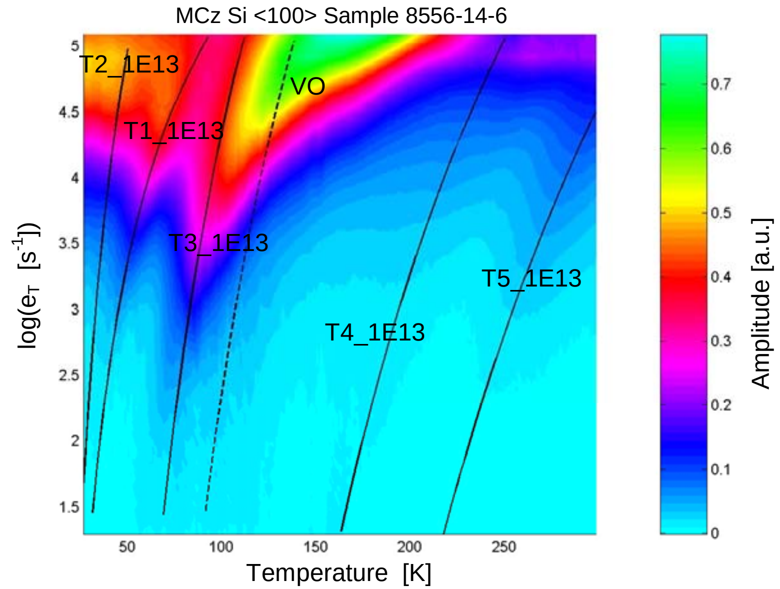
After 30 mins, start of observing weak C_iC_s and W;
W continues to increase after 12 hrs and 24 hrs.

After 450 C, 'point defects' to 1e14 cm^{-2};
increasing dominance of broad band at higher fluences.

5. Photo Induced Transient Spectroscopy
- Example -

1-MeV neutron fluence 1×10^{13} cm^{-2}

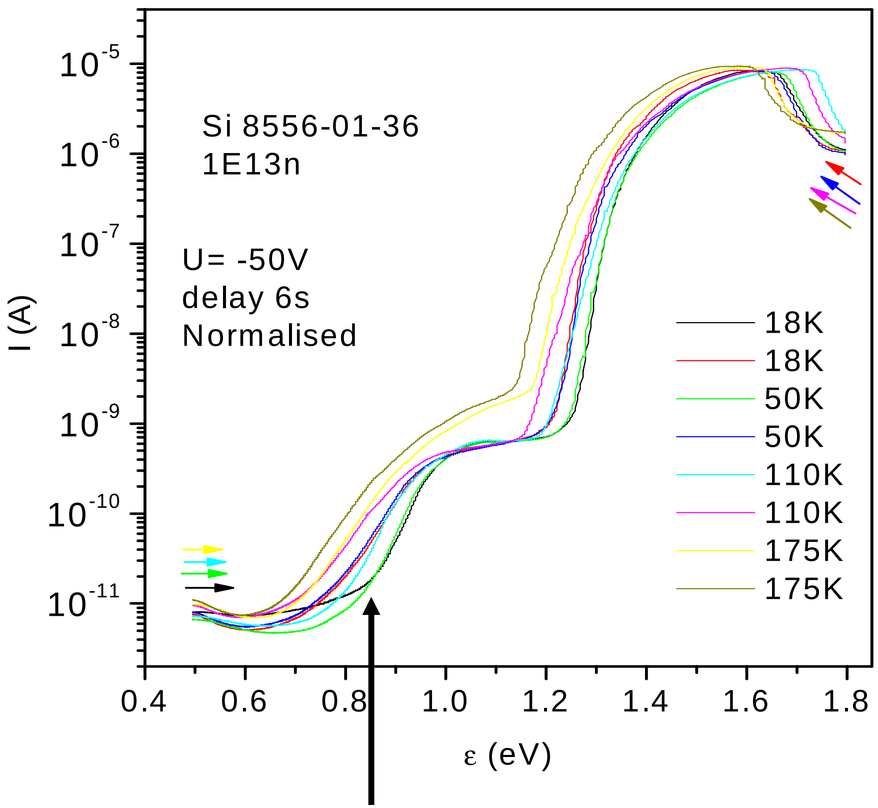
Five well separated spectral fringes due to the thermal emission from shallow defect centers T1_1E13, T2_1E13, and T3_1E13, as well as from deep defect centers T4_1E13 and T5_1E13. The shallow levels are predominant.



Trap label	E_a[meV]	A [$s^{-1}K^{-2}$]	e_1 [s^{-1}]	Amp_{e1}[a.u]	E_2 [s^{-1}]	Amp_{e2}[a.u]	Identification
T1_1E13	25±2	(2-5)x10^2	1x10^3	0.048	3.2x10^4	0.41	shallow donor
T2_1E13	30±2	(3-6)x10^4	1x10^3	0.03	3.2x10^4	0.40	shallow donor
T3_1E13	115±5	(8-20)x10^5	1x10^3	0.12	3.2x10^4	0.46	$C_iC_s(B)^{-/0}$ or self-interstitials related
T4_1E13	315±10	(2-4)x10^6	1x10^3	0.018	3.2x10^4	0.091	$V_2^{2-/-} + C_iO_i^{0/+}$
T5_1E13	470±20	(1-5)x10^7	1x10^3	0.024	3.2x10^4	0.11	$V_2^{-/0} + X^{-/0}$

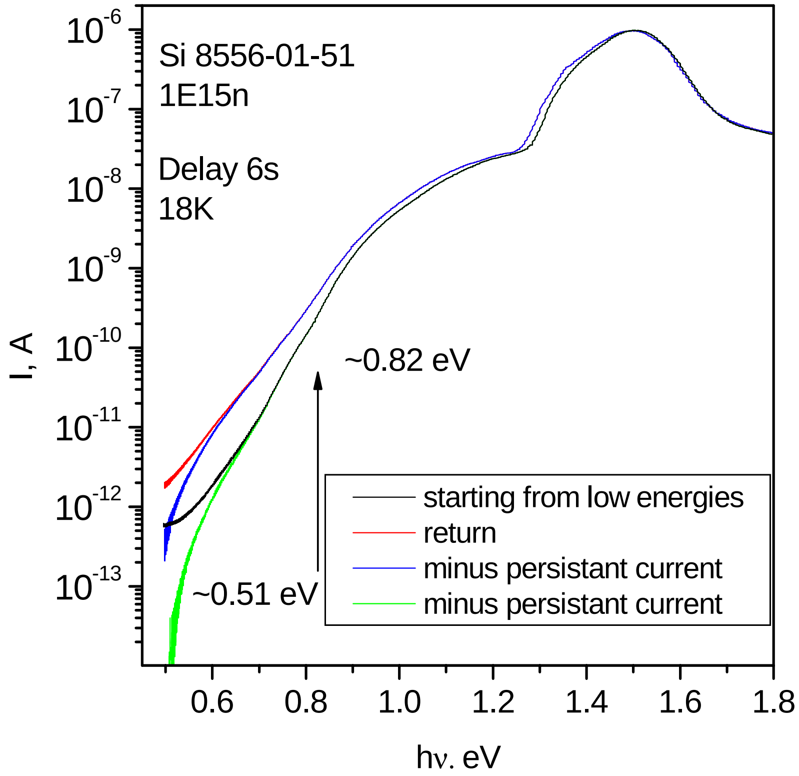
6. Photo Conductivity - Spectra
- Example -

Φ = 1E13 n/cm²

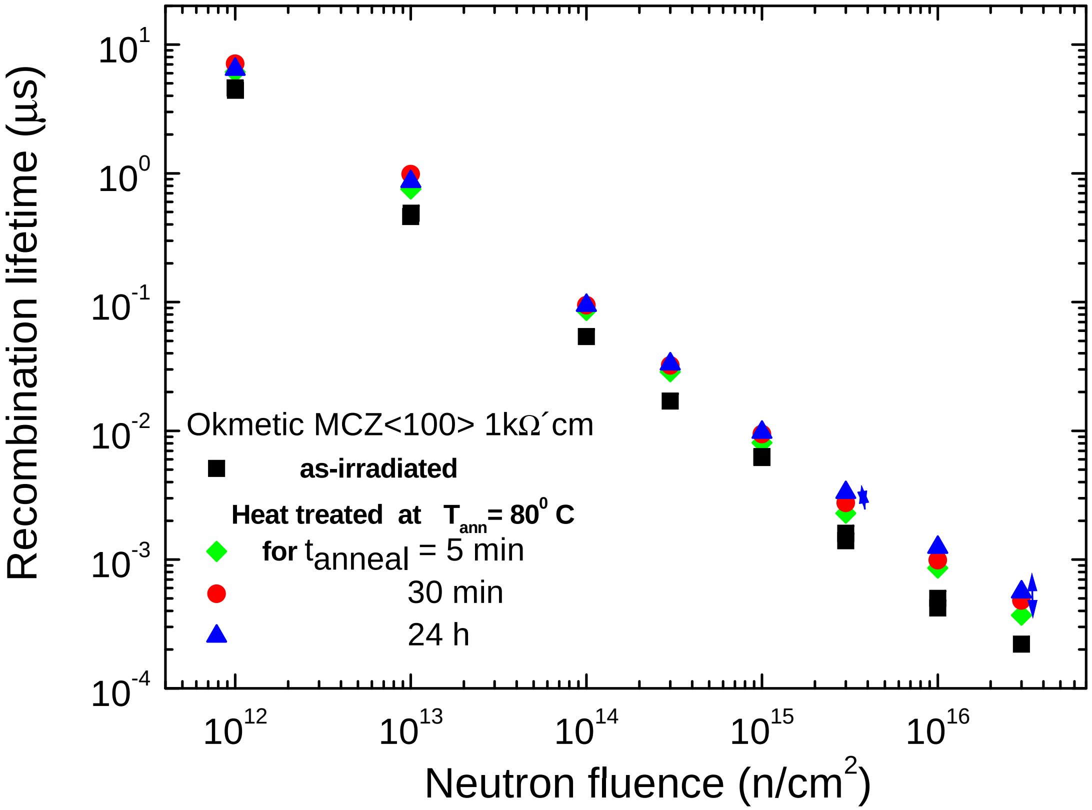


Deep traps

Φ = 1E15 n/cm²



7. Recombination lifetime -



$1/\tau \propto \Phi$, annealing improves lifetime

Outlook

Most surprising result from TCT:
isochronal annealing shows reduction of electron trapping

Strong changes also observed after high temp. steps in DLTS, TSC, PL and FTIR

Consequence: start with 80°C annealing and then go in 40°C steps up to at least 240°C or even higher

Search for close to midgap defects using lower resistivity material, epi most likely available!

New results will be presented in the next talks