WP15.5 - Si for large fluence irradiation monitoring

Variations of carrier recombination and trapping parameters in Si irradiated with various particles

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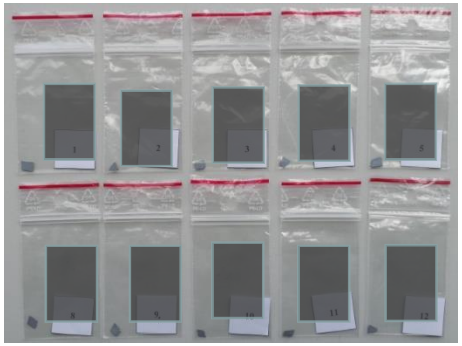
Our purpose in AIDA-2020 is to find a most convenient Si for the irradiation fluence monitoring and imaging: to find a cost effective solution, therefore we analyze, the **high resistivity**, **electronic grade**, **solar energy grade**, **multicrystalline samples**, and we still wait a special **"cheap Si"** wafers of Si from Lancaster U, and in general we concentrate **on details of different Si differently irradiated**.

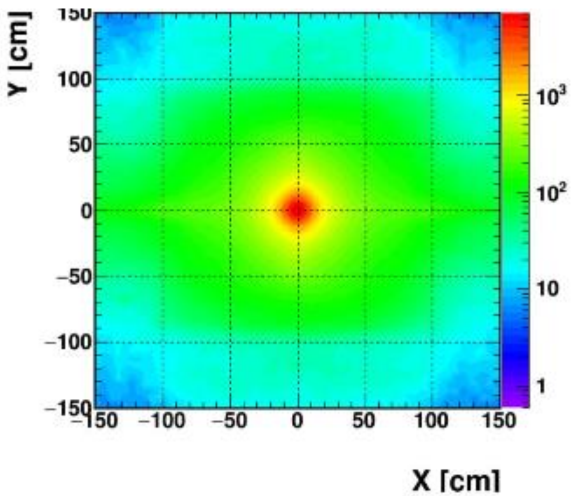
The series of samples are ready for calibration at CERN).

The device for integrated fluence monitoring

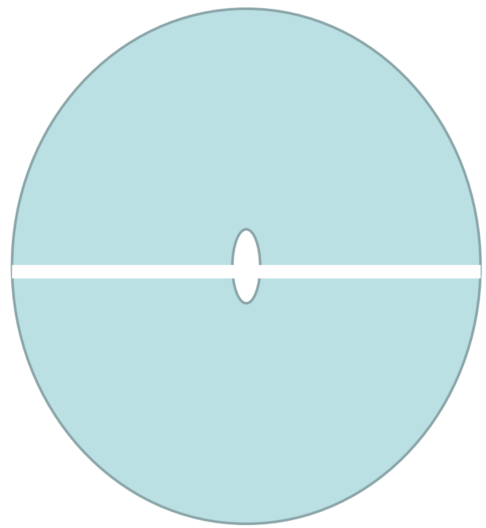
- The device for the contactless fluence monitoring delivered to CERN, the instruction book given, the seminar for the staff members organized, Vilnius team member is ready to come if necessary.
- The calibration procedure has started, and to proton and neutron irradiation the irradiation by pions was added.



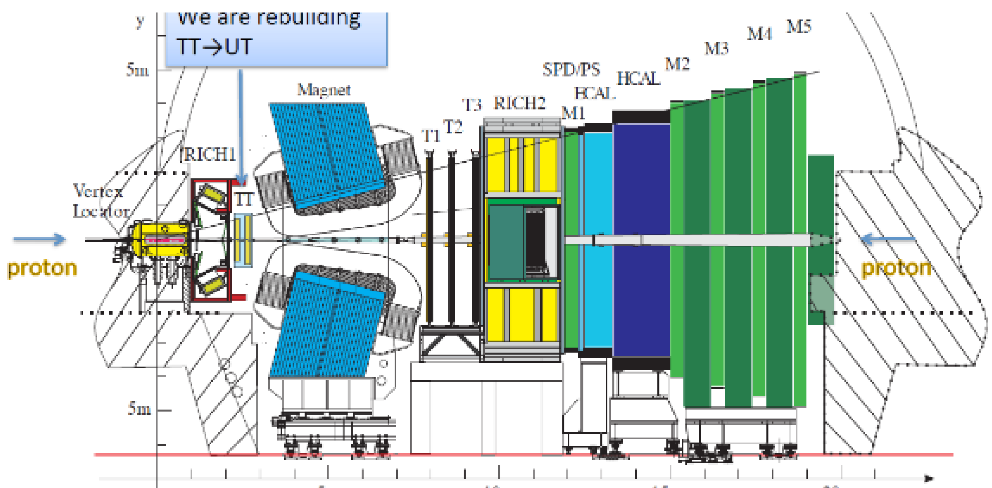
Fluence imaging (our proposal for LHC(b) - our vision):



Non-uniform irradiation profile depending on distance from beam center.



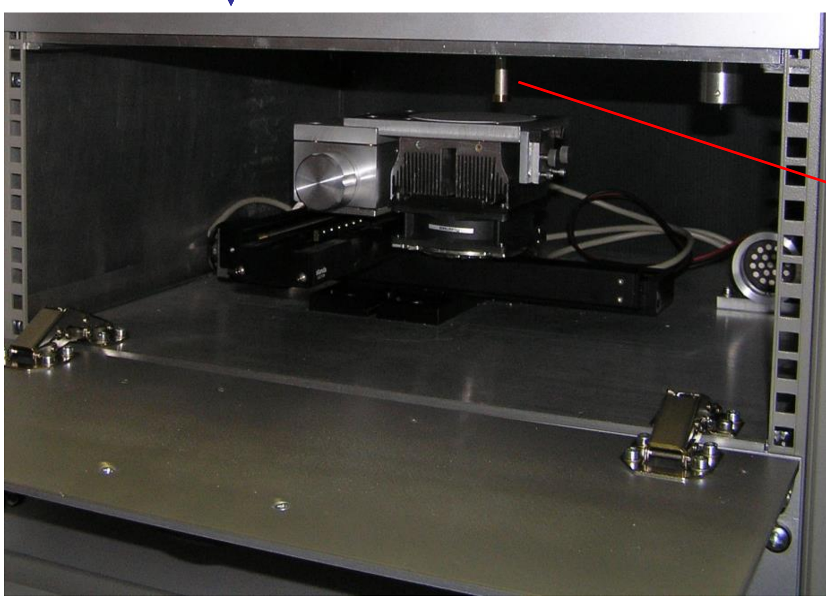
1. Two Si wafer pieces (Fig.) put around the proton beam.
2. Irradiate.
3. Remove.
4. Scan the lifetime distribution across both pieces.
5. Transform the lifetime map to the integrated fluence image.



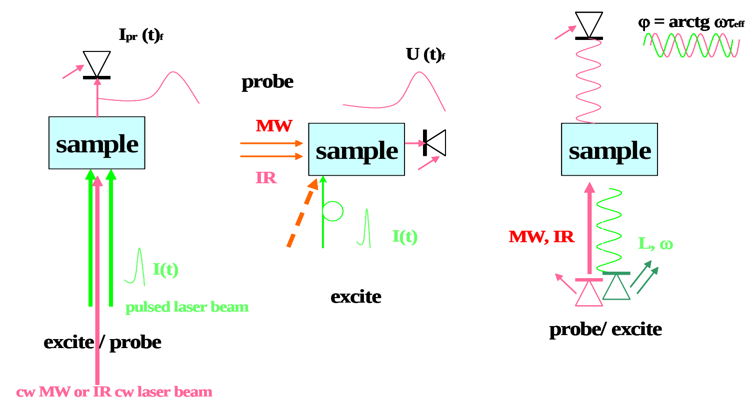
The fluence range 1e12-more that 1e16 hadrons/cm2.

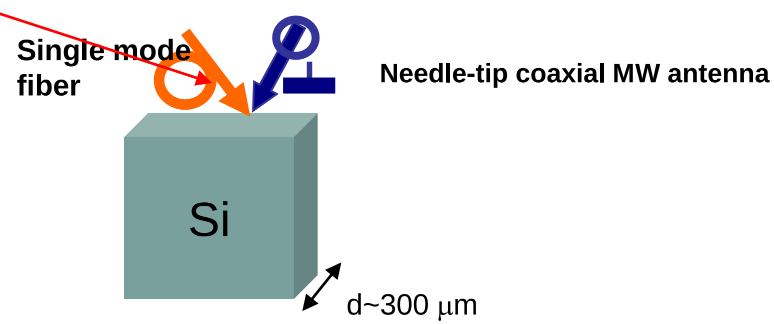
(If the irradiation will be more than 3e16 cm-2, then this area will be necessary to scan by other method, purely optical)

This device for 2D integrated fluence imaging up to 3“.

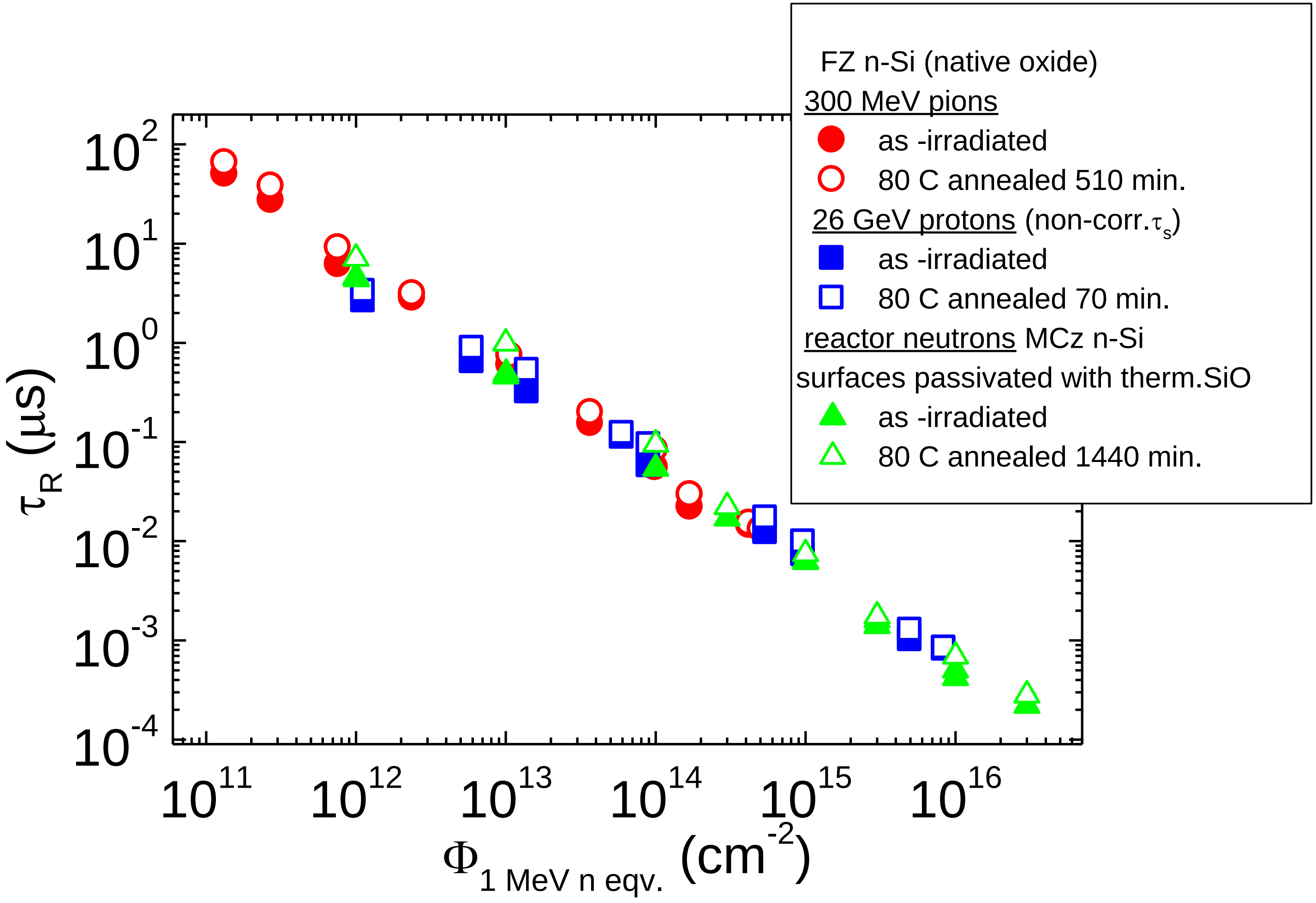


It can scan sample in different regimes: transmission, reflectance and probe

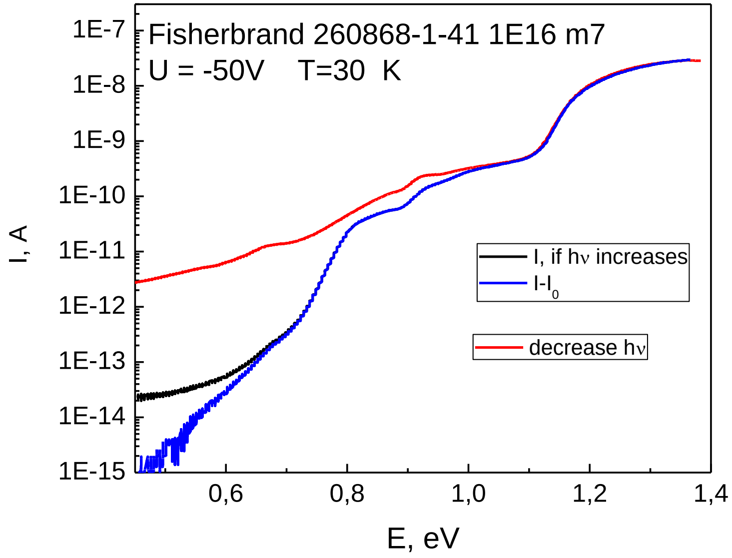


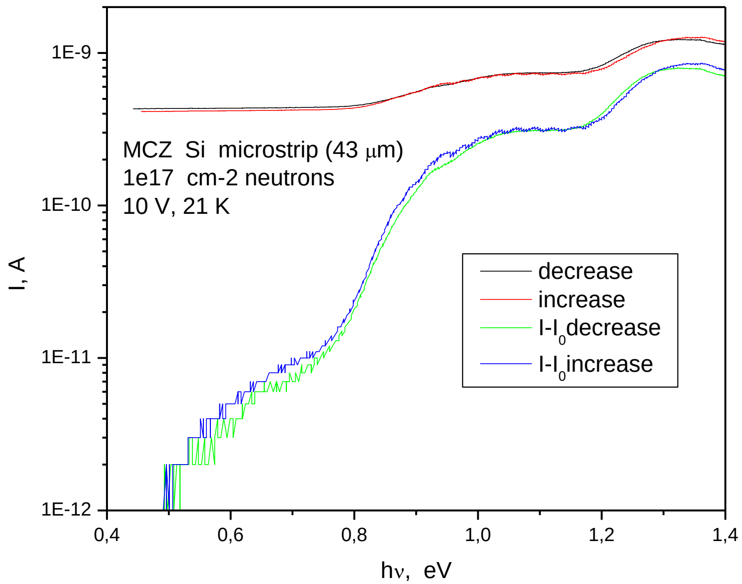


Comparison of characteristics of the pion, neutron and proton as irradiated and isothermally (T_{an} =80 C) annealed Si



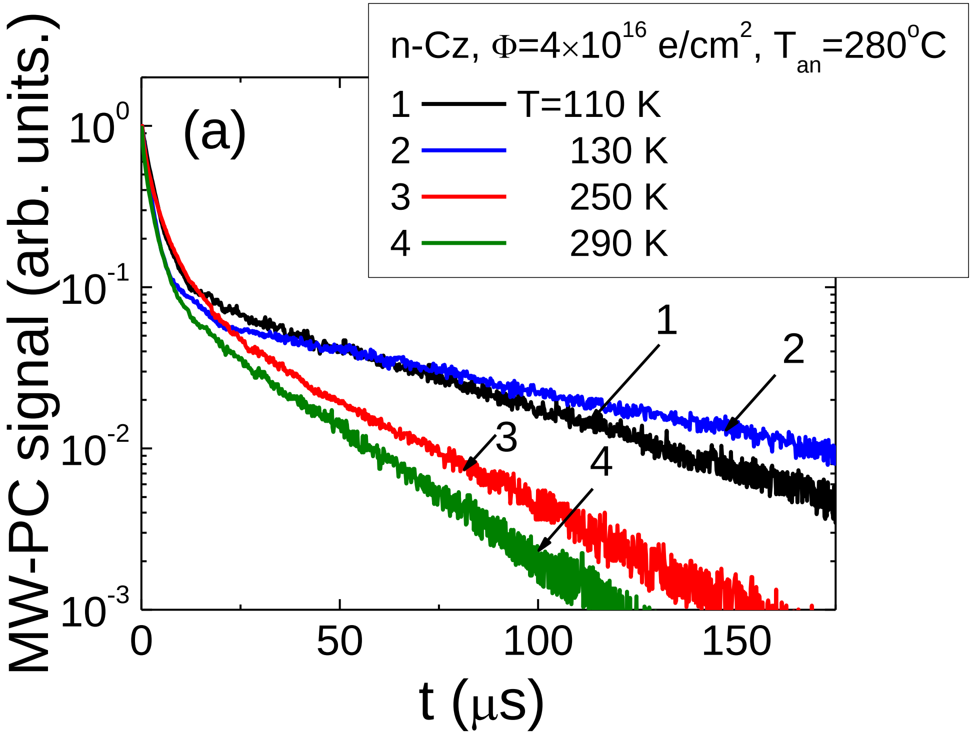
Deep level spectroscopy





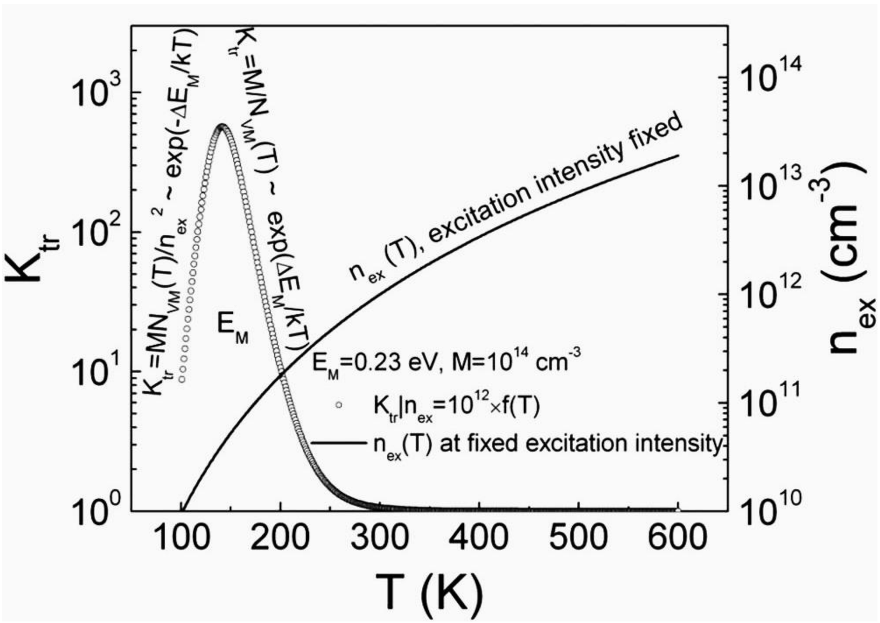
- The high neutron fluence introduce deep donors that increased the dark conductivity
- The main deep centers are at ~0,5 and ~0,8 eV (optical activation energy)

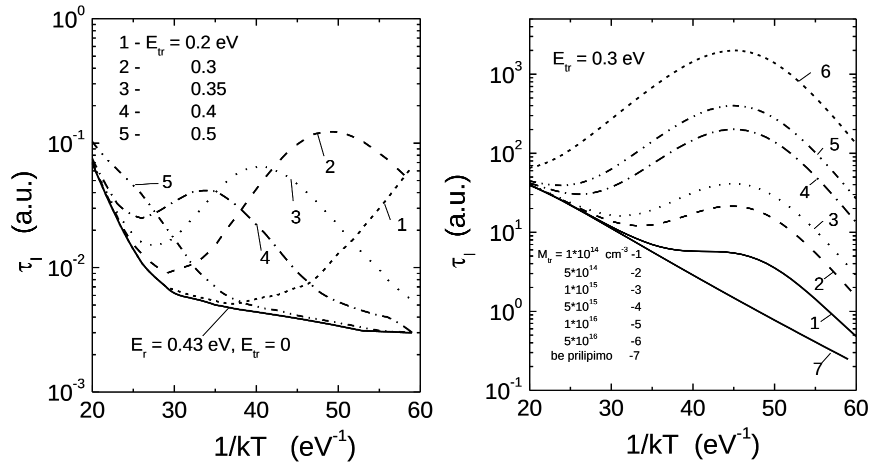
Recombination and trapping



Trapping and recombination lifetime variations dependent on trap concentration, level activation energy and excitation density

$$\tau_{inst,tr} = \tau_R K_{tr}; \quad K_{tr} = 1 + \frac{T_{tr} N_{C,V,e,h,Ttr}}{(N_{C,V,e,h,Ttr} + \Delta n)^2}$$

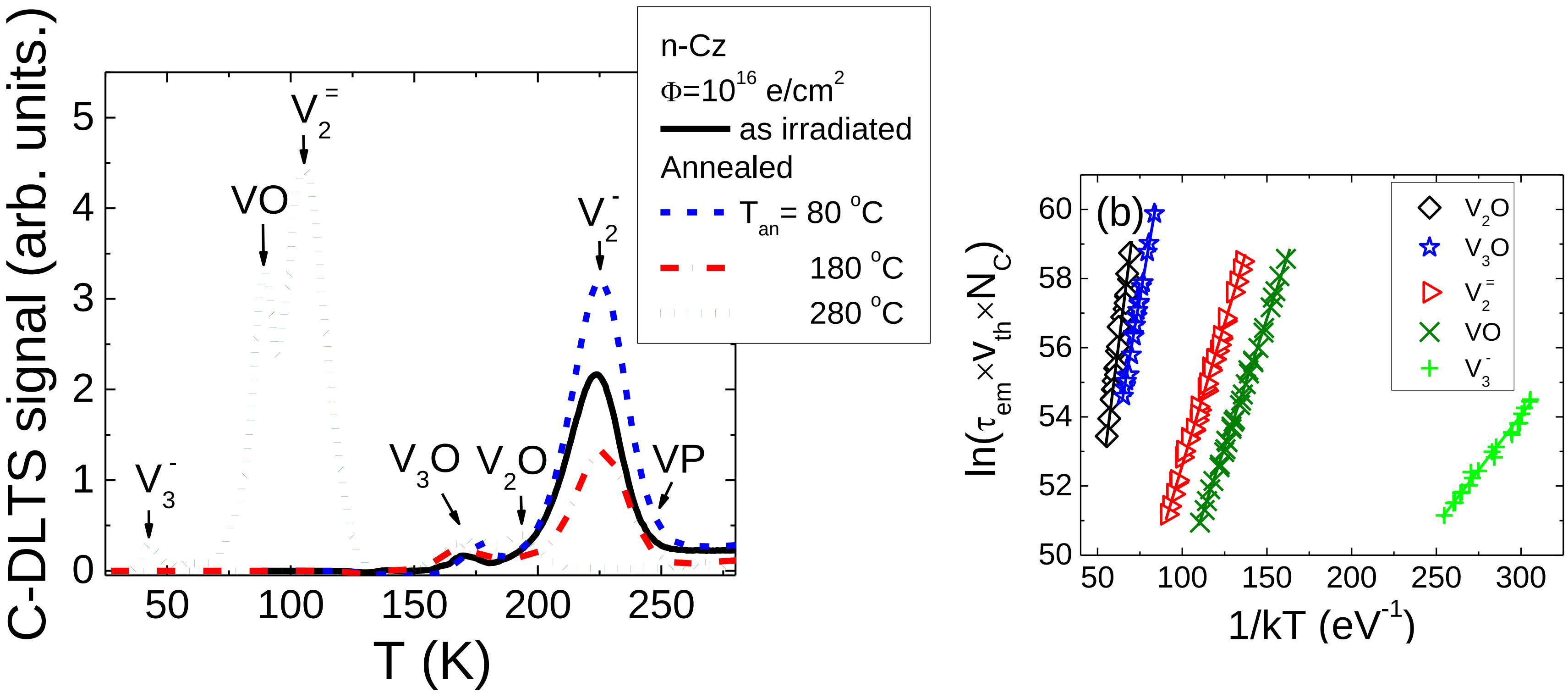




a- Simulated trapping coefficient dependence on temperature for trapping level with activation energy of 0.23 eV in Si.

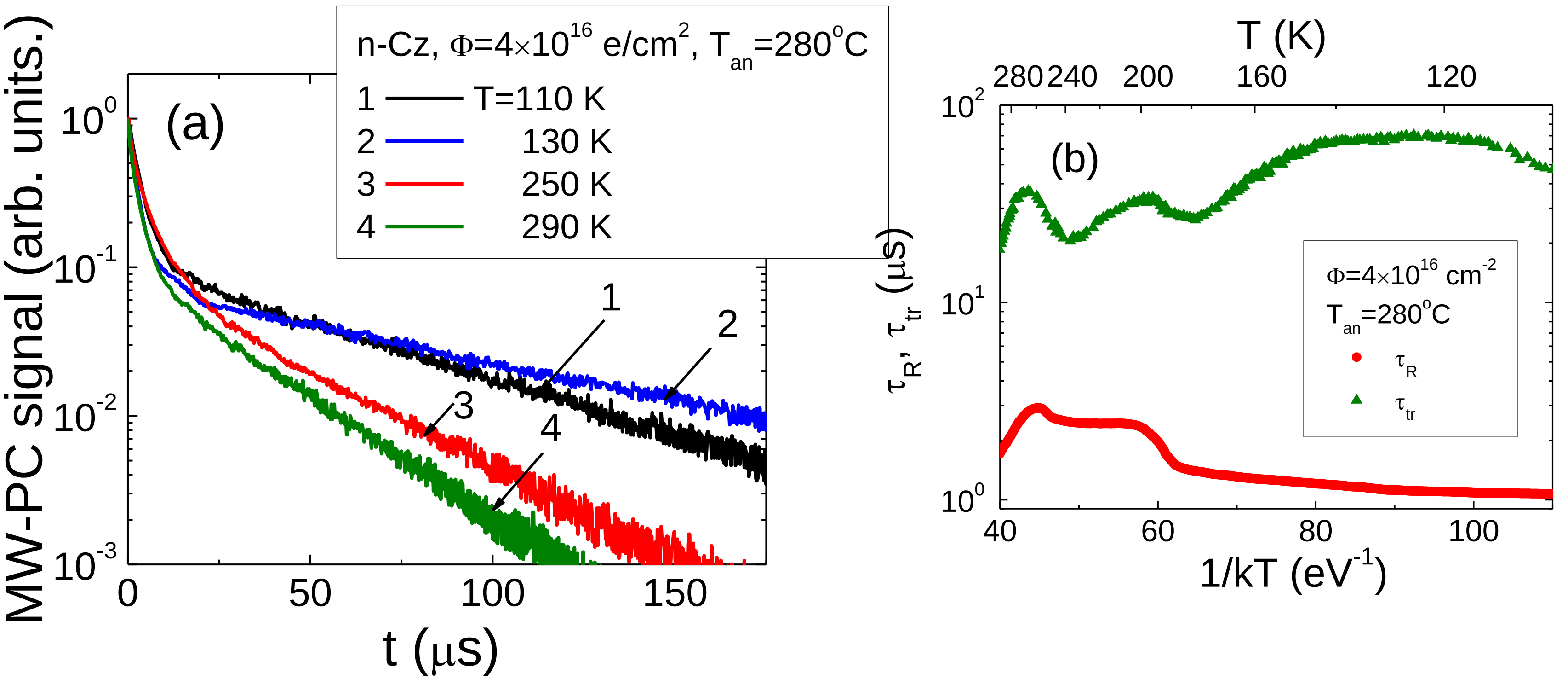
b- Variations of recombination and instantaneous trapping lifetimes as a function of reciprocal thermal energy varying activation energy and concentration of trapping centres.

DLTS spectra in electron irradiated Si samples after isochronal (24 h) anneals



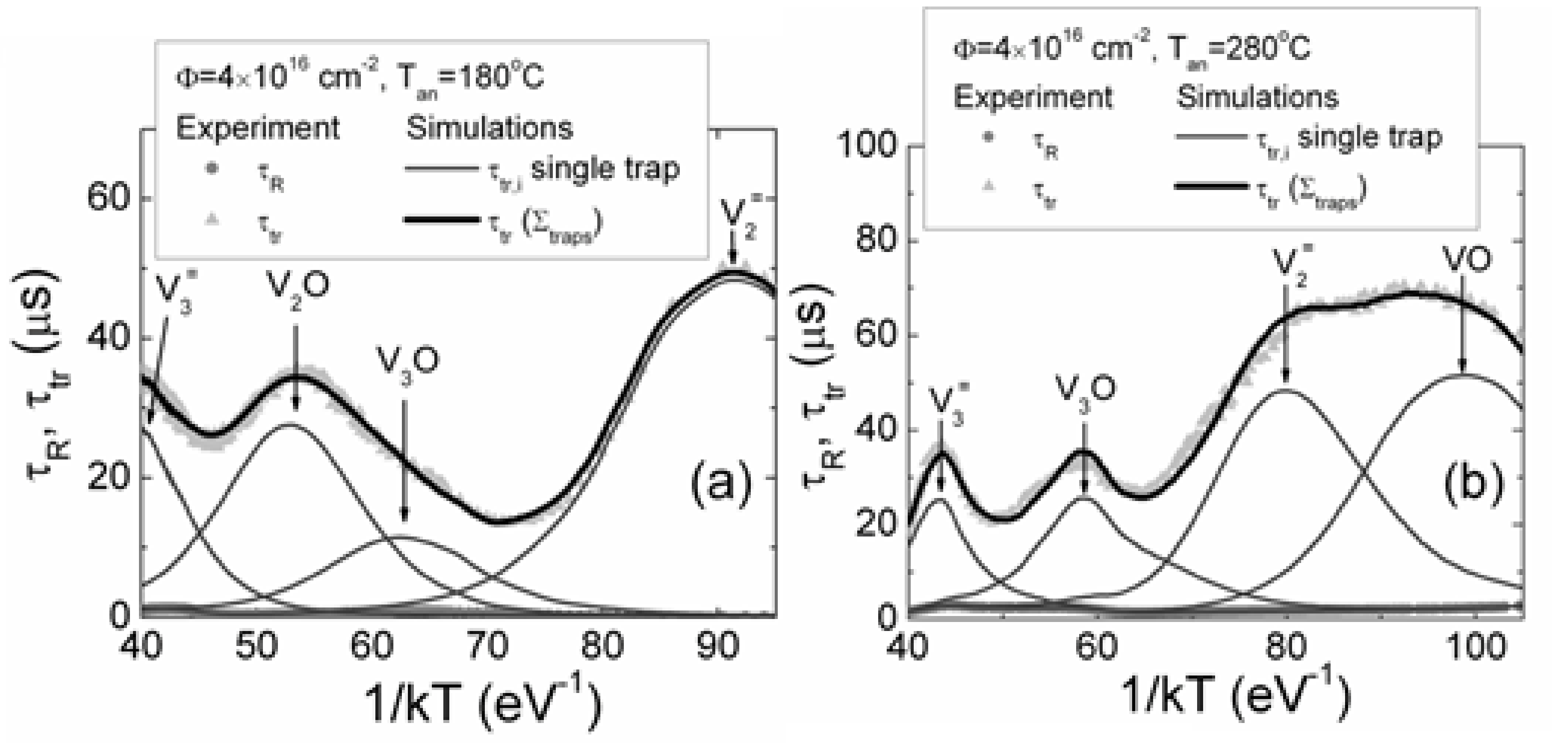
DLTS spectra dependent on annealing temperature recorded on Schottky diodes irradiated with fluence of $\Phi=10^{16}$ e/cm^2. b- The Arrhenius plots obtained for different spectral peaks obtained in diodes annealed at 280°C.

MW-PC characteristics in electron irradiated Si samples after isochronal (24 h) anneal at T_{an} =280 C varying scan temperature *T* for transients



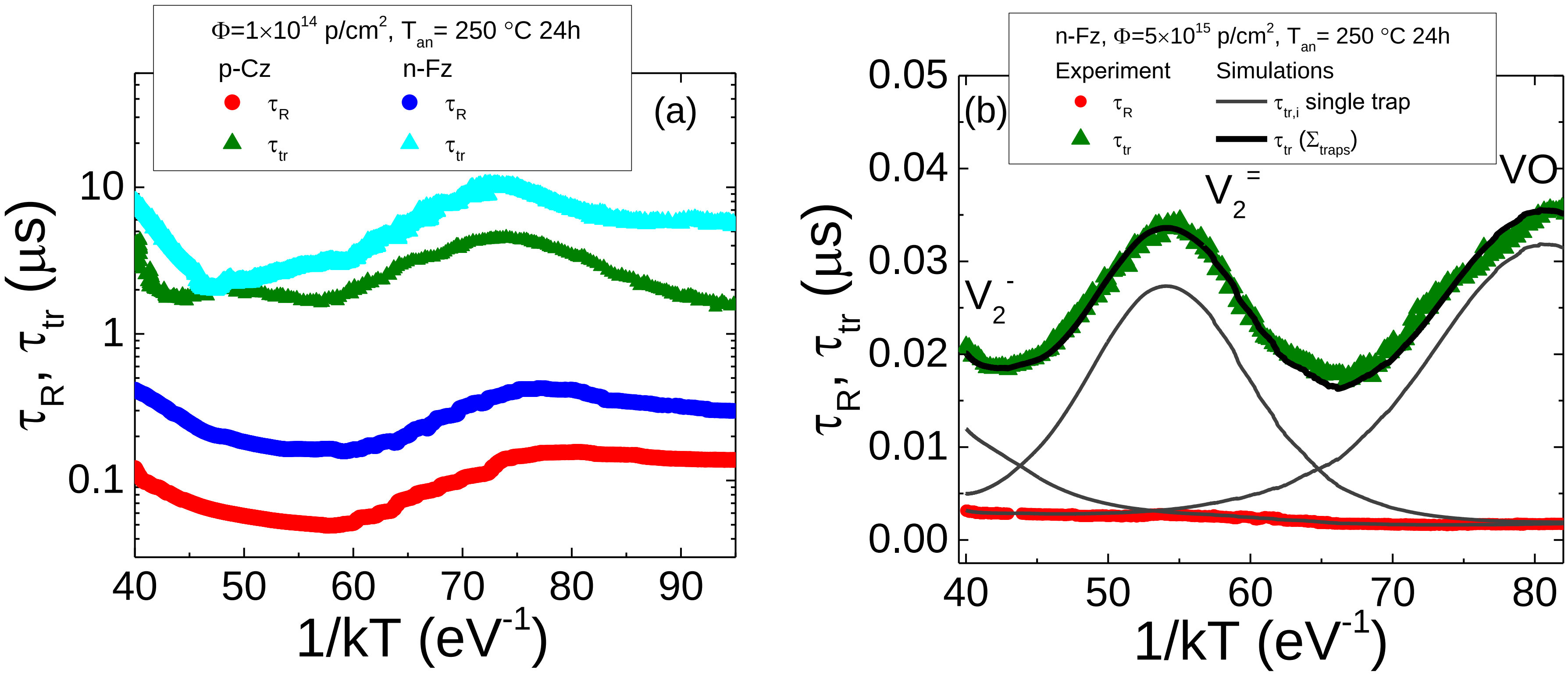
a- The MW-PC transients recorded on the diode sample irradiated with fluence 4×10^{16} e/cm^2 using different scan temperatures *T*. b-Variations of the carrier recombination (τ_R) and trapping (τ_{tr}) lifetimes as a function of the reciprocal thermal energy (kT) for sample irradiated with fluence 4×10^{16} e/cm^2 after heat treatment at T_a= 280°C.

Trapping spectra measured by MW-PC in 6.6 MeV electron irradiated Si samples after isochronal (24 h) anneal at *Tan* =280 C varying scan temperature *T* of transients



Comparison of the simulated (curves) and experimental (symbols) variations of the carrier trapping lifetimes τ_{tr} as a function of reciprocal thermal energy for samples irradiated with fluence 4×10^{16} e/cm^2 and annealed for 24 h at temperatures T_{an}=180^{0}C (a) and T_{an}=280^{0}C (b). Here, the bold curve represents a sum of emission flows from different trapping levels those form the single thermal emission peaks, shown by thin solid curves. Simulations of the resultant $\tau_{tr}(T)$ spectrum were performed including temperature dependent changes of the recombination lifetime $\tau_R(T)$.

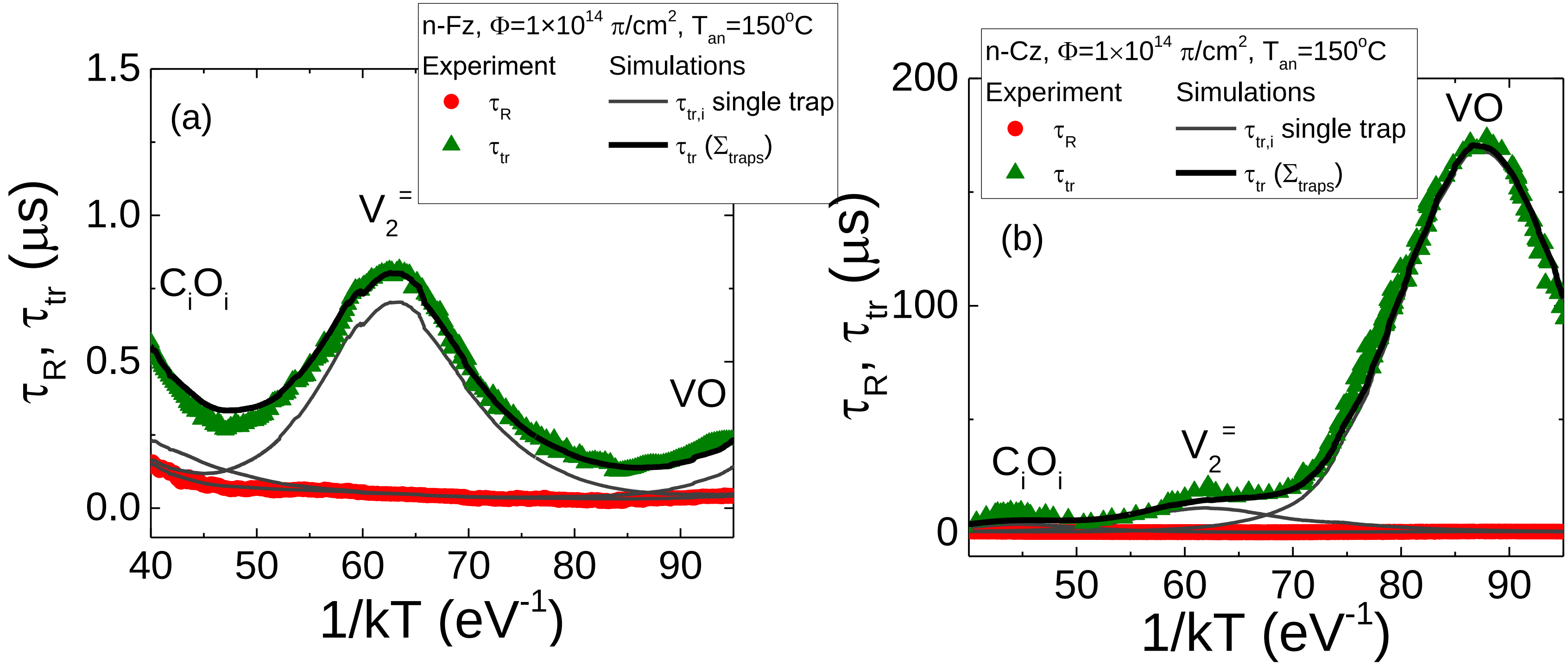
Trapping spectra measured by MW-PC in proton irradiated n-Fz and p-Cz Si samples after isochronal (24 h) anneal at *Tan* =250 C varying scan temperature *T* of transients



a-Variations of the carrier recombination (τ_R) and trapping (τ_{tr}) lifetimes as a function of the reciprocal thermal energy (kT) for p-Cz and n-Fz samples irradiated with fluence 1×10^{14} e/cm^2 after heat treatment at T_{an}= 250°C.

b- Comparison of the simulated (curves) and experimental (symbols) variations of the carrier trapping lifetimes τ_{tr} as a function of reciprocal thermal energy for n-Fz Si sample irradiated with fluence 5×10^{15} e/cm^2 and annealed for 24 h at temperatures T_{an}=250^{0}C

Trapping spectra measured by MW-PC in pion irradiated Si samples after isochronal (24 h) anneal at *Tan* =150 C varying scan temperature *T* of transients



Comparison of the simulated (curves) and experimental (symbols) variations of the carrier trapping lifetimes τ_{tr} as a function of reciprocal thermal energy for n-Fz Si (a) and n-Cz Si (b) samples irradiated with fluence 1×10^{14} e/cm^2 and annealed for 24 h at temperatures T_{an}=150^{0}C

Summary

- Different Si crystals were investigated and their possibilities for the hadron fluence monitoring and for the hadron beam imaging were determined.
- Recombination prevails in the as-irradiated material, and recombination lifetimes fit a single curve in lifetime-fluence dependence for neutrons, protons and pions as well as for various technology Si materials
- Isothermal (80C) anneals (hadron irradiated Si) lead to enhance of trapping effect, - 2-componential decay transients with long asymptotic decay
- Amplitude and instantaneous lifetime of trapping component depends on irradiation fluence
- Trapping indicates increase of the role of point defects. Spectra of trapping lifetime correlate with those of O-I-DLTS, while variation of peaks ascribed to different point traps vary with temperature (100 -300 C) of isochronal (24 h) anneals, indicating non-trivial transforms of radiation defects.

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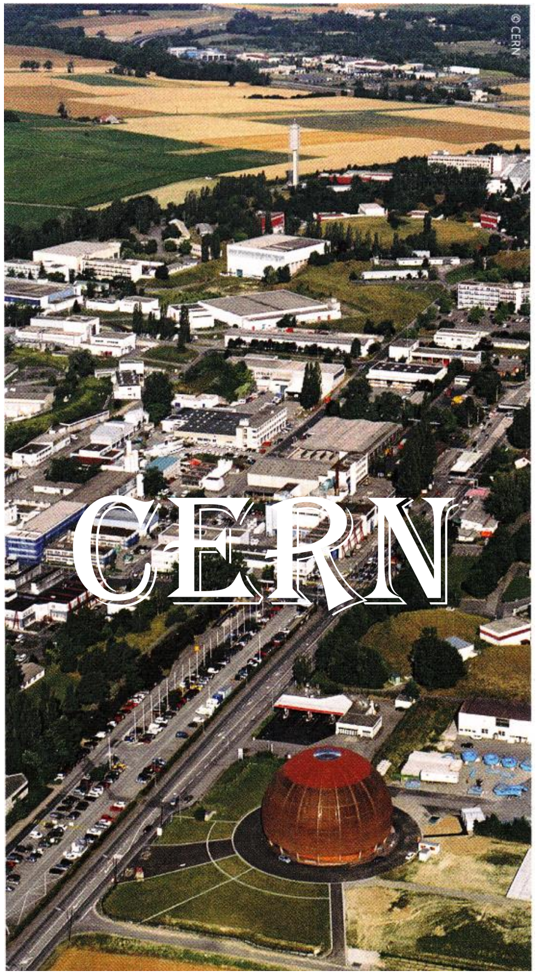
This research was performed in framework of AIDA-2020 grant



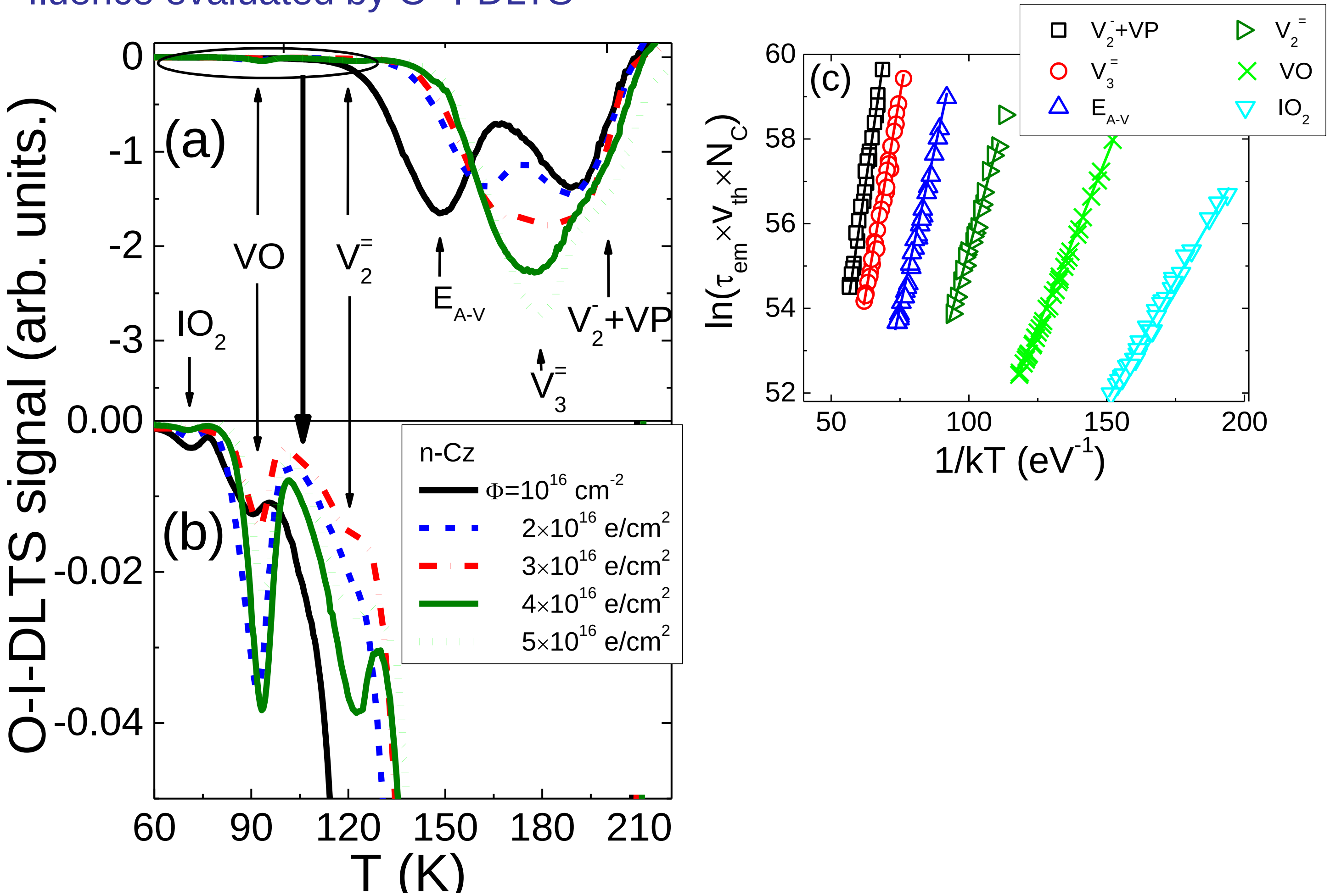
THANK YOU

FOR YOUR ATTENTION!

Parameters of the carrier emission centres dependent on heat-treatment temperature extracted by O-I-DLTS and MW-PC techniques

Defect	Heat-treatment	Non-annealed		Annealed at 80°C		at 180°C		at 280°C	
	$\Phi=10^{16}$ e/cm^2	1	5	1	5	1	5	1	5
	Method	Concentration of trapping centres (10^{14} cm^{-3})							
V_2^-/ V–P	DLTS	0.83	2.2	1.2	2.1	0.7	0.21	-	-
V_2O	DLTS	0.083	-	0.12	-	0.083	-	0.21	0.23
	MW-PC	-	-	-	-	-	3.4	-	5
V_3O	DLTS	0.035	-	0.18	-	0.15	-	0.17	0.065
	MW-PC	-	-	0.97	1.8	-	-	-	-
$V_3^=$	DLTS	-	>10	>100	>100	-	>100		-
	MW-PC	-	-	6	15	-	9	4	3
$V_2^=$	DLTS	11	6.4	14	8.5	-	8.1	1.9	-
	MW-PC	-	-	1.4	-	1.2	0.2	0.5	-
VO	DLTS	3.1	5.6	4.8	7.9	2.7	5	1.4	-
IO_2	DLTS	-	0.072	0.95	0.19	2.7	0.14		
V_3^-	DLTS	-	-	0.84	2.2	0.96	0.1	0.96	0.1
A-V	DLTS	-	-	>100	-	>100	-	-	-

Trap spectra in 6.6 MeV electron irradiated Si samples as a function of fluence evaluated by O- I-DLTS



The Arrhenius plots obtained for different separated spectral peaks are illustrated in figure (c) for sample irradiated with fluence of $\Phi=1\times10^{16}$ e/cm^2.