Fluence dependent recombination lifetime in neutron and proton irradiated MCz , FZ and epi-Si structures

E.Gaubas, J.Vaitkus, T.Čeponis, A.Uleckas, J.Raisanen, S.Vayrynen, and E.Fretwurst

Vilnius University, Institute of Materials Science and Applied Research
Helsinki University, Accelerator Laboratory
University Hamburg

Outline

- Objectives of investigations
- Samples, irradiations and experiments
- Fluence dependent lifetime variations
- Characteristics of lifetime cross-sectional profiles
- Summary

Objectives / investigations

- Direct measurements of recombination lifetime fluence dependences:
  - comparative analysis of carrier decay in MCZ, FZ and epi-Si neutron irradiated structures
- Control of possible anneal of defects:
  - heat treatments 80C
- Recombination lifetime variations with energy of protons
- Recombination characteristics in 2 MeV proton irradiated n-FZ Si
  - combined investigations of MWR, DLTS and RR in 2MeV proton irradiated structures
- Cross-sectional scans within structure depth to control defect production profiles

Samples

1

Irradiation plan March 2007 TRIGA reactor Resp. Gregor
arrival HH 15-06-2007, 12:20 in cold box

Material: Wacker FZ <111> 2 kOhmcm 290 µm Process STM W337

FZ

WODEAN

phi_n [cm-2]	W337 FZ
1.00E+13	**B11**
1.00E+13	**E8**
1.00E+14	**Q5**
1.00E+14	**G13**
1.00E+15	**H2**
1.00E+15	**H3**
1.00E+16	**Q6**
1.00E+16	**I13**

Irradiation TRIGA reactor March 2004

Material: ITME n-EPI <111> 50 Ohmcm 50 µm Process: CIS

n- epi

phi_n [cm-2]	6336-04 n-EPI 50 µm	annealing 80 °C t_max [days]	V_dep [V] at t_max
2.00E+14	06	135.3	59.0
6.00E+14	08	135.3	3.2
1.00E+15	11	135.3	18.7
2.00E+15	17	135.3	90.9
4.00E+15	24	148.4	240.8
8.00E+15	28	135.3	450.0
1.00E+16	32	135.3	478.0
not irradiated	34	x	x
not irradiated	35	x	x

Irradiation TRIGA reactor November 2006
arrival HH: 8. January 2007, by Gregor

Material: ITME p-EPI <111> 150 Ohmcm 50 µm Process: CIS

p- epi

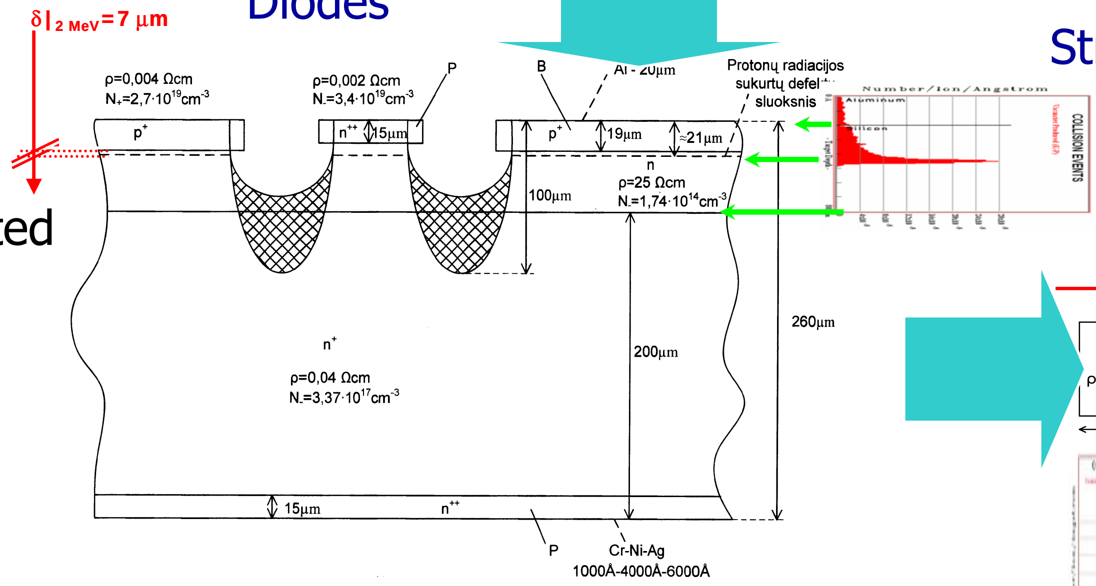
phi_n [cm-2]	260868-01 p-EPI 50 µm	annealing 80 °C t_max [days]	V_dep [V] at t_max
3.00E+13	16	31.3	88.1
1.00E+14	19	31.3	52.8
3.00E+14	27	31.3	47.9
1.00E+15	33	31.3	89.0
3.00E+15	36	31.3	268.0
1.00E+16	41	2.3	671.0
not irradiated	43*	x	x
not irradiated	44*	x	x

* breakdown voltage about 60 V, guard ring not working

Neutron irradiated

2

Diodes



Proton irradiated

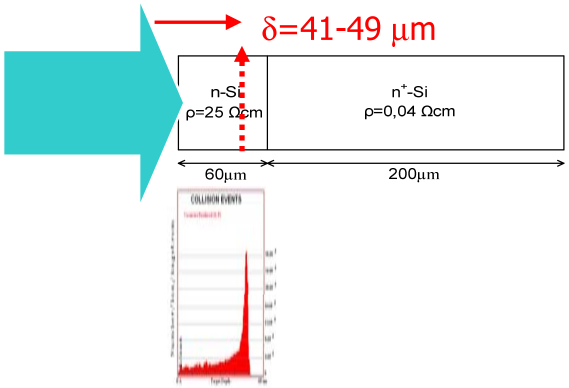
FZ n-Si

VU-HUAL

Structures tested

1.9 and 2.0 MeV protons

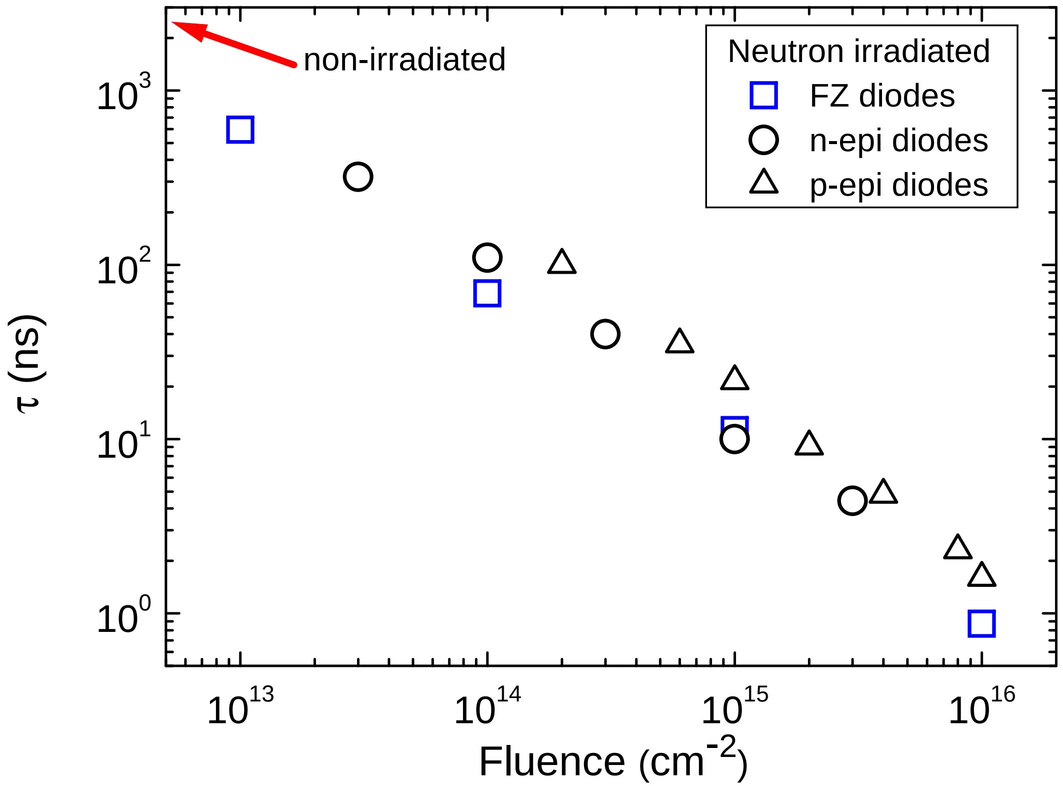
Wafer structures



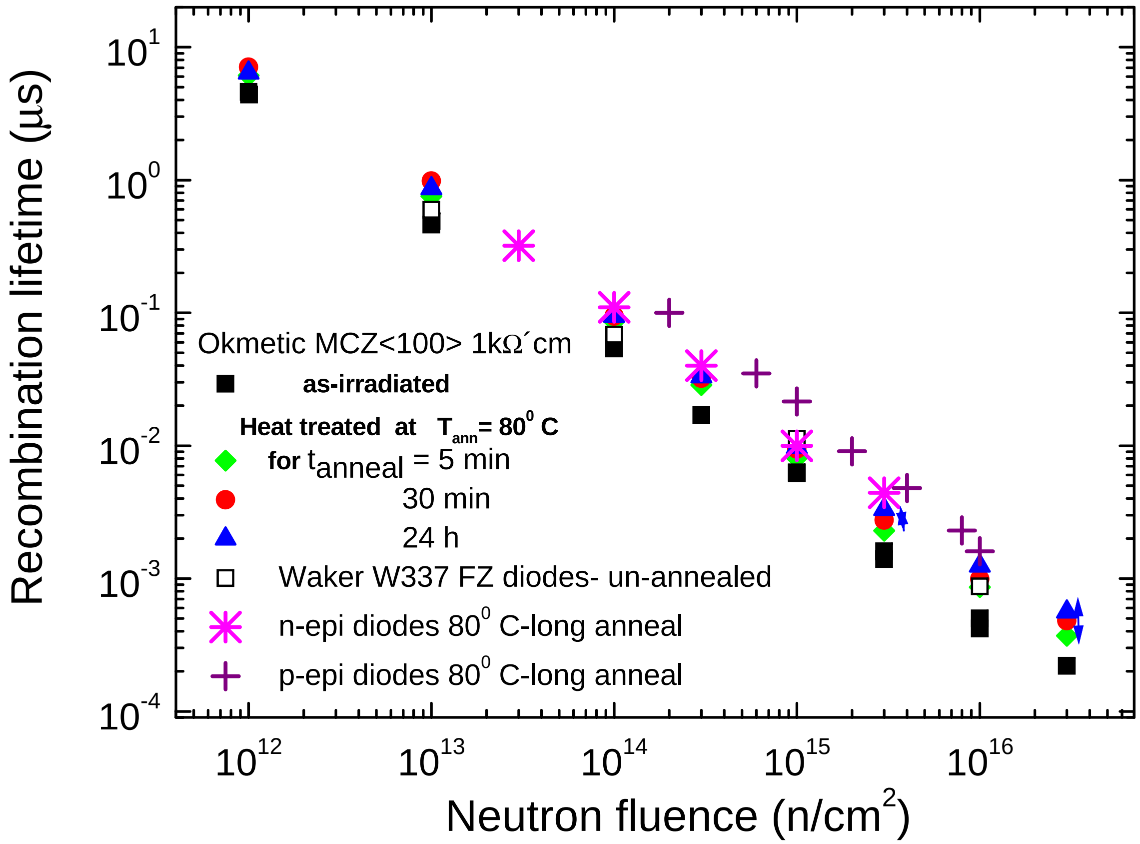
M

Mesaurements: MW-PCD, RR, C-DLTS

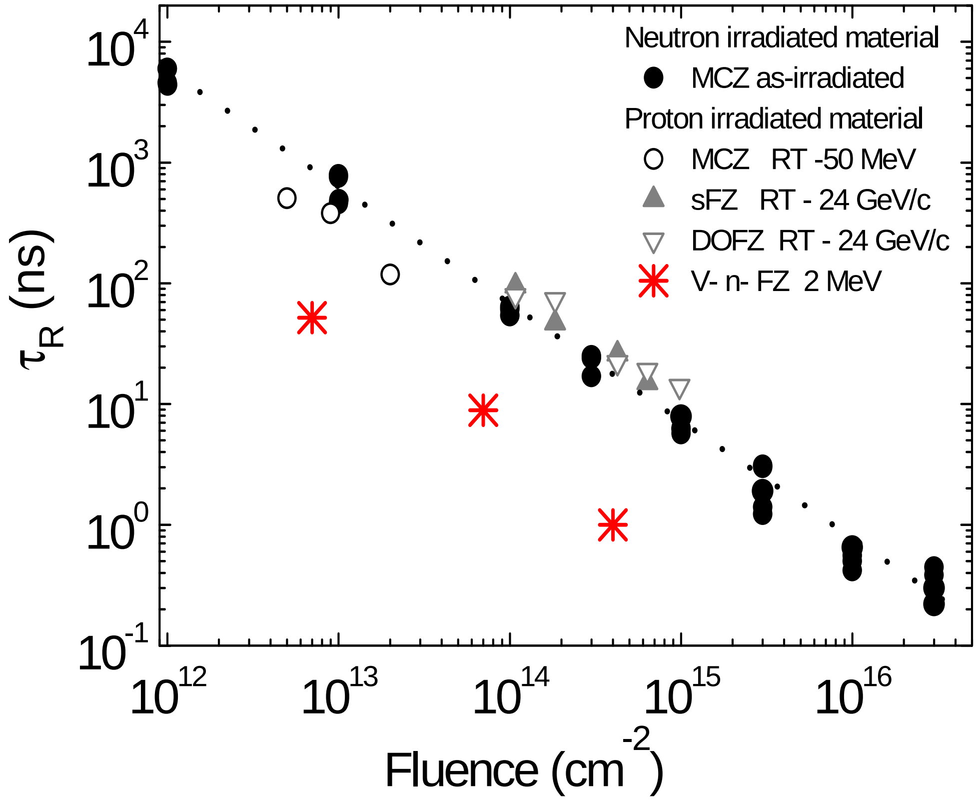
Neutron fluence dependent recombination lifetime in FZ and epi- Si

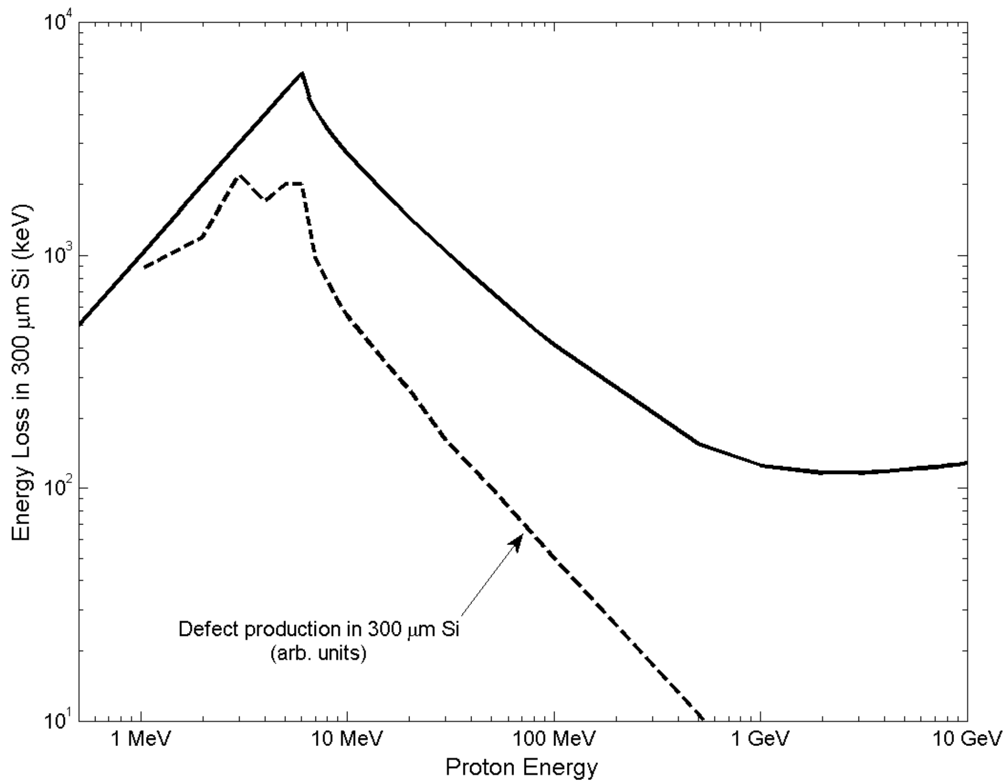


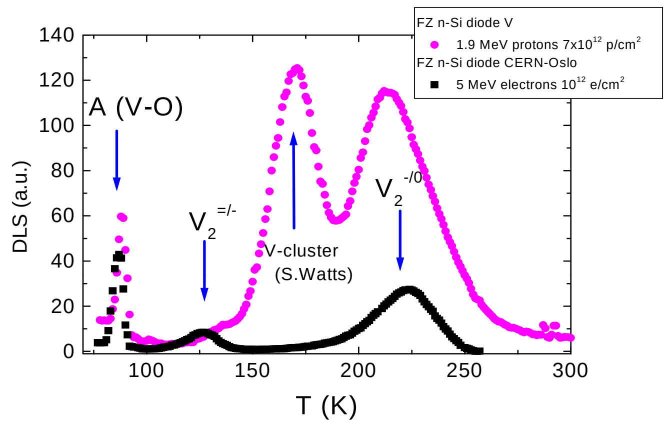
Lifetime in neutron irradiated Si under heat treatments at 80C



Fluence dependent lifetime variations in different particle energy irradiated structures

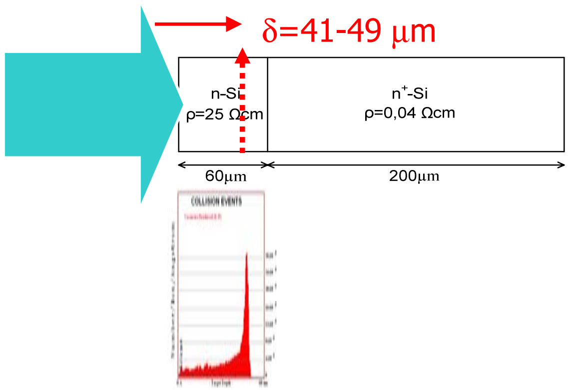




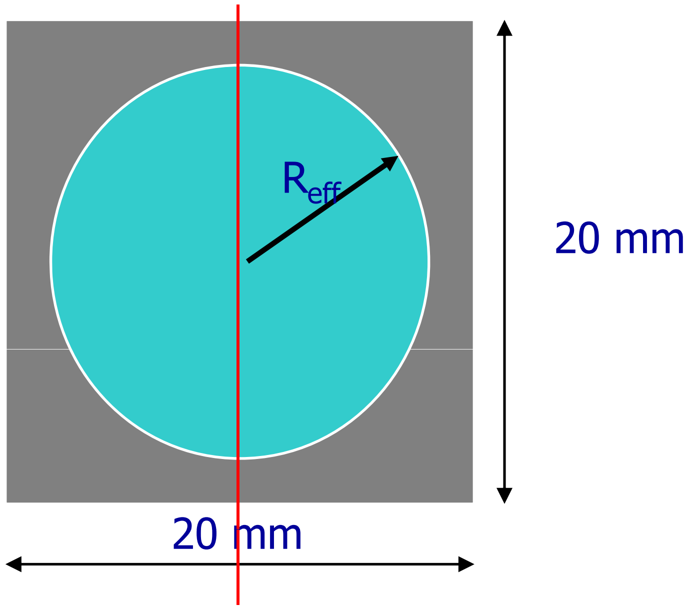


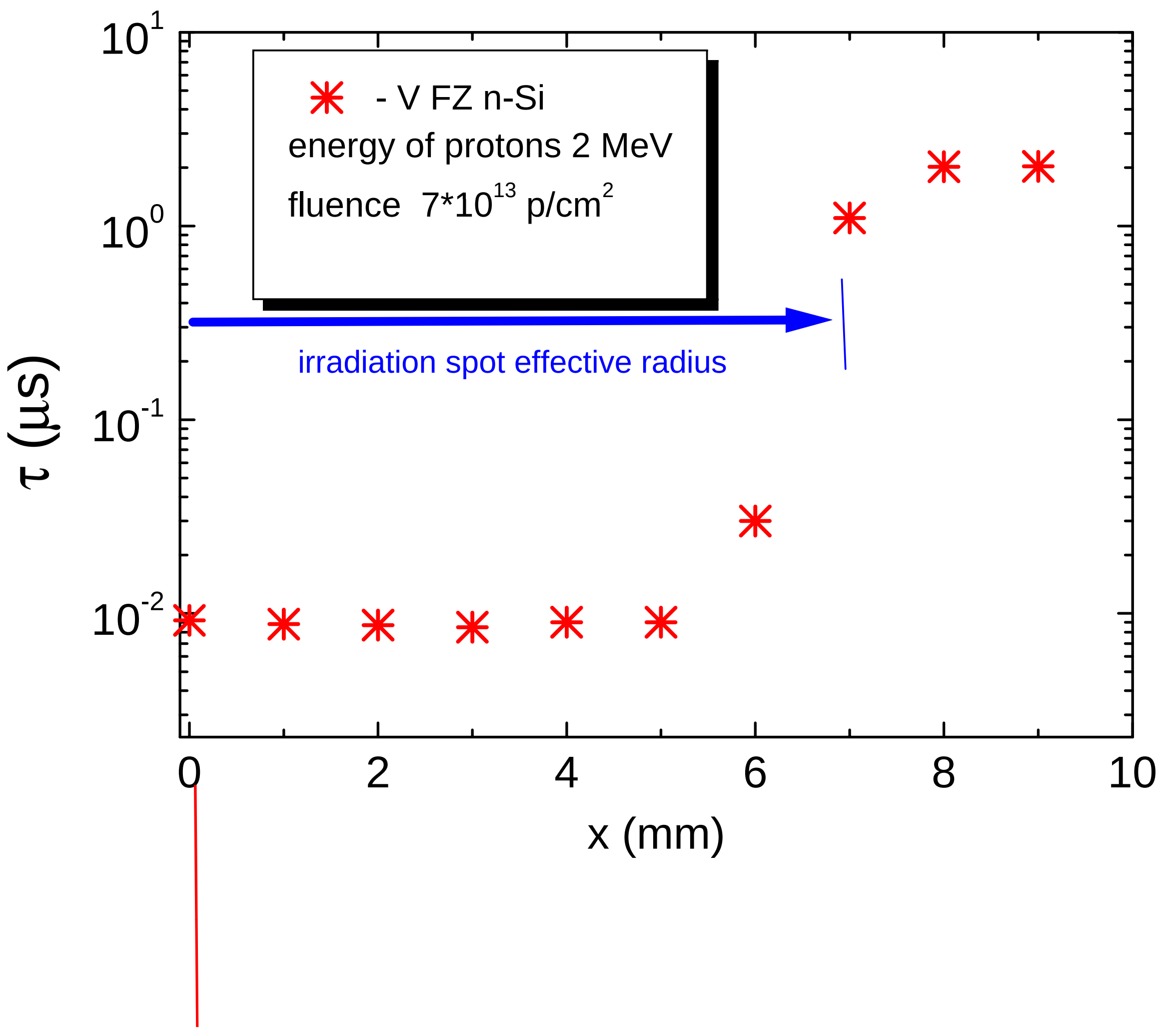
Lateral lifetime variation

1.9 and 2.0 MeV protons



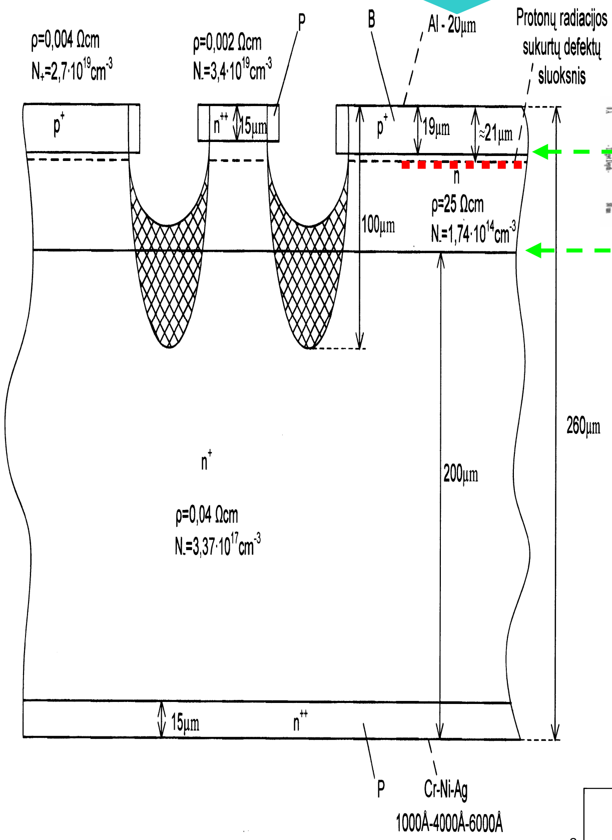
Wafer structures

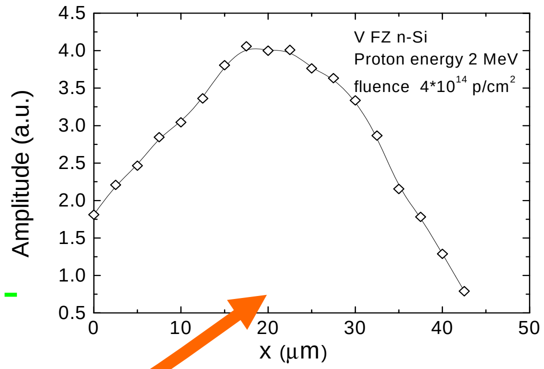


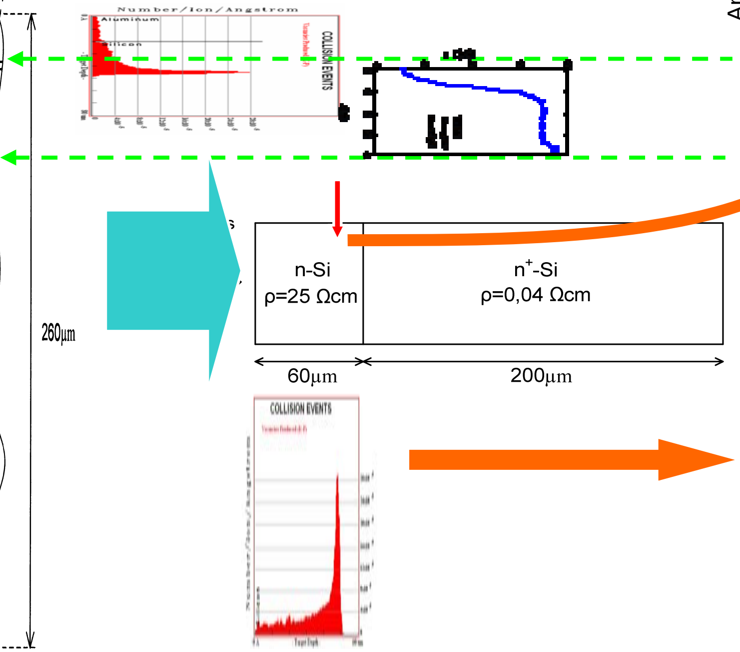


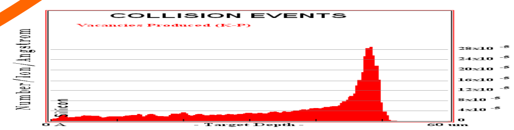
MW-PCD-depth – scans

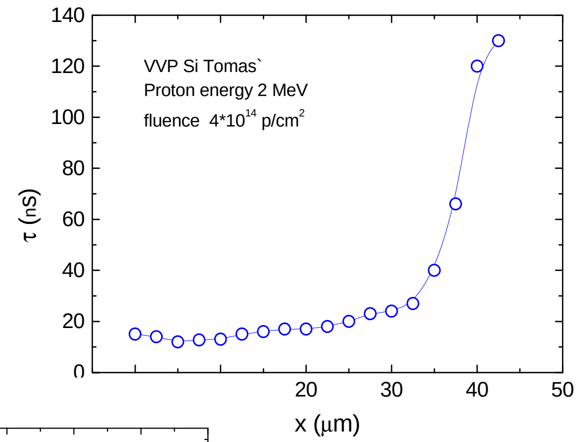
2 MeV protons irradiated FZ n-Si

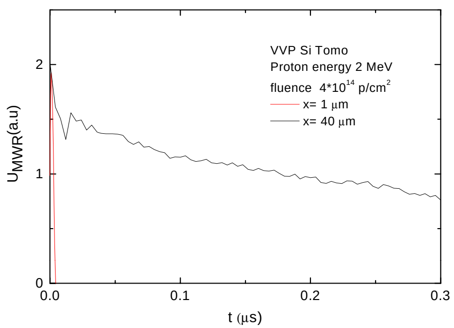


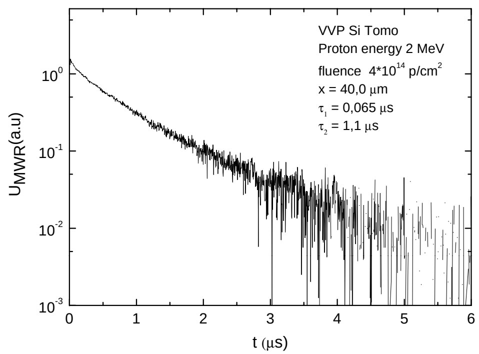




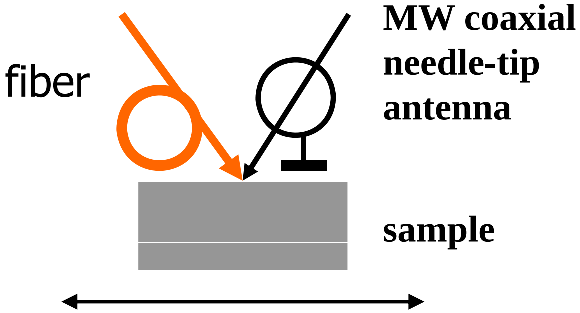


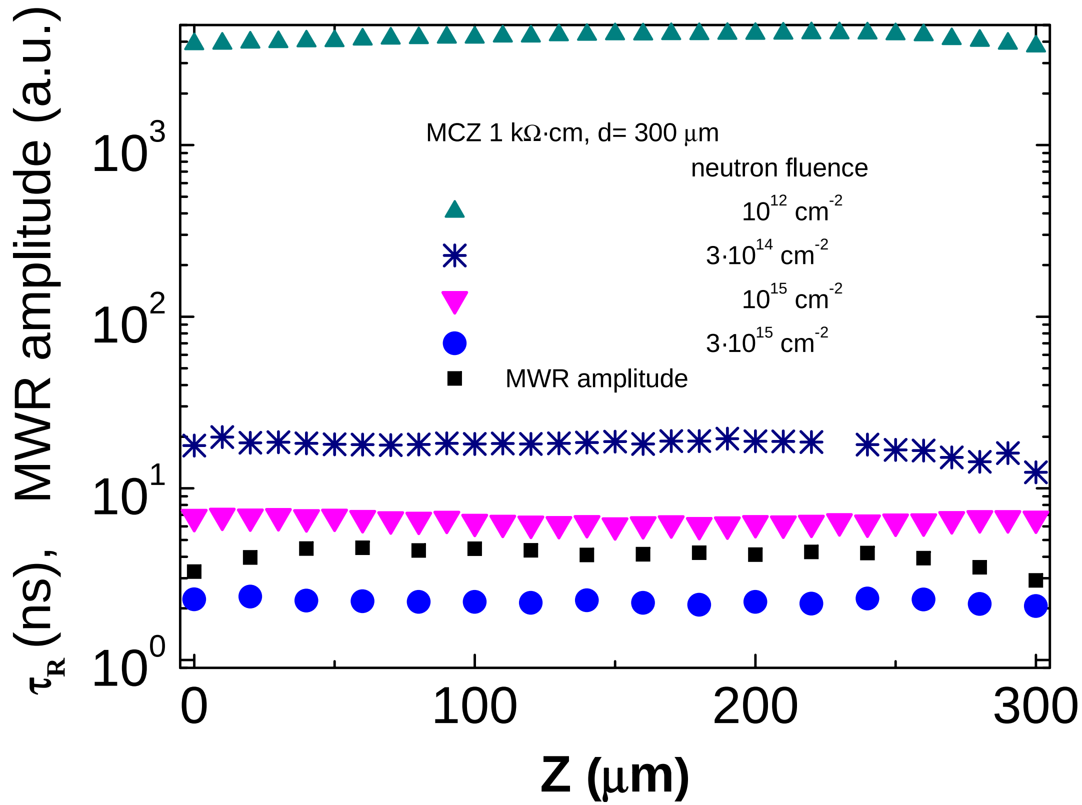




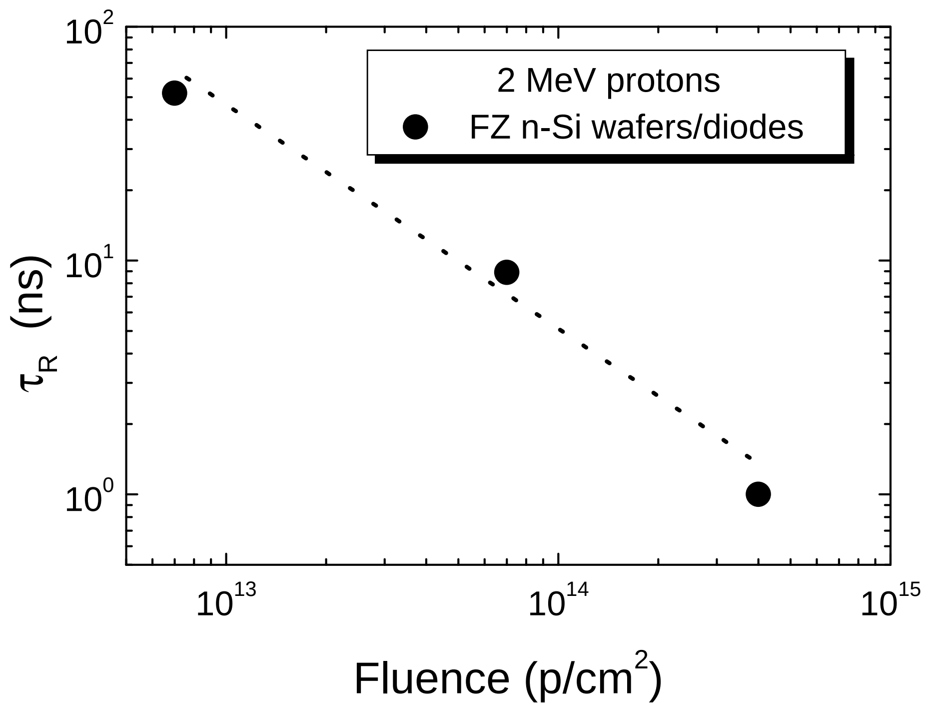


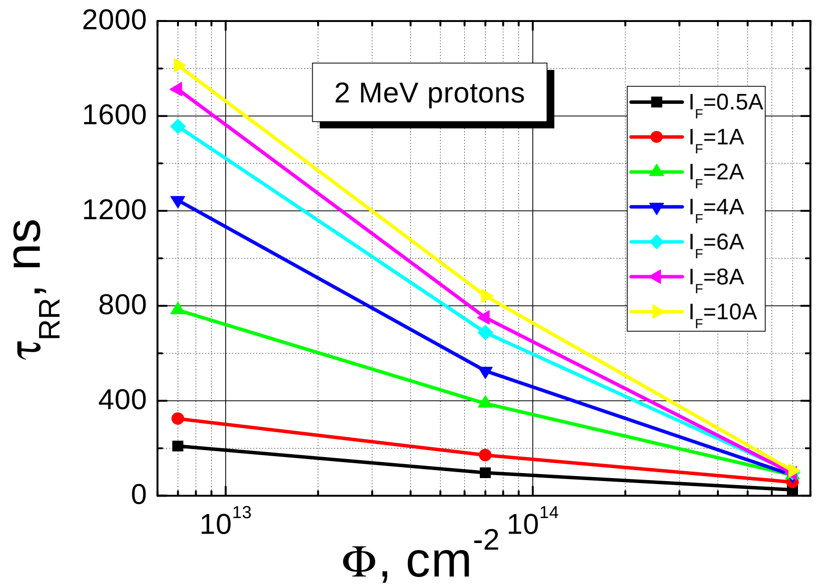
Cross-sectional scans within depth of neutron irradiated wafer

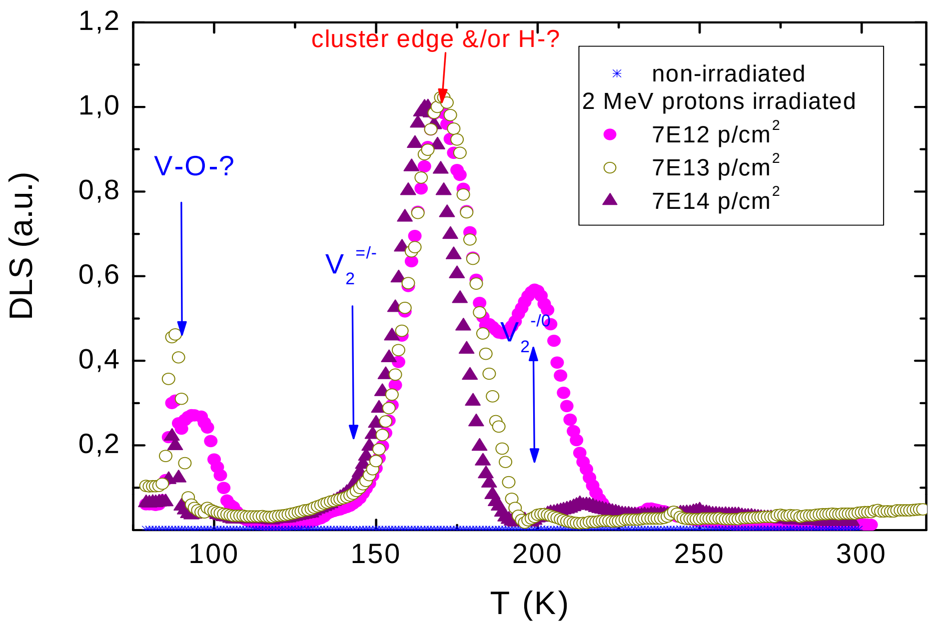




Fluence dependent variations of MW-PCD, DLTS and RR characteristics in 2 MeV protons irradiated FZ n-Si







SUMMARY

- ***Lifetime decreases from few μs to about of 200 ps with enhancement of neutron irradiation fluence ranging from 10^{12} to $3 \cdot 10^{16}$ n/cm^2, as measured directly by exploiting microwave probed photoconductivity transients and verified by dynamic grating technique.***

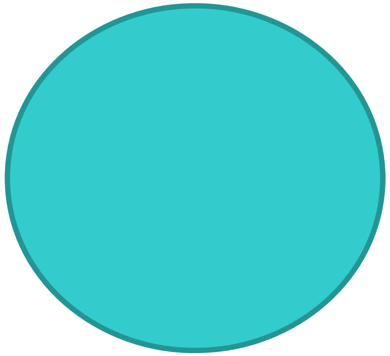
- ***Lifetime values are nearly the same for neutron irradiated wafer and diode samples. These values are close to that in >20 MeV proton irradiated various Si diodes.***

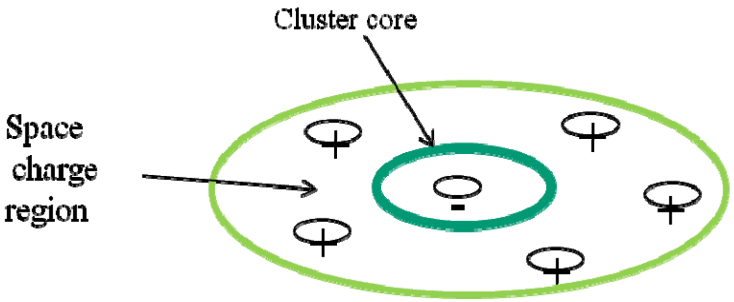
- ***Small increase of lifetime values under annealing can be implied.***

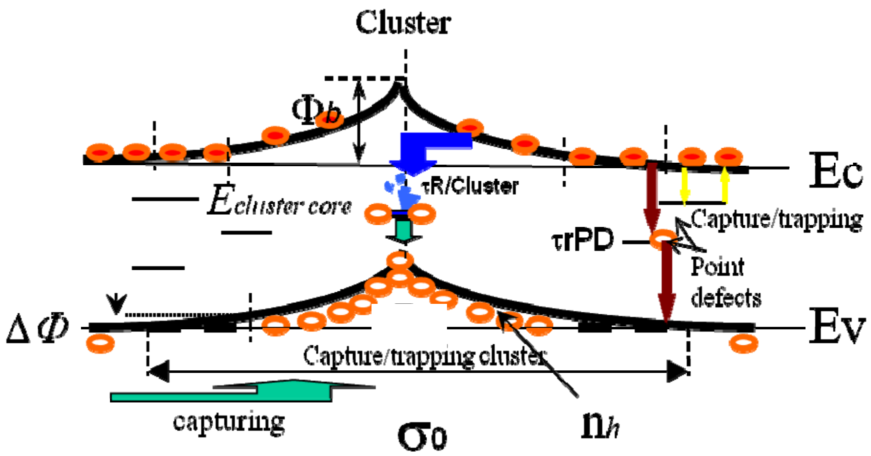
- ***Lifetime values are nearly invariable within wafer thickness for high energy neutrons, while the lifetime depth profile is inhomogeneous for 2 MeV protons irradiated structures.***

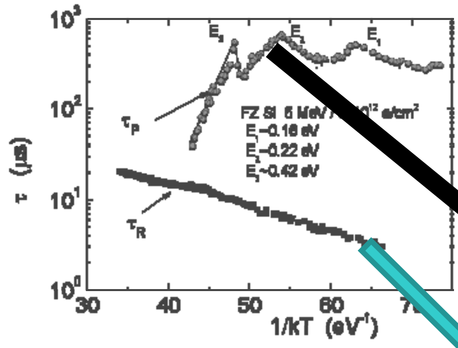
- ***Production of recombination defects in ~2 MeV protons irradiated FZ Si is efficient, and lifetime depth profiles correlate with stopping range of particles.***

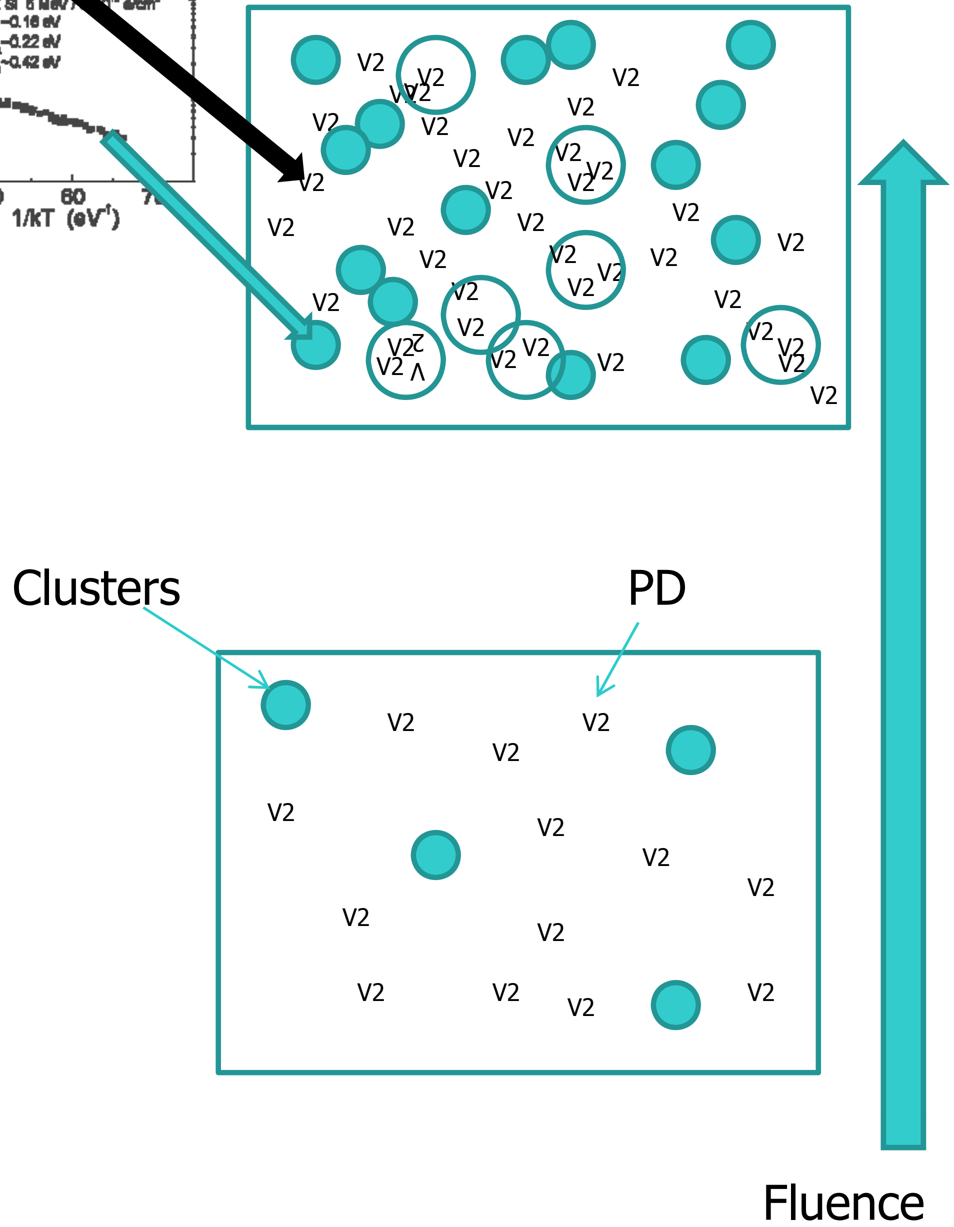
Thank You for attention!




Cluster core
Space charge region

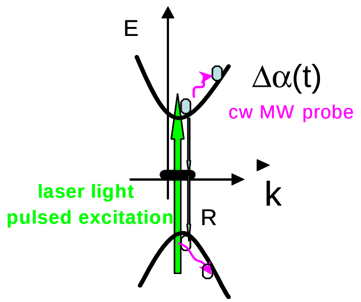

Cluster
Φb
Ec
E cluster core
τR/Cluster
Capture/trapping
τrPD
Point defects
ΔΦ
Ev
Capture/trapping cluster
capturing
σ0
nh


τ (μs)
1/kT (eV⁻¹)
τP
τR


Clusters
PD
Fluence

Measurement techniques and instruments

Microwave probed photoconductivity (MW-PCD) in MW reflection mode (MWR)

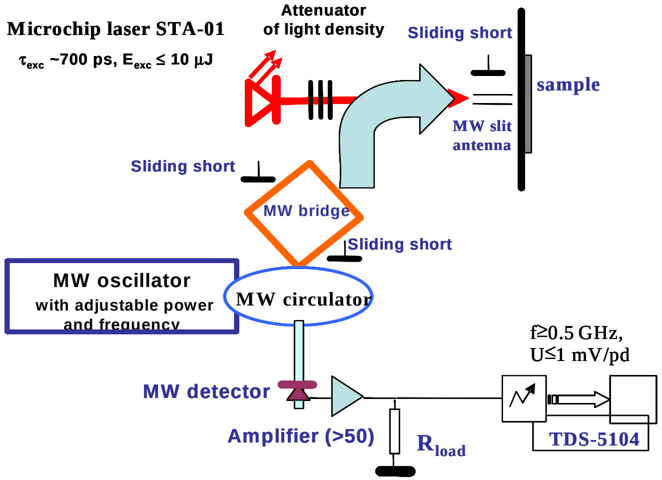


MWR $\lambda > 100\mu m \Rightarrow \alpha_0 = (4\pi/c\ \sqrt{\varepsilon})\sigma_{dc}$,

transient:

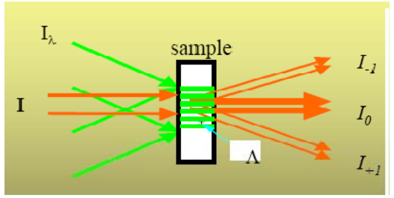
$\Delta\alpha(t) \propto \Delta\ \sigma(t) \propto \mu_{FC}\ n_{exFC}\ (t)$

E.Gaubas. Lith. J. Phys., 43 (2003) 145.

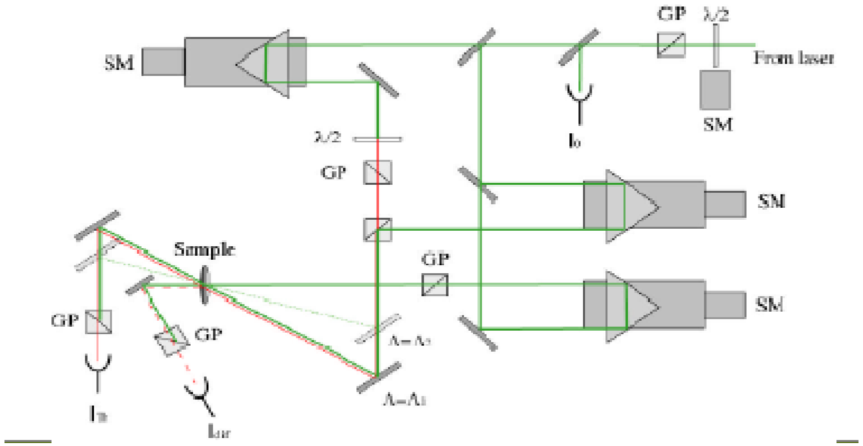


The microwave probed photoconductivity (MW-PCD) technique is based on the direct measurements of the carrier decay transients by employing MW absorption by excess free carriers. Carriers are photoexcited by 1062 nm light generated by pulsed (700 ps) laser and probed by 22 GHz cw microwave probe.

Dynamic gratings (DG)

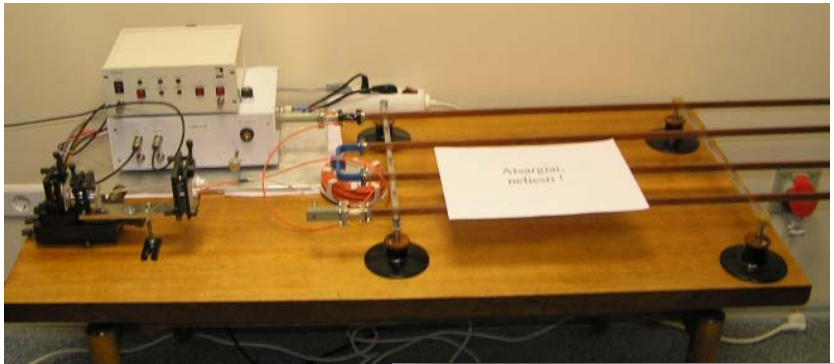


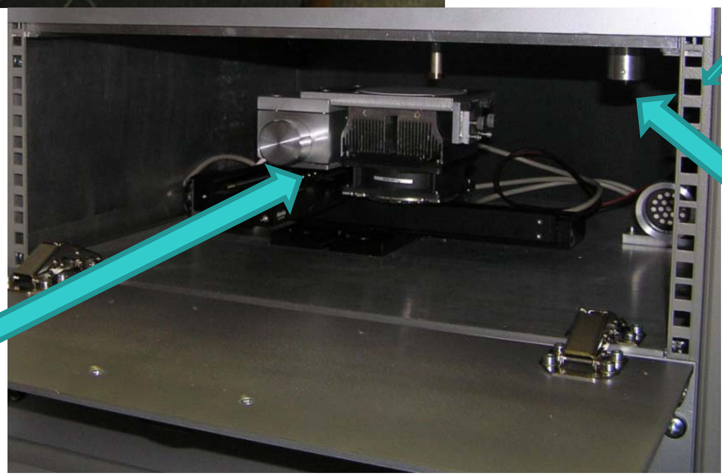
K.Jarasiunas, J.Vaitkus, E.Gaubas, et al. IEEE Journ. QE, QE-22, (1986) 1298.



Diffraction efficiency ($\eta = I_{-1}/I_0$) on light induced dynamic grating is a measure $\eta \propto (\Delta N)^2$ of excess carrier density, while its variations in time $\eta(t) \propto \exp(-2t/\tau_G)$ by changing a grating spacing (Λ) enable one to evaluate directly the parameters of grating erase $1/\tau_G = 1/\tau_R + 1/\tau_D$ through carrier recombination (τ_R) and diffusion $\tau_D = \Lambda^2/(4\pi^2 D)$ with D as a carrier diffusion coefficient.

MW instruments at VU

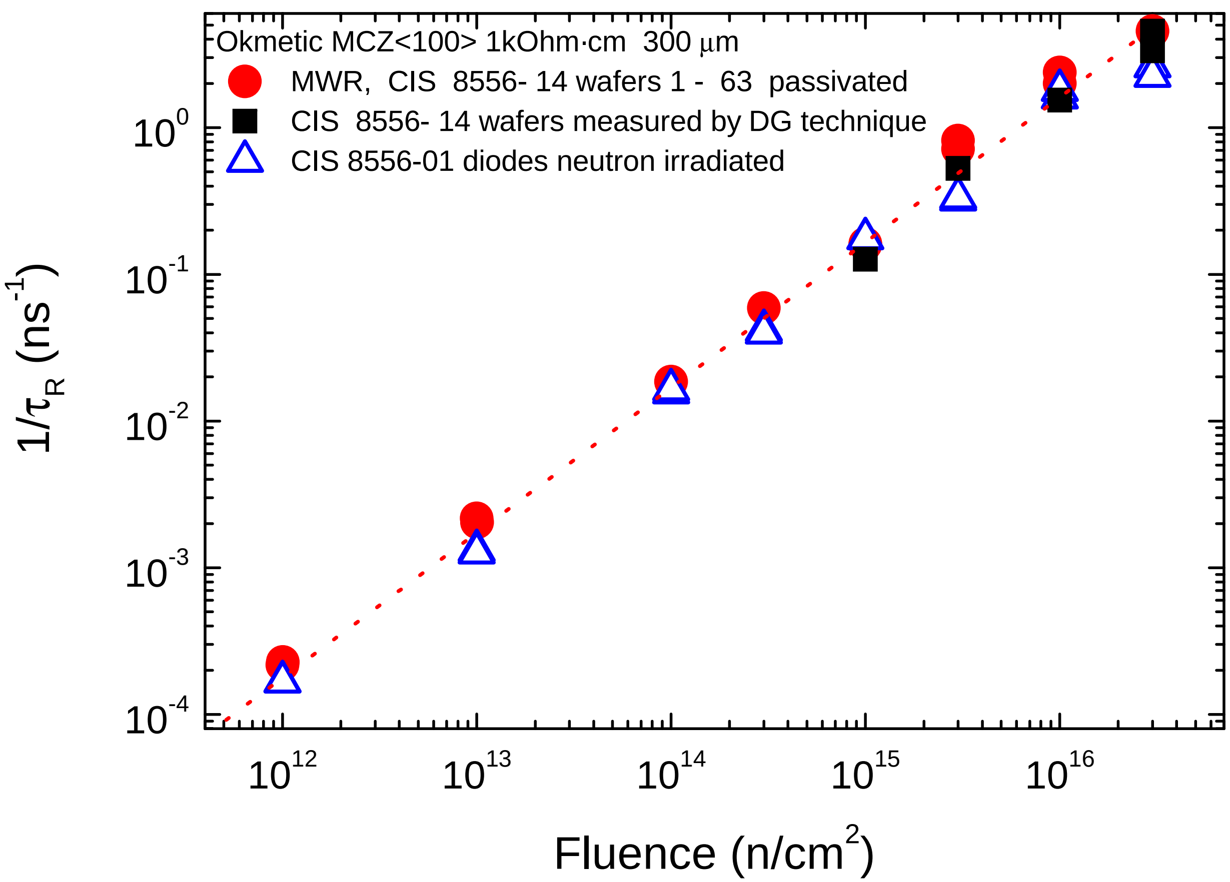




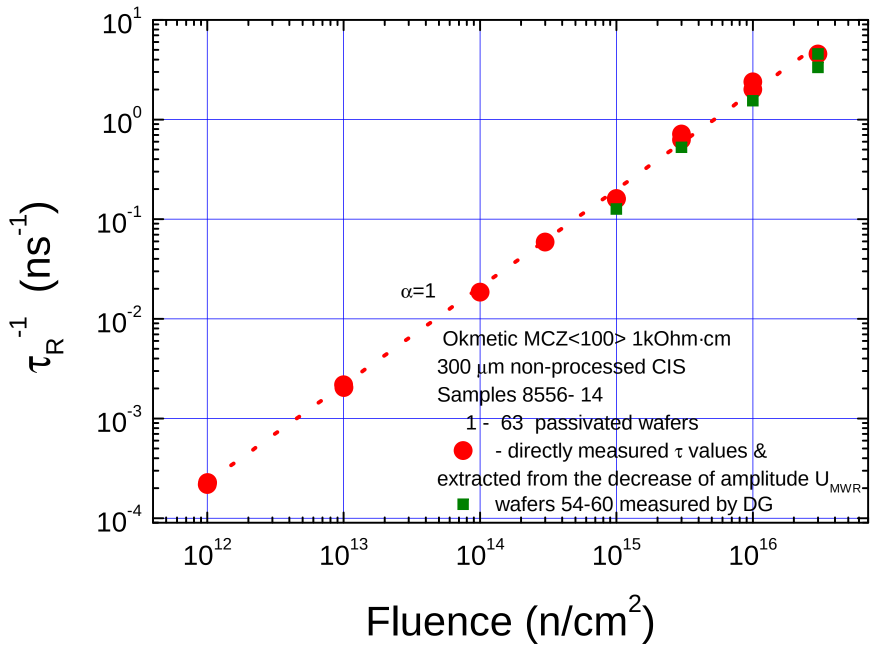
Lateral mapping

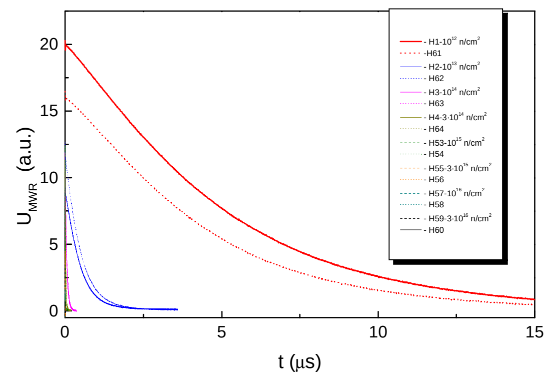
Cross-sectional scan

Recombination lifetime in wafer and diode samples measured by MWR

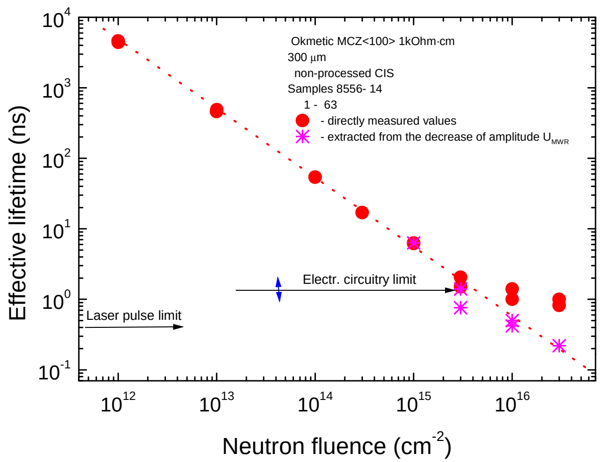


Neutron fluence dependent recombination lifetime in MCZ Si





- $\tau_R \Leftarrow \Delta t|_{U \sim \exp(-1)}$
- $\tau_R \Leftarrow g_{exc}\tau_{Rs}/g_{exc}\tau_{RL}\ (U_{MWRs<2\,ns}/U_{MWRL>5\,ns})$



Combined direct techniques