Fluence and isochronal anneal dependent variations of recombination and DLTS characteristics in neutron and proton irradiated MCz , FZ and epi-Si structures

J.Vaitkus, T.Čeponis, **E.Gaubas,** A.Uleckas, J.Višniakov, and J.Raisanen

Vilnius University, Institute of Materials Science and Applied Research
University of Helsinki

ABSTRACT

A comparative analysis of the recombination, generation and reverse recovery lifetime dependent on stopped protons fluence and isochronal anneal temperature is presented for FZ Si structures. In DLTS, heat treatments indicate transformations of majority and minority carrier traps. These changes are also revealed by variations of the excess carrier decay lifetime. The main transformations can be attributed to hydrogen implantation related defects (VOH etc).Also, a comparative study of the impact of penetrative neutrons and protons on recombination and DLTS characteristics in MCz, FZ and epi-Si structures has been carried out. A nearly linear decrease of the recombination lifetime with fluence of the reactor neutrons from 10^{12} to $3{\cdot}10^{16}$ n/cm^2 in the MCz grown Si samples corroborates a non-linear introduction rate of dominant recombination centers. An increase of lifetime and a change of carrier decay shape (process) in reactor neutrons irradiated MCZ Si, dependent on fluence, appears under annealing at elevated temperatures (>180 C, for 24 h). Lifetime behavior with heat treatment temperature shows an enhancement of competition between recombination and trapping centers which is the most pronounced for moderate fluences irradiated material.

Outline

- Motivation of investigations - comparative analysis of the impact of penetrative and stopped hadrons
- Samples: neutron and proton irradiated MCz, FZ and epi-Si structures
- Fluence and anneal dependent variations of recombination lifetime and DLTS spectra
- Summary

Objectives / investigations

Direct measurements of recombination lifetime fluence dependences:

- comparative analysis of carrier decay transients in MCZ, FZ and epi-Si neutron irradiated structures

- Control of possible anneal of defects by comparing neutron and 2 MeV proton irradiated material:

- heat treatments 80C +180 + 280 + 380C , 24 h
- 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

Neutron irradiated

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

FZ

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

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**

MCZ wafer pieces

n- epi

Irradiation TRIGA reactor March 2004

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

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

p- epi

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

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

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

heat treatments
80C +180 + 280 + 380C , 24 h

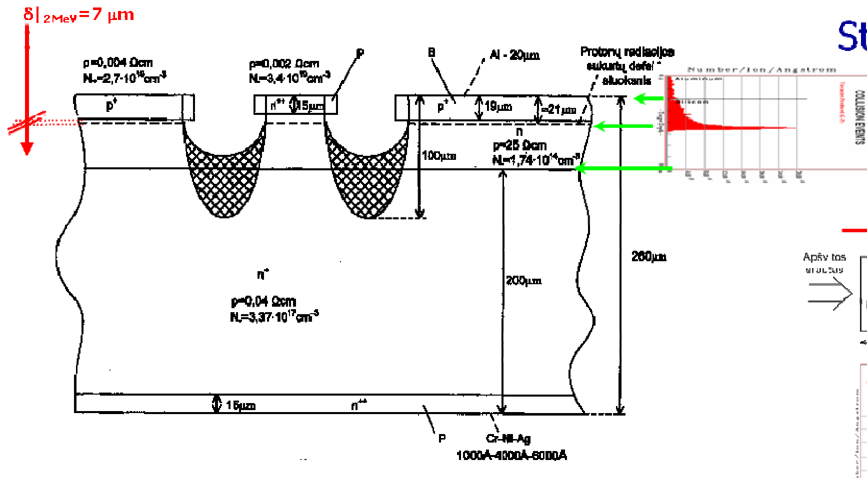
2

Samples

Proton irradiated

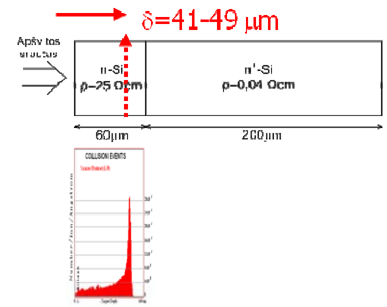
FZ n-Si

Structures tested



Diodes

1.9 and 2.0 MeV protons



Wafer structures

recombination characteristics in 2 MeV proton irradiated n-FZ Si:

-close thickness to epi-, resistivity 25 Ω cm;

- close absolute values to neutron irradiated MCZ and FZ Si

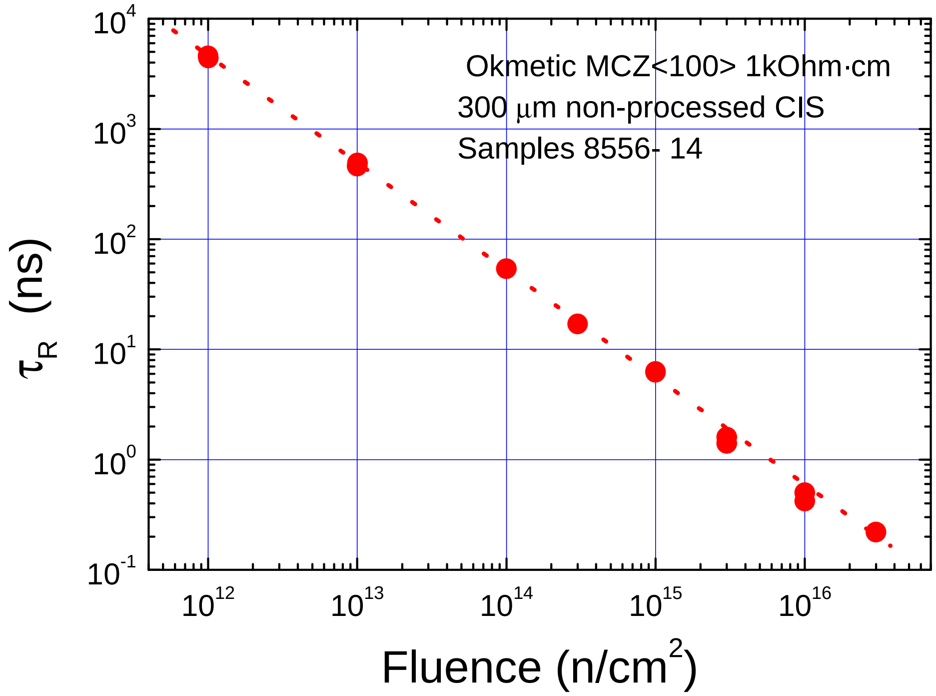
- combined investigations of MWR, DLTS and RRT on fluence and anneal,

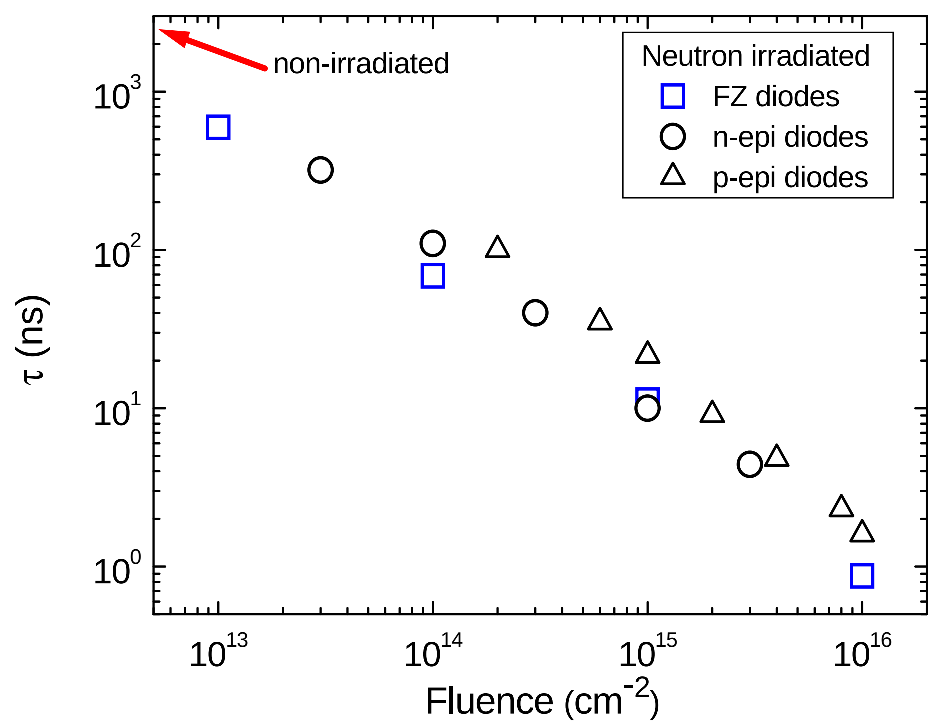
- comparison of cross-sectional recombination lifetime profiles

heat treatments

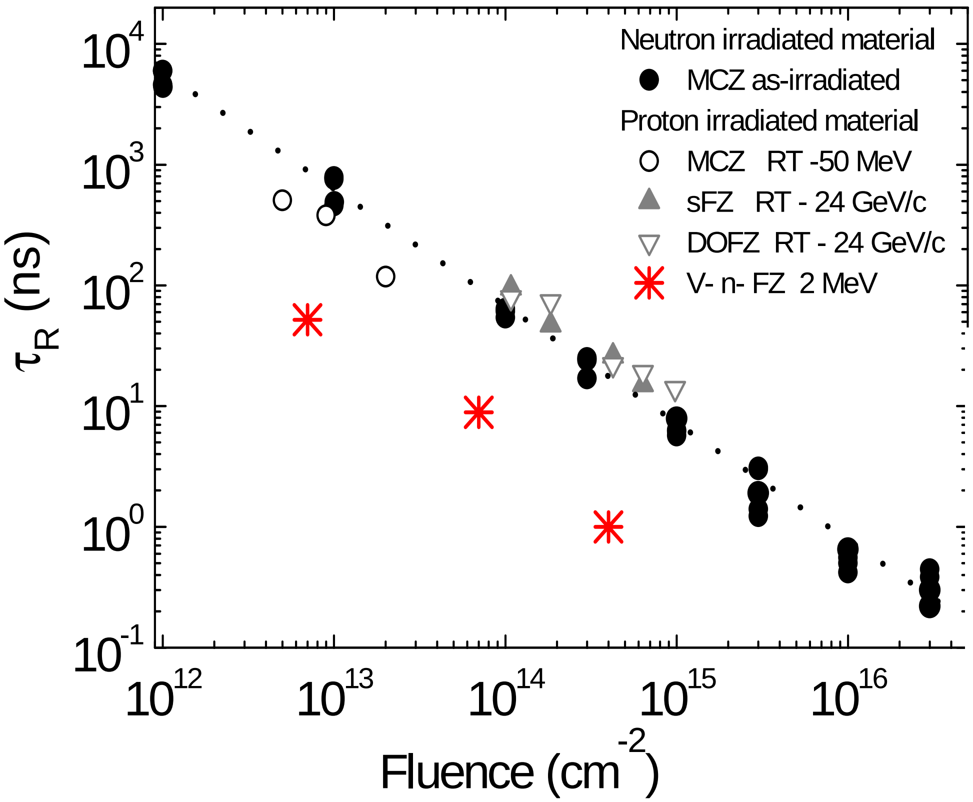
80C +160 + 240 + 280C + 320C , 24 h

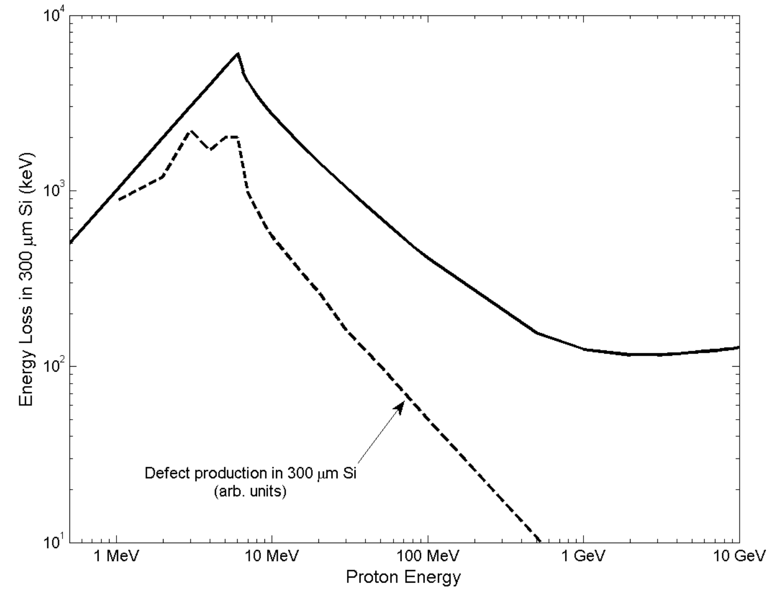
Neutron fluence dependent recombination lifetime in MCZ and epi- Si

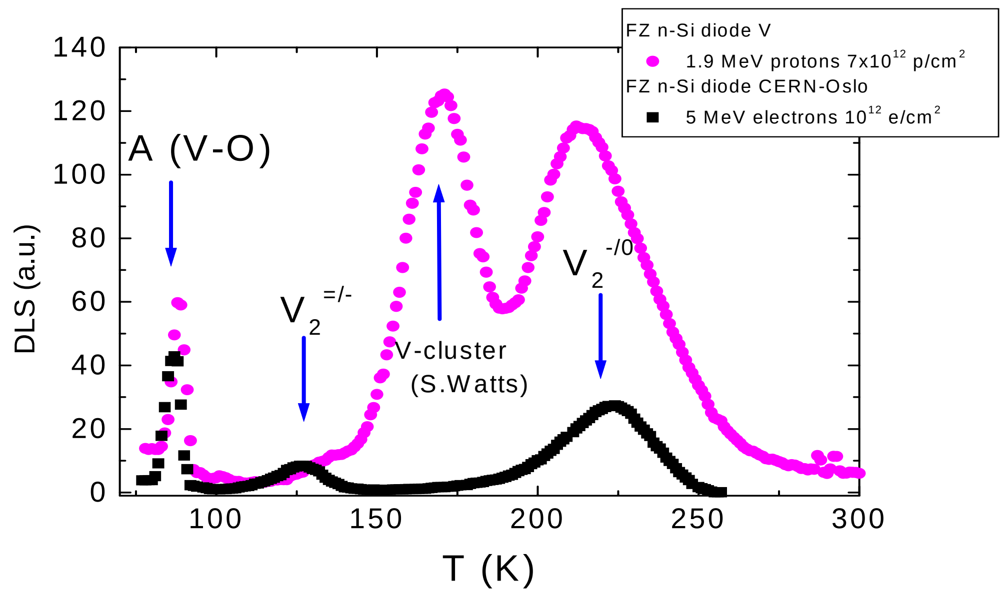




Fluence dependent lifetime variations in different particle energy irradiated structures

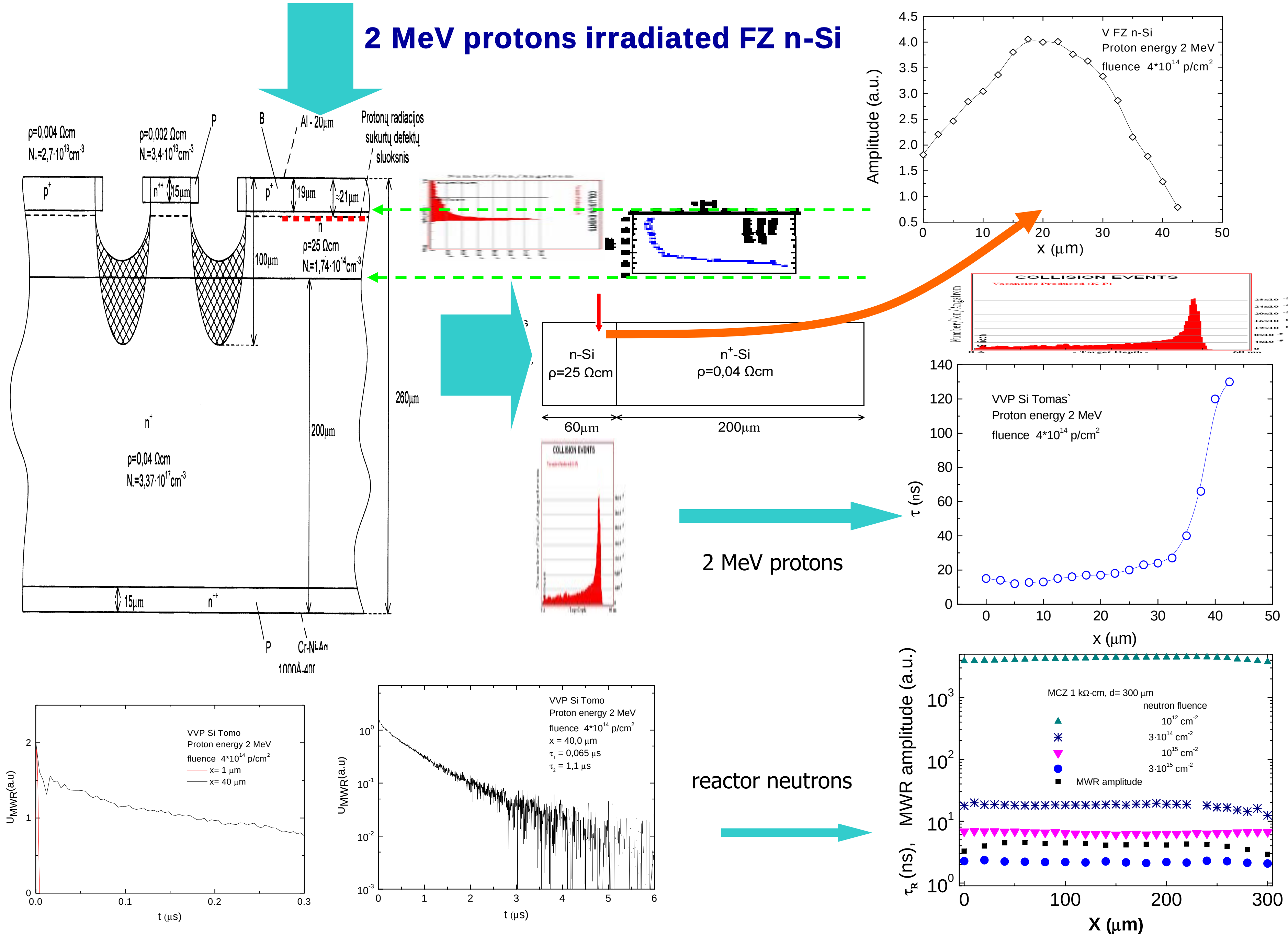






MW-PCD-depth – scans

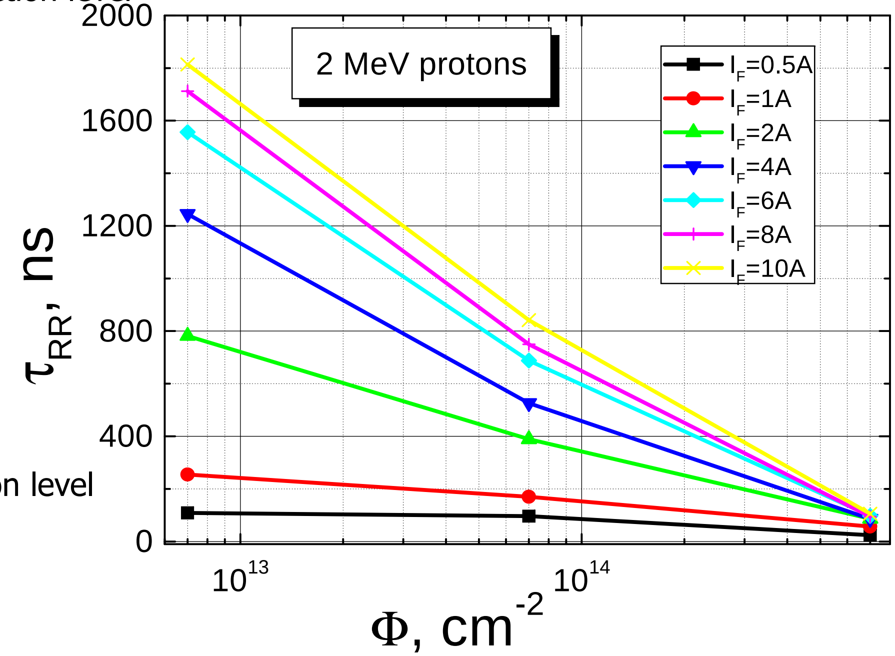
2 MeV protons irradiated FZ n-Si



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

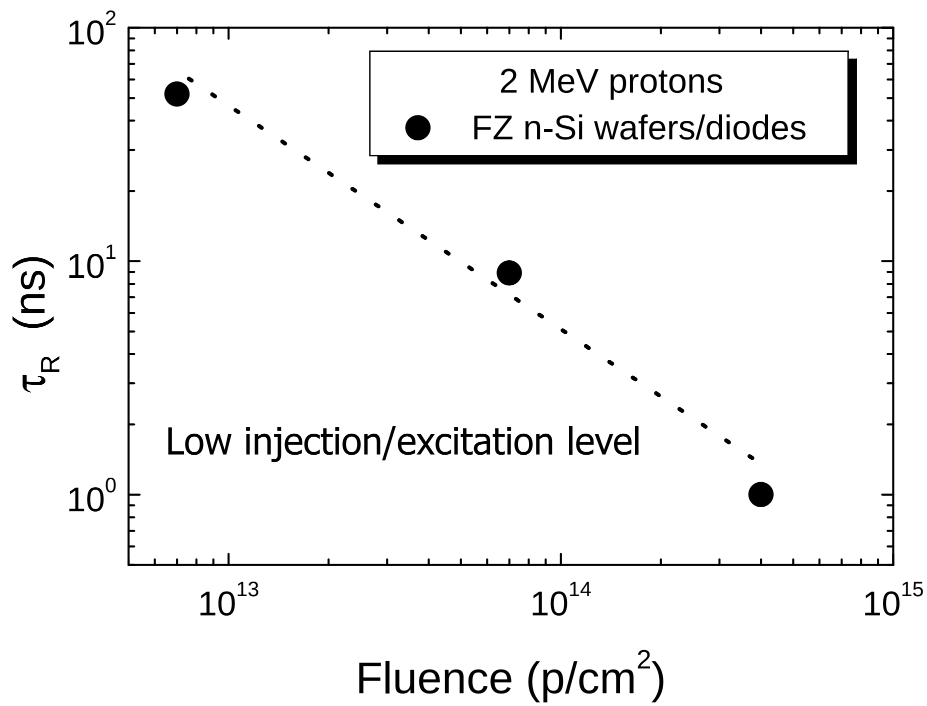
Diodes: power rectifiers/ pin switches

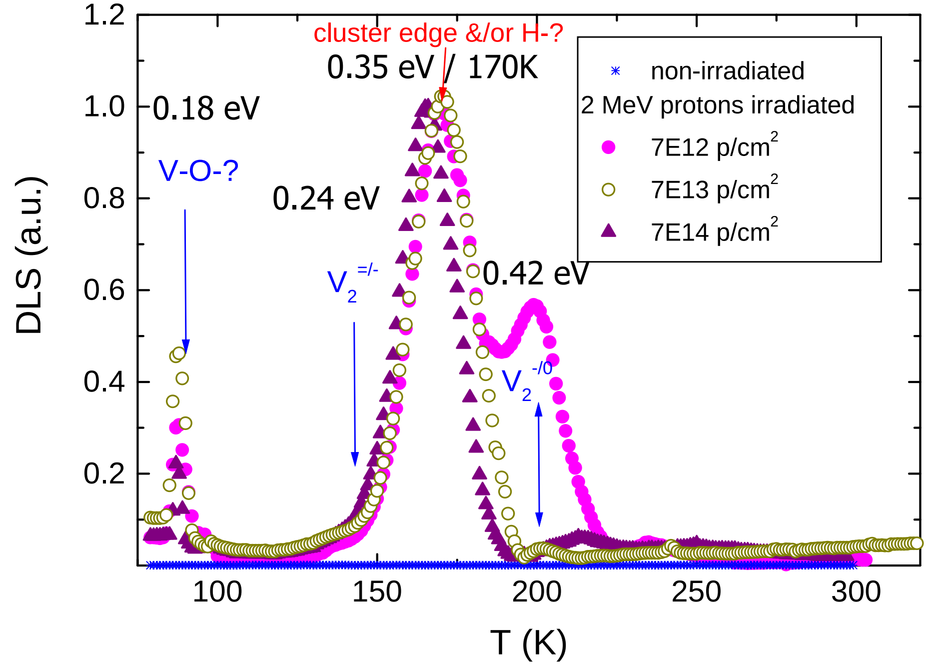
High injection level



Low injection level

Wafer substrates and diodes





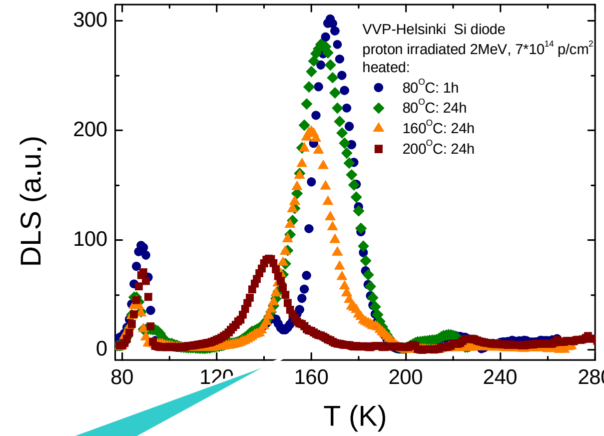
Variation of DLT spectra and RRT with anneal and fluence

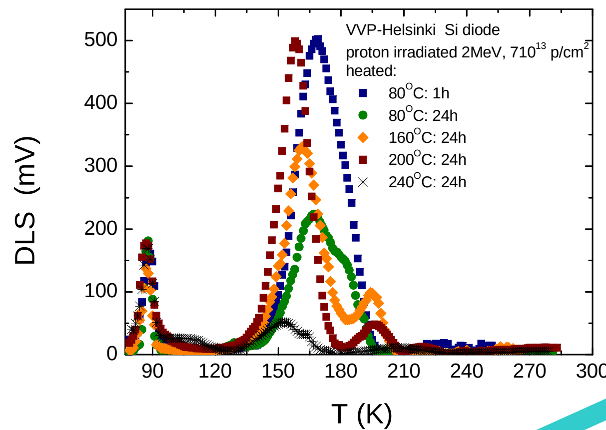
Anneals: 80C +160 + 240 + 280C + 320C , 24 h

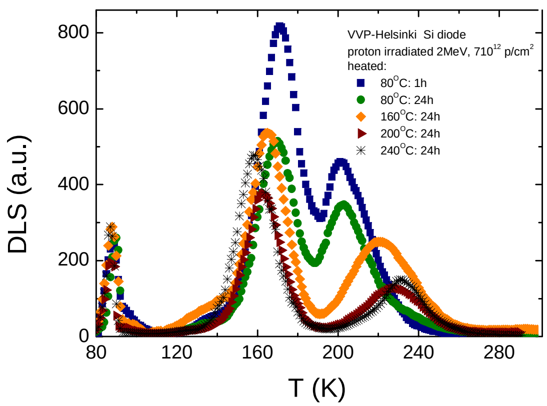
A decrease of amplitude of the DLTS peaks with increase of the isochronal (24 h) anneal temperature together with transform of the 170 K peak into 140 and 225 K peaks.

This decrease of the amplitude of the majority carrier peaks is accompanied by the enhancement of the minority carrier peaks

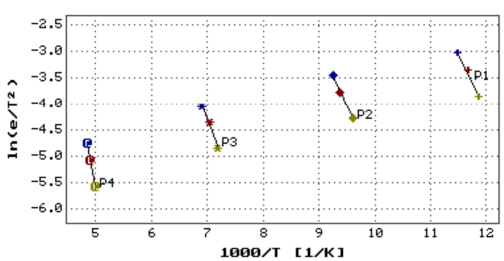
DLTS

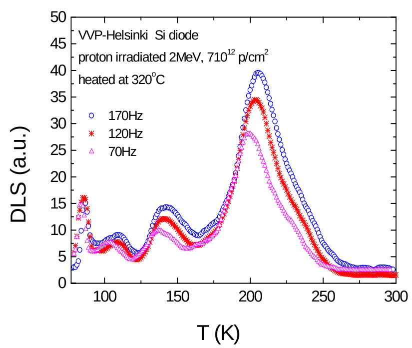






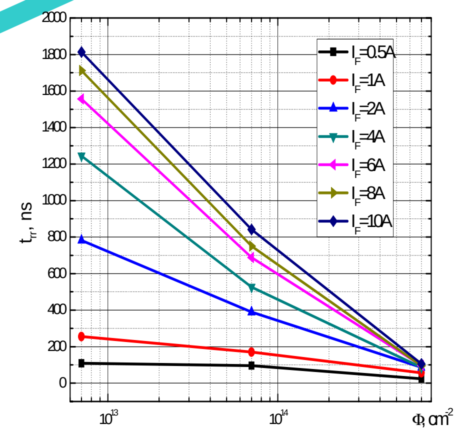
Increasing proton fluence



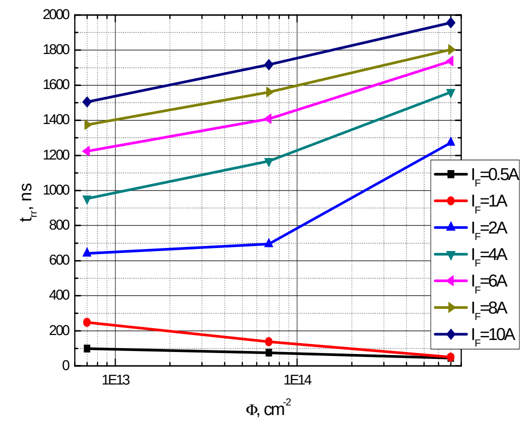


RRT

as-irradiated



annealed at 240⁰ C



Majority carrier traps

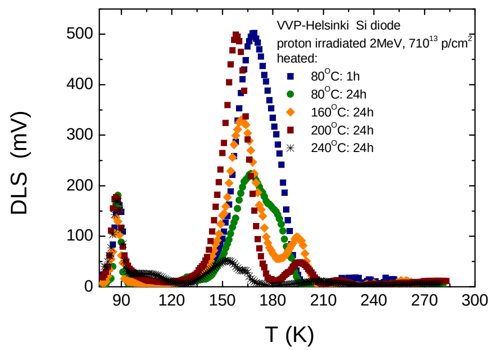
	E (meV)	σ (cm²)
P1	186	8.67E-13
P2	203	2.9E-14
P3	250	2.75E-15
P4	495	3 E-12

Variation of the DLT spectra for majority and minority carrier traps

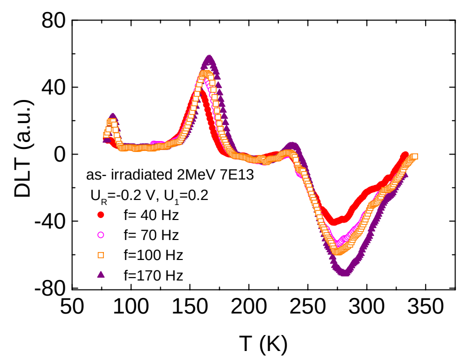
Shift of the DLTS peaks with decrease of absolute amplitude

as-irradiated

U_R=-10V, majority carrier traps

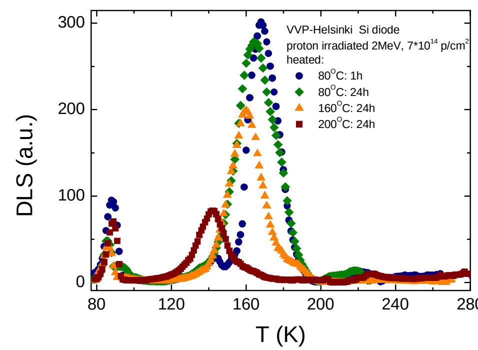


U_R=-0.2 V, majority+minority carrier traps

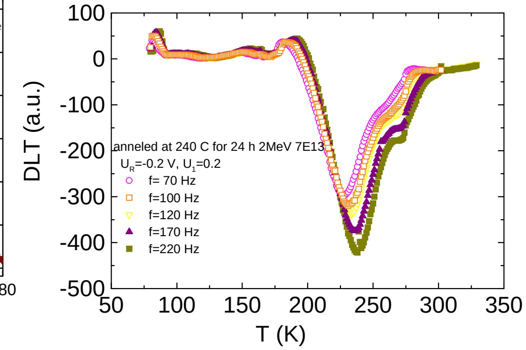


annealed at 240 C 24h

U_R=-10V, majority carrier traps

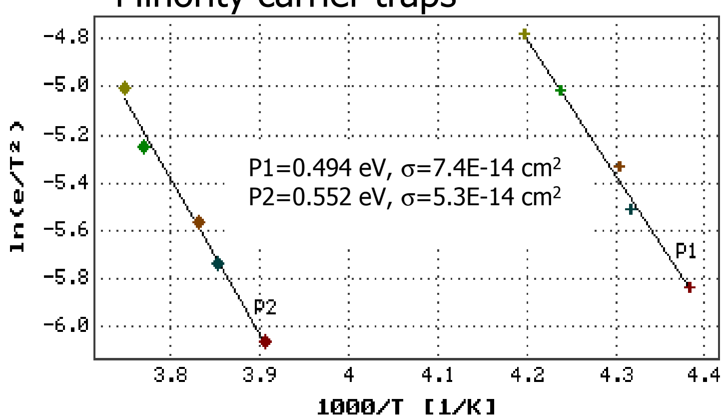


U_R=-0.2 V, majority+minority carrier traps

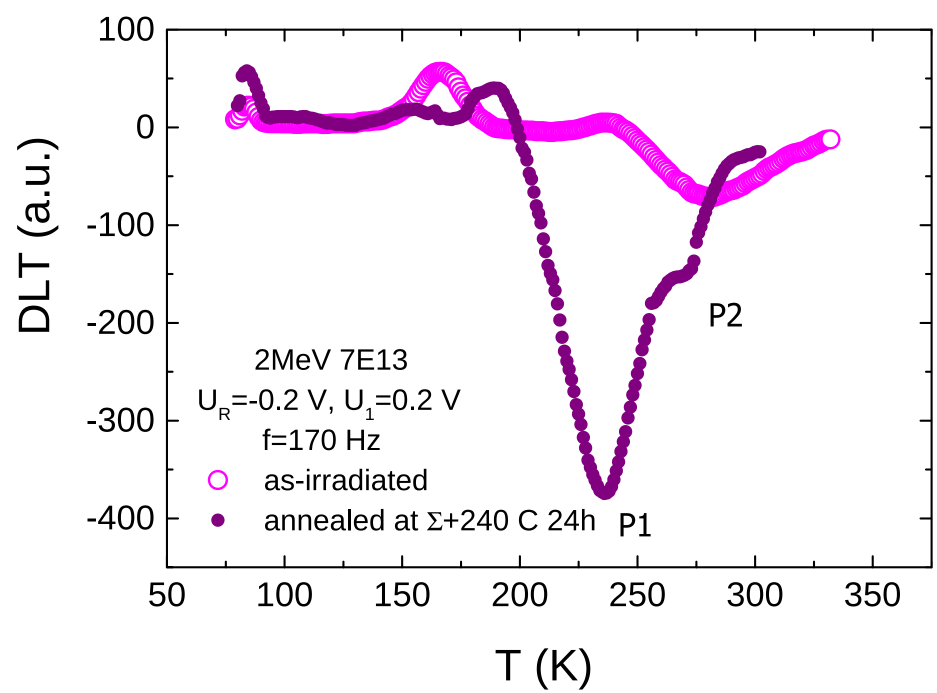


Decrease of the peak amplitude ascribed to majority carrier traps is accompanied by increase of the minority carrier peaks

Minority carrier traps



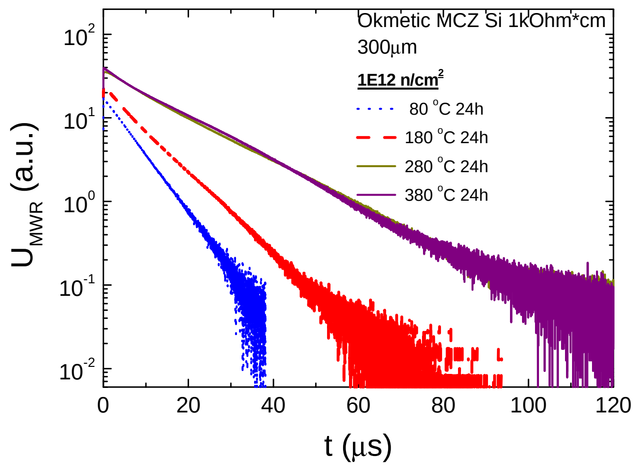
2MeV 7E13 p/cm2, annealed 240º C 24 h



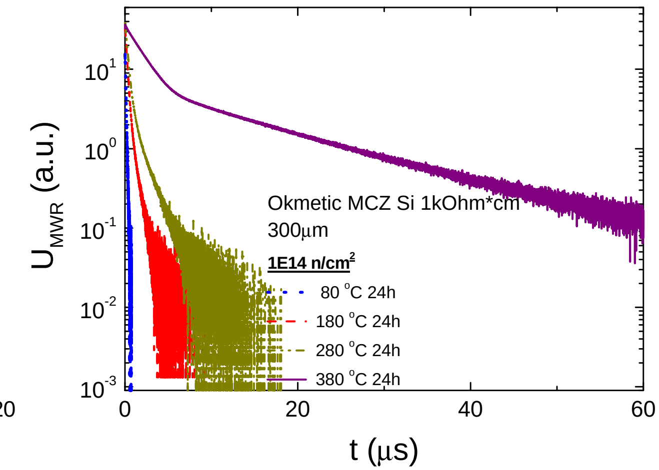
Lifetime in neutron irradiated MCZ Si under heat treatments

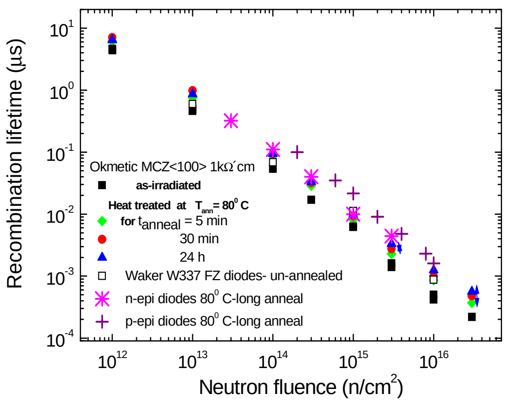
Anneals:
80C +180 + 280 + 380C, 24 h

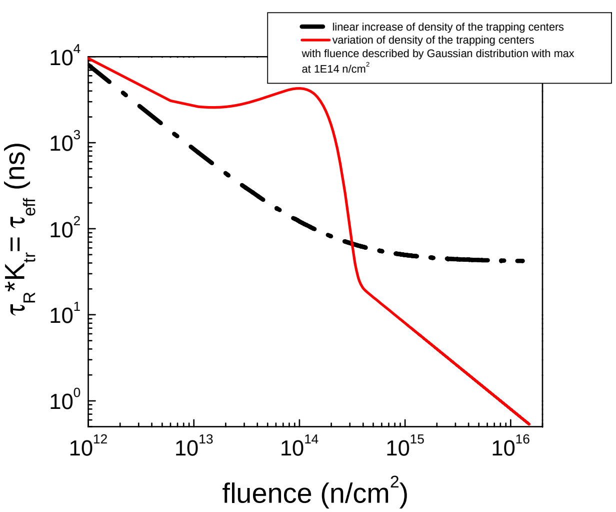
Recombination

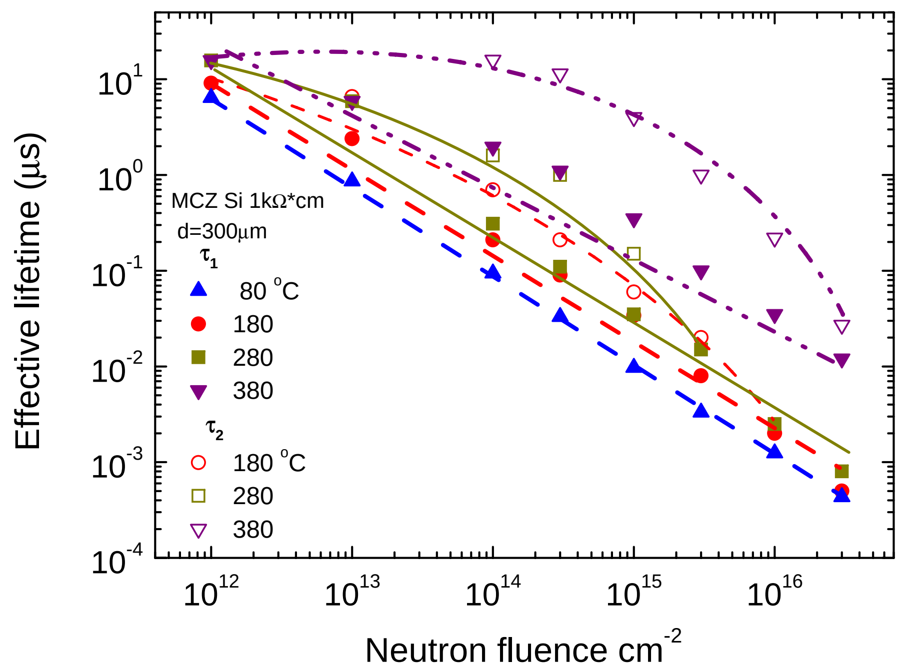


Recombination+ trapping effect









SUMMARY 1

• 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 in the as-irradiated material.

•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. However, absolute values of recombination lifetime are significantly shorter in the 2 MeV protons irradiated FZ Si when using the same scale of fluences.

•A nearly linear decrease of the recombination lifetime with fluence of the reactor neutrons from 10^{12} to $3{\cdot}10^{16}$ n/cm2 in the MCz grown Si samples corroborates a non-linear introduction rate of dominant recombination centers.

SUMMARY 2

•For 2 MeV protons (stopped within the base range of a PIN diode) irradiated Si, production of recombination defects in ~2 MeV protons irradiated FZ Si is efficient, and lifetime depth profiles correlate with stopping range of particles. In DLTS, heat treatments indicate transformations of majority and minority carrier traps. These changes are also revealed by variations of the excess carrier decay lifetime. The main transformations can be attributed to hydrogen implantation related defects (VOH etc).

• An increase of lifetime and a change of carrier decay shape (process) in reactor neutrons irradiated MCZ Si, dependent on fluence, appears under annealing at elevated temperatures (>180 C, for 24 h). Lifetime behavior with heat treatment temperature shows an enhancement of competition between recombination and trapping centers.

Thank You for attention!