Characterization of the carrier recombination and trapping processes in the proton irradiated silicon by microwave absorption transients

J.Vaitkus [1)] , E. Gaubas [1)] , G.Niaura [2)] , J. Härkönen [3)] , E.Tuovinen [3)] , P. Luukka [3)] , and E. Fretwurst [4)]

[1)] *Institute of Materials Science and Applied Research, Vilnius University,* **Lithuania**
[2)] *Institute of Chemistry,* **Lithuania**
[3)] *Helsinki Institute of Physics, Helsinki University,* **Finland**
[4)] *Institute for Experimental Physics, Hamburg University,* **Germany**

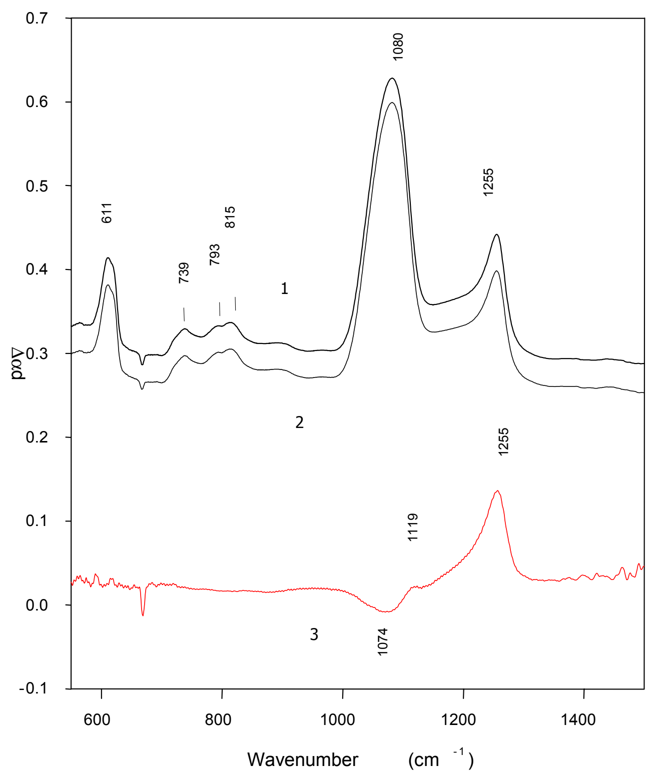
Motivation

☼ difference in defect formation rate and defects type in the ranges of moderate and the highest irradiation fluences can be resolved by the inverse lifetime vs. fluence dependences in wide range of $10^9 \rightarrow 10^{15}$ cm^{-2} of proton irradiations

☼ activation factors of the fast recombination centers and of the slow trapping ones can be determined from carrier lifetime variations with temperature and correlated with parameters estimated by electrical methods for evaluation of CCE

Samples

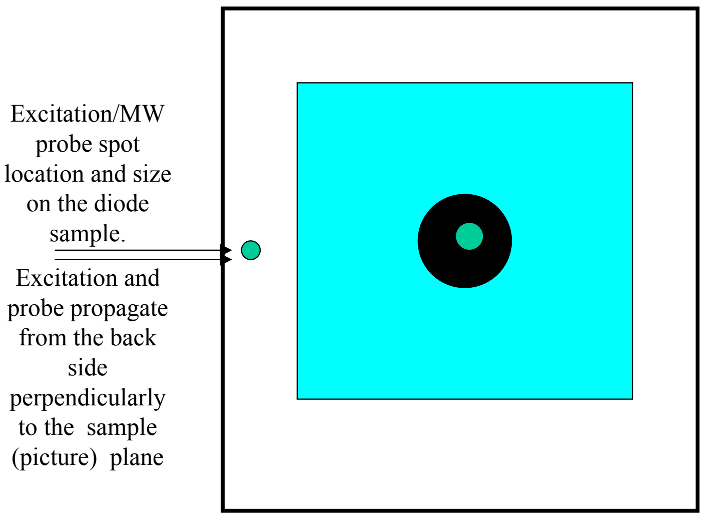
☼ High resistivity oxygenated silicon (initial and irradiated) wafers and irradiated diode structures were investigated. Oxygen associated defects in the initial material were modified by the annealing (450 C, 0.5h, 24h) technology and have been controlled by Fourier transform infrared (FTIR) spectroscopy at 300 K.

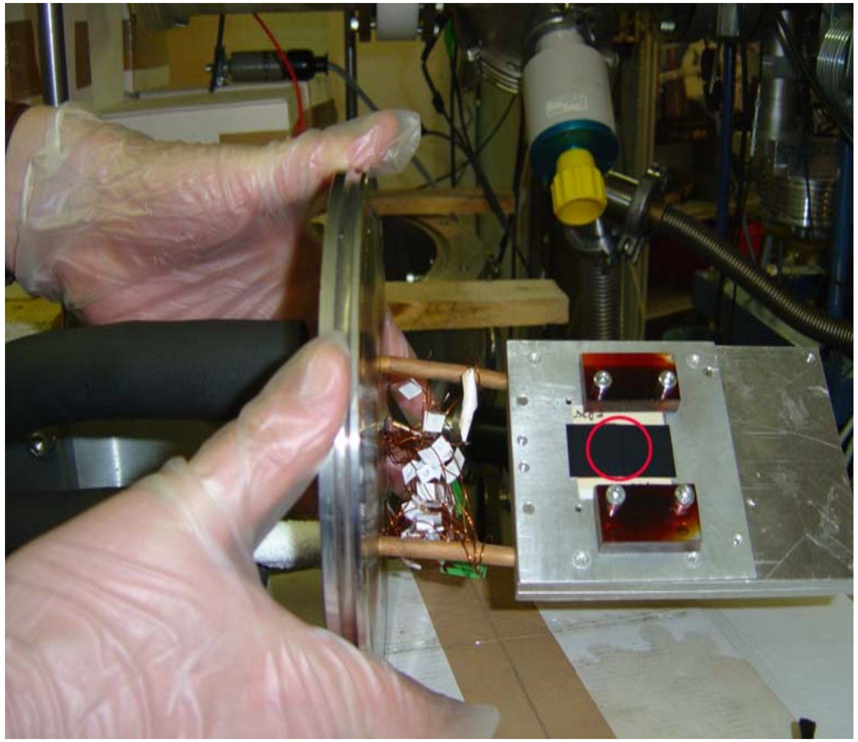


Absorbance FTIR spectra in the initial oxygenated (1) and untreated (2) samples and the differential spectra (3), respectively, measured at 300K.

Irradiations

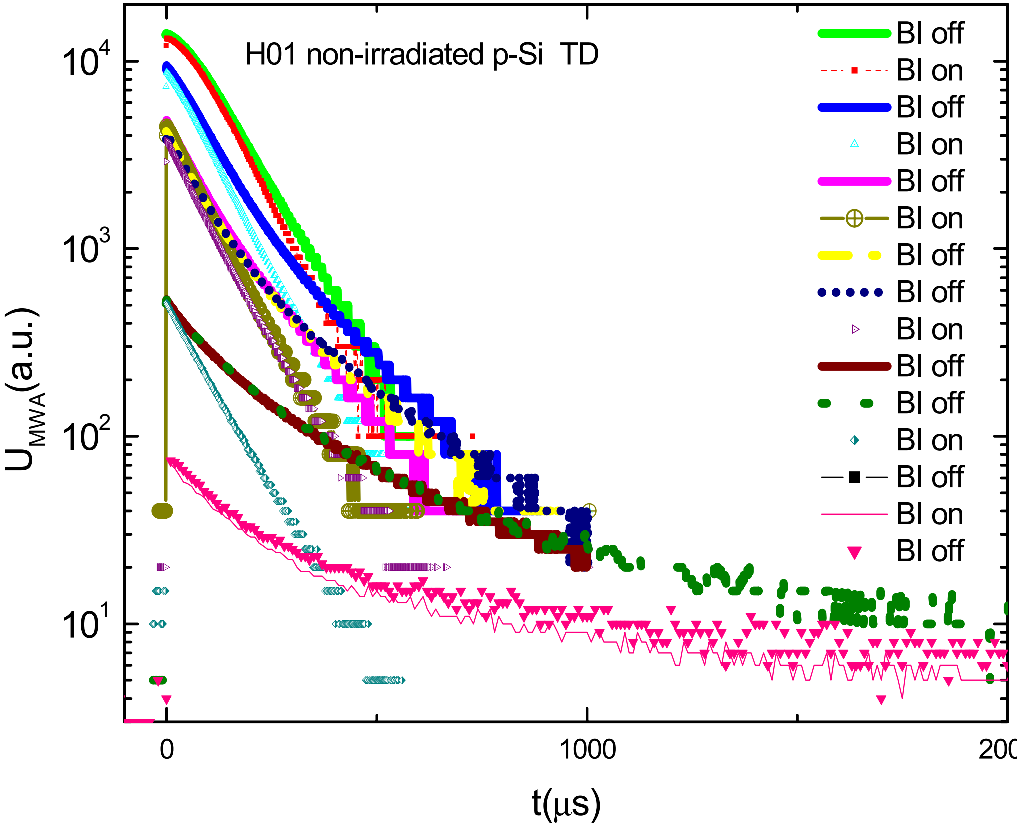
☼ Silicon wafers (simultaneously oxygenated and untreated wafers) and diode structures were irradiated with protons of energy of 10 MeV and 50 MeV at various radiation fluences in the range from 5×10^{12} to 10^{15} cm^{-2}.





Carrier recombination and trapping

☼ *Fast recombination (capture) and slow trapping constituents within transients of microwave absorption by free carriers (MWA) have been distinguished by combining analyses of the excess carrier decays dependent on the excitation intensity and bias illumination (BI).*



Variation of MWA decays with excitation intensity (proportional to the initial amplitude)

with and without additional cw illumination

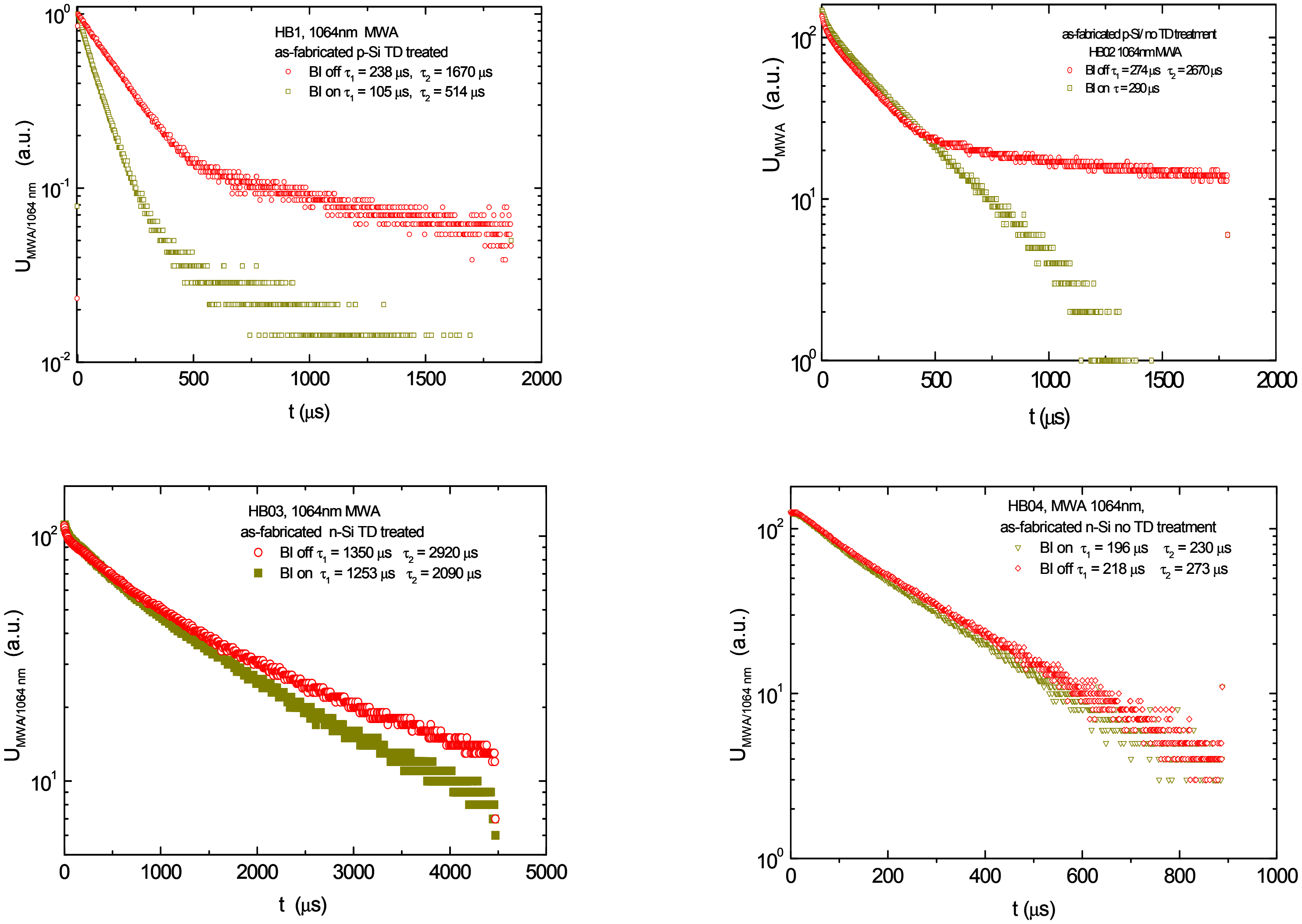
measured in oxygenated (TD) p-type unirradiated initial material

Carrier recombination and trapping

TD treated | no TD treatment

p-Si

n-Si

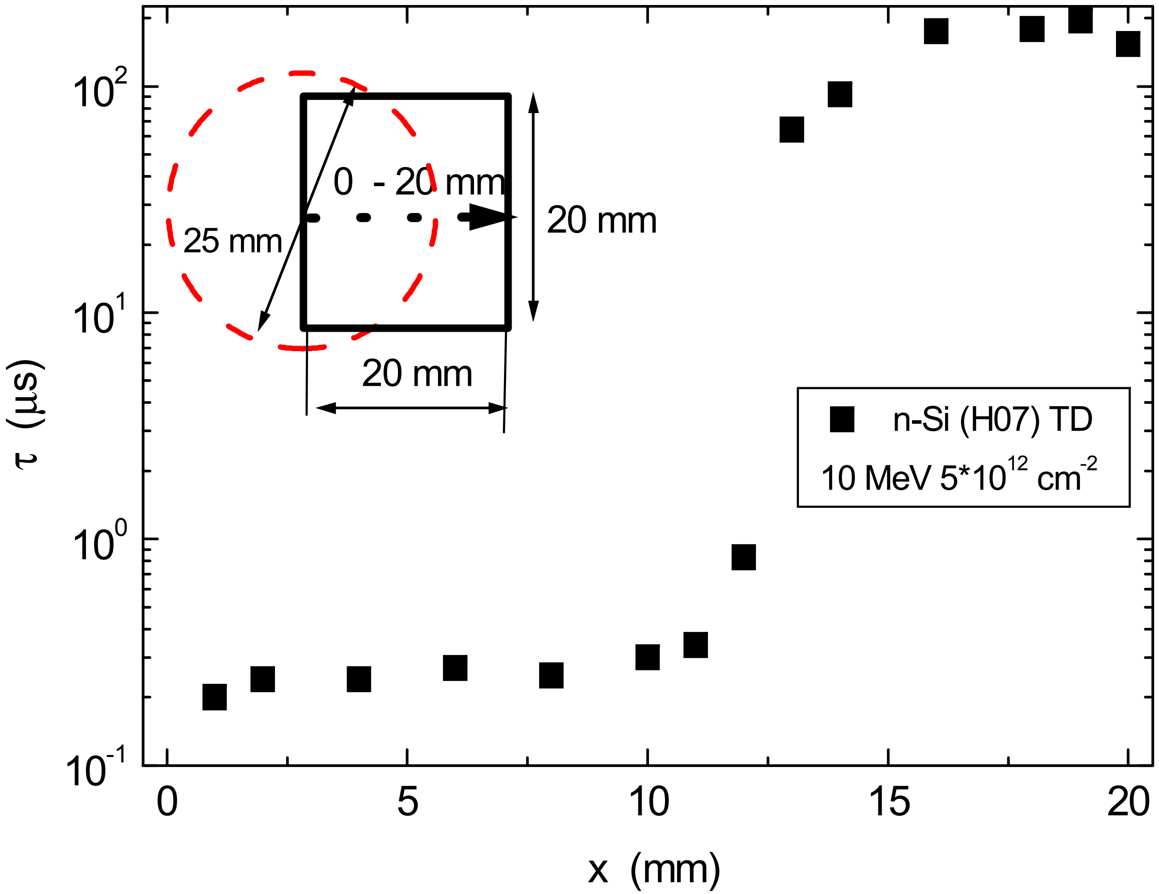


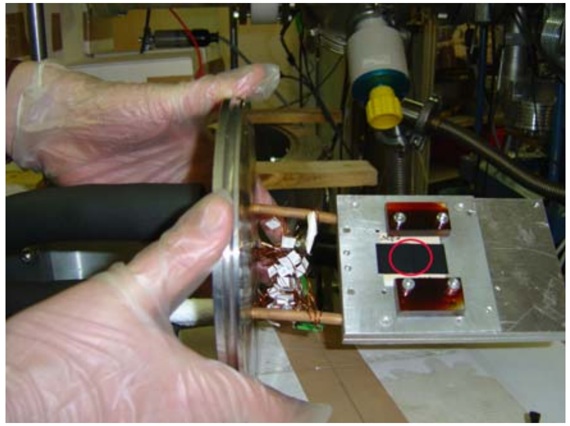
a b

MWA decays measured in p- and n-type oxygenated (TD) –(a) and untreated (no TD) –(b) initial Si wafers at 300K.

Irradiation spot dependent lifetime variations

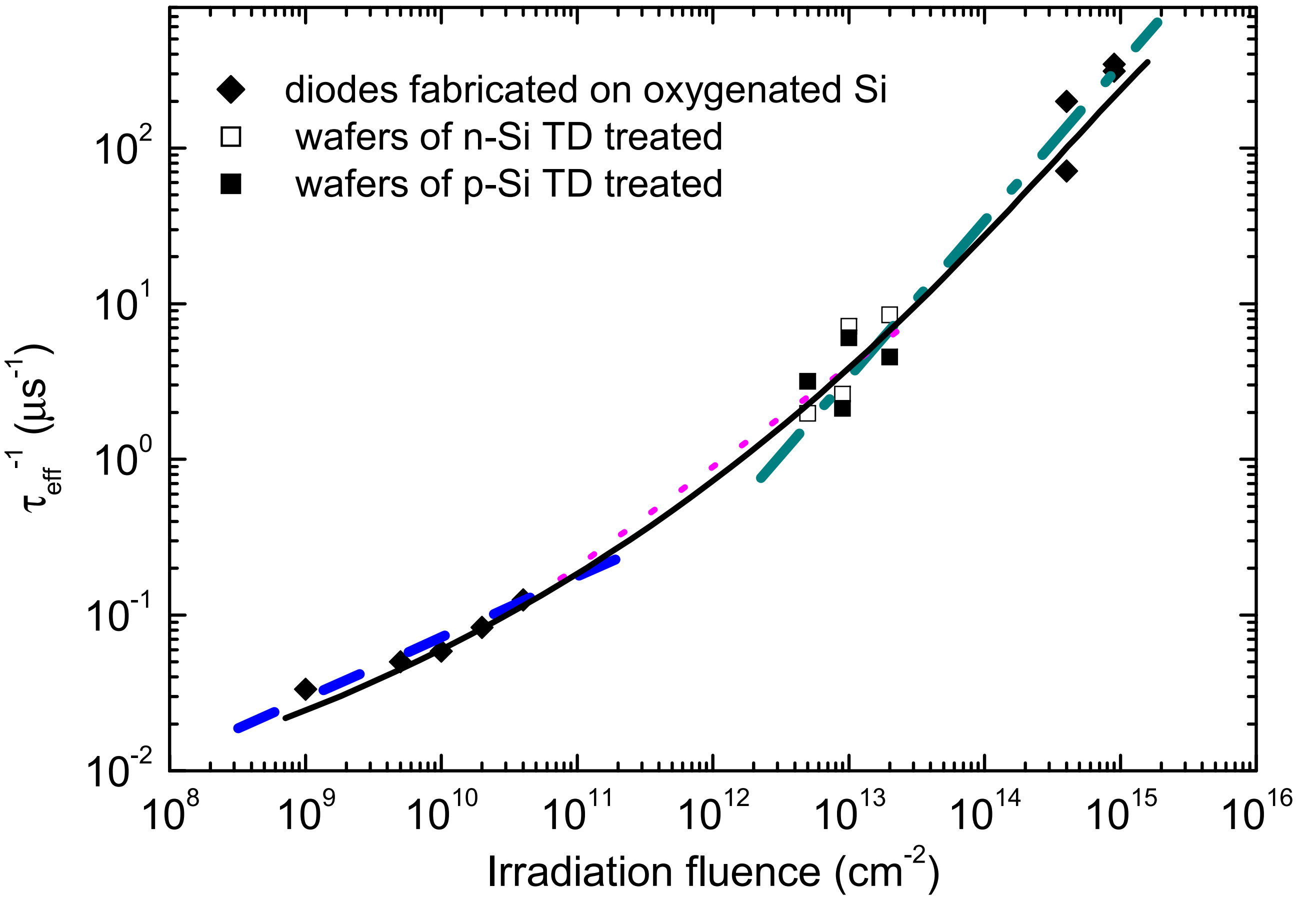
☼ *Recombination lifetime decreases with irradiation, and trapping at 300 K is suppressed.*





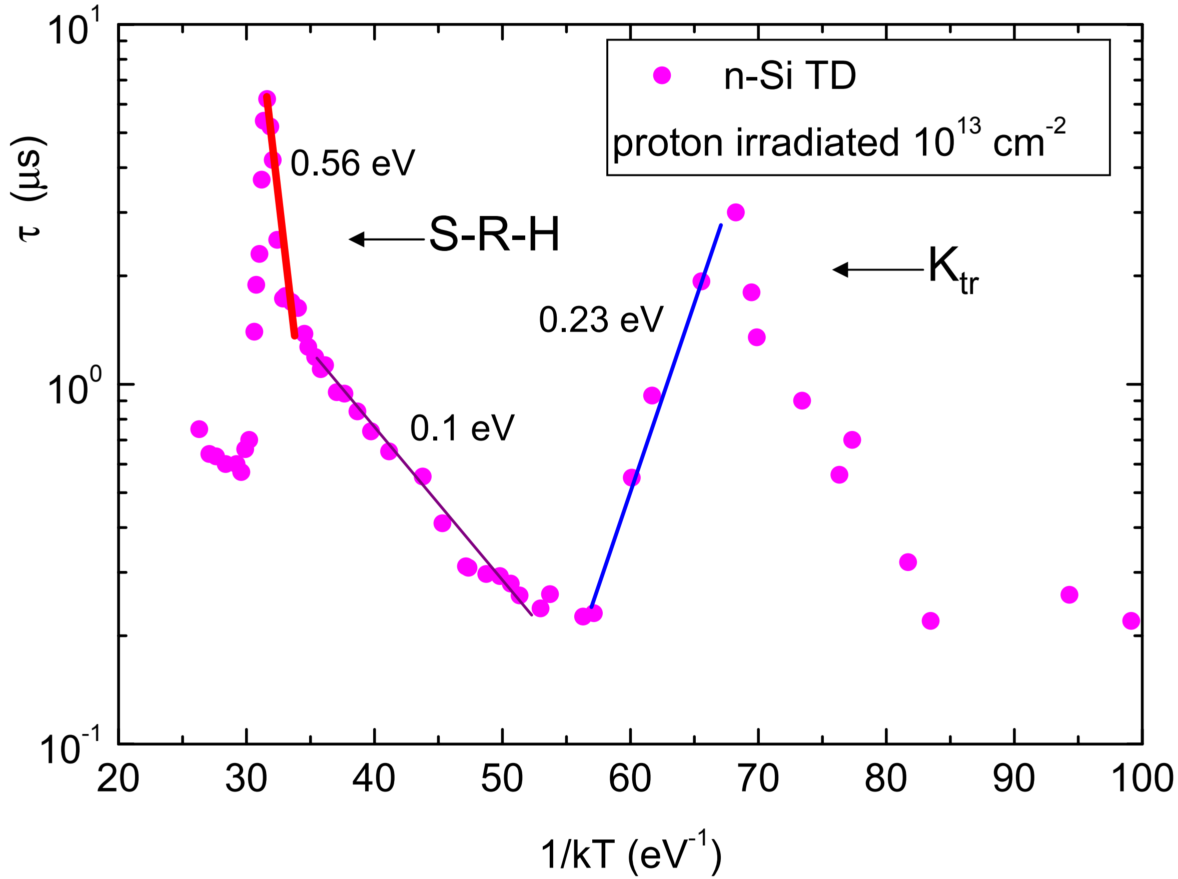
Fluence dependent lifetime variations

☼ *reciprocal recombination lifetime indicates changes of the concentration of the radiation defects, and different slopes in the τ^{-1} vs. fluence characteristic demonstrate variation of dominant defects type*

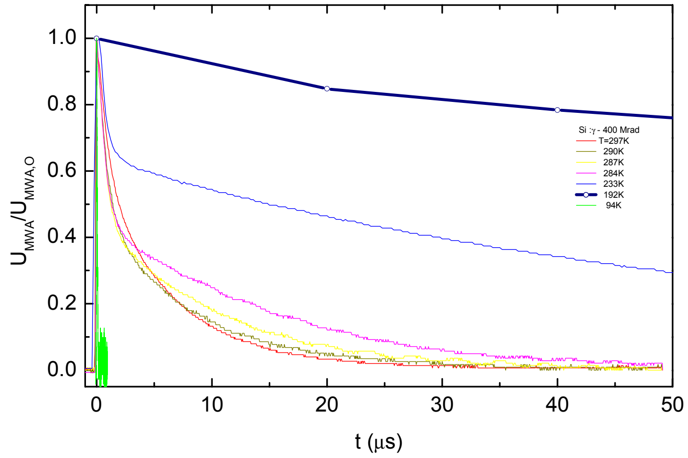


Temperature dependent lifetime variations

☼ *trapping appears in low temperature range, while S-R-H recombination dominates at elevated temperatures in the proton irradiated material*

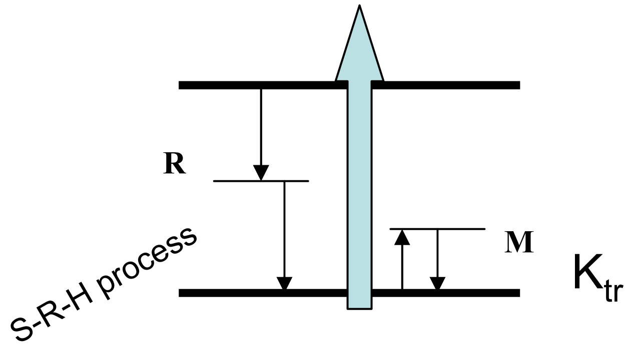


Carrier lifetime vs. reciprocal thermal activation energy in the oxygenated proton irradiated wafer



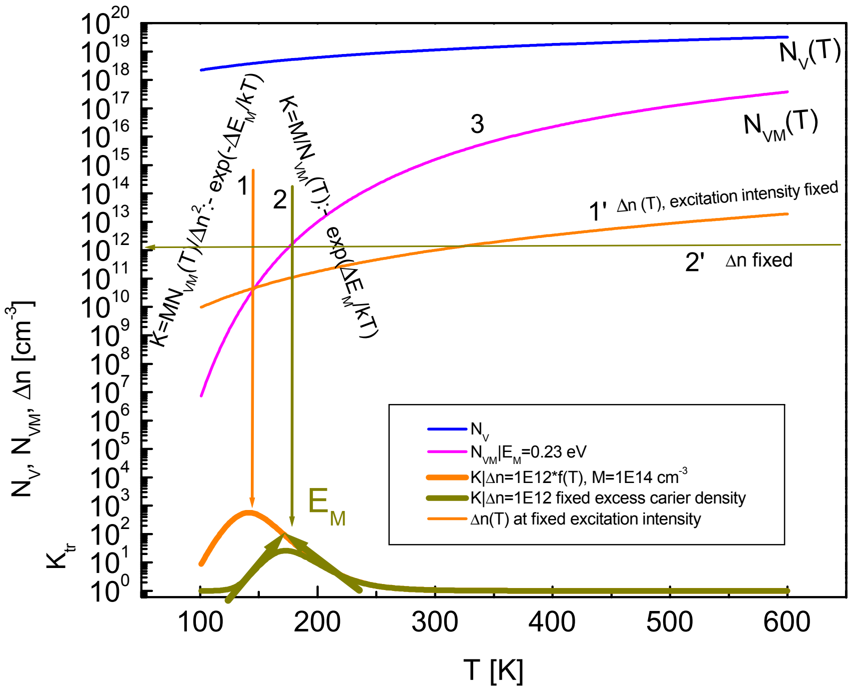
Evolution of the MWA transients in low temperature range in the oxygenated proton irradiated diode

Simulation of the temperature dependent lifetime variations

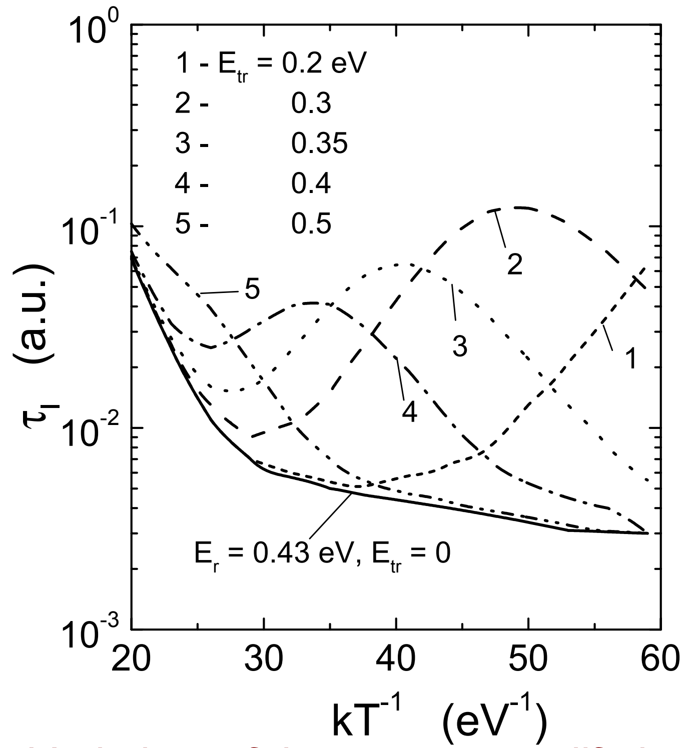


$$\tau_{inst} = \tau_R K_{tr}\,, \qquad K_{tr}=[1+M\, N_{VM}/(N_{VM}+\Delta n)^2\,]$$

$$N_{VM}=N_V \exp(-\,\Delta E_M/kT)$$



Variation of trapping coefficient K_{tr} with temperature, and formation of lifetime extrema at either fixed excess carrier density or for invariable excitation intensity



Variation of instantaneous lifetime with trap level position *vs. inverse thermal activation factor at simultaneous recombination and trapping*

Summary

☼ the inverse lifetime of the fast recombination nonlinearly varies with proton irradiation fluence manifesting difference in defect formation rate and defects type in the ranges of moderate and the highest irradiation fluences

☼ activation factors of the fast recombination centers E_R=0.56 eV and of the slow trapping ones E_M =0.23 eV have been evaluated from carrier lifetime variations with temperature in the range of 90 →450 K. These trap activation energy values correlate well with those determined by electrical methods.

Thank You for attention!