Profiling of carrier lifetime and electrical characteristics in PIN and LGAD structures

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Outline

- ❑ Motivation

- ❑ Principles of measurement techniques and instruments
  - Carrier lifetime profiling by edge scanning of microwave probed photoconductivity transients
  - Instrumentation for electrical characterization

- ❑ Samples

- ❑ Profiling of carrier lifetime and electrical characteristics
  - Profiling of carrier lifetime in structures irradiated with reactor neutrons
  - Profiling of carrier lifetime and electrical characteristics in structures irradiated with stopped protons
  - Profiling of carrier lifetime and electrical characteristics in non-irradiated LGAD structures

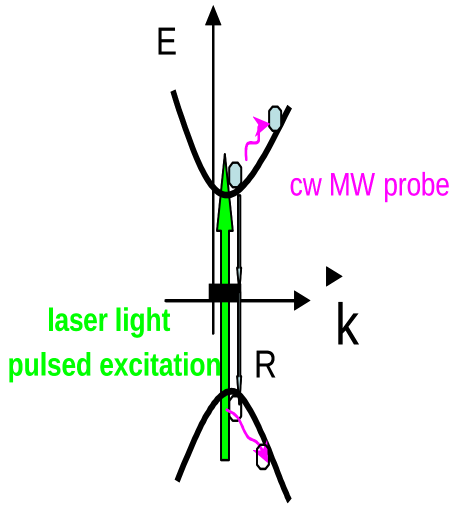
- ❑ Conclusions

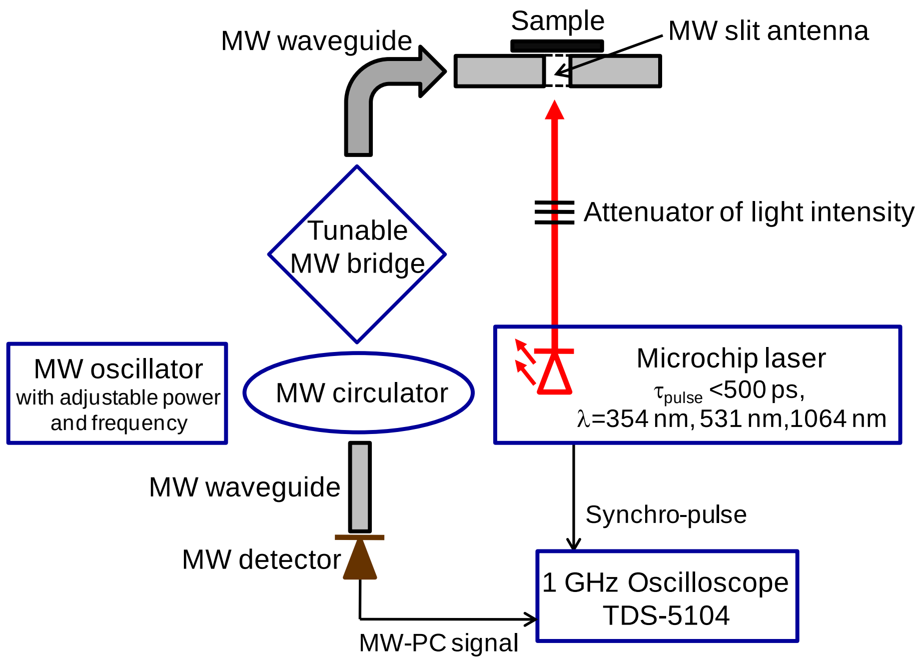
Motivation

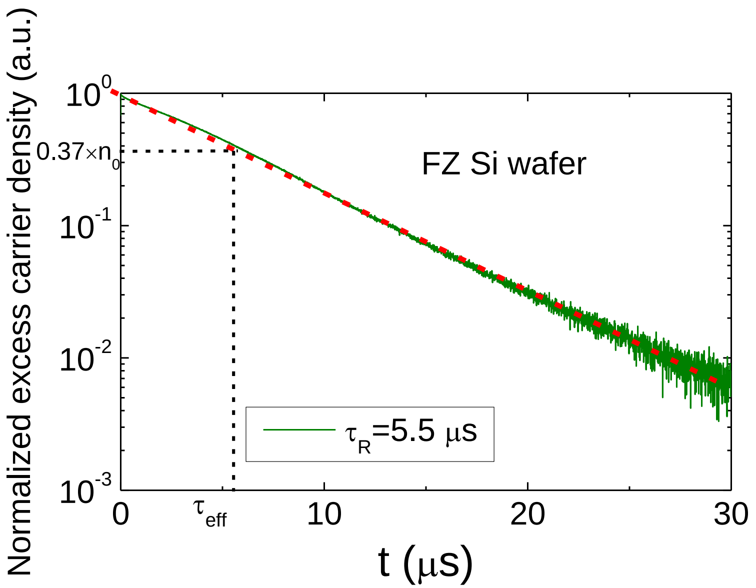
- Carrier lifetime profiles within different structures irradiated by various particles and energies to evaluate stopping range of various radiations.

- MW-PC edge scanning technique for depth profiling of carrier lifetime within different structures to trace technological structure of sensors.

Measurement techniques and instruments



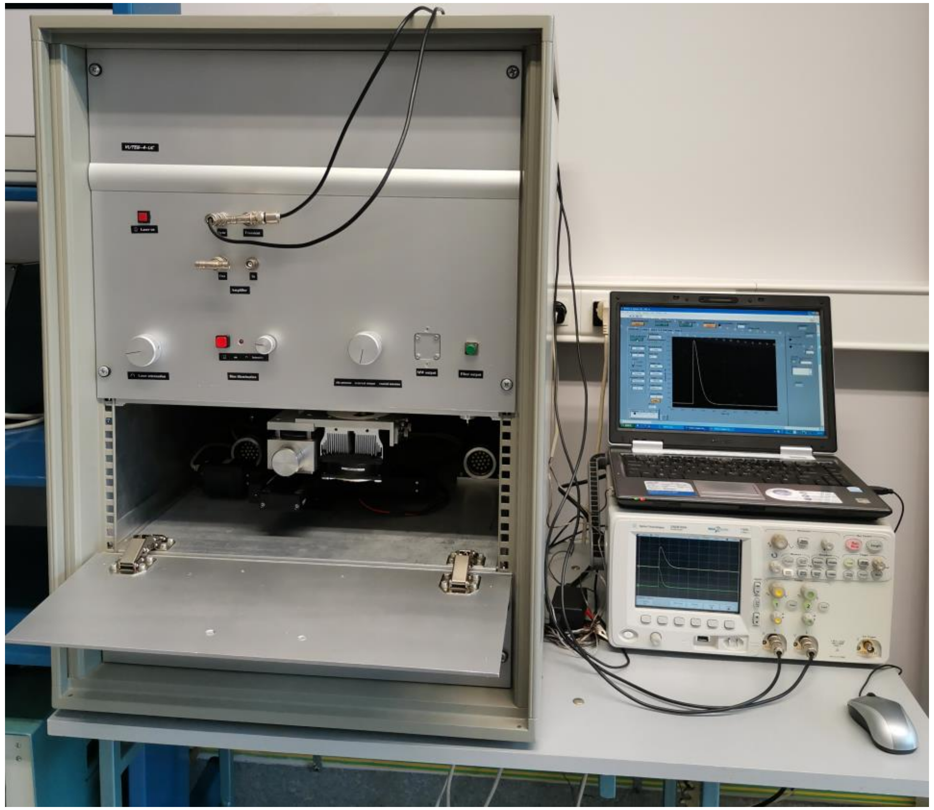




$$\tau_R = n / \left(- \frac{\partial n}{\partial t} \right) \bigg|_{\exp(-1)}$$

The microwave probed photoconductivity technique is based on the direct measurements of the carrier decay transients by employing MW absorption by excess free carriers.

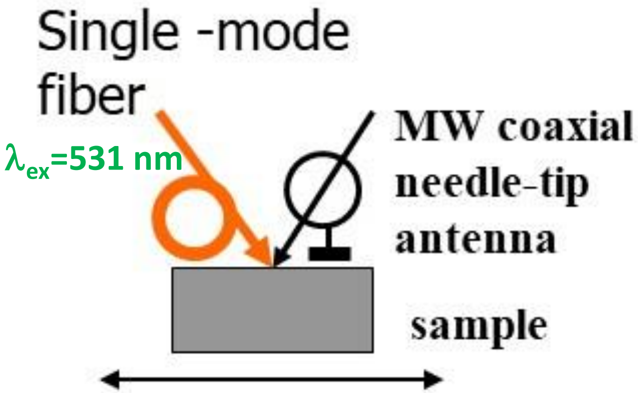
Measurement techniques and instruments



Vilnius University proprietary made instrument VUTEG-4.

Technical capabilities of the instrument VUTEG-4:

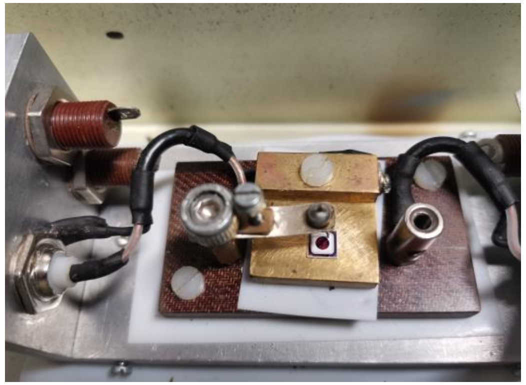
- 2D recombination lifetime scanning of Si wafers of dimensions up to 12 cm in diameter.
- Scan regime of wafer edge is foreseen in this instrument, which is implemented using a needle-tip MW antenna probe intersecting with a single mode fibre tip.
- Assurance of the nitrogen gas and temperature stabilized environment during measurements.



Experiment geometry for cross-sectional profiling of recombination lifetime.

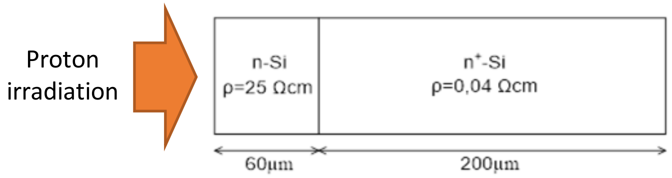
Measurement techniques and instruments

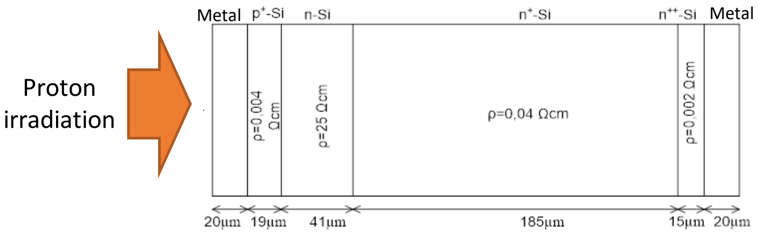
Instrumentation for IV measurements : Keithley 6430 sub-femtoamp electrometer equipped with double shielded sample holder.



Instrumentation for CV measurements : QuadTech 7600 LRC meter equipped with galvanically insulated voltage source (0–500 V).

Samples





MCZ (homogeneous structure) and FZ (n-n$^+$) Si wafer fragments

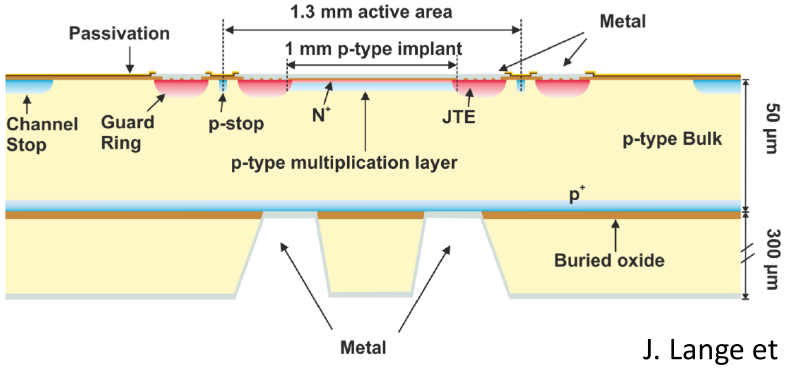
- surface passivated;
- 260-1000 μm thick;
- irradiated with 1.5 MeV, 1.6 MeV, 2.0 MeV protons and reactor neutrons.

PIN diodes

- produced by enterprise Vilniaus Ventos Puslaidininkiai on 4“ Si 260 μm thickness wafers;
- irradiated with various energy of protons.

LGAD structures

- produced by CNM Barcelona on 4" silicon-on-insulator (SOI) wafers with nominally 50 μm thickness on a 300 μm thick support wafer and 1 μm buried oxide;
- single pad diodes of an overall active area of 3.3×3.3 mm^2 (LGB);
- cut and boundary polished for profiling of carrier lifetime.



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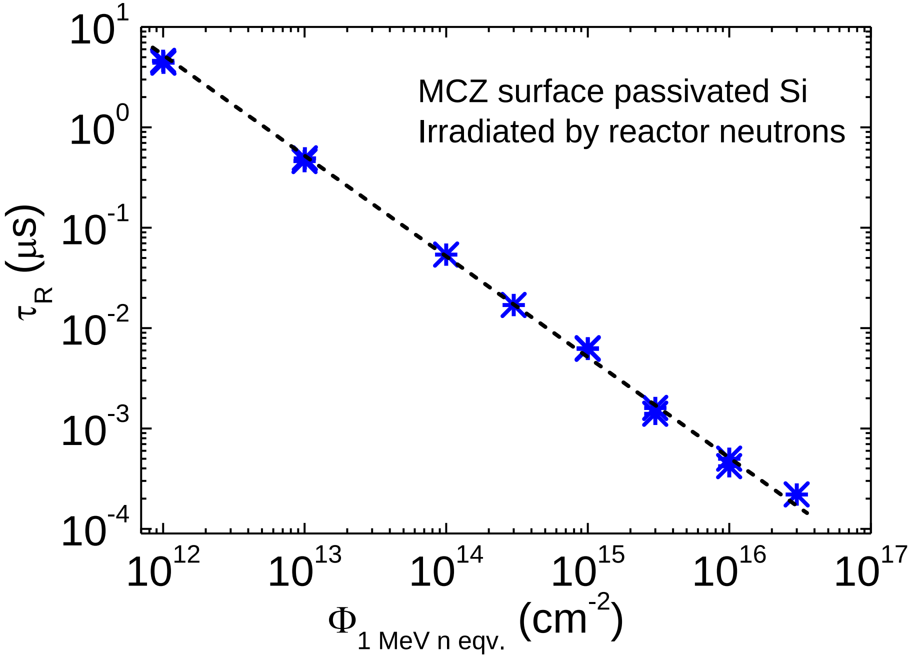
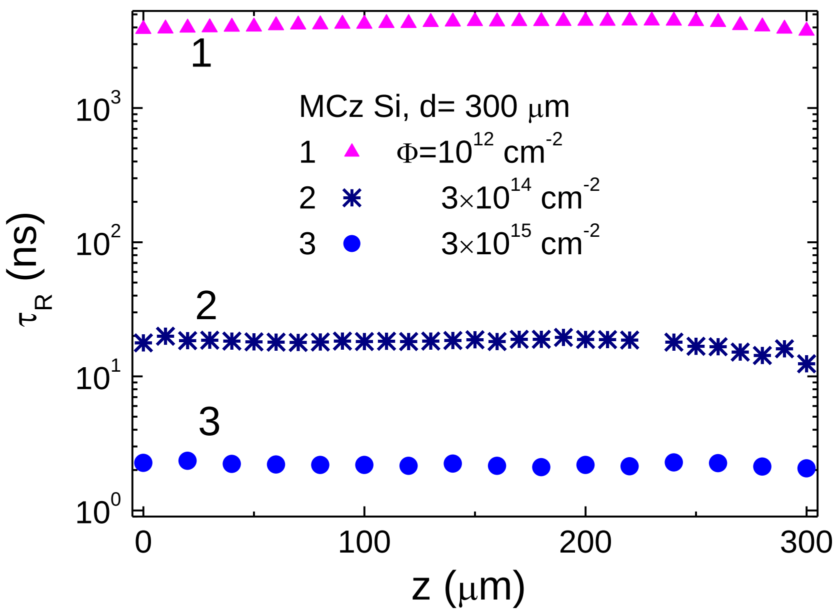
Profiling of carrier lifetime in MCZ Si wafers irradiated with reactor neutrons

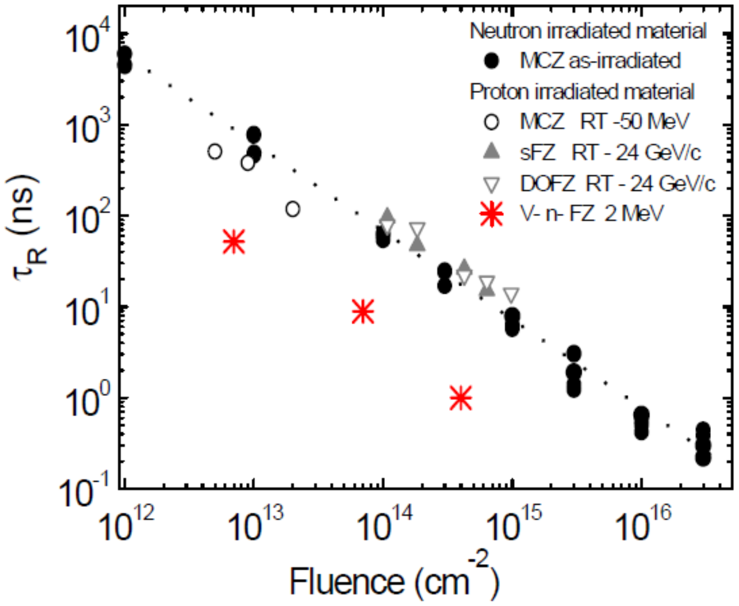


Recombination lifetime as a function of reactor neutron irradiation fluence in MCZ Si wafers.

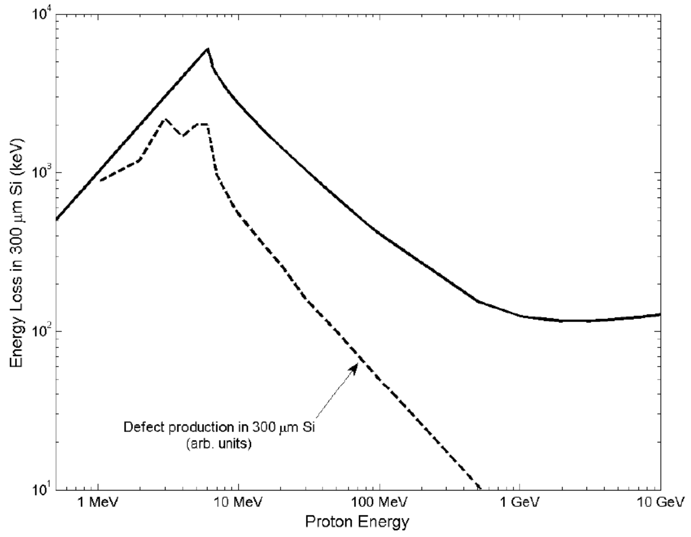


Carrier lifetime depth-distribution profiles measured in 300 μm-thick MCZ Si wafers after neutron irradiation using different fluences.

Fluence dependent lifetime variations in different particle energy irradiated structures



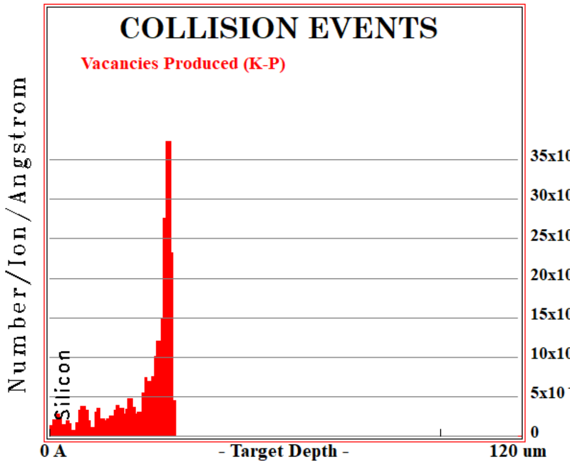
Fluence dependent lifetime variations in various particle energy irradiated structures.

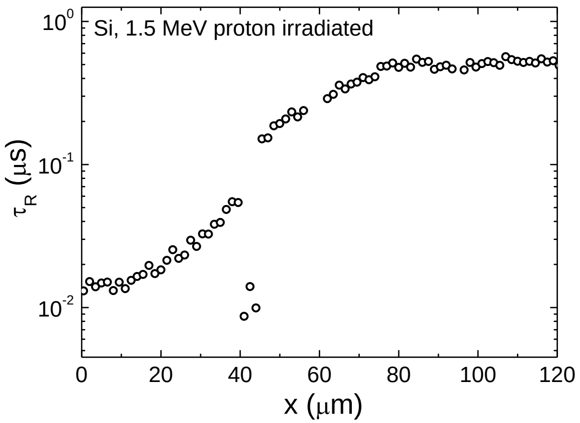


TRIM simulated energy loss and defect production rate within 300 µm thick Si as a function of proton energy.

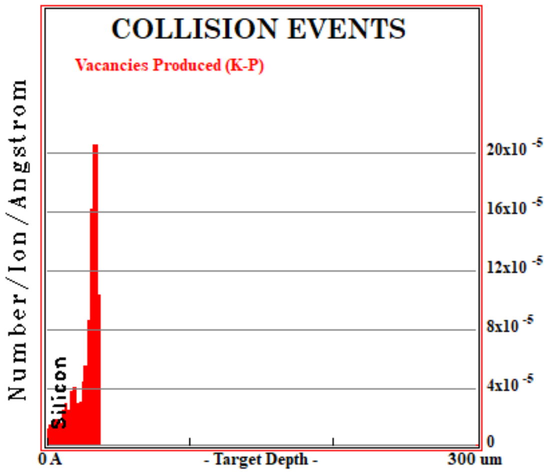
Profiling of carrier lifetime in homogeneous Si structures irradiated with stopped protons

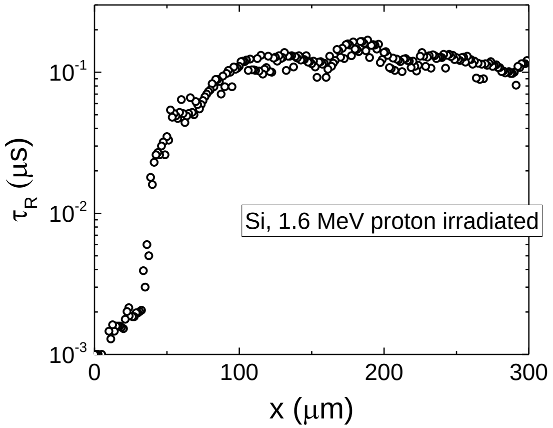
1.5 MeV protons, $\Phi=10^{14}$ cm^{-2}





1.6 MeV protons, $\Phi=10^{15}$ cm^{-2}





- The profile of carrier lifetime correlates with the TRIM simulated defects distribution profile.
- Small discrepancy between the simulated and measured projectile range position and the spread of measured profile can be explained by lateral diffusion of carriers and the experimental errors due to the fibre spot diameter (≈6 μm) and the defect peak dispersion (width of δ-layer at half of its peak amplitude is ≈10 μm).

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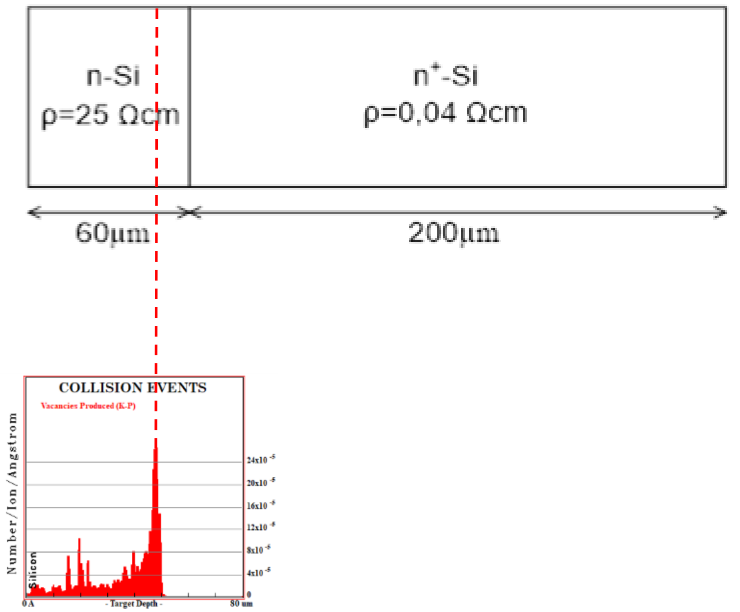
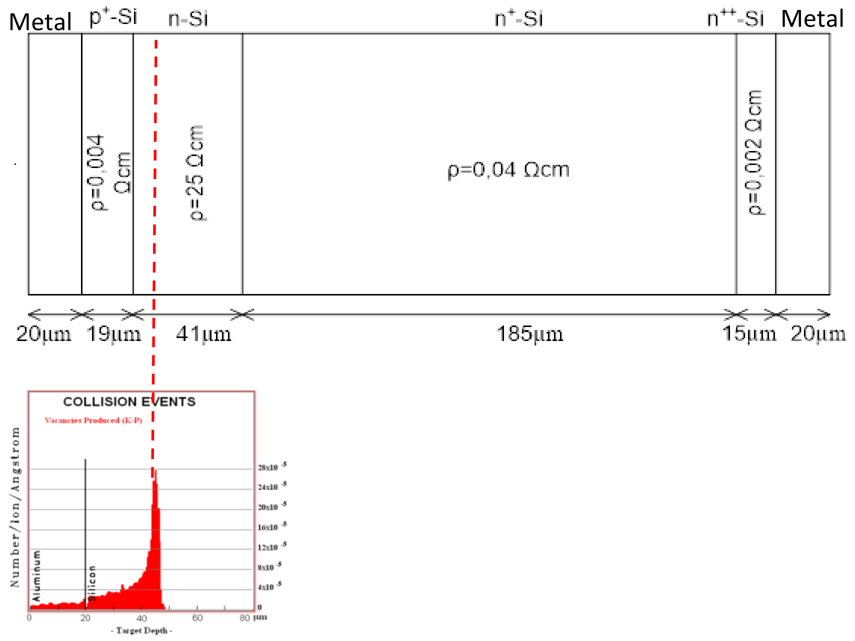
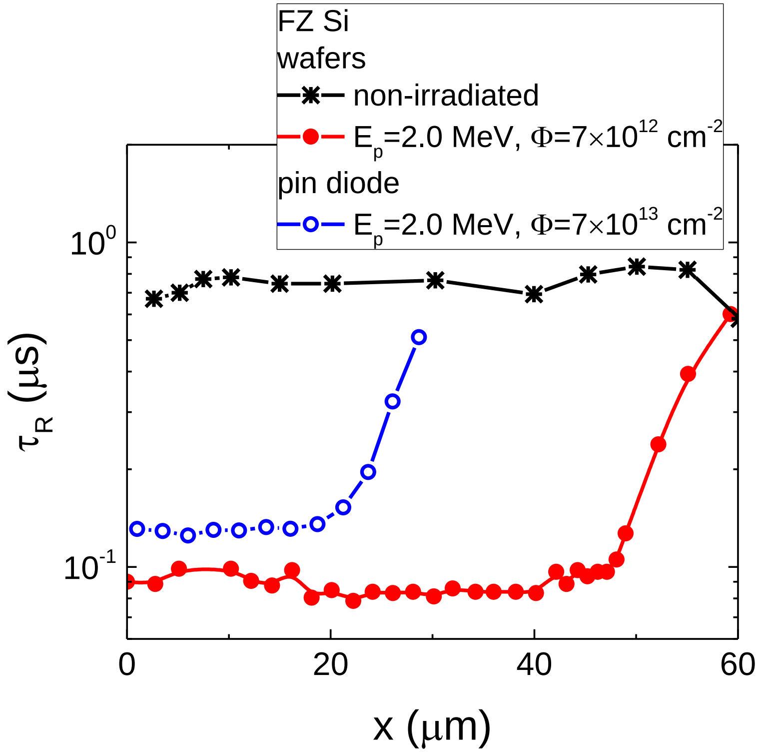
Profiling of carrier lifetime in Si and pin diode structures irradiated with stopped protons



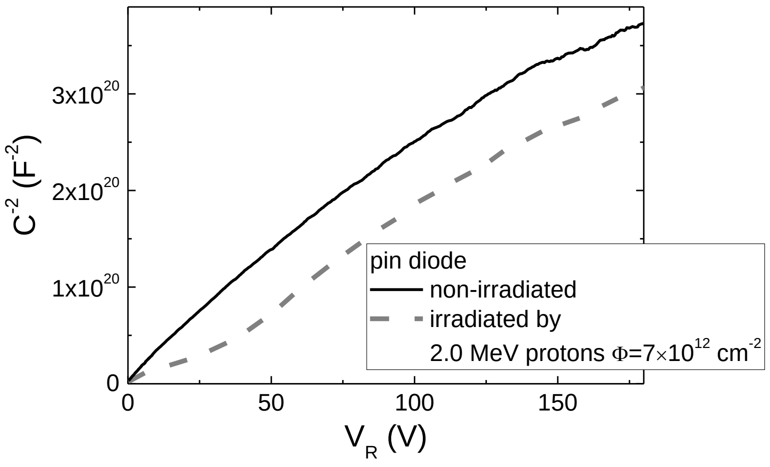


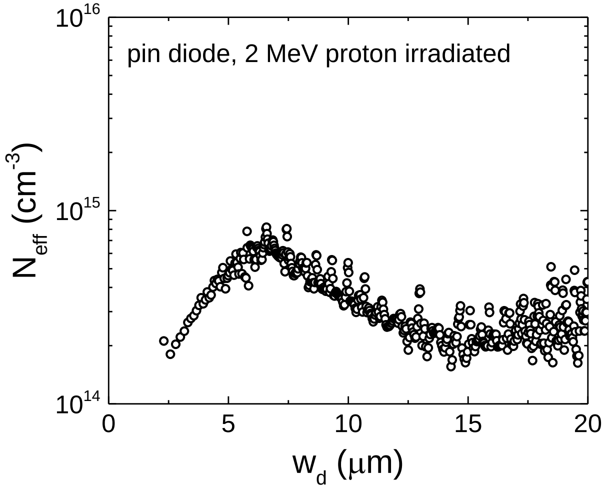
Simulated defect profile in Si wafer (left) and pin diode (right) structures after 2.0 MeV proton irradiation.



Measured profiles of carrier recombination lifetime in Si wafer and pin diode structures irradiated with 2.0 MeV protons at different fluences.

Electrical characteristics in proton irradiated pin diodes

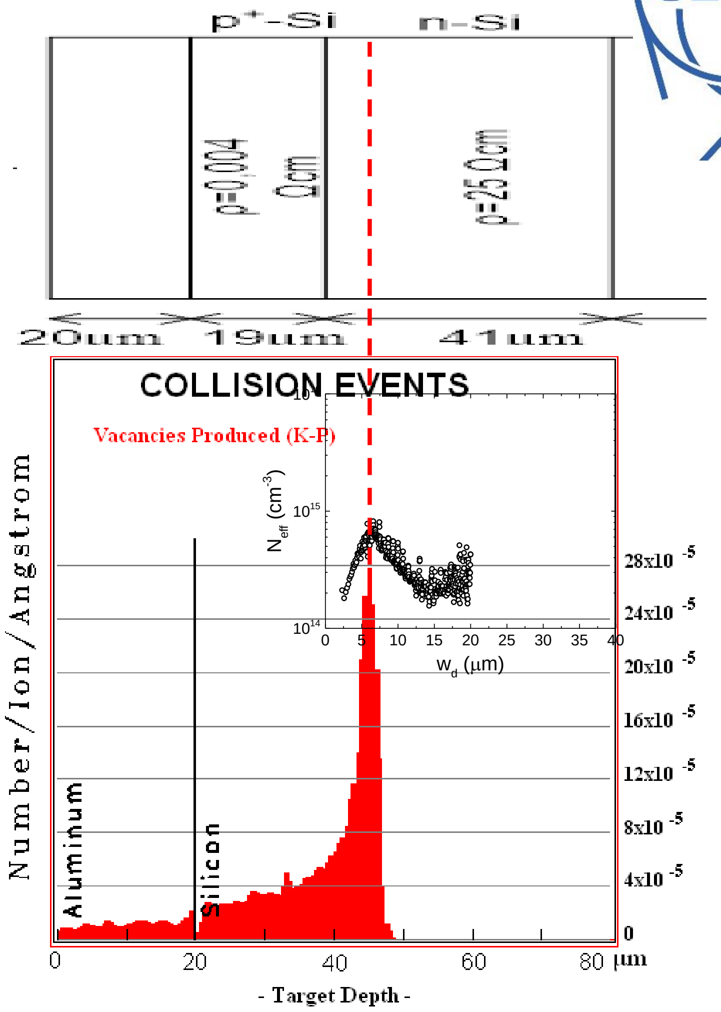




C-V characteristics (left) and calculated N_{eff} profile (right) in Si pin diodes irradiated by 2.0 MeV protons.

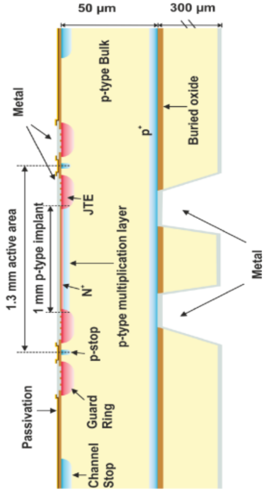
$$N_{eff}(x) = -\frac{C^3}{q\varepsilon\varepsilon_0 S^2 \dfrac{dC}{dU_R}}$$

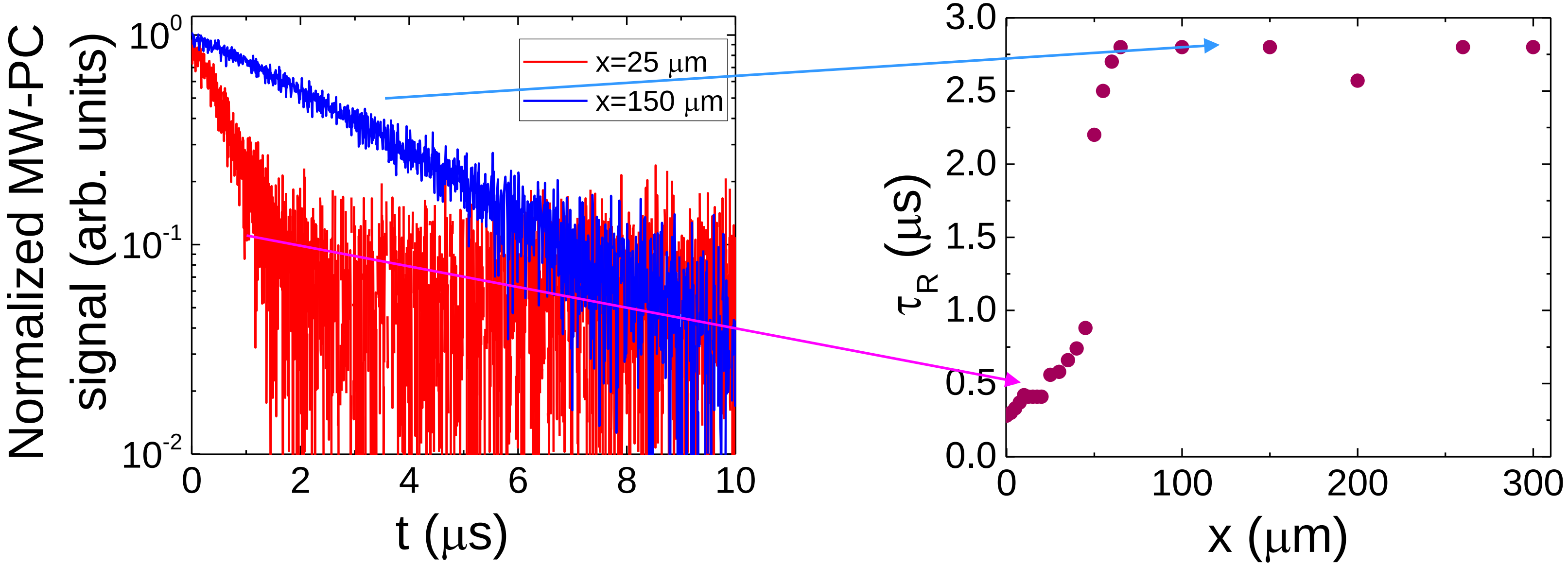
$$w_d = \frac{\varepsilon\varepsilon_0 S}{C}$$



Comparison of N_{eff} profile obtained from CV characteristic with the simulated defect profile in pin diode irradiated by 2.0 MeV protons.

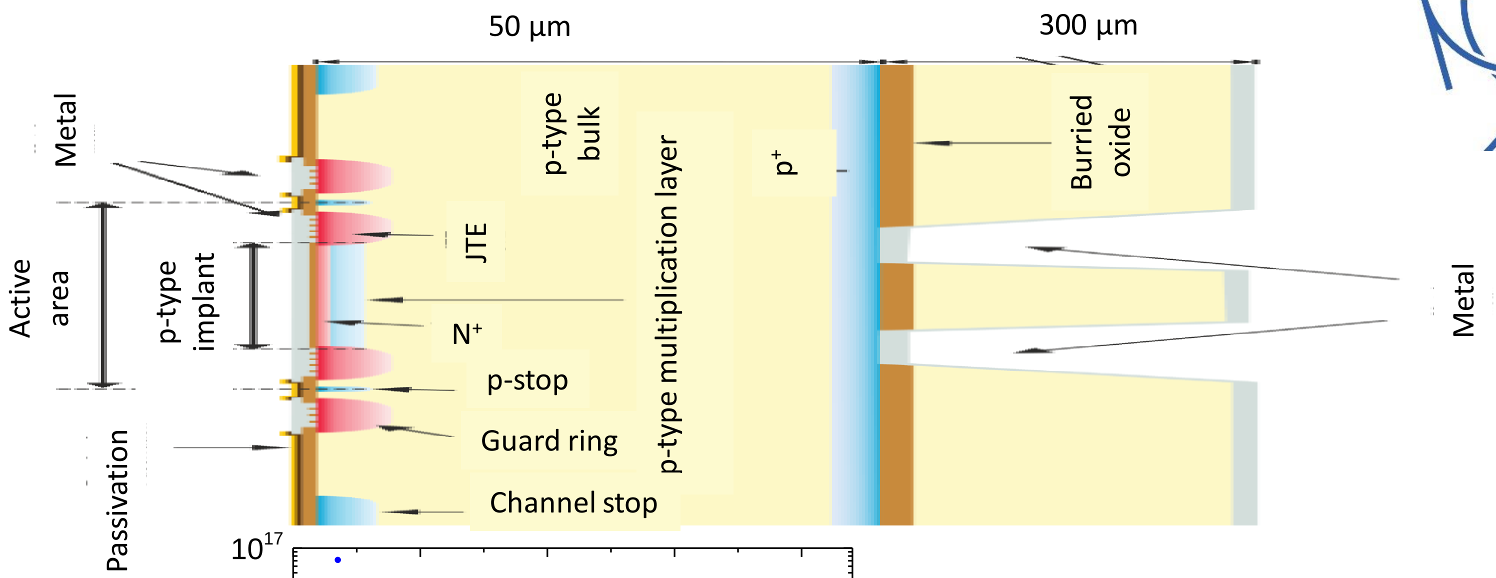
Profiling of carrier lifetime in LGAD structures

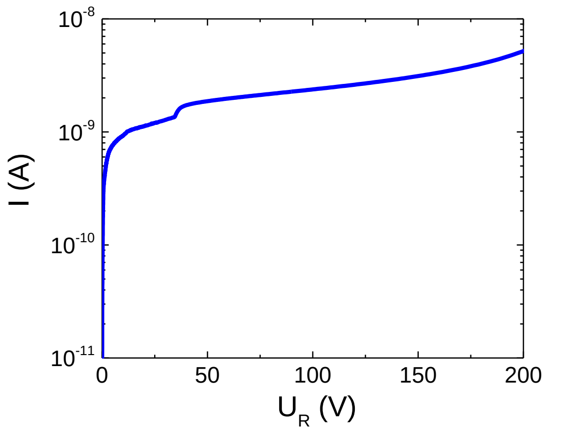


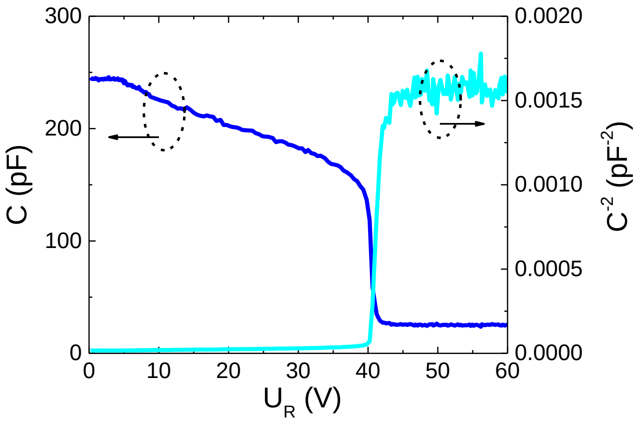


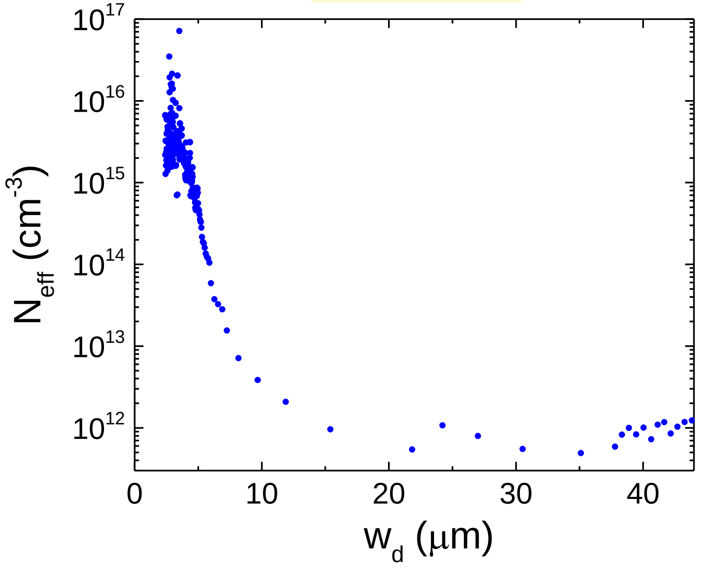
MW-PC characteristics (left) and measured profile of carrier lifetime (right) in Si LGAD structure.

Electrical characteristics in LGAD structures









I-V (top left) and C-V (bottom left) characteristics and calculated N_{eff} profile (right) in Si LGAD.

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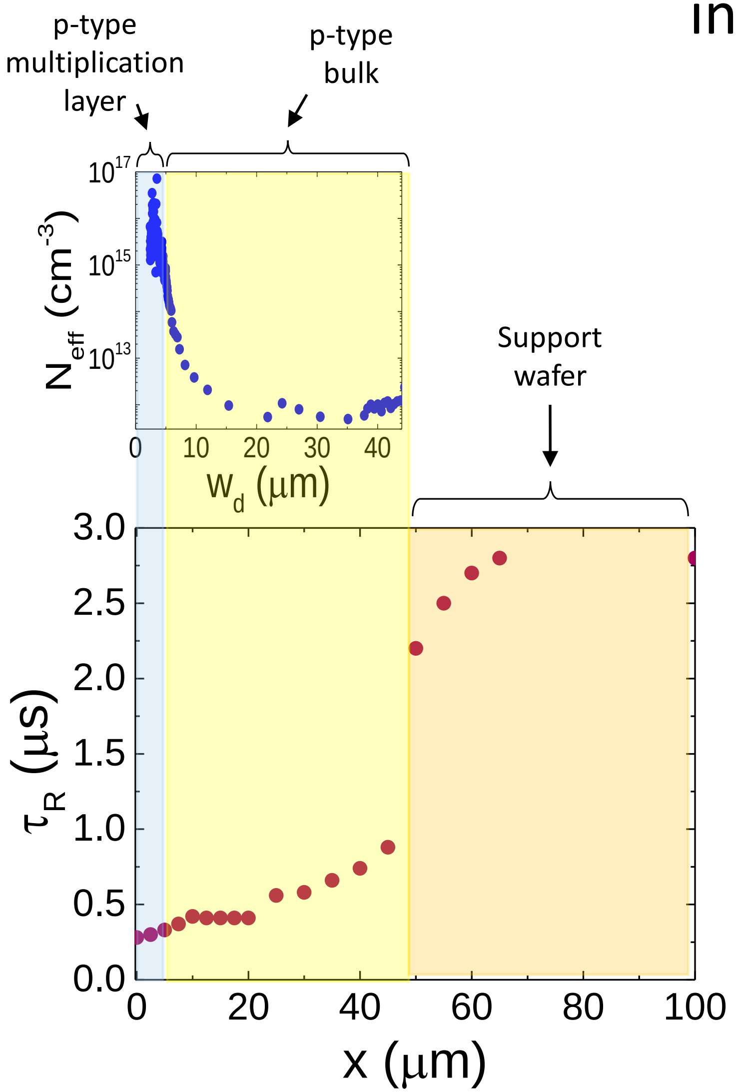
Carrier lifetime and doping concentration profiles in LGAD structures



Comparison of carrier lifetime and effective doping profiles measured in LGAD.

Carrier lifetime profile measured by edge scanning of MW-PC transients correlates with that of effective doping measured by C-V technique within LGAD structure.

Conclusions

- The carrier lifetime profiles obtained by edge scanning of microwave probed photoconductivity transients correlate with the stopping ranges of incident particles and with profiles obtained from electrical characteristics.

- The doping profile evaluated using CV characteristics correlates with that of the carrier recombination lifetime in non-irradiated LGAD structures.

- The edge scanning of microwave probed photoconductivity transients might be promising for depth profiling of carrier lifetime within multiplication layer of irradiated LGAD structures.

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Thank you for your attention