Possibilities of large fluence irradiation dosimetry using multi-crystalline Si

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Outline

- Motivation
- Samples
- Measurement technique and instrument
- Carrier lifetime variation with fluence
- Characteristics of the mc-Si and electronic grade- Si

Motivation

- To search for cheap materials in order to make the wafer fragment sensors

- Carrier lifetime variations in mc-Si of elevated doping irradiated by protons

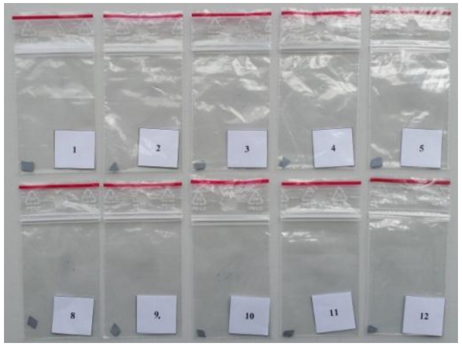
- To widen applications of VUTEG-5-AIDA instrument for dosimetry

2020

Samples

Multi-crystalline Si (mc-Si) substrates for commercial solar-cell production:
- **surface non-passivated**
- **190 μm thick wafers of dimensions 15.6×15.6 cm^2**
- **moderately doped p-type, 10^{15} cm^{-3}**
- **fragmented as crystal isles**

Preparing of mc-Si tentative dosimetry sensors:
- **cut of the same crystalline "isle"**
- **5 pieces for irradiation from the same "isle"**
- **several sets from different mc-Si "isles"**



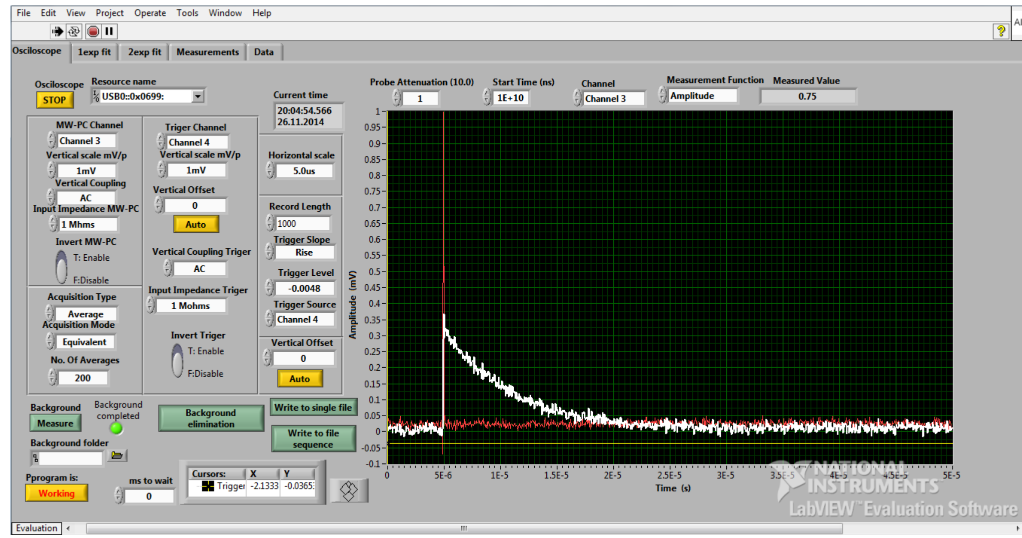
Irradiation:
- **at tandem accelerator in University of Helsinki**
- **8 MeV protons**
- **using proton beam scans**

Measurement technique and instrument

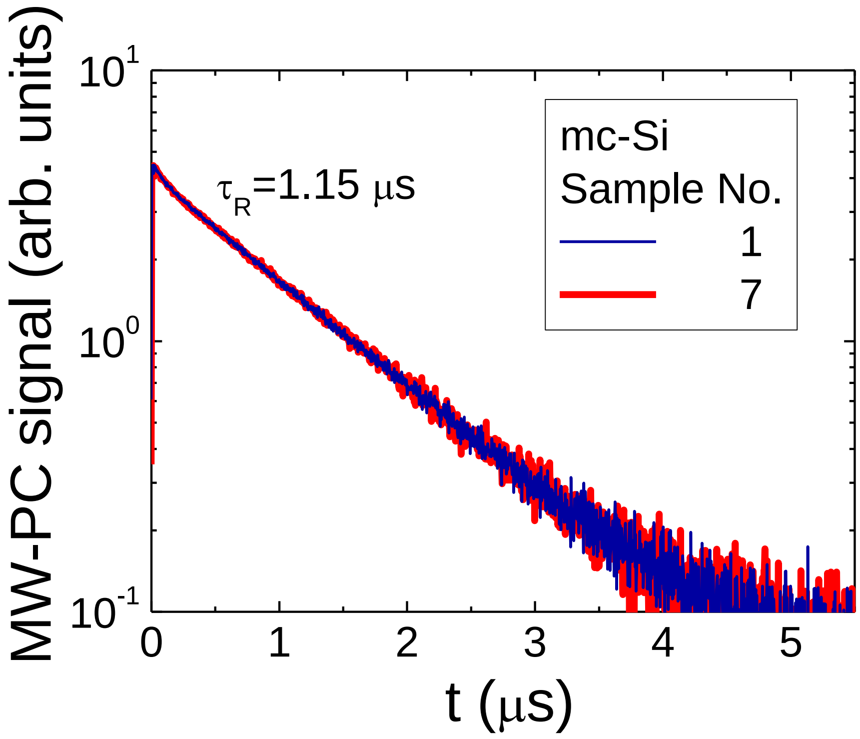
Springs for fixing of plastic bag

Sample within the plastic bag

VUTEG-5-AIDA

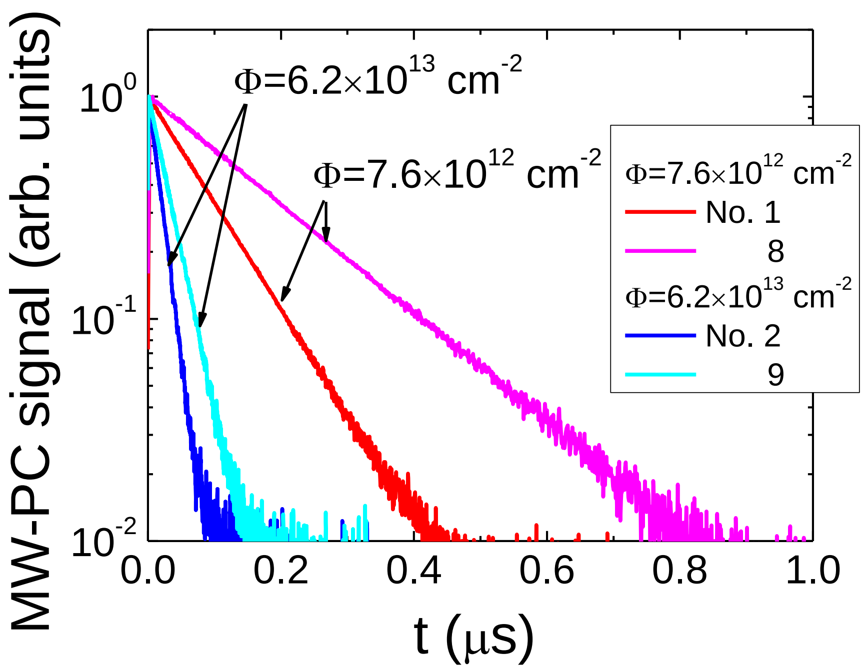


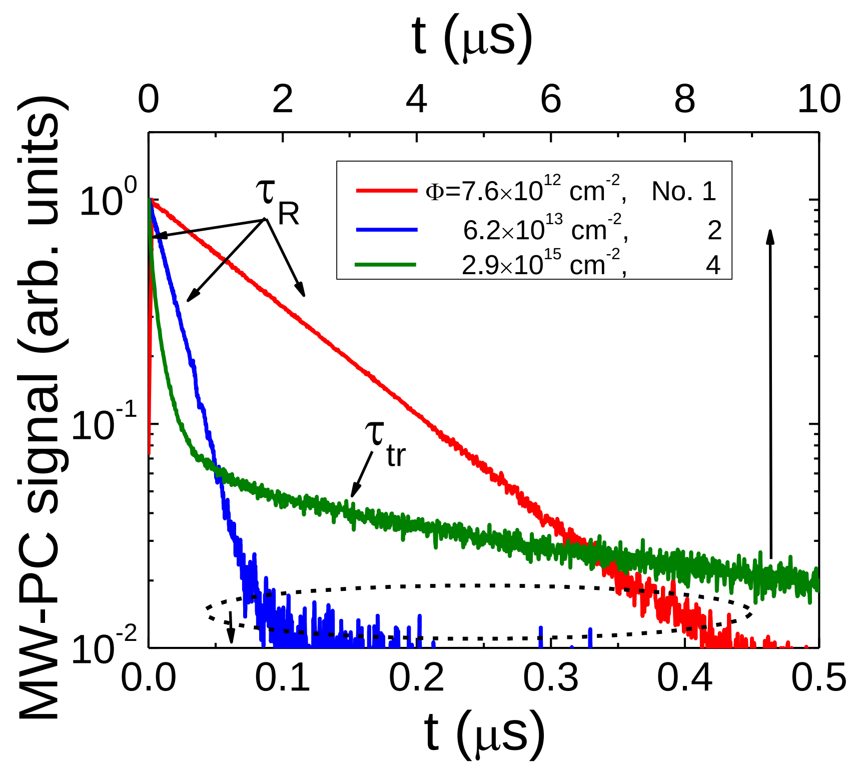
MW-PC transients in the initial mc-Si material



- carrier decay transients are single exponential
- obey an effective lifetime value of the diffusion limited surface recombination
- the same effective lifetime for different samples and crystal "isles"

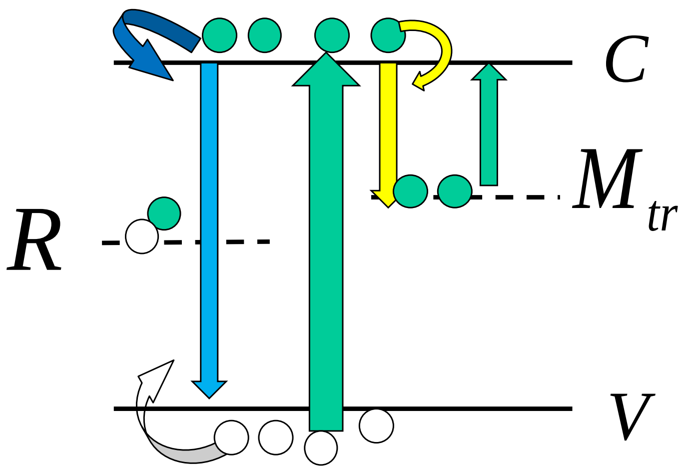
MW-PC transients in the as-irradiated mc-Si





- transients are single exponential only in low fluence irradiated samples (with shorter τ_R relative to non-irradiated samples);
- trapping effect (two-componential decay) appears in samples irradiated with elevated fluences;
- trapping effect indicates competition of several type radiation defects and synergy in redistribution of carrier decay flows.

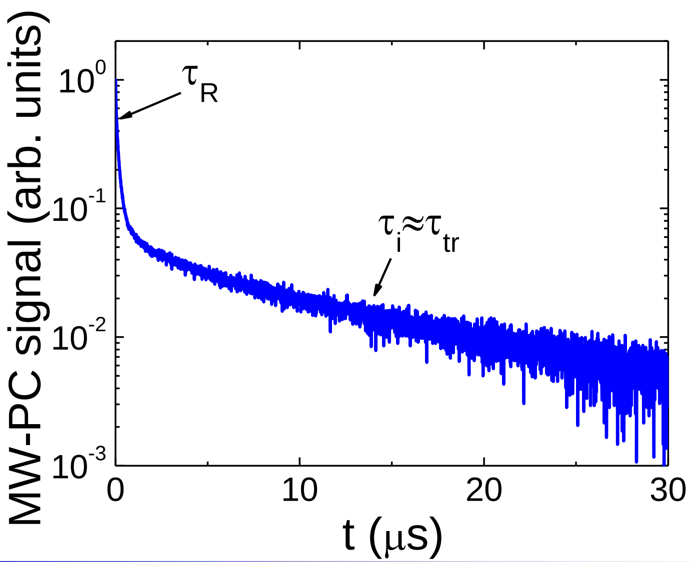
Multi-trapping (carrier capture/thermal release) effect

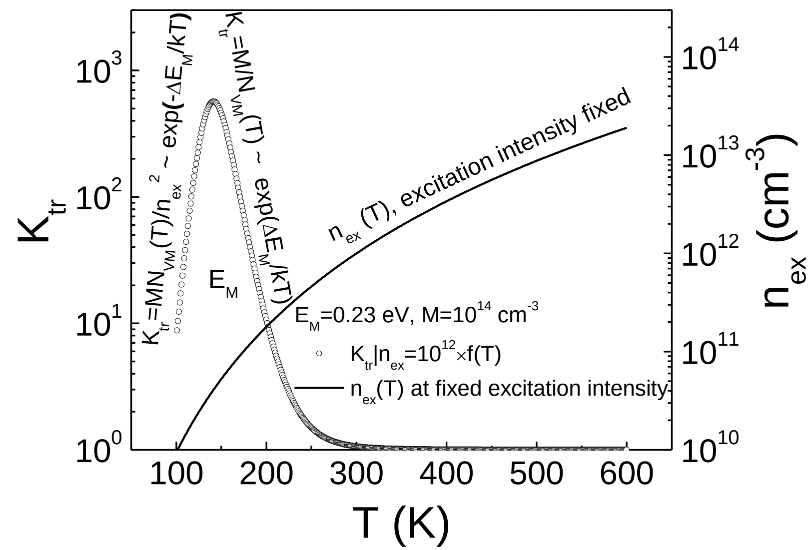


$$n(t) = n_0 \exp[-\frac{t}{\tau_R \times K_{tr}(n(t))}]$$

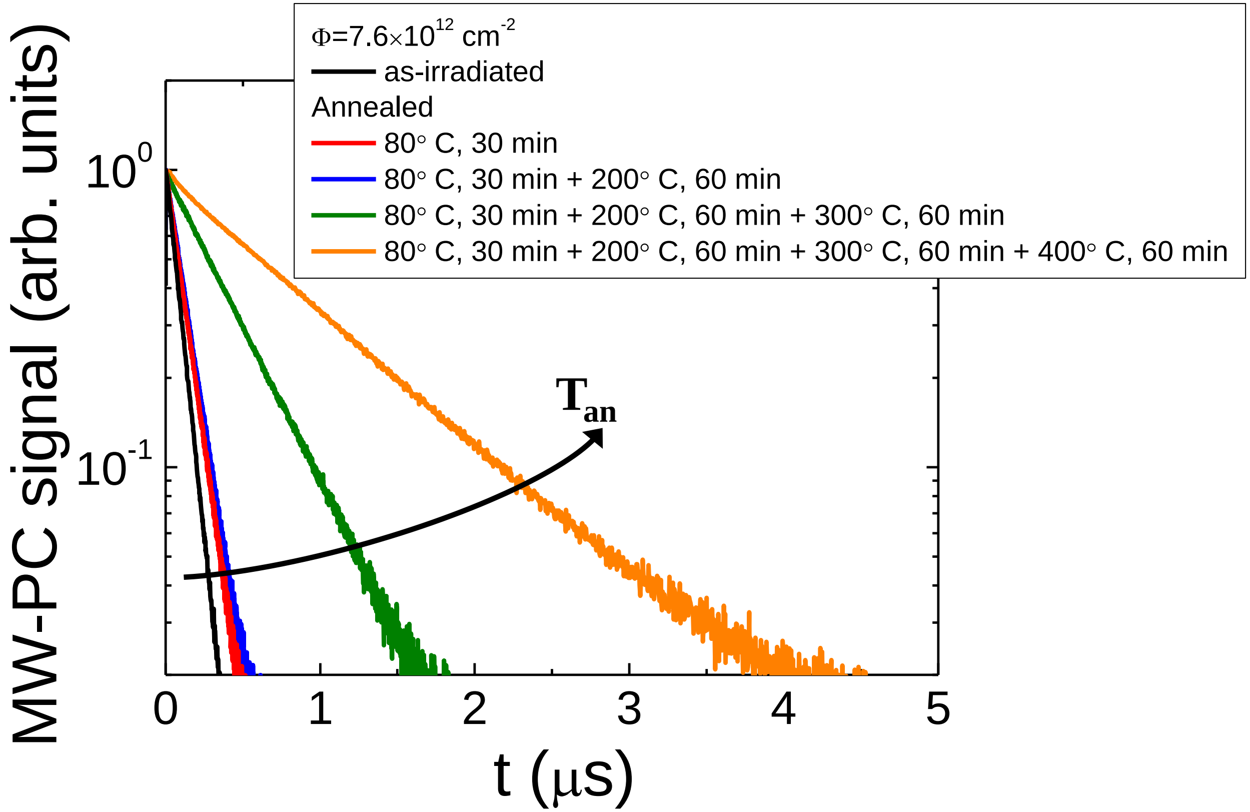
$$\tau_i = \tau_R[1 + \frac{M_{tr} N_{CM}}{(N_{CM} + n)^2}] = \tau_R K_{tr}$$

$$N_{CM}(T) = N_C \exp[-\frac{\Delta E_M}{kT}]$$





MW-PC transients in the irradiated and annealed mc-Si



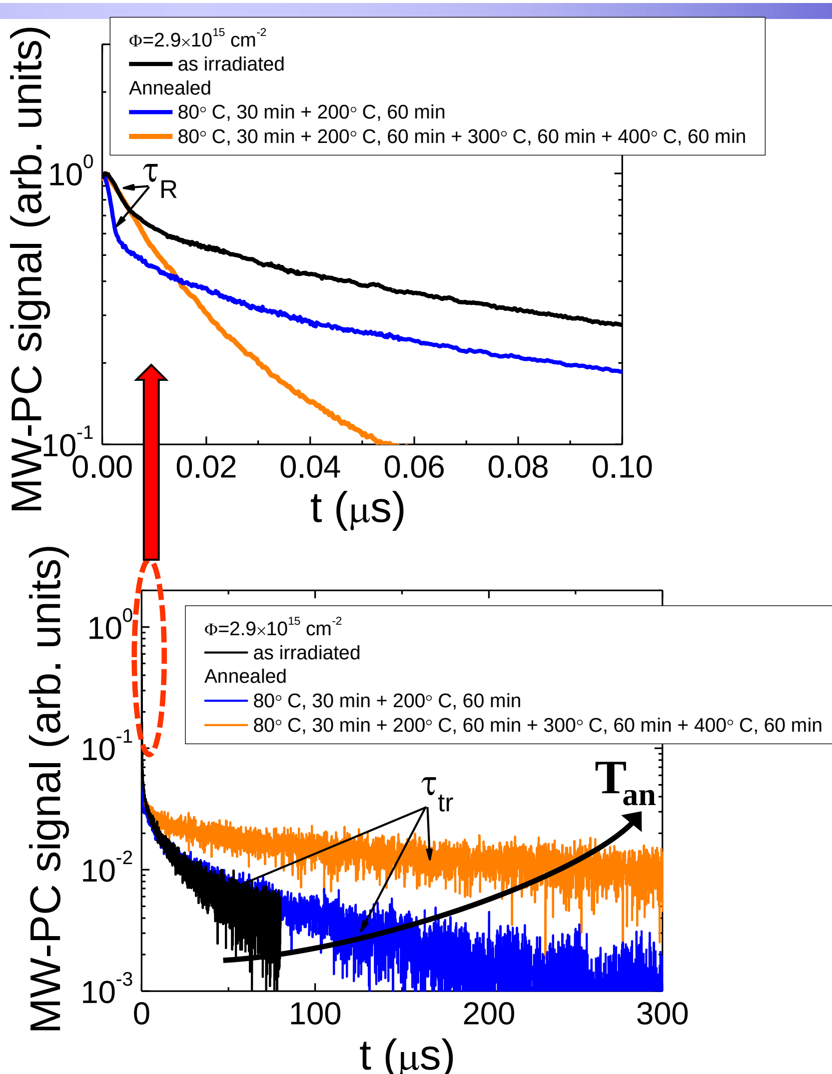
- Anneal leads to transforms of radiation defects and to reduction of concentration of recombination centers

MW-PC transients in the irradiated and annealed mc-Si

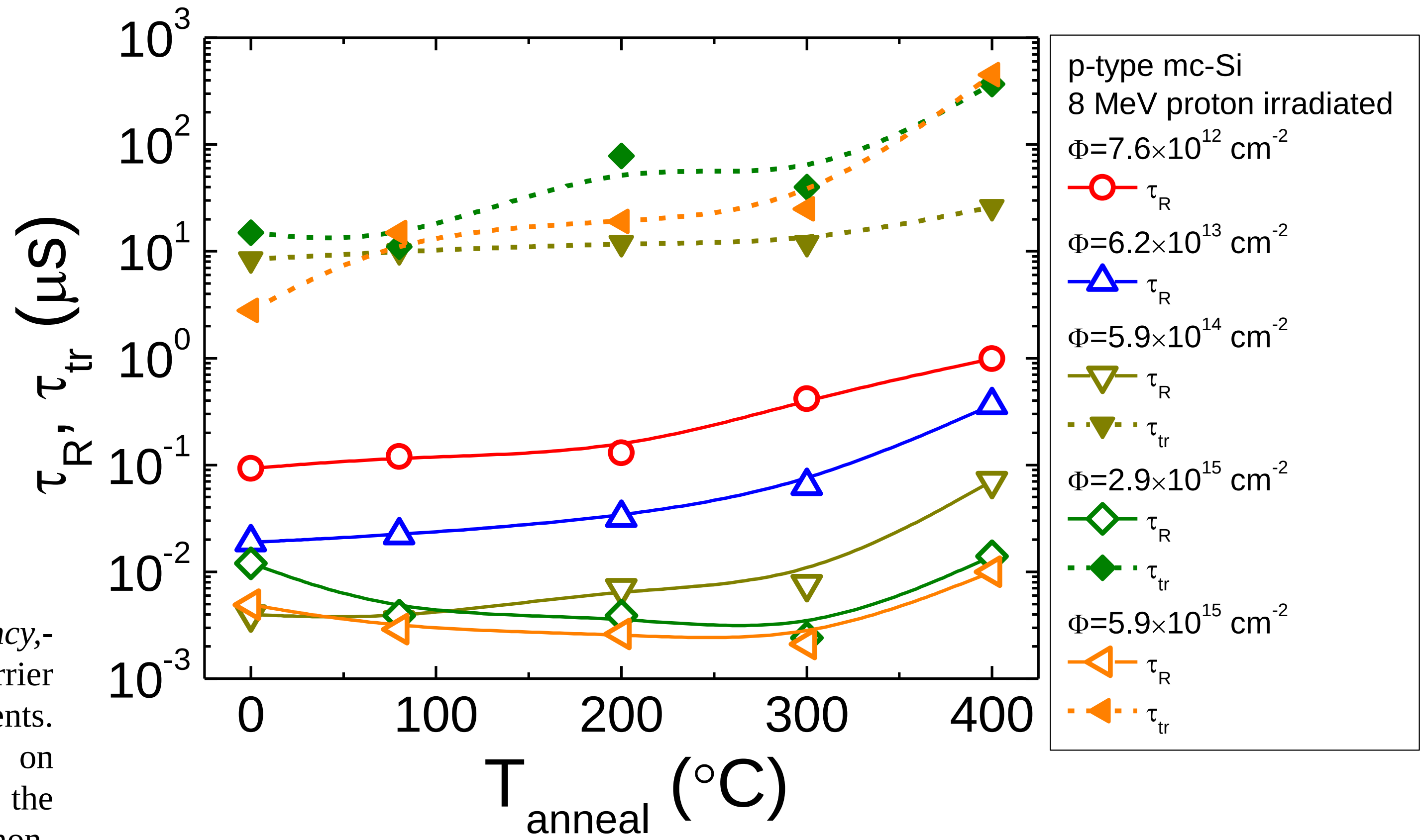
- In heavily irradiated mc-Si, anneals determine more complicated transforms of recombination centers while concentration of trapping centers increases:

- *Recombination centers* are responsible for carrier capture/ reduction of CCE;

- *Trapping centers* determine carrier thermal emission/ enhancement of leakage current



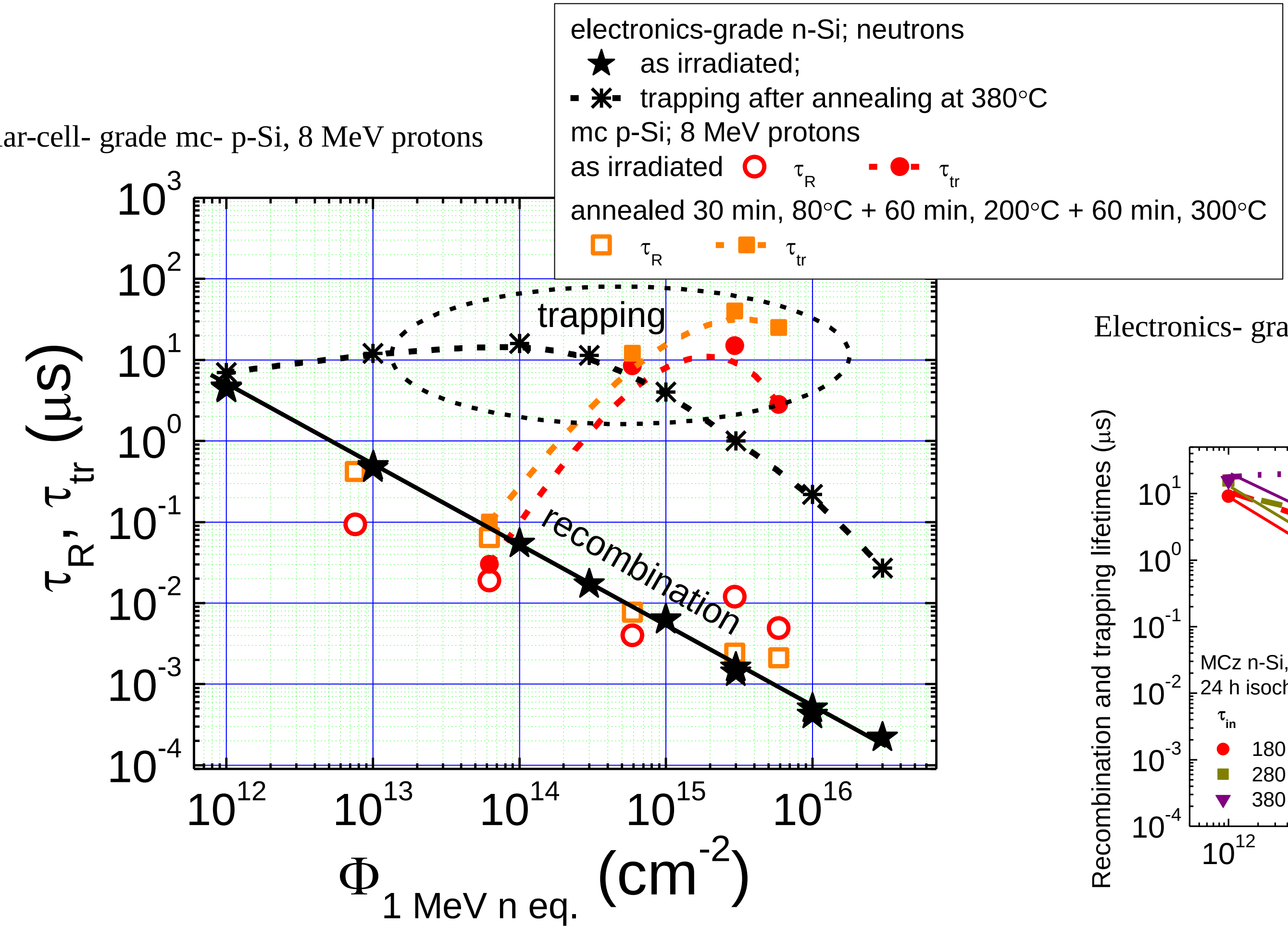
Anneal dependent τ_R & τ_{tr} in mc-Si



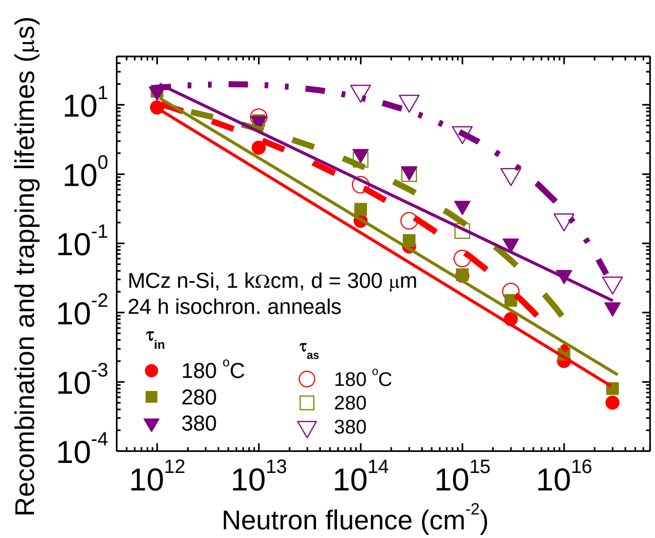
General tendency,- enhancement of carrier lifetime under heat treatments. However, it depends on irradiation fluence, and the increase of τ_R and τ_{tr} is non-monotonic, especially in the range of intermediate temperatures

Comparison of fluence dependent τ_R in mc-Si & eg-Si

Solar-cell- grade mc- p-Si, 8 MeV protons



Electronics- grade (eg) MCz n-Si, reactor neutrons



Conclusions

- SC standard mc-Si sensors suitable only for qualitative ranging of irradiation (appearance of trapping reduces precision of τ_R extraction)
- Rather big variations within fluence dependent τ_R in mc-Si due to initial material quality (trapping indicates intrinsic defects)
- Proton beam scan irradiation regime may be an additional reason for scattering of τ_R values (more homogeneous irradiation, e.g. reactor neutrons, would be desirable)

Acknowledgements

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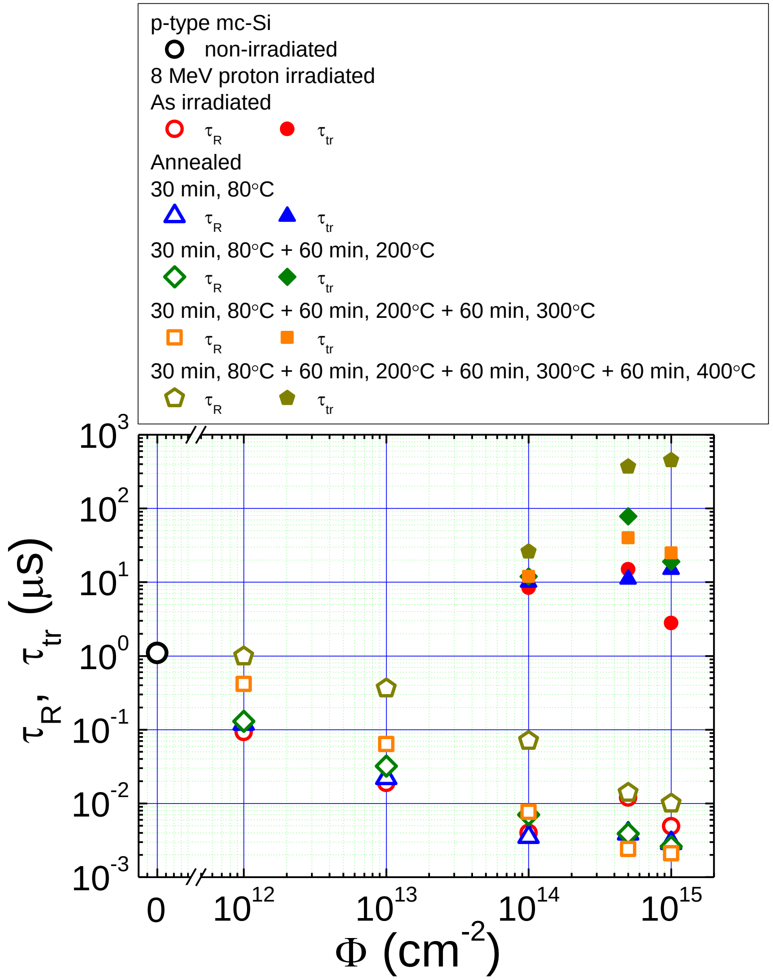
Thank you for attention!

Fluence and anneal temperature dependent variations of carrier lifetimes



Irradiation fluences and equivalence to 1 MeV neutrons

Sample	proton fluence (cm^{-2})	theoretical n-eqv fluence (cm^{-2})	experimental n-eqv fluence (cm^{-2})
1	1.29×10^{12}	7.61×10^{12}	3.74×10^{12}
2	1.06×10^{13}	6.25×10^{13}	3.07×10^{13}
3	1.00×10^{14}	5.90×10^{14}	2.90×10^{14}
4	5.00×10^{14}	2.95×10^{15}	1.45×10^{15}
5	1.00×10^{15}	5.90×10^{15}	2.90×10^{15}
8	1.29×10^{12}	7.61×10^{12}	3.74×10^{12}
9	1.06×10^{13}	6.25×10^{13}	3.07×10^{13}
10	1.00×10^{14}	5.90×10^{14}	2.90×10^{14}
11	5.00×10^{14}	2.95×10^{15}	1.45×10^{15}
12	1.00×10^{15}	5.90×10^{15}	2.90×10^{15}

Ref.: D. Bechevet et al. Nuclear Instruments and Methods A **479** (2002) 487.