AMORPHOUS SILICON CARBIDE REAR-SIDE PASSIVATION AND REFLECTOR LAYER STACKS FOR MJ SPACE SOLAR CELLS BASED ON GE SUBSTRATES

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44th IEEE PVSC, Washington D.C.,
26th-30th of June 2017

SiLaSpaCe

Fraunhofer
ISE

Motivation

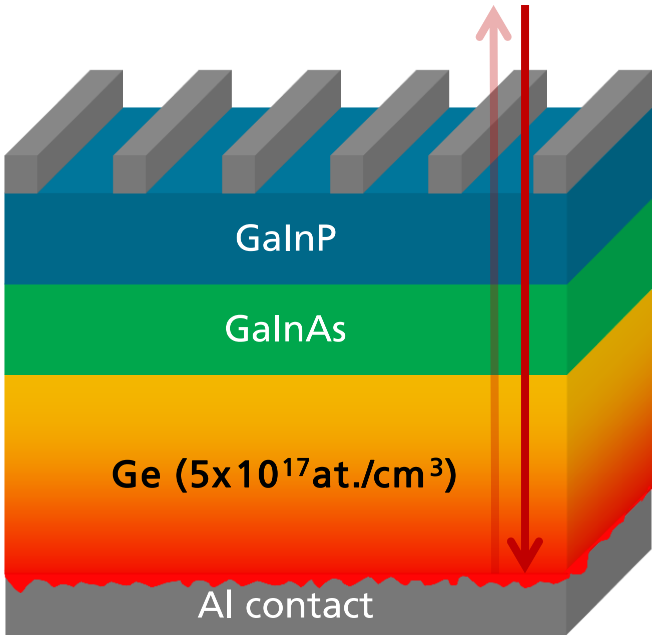
III-V Multi-Junction Space Solar Cell

Trends in III-V space solar cells

- Additional junctions
  - ➔ increase efficiency
- Thinner Ge cells
  - ➔ reduce weight

Demands for Ge substrate

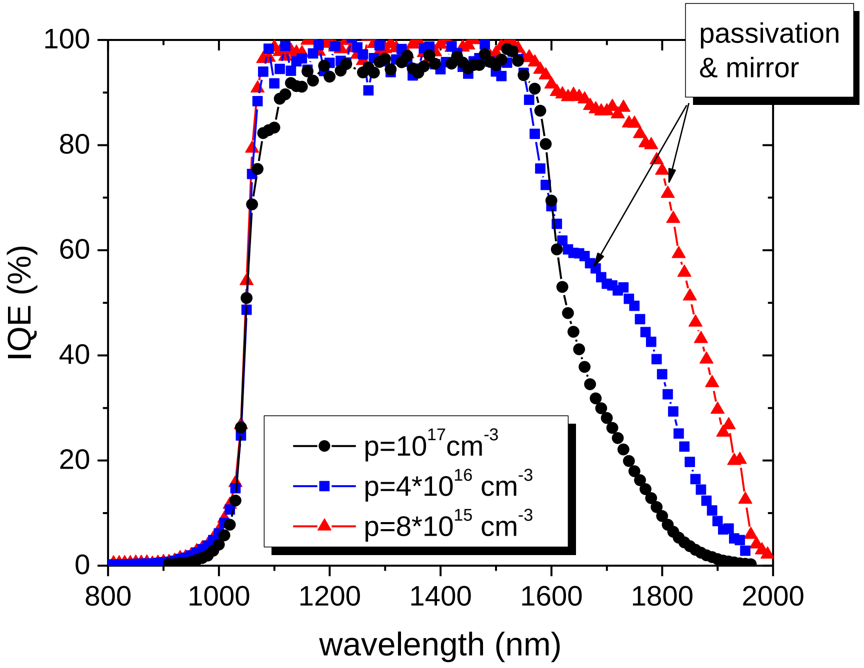
- Improved diffusion lengths
- Surface passivation



Motivation
III-V Multi-Junction Space Solar Cell

Project goals of SiLaSpaCe

- Decrease doping level of Ge
  - ➔ improve diffusion length
- Rear-side passivation (a-Si_xC_{1-x}:H) & Mirror layer (a-SiC:H)
  - ➔ increase overall current
  - ➔ reduce cell temperature

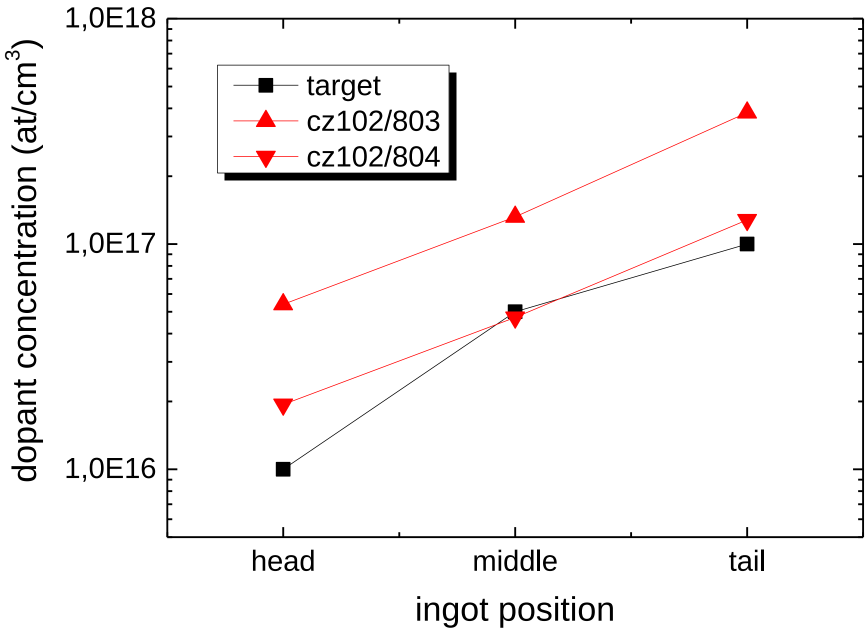


Content

- Fabrication of p-type Ge wafers with wide doping range
- Surface cleaning and passivation of Ge
- Accelerated aging with electrons

Germanium Wafer Fabrication
Crystallization with Dopant Gradient

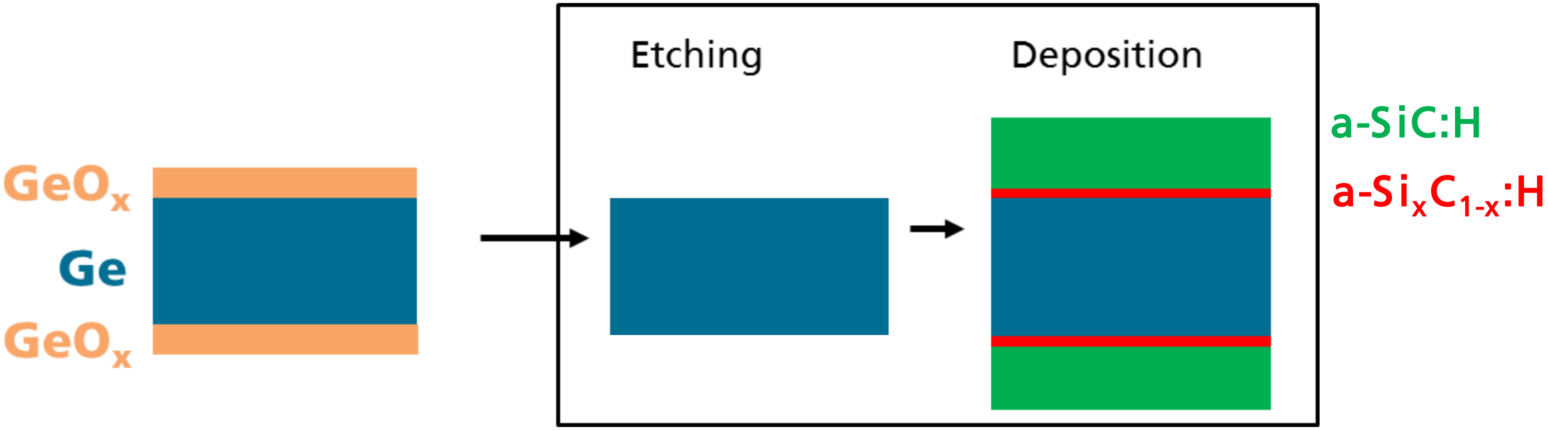
- Standard process for p-type:
  - constant Ga doping level in range of 10^{17} – 10^{18} at/cm³
- Doping gradient for project $1x10^{16}$ – $1x10^{17}$ at/cm³
- Coverage of whole doping range with 2 runs
- "high" ≈ $1x10^{17}$ at/cm³
  "middle" ≈ $6x10^{16}$ at/cm³
  "low" ≈ $2x10^{16}$ at/cm³



Surface Passivation of Ge

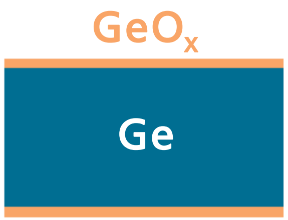
Preparation of “Lifetime” Samples

- Loading of samples “out-of-box”
- Plasma Enhanced Chemical Vapor Deposition / Etching (PECVD)
  - Gases: H_2, Ar, SiH_4, CH_4 (B_2H_6)
  - Temperature @ 270 °C



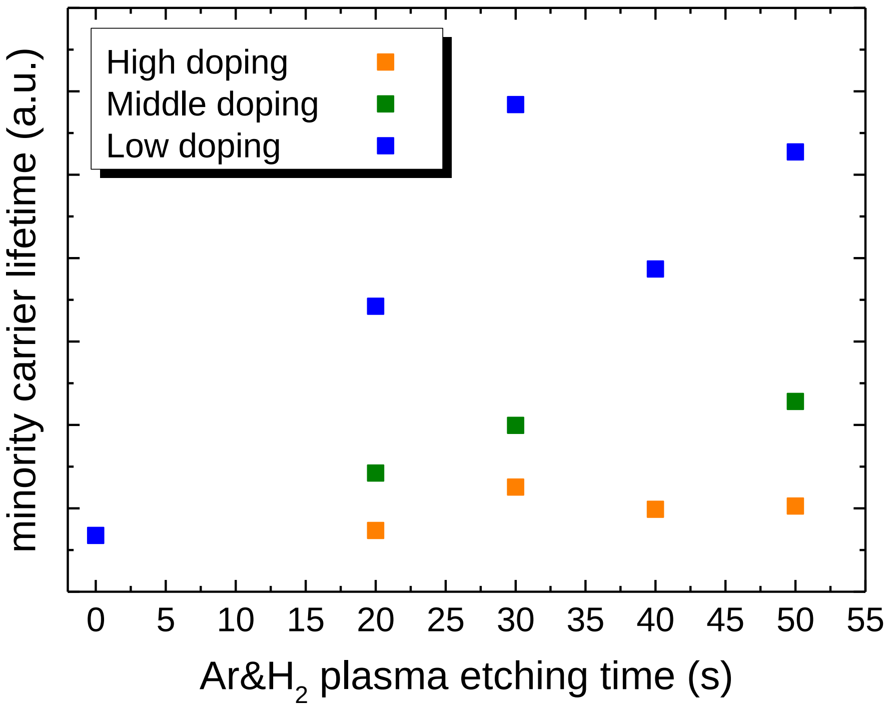
Surface Passivation of Ge

Plasma Etching of GeO_x

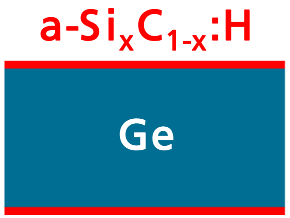


- Ar/H_2 as etching gases
- Variation of etching time
- Deposition of a-Si_xC_{1-x}:H layer

- Improvement up to 30 s
- No bulk damage?



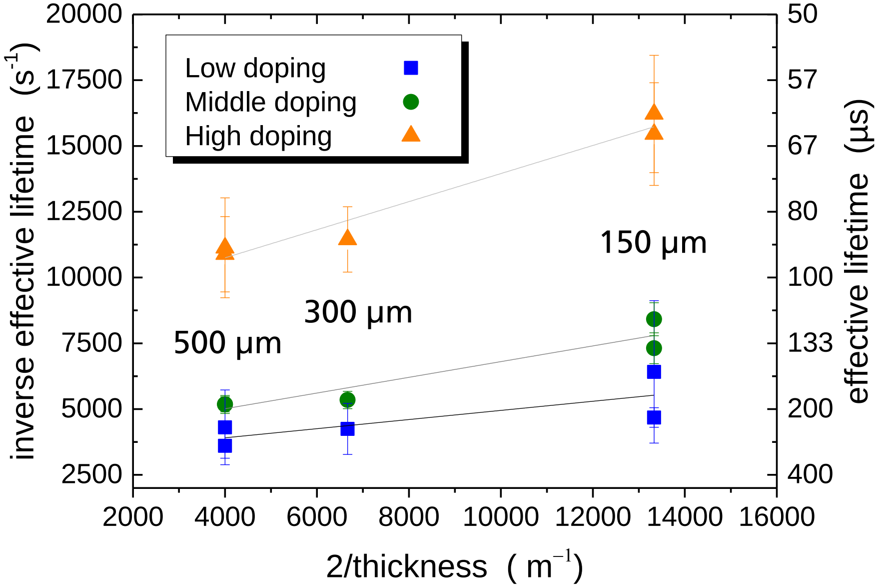
Surface Passivation of Ge
Minority Carrier Lifetimes



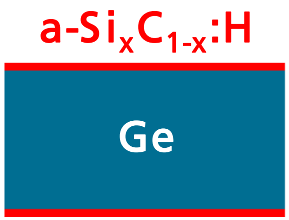
- Lifetime samples with
  W = 150 µm, 300 µm and 500 µm
- Extraction of τ_{bulk} and S_{eff}

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_{bulk}} + \frac{2}{W} \times S_{eff}$$

doping level	S_{eff} (cm/s)	τ_{bulk} (µs)
low	17	311
middle	30	262
high	53	116



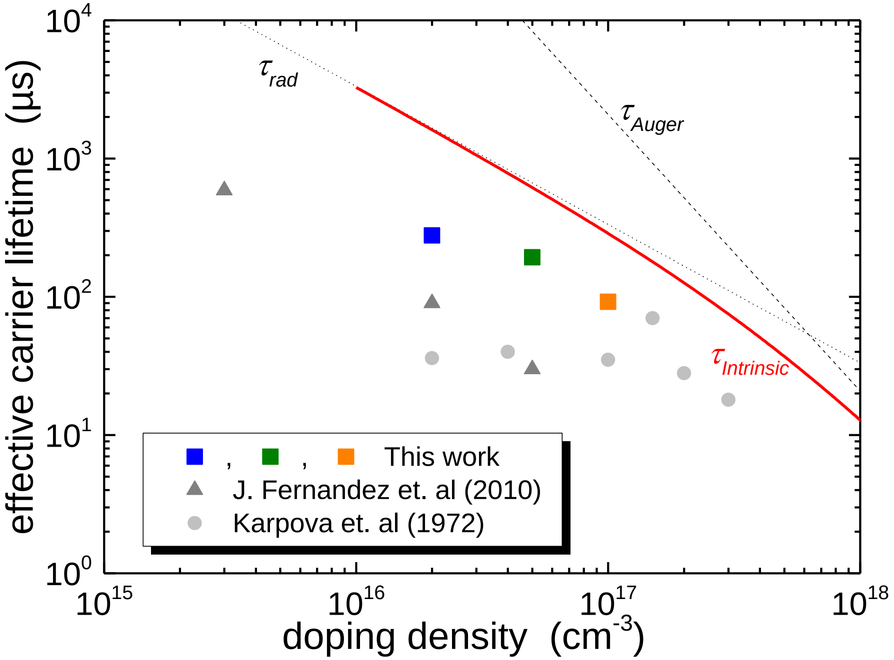
Surface Passivation of Ge
Minority Carrier Lifetimes



$a\text{-}Si_xC_{1-x}:H$

Ge

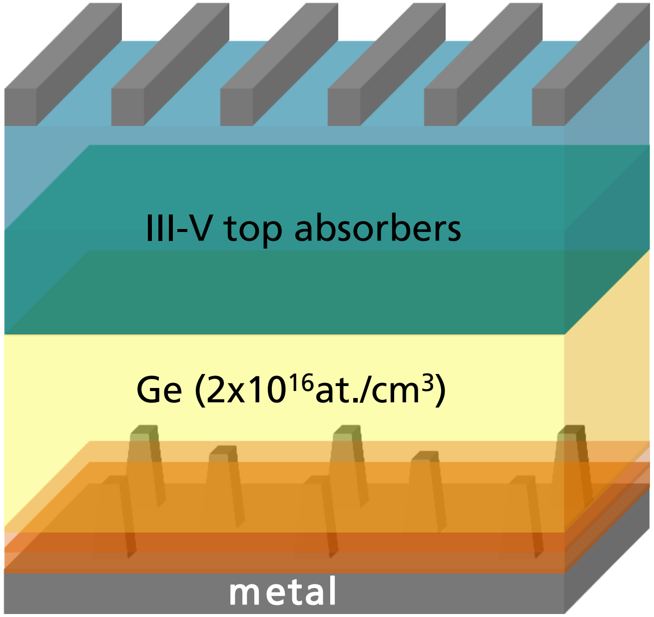
- τ_{eff} measured already close to theoretical limit
- Best reported values in this doping range



Surface Passivation of Ge

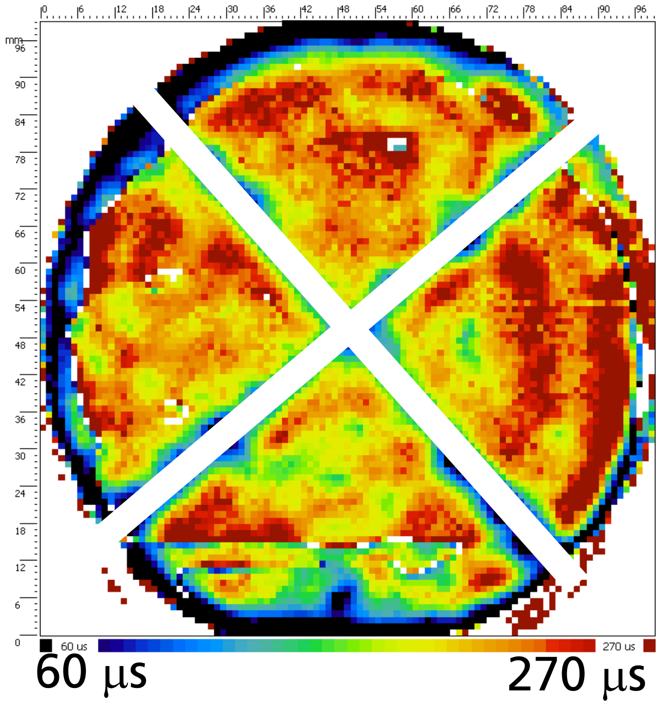
Thermal Annealing

- Motivation
  - Processes integration
  - Understanding of passivation mechanism
- Experiment:
  - Temp. = 400 °C – 500 °C
  - Time = 5 – 30 min
  - Laboratory atmosphere



Surface Passivation of Ge

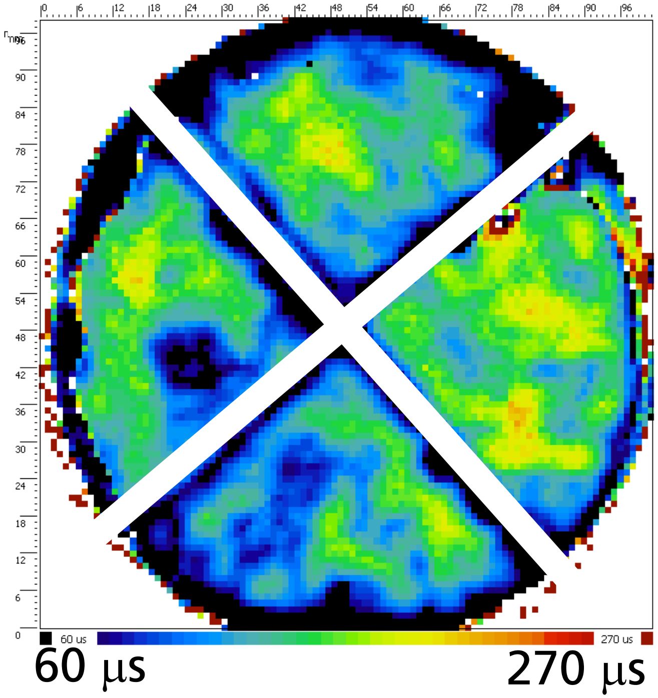
Thermal Annealing @ 500 °C



Surface Passivation of Ge
Thermal Annealing @ 500 °C

- 5 min leads to lifetime decrease of ≈ 100 µs
- Blistering effects on surface visible

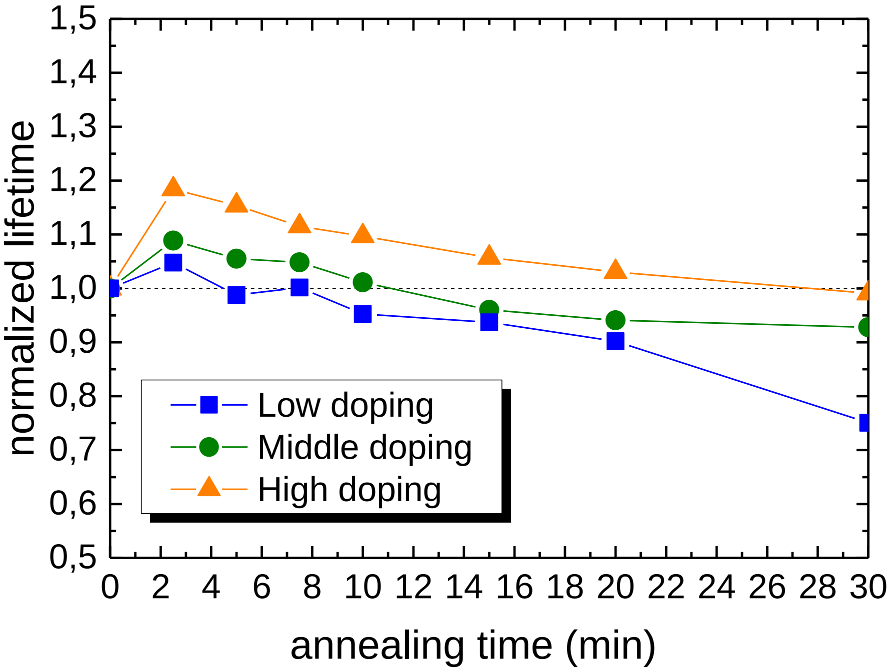
→ Effusion of hydrogen



Surface Passivation of Ge
Thermal Annealing @ 400 °C

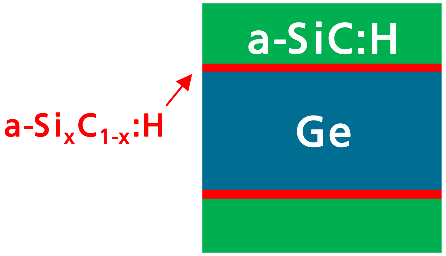
- ≤ 10-15 min positive trend

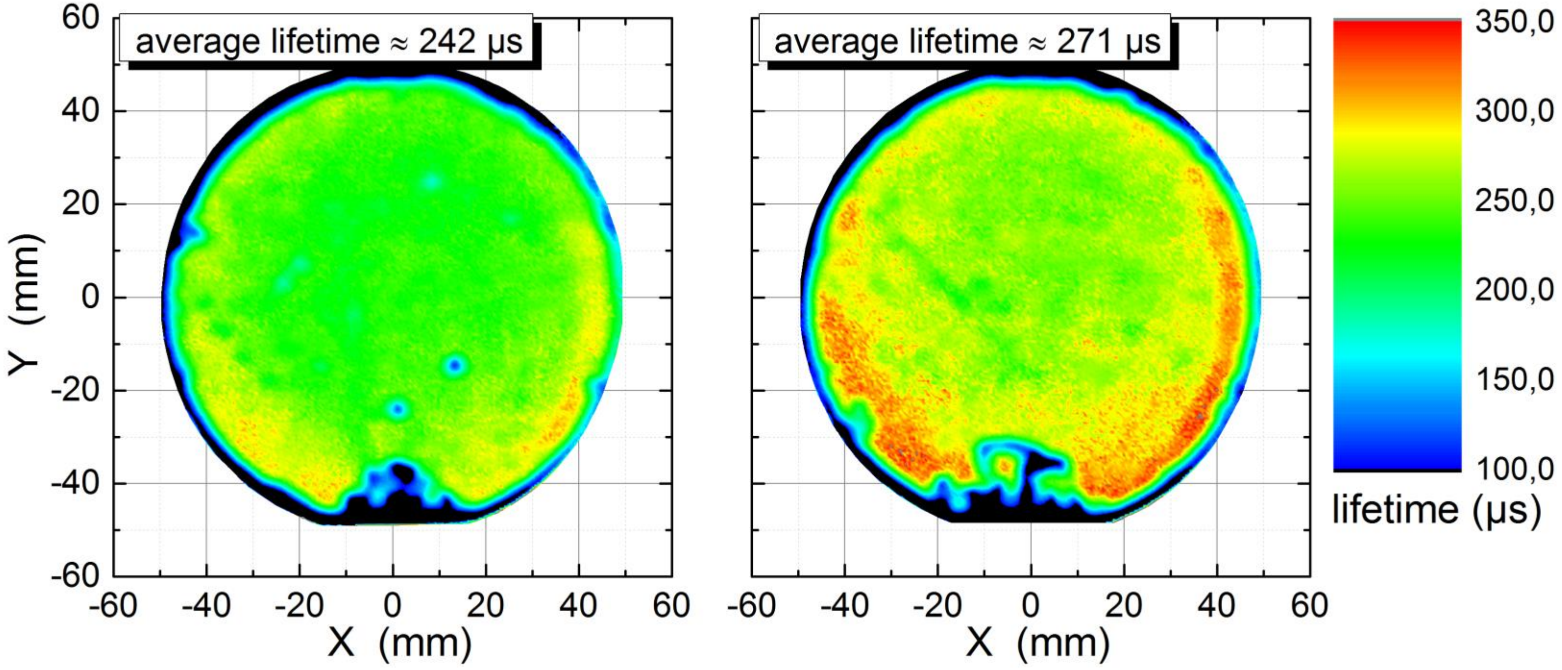
→ No degradation expected for contact annealing



Surface Passivation of Ge

Mirror Layer Deposition



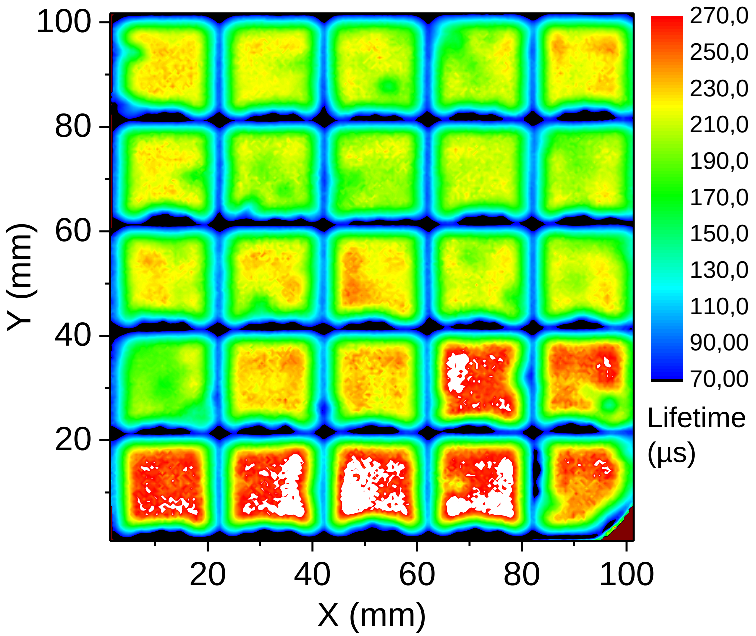


- Deposition of SiC mirror layer (100 – 200 nm) + annealing

➔ Doped mirror layer leads to improved lifetimes

Accelerated Aging
Electron Irradiation

- Motivation
  - Sufficient diffusion lengths after irradiation?
- > 100 samples prepared with variation of
  - Ge bulk doping
  - Mirror layer thickness
  - Mirror layer doping
  - Thermal annealing



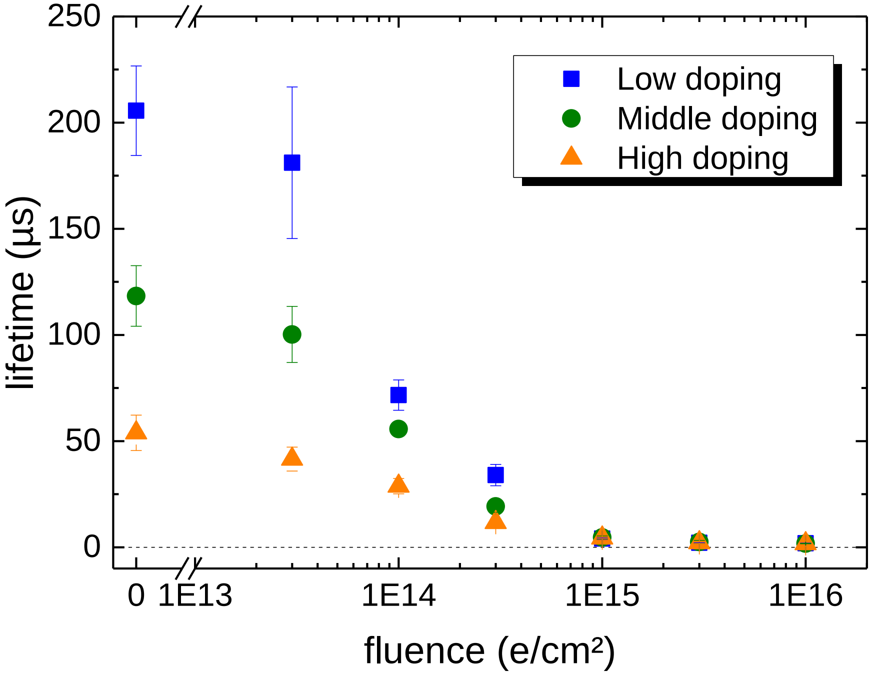
total fluence (e/cm^2)	3x10^{13}	10^{14}	3x10^{14}	10^{15}	3x10^{15}	10^{16}

Accelerated Aging
Electron Irradiation

- Strong degradation from $1x10^{14}$ e/cm² and higher
- All Ge samples reach similar level at $1x10^{15}$ e/cm²

→ Realistic irradiation condition?

→ Photon annealing?



Prince, M. B. (1953): Drift mobilities in semiconductors; Ge. In: *Phys. Rev.* 92 (3), S. 681–687.

Summary

- Plasma process for surface cleaning and passivation of Ge wafers works very well
- Thermal stability up to 400 °C
- Implementation of mirror layer successful
- Surface passivation effect not verified so far
- Electron irradiation effect mainly dependent on dopant level in Ge

Acknowledgements

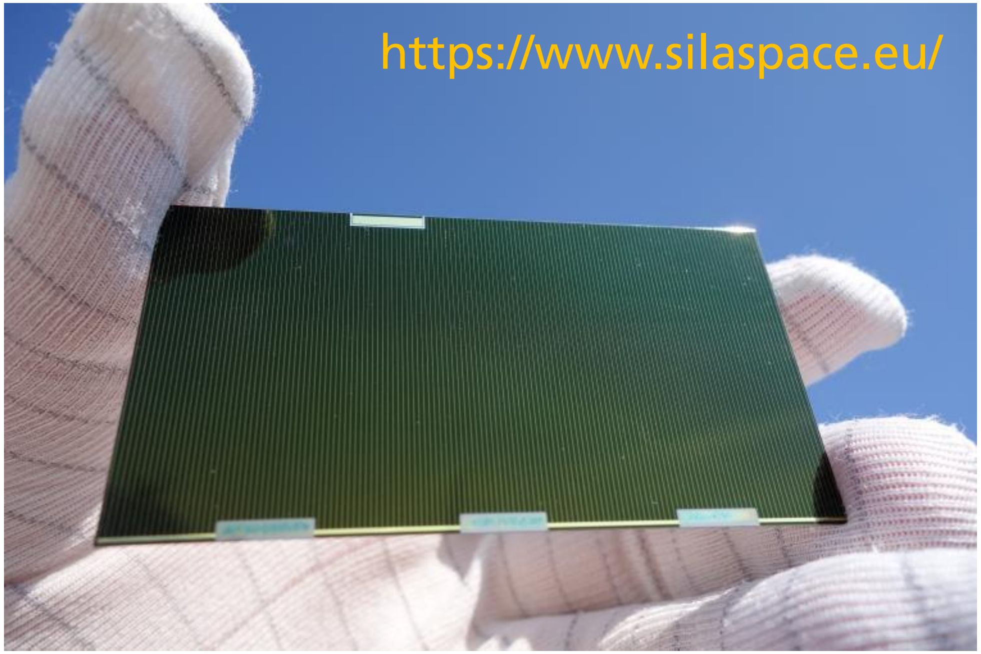
- Thanks to F. Dimroth and E. Oliva for fruitful discussions

- This work has received funding from the European Union’s Horizon 2020 research and innovation programme within the project SiLaSpaCe under grant agreement No 687336

Funded by
the European Union

Thank you for your attention!

SiLaSpaCe



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