Dose rate and temperature dependence of ion-beam-induced defect evolution in germanium

related publication:

Posselt, M.; Bischoff, L.; Grambole, D.; Herrmann, F.
Competition between damage buildup and dynamic annealing in ion implantation into Ge
Appl. Phys. Lett. **89** (2006) 151918

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Motivation

investigation of the competing influence of dose rate and implantation temperature on defect evolution, i.e. the competition between damage buildup and dynamic annealing

consideration of channeling implantation:
damage *and* range profiles are influenced by defect evolution

Experiment

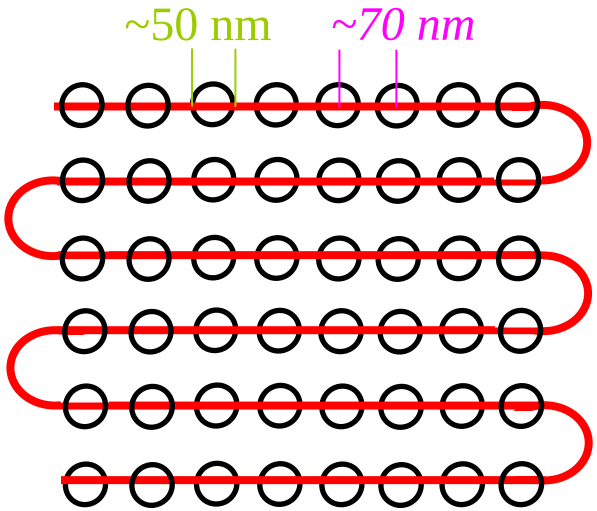
Focused Ion Beam (FIB) system

nominal dose rate: ~10^{19} cm^{-2} s^{-1}

30 keV Ga implantation into (001) Ge

beam spot size (pixel): ~ 50 nm

meander-like beam scan



*variation of the **effective dose rate**:*

change of the pixel dwell time (PDT) and/or the area over which the FIB is scanned

direction of ion beam: **0^0 tilt ([001] channeling)**

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implantation at two very different effective dose rates:

each pixel was irradiated only once, effective dose rate **~ 10^{19} cm^{-2} s^{-1}**

a constant PDT of ~1 μs was applied,
the desired dose was achieved by many repetitions of the beam scan,
effective dose rate ***~ 10^{11} cm^{-2} s^{-1}***

implantation temperatures: ***RT*** *and* ***250 ^{0}C***

doses: 5×10^{12} ... 5×10^{14} cm^{-2}

analysis: *damage profiles: micro-RBS/C (Rossendorf)*
Ga profiles: SIMS (Evans Analytical Group)

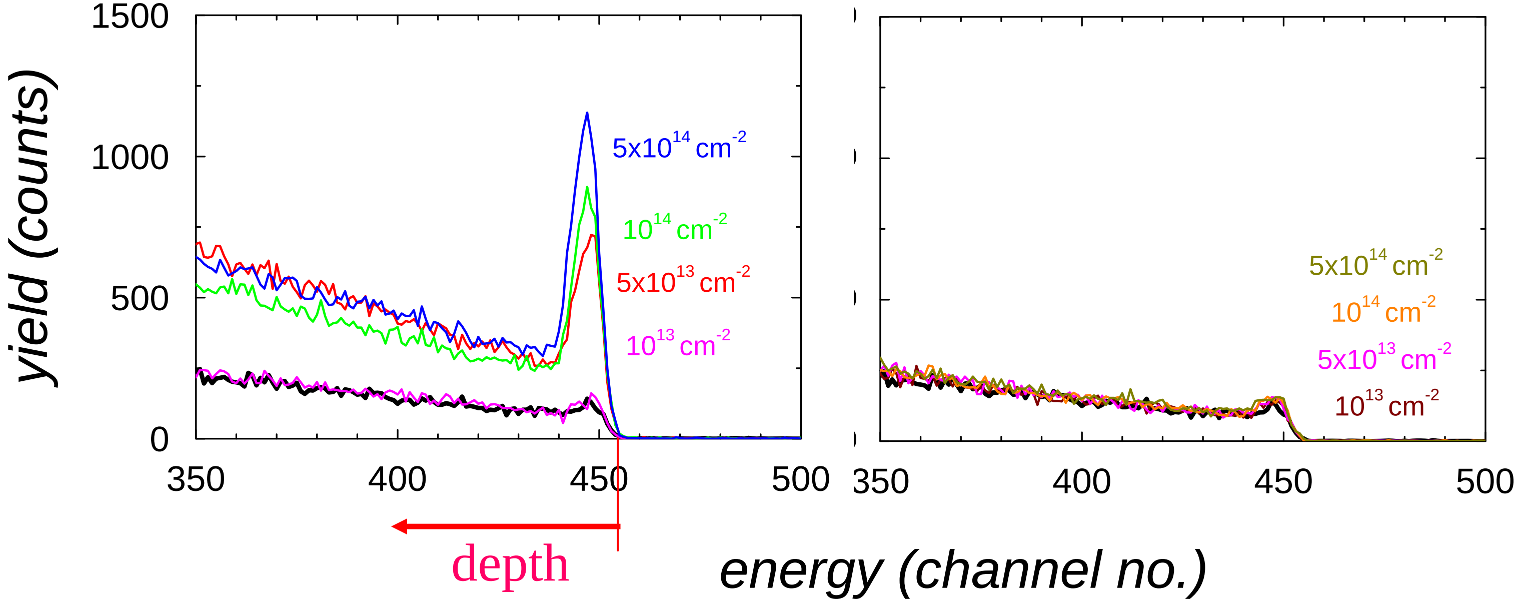
Results and discussion

250 ^{0}C

30 keV Ga implantation into (001) Ge,
0^0 tilt **([001] channeling)**

micro-RBS/C data

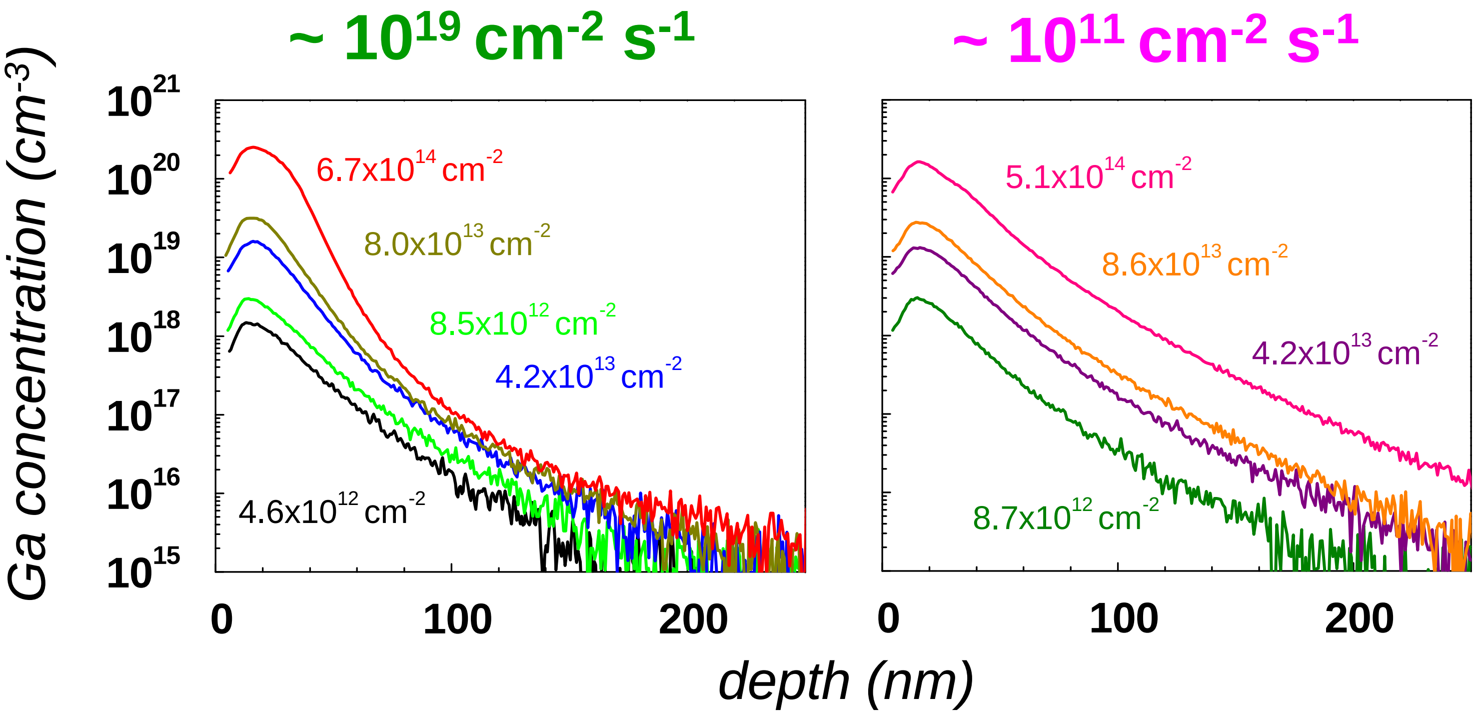
~ 10^{19} cm^{-2} s^{-1} **~ 10^{11} cm^{-2} s^{-1}**



damage buildup

dynamic annealing

SIMS data



damage buildup

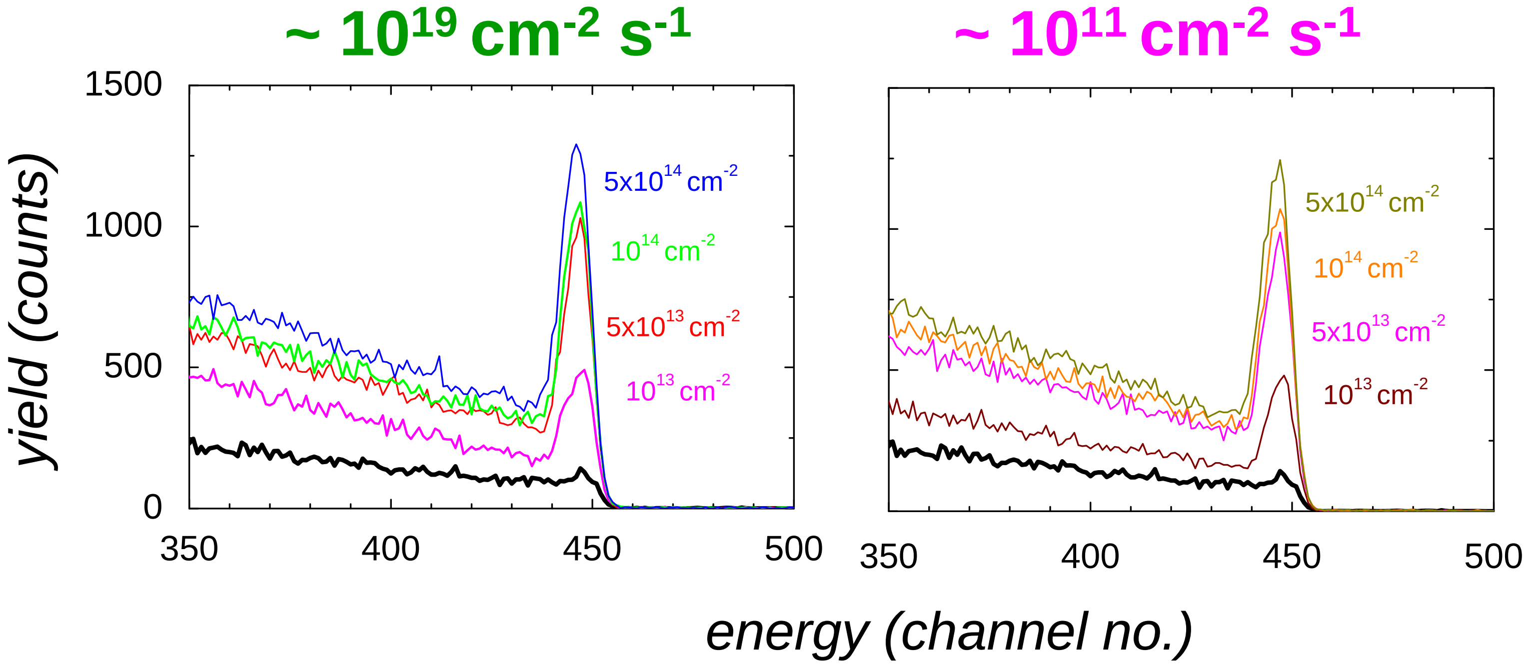
dynamic annealing

→ dose dependence of the shape of Ga profiles

RT

30 keV Ga implantation into (001) Ge, 0^0 tilt **([001] channeling)**

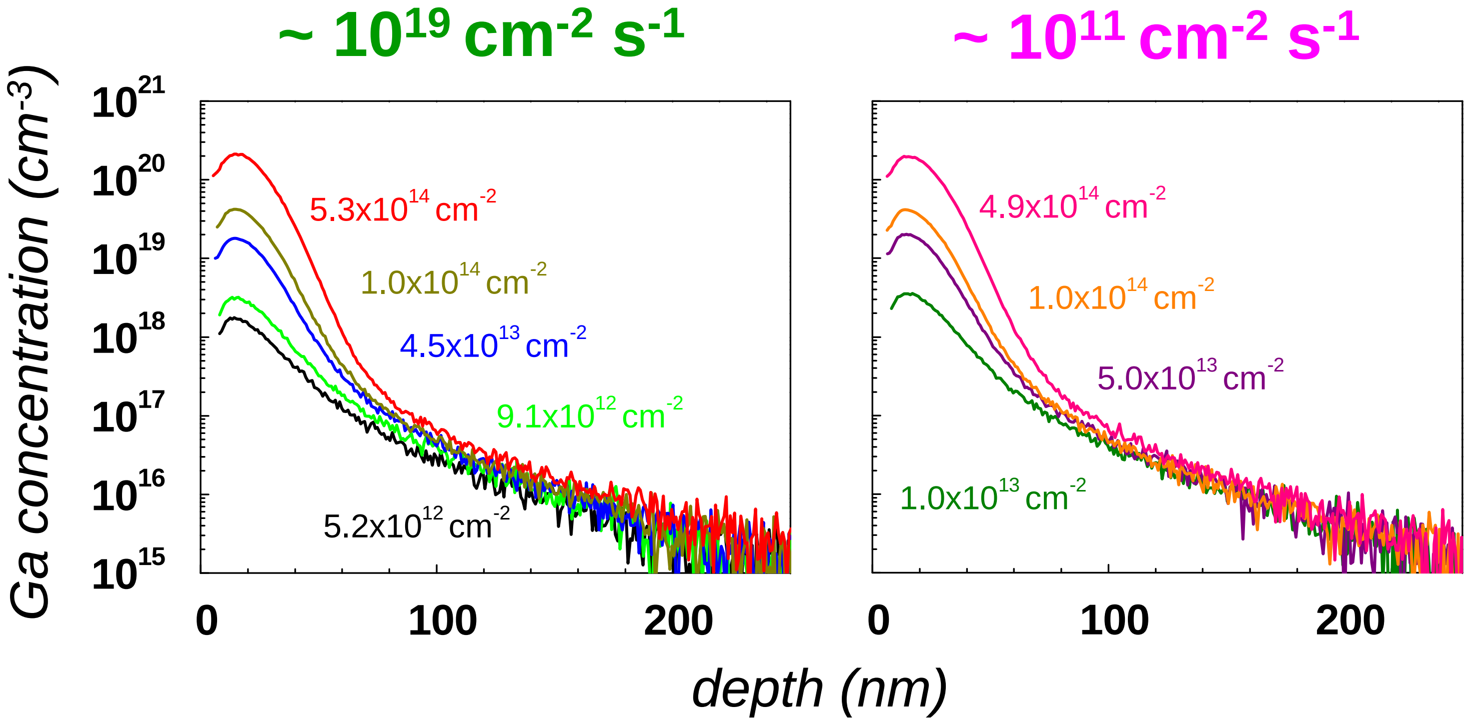
micro-RBS/C data



damage buildup

damage buildup

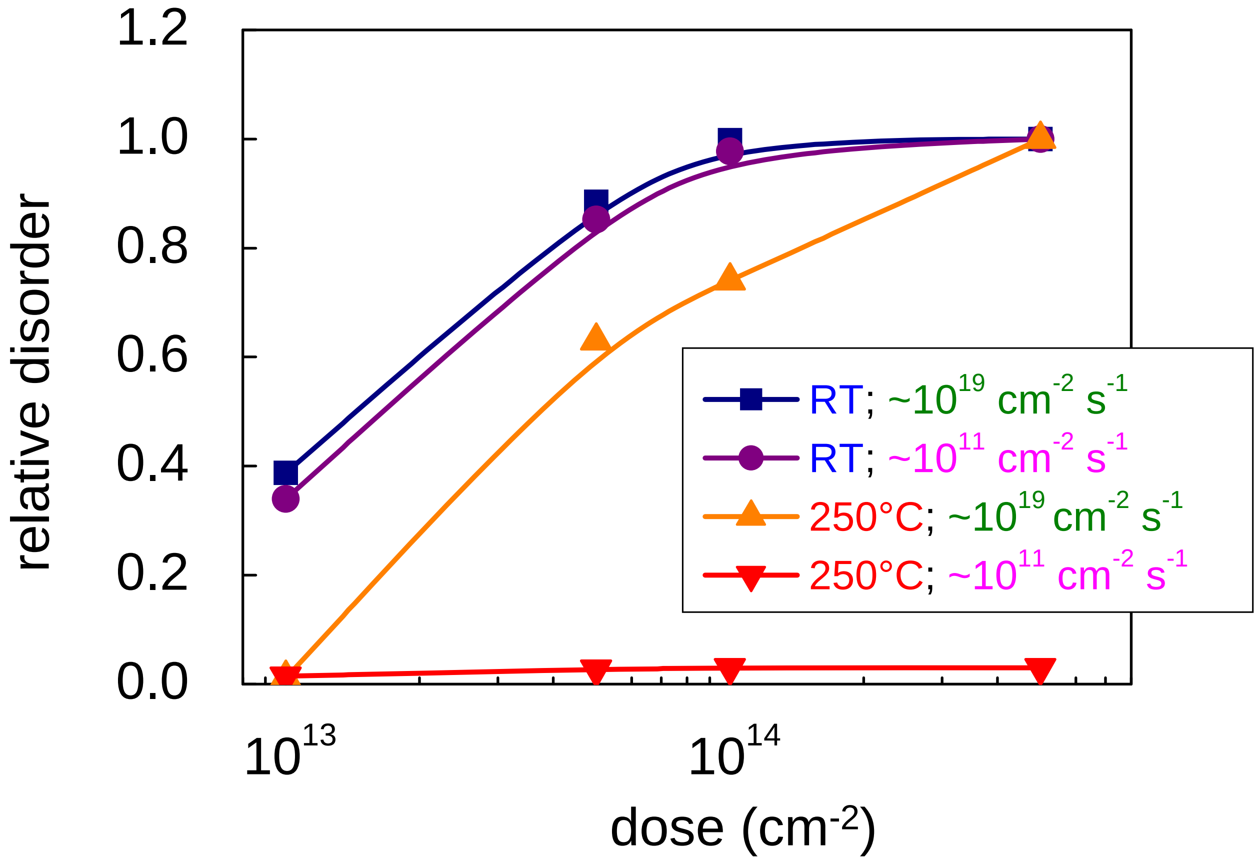
SIMS data



damage buildup

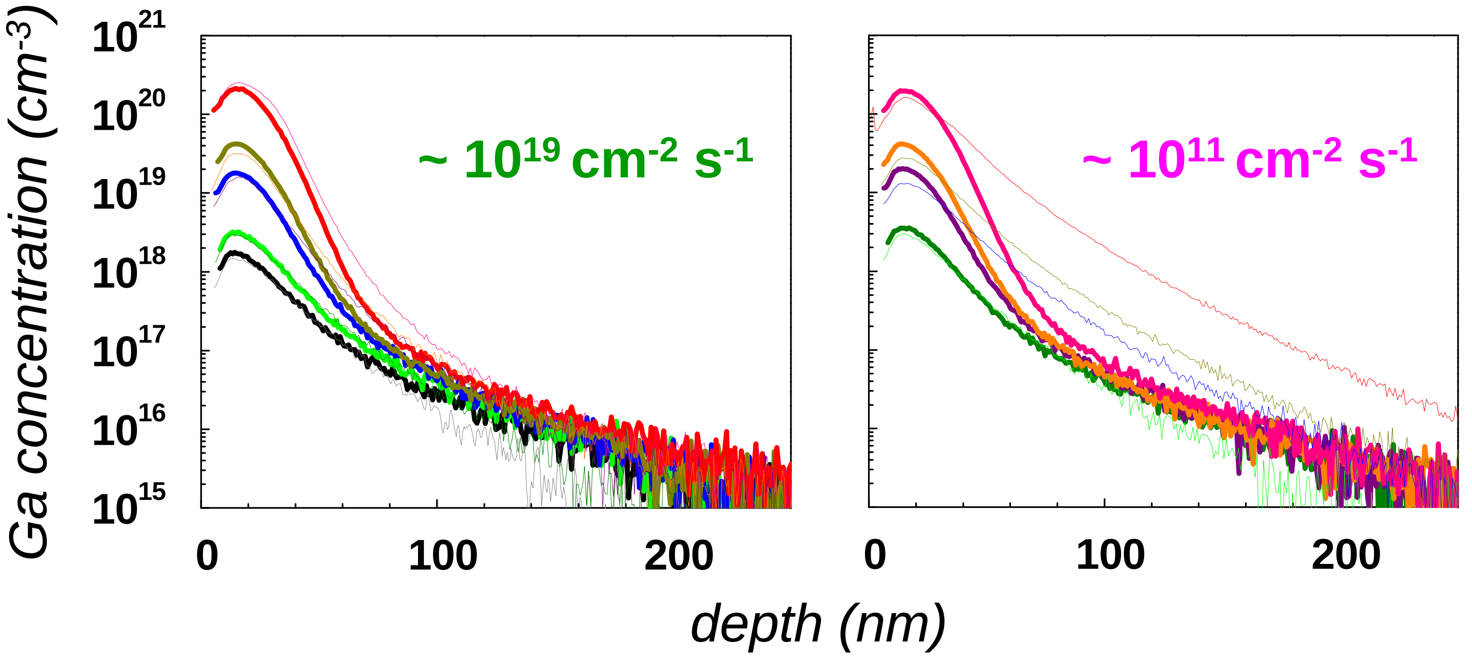
→ dose dependence of the shape of Ga profiles

summary of micro-RBS/C data



dependence on effective dose rate and temperature

summary of SIMS data



thick lines:

RT

thin lines:

250 ^{0}C

dependence on effective dose rate and temperature

local defect reduction between consecutive ion impacts

characteristic lateral cross-section of a damaged region:

target region (with cross section σ_0) where the amount of nuclear energy deposition per atom is larger than a critical value E_c

$$\sigma_0 = \frac{S_n}{E_c}$$

$E_c \sim 5$ eV: **$5\ \mathrm{nm}^2$**

period between consecutive ion impacts into the same region:

$$\tau_i = \frac{1}{\dot{D}\,\sigma_0}$$

$10^{19}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$: 1 µs **$10^{11}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$: 100 s**

RT:
no defect reduction between
1 µs and 100 s

250^0C:
complete defect reduction
between 1 µs and 100 s;
defect lifetime less than 100 s

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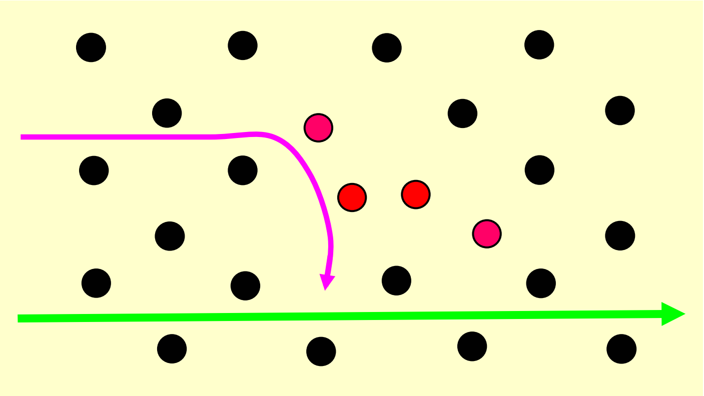
Atomistic simulation of Ga range profiles

using the Crystal-TRIM code

phenomenological model
for damage buildup
and dynamic annealing

$$p_d(E_n^A)$$

dechanneling
due to **damage buildup**

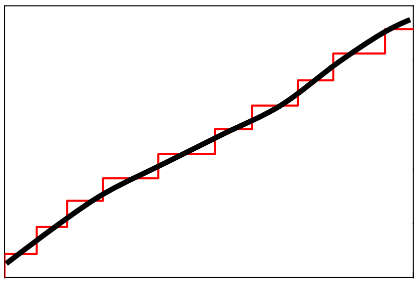


p_d	probability that in a certain volume element the ion collides with a target atom of a damaged region
E_n^A	nuclear energy deposition per target atom in a certain volume element *(ballistic processes)*

(atomic) damage probability

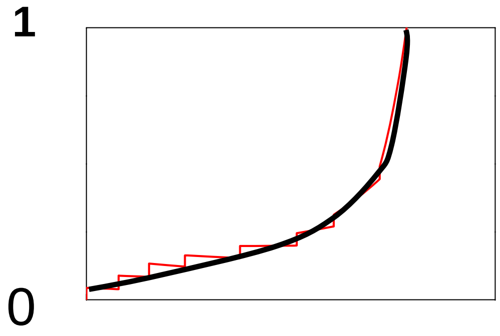
nuclear energy deposition per atom

$E_n^A(t)$

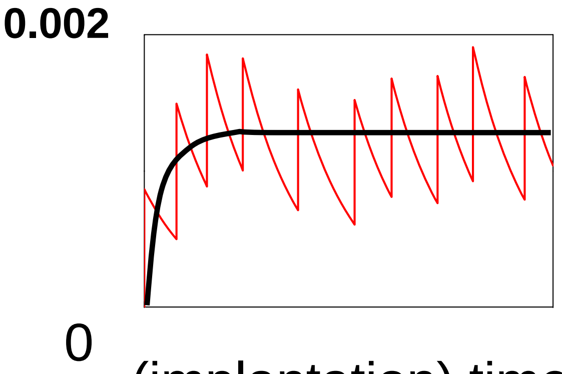


$p_d(t)$

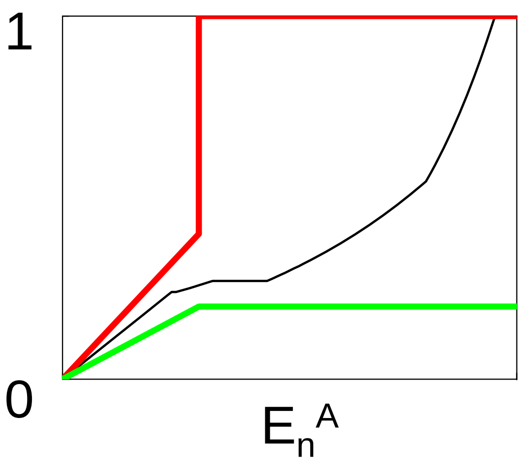
damage buildup



dynamic annealing



$p_d(E_n^A)$



***only 2 parameters**, dependent on:*

- *ion species*
- *temperature*
- *dose rate*

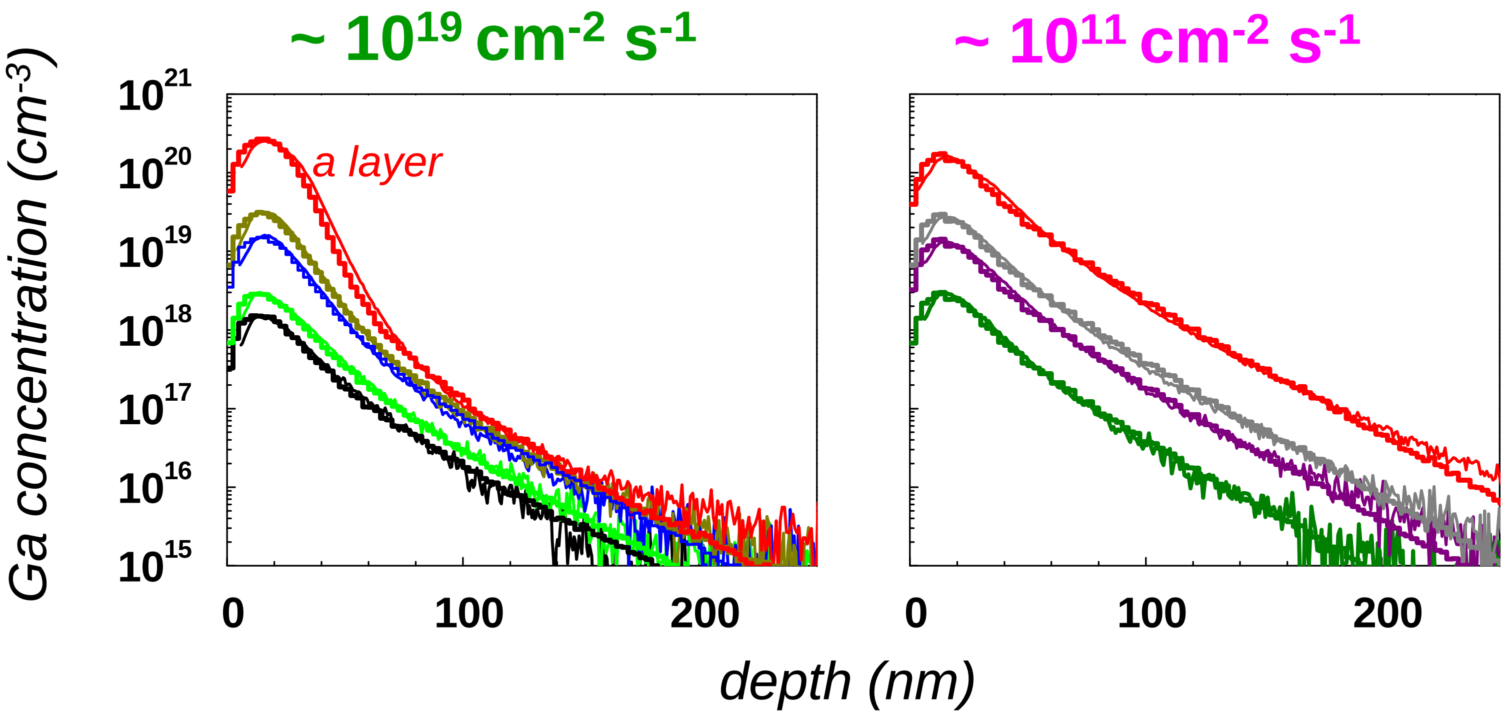
linear increase: C_a

damage level after a single ion impact (per E_n^A)

simulation results

250 ^{0}C

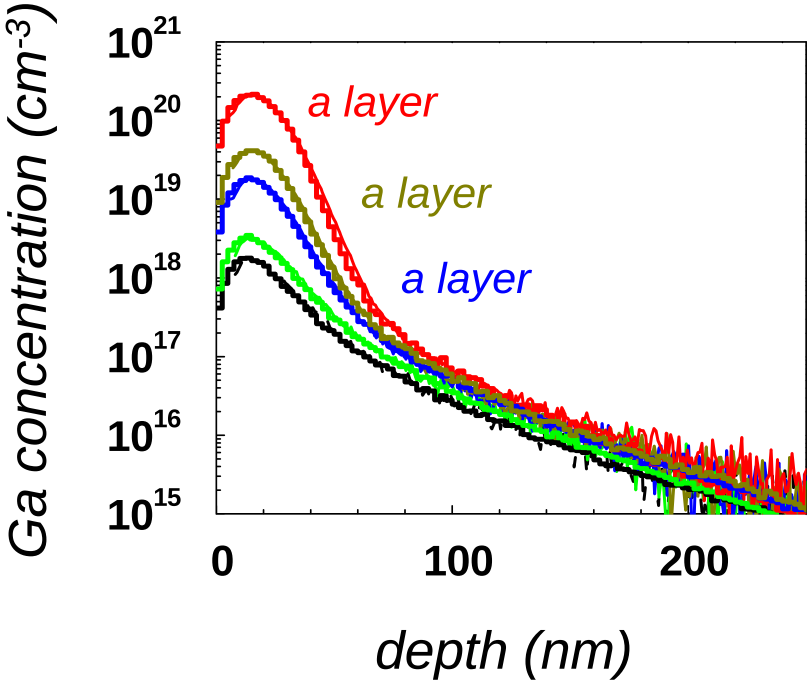
30 keV Ga implantation into (001) Ge,
0^0 tilt **([001] channeling)**



RT

30 keV Ga implantation into (001) Ge, 0^0 tilt **([001] channeling)**

$\sim 10^{19}$ cm^{-2} s^{-1}



comparison with results for Si and SiC

Appl. Phys. Lett. 79, 1444 (2001)

J. Appl. Phys. 93, 1004 (2003)

damage level

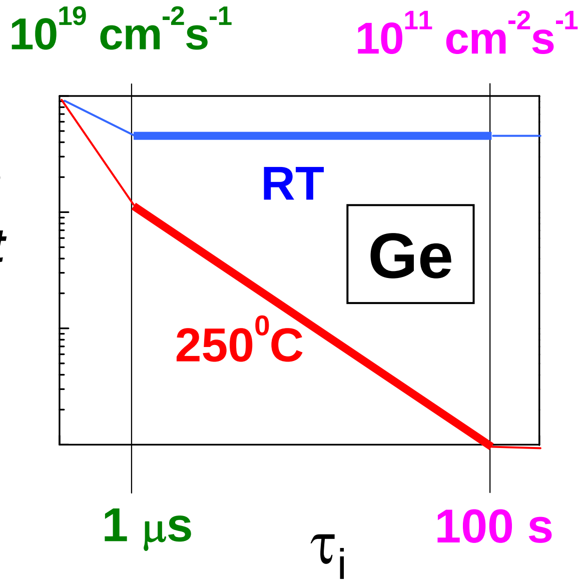
per eV nuclear energy deposition

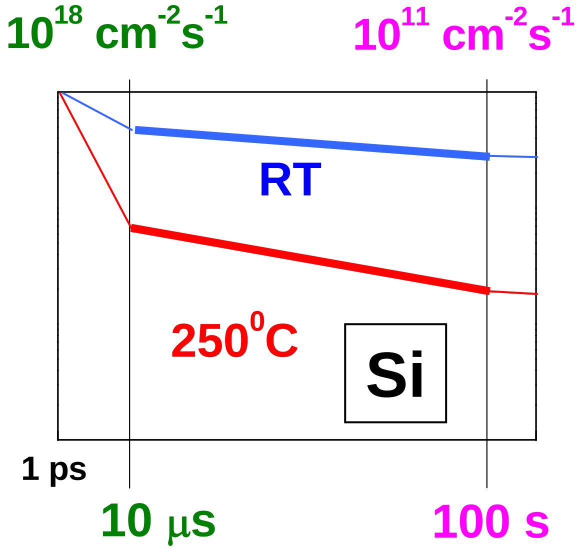
after a single ion impact

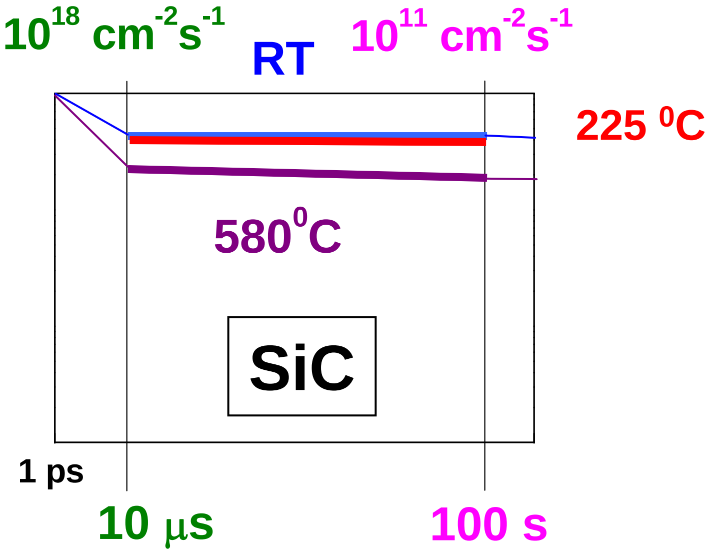
into a perfect crystal

in units of lg (C_a)

vs.time







Conclusions

competition between damage buildup and dynamic annealing was studied by the dose rate and temperature dependence of range and damage profiles obtained by channeling implantation

time scale for dynamic annealing was estimated

range profiles could be reproduced by atomistic computer simulations that employ a phenomenological model for damage buildup and dynamic annealing

compared to Si and SiC, dynamic annealing in Ge occurs in a narrower temperature range

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for SIMS measurements and helpful discussions