Ga contamination in silicon by Focused Ion Beam milling: Dynamic model simulation and Atom Probe Tomography experiment

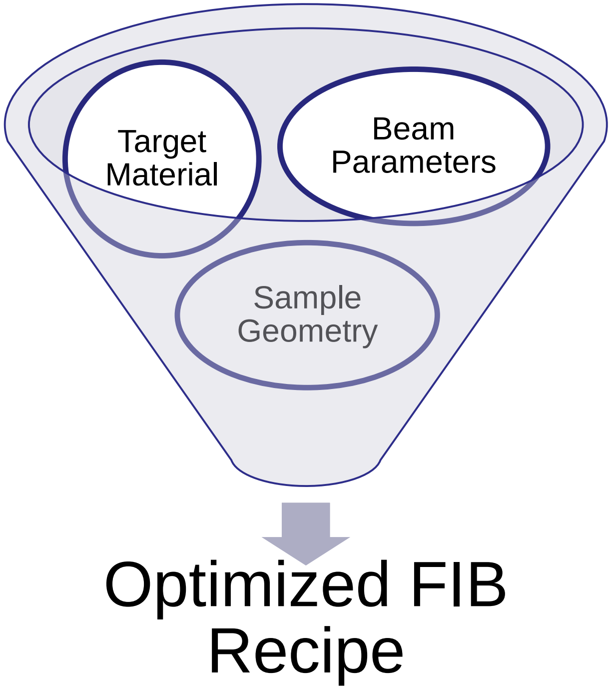
Jin Huang[1], Markus Löffler[1], Wolfhard Moeller[2], and Ehrenfried Zschech[3]

[1]Dresden Center for Nanoanalysis, cfaed, TU Dresden
[2]Helmholtz-Zentrum Dresden-Rossendorf
[3]Fraunhofer IKTS

HALLE (SAALE), Germany, September 19-22, 2016

Objectives

- Thin/Ultra-thin lamellae are increasing needed, so are optimized Focused Ion Beam recipes.
- Recipes are material/beam dependent. Inexperienced users are unlikely to make such lamellae.
- FIB recipes are empirical or based on simple calculations. Design of experiment cycle is long.
- Develop a physical model that can describe the FIB process. Outcomes can be estimated.



Outline

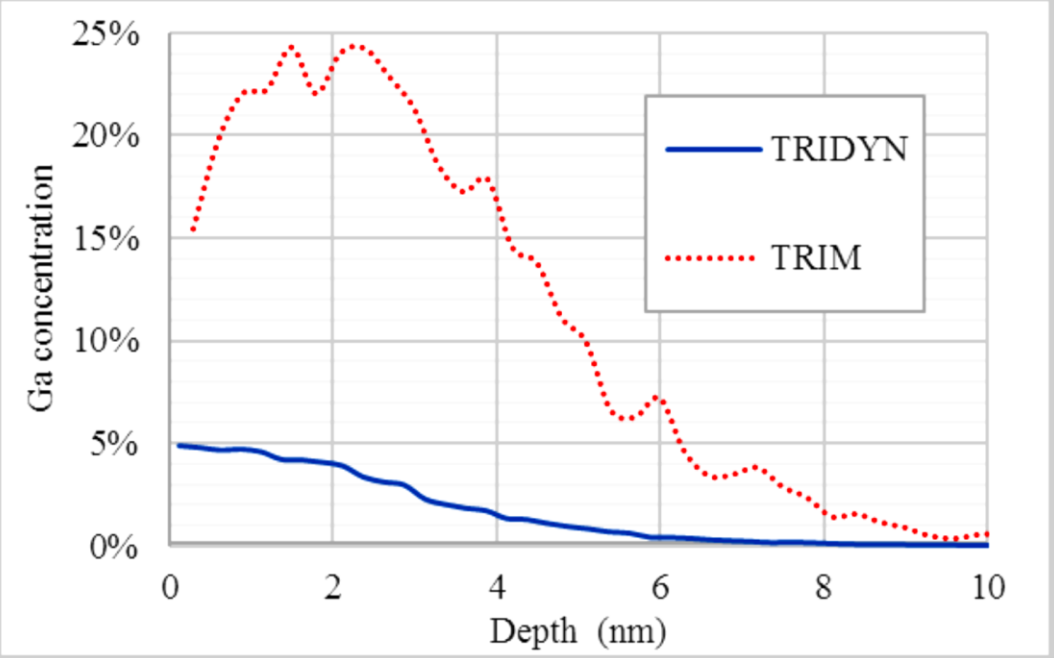
- Dynamic Binary Collision Approximation
  - Brief introduction on Binary Collision Approximation
  - Its application on Focused Ion Beam
- Atom Probe Tomography
  - Experiment design
  - Results
- Discussion and conclusion between the simulation and experiment

Dynamic Binary Collision Approximation

- BCA is widely used for ion implantation simulation
  - Ion doping concentration prediction
  - Provides a fast and economic approach to simulate ion-solid interaction
  - Simulation Package: **TRIM**
- Dynamic BCA model is able to treat the dynamic alterations of local composition which arise from the ion implantation
  - Simulation package: **TRIDYN**
- Previously, TRIDYN has been used to calculate the sputter yield during high-dose ion processes for semiconductor manufacturing purpose.
- Focused Ion Beam is a typical **high-dose ion implantation process**. In this work, TRIDYN is used to describe the FIB process and the predicted Ga concentration is evaluated.

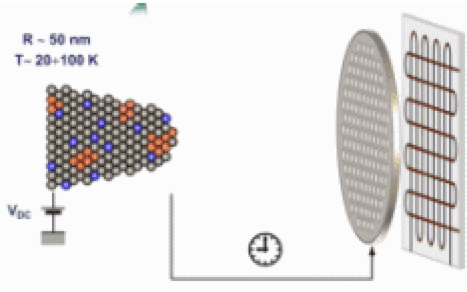
Dynamic Binary Collision Approximation

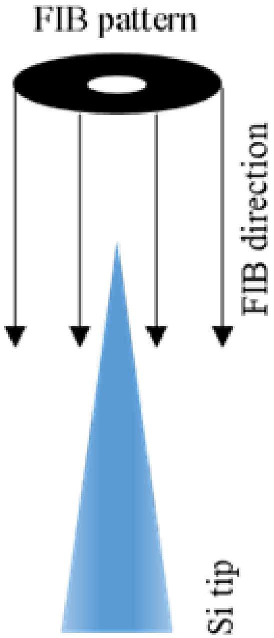
- 1D simulation
- Pure Si substrate
- 5kV Ga ions
- 7˚ glancing
- Dose:1 ion/Å^2

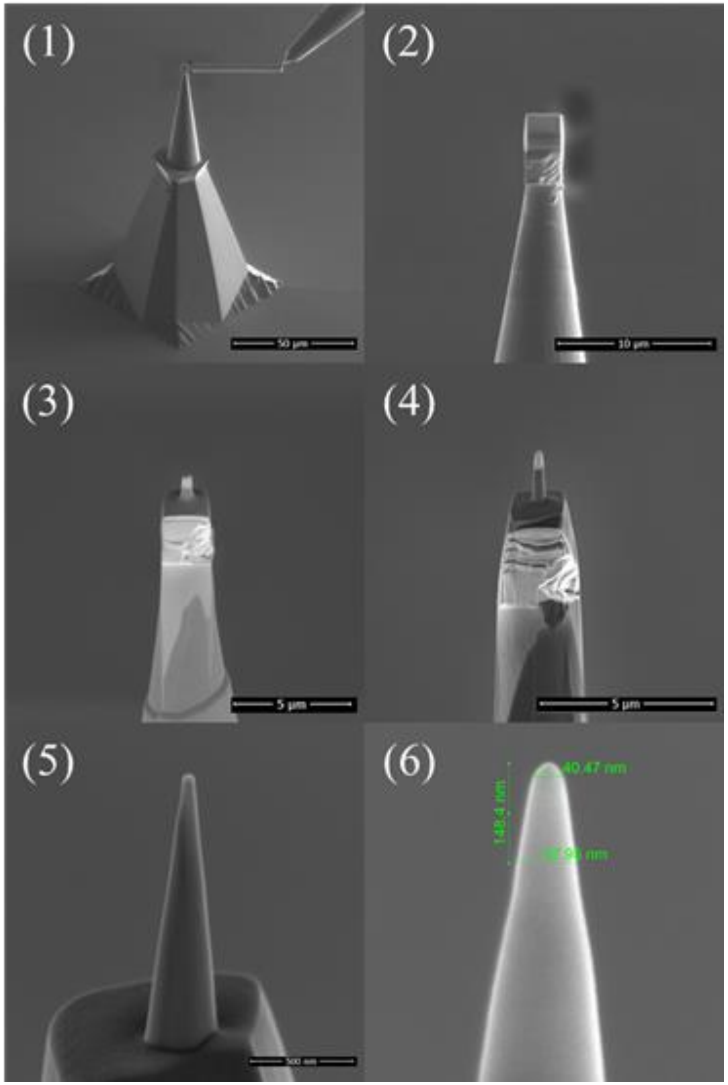


- Ga concentration along the substrate depth after a typical FIB process, simulated by two simulation models
- TRIDYN predicts a different (more realistic) Ga concentration from TRIM's. TRIM higher.

Atom Probe Tomography

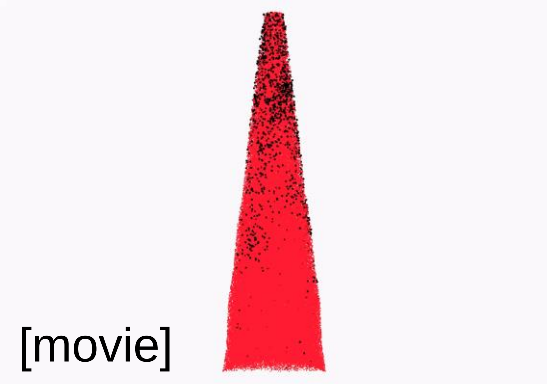


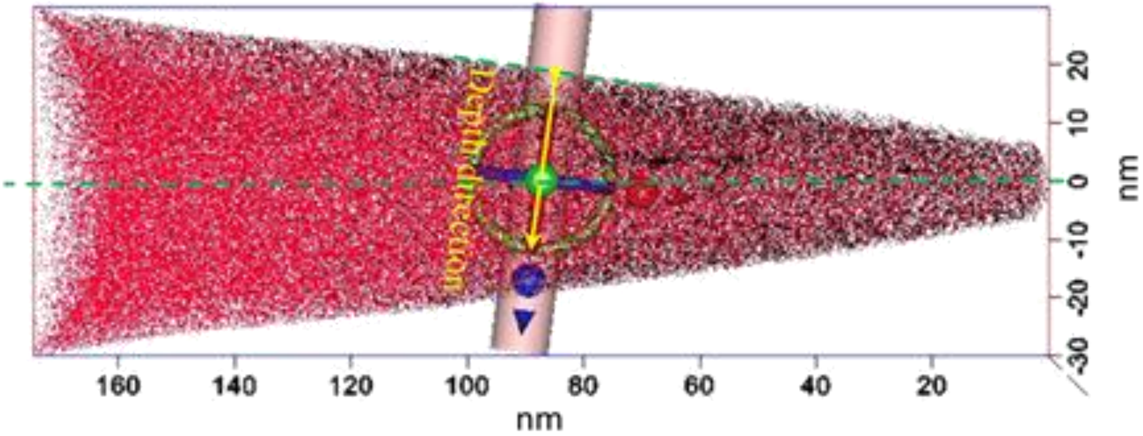




- Atom Probe Tomography is capable of providing the composition at atomic level.
- A ring shape FIB pattern is apply on Si.
- Reduce ion voltage and inner circle diameter so that a cone is formed.
- 5kV is used in the last step. The cone is shrunk at least 100nm in diameter, so that Ga implants from previous steps are removed.

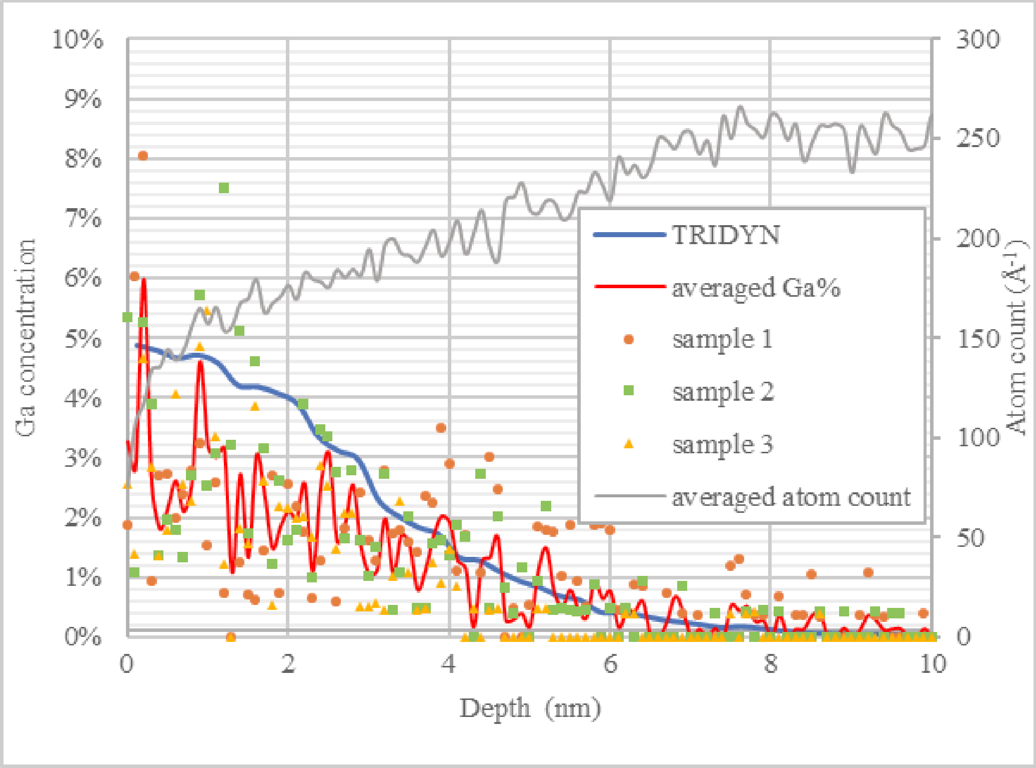
Atom Probe Tomography





- The APT analysis of these three tips were performed using a Cameca LEAP 3000X Si tool.
- 3 sets of tomography data (4 to 7 million atoms each)
- A snapshot of one of the reconstructed tomography is shown. A ø10 nm cylindrical sampling volume is inserted perpendicularly to on the surface of the cone, crossing its axis at the center.
- The atomic fraction of Ga along the cylindrical volume is extracted along the depth direction

Atom Probe Tomography



- Ga concentration along the Si substrate depth obtained from three APT experiments.
- Strong scattering at the shallow surface is caused by insufficient detected atom count. Local variation of the cone angle also increases the noise level of the data

Discussion and conclusion

- TRIDYN simulation predicts a different Ga concentration along the ion-irradiated Si substrate compared to TRIM, due to the high ion dose which significantly changes the substrate composition and changing the irradiation dynamically.
- It is expected that the difference exists for other ion energies and incident angles too, as long as the ion dose is high.
- There is a good consistency of TRIDYN simulation and APT experimental results.
- Further experiments with uniform tips and improved sensitivity APT tools can be done.
- This model is also used to predict Si amorphization caused by FIB using TEM analysis.
- To achieve the goal, 3D-modelling/milling rate/scanning beam are to feature.

Thank you

dcn

dresden center for
nanoanalysis

cfaed

CENTER FOR
ADVANCING
ELECTRONICS
DRESDEN

TECHNISCHE
UNIVERSITÄT
DRESDEN