Electron Tomographic Characterization of Er doped SiC

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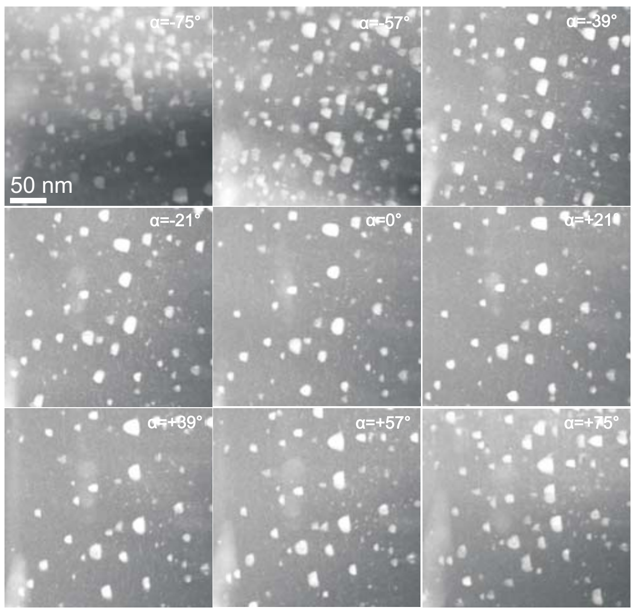
Motivation

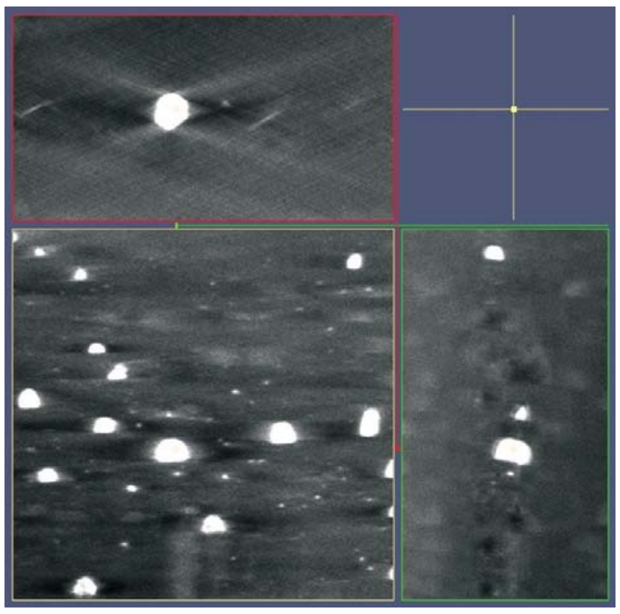
SiC is a promising material for optics, opto-electronic and spintronic applications [1, 2]. Doping with consequent controlled diffusion (e.g. metals for spintronics) should be involved for the most interesting applications.
Due to SiC hardness and extremely low diffusion coefficients traditional doping approaches do not work and high energy ion implantation is one of a few methods which can be applied for those materials. High concentration of structural defects, vacancies and interstitial atoms generated by high energy implantation dramatically complicate diffusion processes and evolution of dopant species.
In order to understand the diffusion mechanisms of dopants in SiC matrix we studied the model system: 4H-SiC implanted with Er. Erbium was selected because of its high atomic number and thus high contrast in HAADF-STEM, which allows atomic resolution imaging of dopant structures. Z-contrast electron tomography was applied as the main method, which reveals the structural features not accessible by other means. Evaluation of tomographic data gave rise to a new understanding of diffusion processes and underlined a key role of linear defects as "diffusion pipes".

Experimental

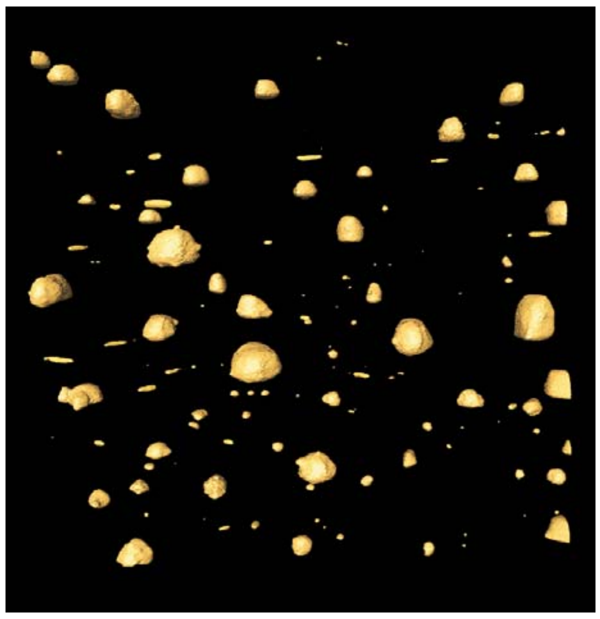
Sample: hexagonal 4H-SiC, implantation of Er (10^{16} cm^{-2}, 700°C) and annealing (3 min, 1600°C) [3, 4]
Acquisition: FEI Titan 80-300 Schottky FEG @ 300 kV, Fischione tomography holder, HAADF-STEM, XPlore3D 2.0 Tomography Suite, spot size: < 0.2 nm, angular range=±75° (Saxton scheme)



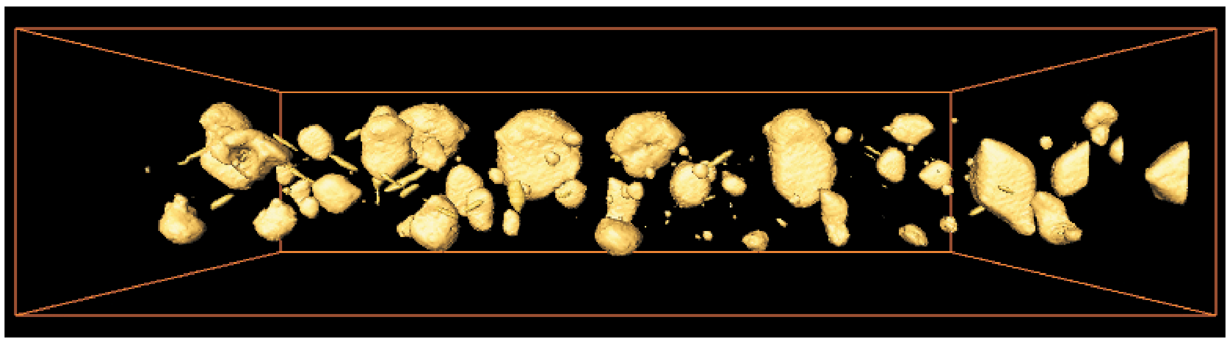
Raw stack (HAADF-STEM, FEI XPLore3D tomo suite)



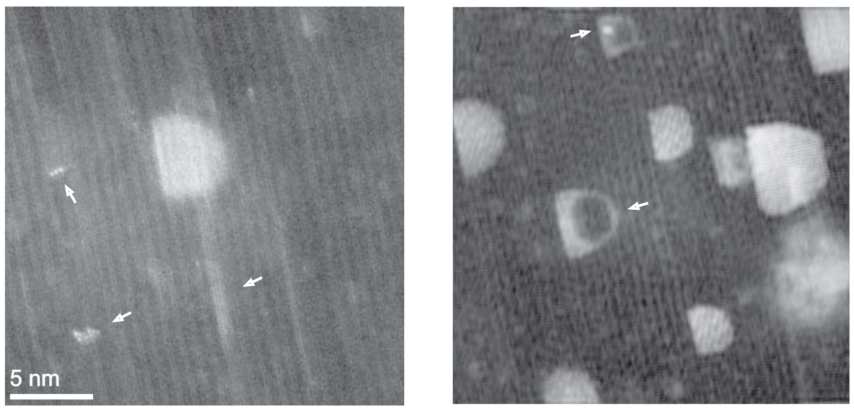
Alignment by cross-correlation and feature-tracking with the particles as markers (IMOD)



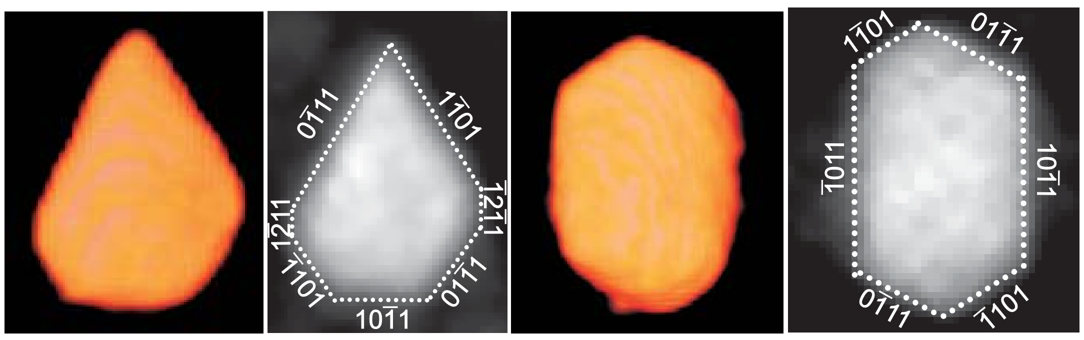
SIRT reconstruction (FEI Inspect 3D); visualization in Amira



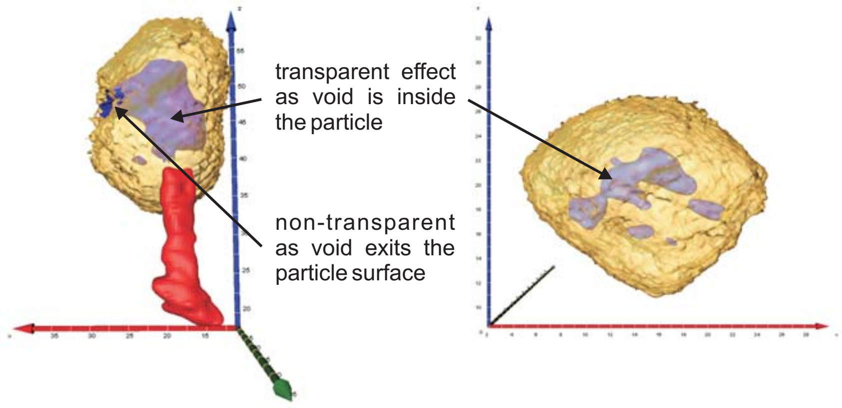
Completely visualized stack demonstrating the diversity in shape formation of the nanocrystals



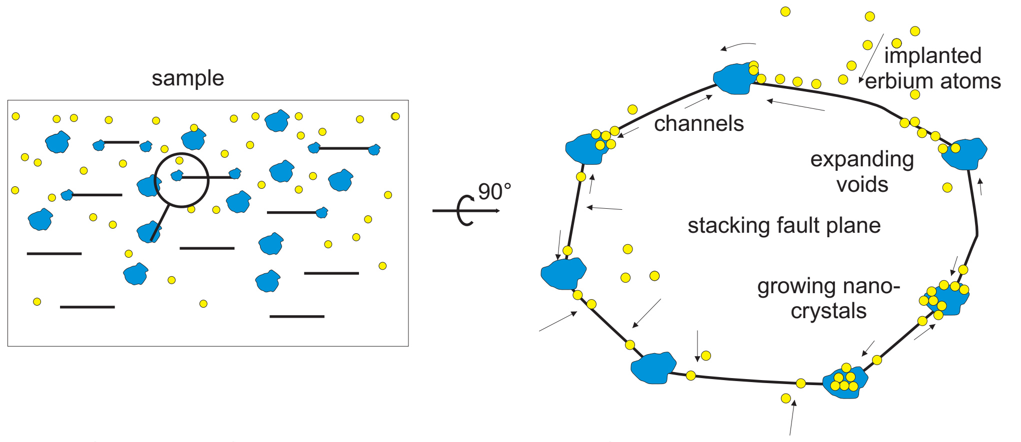
HR-STEM images (Fourier filtered) showing channels on top and side-



Particles of different shapes (view along [11$\bar{2}$0]), adaption of hexagonal SiC matrix [5]



Nanocrystal (yellow), void (blue), channel (red)



Sketch of the model for the crystal growth process of the erbium-silicide particles:
- at annealing temperature vacancies diffuse towards surface and dislocation cores (driven by strain gradient)
- accumulation (clustering) of vacancies leads to formation of voids
- most interstitial Er atoms diffuse slowly to dislocation cores (driven by strain gradient)
- 1D- diffusion (driven by concentration gradient) along dislocations occurs much faster due to wider internal space
- Er-atoms diffusing along pipes end up in previously formed voids and form crystals

Summary

Tomography enables and ensures a more trusty analysis than 2D analysis concerning faceting, channels and voids. For the case of erbium implanted SiC we have observed channels attached to matrix voids which offer space to the nanocrystals' growth. With the completely visualized tomogram we are now able to refine our model of the growth process of erbium nanocrystals within SiC. Future investigations will include the improvement of tomogram resolution and TEM sample preparation techniques (FIB – cutting of selected areas) clarifying our current picture of crystal growth mechanism.

References

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