GoFIB: Fabrication of Ga_2O_3 Polymorphs with Ion Beams

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Introduction

- ✦**Context:** Importance of Ga_2O_3 in power electronics, sensors, and optoelectronics.
- ✦**Polymorphism:** Ga_2O_3 exists in multiple crystalline forms with distinct properties.
- ✦**Objective:** Control phase transitions using ion-beam-induced disorder.
- ✦**Expected Impact:** New synthesis routes for Ga_2O_3-based materials and novel nano-structures.

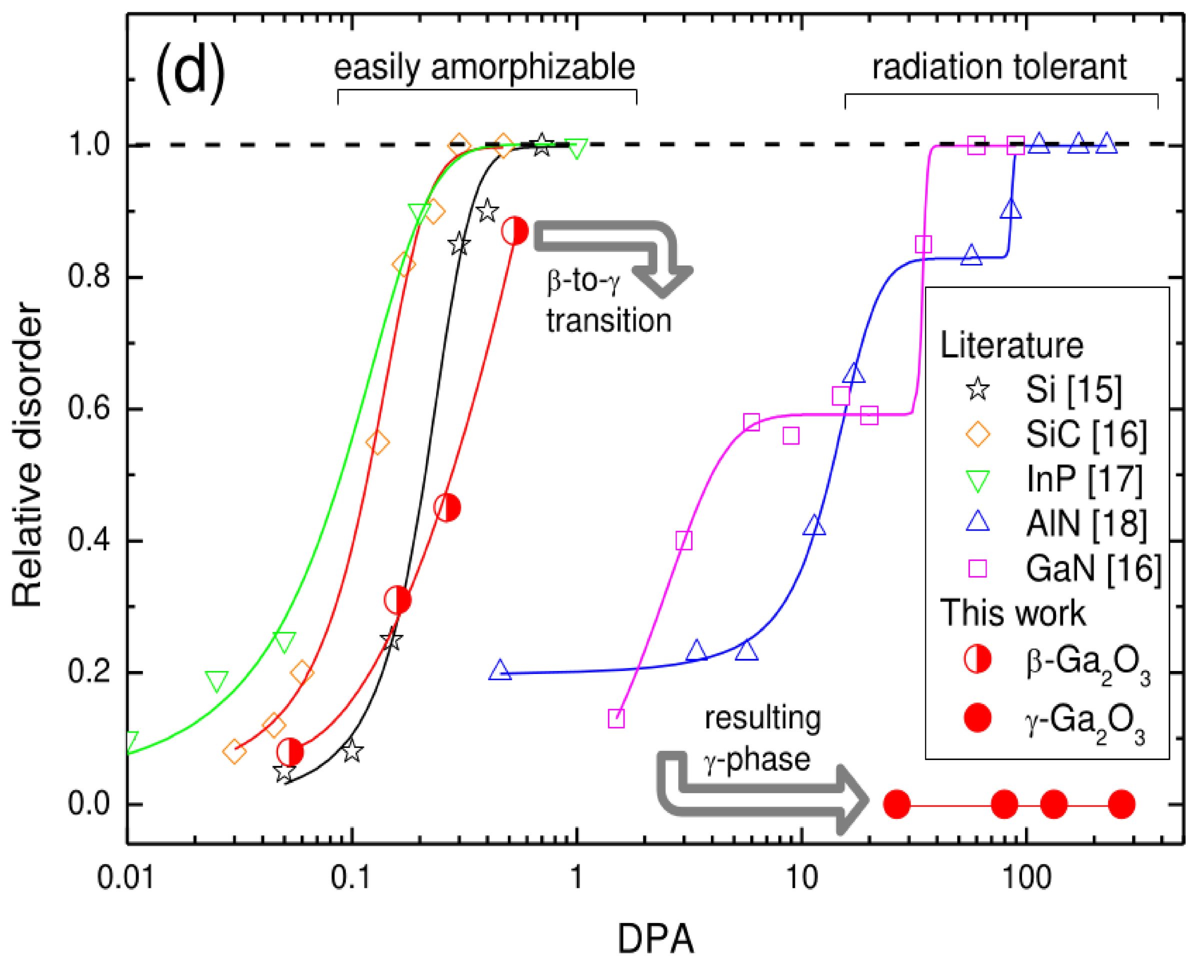
Summary

Key Takeaways:
- ✦Ion beams enable precise phase control in Ga_2O_3.
- ✦γ/β heterostructures demonstrate high radiation tolerance.
- ✦Self-assembling and nanopatterning open pathways for novel polymorph device concepts.

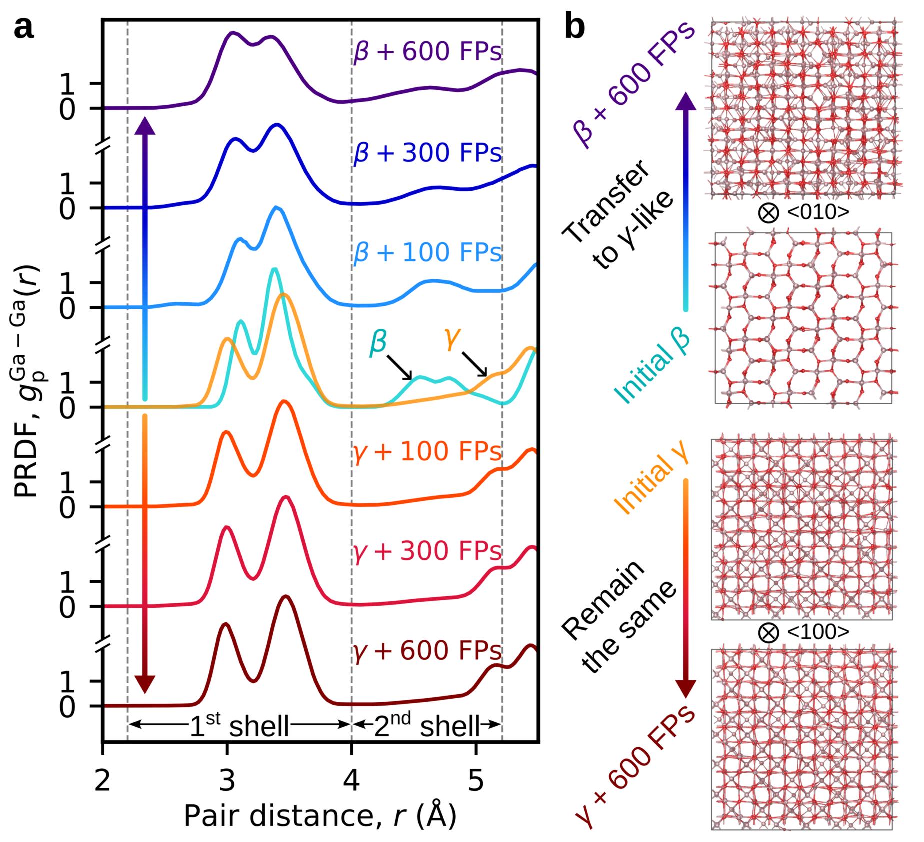
Next Steps:
- ✦Advanced electrical characterization of polymorph interfaces.
- ✦Optimization of ion-beam structuring for industrial scalability.

Radiation tolerance, disorder, and phase transformation

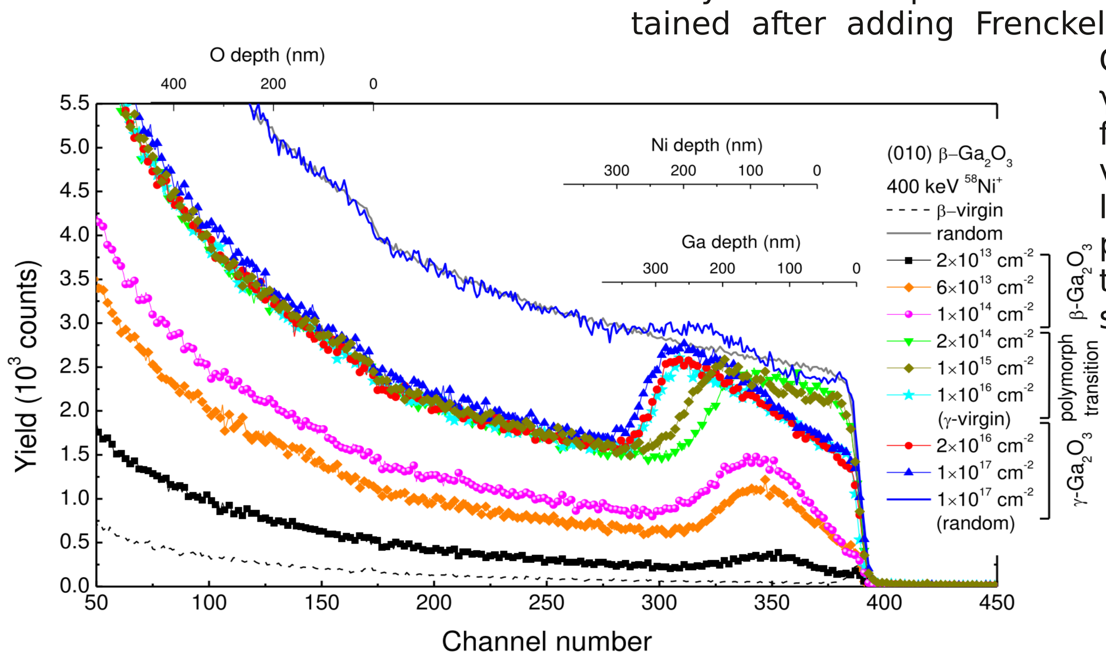
- ✦Exceptionally high radiation tolerance of Ga_2O_3
  - ✦Mostly independent of ion type and energy
  - ✦Results in polymorph conversion from monoclinic β-Ga_2O_3 to cubic defective spinel γ-Ga_2O_3
- ✦MD reveals that the phase transformation is stabilized by oxygen sublattice
- ✦Positron annihilation spectroscopy shows reduction of trapping sites (defects) during phase transformation



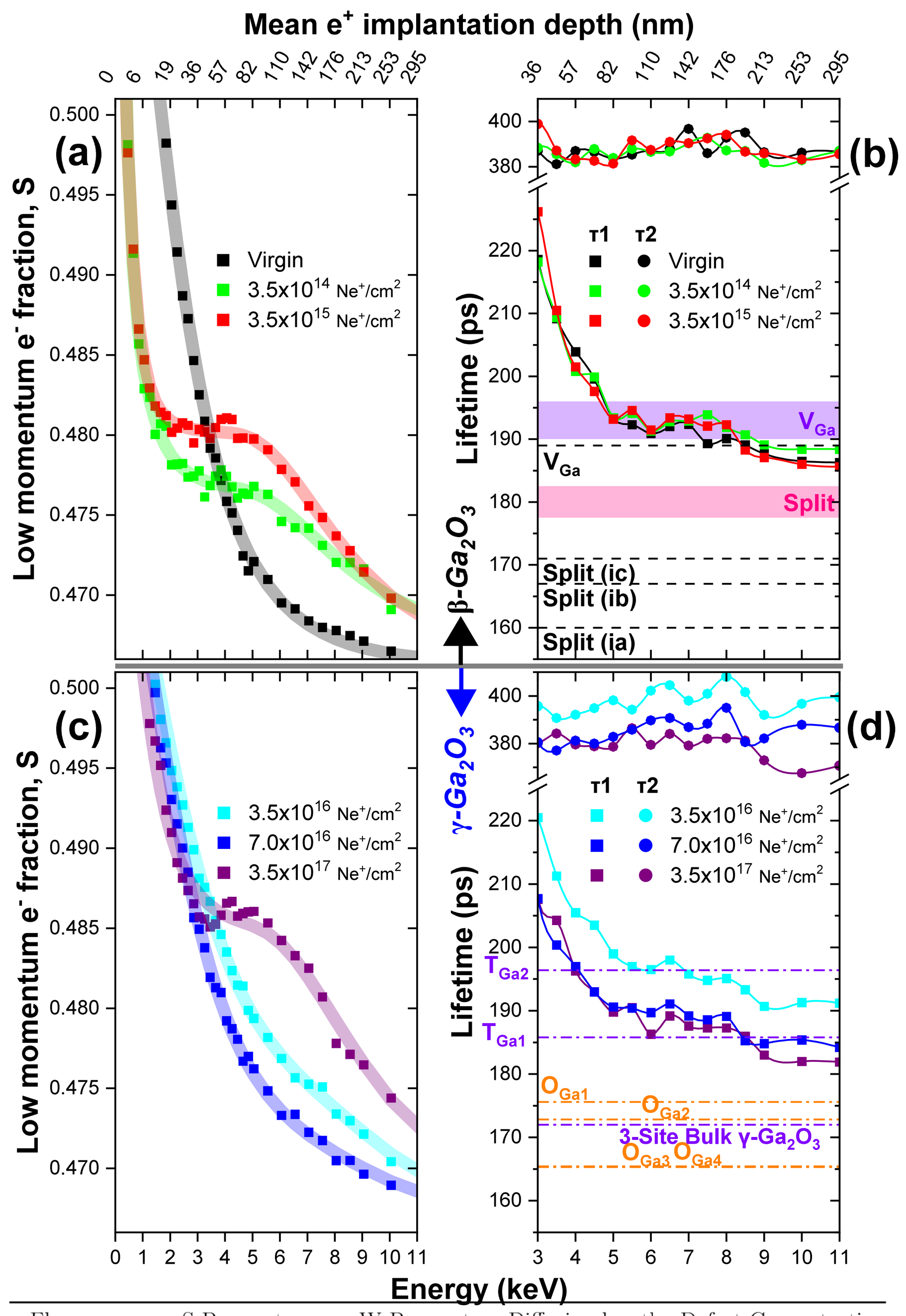
Radiation tolerance of Ga2O3 and select standard semiconductors and previously known radiation hard materials. The relative disorder obtained from RBS/c vs. applied dpa is shown.



Analysis of the partial radial distribution functions obtained after adding Frenckel pairs to pristine β and γ-Ga_2O_3. In both cases γ or a γ-like Ga_2O_3 structure is formed. Further analysis reveals that the oxygen sublattice is exhibiting rapid post cascade recrystallization into the original fcc stacking.



RBS/C spectra of (010) β-Ga_2O_3 samples implanted with 400 keV $^{58}Ni^+$ ions for different fluences as indicated in the legend. The channeling spectrum of the unimplanted (β-virgin) sample is shown by a dashed line for a comparison. Spectra acquired for the random incidence of the He beam are shown too by thick lines.

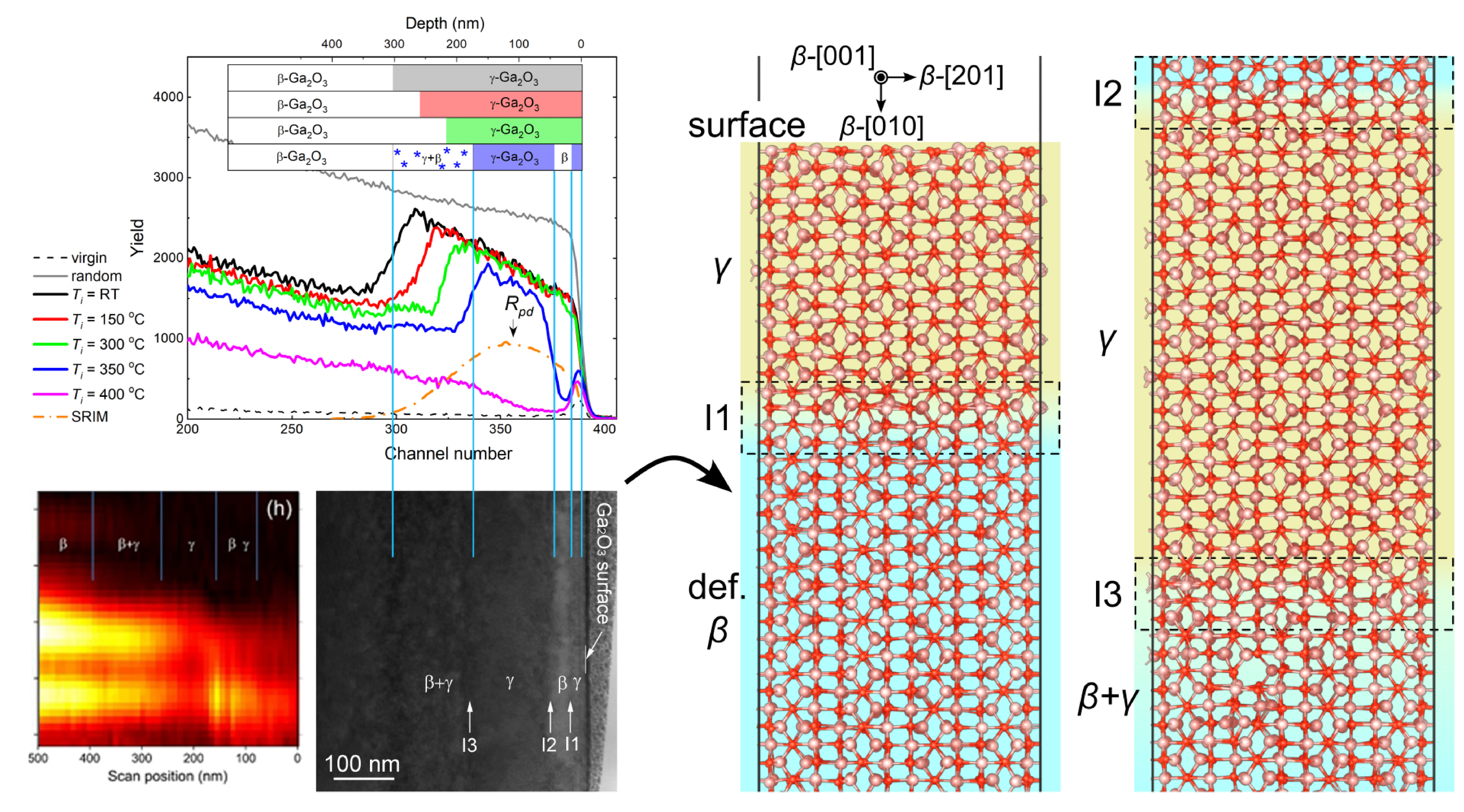


Fluence (Neon/cm^2)	S-Parameter (Surface)	S-Parameter (Layer)	W-Parameter (Layer)	Diffusion length L+ (nm)	Defect Concentration (cm^{-3})
0	0.5213(3)	0.4653(2)	0.0490(1)	27.7(2)	1.81×10^{18}
3.5×10^{14}	0.4883(5)	0.4765(2)	0.0446(1)	8.3(5)	2.7×10^{19}
3.5×10^{15}	0.4990(8)	0.4801(1)	0.0449(1)	3.0(2)	2.1×10^{20}
3.5×10^{16}	0.5097(2)	0.4722(2)	0.0485(1)	39.4(4)	4.24×10^{17}
7×10^{16}	0.5112(3)	0.4694(2)	0.0500(1)	32.8(3)	8.56×10^{17}
3.5×10^{17}	0.5139(4)	0.4847(1)	0.0468(1)	9.6(2)	1.59×10^{19}

Doppler Broadening Variable Energy Positron Annihilation Spectroscopy and Positron Annihilation Lifetime spectroscopy (PALS) results and resulting defect densities. The PALS measurements have been performed at the ELBE facility at HZDR.

Vertical polymorph structuring

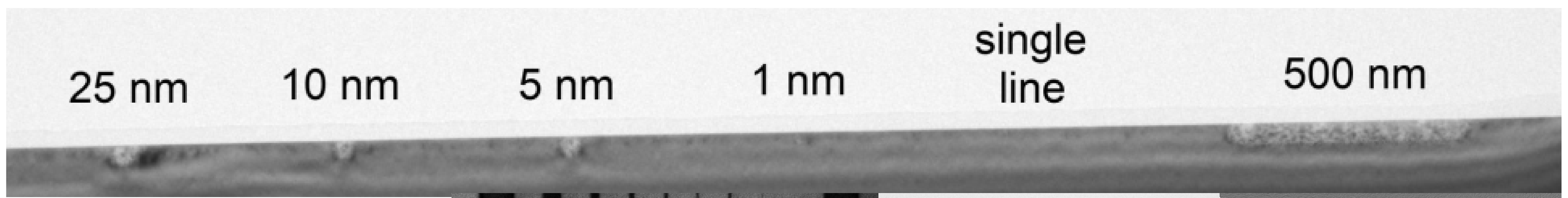
- ✦Dynamic defects annealing results in self-assembling of polymorph heterostructures
- ✦RBS\c, TEM and nanoFTIR results confirm multilayer structure
- ✦machine learned MD reveals atomic structure at the interface



Selforganized fabrication of β/γ multilayer structures in Ga2O3. Temperature dependent RBS/C spectra revcealing the formation of γ−β−γ−β multilayer structures at 350°C. The nano-FTIR absorption spectra map and the corresponding TEM image confirm the distribution of γ−β−γ−β polymorphs in the cross-section. The right side show ML-MD results revealing the atomic configuration at the β/γ interfaces.

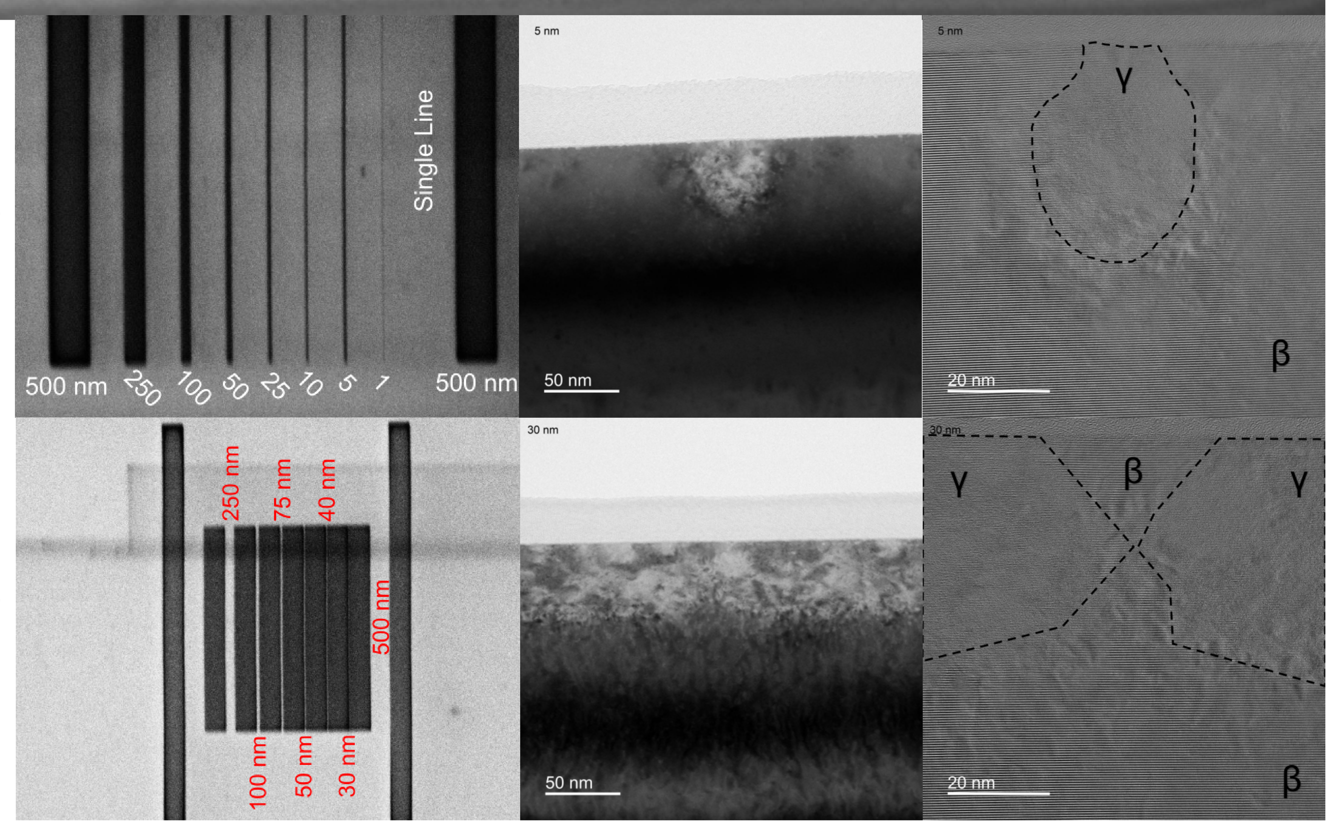
In plane polymorph structuring

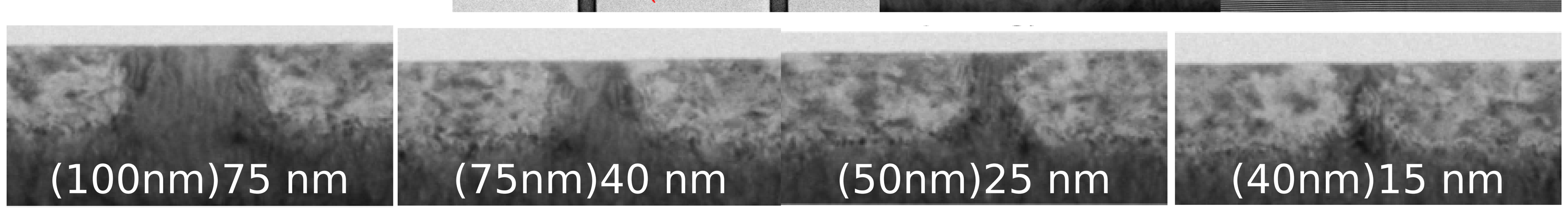
- ✦Focused Ne ion beam irradiation allows lateral patterning
- ✦Feature size limited only by collision cascade



Minimal achievable γ-Ga_2O_3 feature in a β-Ga_2O_3 matrix is approximately 20 nm. Fabricated using a 25 keV Ne (beam resolution ~2nm).

Two γ-Ga_2O_3 areas touching each other leaving a minimal β-Ga_2O_3 bridge behind. Fabricated using a 25 keV Ne (beam resolution ~2nm) and a design gap of 30 nm.





References:

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[2] A. Azarov, J. Garcıa Fernandez, J. Zhao, F.Djurabekova, H.He, R.He, Ø.Prytz, L.Vines, U.Bektas, P.Chekhonin, N.Klingner, G.Hlawacek, and A.Kuznetsov, “Universal radiation tolerant semiconductor,” Nat. Comm., 14, 4855 (2023)
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