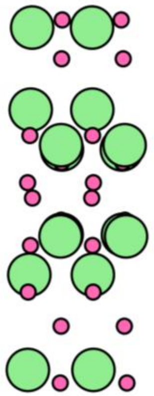
Radiation resistance of gallium oxide

Joanna Matulewicz

PHENIICS Fest
8 June 2026



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dr hab. Renata Ratajczak, National Centre for Nuclear Research, Poland

Outline

MOTIVATION

- What is β-Ga_2O_3?
- Potential applications
- Why is it implanted with rare earth ions?

METHODOLOGY

- Ion implantation
- RBS/c
- XRD
- TEM

RESULTS

- What happens after implantation with rare earth ions

CONCLUSION

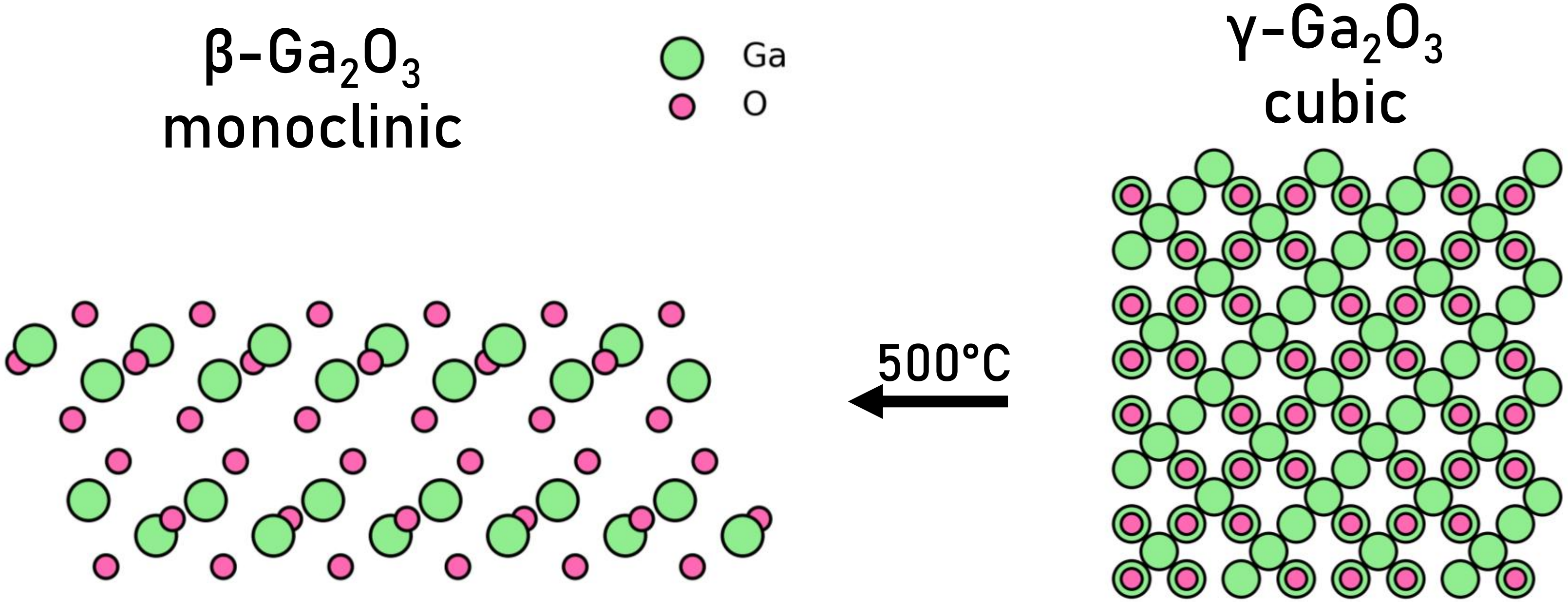
- Next steps

β-Ga_2O_3

- Wide bandgap semiconductor: 4.8 eV
- It can handle high voltage
- It can withstand high temperature
- Resistant to high radiation
- Low cost of production
- Potential use: power electronics, optoelectronics, photodetectors, gas sensors…

Why β-Ga_2O_3?

- Ga_2O_3 is a crystal
- β-Ga_2O_3 is the most stable form of Ga_2O_3



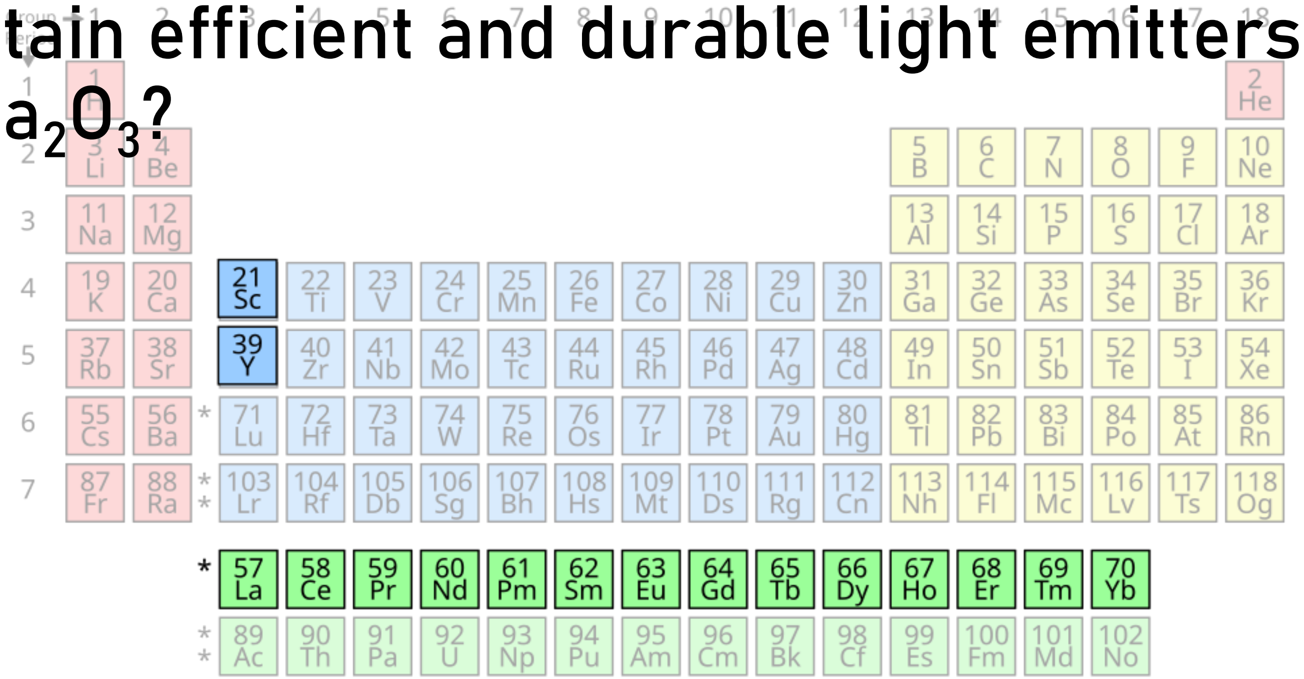
β-Ga_2O_3
monoclinic

γ-Ga_2O_3
cubic

500°C

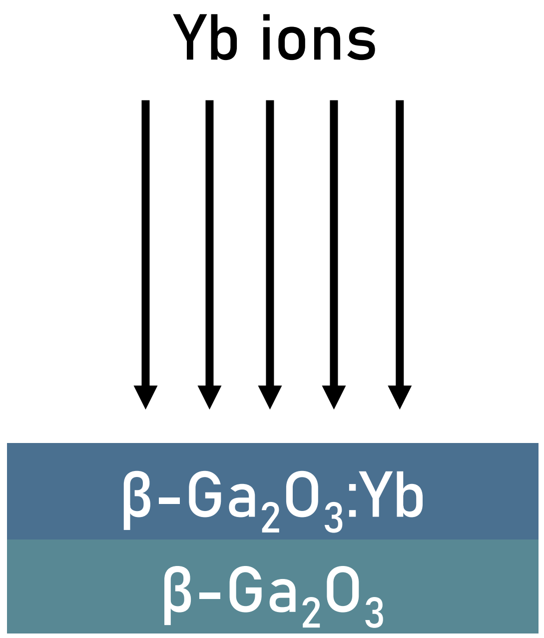
Rare earth doping

- Doping with rare earth (RE) ions modifies the optical response
- Doping with Yb extends the photoluminescence range into infrared
- Can we obtain efficient and durable light emitters based on RE-doped β-Ga_2O_3?



Methodology

Ion implantation | RBS/c | XRD | TEM



Yb ions

β-Ga_2O_3:Yb

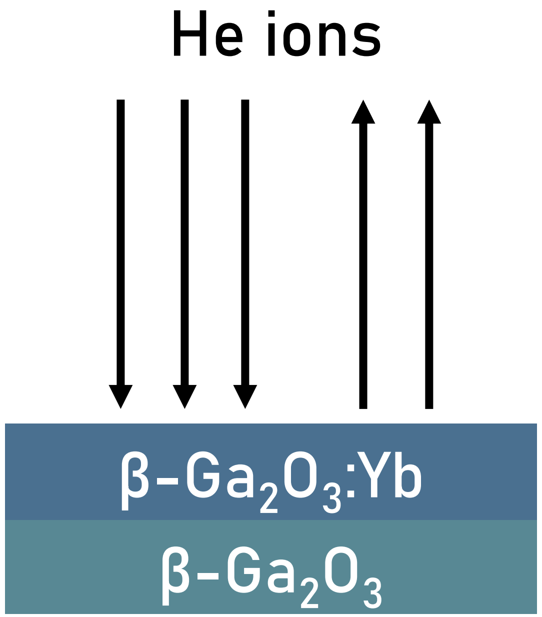
β-Ga_2O_3

Energy: 150 keV

Fluence range:
5×10^{12} - 1×10^{16} ions/cm^2

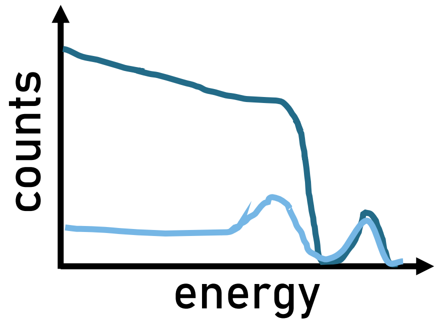
Methodology

Ion implantation | **RBS/c** | XRD | TEM



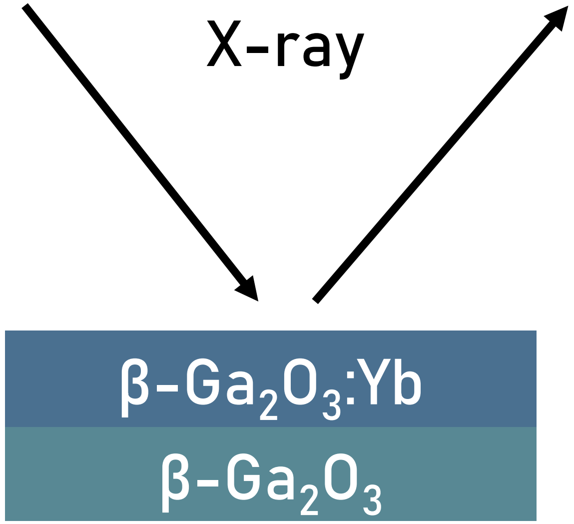
Rutherford Backscattering Spectroscopy in channeling mode

- Quality of the crystal
- Defects analysis



Methodology

Ion implantation | RBS/c | **XRD** | TEM

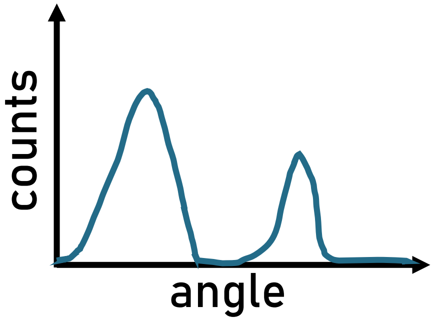

X-ray

β-Ga_2O_3:Yb

β-Ga_2O_3

X-Ray Diffraction

- Quality of the crystal
- Strain
- Crystal phases

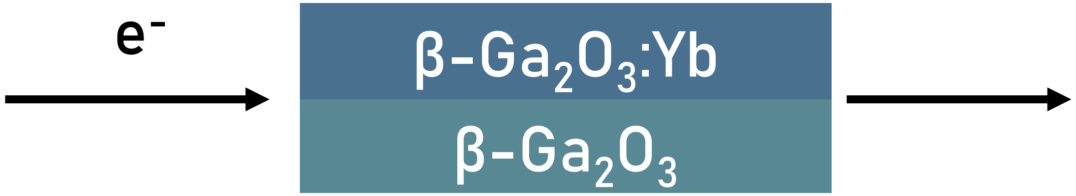


Methodology

Ion implantation
RBS/c
XRD
TEM

Transmission Electron Microscopy

- Imaging
- Identification of crystal phases
- Destructive method

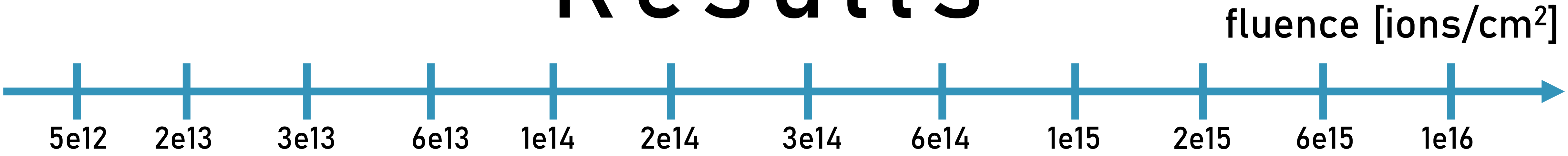


e^-

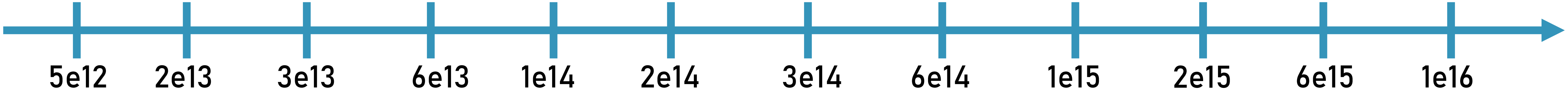
β-Ga_2O_3:Yb

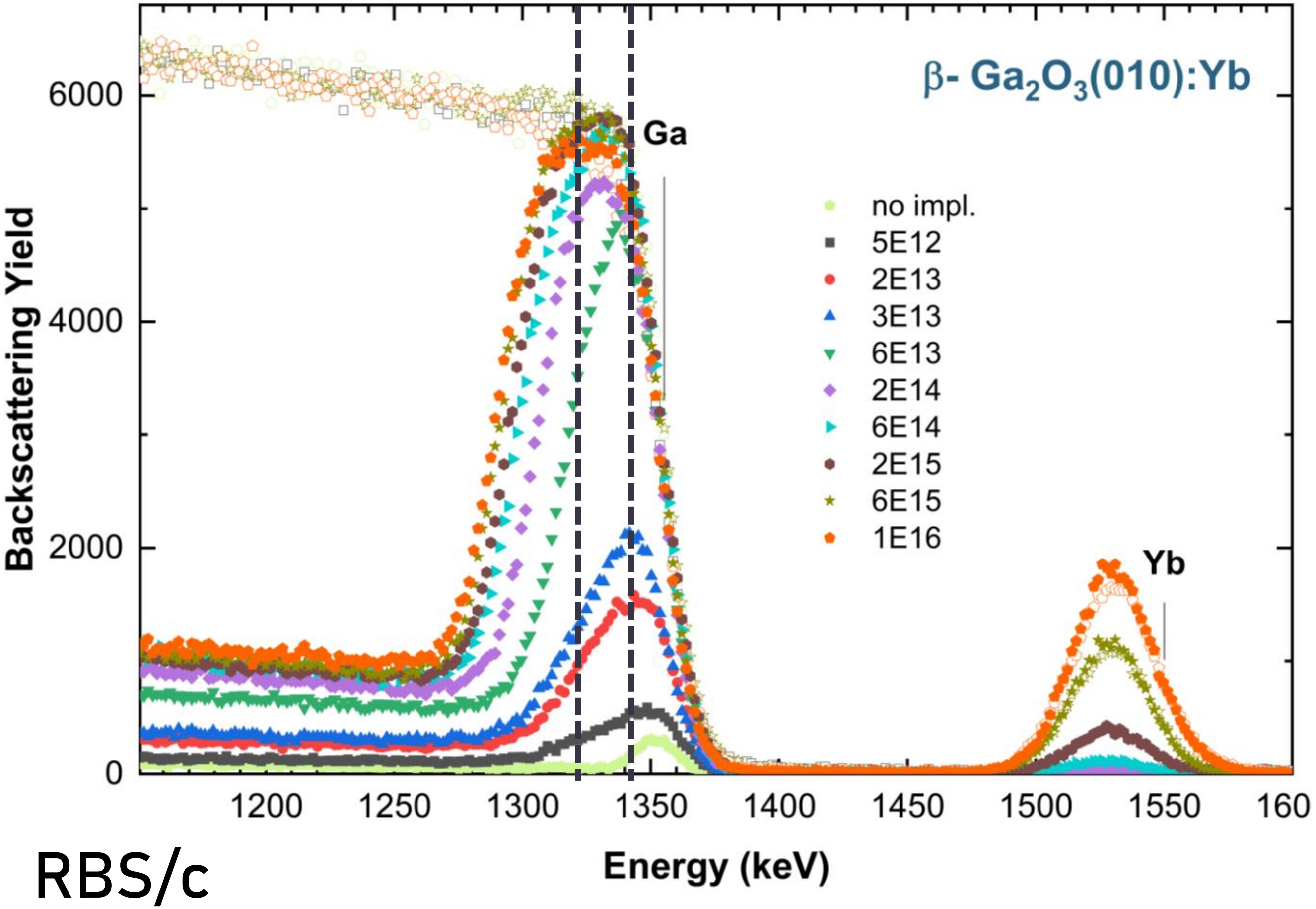
β-Ga_2O_3

Results

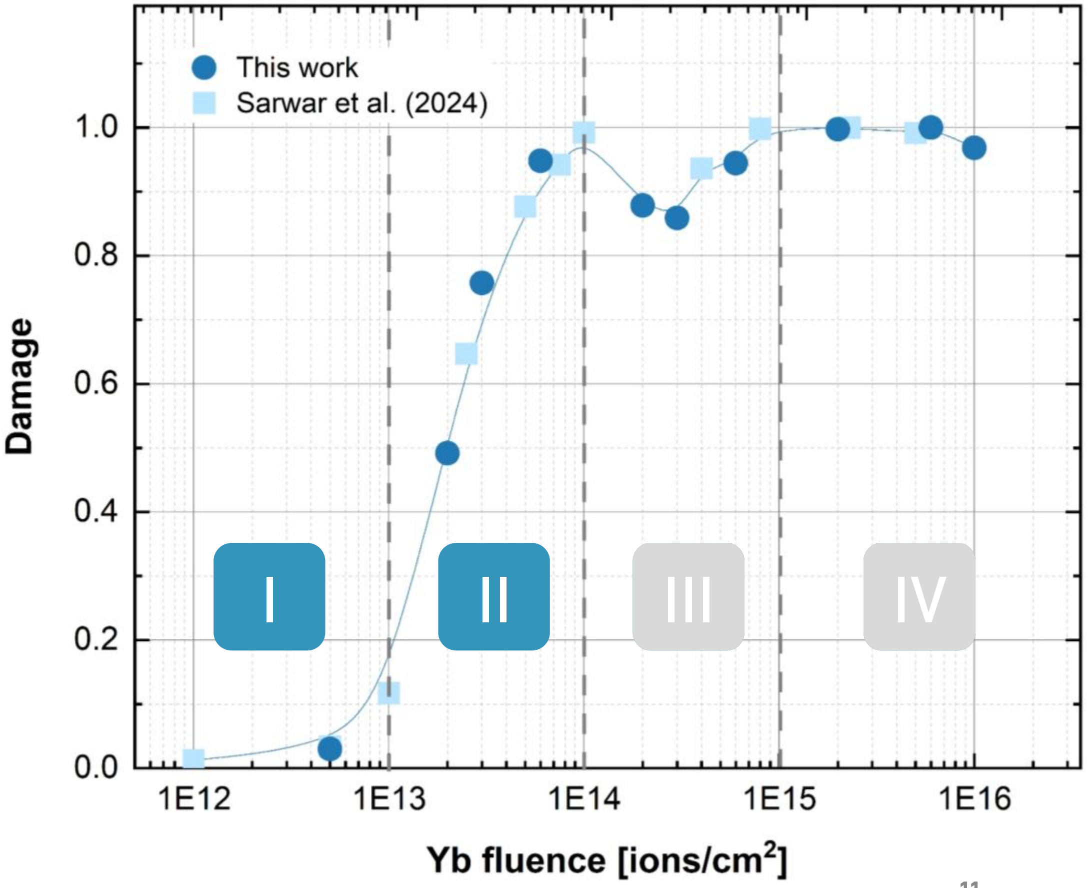

fluence [ions/cm²]
5e12
2e13
3e13
6e13
1e14
2e14
3e14
6e14
1e15
2e15
6e15
1e16

Damage accumulation



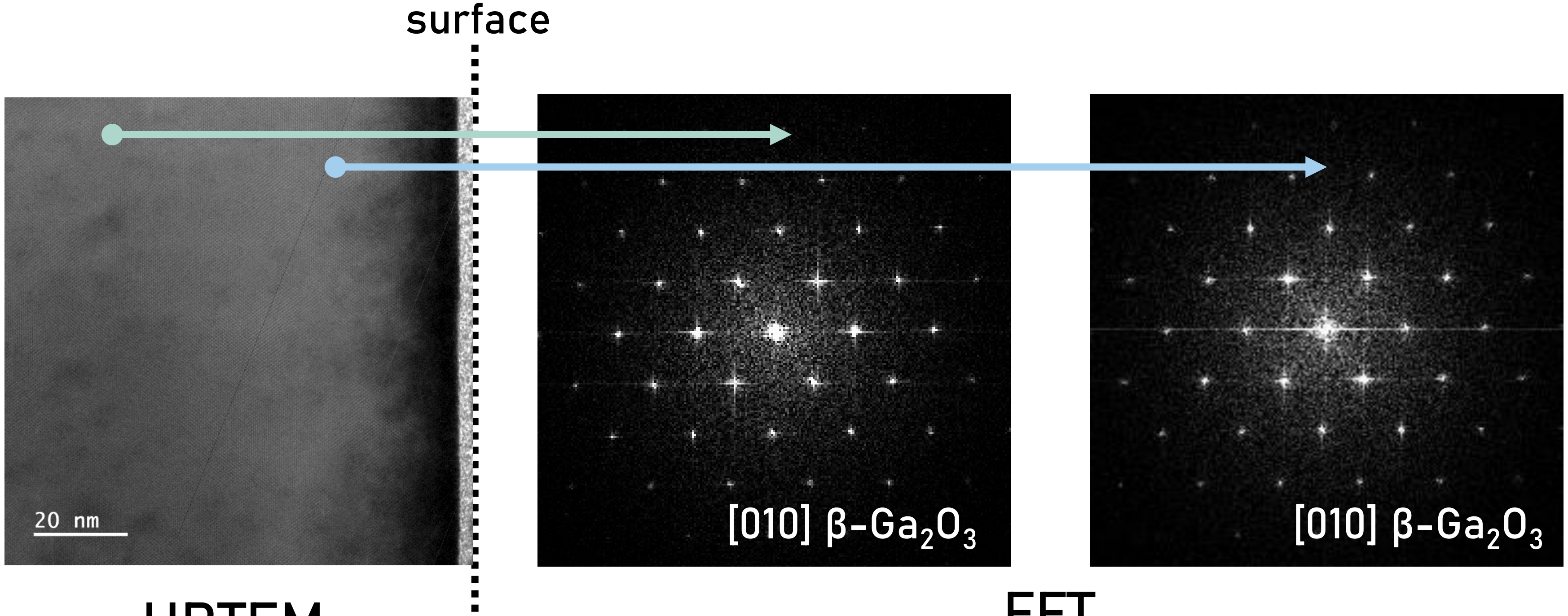


RBS/c



Implantation with low fluences

5e12



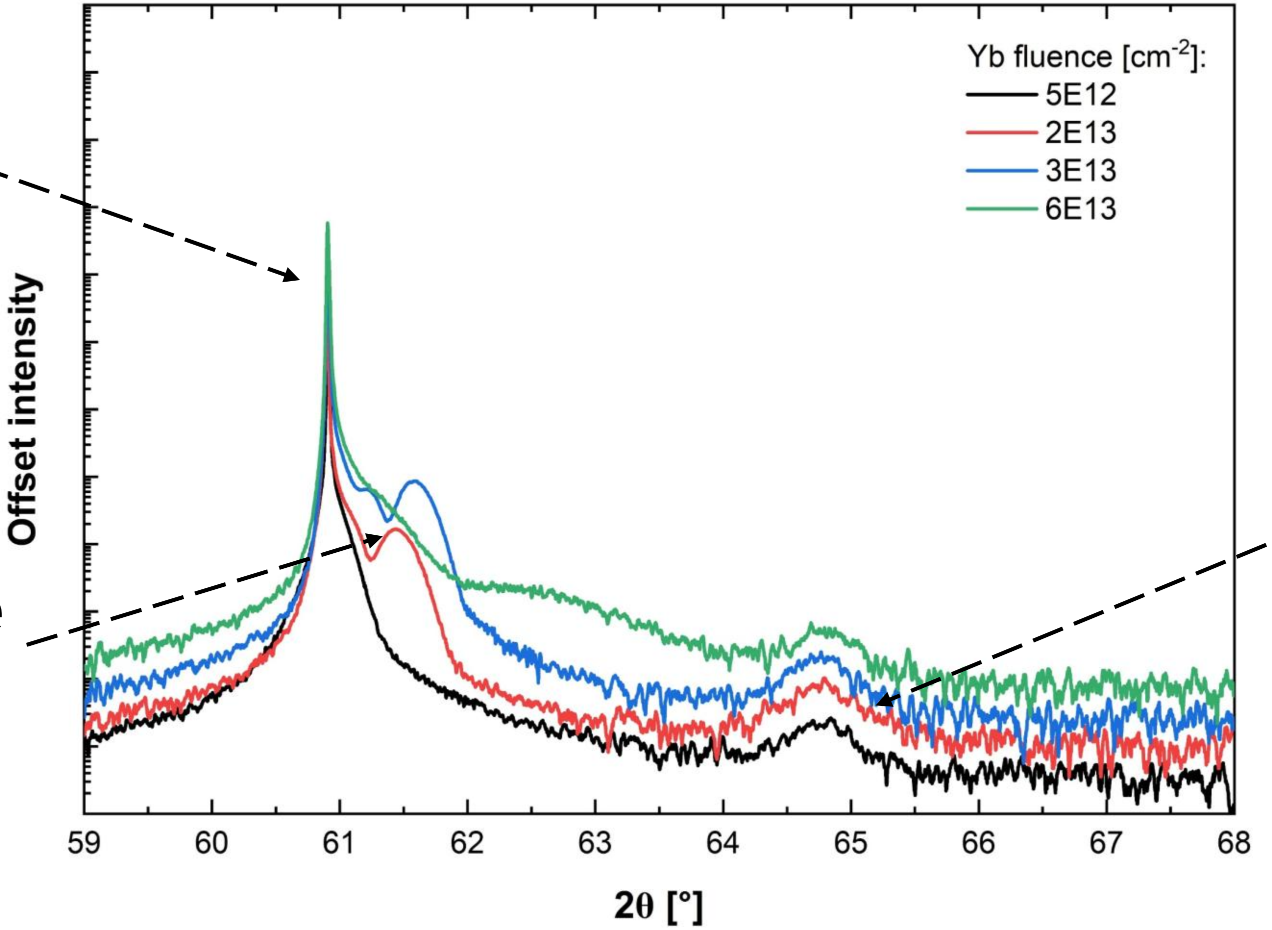
HRTEM

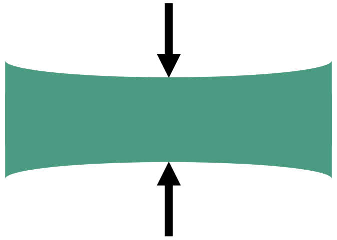
FFT
(Fast Fourier Transform)

Implantation with low fluences

HRXRD

β-Ga_2O_3
(020)



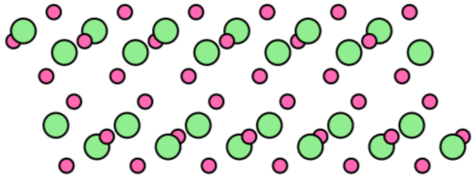


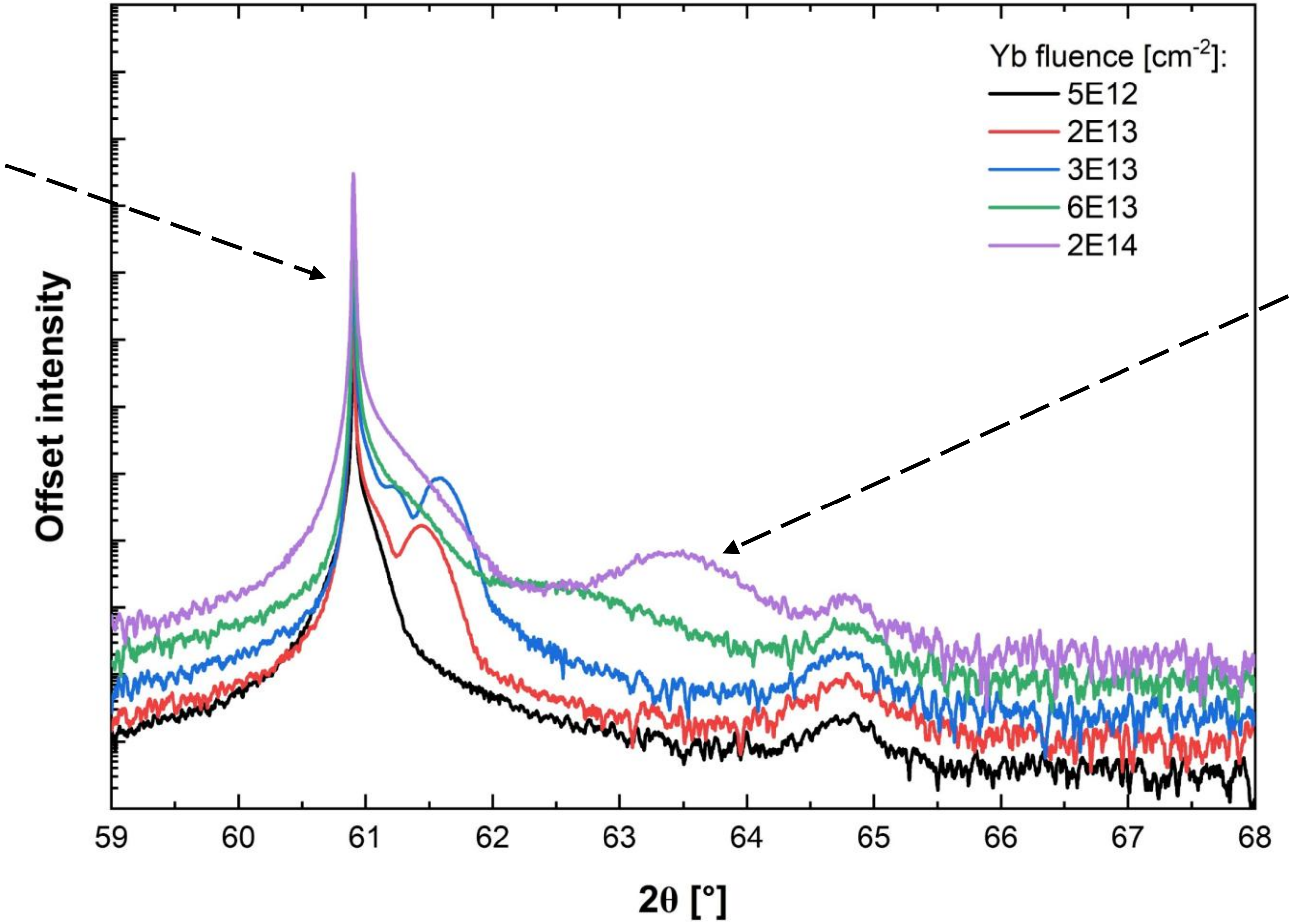
compressive
strain

sample
stage

Phase transition

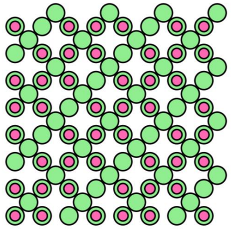
β-Ga_2O_3
(020)



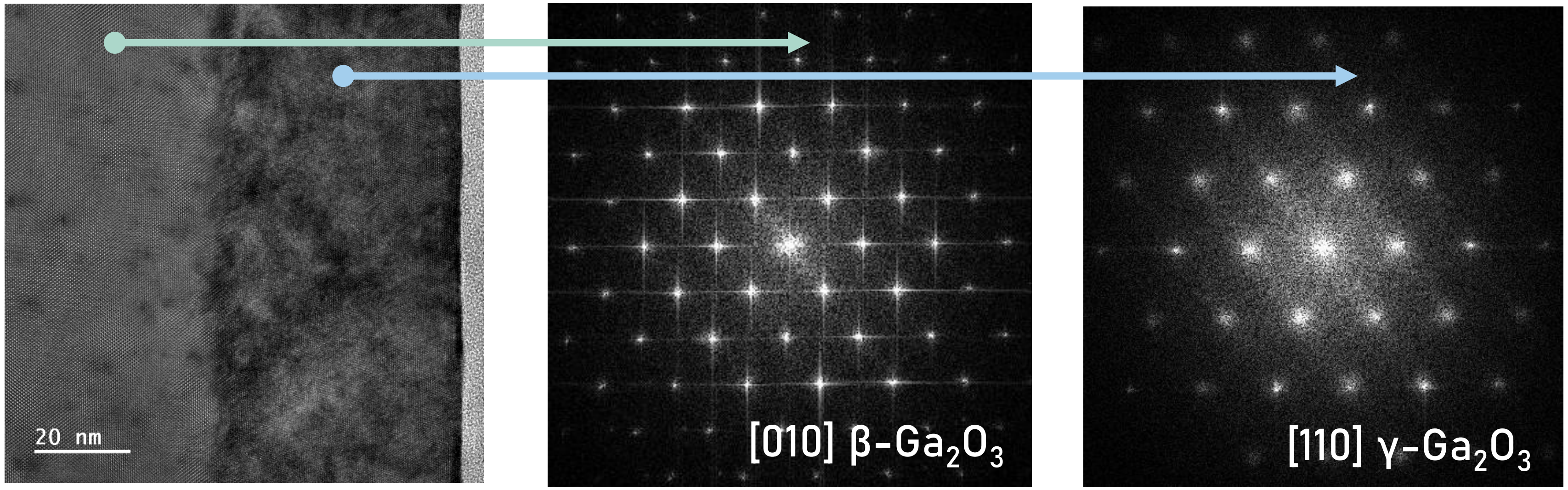


HRXRD

γ-Ga_2O_3
(440)



Phase transition



HRTEM

FFT

Radiation resistance

- Different response to irradiation: transformation from β to γ phase instead of amorphization
- β/γ bilayers exhibit high radiation resistance: no amorphization observed even after irradiation with very high fluences

Amorphization - structural phase transformation from a crystalline solid to a solid that lacks any long-range order

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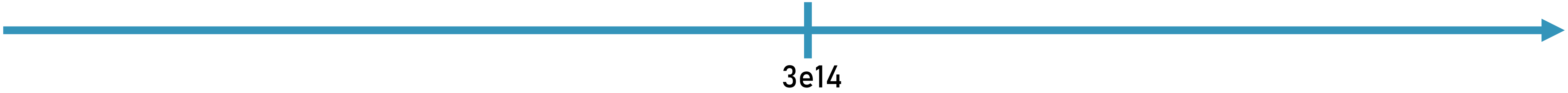
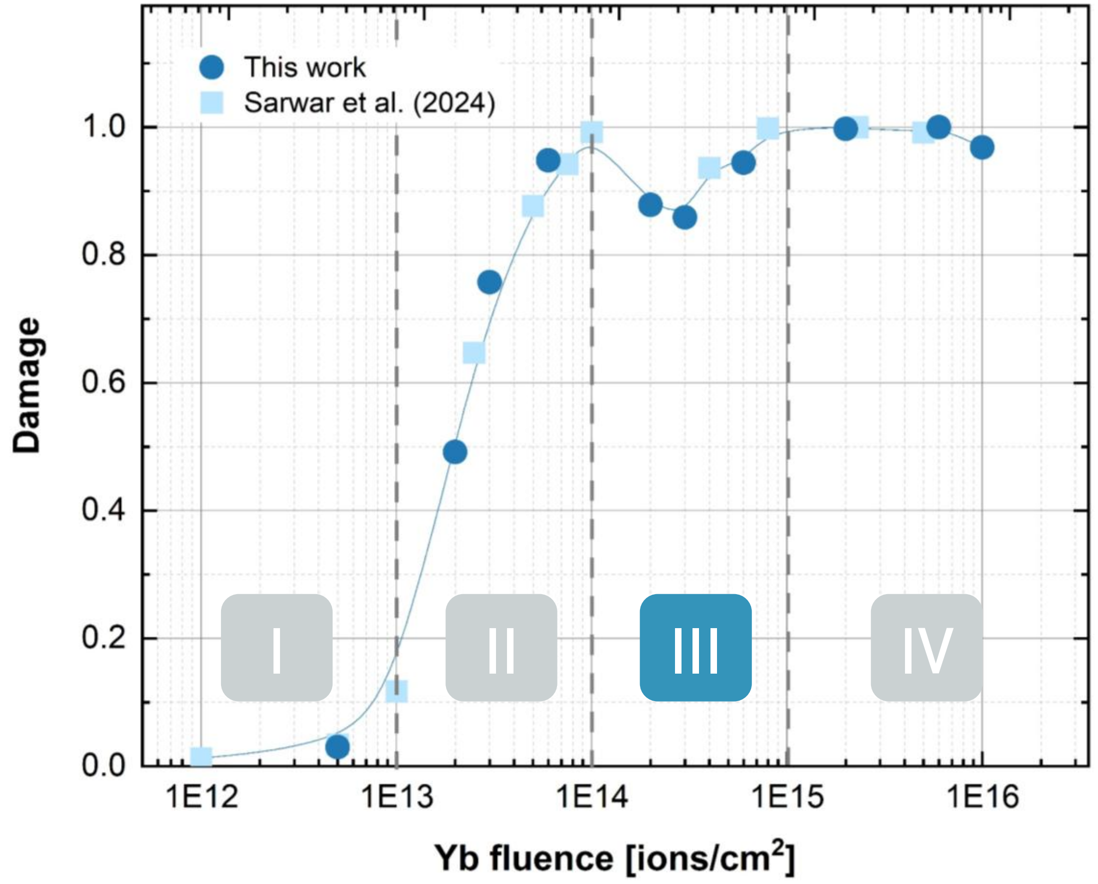
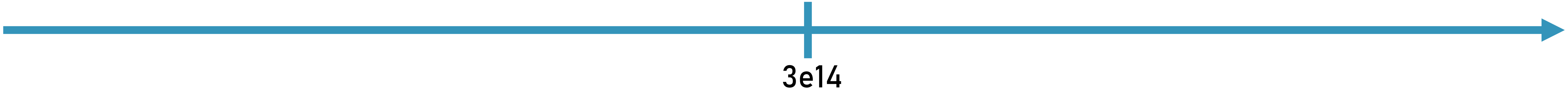
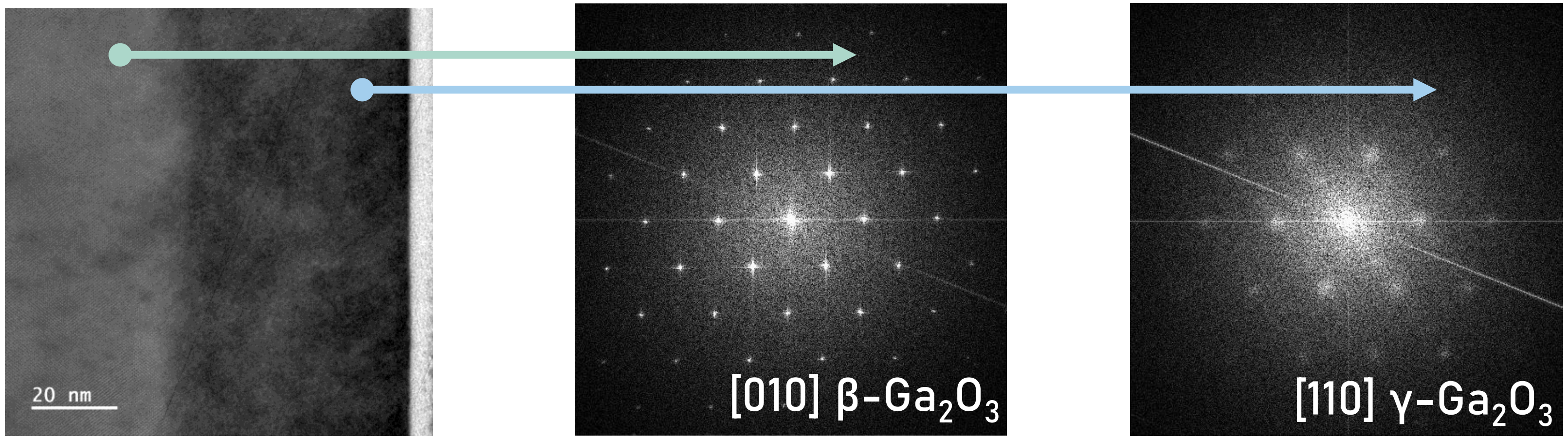
Further implantation





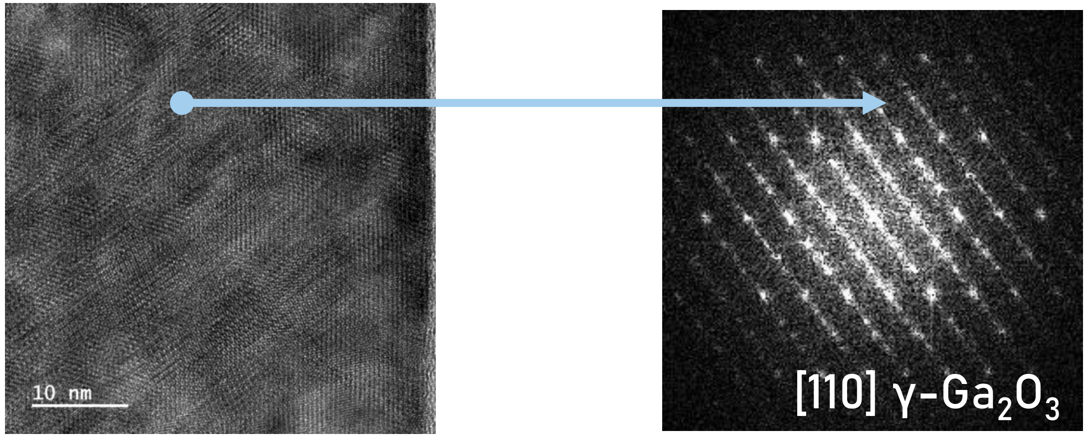
Further implantation





HRTEM

FFT

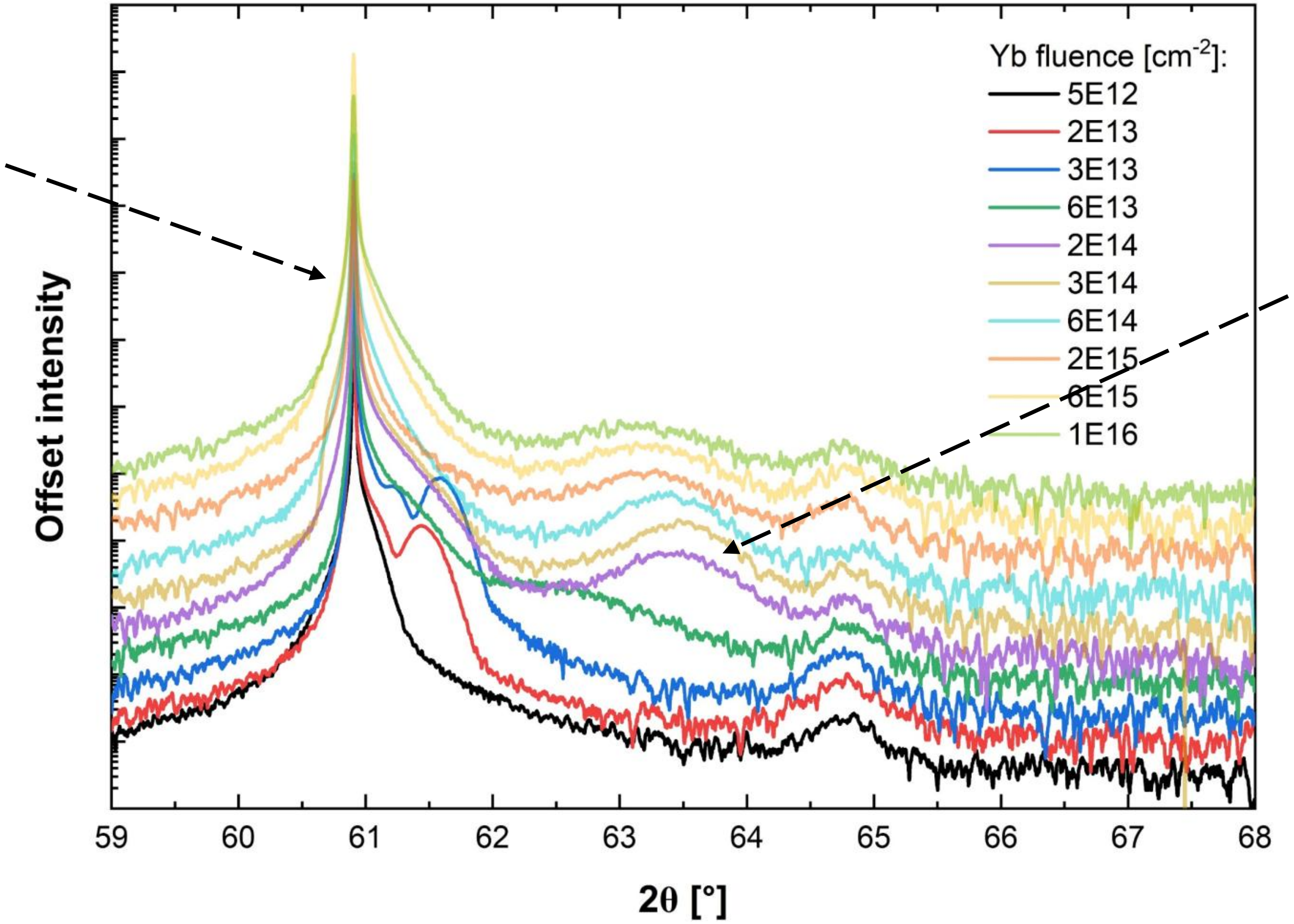


stacking
faults

Further implantation

5e12 2e13 3e13 6e13 2e14 3e14 6e14 2e15 6e15 1e16

HRXRD



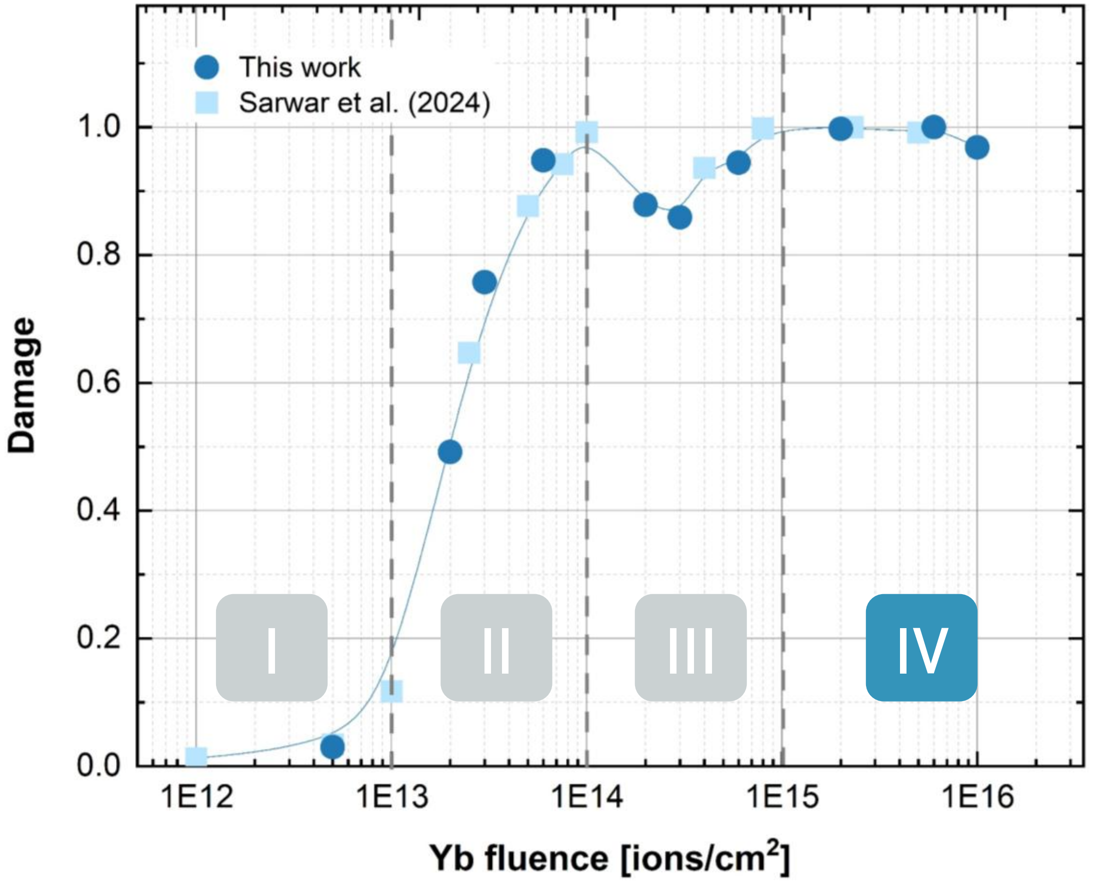
β-Ga_2O_3
(020)

γ-Ga_2O_3
(440)

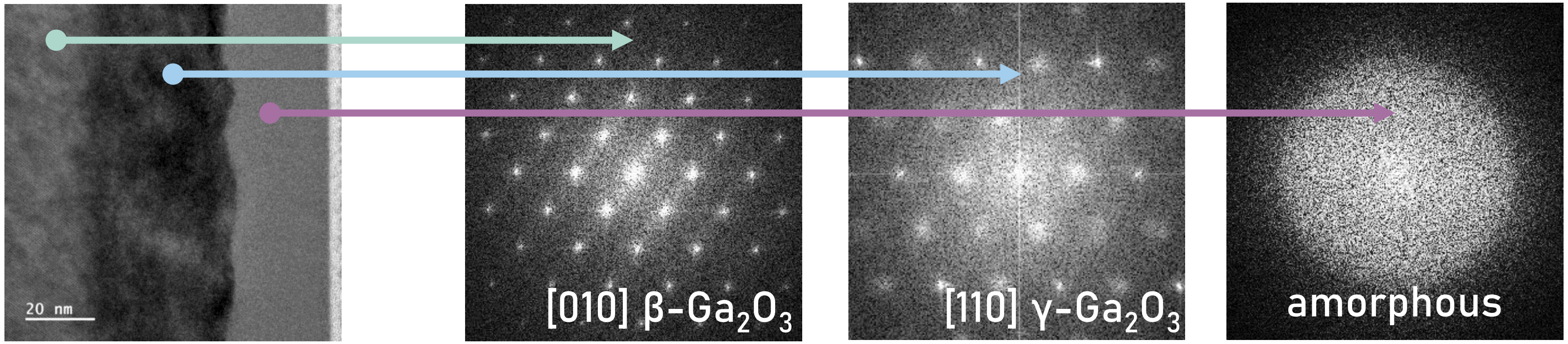
Amorphization

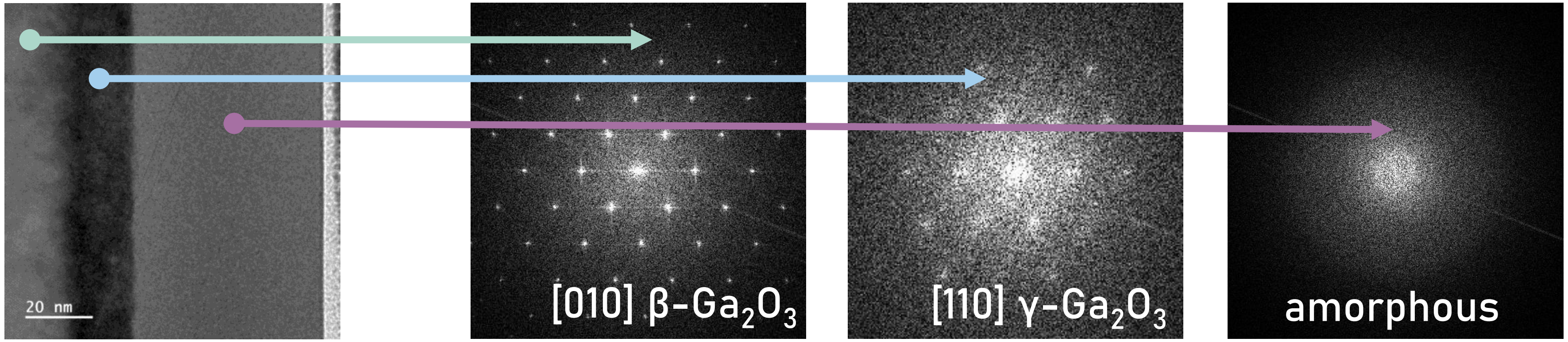
1e15

1e16



Amorphization





Conclusion

- Increasing compressive strain
- Strain relaxation
- Formation of γ phase
- Stacking faults
- Progressive amorphization

Conclusion

- The results challenge the concept of extreme radiation resistance of the γ phase or suggest that its stability may depend on irradiation conditions
- A chemical effect of RE ions may play a significant role
- Next step: implantation with a noble gas Xe

Acknowledgements

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