Post-implantation Defect Accumulation in Crystal Lattice of β-Ga_2O_3 Implanted with Yb ion

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Motivation

Optical tuning of wide bandgap oxides particularly β-Ga_2O_3, from UV to infrared could open up tremendous possibilities for gallium oxide applications. One of the most suitable candidates for infrared emission is Yb and ion implantation is the one of the most advantageous techniques for the incorporation of dopant into the host matrix. Due to its ballistic nature, this technique creates crystal lattice damage and the dopant i.e. Yb could be optically inactive. Thermal treatments like Rapid Thermal Annealing (RTA) have been found to be the effective technique for the crystal lattice recovery and optical activation of RE ion [1]. This study is aimed to examine the post-implantation lattice disorder build up and post-annealing structural recovery in the ($\bar{2}$**01**) oriented β-Ga_2O_3 implanted with Yb ion.

Experiment

- **Single crystal β-Ga_2O_3 with ($\bar{2}$01) orientation**
- Wafer purchased from **Novel Crystal Technology**
- Cut into **1x1** cm at **IF PAN** by using wire saw and laser cutter

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- **Implantation with RE** performed at **HZDR, Germany.**
- Energy **1**50 keV
- **Yb fluences→** 1e**1**2, 5e**1**2, **1**e**1**3, 2.5e**1**3, 5e**1**3, 7.5e**1**3, **1** e**1**4, 4e**1**4, 8e**1**4, 2.3e**1**5 and 5e**1**5 atoms/cm²

↓

- **Rapid thermal annealing RTA O_2 at 800°C for 10 min**

Characterization

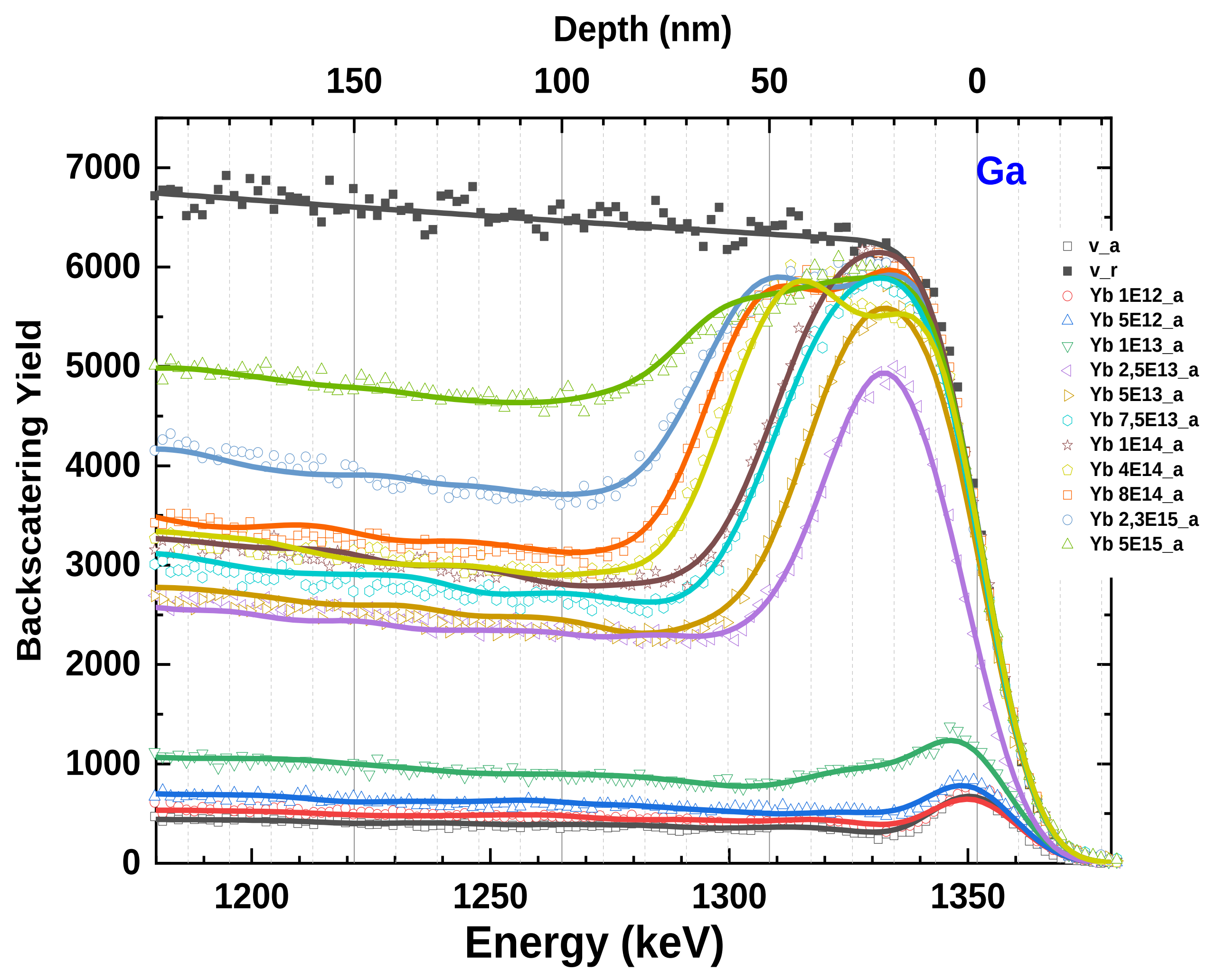
RBS/c was used for the experimental structural analysis of the samples

SRIM → theoretical calculation of defect distribution and ions range

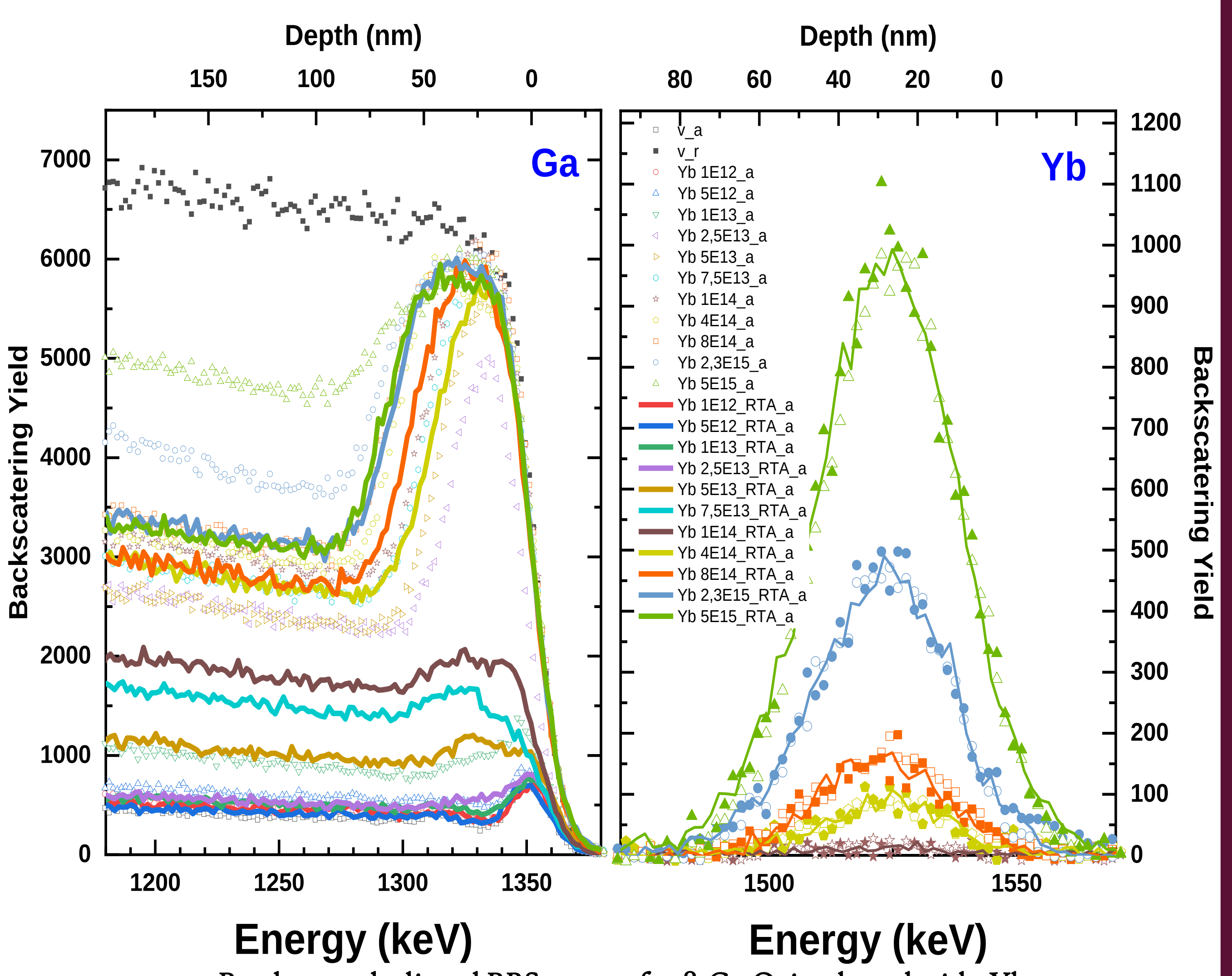
SIMNRA → Quantification of RE concentration and its depth profile based on obtained RBS/c spectra

McChasy→ Quantification of defect concentration and its depth profile based on obtained RBS/c spectra.

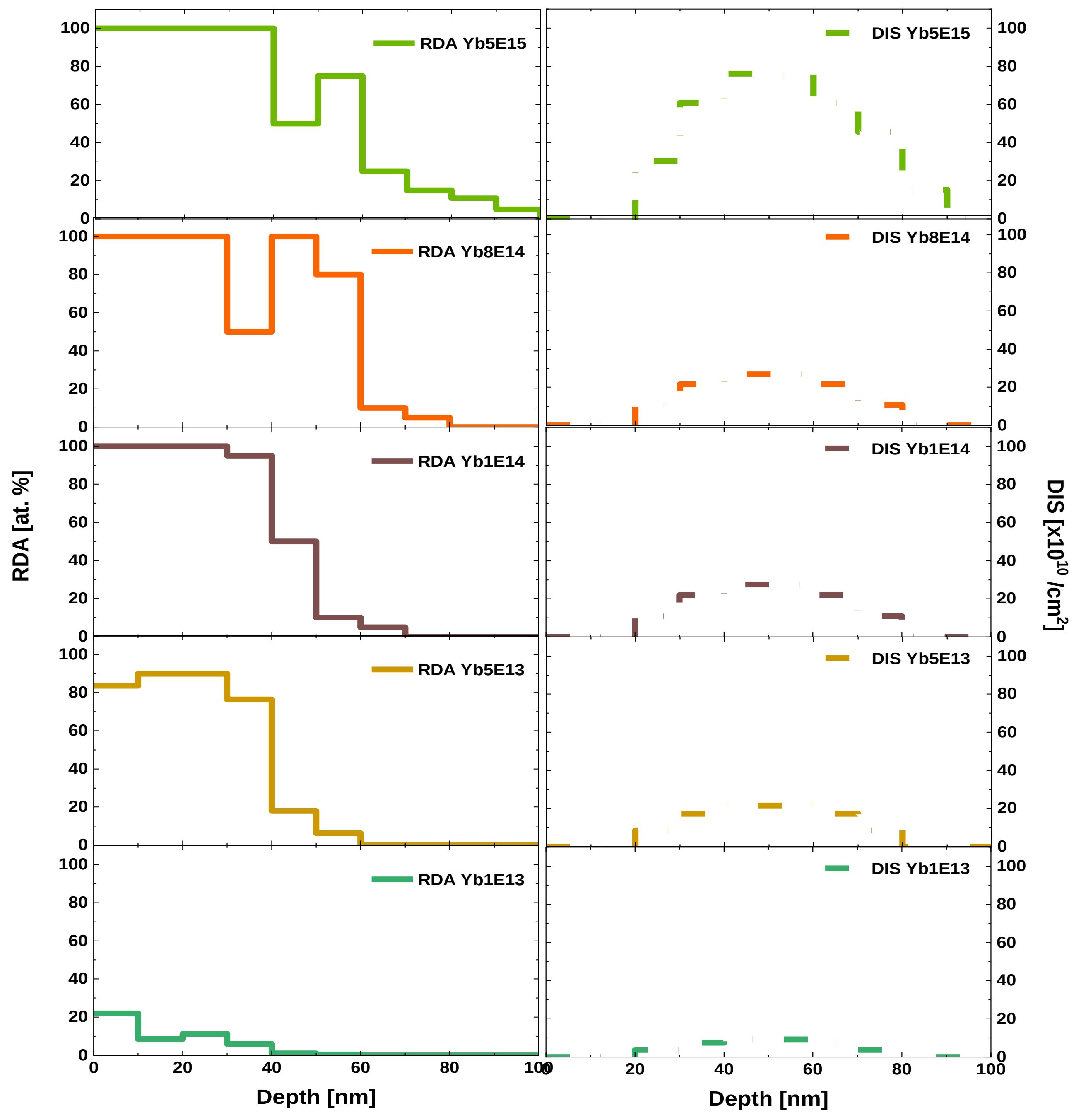
Rutherford Backscattering Spectrometry (RBS/c)



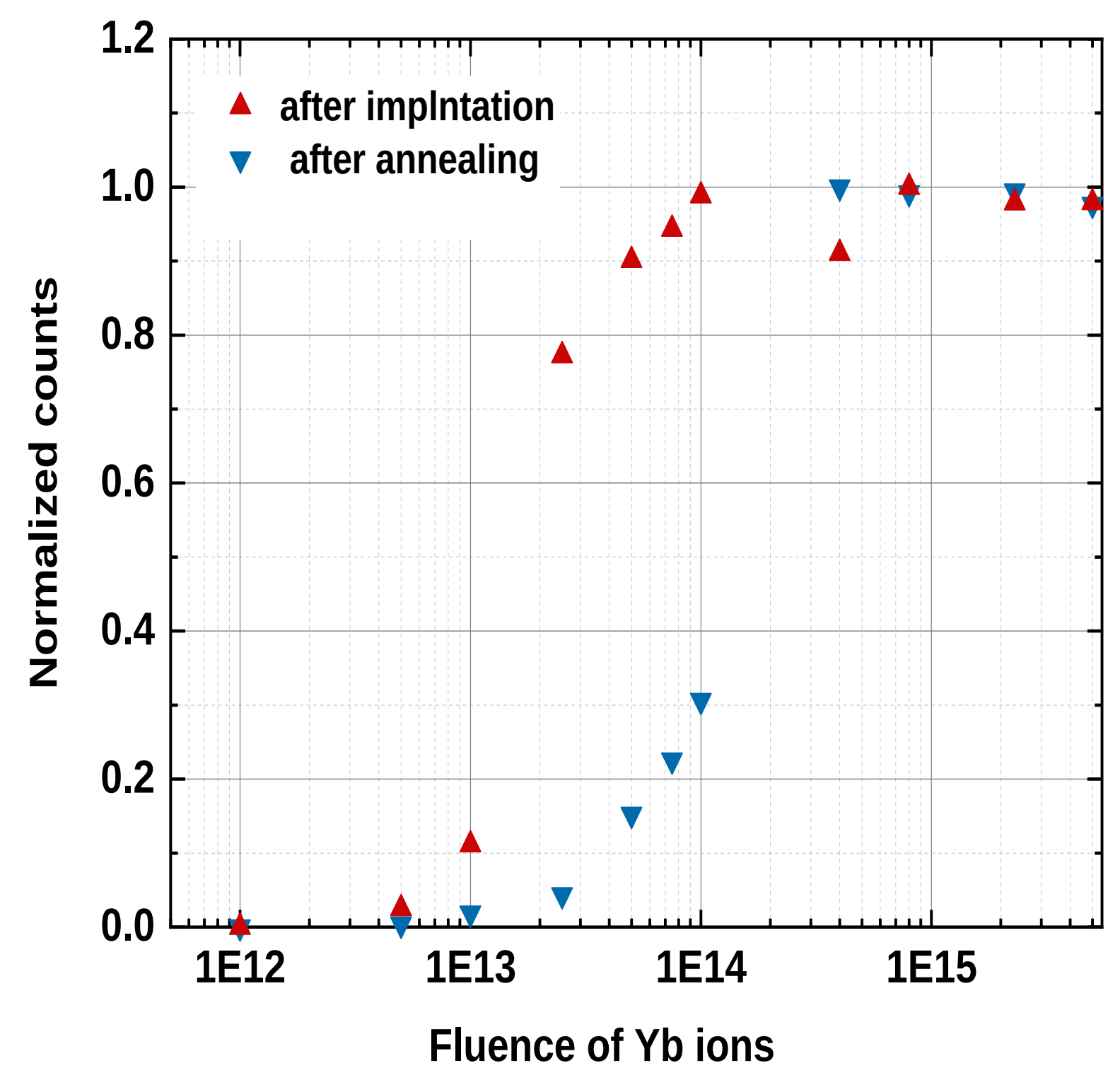
Random and aligned RBS spectra for β-Ga_2O_3 implanted with Yb . The solid lines show the results of MC simulations of the spectra



Random and aligned RBS spectra for β-Ga_2O_3 implanted with Yb annealed in oxygen at 800°C for 10 min.



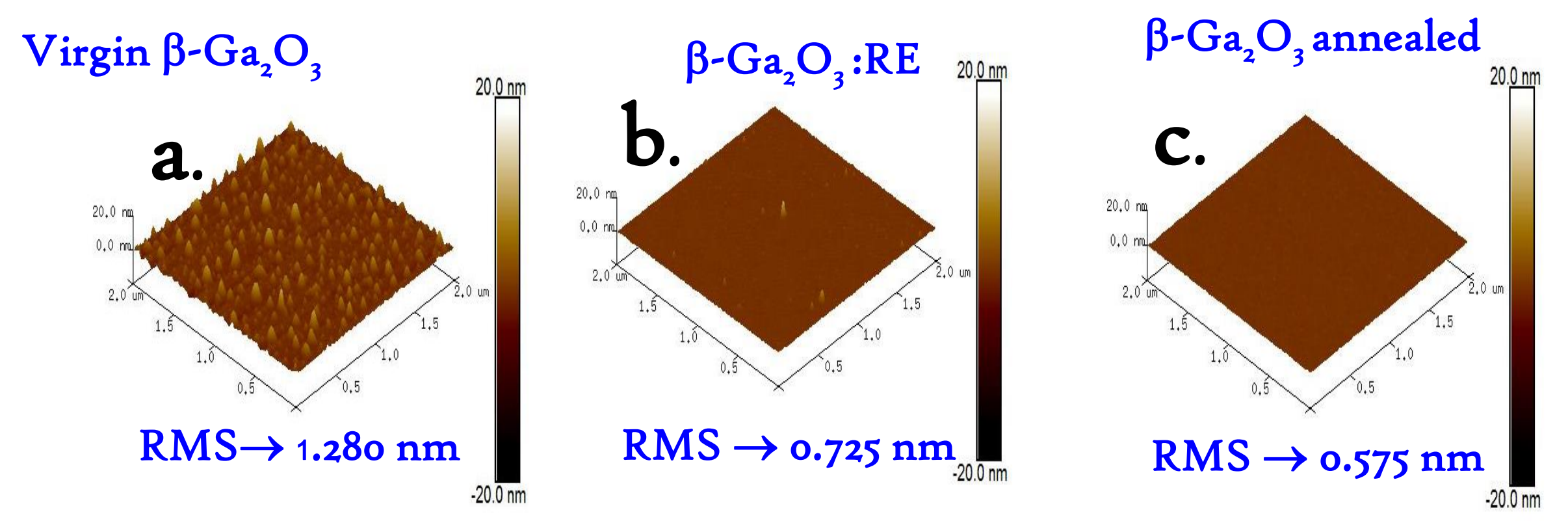
Distribution of Randomly Displaced Atoms (RDA) and Dislocations, extended defects (DIS) defects for Yb implanted β-Ga_2O_3 obtained by McChasy Simulations



Dependence of counts with the increase of ion fluence

- Increase of damage peak with ion fluence
- Starting from 4e14 at/cm2 the damage peak is doubled
- RTA in Oxygen at 800°C for 10 min.
- After annealing, decrease in intensity of the damage peak
- Defect structure formed near the surface at higher doses (4e14 at/cm2) is resistant to annealing, while the deeper defect structure disappears after annealing
- Yb ions after implantation into ($\bar{2}$**01**) oriented β-Ga2O3 occupy interstitial positions in matrix. Their positions remain unchanged following annealing

Atomic Force Microscopy (AFM)



AFM images of a)virgin β-Ga_2O_3 , b) implanted with Yb 1e14 atoms/cm² and c) annealed in oxygen at 800°C for 10 min.

- Virgin sample showed roughness of 1.280 nm indicated as RMS.
- After ion implantation, the roughness decreased → amorphization of the surface
- Further decrease in roughness to 0.575 nm after the annealing.

Conclusions

- Rutherford backscattering spectrometry in channeling mode was used to assess the post-implantation damage and post annealing recovery of the crystal structure of ($\bar{2}$**01**) oriented β-Ga_2O_3 implanted with RE.
- The RBS/c studies supported by the McChasy simulation show that above the critical fluence (2e14 Yb ions/cm2) the plastic deformation occurs in the most distorted region.
- Above the threshold for plastic deformation, two separate damage zones are visible
- Annealing in the oxygen atmosphere at 800°C for 10 minutes reduces damage for the lower used doses
- The complete recovery is observed for the samples implanted with low doses up to 2.5 e13 at/cm²
- The defect structure formed near the surface, visible for higher doses (starting from 4e14 at/cm2) is resistant to annealing, while the deeper created defect structure disappears after annealing. It suggests that the deeper damage zone is related to phase transformation [2]. The damaged region closer to the surface is most likely associated with amorphization [3]
- The AFM images show the decrease of roughness after implantation and annealing associated with amorphization of the surface at a particular fluence.
- According to our previous findings [4], the post-implantation damage in ZnO:RE is lesser as compared to β-Ga_2O_3 :RE in 010 orientation.

References

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