Nitrides vs Oxides: Ion-induced Damage Formation in GaN and Ga_2O_3

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The damage accumulation in three gallium compounds: α-Ga_2O_3, β-Ga_2O_3 and GaN during P ion irradiation at room temperature was experimentally studied and compared. The main differences in the radiation accumulation of structural defects in these semiconductors are revealed. We conclude that GaN and α-Ga_2O_3 are much more radiation resistant when irradiated with ions of medium masses than β-Ga_2O_3. This study builds upon our previous works on radiation damage in β-Ga_2O_3 [1,2].

Experimental

All epilayers have been grown on *c*-plane sapphire substrates, GaN by MOCVD, corundum α-Ga_2O_3 in hot-wall HVPE reactor. Monoclinic β-Ga_2O_3 was commercial specimen cut from single crystal edge-defined film-fed grown by Tamura Corporation. Samples have been irradiated using 500 kV HVEE implanter by 40 keV P^+ ions in a wide dose range. All the implants were carried out at room temperature (RT) and at 7° off the channeling directions. The ion doses were normalized to the average number of displacements per atom (DPA). Values of DPA were calculated using TRIM code (version SRIM 2013) [3] with effective threshold energies for atomic displacements of 25 eV for all Ga, O and N sub-lattices. Implantation-produced disorder was measured by Rutherford backscattering/channeling (RBS/C) spectrometry with 0.7 MeV $^4He^{2+}$ ions incident along the channeling direction and backscattered to 103°. The effective number of scattering centers (referred to below as "relative disorder") was deduced from RBS/C spectra using one of the conventional algorithms [4].

The parameters of irradiations used in this study are presented in Table 1.

Table 1. Irradiation parameters.

Target	Fluence range 10^{14} cm^{-2}	Dose range DPA	Flux 10^{12} cm^{-2}×s^{-1}	Dose rate 10^{-3} DPA×s^{-1}	1 DPA 10^{14} cm^{-2}
α-Ga_2O_3	0.9-43.3	0.15-6.9	1.51	2.4	6.3
β-Ga_2O_3	0.9-11.1	0.15-1.8	1.51	2.4	6.3
GaN	5-150	1.0-29	1.9	3.6	5.0

RBS/C Spectra

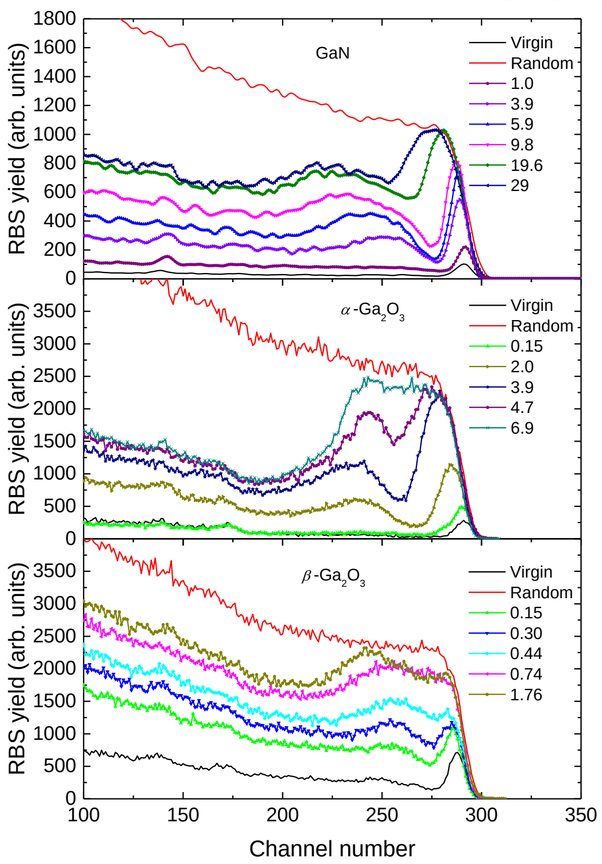

Fig. 1. RBS/C spectra obtained from (a) GaN, (b) α- and (c) β-Ga_2O_3 after implantation with 40 keV P ions to different doses as indicated in the legends.

For all compounds, at low DPA disorder depth profiles look similar, despite quite different doses needed to obtain measurable change in the backscattered yield. Initially surface peak starts to increase, and then second one appears in the crystal bulk. However, with a dose increase, all three materials show a drastically different behavior in damage accumulation, as shows in Fig. 3-5.

Depth profiles

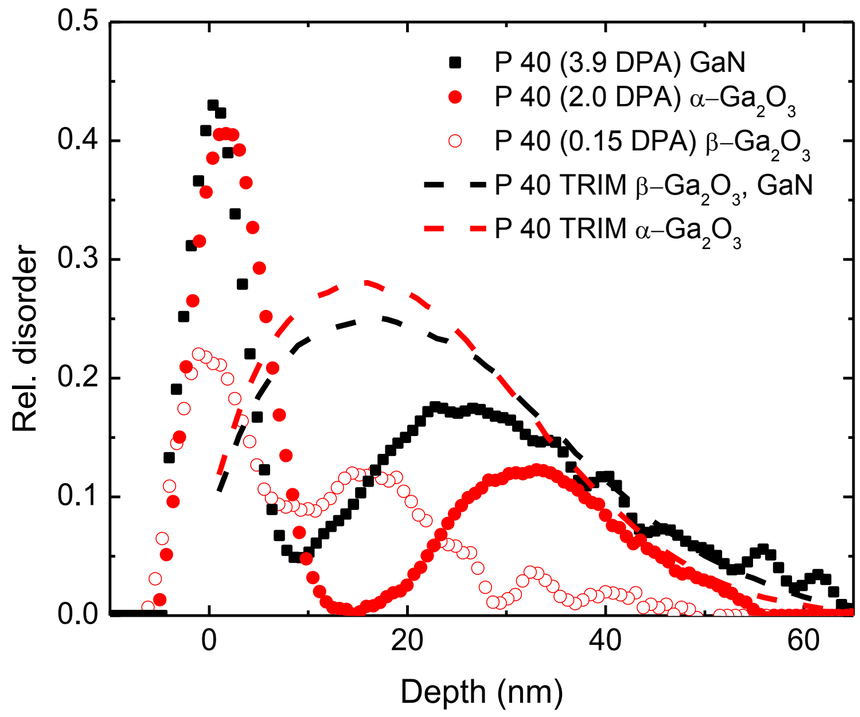

Fig. 2. Relative disorder *vs*. depth for GaN, and α- and β-Ga_2O_3 targets. Vacancy generation functions are shown in arbitrary units by dashed lines. See inset for details.

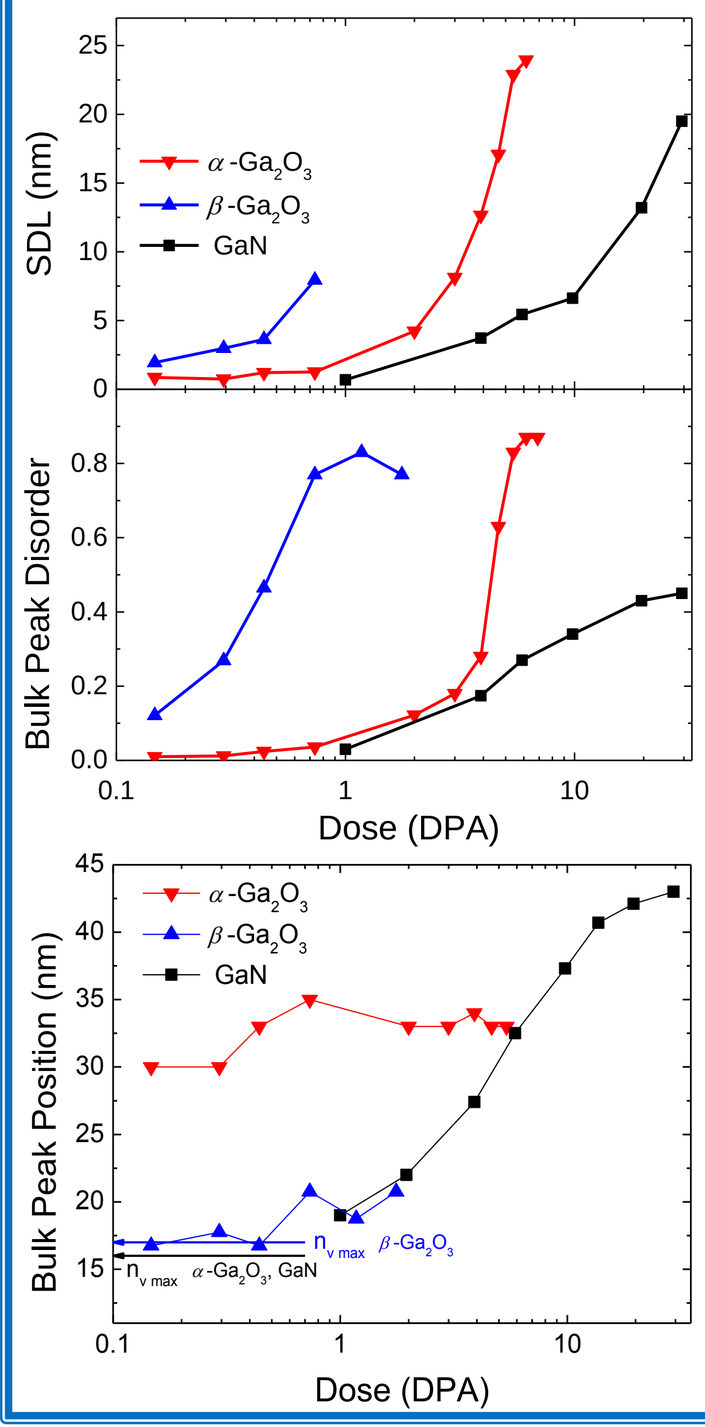

Fig. 3. Dose dependence of thickness of the surface disordered layer in GaN as well as α– and β-Ga_2O_3 implanted at RT with 40 keV P ions.

Fig. 4. Dose dependence of bulk defect peak height in GaN as well as α– and β-Ga_2O_3 implanted at RT with 40 keV P ions.

Fig. 5. Bulk peak position in GaN and both Ga_2O_3 polymorphs bombarded at RT by 40 keV P ions. The arrows indicate positions of maxima of primary defects generation functions in gallium compounds as calculated by TRIM code simulations.

Conclusions

- Metastable α-Ga_2O_3 has been shown to have a high radiation damage resistance in comparison to β-Ga_2O_3.
- Damage accumulation rate in the crystal bulk and at the surface of β-Ga_2O_3 is about an order of magnitude higher than those of α-Ga_2O_3 and GaN.
- In the β-Ga_2O_3 BDP is situated at the position of maximum of primary defect generation, while in α-Ga_2O_3 – near the maximum of implanted atom distribution. The position of the maximum of BDP formed in β-Ga_2O_3 and α-Ga_2O_3 only slightly changes with the ion dose, in contrast to GaN.
- The bulk defect peak saturation level for both Ga_2O_3 polymorphs is approximately twice higher than that for GaN (0.9 vs. 0.45).

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3. Ziegler, J. F.: SRIM-2013 software package, available online at http://www.srim.org.
4. Schmid, K. Radiat. Eff. 17, 201 (1973).