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Structure and optical properties of sapphire implanted with boron at room temperature and 1000 °C

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Abstract

Many previous studies of ion-implanted sapphire have used gas-forming light ions or heavier metallic cations. In this study, boron (10^{17} cm^{-2}, 150 keV) was implanted in *c*-axis crystals at room temperature, 500 and 1000 °C as part of a continuing study of cascade density and "chemical" effects on the structure of sapphire. Rutherford backscattering-ion channeling (RBS-C) of the RT samples indicated little residual disorder in the Al-sublattice to a depth of 50–75 nm but almost random scattering at the depth of peak damage energy deposition. The transmission electron micrographs contain "black-spot" damage features. The residual disorder is much less at all depths for samples implanted at 1000 °C. The TEM photographs show a coarse "black-spot damage" microstructure. The optical absorption at 205 nm is much greater than for samples implanted with C, N, or Fe under similar conditions.

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Keywords: Ion implantation; Sapphire, Defect structure

1. Introduction

Many details of the defect structure produced by ion implantation of sapphire (single crystal α-Al_2O_3) have been studied and a general understanding has been achieved. Sapphire exhibits essentially no deviation from stoichiometry and limited solubility of impurities. The nonequilibrium introduction of implanted species requires the formation of second phases and/or defect-impurity complexes that compensate for unbalanced charges.

Implantation of inert gases at fluences $\geqslant 10^{17}$ ions cm^{-2} causes blisters and exfoliation of the surface [1]. Transmission electron microscopy has detected bubbles in RT nitrogen-implanted sapphire at fluences as low as 3×10^{16} N cm^{-2} [2]. This band of bubbles causes de-channeling in the RBS-C spectra. Blistering and exfoliation of the surface have been reported for RT implantation of 2×10^{17} N cm^{-2} [3]. Alves et al. detected a second source of de-channeling in the Al-sublattice at the depth of the Al recoils and suggested that it might be due to Al-interstitials [4].

Many implanted cations form nanometer-sized metallic particles at fluences greater than about 3×10^{16} ions cm^{-2}. As an example, as much as 50% of iron is in this form for implantations fluences of 10^{17} Fe cm^{-2} [5]. The remaining Fe resides in the valence states of Fe^{2+} and Fe^{4+} that are associated with oxygen vacancies that contain trapped electrons (i.e. F- and F^+-centers).

A study of boron implantation is of interest for several reasons. The usual valence is 3+, the same as Al, thus it might replace Al on the Al-sublattice. The damage cascades for light ions differ significantly from those of heavier ions. Simulations using SRIM 2004 show that the displaced Al and O and the implanted B exhibit negative skewness of the range distributions, whereas, implantation of heavier

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ions produce a more symmetric distribution. There are few recoils beyond the range of the light ions but significant recoils at depths greater than the range of the heavier ions. These calculations suggest that there should be little damage beyond the range of the B ions; there should be many Al and O recoils but few B ions near the surface; and, the B ions may be closely associated with the vacancies created by the knock-ons.

2. Experimental procedures

High purity single crystals of α-Al_2O_3 (Crystal Systems, Inc., Bedford, MA) with optically polished surfaces parallel to {0001} planes were implanted with 1×10^{17} B cm^{-2} (150 keV) at RT, 500 and 1000 °C. The beam was tilted 7° from the *c*-axis to prevent channeling and the current density was kept below 2 μA/cm^2 to reduce beam heating effects. RBS-C measurements were performed with 2.0 or 2.65 MeV He^+ beams and silicon barrier detectors placed at 140° and 180° in the standard IBM geometry. Optical absorption measurements were made with a Varian Cary 5G IR–VIS–UV spectrometer. Cross-sectional TEM specimens were prepared by mechanical polishing and focused ion beam (FIB) thinning. The specimens were examined at 200 kV with HF-2000 and HD-2000 STEM.

3. Discussion of results

The RBS-C spectra from the *c*-axis direction of samples show that the unimplanted crystals contain very little disorder, Fig. 1. The spectra taken with the ⟨0001⟩ axis aligned with the He^+ beam for the sample implanted at room temperature show increasing de-channeling at a depth of about 50 nm to almost random values at depths of 200–300 nm, Fig. 1. Spectra taken with $\langle 02\bar{2}1\rangle$ aligned show similar de-channeling effects which suggest a random distribution of the damage (or oriented parallel to the surface). The random values in the region of the B profile could indicate the presence of a buried amorphous layer or a high density of defects without the complete loss of crystallinity.

The cross-sectional TEM photographs of the RT implanted samples, e.g. Fig. 2, and SAD electron diffraction pattern, Fig. 3, of the implanted regions give no indication of an amorphous structure in the implanted region. The "damage" or implantation-induced defect structure extends to about 400 nm or equal to about $R_p + 2\Delta R_p$

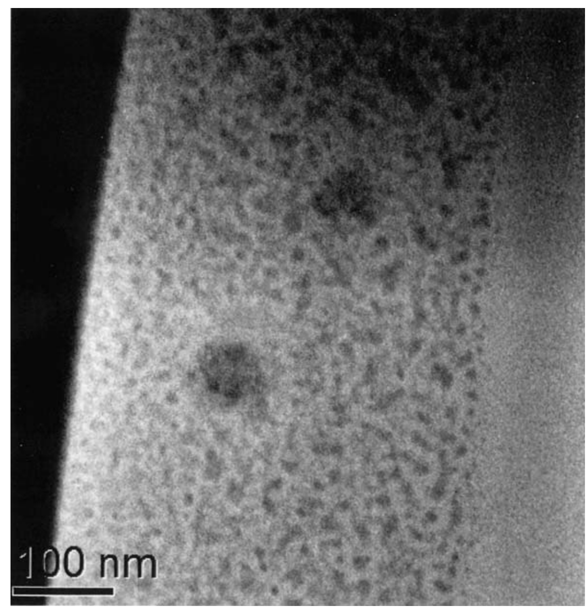

Fig. 2. Cross-sectional TEM photograph for sample implanted at room temperature. An abrupt transition between the implanted and unimplanted regions is visible.

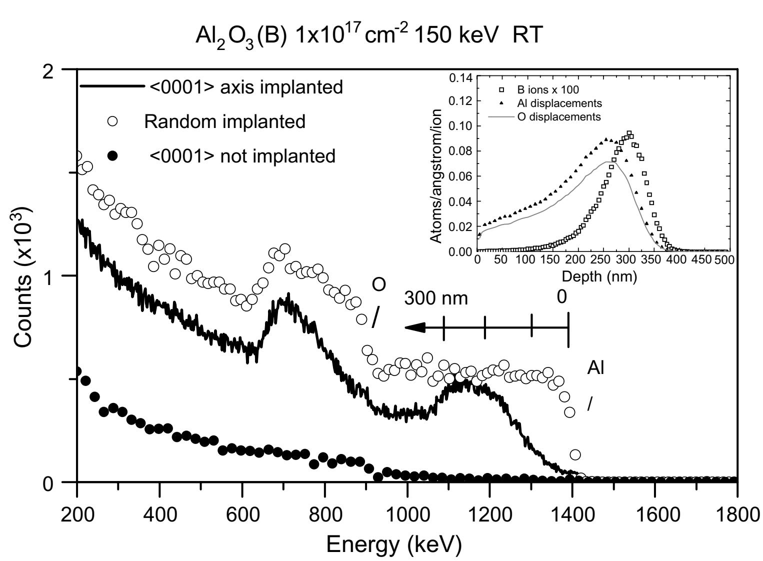

Fig. 1. Random and *c*-axis aligned RBS spectra obtained with 2.65 MeV He^+ for the sample implanted with 1×10^{17} B cm^{-2} (150 keV) at room temperature. The maximum of the damage distribution is centered at 300 nm. The insert shows the B and damage profiles predicted by SRIM.