Electron nanoprobe analysis of H_2^+/He^+-irradiated alumina to understand the space weathering process

*Yohei Igami[1], Shunsuke Muto[1], Masahiro Ohtsuka[1], Aki Takigawa[2], Akira Miyake[2]

1. Institute of Materials and Systems for Sustainability, Nagoya University, 2. Graduate School of Science, Kyoto University

Minerals on the surface of celestial bodies free from atmosphere can be subject to so-called space weathering, exhibiting characteristic structures different from terrestrial weathering. Based on the analyses of minerals brought back from the asteroid Itokawa by the Hayabusa spacecraft, the space weathering on the Itokawa surface has been suggested to be mainly caused by solar-wind irradiation mostly of hydrogen and helium ions [1, 2]. In addition, dust grains in the interstellar medium are amorphized by collision of hydrogen and helium ions accelerated by shock wave propagation originating from a supernova explosion [3].
In this study, we employed H_2^+/He^+ irradiation to alumina (α-Al_2O_3), which was analyzed in nanometer scale using a scanning transmission electron microscope equipped with electron energy loss spectrometer (STEM-EELS). The target mineral, alumina, having a most basic oxide crystal structure (corundum structure), is a common mineral found around dying stars and in presolar grains identified from primitive chondrites [4].
The H_2^+/He^+ irradiation was conducted at the Wakasa-wan Energy Research Center. 20 keV He^+ and 40 keV H_2^+ were irradiated to two target alumina samples, respectively, both at the dose of ~10^{18} ions/cm^2. Cross-sectional ultra-thin sections were prepared from the irradiated samples using a focused ion beam (FIB, HITACHI ETHOS NX5000), the sections of which were analyzed with a 200 kV-TEM (JEOL JEM-2100) to obtain BF/DF-TEM images and STEM-EEL spectrum imaging (SI) data.
High densities of dislocations, nano-voids, and nano-cracks due to void coalescence were observed over the area from the surface to the depth of 300 nm for both the H_2^+-irradiated and He^+-irradiated samples. The SI dataset from the H_2^+-irradiated sample alone indicated generation of O-H species accompanied by reduction of Al, highly localized adjacent to the nano-cracks. This suggests that a chemical reaction between hydrogen and alumina selectively occurred on the unstable surface along the nano-cracks. The EEL spectra from the He^+-irradiated sample, on the other hand, exhibited small He-K edges over the irradiated region, and their peak positions were slightly shifted from the reference position toward the higher energy side. The total helium gas volume fraction incorporated was estimated to be less than 3% of the total void volume, using the helium gas pressure and amount evaluated from the peak shift and intensity of the He-K edge. The injected helium ions likely clustered to form bubbles in the α-alumina, almost all of which escaped away from the thin section of ~100 nm.

References

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