H^+ irradiation experiments to pyroxene and olivine for simulating space weathering by solar wind.

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The space weathering observed on the surface of asteroids is caused by micrometeorite bombardment, solar wind irradiation, and cosmic ray irradiation [1-3]. From the analysis of the regolith particles that Hayabusa spacecraft recovered from an S-type asteroid, 25143 Itokawa, the evidences of the space weathering on Itokawa, such as vesicle structures (blisters) and amorphous layers (space-weathered rims), have been confirmed [4-6]. It has been proposed that the blisters and space-weathered rims might have been formed mainly through solar wind irradiation rather than by micrometeorite bombardment [4].
Solar wind consists of 1 keV H^+ ions (95.41 %) and 4 keV He^+ ions (4.57 %) [7]. Irradiation experiments of 1 keV H^+ ions and 4keV He^+ ions to minerals consisting of the Itokawa regolith are important in order to evaluate the influence of solar-wind irradiation on formation of the blisters and space-weathered rims on the Itokawa regolith. Many irradiation experiments of 4 keV He^+ ions have been already performed, but the irradiation experiment of 1 keV H^+ ions has been hardly carried out [e.g., 8].
In this study, we examined the performance of the ion-irradiation equipment under development in ISAS/JAXA and then performed the irradiation experiments of 1 keV H^+ to orthoenstatite and olivine with different compositions, which are the major minerals consistent of ordinary chondrites.
We measured the shape and size of the ion beam by moving the one-dimensional multipoint Faraday cup. The half maximum full-width of the ion was 1.2-2.7 mm and the current density was 0.52-1.22 $\mu m/cm^2$. We verified the stability of the ion beam at least for ten hours. The confirmed performance of the ion irradiation system enables the 1 keV H^+ irradiation with a dose of at least 10^{17} ions/cm^2.
As targets of irradiation experiments, we prepared rectangular samples of orthoenstatite (En_{99}, Tanzania), forsterite (Fo_{100}, synthetsis), and olivine (Fo_{92}, San Carlos). The sample size is 3 mm x 5 mm x 0.5 mm. We mechanically polished the samples (until 0.25 μm roughness) and performed the chemical polishing with colloidal silica to remove the damage layer of the surface. Finally, the surfaces of samples were cleaned by the ultrasonic cleaning. The irradiated samples were observed with an FE-SEM (JEOL JSM 7001F). FIB-lift-out sections were prepared with FE-FIB (FEI Helios NanoLab 3G CX) and observed with FE-TEM (JEOL JEM 2100F).
On the surface of the irradiated enstatite (10^{17} ions/cm^2), an amorphous layer (26 nm) was observed. The thickness of the amorphous layer is consistent with the width of the damage layer promoted by 1keV H^+ irradiation calculated with the SRIM [9]. However, amorphous layer was also observed in the unirradiated area, which indicates that the damage due to the mechanical polishing in the sample preparation had not been removed by the chemical polishing. The blisters of 30 nm in diameter and 3×10^{10} cm^{-2} in density, and the sharper boundary of amorphous layer were observed only in the irradiated area. Compared with the Itokawa particles [4-6], the irradiated enstatite sample and Itokawa particles show similar size, density, and formation depth of the blisters, although the thickness of the amorphous layer of the irradiated enstatite (26 nm) is less than Itokawa enstatite particles (40-50 nm). The thicker amorphous layers on the Itokawa particles are due to deeper implantation depth of 4 keV He^+ than 1 keV H^+ [4,9]. These results suggest that the blisters on the surface of Itokawa particles were mainly formed by 1 keV H^+ ion

irradiation, but the thickness of the amorphous layer was due to 4 keV He^+ irradiation.

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