H^+ ION IRRADIATION EXPERIMENTS OF ENSTATITE: SPACE WEATHERING BY SOLAR WIND.

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Introduction: Space weathering occurred on air-less bodies such as asteroids is caused by micrometeorite bombardment and irradiation of solar wind and/or cosmic ray [1-3]. The analysis of the regolith particles returned from an S-type asteroid Itokawa shows evidences of the space weathering on Itokawa, such as vesicle structures (blisters) in partially amorphous layers called space-weathered rims [4-6]. It has been proposed that the blisters and space-weathered rims might have formed mainly by solar wind irradiation rather than by micrometeorite bombardment [4].

The solar wind consists of typically 1 keV H^+ ions (95.41 %) and 4 keV He^{++} ions (4.57 %) [7]. Irradiation experiments of 1 keV H^+ ions and 4 keV He^+ ions to minerals consisting of the Itokawa regolith are important in order to evaluate the influence of solar-wind irradiation on the formation of blisters and space-weathered rims on the Itokawa regolith. Many irradiation experiments of 4 keV He^+ ions have been already performed [e.g., 8], but the structural changes by irradiation of 1 keV H^+ ions have been poorly understood. In this study, we performed irradiation experiments of 1 keV H^+ to orthoenstatite, which are the major minerals consisting of ordinary chondrites.

Experiments: As targets for irradiation experiments, we prepared rectangular samples of orthoenstatite (En_{99}, Tanzania). The sample size is 3 mm x 5 mm x 0.5 mm. We mechanically polished (until 0.25 μm roughness) and performed the chemical polishing with colloidal silica to remove the damage layer of the surface.The low-energy ion irradiation equipment developed in ISAS/JAXA was used in the experiments. The polished enstatite samples were irradiated with 1 keV H^+ ions with dose of 10^{16}, 10^{17}, 3×10^{17}, and 10^{18} ions/cm^2. The surface structures of irradiated samples were observed with an FE-SEM (JEOL JSM 7001F). Focused ion beam (FIB) lift-out sections were prepared with an FE-FIB (FEI Helios NanoLab 3G CX) and observed with a field-emission transmission electron microscope (FE-TEM; JEOL JEM 2100F).

Results and discussion: No change of the surface structure was observed on the irradiated enstatite with dose of 10^{16} ions/cm^2. Blisters of 60–110 nm in diameter and partially amorphous layers of ~30 nm in thickness were observed on the surface of the enstatite samples irradiated with dose of higher than 10^{17} ions/cm^2. This indicates that the threshold dose of blistering and amorphization is ~0.5×10^{17} ions/cm^2. The blisters grew with dose from 1×10^{17} to 3×10^{17} ions/cm^2 but shrank after irradiation of 10^{18} ions/cm^2. The blister size change with dose may be caused by change of the crystal structure due to ion implantation.The implanted hydrogen diffuses within the enstatite and the internal gas pressure increases to form blisters [9]. Further irradiation destroyed the crystal structure, increased the diffusion rate of a hydrogen gas, and reduced the retention of gas.

The thickness of the amorphous layer of the irradiated enstatite is less than Itokawa enstatite particles (30–60 nm). The thicker amorphous layers on the Itokawa particles may be due to deeper implantation depth of 4 keV He^+ ions than 1 keV H^+ ions [4,10]. The blisters formed by irradiaton with dose of 10^{18} ions/cm^2 locate immediately beneath the surface, and their size is tens nm (Fig. 1), which are clearly different from irradiated enstatite by higher energy hydrogen ions [10] and very similar to Itokawa particles [4-6]. These results indicate that the blisters on the surface of Itokawa particles mainly formed by implantation of the solar wind 1 keV H^+ ions, whereas the thickness of the amorphous layer is explained by irradiation of the solar wind 4 keV He^{++} ions.

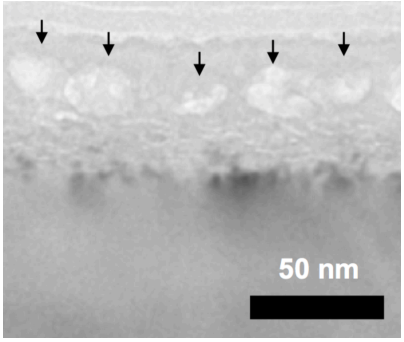

Fig. 1: TEM image of an irradiated enstatite surface (10^{18} ions/cm^2). Arrows indicate bubbles/blisters near the surface.

References: [1] Pieters C. T. et al. (2000) *MAPS* **35**, 1101. [2] Hapke B. (2001) *J. Geophys. Res*. **106**, 10039. [3] Clark B. E. et al. (2002) in *Asteroid Space Weathering and Regolith Evolution, Asteroids III*., 585. [4] Noguchi T. et al. (2014) *MAPS*. 49, 188-214. [5] Matsumoto T. et al. (2015) *Icarus* 257, 230-238. [6] Matsumoto T. et al. (2016) *GCA*. **187,** 195. [7] Reisenfeld D. B. et al. (2007) *Space Sci*. **130**, 79. [8] Demyk K. et al. (2001) *A&A* **368**, L38. [9] Muto, S. and Enomoto, N. (2005) *Materials trans*. **46**, 2117. [10] Uchida H. et al. (2017) *JpGU*, abstract PPS10-01. [11] Ziegler J. F. et al. (2008) *The stopping and range of ions in matters*.