Hydrogen ion irradiation of various minerals simulating the space weathering.

Haruka Uchida[1], *Aki Takigawa[1,2], Akira Tsuchiyama[1], Kohtaku Suzuki[3], Yoshinori Nakata[3], Akira Miyake[1], Akiko Takayama[1]

1. Division of Earth and Planetary Science, Kyoto University, 2. The Hakubi Center for Advanced Research, Kyoto University, 3. The Wakasa Wan Energy Research Center

The space-weathering on air-less bodies is caused by solar-wind irradiation and bombardment of micrometeorites [1, 2]. The space-weathered rims such as amorphous layers and blisters on the surface were observed on regolith particles from Lunar and asteroid Itokawa [3, 4]. There are limited irradiation experiments of minerals by hydrogen ions, which is the dominant gas species in the solar wind [e.g., 5]. In this study, we performed irradiation experiments of hydrogen ions to carious minerals to examine the difference of surface structure changes due to ion irradiation between materials with different crystal structures and chemical compositions.
The target materials for ion irradiation are forsterite (Fo_{100}, syn.), olivine (Fo_{92}, San Carlos, USA) , enstatite (En_{99}, Tanzania), spinel($MgAl_2O_4$, syn.), corundum (Al_2O_3, syn.), enstatite glass($MgSi_{0.97}Al_{0.03}O_3$, syn.), serpentine (Mg#=0.98, South India) , pyrrhotite ($Fe_{0.90}S$, Chihuahua, Mexico), iron meteorite ((Fe, Ni), Nantan meteorite (ⅢCD)). Samples are mechanically polished and cut into 3×5×0.5 mm rectangles. The damaged layers due to polishing were removed by chemical polishing with colloidal silica.
Experiments were carried out with the low-energy ion implantation equipment in The Wakasa Wan Energy Research Center. The samples were irradiated by 40 keV H_2^+ ions (corresponding to 20 keV H^+ ions) with the doses of 10^{16}, 10^{17}, and 10^{18} ions/cm^2. The cooling stages were used for experiments longer than 60 min to keep the samples at room temperature. We observed the surfaces of the irradiated samples with with an FE-SEM (JEOL JSM 7001F). FIB-lift-out sections were prepared with an FE-FIB (FEI Helios NanoLab 3G CX) and observed with FE-TEM (JEOL JEM 2100F).
We observed forsterite, olivine, and pyrrhotite irradiated by hydrogen ions with a dose of 10^{18} ions/cm^2, and irradiated enstatite with dosed of 10^{17} and 10^{18} ions/cm. The TEM observation showed that vesicles were observed under blisters on irradiated enstatite with a dose of 10^{18} ions/cm. The crystal structure of orthoenstatite remained in the very surface of the blister skin. An amorphous structure was observed just above the vesicles. The irradiated enstatite with a dose of 10^{17} ions/cm only showed a slight deformation of the crystal structure. These observation shows that the threshold dose of the enstatite amorphization by 20 keV hydrogen ion irradiation is between 10^{17} and 10^{-18} ions/cm^2. We did not confirm completely amorphous areas in FIB lift-out sections of the irradiated forsterite, olivine, and pyrrhotite, while blister skins of irradiated serpentine were amorphous.
Diffusion rates of hydrogen in silicates and oxides with ionic bonds such as enstatite, forsterite, and olivine are much slower than the experimental duration [e.g., 6]. Thus, the implanted hydrogen may move through vacancies formed by irradiated ions and recoiled atoms, and then bubbles nucleate and grow to form the blisters due to the high pressure of the hydrogen gas [7]. On the other hand, hydrogen diffusion rates in amorphous enstatite and iron meteorite may be very rapid compared to the experimental duration [13, 14]. Hydrogen escaped from the surfaces and could not accumulate to form blisters on enstatite glass and iron meteorites.
We constrained on the threshold dose of the enstatite amorphization by hydrogen ion irradiation. The difference of the threshold doses of blister formation and amorphization, and of the blister structures indicates that we can evaluate the solar-wind irradiation age of the asteroidal regolith more quantitatively form the combination of blister and crystal structures of multiple minerals consisting one regolith.

[1] Hapke (2001) JGR, 106, E5, 10039-10073. [2] Clark B. E. et al. (2002) in Asteroid Space Weathering and Regolith Evolution, Asteroids III. pp. 585–599.. [3] Noguchi et al. (2014) MAPS, 49, 188-214. [4] Margolis et al. (1971) LPSC, 2, 909. [5] Demyk et al. (2004), A&A, 420, 233-243. [6] Stalder and Skogby (2003) PCM, 30, 12-19. [7] Muto and Enomoto (2005), Materials Trans., 46, 2117-2124. [8] Shang et al. (2009) GCA, 73, 5435-5443. [9] Hagi, Hayashi, and Ohtani (1978) J. Japan Inst. Metals, 8, 801-807.

Keywords: space weathering, asteroid, ion irradiation

