Space weathering structures on the surface micro-nano morphologies of Itokawa regolith particles.

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Introduction:

Surface morphologies of regolith particles of asteroid Itokawa have information about surface processes of a small asteroid without atmosphere. X-ray micro-tomography (CT) analysis on the three-dimensional (3D) shapes of the Itokawa particles revealed that some particles (~25 %) have rounded edges as well as angular edges [1]. The rounded edges are considered to be formed as a result of solar wind sputtering or mechanical abrasion as grains migrate due to micrometeoroid impacts to Itokawa. Micro-nano morphologies of their surfaces were observed using a field emission scanning electron microscope (FE-SEM) [2]. It was revealed that surfaces with angular edges have distinct structures such as sharp fine steps while surfaces with rounded edges have fainted structures such as ambiguous steps. These surfaces can be regarded as “fresh” and “matured” surfaces, respectively.

On the other hand, transmission electron microscope (TEM) analysis found surface modifications of the particles within <~100 nm in depth, indicating space weathering by solar wind radiation [3,4]. Solar wind noble gas implantation to Itokawa particles was also detected by noble gas isotope analysis [5]. Based on comparison between the CT and TEM analyses, both surfaces with rounded and angular edges have relatively thick modified structures, which should be exposed relatively long durations by the solar wind, and there might not be correlation between the edge roundness and the exposure duration by the solar wind [6]. The rounded edges might have been formed by mechanical abrasion rather than sputtering by the solar wind. However, direct comparison between the surface structures by TEM with nm scale and CT with several μm scale is not enough for detailed discussion. So, it is necessary to observe surface morphologies formed by solar wind irradiation at FE-SEM scale, which can identify structures of several tens nm to few μm.

In this study, we compared the surface micro-nano morphologies by FE-SEM [2] with the surface modification structures by TEM [4]. Ion irradiation experiments were also performed to identify morphological features of the surfaces irradiated by the solar wind on regolith particles.

Experiments:

The irradiation experiments were performed at The Wakasa Wan Energy Research Center, Tsuruga, Japan. An olivine sample from Sri Lanka with the composition of Fa_{70}, which is almost the same as Itokawa regolith olivine ($Fa_{28.6\pm1.1}$) [7], was chosen for an analog of Itokawa regolith. A single crystal of the olivine sample was crushed and fragments with similar sizes as the Itokawa particles (~50 to 100 μm?) were picked up. The olivine fragments were placed on Au plates and irradiated with H^+, H_2^+ and He^+ ions accelerated at 10 to 50 keV with fluence of 1×10^{16}, 1×10^{17} for all ions and 1×10^{18} ions/cm^2 for H_2^+ and He^+ ions. Morphological changes of olivine surfaces were observed using FE-SEM (JSM7001F at Kyoto University) before and after the irradiation. The samples were not coated by any electric conductors. To avoid charge up effect during the FE-SEM observation, secondary electron (SE) images were obtained at a low accelerating voltage (2 kV) in vacuum for observation with high-resolution.

Results and Discussions:

Olivine samples irradiated at fluence of 1×10^{16} and 1×10^{17} ions/cm^2 did not show any noticeable morphological changes. On the other hands, samples irradiated by H_2^+ and He^+ ions at fluence of 1×10^{18} ions/cm^2 show numerous blister structures on their surfaces (Fig. 1). The blister sizes are several hundreds nm to 3 μm. Observation on broken blisters indicated that the blisters have vesicle structure. In previous irradiation experiments to a thin section of San Carlos olivine, appearance of abundant bubbles or voids beneath the surfaces was reported after He^+ irradiation [8]. The bubbles were suggested to be filled with He gas. Blisters observed in this study should have been also formed by nucleation and growth of vesicles filled with the gas beneath the surfaces.

In the previous TEM observation for ultra-thin sections of Itokawa regolith particles, vesicles were observed, which were probably formed by solar wind He implantation [4]. The morphology of the vesicles is similar to the blister structures. In the FE-SEM observation on Itokawa particle surfaces, some surfaces are covered with numerous convex structures several tens nm in size (Fig. 2). These structures are similar to blisters formed on the olivine sample by the He^+ irradiation experiments although the blister size on the olivine sample is larger than that of Itokawa particles. It was reported that the blister size increases with increasing the ion energy in previous experiments, where tungsten plates were irradiated with deuterium ions [9]. Therefore, the difference between blister sizes is due to the difference of the ion energy; energy of He^+ in the solar wind is ~4 keV and smaller than the energy in the present experiments. In fact, the vesicle size observed by TEM [4] is similar to the size of the blister structure on the Itokawa particle surfaces.

It is proposed that the surface modification structures including vesicles (blisters) on the Itokawa particles were formed by solar wind He^+ irradiation [4]. The fluence of 1 × 10^{17} and 1 × 10^{18} He^+ ions/cm^2 corresponds to the He^+ irradiation duration of ~500 and ~5000 years, respectively. As the blister structure was not formed by the fluence of 1 × 10^{17} ions/cm^2, the blisters on the Itokawa particles should be formed between 500 and 5000 years. Solar track density observed in an Itokawa particle with surface modification structure including vesicles suggests that the irradiation duration is the order of 10^4 years [4]. The irradiation durations deduced from the blister formation is consistent with this duration, and this confirms that the surface modification by space weathering should be produced in a very short duration compared with estimated residence time of regolith on the smooth terrain of Itokawa (<~3 Myr [5]).

The blister structure is present on the Itokawa particles both with rounded and angular edges. Accordingly, there is no correlation between roundness of edges and existence of the blister structure on the surfaces. This suggests that the rounded shapes of Itokawa particles would not have been caused by solar wind sputtering. Mechanical abrasion by seismic vibration of Itokawa might be main cause of the rounded edges of Itokawa particles, and this might occur for a long time (<~3 Myr [5]) during staying in the regolith. For future work, we plan to perform abrasion experiments using a shaker to evaluate the rate of ablation by seismic vibration on Itokawa.

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References: [1] Tsuchiyama A. et al. (2011) *Science, 333*, 1125-1128. [2] Matsumoto T. et al. (2012) *LPS XLIII*, 1659. [3] Noguchi T. et al. (2011) *Science, 333*, 1121-1125. [4] Noguchi T. et al. (2012) *Met. Planet. Sci. submitted.* [5] Nagao K. et al. (2011) *Science, 333*, 1128-1131. [6]T suchiyama A. et al. (2012) *this volume.* [7] Nakamura T. et al. (2011) *Science, 333,* 1113-1116. [8] Carrez P. et al. (2002) *Met. Planet. Sci, 37,* 1599-1614 [9] Wang W. et al., (2002) *Jornal of Nuclear Materials, 299*, 124-131

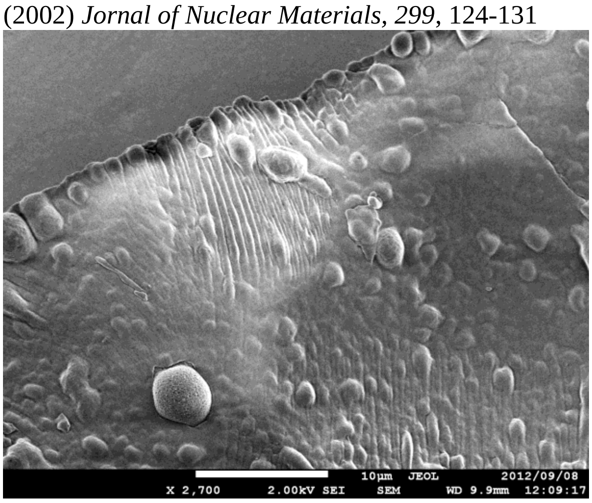

Figure 1: A SE FE-SEM image of blister structure on an olivine particle surface irradiated by 20 keV He^+ at fluence of 1 × 10^{18} ions/cm^2.

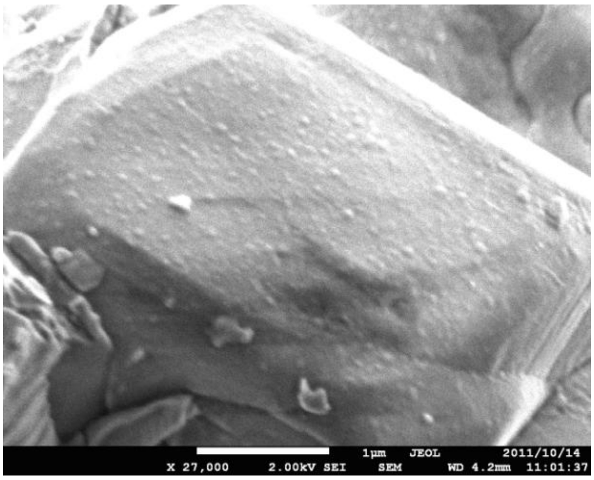

Figure 2: A SE FE-SEM image of blister structure on an Itokawa particle surface (RA-QD02-0033).