SPACE WEATHERING OF MAGNETITE SIMULATED BY PULSED LASER AND ION IRRADIATION EXPERIMENTS

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Introduction: Space weathering refers to the chemical, microstructural, and optical changes on the surfaces of airless planetary bodies caused by high-velocity micrometeoroid impacts and solar wind irradiation [1]. Space weathering may alter the spectral properties of airless surfaces by changing the spectral slope, darkening/brightening, and attenuating absorption bands in the visible and near-infrared. These spectral changes make it difficult to establish a link between meteorites and their parent bodies [2], and accurately characterize the mineralogical composition of these surfaces via remote sensing spectroscopy. Analyses of returned regolith samples and laboratory experiments simulating space weathering processes have concentrated on studying silicate minerals, the most abundant phases in lunar soils and ordinary chondrites. However, little is known about the space weathering of magnetite, which is an important mineral phase in carbonaceous chondrites [3], and that has been identified in returned samples from asteroid Ryugu [4,5,6,7,8], and on the surface of asteroid Bennu through remote sensing observations [9]. To better understand the response of magnetite under space weathering conditions, we simulated micrometeoroid bombardment and solar wind irradiation using pulsed laser and ion irradiation experiments, respectively.

Methods: We used synthetic magnetite powders with grain sizes <45 µm that were pressed into pellets at 1500 psi. To reproduce micrometeoroid bombardment on the magnetite pellets, we used pulsed-laser irradiation, employing an Nd-YAG laser with 3.5 mJ per pulse and pulse durations of 4-6 ns. To simulate solar wind irradiation, we performed 1 keV H^+ and 4 keV He^+ irradiation experiments using fluxes ~1 x 10^{13} ions/cm^2/s and total fluences of 8.7×10^{17} H^+/cm^2 and 3.6×10^{16} He^+/cm^2, equivalent to exposure times of ~750 years at 1 AU at the surface of asteroid Bennu, respectively. In addition, we conducted reflectance spectroscopy measurements in the visible near-infrared region (0.3-2.5 µm) for the laser and ion irradiated pellets. We analyzed the microstructural and chemical properties of individual magnetite grains after pulsed-laser and ion irradiation using transmission electron microscopy (TEM) and energy-dispersive X-ray spectroscopy (EDS).

Results and Conclusions: TEM analysis of the pulsed laser irradiated sample reveals the presence of a discontinuous crystalline rim in the outermost part of the magnetite grain with a thickness that varies from 5-15 nm. EDS observations show that this rim is enriched in Fe around 5 at% compared to the unaltered region. The 1 keV H^+ irradiated sample exhibits a crystalline rim in the outer 35 nm in the grain enriched ~20 at% in Fe compared to the unirradiated surface. However, we identified an increase of O in the outer 15 nm of the rim likely caused by atmospheric oxidation after the irradiation experiments. The 4 keV He^+ irradiated magnetite presents elongated structural defects in the upper 50 nm but no changes in the concentration of O and Fe were identified via EDS. No amorphization was observed in the pulsed laser or ion irradiated samples. Reflectance spectroscopy reveals that the 4 keV He^+ irradiated sample is darker than an unirradiated pellet used as a reference, whereas the pulsed laser irradiated magnetite is brighter. However, the most significant change is observed in the 1 keV H^+ irradiated sample, which is brighter than the unirradiated pellet in the visible wavelengths, reaching up to 2x the reflectance values of the unirradiated sample at the ~470-570 nm region. These results suggest that under space weathering, the concentrations of O and Fe in magnetite rims are altered along with its reflectance and spectral slope. Preliminary analysis of Ryugu regolith particles show the presence of a layer rich in metallic iron nanoparticles ($npFe^0$) on the surface of a magnetite grain [6], which is consistent with the depletion of O that is observed in our experiments. This loss of O could create a reducing environment for the Fe present in magnetite and promote the development of a metallic iron-rich layer. We expect a similar chemical behavior (depletion of O and enrichment of Fe) on magnetite grains that will be returned from asteroid Bennu. Additionally, the resistance of magnetite to amorphization has been also observed in sulfide minerals from asteroid Itokawa, suggesting that Fe-oxides and sulfide phases are more resistant to solar wind irradiation damage compared to silicate minerals.

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