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From laser experiments to nature: How accurately can we reproduce space weathering?

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Abstract

The present contribution aims to discuss the possibility to reproduce space weathering effects via femtosecond laser experiments in the light of space weathering defects found in Hayabusa regolith grains.

1. Introduction

The surfaces of the airless solid bodies of the solar system are exposed to the irradiation of the solar wind and to the bombardment of micrometeoroids. The ensemble of the effects caused by these surface processes is known as space weathering [1].

Since the first recognition of space weathering in nature, numerous experiments have been successfully carried out to reproduce its spectral effects. The most common experiments are ion irradiation (simulation of the solar wind; [2]) and nanosecond laser experiments (simulation of micrometeoroid impacts [2-4]). Only a few studies further investigated the microstructural modifications produced by the experiments [5, 6], probably due to the paucity of regolith materials to compare with.

Nowadays, the only regolith material available is from the surfaces of the Moon and asteroid 25143 Itokawa [7, 8]. The sample return missions are a new frontier of the space exploration and in the following years, other regolith materials will be available. These missions are the key to understand surface processes on primitive bodies in the solar system.

In this work, we present the results of an investigation of Itokawa grains. These natural observations will be compared to results femtosecond laser experiments to assess the capabilities of this experimental approach to reproduce space weathering effects [9, 10].

2. Samples and Methods

In the framework of 4th International Announcement of Opportunity for Hayabusa sample investigation, we received five Itokawa particles. Currently we have focused on the investigation of particle RB-QD04-0092, which was sliced by focused ion beam (FIB) and then studied by analytical transmission electron microscopy (TEM).

3. Observations on RB-QD04-0092

The RB-QD04-0092 is a flat grain (29 x 25 x 8 µm) consisting of enstatite (En_{75-80}) and olivine (Fo_{71-78}). The grain shows a polycrystalline rim, that indicates an exposure to the solar wind [11]. Solar flare tracks have been found in both minerals and their density is comparable with literature data ($10^8 – 10^9$ cm^{-2}; [12, 13]). In addition to these features, olivine and enstatite show typical shock effects known for shocked meteorites, that is, [001] dislocations in olivine and clinoenstatite lamellae. This is the first report of clinoenstatite lamellae in Hayabusa-returned samples.

Contrary to other literature observations, no (sulfur)-iron nanoparticles and amorphized rims [7] have been found. The absence of these features can be explained either due to the superimposition of the irradiation of solar wind or due to the gardening process and secondary impacts. A combination of both mechanisms is also possible.

4. Femtosecond laser experiments

Recent femtosecond laser experiments considerably improved the state-of-the-art knowledge on space weathering [9, 10]. The irradiation with femtosecond laser light induces a nanosecond shock wave with the initial pressure of several tens GPa, which results in the formation of microcraters with a layered subsurface structure, similar to those observed in lunar samples [14]. The topmost layer is amorphous. In olivine, it can be partially recrystallized and contains iron nanoparticles in its lowermost part. The underlying layer is defect-rich. In olivine, it is dominated by dislocations [9], instead, in pyroxenes, parallel planar lamellae (amorphous in the upper part) and clinoenstatite lamellae are common [10]. Reflectance spectra of both minerals are altered, similarly to space weathered asteroid surfaces [9].

5. Conclusions

The preliminary comparison of the microstructural features of Itokawa regolith and irradiated minerals supports the employment of the femtosecond laser experiments for reproducing and characterizing the shock defect modifications. Although the spectral alteration of natural and experimental materials is similar, the mechanisms of formation of the amorphous layer and the iron nanoparticles might be different, because the experimental irradiation with laser light is not comparable with the natural bombardment with solar wind particles. To improve the understanding of these mechanisms and of the impact history of asteroidal regolith, further experimental studies and observations on Hayabusa-returned grains will be necessary.

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