EPSC Abstracts
Vol. 12, EPSC2018-284, 2018
European Planetary Science Congress 2018

Space weathering in enstatite single crystals: Femtosecond laser pulse experiments simulate micrometeoroid impacts

Doreen Schmidt (1), Kilian Pollok (1), Gabor Matthäus (2), Harald Mutschke (3), Stefan Nolte (2) and Falko Langenhorst (1)
(1) Institute of Geosciences, Friedrich Schiller University (FSU), Carl-Zeiss-Promenade 10, 07745 Jena, Germany (2) Institute of Applied Physics (IAP), FSU, Albert-Einstein-Str. 15, 07745 Jena, Germany (3) Astrophysical Institute and University Observatory (AIU), FSU, Schillergässchen 2-3, Jena 07745, Germany (doreen.turner@uni-jena.de)

Abstract

Oriented slices of enstatite single crystals were irradiated by femtosecond laser pulses. Reflectance spectra of the irradiated surfaces show distinct darkening compared to the unprocessed surfaces as a typical feature of space weathered material. The microcraters contain a glass layer at the surface, but there is no formation of iron nanoparticles. The crater surfaces show different fracturing depending on their orientation. Also, the microstructures in the depth of the craters and therefore the deformation mechanisms differ according to the orientation.

1. Introduction

Space weathering, occurring on airless bodies in the solar system, alters the surfaces of planetary materials by micrometeoroid bombardment and solar wind irradiation. The effects of space weathering are responsible for the differences in reflectance spectra between pristine and weathered planetary materials such as darkening and reddening [1]. Pulsed laser experiments are known to reproduce space weathering effects on olivine like melting, the formation of iron nanoparticles and deformation features like dislocations [2] as well as other planar shock effects [3]. Comparable observations are made on natural olivines in lunar or asteroidal samples [4,5]. In this context we pursued further laser experiments on pyroxene, which is besides olivine one of the most important planetary minerals.

2. Material and Methods

Kilosa enstatite containing about 4 wt% Fe (En_{93}) was cut perpendicular to the crystallographic axes, i.e. parallel to the (100), (010) and (001) planes. Additionally, samples were prepared parallel to the (210), (211) and (301) planes. The samples were sliced plane-parallel to a thickness between 0.5 and 1.0 mm and double sided polished.

Laser irradiation was performed on the polished surfaces under vacuum (10^{-3} mbar) using a Ti:sapphire laser at 800 nm wavelength. Each pulse had a spot size of 38 µm ($1/e^2$) and a duration of 100 fs. We used a laser energy of 3 mJ resulting in a laser intensity of 10^{15} W/cm^2. This reproduces well the spatial and temporal conditions of natural micrometeoroid impacts. 20 x 20 shots were executed with a spacing of 100 µm to produce a grid with an irradiated area of 2 mm^2.

NUV-VIS-NIR spectral measurements were performed in reflectance at near-normal incidence with a Perkin Elmer Lambda 19 spectrometer. The spectral range of 200-2,500 nm was measured with a scan speed of 120 nm/min and a 1 nm step size. The acquired spectra were corrected with respect to a calibrated aluminum mirror.

The recovered material was investigated with SEM (FEI Quanta3D FEG) and TEM (FEI Tecnai G 2 FEG). Sample preparation for TEM was done with focused ion beam (FIB) technique by cutting 100 nm thin lamellae perpendicular to the irradiated surface.

3. Results

3.1 Surface Analysis of the Microcraters

The laser single shots produced mainly spherical to partly irregularly shaped microcraters with a distinct splash-like layer. There are different amounts of radially ejected material. The samples parallel to (001) and (210) show strong fracturing at the crater surfaces, subordinately also the (100) cut sample. The craters produced on the (001) plane have cracks mainly subparallel to the traces of the cleavage planes on {210} and (100) with smaller subspherical cracks at the crater rim. The fractures of the (210) sample show a preferred orientation parallel to the [001] direction, whereas the (100) sample is fractured mainly subparallel to [010] and [001]. There are no fractures at the crater surfaces of the samples parallel to the (010), (301) and (211).

3.2 Spectroscopy

Reflectance spectra of the processed samples show a decrease in intensity with respect to the unprocessed surfaces. This is known as spectral darkening. If the reflectance at longer NIR wavelengths is less reduced than in the shorter UV-VIS range, the spectrum gets redder. This effect is observed in most samples, but the intensity of reddening varies strongly between the differently orientated samples.

3.3 Microstructures

TEM investigations of the craters reveal a layered structure independent of the sample orientation. From top to bottom there is a glass layer, a dominant mechanically deformed layer containing shock defects and the undeformed substrate. All samples show parallel planar lamellae, that are amorphous in the upper part of the deformed layer and become thinner towards the bottom until they turn to microfractures or stacking faults. At the interface to the glass layer there are always two conjugated directions of the amorphous features, which have an angle of 30-50° to the surface normal. Deeper in the deformed layer the samples have either domains with subparallel lamellae in different orientations, or the layer contains homogeneously lamellae with one dominant or two conjugated directions. Activated cleavage planes can only be observed in the (210) sample, where the lamellae are parallel to the (100) cleavage. The transformation to clinoenstatite can be seen in the (301) sample. It occurs in the lower part of the deformed layer associated with microfractures and dislocations.

4. Discussion

The main deformation features in our shocked enstatite are microfractures and lamellae that probably represent shear planes. Frictional heating along these shear planes leads to amorphization. These experimentally produced structures are in good agreement with observations in natural samples like the Martian Meteorite Allan Hills 84001 [6]. We did not observe the formation of iron nanoparticles, which are generally regarded to be the main cause for the spectral darkening and reddening in naturally space weathered pyroxene [5] or have been observed in other experimentally irradiated pyroxene powder pellets [7].

Acknowledgements

We thank the DFG for support within the Leibniz program (LA830/14-1) and the research unit FOR 2285 “Debris Disk in Planetary Systems” (LA830/20-1).

References

[1] Bennett, C. J. et al.: Space-Weathering of Solar System Bodies: A Laboratory Perspective, Chemical reviews 113:9086–9150, 2013.

[2] Fazio, A. et al.: Femtosecond laser irradiation of olivine single crystals: Experimental simulation of space weathering, Icarus 299:240–252, 2018.

[3] Seydoux-Guillaume, A.-M. et al.: Dominance of mechanical over thermally induced damage during femtosecond laser ablation of monazite, European Journal of Mineralogy 22:235-244, 2010.

[4] Noble, S. K. et al.: The Microstructure of a Micrometeorite Impact into Lunar Olivine, Space Weathering of Airless Bodies: An Integration of Remote Sensing Data, Laboratory Experiments and Sample Analysis Workshop, Houston, USA, 2-4 November 2015, LPI Contribution No. 1878, Abstract 2034.

[5] Noguchi T. et al.: Space weathered rims found on the surfaces of the Itokawa dust particles, Meteoritics & Planetary Science 49:188-214, 2014.

[6] Barber, D.J. and Scott, E.R.D.: Shock and thermal history of Martian meteorite Allan Hills 84001 from transmission electron microscopy, Meteoritics & Planetary Science 41: 643-662, 2006.

[7] Nakamura, K. et al.: Laboratory Simulation of Space Weathering: Comparison Study of Microstructures of the Laser Irradiated Olivine and Pyroxene, 65th Annual Meeting of the Meteoritical Society, Los Angeles, USA, 21-26 July 2002, Abstract 5186.