LASER SIMULATED HYPERVELOCITY MICROMETEOROID IMPACTS: ORIENTATION DEPENDENT SHOCK EFFECTS IN ENSTATITE SINGLE CRYSTALS.

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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 schock effects in general [3]. Comparable observations are made on natural olivines like in lunar or asteroidal samples [4,5]. We performed laser experiments on pyroxene, which is besides olivine one of the most important planetary minerals.

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 with parallel to the (210), (211) and (301) planes.

The femtosecond laser experiments were conducted at the Institute of Applied Physics at FSU Jena. 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. Laser energy was varied between 3.5 and 0.2 mJ resulting in a maximum laser intensity with at least 10^{14} W/cm^2. This reproduces well the spatial and temporal conditions of natural micrometeoroid impacts. 10 shots per applied laser energy were executed with a spacing of at least 100 µm to avoid an overlap of the affected areas.

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

Results: The laser single shots produced mainly spherical to partly irregular shaped microcraters with a distinct melt layer in typical ejecta morphology at the rims. The samples parallel to (001) and (210) show strong fracturing at the crater surfaces, subordinately also the (100) cut sample. There is a correlation between fracture density and laser energy. 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. The fractures of the (100) sample are mainly subparallel to [010] and [001]. The samples parallel to the (010), (301) and (211) planes do not show fractures at the crater surfaces.

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.

Discussion and future work: The main deformation features in our shocked enstatite are microfractures and lamellae that probably act as shear planes. Frictional heating along this 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 the 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]. Further experiments are therefore intended to be performed with a more Fe rich enstatite.

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