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Excimer Laser Experiments on Mixed Silicates Simulating Space Weathering on Mercury

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Abstract
In this work, we present near and mid-infrared spectra of olivine-pyroxene mineral mixtures irradiated with a pulsed ArF UV excimer laser. Our experimental set-up simulates micrometeorite bombardment as one possible source of space weathering. The absence of transparency features of the irradiated samples indicates grain coarsening upon laser bombardment. Furthermore, the obvious darkening of the irradiated sample surface might be an effect of agglutination.

1. Introduction
The joint ESA/JAXA mission BepiColombo to Mercury will allow the determination of the mineralogical composition of the hermean surface. Particularly the on-board mid-infrared spectrometer MERTIS (Mercury Radiometer and Thermal Infrared Spectrometer), will measure the spectral features of the hermean surface in the 7-14 µm range, with a pixel scale of about 500 meters [1,2].

In the IRIS (Infrared and Raman for Interplanetary Spectroscopy) laboratory of the Institut für Planetologie in Münster we generate spectral data for the compilation of the database, which will be used for the exact interpretation of the spectral information delivered by MERTIS.

Owing to the absence of an atmosphere as well as the short distance to the sun, the surface of Mercury has been subjected to space weathering (SW) of varying strength. The thin exosphere and the magnetic field allow solar wind particles and impactors of various sizes to reach its surface and modify it significantly over long periods with regard to the long exposure times. Altogether, those processes are referred to as SW [3,4].

Various authors simulated SW processes with different experimental set-ups [5,6]. However, so far most studies of analog material (except for meteorite studies) are based on mono-mineralic samples. In our study, we altered terrestrial analog mineral mixtures by pulsed-laser irradiation in order to investigate the effect of SW processes caused by macro to micro impactors.

To study the effects of SW on infrared (IR) spectroscopy, IR spectra were taken before and immediately after irradiation in the MERTIS-relevant mid-infrared range as well as in near-IR (NIR). Contamination is avoided by keeping the mixtures in vacuum from irradiation until IR measurements. Changes within the irradiated samples at nanometer scale are then examined with transmission electron microscopy (TEM).

2. Sample and Techniques
Samples: Olivine (Ol=Fo_{91}) from Dreiser Weiher, Germany, and pyroxene (Px=En_{87}) from Bamble, Norway, were analyzed using an electron microprobe analyzer. For subsequent IR measurements and laser experiments, the silicates were first ground in a steel mortar and the grain size fraction from 63 µm to 125 µm was then pressed at ~ 8 bar for 10 min to obtain powder pellets (d = 5 mm, h = ~5 mm). As a starting material, mixtures of olivine and pyroxene with 70/30 and 30/70 (both in weight %) were prepared.

Techniques:

- Light microscopy: A polarized light microscope was used to determine the purity of the samples and to depict the irradiated surface (Fig. 1).
- Electron microscopy: We characterized the samples chemically with detailed quantitative analyses by using a JEOL JXA-8530F Hyperprobe electron probe micro analyzer (EPMA) equipped with five wavelength dispersive spectrometers (WDS) at the Institute for Mineralogy in Münster.
- IR spectroscopy - FTIR on bulk powders:

FTIR analyses were performed with a Vertex 70v spectrometer at the IRIS laboratory in Münster. First analyses of single minerals as well as mineral mixtures were made at 20°(i) and 30°(e) with an A513 variable mirror reflectance stage. Measurements in vacuum were done in a Harrick Reaction chamber using a Praying Mantis™ diffuse reflectance stage. The pressed pellets were kept in vacuum within the Reaction Chamber covered with a custom-made dome. 512 scans were accumulated for a high signal-to-noise ratio of each analyses. A commercial diffuse gold standard (INFRAGOLD™) was used for MIR and a Spectralon™ standard for NIR background calibration.

- Irradiation experiments:

The laser experiments were performed at the Physikalisches Institut in Münster with an 193 nm ArF UV excimer laser. The laser beam passes a MgF_2 window installed on top of the dome before hitting the sample surface. Following (or equal to) experiments done by [6] on single minerals, we start with an energy density of 1 J/cm^2 for each 10 ns pulse. The laser was manually moved across the sample surface in discrete steps. The sample spot in focus was ~ 0.2 mm^2.

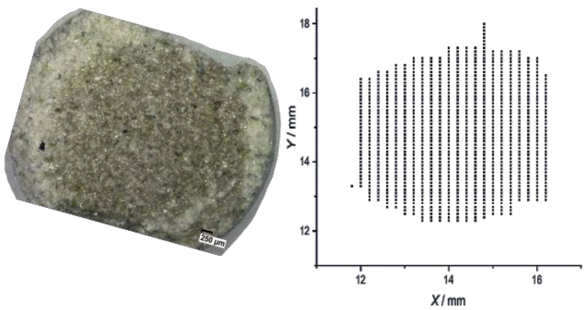

Fig. 1: Left: Image of the sample surface of the mixture Px70/Ol30 after irradiation with an energy density of 2.45 J/cm^2 for each 10 ns pulse with 3 shots per point. Right: Positions of shots.

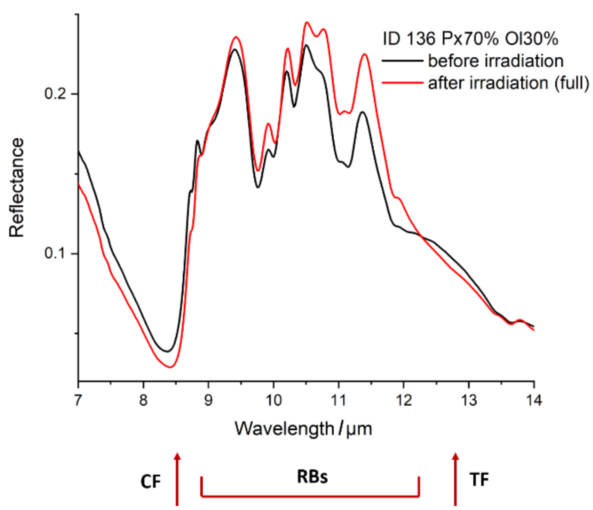

Fig. 2: Mid-IR reflectance spectra in the MERTIS-relevant wavelength range of 7 – 14 µm of pyroxene (Px) and olivine (Ol) in the mixing the ratio 70/30. Spectra before (black) and after (red) irradiation of the differently irradiated surfaces are shown.

3. First Results

Images taken with a light microscope confirmed the pure character of the single silicates used for laser experiments.

First IR spectra obtained at 20°(i) and 30°(e) with an A513 variable mirror reflectance stage of olivine, pyroxene, and mixtures of olivine and pyroxene with 70/30 and 30/70 (in weight %, grain size fractions: 63 – 125 µm) were compared with data of a deconvolution program for silicates of the same composition and mixing quantity. The spectral unmixing of these mixtures is in very good agreement with the sample mixtures [7,8].

Pure olivine and pyroxene show typical Christiansen Feature (CF) and Reststrahlen bands (RB) for these silicates [9]. The Ol70/Px30 mixture shows a significant blue shift of the CF. A new RB shoulder at 9 µm and a peak split of the original olivine RB at 10.6 µm is visible. The RB shoulder at 11.3 µm turns out as a separate RB feature.

The CF of the Px70/Ol30 mixture shifted to higher wavelengths similar to the former pyroxene RB at 10.4 µm with a red shift to 10.5 µm and a significantly higher reflectance.

It is remarkable that the olivine rich mixture exhibits rather more of the genuine olivine RBs than pyroxene in the pyroxene rich mixture.

Results of IR investigations in vacuum within the Reaction Chamber on the same mineral mixtures but on pressed powder pellets before laser irradiation show a strong transparency feature (TF). After irradiation (Fig. 1) this TF disappears (Fig. 2).

The TF is a hint for the grain size of the investigated powder. The absence of this feature is indicative of grain coarsening. The darkening (Fig. 1) of the irradiated sample surface is possibly also an effect of agglutination [10].

Acknowledgements

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