GROWTH OF NANO IRON INCLUSIONS IN FILMS PRODUCED BY PULSED LASER IRRADIATION OF OLIVINE: SIMULATIONS OF SPACE WEATHERING ON MERCURY.

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Introduction: Space Weathering (SW) of the regolith of airless planetary bodies produces nanometer thick coatings on the regolith grains. These coatings/films are generally believed to be formed by: 1) redeposition of vapor produced during micrometeorite impacts on regolith grains or 2) of sputtered elements produced during interaction of energetic solar wind and cosmic ray particles with the regolith grains. Such films contain nanophase iron inclusions ($npFe^0$) that have been well documented within lunar soil grains [e.g., 1]. Mean size of $npFe^0$ inclusions have been experimentally shown to affect the VNIR spectra and has important implications for planetary spectroscopy [2]. Another important product of SW are melt spherules and agglutinates that contain rather larger iron inclusions as compared to those described above.

For solar system bodies with high surface temperatures (e.g., Mercury), the $npFe^0$ inclusions can grow within an amorphous matrix due to a process called Ostwald ripening [3]. However, it is difficult to calculate the mean size of iron nano inclusions at a particular temperature due to the paucity of experimental studies on the growth of iron nano inclusions within an amorphous matrix.

In our present study we prepared amorphous silicate films by pulsed laser irradiation on San Carlos olivines. These films were then annealed at different temperatures for different durations and the changes within the films were studied using a transmission electron microscope (TEM). One of the primary objectives was to show that the growth process of the nano inclusions confirm the Ostwald ripening theory. According to Ostwald ripening theory growth kinetics of particles obey the equation,

$$r^3 - r_0^3 = Kt \text{ and } K = \frac{8\gamma DcV^2}{9RT}$$

Where r is the mean radius at time t, r_0 is the initial mean radius, γ is the interfacial energy, D is the diffusion coefficient, V is the molar volume of the solute, c is the solubility, R is the gas constant, and T is the temperature.

Samples and Experimental Procedures: Inclusion free and well characterized San Carlos olivine samples were used for the experiment. Thin amorphous films were deposited on fused silica substrates using the Pulsed Laser Deposition (PLD) technique. A cylinder of San Carlos olivine with about 8 mm diameter and 2 mm thickness was irradiated by about 20 ns long laser pulses with 192 nm wavelength, a laser fluence of about 2 J/cm^2, and a reptition rate of 10 Hz. The laser pulses were produced by an Excimer Laser (LPX 305i). The substrate was placed on fused silica slices that cover a SiC resistance heater. The temperature of the substrate surface is measured using a pyrometer, which was cross-calibrated using thermocouples and melting points of Zn and Al. More details of the PLD setup can be found in [4]. The first film was deposited on a substrate that was kept at room temperature during the deposition process. In the subsequent experiments, the substrate was heated up to 450°C during the film deposition. The film deposited on a hot substrate was later annealed in-situ inside the PLD chamber at 700°C for 18 hours. The other film deposited on a substrate at normal room temperature was also annealed in-situ inside the PLD chamber at 600°C for 27 hours. Other substrates were annealed within a gas mixture oven under flowing Ar gas. Subsequent TEM studies were carried out using a Zeiss Libra 200 FE TEM operating at 200 KeV.

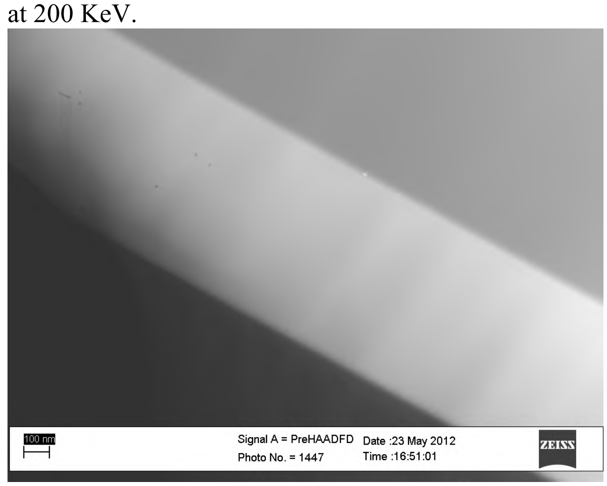

Fig.1: STEM-HAADF (Scanning Transmission Electron Microscopy-High Angle Annular Dark Field) image of the film deposited on an unheated substrate. The black part is the substrate.

Preliminary Results: Films deposited on unheated substrates were completely homogeneous and amorphous (Fig. 1) whereas the films deposited on hot substrates had many nanostructures that were difficult to resolve under the TEM as they were less than 1 nm in size. After annealing the film, deposited on an unheated substrate, at 600°C for 27 hours no change was found. However, the film deposited on a hot substrate contained many nano inclusions of iron ranging in size from 4-6 nm after annealing at 700°C for 18 hours. Another film, as above, was annealed in a gas mixture furnace under flowing Ar gas at 700°C for 27 hours. TEM study of the film is however not yet complete.

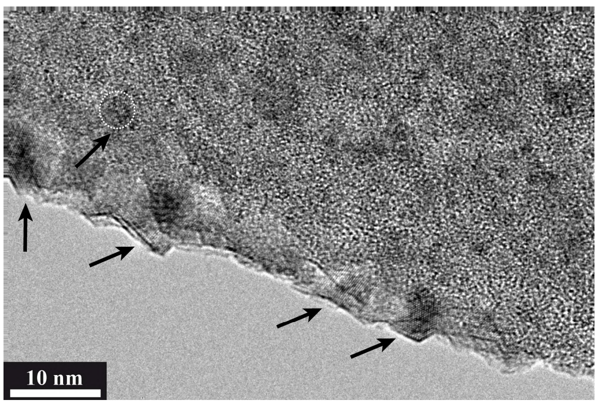

Fig.2: STEM-HAADF image of the film annealed at 700°C for 18 hours. The iron inclusions are indicated by arrows.

Conclusions: The nano inclusions of iron grew in size within the amorphous film, prepared by laser irradiation of San Carlos olivine, after annealing it under high vacuum at 700°C for 18 hours. More experiments are ongoing to anneal the films at different temperatures and with different duration to observe the change in size of the iron inclusions. If the growth process obeys the Ostwald ripening equation, the growth kinetics of the iron inclusions can be calculated, which will then be used to extrapolate the size of iron inclusions within the amorphous patinas on regolith grains and impact melts on the surface of Mercury at 450°C. The same will be done for films prepared from low iron bearing olivine samples.

Furthermore, we plan near- and mid-infrared studies of the material produced in the space weathering experiments [5].

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