COMPOSITIONAL AND MICROSTRUCTURAL EVOLUTION OF OLIVINE DURING PULSED LASER IRRADIATION: INSIGHTS BASED ON A FIB/FIELD-EMISSION TEM STUDY

R. Christoffersen[1], M. J. Loeffler[2], C. A. Dukes[3] and R. A. Baragiola[3,†], [1]Jacobs, NASA Johnson Space Center, Mail Code XI, Houston, TX 77058, USA, (roy.christoffersen-1@nasa.gov), [2]NASA GSFC, Greenbelt, MD 20771, USA, [3]University of Virginia, Laboratory of Atomic and Surface Physics, Charlottesville, VA 22904, USA, [†]deceased.

Introduction: The use of pulsed laser irradiation to simulate the short duration, high-energy conditions characteristic of micrometeorite impacts is now an established approach in experimental space weathering studies [1, 2]. The laser generates both melt and vapor deposits that contain nanophase metallic Fe ($npFe^0$) grains with size distributions and optical properties similar to those in natural impact-generated melt and vapor deposits [3]. There remains uncertainty, however, about how well lasers simulate the mechanical work and internal (thermal) energy partitioning that occurs in actual impacts [4]. We are currently engaged in making a direct comparison between the products of laser irradiation and experimental/natural hypervelocity impacts. An initial step reported here is to use analytical TEM is to attain a better understanding of how the microstructure and composition of laser deposits evolve over multiple cycles of pulsed laser irradiation.

Experimental Methods: We irradiated pressed-powder pellets of San Carlos olivine (Fo_{90}) with up to 99 rastered pulses of a GAM ArF excimer laser. The irradiated surface of the sample were characterized by SEM imaging and areas were selected for FIB cross sectioning for TEM study using an FEI Quanta dual-beam electron/focused ion beam instrument. FIB sections were characterized using a JEOL2500SE analytical field-emission scanning transmission electron microscope (FE-STEM) optimized for quantitative element mapping at <10 nm spatial resolutions.

Results: In the SEM the 99 pulse pressed pellet sample shows a complex, inhomogeneous, distribution of laser-generated material, largely concentrated in narrow gaps and larger depressions between grains. Local concentrations of $npFe^0$ spherules 0.1 to 1 µm in size are visible within these deposits in SEM back-scatter images. Fig. 1 shows bright-field STEM images of a FIB cross-section of a one of these deposits that continuously covers the top and sloping side of an olivine grain. The deposit has 3 microstructurally distinct sub-layers composed of silicate glass with varying modal fractions and size distributions of $npFe^0$ spherules, along with nanocrystalline silicate material (Fig. 1). A relatively thin (50-300 nm) topmost surface layer has a high-concentration of $npFe^0$ spherules 5-20 nm in size (Fig. 1a). Element mapping shows the layer to be enriched in Fe by a factor of 2.5 relative to the olivine substrate, with Mg and Si depleted by 20% and 10% respectively. This is compositionally complementary to the underlying, middle layer of the deposit that is depleted in Fe, enriched in Mg and has a much lower $npFe^0$ concentration. A third layer of nanocrystalline olivine occurs at the substrate interface.

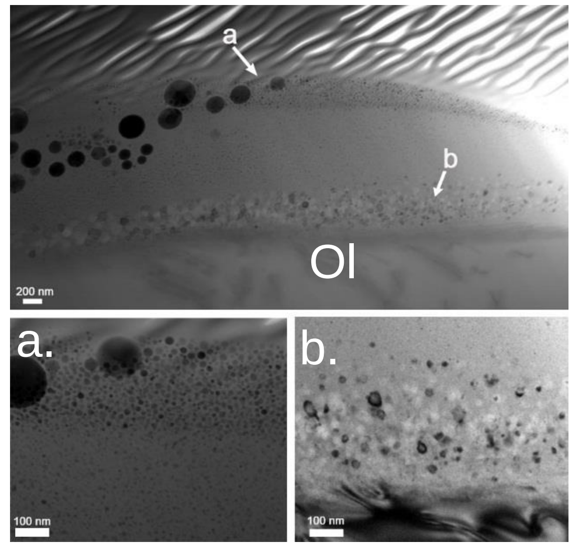

Fig. 1. Bright-field FE-STEM image of layers of laser-deposited material on Fo_{90} olivine grain (Ol).

Discussion: The FE-STEM results suggest the topmost layer is a vapor deposit, underlain by a thicker microstructurally complex melt-generated layer. The compositional relations suggest the melt layer was partially vaporized, preferentially losing more volatile elements (e.g., Fe). The vaporized material re-condensed to form the thin, $npFe^0$-rich surface deposit during or immediately after the scan cycle. Nanocrystalline olivine that grew within the melt layer as it formed and cooled is similar in volume and microstructure to what we have observed in the impact melt lining of a micrometeorite impact crater in olivine [5]. This suggest the time-temperature relations attained in the laser sample may not be too different from a micrometeorite impact. Our TEM observations, however, do not show evidence for the same level of mechanical damage (e.g., fracturing) seen around the natural micrometeorite crater [5].

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