

RADIATION PROCESSING AND THE ORIGINS OF INTERPLANETARY DUST

J. P. Bradley¹, C. Dukes², R. Baragiola², L. McFadden³, R. E. Johnson², and D. E. Brownlee⁴,
¹MVA Inc. 5500/200 Oakbrook Pkwy, Norcross, GA 30093; ²Laboratory for Atomic and Surface Physics,
 Univ. of Virginia, Charlottesville, VA 22903; ³Astronomy Dept., University of Maryland, College Park,
 MD 29742-2421; ⁴Dept. of Astronomy, University of Washington, Seattle, WA 98195.

The anhydrous chondritic (CP) class of interplanetary dust particles (IDPs) are considered to be pristine (unprocessed) objects because of their fragile, porous microstructures and lack of evidence of significant parent body alteration [1]. During their recent 10^4 - 10^5 year lifetimes in solar orbit, IDPs accumulate high densities of implanted solar flare tracks as well as solar wind irradiated amorphous rims along their outer surfaces [2]. Some grains *in* anhydrous IDPs were also exposed to an earlier irradiation episode(s) [3]. These grains are of major significance because their exposure predates accretion of IDPs and, in the case of cometary IDPs, the exposure predates comet accretion. Since comets are primitive small bodies, it is conceivable that the grains are surviving solar nebula or presolar interstellar grains. The most well-characterized grains are GEMS (glass with embedded metal and sulfides) [3]. Several researchers have noted that properties of GEMS strongly resemble those of "amorphous silicates" which are ubiquitous throughout the interstellar medium [3-6]. This is the more significant because the half dozen or so known properties of interstellar silicates, as determined from astronomical observations, are "exotic" and mutually exclusive of one another [7-8]. If GEMS are indeed interstellar "amorphous silicates", then one of the main raw ingredients of the Solar System has been found.

In addition to GEMS, there are other pre-accretionally irradiated grains within anhydrous IDPs. However, recognizing the full range of irradiation effects in ultrafine-grained IDPs is difficult because almost no data exist on the nanometer-scale chemical and structural effects of exposure to ionizing radiation. We have initiated a series of experiments using H^+ and He^+ ions. A 5 X 8 X 1mm thick disc of San Carlos olivine, highly polished on both sides, was mounted on an aluminum substrate. An ion beam incident at 32° to the olivine surface was rastered over $\sim 8 \times 8$ mm areas of each surface under ultra-high vacuum ($\sim 1 \times 10^{-10}$ torr) in a Perkin-Elmer 560 XPS/SAM system. One side received 1 keV H^+ with a dose of $2.2 \times 10^{18} H^+/cm^2$ at 12 microA/cm², and the other 4 keV He^+ with a dose of $3.3 \times 10^{17} He^+/cm^2$ at 12 microA/cm². XPS was performed on the surfaces before and after the irradiations. The irradiated surfaces were also analyzed using 200 keV analytical electron microscopy. A diamond scribe was used to remove small ($< 100 \mu m$) chips from the irradiated surfaces. Selected chips were mounted in epoxy and thin-sectioned in cross-sectional orientations using ultramicrotomy.

Figures 1 and 2 show darkfield electron micrographs of the irradiated surfaces. The average rim thickness on the 1 keV H^+ side is ~ 25 nm, while on 4 keV He^+ side the rim is ~ 50 nm. The rim on the H^+ side is almost completely amorphous and the bulk olivine interface exhibits nanometer-scale roughness (Fig. 1). The composition of the rim was measured using a 200 keV nanoprobe and energy-dispersive x-ray spectroscopy (EDS). Relative to bulk olivine, Mg/Si is $\sim 48\%$ depleted and Fe/Si is $\sim 43\%$ enriched in the rim. Mg becomes progressively depleted towards the surface of the rim. Similar chemical effects were observed in olivine irradiated with 20 keV H^+ [3]. The rim on the He^+ side is amorphous in the upper ~ 20 nm but the lower part is polycrystalline (Fig. 2). Mg/Si is $\sim 36\%$ depleted and Fe/Si is $\sim 11\%$ enriched. XPS spectra from both surfaces indicate that a significant fraction of the Fe^{2+} has been reduced to metallic Fe (Fig. 3), and a few nanocrystals consistent with Fe metal were observed in lattice fringe images of the rims. The compositions and oxidation states in the uppermost 5 nm of the rims are being further investigated using XPS by monitoring the O(1s), Mg(2s), Al(2p), Si(2p), and Fe ($2p_{1/2}$ & $2p_{3/2}$) peaks.

Our experiments confirm that irradiation of (Fe-bearing) silicates causes formation of glass and nanocrystals of metal, both of which are major components of GEMS. If H^+ and He^+ irradiation are responsible for the mineralogy and petrography of GEMS, then energies and doses significantly higher than those used in our experiments may be implicated. The nanometer-scale roughness of the H^+ irradiated bulk olivine interface is a radiation "fingerprint" (Fig. 1), and we are now finding it on some Fe-rich sulfides as well as enstatite platelets which are believed to be primary nebula condensates [9].

RADIATION EFFECTS IN IDPS: Bradley et al.

Whether these grains are contemporaneous with GEMS or whether they were irradiated in a variety of astrophysical environments (e.g. solar nebula, stellar atmospheres, interstellar shocks) is only one of the exciting questions emerging from studies of irradiation effects in IDPs. The anhydrous CP subset of IDPs are indeed pristine (unprocessed) objects, at least in terms of known solar system parent body processes (e.g. metamorphism and aqueous alteration), but some of their grains were heavily processed by irradiation *prior to* accretion of the IDP parent bodies.

REFERENCES [1] Schramm, L. S. et al. (1989) *Meteoritics* 24, 99; [2] Thiel, K. et al. (1988) *Nucl. Tracks Rad. Meas.* 19, 685; [3] Bradley, J. P. (1994) *Science* 265, 925; [4] Flynn, G. J. (1994) *Nature* 371, 287; [5] Martin, P. G. (1995) *Ap. J.* 455, L63; [6] Goodman, A. A. and Whittet, D. C. B. (1995) 455, L181; [7] Mathis, J. S. (1993) *Rep. Prog. Phys.* 56, 605; [8] Aitken, D. J. et al. (1988) *Mon. Not. R. Astr. Soc.* 230, 629; [9] Bradley, J. P. et al. (1983) *Nature* 301, 473.

ACKNOWLEDGEMENT This research is supported by NASA Contract # NASW-5035.

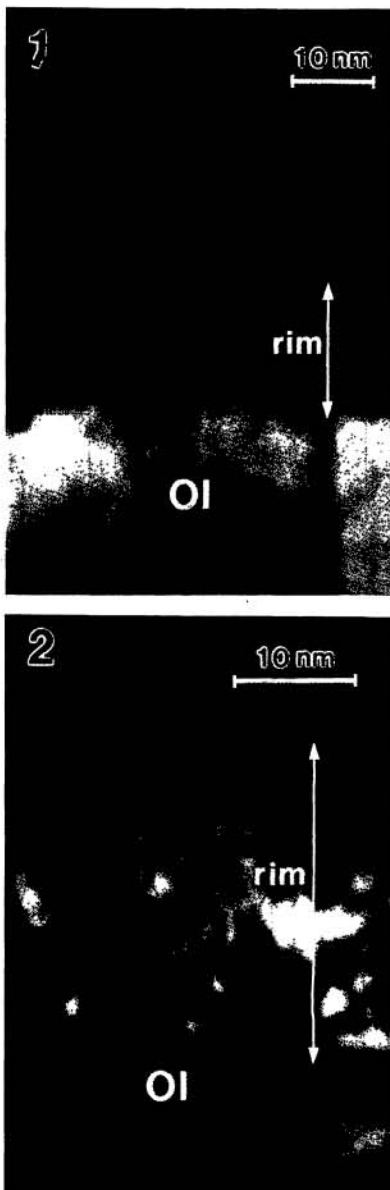


FIGURE CAPTIONS

Figure 1 Darkfield electron micrograph of H⁺ irradiated surface of olivine (Ol).
 Figure 2 Darkfield electron micrograph of He⁺ irradiated surface of olivine (Ol).
 Figure 3 XPS spectra from surface of olivine showing Fe 2p_{1/2} and 2p_{3/2} peaks before (open circles) and after (close circles) 4 keV He⁺ bombardment. The shift in peak binding energy indicates reduction of Fe²⁺ to metal (Fe⁰).

