

**Formation of OH/H<sub>2</sub>O by 1 keV Proton Irradiation of Apollo 16 Lunar Highland Soil.** M.J. Schaible, C.A. Dukes, E. H. Mitchell, and R.A. Baragiola, Laboratory for Atomic and Space Physics, University of Virginia, Charlottesville, VA 22904. E-mails: ms5vf@virginia.edu, cdukes@virginia.edu, emma.mitchell@virginia.edu, raul@virginia.edu

**Introduction:** The question of whether water exists on or within the Moon has long been debated. Though early measurements of returned lunar soil suggested a virtually anhydrous planetary surface [1], near-infrared spectroscopy measurements by three separate spacecraft showed a broad absorption band near 3  $\mu\text{m}$ , attributable to the OH stretch absorption of water, at or near the lunar surface [2-4]. The absorption is present across the entire lunar surface and is stronger toward the lunar poles. Water or ice in the polar regions is substantiated by observation of a water vapor plume during the LCROSS mission [5].

The apparent ubiquitous nature of OH/H<sub>2</sub>O is surprising since there are many mechanisms (sputtering and impact vaporization) that can remove surficial water, but few clear mechanisms for replenishment. One formation mechanism, indicated by the relatively global spatial distribution of the OH signal, follows the interaction of the solar wind protons with oxides in the lunar soil. Low energy protons impact the surface penetrating up to  $\sim 50$  nm, breaking bonds and implanting hydrogen which subsequently may be combined with nearby oxygen atoms to form hydroxyl or water.

Previous experiments investigating the formation of water products by 1 keV hydrogen irradiation on terrestrial ilmenite and anorthite gave null results for OH/H<sub>2</sub>O [6]. We continue these studies, and report here findings for H<sup>+</sup> irradiation of lunar highland soils.

**Experiment:** To test the solar wind hypothesis, experiments are performed in an ultrahigh vacuum chamber pumped to a base pressure of  $< 5 \times 10^{-9}$  Torr. Lunar highland soil samples of varying maturity (65901, 61241) are mounted onto a copper platen, out-gassed by heating. The samples are first analysed with X-ray photoelectron spectroscopy (XPS) to determine their surface composition and chemistry, then characterized with vis-NIR diffuse reflectance. The samples are then irradiated using rastered 1 keV hydrogen ions to fluences in the range:  $10^{14}$  -  $10^{19}$  H<sup>+</sup> cm<sup>-2</sup>. During irradiation, the sputtered ion flux is monitored with a secondary ion mass spectrometer (SIMS).

The lunar soil is again characterized with XPS after irradiation to monitor changes to the O 1s peak. *In situ* diffuse reflectance of the soil measures changes in the 2.8 - 3.0  $\mu\text{m}$  region, indicating the production of hydrous species. After a final irradiation at  $10^{19}$  H<sup>+</sup> cm<sup>-2</sup>, we observe the OH/H<sub>2</sub>O content of the surface layers of the soil through the ion penetration depth by sputtering the altered layers and monitoring ions via SIMS.

This technique will allow us to identify the composition of outermost surface of the lunar grains and to measure the sputter removal of OH/H<sub>2</sub>O as a function of depth with near monolayer resolution.

A second chamber is being used to analyze lunar thin sections in vis-NIR transmittance. For these experiments we will use 30- $\mu\text{m}$  sections of lunar highland rocks. *In situ* diffuse reflectance measurements can then be correlated to the transmission spectra for the 0.7 - 8 micron range to ascertain that the IR sampling depth exceeds the maximum H<sup>+</sup> penetration depth ( $\sim 50$  nm). Ions ejected from the lunar material during and after H<sup>+</sup> bombardment are monitored with SIMS.

**Discussion:** Previous experiments with terrestrial anorthosite and ilmenite provide an upper limit of 0.1% band depth in the OH spectral region after saturation fluences [6]. These results are consistent with the EPOXI observations by Sunshine et al. that show OH/H<sub>2</sub>O water depletion during the lunar day, as the solar wind sputter removes adsorbed water that redeposits during lunar evening/night [4], and supported by laboratory measurements by Gruen et al. [7] for 15 keV protons on sapphire. However, studies have found significant ( $\sim 60\%$ ) differences in the rate of surface change in the irradiation of powders and thin sections [8]. In fact, recent data on lunar soil powders have shown positive results for the production of OH/H<sub>2</sub>O after hydrogen ion irradiation [9] but such measurements need to be repeated in ultrahigh vacuum and with mass analyzed ions. In any case, we expect measurements on lunar powder to enhance sputter redeposition and reduce the rate of oxygen loss. A comparison of O-H band depth change after proton bombardment will be compared with the 3-14% enhancement observed by spacecraft measurements.

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**References:** [1] Taylor, L.A. et al (1995) *LPSC XXVI*, 1399. [2] Clark R.N. (2009) *Science*, 326, 562. [3] Pieters C.M. et al. (2009) *Science*, 326, 568. [4] Sunshine J.M. et al. (2009) *Science*, 326, 565. [5] Colapetre, A. et al. (2010) *Science* 220, 463. [6] Burke, D. et al. (2011) *Icarus*, 211, 1082. [7] Gruen, D.M. et al. (1976) *J. Chem. Phys.* 65, 363. [8] Loeffler, M.J. et al. (2009) *JGR*, **114**, E03003. [9] Ichimura, S. et al. (2011) *LPSC* 41, 2724.