CHARACTERIZATION OF A LABORATORY SIMULATED LUNAR PHOTOELECTRON SHEATH.

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Introduction: Surfaces in space are exposed to a variety of charging environments. A balance of currents due to plasma bombardment, photoemission, electron and ion emission and collection, and secondary electron emission determines the surface's charge. When the Moon is outside of the Earth's magnetosphere, charging on the lunar dayside (sunlit) surface is dominated by photoelectrons emitted due to solar UV radiation, which creates a positive surface potential, while a negative night side surface potential is built up by the collection of electrons [1]. The interaction of charged dust grains with the photoelectron sheath is often invoked to explain the many observations that indicate dust lofting, levitation and transport above the lunar surface.

Two sets of instruments have returned *in situ* measurements that provide estimates of the lunar surface potential, and the Lunar Prospector orbiter provides additional measurements of the electron distribution around the Moon. The Apollo Suprathermal Ion Detector Experiment (SIDE) measured the energy of ions at the lunar surface, which can be used to estimate the accelerating electric field [2]. However, it is difficult to derive the lunar surface potential from this estimate because the Debye length (λ_D) on the lunar surface varies from ~1 m in the denser dayside plasma environment to >> 100 m on the night side. SIDE was situated approximately 50 cm above the surface, comparable to λ_D on the dayside, but measuring only a fraction of the surface electric field on the night side.

The Charged Particle Lunar Environment Experiment (CPLEE) measured both ions and electrons in the 40 eV to 200 keV energy range 26 cm above the surface, detecting 200 eV electrons while the Moon was in the Earth's magnetotail. These high-energy electrons were likely photoelectrons emitted from the lunar surface with energies of a few eV due to incident solar UV radiation. Subsequently, the photoelectrons gained energy due to a strong electric field generated by surface potentials up to +200 V that can be present when the Moon is in the Earth's magnetotail, shielded from the solar wind [3].

The Moon's plasma sheath is characterized by a typical photoelectron density of approximately 60 cm^{-3} and a Debye length on the order of 1 m [4]; however, both the density and size of the sheath fluctuates according to the variation in UV flux with the solar cycle [5]. Laboratory measurements of the photoelectron yield from lunar soil samples under solar-like illumination produces emission currents of about 5 $\mu A/m^2$ [6]. During a solar maximum, emission currents will increase to around 16 $\mu A/m^2$ due to an enhanced solar UV photon flux, and solar flares will result in emission currents on the order of 40 $\mu A/m^2$ [5].

Experimental Setup: In order to simulate the lunar surface environment in the laboratory, a photoelectron sheath with a characteristic Debye length much smaller than the size of the vacuum chamber is required. Previous experiments have used a 1 kW Hg-Xe arc lamp to generate photoemission from surfaces with current densities on the order of 0.1$\mu A/cm^2$ [7]. While these experiments were able to demonstrate that dust particles charge negatively in the electron cloud above a photoemitting surface, the number density of photoelectrons above the surface is insufficient to generate a realistic sheath with significant space charge [7]. We use commercially available xenon excimer lamps (Osram Xeradex) that emit ~10 W of ultraviolet radiation in a narrow band centered at 172 nm (7.21 eV). In initial experiments with these lamps in vacuum, we have observed photocurrent densities of ~1 $\mu A/cm^2$ from a Zr surface positioned 10 cm from the lamp. Assuming a photoelectron energy of 2 eV, this corresponds to a sheath Debye length on the order of 0.1 m. Photon density decreases with distance from the lamps, resulting in decreased photoelectron densities above surfaces farther from the lamp.

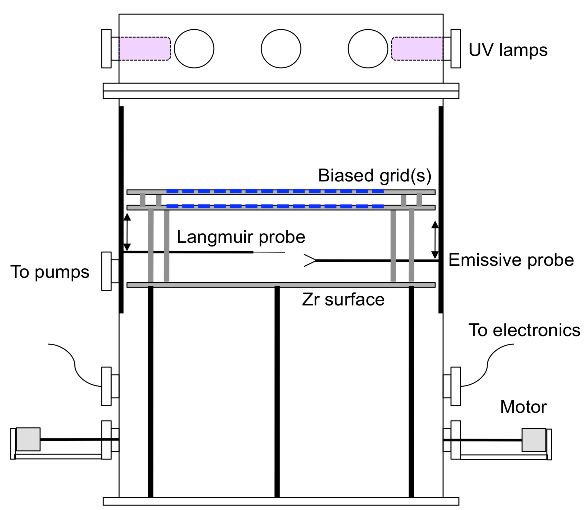

Figure 1. Experimental setup for UV photoemission studies in vacuum.

Experiments are conducted in a 0.6 m^3, 60-cm diameter vacuum chamber, with two to four Xe excimer lamps positioned inside the top of the chamber (Figure 1). A 50-cm diameter aluminum table is covered by thin sheets of zirconium metal. Zr is chosen because it has a relatively low work function, W = 4.05 eV, and a high photoelectric yield [8].

We measure the electron density and temperature in the plasma with a cylindrical Langmuir probe. The probe is constructed of a 0.5mm tungsten wire approximately 4 cm in length at the end of an insulating glass tube. An emissive probe is used to measure local potentials within the plasma to determine the electric field above the surface. The probe is constructed of an emitting 0.025mm thick tungsten filament about 5 mm in length at the end of a ceramic tube. The probes are attached to linear rails that allow for vertical motion inside the chamber. Probe motion and data collection are controlled through a LabView program interface.

Because of the high energy of the UV photons, the signal we measure above the Zr surface is contaminated by excess electrons produced from the walls of the chamber. In order to reduce this excess effect, we place a nickel grid above the Zr plate that can be biased negatively to repel the electrons emitted from the walls. We can also use a double grid set-up to further reduce the excess electrons.

We use the Langmuir probe to measure the photoelectron sheath above the floating Zr plate when the grid is biased to -10 V. The measured sheath has an electron density, $n_e=10^{11}$ m^{-3}, an electron temperature, $T_e \approx 1$ eV, and a resulting Debye length, $\lambda \approx 2.5$ cm.

Sheath Potential Measurements: Our setup allows an emitting surface to reach a floating potential several volts more positive than the surroundings or the biased grid. Because the Debye length is on the order of 2.5 cm above the surface, we are able to characterize the sheath up to several scale heights. We take emissive probe scans between the Zr surface and the biased grid to measure the potential structure formed due to by the photoemission sheath, as seen in Figure 2. A sheath structure is clearly seen in the first ~2.5 cm above the surface, and a linear decrease is seen above that as the potential approaches the grid bias.

Model Comparisons: We compare our experimental with a theoretical model of the photoelectron distribution and potential profiles in a photoelectron sheath. The model is a 1-D particle-in-cell (PIC) code that can simulate the lunar photoelectron sheath or be tailored to simulate the boundary conditions given by our experimental setup (a full description of the code is given in [9]).

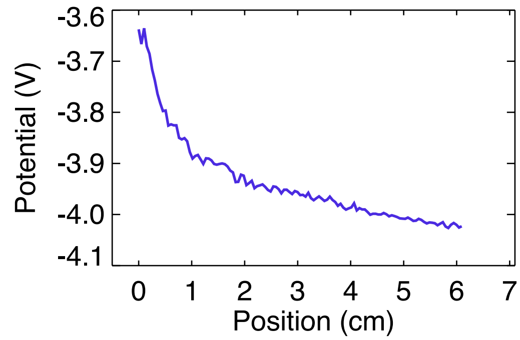

Figure 2. Sample emissive probe potential profile measurement above the Zr surface (at x=0) for the case of a grid (at x=7.1) biased to -5 V.

Additional sheath measurements: In addition to measurements above the well-characterized Zr surface, we measure the potential profile above a surface covered with CeO_2 powder. We chose this material because it has been used in other dusty plasma experiments [10], it is a good photoemitter, and it allows us to take measurements above a surface with vastly difference material properties. We also begin to explore the effect of creating a lit-dark boundary on the photoemitting surface by placing shades in the chamber to prevent the UV light from reaching the surface.

References: [1] Manka, R. H. (1973) *Photon and Particle Interaction with Surfaces in Space*, ed. R. J. L. Grard, 347. [2] Freeman, J. W., Fenner, M. A., Hills, H.K. (1975) *Photon and Particle Interaction with Surfaces in Space*, ed. R. J. L. Grard, 363. [3] Reasoner, D. L., Burke, W. J. (1973) *Photon and Particle Interaction with Surfaces in Space*, ed. R. J. L. Grard, 369. [4] Colwell, J. E. *et al.* (2007) *Rev. Geophys.*, 45, RG2006. [5] Sternovsky, Z., et al., 2008. *JGR*, 103, A10104. [6] Willis, R. F. *et al.*, 1973) *Photon and Particle Interaction with Surfaces in Space*, ed. R. J. L. Grard, 389. [7] Sickafoose, A. A. *et al.* (2000) *Phys. Rev. Let.*, 6034. [8] Michaelson, H. B. (1977) *J. Appl. Phys.*, 48, 4729-4733. [9] Poppe, A. and Horanyi, M. (2010) *JGR,* 115, A08106. [10] Fortov, V. E., et al. (1998) *J. Exp. and Theor. Phys.*, 87, 1087-1097