MINIATURE SCANNING ELECTRON MICROSCOPE FOR *IN-SITU* PLANETARY STUDIES: ELECTRON GUN DEVELOPMENT.

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Introduction: Exploration of planetary bodies requires sophisticated, high precision instrumentation, with an emphasis on low mass, low power and miniaturization. Planning for a return to the Moon and the establishment of manned lunar outposts, NASA's Vision for Space Exploration, these constraints are paramount. All activities on the Moon will involve the lunar regolith, the blanket of broken rock and mineral matter, including the finer portions, the soil. It is to the science and engineering of the regolith that most of our studies will initially be directed, as this is the source of many of the materials that will enable such an undertaking (e.g., source of oxygen, hydrogen, habitat structures). Therefore, analysis of the lunar regolith will aid our preparation for many of the challenges associated with a mission of this magnitude.

Specifically relevant are those challenges for *In-Situ* Resource Utilization, necessary for any successful realization of a lunar outpost [1, 2]. In addition, we wish to continue to expand our basic science knowledge pertaining to the lunar surface, as our present sample base is currently limited to Apollo and Luna samples that represent < 10% of the lunar surface [3, 4], as well as several recently found lunar meteorites.

Miniature SEM Project: Intended for direct investigation of lunar soil, for use during a sortie in the field for example, we are developing a miniaturized Scanning Electron Microscope (SEM) that will permit *in-situ* size/shape/morphological and chemical characterization of lunar soil, either precluding the need for sample return or allowing differentiation of unique samples tagged for Earth return. This mini-SEM will be ~3" to 4" inches in length and roughly 1" in diameter. Our ultimate imaging resolution will be dictated by the science and desired analyses. We expect this point-to-point resolution to be around 100nm, but will be able to accommodate higher resolution if necessary.

SEMs are routinely used in laboratories to determine the physical and chemical characteristics of the smaller portions of the regolith, the soil [5]. The main components include: an electron gun, focusing lenses, deflection/scanning system, sample chamber/interface, detector systems and vacuum system (a more complete description of SEMs can be found in [6]). The study we present here concerns the development of an electron gun appropriate for the lunar environment.

Electron-Gun Configuration: The electron gun under development is a cold field emitter that utilizes an off-the-shelf Hitachi tungsten cathode. The Butler triode configuration is employed, and consists of a field emitter tip followed by a first and second anode [7]. A large applied field between the field emitter tip and the first anode causes electrons to tunnel out of the tip [8]. These electrons are then accelerated towards the second anode, which is typically set to ground. The accelerating voltage of the gun is the voltage between the field emitter tip and the second anode. The maximum accelerating voltage for this gun is 10kV.

This is a somewhat traditional approach to electron gun design (from the choice of field emitter source to the gun configuration) and has many advantages over other electron guns. The Hitachi cold field emission tip is a single-crystal wire that is spot welded to a larger-diameter tungsten wire. This makes for a very strong connection, necessary to withstand launch conditions (e.g., large vibrational forces). This emitter has been routinely used in Hitachi SEMs for many years. It is proven technology and has been well-characterized. The Butler triode gun configuration has been proven to work consistently and has been implemented in multiple commercial SEMs. In addition, cold-field emitters typically produce much higher current densities than thermionic sources (non-field emission), have a large source brightness (10^8 A/cm^2 sr at 20keV), and possess long lifetimes (>1000 hours), low-energy spread (~0.3eV), and small virtual-source size (~3-5nm) [6, 9, 10]. The low-energy spread allows for optimal operation at low accelerating voltages (useful for imaging non-conductive samples), and the small virtual source size minimizes demagnification of the beam (ultimately simplifying our focusing-lens system and reducing power requirements).

Design Considerations: There are two critical design parameters that we address: 1) Mechanical considerations, in that there must be a mechanism for finely aligning the field-emitter tip to the first anode, both horizontally in the X-Y plane and vertically in the Z-plane. These alignments are critical for establishing the appropriate electrical field between the field emitter tip and first anode; 2) Precise control of the voltage difference between the first anode and the field-emitter tip. This potential ultimately controls the emission current by controlling the field strength. If the field is too high, the tip can be damaged, and if the field is too low, there will be no emission.

Mechanical Design. A first-iteration mechanical design for our electron gun has been completed and the gun has been fabricated. Horizontal alignment is accomplished using 3 set screws opposite springs. Vertical alignment is accomplished via a finely threaded, graduated mechanism which allows the field emitter tip to be placed at the desired distance from the first anode, to within ±5µm. Locking screws hold the cathode in place once it has been aligned. Alignment of the tip to the first anode is verified in a traditional SEM located in the Materials and Processes Lab at MSFC. A macor ceramic spacer is used to electrically isolate the field emitter tip from the first anode and to isolate the second anode from the first anode.

Electrical Design & Control System. Appropriate high-voltage power supplies and a control system for the electron gun are being developed by collaborators at the University of Alabama Huntsville (UAH) and with input from additional team members. The version of the system described here was designed using commercial miniature power supplies and was developed for testing the electron gun in a laboratory environment. Further miniaturization is possible with custom designed power supplies and repackaging.

This high-voltage system consists of three compact off-the-shelf switching power converters procured from Ultravolt [11]. Two of the these power supplies are used to generate the voltages on the field emitter tip and first anode, and the third functions as an isolator, which allows the first anode power supply to be ground referenced to the field emitter high voltage. This eliminates the voltage tracking problems associated with using two individual ground referenced supplies. Power for the High Voltage supplies is provided by a commercial laboratory supply for testing at present, but this supply can be easily replaced by a battery or alternate portable source at a later time. The total power needed to run these three supplies is roughly 10 Watts.

Full control and monitoring for the power supply configuration are accomplished with a combination of LabView and electronic circuits in order to aid in signal buffering and control. LabView allows adjustment of the field emitter tip potential and the emission current (controlled by the first anode voltage). In the future, we will control the system with a microcontroller. A "flashing" circuit has also been developed which will allow us to heat the field emission tip (to temperatures above 2500K), keeping it atomically clean.

Summary: Good progress is being made on the design and fabrication of a miniature SEM, keeping in mind the scientific and engineering needs of sample characterization with the planned return of landers and humans to the Moon. Testing of the electron gun will take place in a custom vacuum chamber at MSFC specifically designed for this. Results from these tests will be presented as well as a plan for integration of the electron gun onto an electron focusing column (previously developed at MSFC using internal funding) and design plan for further miniaturization of the system. Additional design considerations will be made throughout the project to accommodate other planetary surfaces (such as Mars), where operating in environmental mode offers added benefits.

References: [1] Chambers, J. G., et al. (1994) *Engineering, Construction, Operations in Space IV*, vol. II, 878-888. [2] Chambers, J. G., et al. (1995) *JGR-Planets, 100*, E7, 14, 391-14,401. [3] Heiken, G. T., Vaniman, D. T. and French, B. M. (1991) *Lunar Sourcebook,* 638. [4] Jolliff, B. L., et al. (2006) *Rev. Mineral. Geochemi*. 60, 721pp. [5] McKay, et al. (1991) *Lunar Sourcebook,* Ch 7, 285-356. [6] Goldstein, J. et al. (2003) *Scanning Electron Microscopy & X-Ray Microanalysis*, Springer Press, New York, NY. [7] Butler, T. W. (1966) *6th International Congress Electron Microscopy (Kyoto)* 1, 193. [8] Gomer R. (1961) *Field Emission & Field Ionization*, Harvard University Press, Cambridge, MA. [9] Crewe et al. (1971) *Rev. Sci. Instr*. 42, 411. [10] Tuggle et al. (1985) *J. Microsc*. 140, 293. [11] http://www.ultravolt.com/.

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