IEEE Trans. on Plasma Sci., **41**(12), 3453-3458 (2013) DOI: 10.1109/TPS.2013.2281399

Small Scale Simulation Chamber for Space Environment Survivability Testing

Robert H. Johnson, Lisa D. Montierth, JR Dennison
James S. Dyer, and Ethan R. Lindstrom

Abstract*— A vacuum chamber was designed that simulates the space environment to facilitate tests of material modification due to space environment interactions. Critical environmental elements to be simulated include an ultra high vacuum, a FUV/UV/VIS/NIR solar spectrum, an electron plasma flux, temperature extremes, and long duration exposure. To simulate the solar electromagnetic spectrum (EMS), a solar simulator was used with a range of 200 nm to 2000 nm. A Krypton lamp provides surrogate radiation for the prominent far ultraviolet hydrogen Lyman-α 120 nm emission not produced by the solar simulator. A mono-energetic electron flood gun (20 eV to 15 keV) provides a controlled electron flux. Electron and EMS incident fluxes of up to four suns intensity at 95% uniformity across the full 100 cm^2 sample surface are possible to reduce exposure time for accelerated testing. A temperature range from 100 K to 450 K is achieved using an attached cryogenic reservoir and resistance heaters. The versatile sample holder and radiation mask allow for cost-effective, customizable investigations of multiple small-scale samples under diverse conditions. *In situ* monitoring capabilities allow measurements to be taken at frequent intervals during the course of the exposure cycle, while the samples are still under vacuum. An automated data acquisition system monitors and records the temperature, pressure, electron, and EMS fluxes. Calibrated reflectivity, absorptivity, and emissivity of the samples can be measured using *in situ* integrating sphere and IR absorptivity/emissivity probes.

***Index Terms*—materials testing, space environment interactions, instrumentation, electromagnetic flux, electron flux**

I. INTRODUCTION

Interactions with the space environment can certainly modify materials and cause unforeseen and detrimental effects to spacecrafts. If these are severe enough the spacecraft will not operate as designed or in extreme case may fail altogether. For example, changes in reflectivity and emissivity of surface materials due to exposure to UV radiation [1], temperature fluctuation [2], charged particle flux [3], contamination [4-6], or surface modifications [7] can lead to changes in optical, thermal, and charging properties of the materials. Alternately, exposure to higher fluence radiation can generate atomic scale defects in materials leading to changes in the optical, electrical, and mechanical properties [1,8]. Further, the evolution of the charging, discharging, electron transport, and arcing properties of surface and bulk materials as a result of prolonged exposure to the space environment has been identified as one of the critical areas of research in spacecraft charging [9]. Evolution of these charging properties has been shown to potentially lead to significant charging risks [10,11].

The key to predicting and mitigating these harmful effects is to develop a broad knowledgebase of the changes produced in the very broad range of materials in spacecraft applications under a wide range of environmental conditions and how these changes affect the materials properties critical to space operations [12-16]. One approach is to analyze the changes to representative samples flown in space under well-documented space environments, as has been done in the LDEF [17] and MISSE [4,18,19] missions. However, the enormous range of materials and environmental combinations to investigate, the limited ability to monitor materials changes during the course of space exposure, the very limited number of returned-sample studies, and the inaccessibility for return-sample missions for most space environments necessitate additional methods of investigation. This is the ability to accurately simulate space environment effects through long-duration, well-characterized testing in an accelerated, versatile laboratory environment [4], [20,21]. Such is the motivation for developing the Space Survivability Testing (SST) chamber described here.

II. SPACE SIMULATION CAPABILITIES

There are a number of characteristics that are necessary for a realistic simulation of different space environments. Some of these critical characteristics are simulated in the SST chamber, including electromagnetic solar (EMS) radiation, electron flux, vacuum, and temperature. Other characteristics, not yet simulated in the SST chamber, include higher energy electron flux, proton or ion flux, plasma, and atomic oxygen flux. The EMS spectrum (shown in Figure 1(a)) is dominated by blackbody radiation from the sun peaked in the visible; the vast majority of incident power is from UV/VIS/NIR radiation from ~250 nm to ~5000 nm that results in most material heating. Photo-excitation, ionization and defect generation, however, result from higher energy (≳5 eV or ≲250 nm) incident radiation. The power in the spectral region <250 nm has its strongest component from the hydrogen Lyman-α

Research was supported by funding from the Utah State University Space Dynamics Laboratory.

Robert Johnson and JR Dennison are with the Materials Physics Group in the Physics Department at Utah State University in Logan, UT 84322 USA (e-mail: bj68127@yahoo.com, JR.Dennison@usu.edu). Lisa Montierth, Jim Dyer, and Ethan Lindstrom work with the Space Environment Effects Group in the Utah State University Space Dynamics Laboratory in North Logan, UT 84341 USA (e-mail: lisa.montierth@sdl.usu.edu, ethan.lindstrom@sdl.usu.edu, jim.dyer@sdl.usu.edu). Johnson and Montierth are undergraduate students in the Mechanical Engineering Department, Utah State University.

Color versions of one or more figures in this paper are available online at http://ieeexplore.ieee.org.

Digital object identifier .

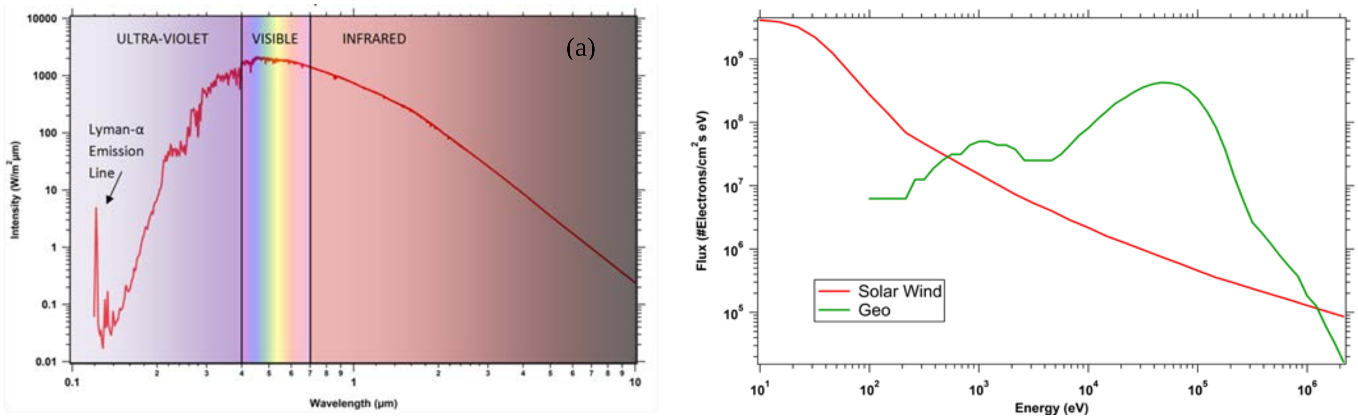


Fig. 1. (a) AM0 solar electromagnetic spectrum [32]. The ranges of the different spectral components and the two SST sources are shown. (b) Typical space electron flux spectra for solar wind at the mean earth orbital distance [33], and geostationary earth orbit [30] and low earth orbit [30].

emission line at 121.6 nm (see Figure 1(a)). The Ly-α emission can dominate many important materials properties; *e.g.*, Ly-α emission is responsible for between 15% and 85% of photoemission from typical spacecraft materials [10,22,23].

The electron flux shown in Figure 1(b) is dominated by electron energies ≲30 keV. These electrons are responsible for most surface charging effects [24,30]. Even though fluxes of higher energy electrons are reduced by more than four orders of magnitude, they are largely responsible for significant effects such as deep dielectric charging [25], single event interrupts [26], and radiation damage [8], [27].

The vacuum of space is typically $<10^{-7}$ Pa, but can be $>10^{-3}$ Pa in local space environments due to outgassing or mass ejection. Pressure variations have significant impact on contamination rates, susceptibility to arcing, and thermal transport. Spacecraft are typically designed with an operational temperature range from 200 K to 350 K, but can extend to higher [28] or lower [28-30] temperatures in orbits far from Earth or when purposefully shielded from solar radiation [29]. Mechanical and electrical properties of materials are particularly susceptible to temperature changes.

III. EXPERIMENTAL TEST CHAMBER DESIGN

A versatile ultrahigh vacuum test chamber has been designed for long duration testing of materials modifications due to exposure to simulated space environment conditions (see Figure 2). It provides a controlled temperature and vacuum environment with stable, uniform, long-duration electron and UV/VIS/NIR fluxes at up to 4 times sun equivalent intensities for accelerated testing for a sample area of 10 cm by 10 cm. The chamber is particularly well suited for cost-effective tests of multiple small-scale material samples over prolonged exposure. Critical environmental components simulated include FUV/UV/VIS/NIR solar spectrum fluxes, low energy electron plasma fluxes, vacuum, and temperature.

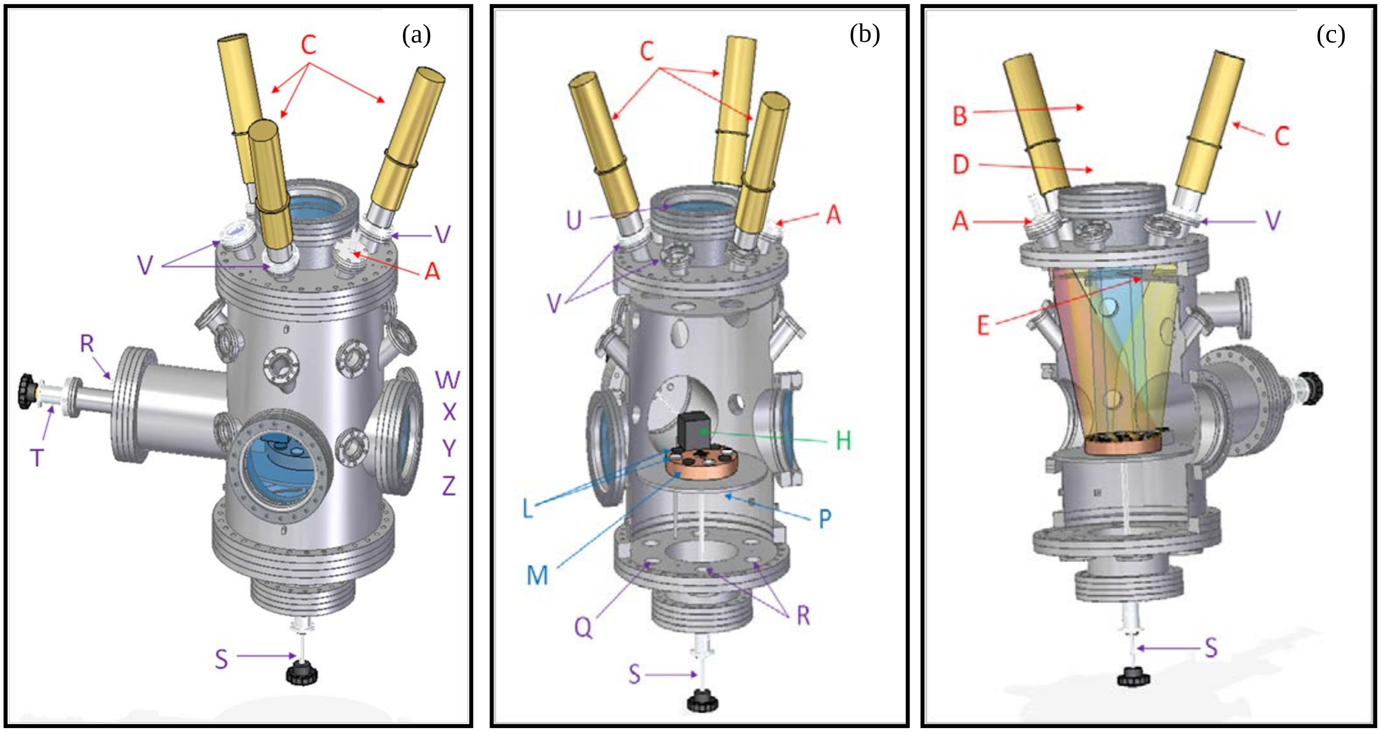
The vacuum chamber uses standard mechanical and turbomolecular pumps (X; See the legend of Figure 2 for definitions and Figures 2, 4 and 5 for use of these letters.) for roughing and an ion pump (Y) for continuous maintenance-free operation. Standard UHV Conflat^{TM} flanges, feedthroughs, and valves are used. Neutral gas density and composition can be regulated from the base pressure (high vacuum $<10^{-5}$ Pa) to ambient, and is monitored with Convectron^{TM}, ion gauges (Y) and a residual gas analyzer (Z).

A. *Radiation Source Design*

The UV/VIS/NIR solar spectrum is simulated using an external, normally incidence and collimated commercial class AAA solar simulator source (Photo Emission Tech, Model SS80AAA). The solar simulator (B) uses a Xe discharge tube, parabolic reflector, and collimating lens with standard Air Mass Zero (AM0) filters (Photo Emission Tech) (D) to shape the incident radiation spectrum to match the NIR/VIS/UVA/UVB solar spectrum (from 200 nm to 1700 nm) at up to 4 times sun equivalent intensity for accelerated testing over a ~100 cm^2 area of 10 cm X 10 cm. Light intensity feedback is used to maintain the intensity temporal stability to with <2% during the sample exposure cycle, using standard calibrated solar photodiodes mounted internally on the sample mounting block. Solar simulator normally incident UV/VIS/NIR light passes through a sapphire viewport (U). Xe bulbs have >1 month lifetimes and are readily replaced *ex situ* for long duration studies.

Incident FUV (far ultraviolet) solar radiation is simulated by Kr discharge resonance line sources (Resonance Limited, Model KrLM-L) (C), with a primary emission line at 124 nm and secondary emission line at 117 nm, with up to 4 times sun equivalent intensity. This provides an adequate substitution for the solar vacuum ultraviolet spectrum (~200 nm to ~10 nm), which is dominated by the H Lyman-α emission line at 122 nm. Three lamps oriented 120º apart provide >98% flux uniformity. The Kr source computer automation system allows monitoring and up to 1 kHz modulation of the output intensity, plus closed-loop temperature control of the source heater and RF output. Kr bulbs have ~5 month lifetimes for long duration studies; they are sealed sources with MgF_2 windows (V), but cannot currently be replaced under vacuum.

An electron flood gun (A) provides a uniform, monoenergetic (~20 eV to ~15 keV) flux needed to simulate the solar wind at more than 100X its cumulative electron flux. Electron fluxes at the sample surface of $\leq 5\cdot 10^6$ electrons-cm^{-2} (~1 pA-cm^{-2} to 1 µA-cm^{-2}) with >95% uniform flux distribution over the full sample area are continuously monitored during the sample exposure cycle using a standard Faraday cup mounted on the sample block. The electron gun and control electronics were custom designed at USU after work by Swaminathan [31]. Beam blanking with a retarding



Legend of Components

Radiation Sources
A Electron Gun
B UV/VIS/NIR Solar Simulator
C FUV Krypton Discharge Lamps
D Air Mass Zero Filter Set
E Flux Mask

Analysis Components
F UV/VIS/IR Reflectivity Spectrometers
G IR Emissivity Probe
H Integrating Sphere
I Photodiodes–UV/VIS/IR Flux Monitor
J Faraday Cup–Electron Flux Monitor
K Platinum Resistance Temperature Probe

Sample Carousel
L Samples
M Rotating Sample Carousel
N Reflectivity/Emissivity Calib. Standards
O Resistance Heaters
P Cryogen Reservoir

Instrumentation (Not Shown)
Data Acquisition System
Temperature Controller
Electron Gun Controller
UV/VIS/NIR Solar Simulator Controller
FUV Kr Resonance Lamp Controller
Spectrometers and Reflectivity Source

Chamber Components
Q Cryogen Vacuum Feedthough
R Electrical Vacuum Feedthrough
S Sample Rotational Vacuum Feedthrough
T Probe Translational Vacuum Feedthrough
U Sapphire UV/VIS Viewport
V MgF UV Viewport
W Turbomolecular/Mech . Vacuum Pump
X Ion Vacuum Pump
Y Ion/Convectron Pressure Gauges
Z Residual Gas Species

Fig. 2. Space Survivability Test (SST) chamber. (a) Chamber exterior view. (b) Chamber vertical cutaway view. (c) Cutaway view of beam trajectories. (i) UVA/VIS/NIR light (yellow). (ii) UVF light (blue). (iii) Electron beam (red).

grid is computer controlled and the flux can be manually adjusted during an exposure cycle. The electron gun has dual “hot swappable” filaments for continuous exposure over long duration testing.

The chamber maintains ≥95% uniformity of the EMS and electron radiation exposure over the full sample area (see Figure 3). The long-term exposure variability of individual samples can be further reduced by periodically rotating the sample stage. The footprint of the incident radiation on the sample surface is determined by a flux mask (E) located near the chamber’s top ports that restricts the flux boundaries to the sample stage, limiting equipment exposure and reducing scattering to accommodate uniform exposure. The solar simulator flux is collimated, but the FUV and electron beams diverge as point sources recessed outside the main vacuum chamber, as shown in Figure 2(c). The flux mask can be readily customized to accommodate different sample geometries. Additional viewports allow for visual inspection of the samples and flux sources during the sample exposure cycle.

B. Versatile Sample Holder Design

Samples are mounted on a OFHC Cu sample carousel (M) connected to a standard rotary vacuum feedthrough (S), used for 355° rotation to position samples under the probe translation stage (T) and to enhance flux uniformity by periodic rotation. The sample stage shown in Figures 4 and 5 has six 2.5 cm diameter samples (L), plus four flux sensors (I,J) and platinum resistance temperature probes (K). The sample stage can be readily reconfigured for various sample sizes of up to one 10 cm diameter sample.

A controlled, uniform temperature range from ~100 K to 450 K is maintained to ±2 K by a standard PID temperature controller, using a cryogenic reservoir (P) and resistance heaters (O) attached to a large thermal mass sample stage (M) used to minimize the differences in temperature between samples and thermal fluctuations during the sample exposure cycle. Fluids circulated through the reservoir from a temperature calibration bath (NESLAB Instruments, Inc., FTC-350A) are used for the range 260 K to 360 K; liquid nitrogen is used from ~100 K to ~250 K.

Alternately, sample temperatures from ~30 K to 400 K can

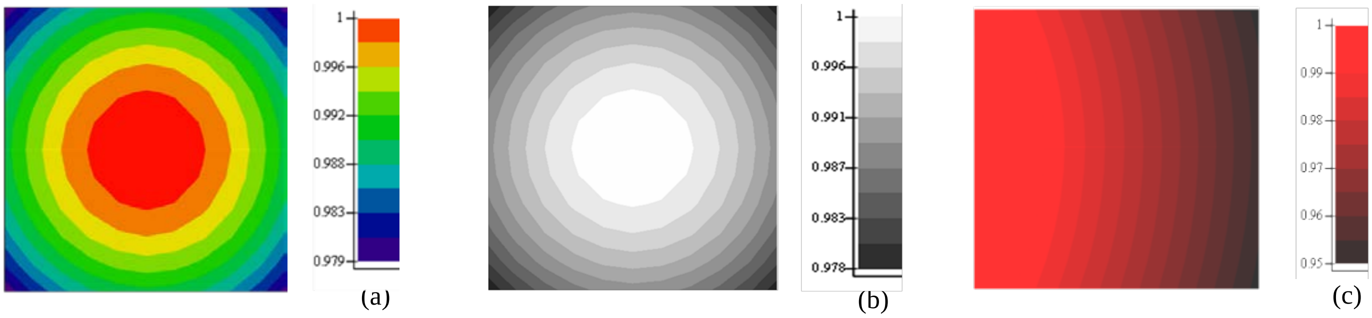


Fig. 3. Contour plots of beam intensity on sample surface: (a) UVA/VIS/NIR light. (b) UVF light. (c) Electron beam. Variation in relative intensity is shown by the color scales at right.

be achieved using a closed-cycle Helium cryostat (Air Products, Displex DE-202-0-SP) and a different sample stage bolted to the flange where the sample stage rotational vacuum feedthrough (S) is fastened. The SST chamber can also be reconfigured as a radiation source for other test chambers by removing the same sample stage flange and bolting the upper source components to other SDL and USU test chambers using the lower 36cm flange.

C. In Situ *Characterization Capabilities*

A Labview-based automated data acquisition system periodically monitors and records the environmental conditions, flux intensities, UV/VIS/NIR reflectivity, and IR emissivity of the samples *in situ* during the sample exposure cycle.

Reflectivity is measured with a compact 2.5 cm diameter integrating sphere (Pike Technology, Model 048-10XX Mid-Infrared IntegratIR) (H) with a fiber optic connection to two optical spectrometers external to the SST chamber. Two calibrated commercial fiber optic spectrometers (StellarNet, Model BLK-C-SR UV-VIS) (StellarNet, Model RW-InGaAs-512) (F) are used to measure diffuse reflectivity of UV/VIS/NIR (200-1080 nm) and NIR (858-1700 nm) ranges with ≲1 nm resolution. Light from a deuterium/W-halogen calibrated light source (Ocean Optics, Model LS-1) enters the integrating sphere through one fiber optic connection; reflected light from the sample exits through another fiber optic to the spectrometers. A split-Y custom fiber optic allows use of a single UHV fiber optic vacuum feedthrough (MDC, Insulator Seal). IR emissivity (4 µm to 15 µm) is measured with a probe (Omega) (G). The integrating sphere and emissivity probe can be extended over the samples with a retractable linear translation stage (T). The sample stage can be rotated to position different samples under the probes. High and low reflectivity/emissivity calibration standards (Labsphere, SRS-99, SRS-10) (N) are mounted behind the probe translation stage for *in situ* calibration of the probes.

Light flux is monitored continuously with photodiodes (I) mounted on the sample stage (M) and equipped with filters to separately monitor NIR, VIS, and UV intensities. Electron flux is monitored continuously with a Faraday cup (J) also mounted on the sample stage. Temperature is monitored continuously with platinum resistance probes (K), also mounted on the sample stage.

REFERENCES

[1]. R. H. Czichy, “Optical design and technologies for space instrumentation,” SPIE, vol. 2210, pp. 420-433, April 1994.

[2]. JR Dennison, C. D. Thomson, and Alec Sim, “The effect of low energy electron and UV/VIS radiation aging on the electron emission properties and breakdown of thin-film dielectrics,” *Proc. of the 8th IEEE Dielectrics and Electrical Insulation Soc. (DEIS) International Conf. on Solid Dielectrics (ICSD)*, Vol. 2, 967-971, (IEEE, Piscataway, NJ, 2004).

[3]. P. Fortescue, J. Stark and G. Swiner, ed, Spacecraft Systems Engineering, 3rd ed., Wiley, pp. 357-361, 2007.

[4]. JR Dennison, John Prebola, Amberly Evans, Danielle Fullmer, Joshua L. Hodges, Dustin H. Crider and Daniel S. Crews, “Comparison of Flight and Ground Tests of Environmental Degradation of MISSE-6 SUSpECS Materials,” *Proc. of the 11th Spacecraft Charging Techn. Conf.*, (Albuquerque, NM, September 20-24, 2010), 12 pp.

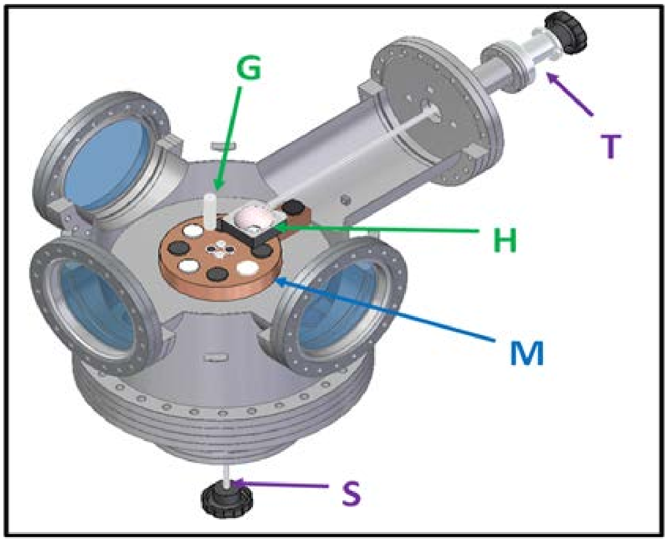


Fig. 4. Sample level cutaway view.

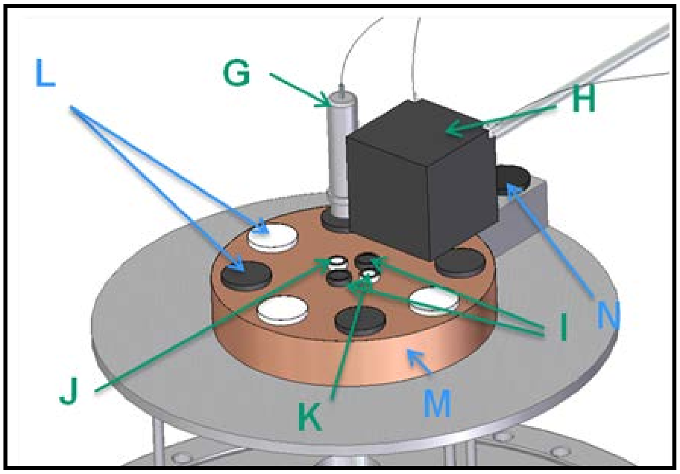


Fig. 5. View of sample carousel and probe translation stage

[5]. R.E. Davies and J.R. Dennison, "Evolution of Secondary Electron Emission Characteristics of Spacecraft Surfaces," *J. Spacecraft and Rockets*, **34**, 571-574 (1997).

[6]. W.Y. Chang, J.R. Dennison, Jason Kite and R.E. Davies, "Effects of Evolving Surface Contamination on Spacecraft Charging," Paper AIAA-2000-0868, *Proc. of the 38th Am. Inst. of Aeronautics and Astronomics Meeting on Aerospace Sci.*, (Reno, NV, 2000).

[7]. Amberly Evans and JR Dennison, "The Effects of Surface Modification on Spacecraft Charging Parameters," *IEEE Trans. on Plasma Sci.*, **40**(2), 291-297 (2012).

[8]. A. Holmes-Siedle and L. Adams, Handbook of radiation effects, 2nd ed., Oxford University Press, pp. 397, 2002. E flux

[9]. D. Ferguson, "New Frontiers in Spacecraft Charging," *IEEE Trans. Plasma Sci.*, vol. 40, no. 2, pp. 1-5, Feb. 2012.

[10]. JR Dennison, R.C. Hoffmann, and J. Abbott, "Triggering Threshold Spacecraft Charging with Changes in Electron Emission from Materials," Paper AIAA-2007-1098, *Proc. of the 45th Am. Inst. of Aeronautics and Astronomics Meeting on Aerospace Sci.*, 16 pages, Reno, NV, January, 10, 2007.

[11]. Lai, S.T. and Tautz, M., "Aspects of Spacecraft Charging in Sunlight," *IEEE Tran. on Plasma Sci.*, Vol. 34, No. 5, October, 2006, pp. 2053-2061.

[12]. JR Dennison, "The Dynamic Interplay Between Spacecraft Charging, Space Environment Interactions and Evolving Materials," *Proc. of the* 12*th Spacecraft Charging Techn. Conf.*, (Kitakyushu, Japan, May 14-18, 2012).

[13]. J.R. Dennison, A. Robb Frederickson, Nelson W. Green, C.E. Benson, Jerilyn Brunson and Prasanna Swaminanthan, "Materials Database of Resistivities of Spacecraft Materials.," Published electronically by NASA Space Environments and Effects Program as part of the *Charge Collector Knowledgebase 3rd Ed.* at http://see.msfc.nasa.gov/scck/

[14]. JR Dennison, Alec Sim, Jerilyn Brunson, Steven Hart, Jodie Gillespie, Justin Dekany, Charles Sim and Dan Arnfield, "Engineering Tool for Temperature, Electric Field and Dose Rate Dependence of High Resistivity Spacecraft Materials Paper Number," AIAA-2009-0562, *Proc. of the 47th Am. Inst. of Aeronautics and Astronomics Meeting on Aerospace Sci.*, 2009.

[15]. J.R. Dennison, C.D. Thomson, J. Kite, V. Zavyalov and, Jodie Corbridge, "Materials Characterization at Utah State University: Facilities and Knowledgebase of Electronic Properties of Materials Applicable to Spacecraft Charging," *Proc. of the 8th Spacecraft Charging Techn. Conf.*, (NASA Marshall Space Flight Center, Huntsville, Al, October 2003), 15 pp.

[16]. W.Y. Chang, Neal Nickles, J.R. Dennison and C.D. Thomson, "An Improved Database of Electronic Properties of Spacecraft Materials for Modeling of Spacecraft Charging," *7th Spacecraft Charging Techn. Conf.*, 23-27 April 2000, Noordwijk, The Netherlands.

[17]. Kinard W, O'Neal R, Wilson B, Jones J, Levine A, Calloway R., "Overview of the space environmental effects observed on the retrieved Long Duration Exposure Facility (LDEF)," Adv Space Res. 1994 Oct;14(10):7-16.

[18]. Kim K D E Groh, Bruce A Banks, Joyce A Dever, Donald A Jaworske, Sharon K Miller, Edward A Sechkar, Scott R Panko, "NASA Glenn Research Center's Materials International Space Station Experiments (MISSE 1-7)," Earth (2008), **10**(11), 10-11.

[19]. JR Dennison, Amberly Evans, Danielle Fullmer, and Joshua L. Hodges, "Charge Enhanced Contamination and Environmental Degradation of MISSE-6 SUSpECS Materials," *IEEE Trans. on Plasma Sci.*, **40**(2), 254-261 (2012).

[20]. J. L.Prebola, , D. H. Crider, , D. S.Crews, "Evaluation of Enhancements to the AEDC Combined Space Environment Chamber", *Proc. of 45th AIAA Aerospace Sci. Meeting*, Reno, NV, January 2007, Paper AIAA-2007-0092.

[21]. Thierry Paulmier, "SPIDER : A New Test Facility For Charge And Ageing Long-Term Relaxation Analysis, *Proc. of the* 12*th Spacecraft Charging Techn. Conf.*, (Kitakyushu, Japan, May 14-18, 2012).

[22]. Grard, Rejean J. L., "Properties of the Satellite Photoelectron Sheath Derived from Photoemission Laboratory Measurements," J. Geophys. Res., 78(16), 2885, 1973.

[23]. B. Feuerbacher and B. Fitton, "Experimental Investigation of Photoemission from Satellite Surface Materials," J. Appl. Phys. 41 1536 (1972).

[24]. Frooninckx, T. B., and J. J. Sojka (1992), Solar Cycle Dependence of Spacecraft Charging in Low Earth Orbit, J. Geophys. Res., 97(A3), 2985–2996.

[25]. Shu T. Lai, "Fundamentals of Spacecraft Charging: Spacecraft Interactions with Space Plasmas," Princeton University Press, 2011.

[26]. Shu T. Lai, "Overview of surface and deep dielectric charging on spacecraft," in Shu T Lai, Spacecraft Charging, Progress in Astronautics and Aeronautics, Reston, VA, 2011.

[27]. D.J. Rodgers and J. Sørensen, "Internal Charging," in Shu T Lai, Spacecraft Charging, Progress in Astronautics and Aeronautics Reston, VA, 2011.

[28]. Michelle M. Donegan, Jennifer L. Sample, JR Dennison and Ryan Hoffmann, "Coating-Induced Charging of the Solar Probe Spacecraft: A Materials and Modeling Study of Environmental Extremes," *J. of Spacecraft and Rockets*, **47**(1), 134-146, (2010).

[29]. During, John. "The James Webb Space Telescope". National Aeronautics and Space Administration. http://www.jwst.nasa.gov/ Retrieved 15 April 2012.

[30]. D. Hastings, and H. Garrett, *Spacecraft-environment Interactions*, Cambridge University Press, 1996.

[31]. Swaminathan, Prasanna V., "Measurements of Charge Storage Decay Time and Resistivity of Spacecraft Insulators," Masters Thesis, Utah State University, Logan, UT 2004.

[32]. ASTM E490 , 2006, "Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables," ASTM International, West Conshohocken, PA, 2006.

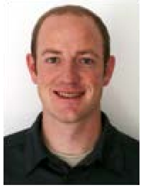
[33]. J. Minnow, private communications, 2010.

Robert Johnson is a recent graduate in Mechanical Engineering from Utah State University, Logan. He has worked with the Materials Physics Group for a year and a half on thermal vacuum chamber design related to spacecraft charging, with a specialty in electron source and detector design..

Lisa Montierth is currently an undergraduate student in mechanical engineering at Utah State University in Logan, UT. She has been in the Space Environment Effects Group at Space Dynamics Laboratory in Logan, UT for one year working principally in mechanical design.

J R Dennison received the B.S. degree in physics from Appalachian State University, Boone, NC, in 1980, and the M.S. and Ph.D. degrees in physics from Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg, in 1983 and 1985, respectively. He was a Research Associate with the University of Missouri—Columbia before moving to Utah State University (USU), Logan, in 1988. He is currently a Professor of physics at USU, where he leads the Materials Physics Group. He has worked in the area of electron scattering for his entire career and has focused on the electron emission and resistivity of materials related to spacecraft charging for the last two decades.

James Dyer received a BS in chemistry from New Mexico Tech, Socorro, NM in 1977 and a PhD in chemistry from Utah State University Logan, UT in 1988. He is a Senior Scientist at USU Space Dynamics Laboratory, where he specializes in space environmental effects, materials chemistry, and contamination control to support the advanced space sensor development programs. Jim is the technical lead of the Thermal-Vacuum Service Center at SDL and has been the contamination control lead on numerous space projects for NASA and DOD.



Ethan Lindstrom received his B.S. degree in physics from Utah State University, Logan, UT, in 2009. After graduation he joined the Space Environment Effects Group at Space Dynamics Laboratory in Logan, UT, where his focus has been space qualification testing of aerospace hardware and material properties measurements for space sensors.