6-2017

USU Space Environment Effects Materials Test Facility Flyer

JR Dennison
Utah State Univerisity

Utah State University MATERIALS PHYSICS GROUP

The Space Environment Effects Materials (SEEM) test facility operated by the Utah State University Materials Physics Group (MPG) is a leading research center for the study of space environment effects on aerospace materials. The MPG performs state-of-the-art ground-based testing of electrical charging and electron transport properties of both conducting and insulating materials, emphasizing studies of electron emission, conductivity, luminescence, and electrostatic discharge in nine custom vacuum test chambers. Our efforts in this field over more than two decades—in cooperation with NASA, AFOSR, and numerous aerospace companies—have been primarily motivated by the space community's concern for charging of crafts caused by plasma environment fluxes and for radiation modification and damage of materials and components. We have studied how variations in temperature, accumulated charge, exposure time, contamination, surface modification, radiation dose rate and cumulative dose affect these electrical properties—or related changes in structural, mechanical, thermal and optical properties—of materials and systems. Our research also has direct application to high voltage direct current (HVDC) power and transmission lines, high voltage power and switching devices, accelerator physics, plasma deposition, super capacitors, semiconductor metal-oxide interfaces, and nanodielectrics.

Recent Publications

1. A Andersen, JR Dennison, AM Sim, C Sim, "Electrostatic Discharge and Endurance Time Measurements of Spacecraft Materials: A Defect-Driven Dynamic Model," *IEEE Tran. Plasma Sci.*, 2015, **43**(9), 2015, 2941-2953.
2. RE Davies and JR Dennison, "Evolution of Secondary Electron Emission Characteristics of Spacecraft Surfaces," *J. Spacecraft and Rockets*, **34**, 571-574 (1997).
3. J Dekany, RH Johnson, G Wilson, AE Jensen, JR Dennison, "Ultrahigh Vacuum Cryostat System for Extended Low Temperature Space Environment Testing," *IEEE Trans. Plasma Sci.*, **42**(1), 2014, 266-271.
4. J Dekany, AM Sim, J Brunson, JR Dennison, "Electron Transport Models and Precision Measurements with the Constant Voltage Conductivity Method," *IEEE Trans. Plasma Sci.*, **41**(12), 2013, 3565-3576.
5. JR Dennison, "The Dynamic Interplay Between Spacecraft Charging, Space Environment Interactions and Evolving Materials," *IEEE Tran. Plasma Sci.*, 2015, **43**(9), 2015, 2933-2940.
6. JR Dennison, A Evans, D Fullmer, JL Hodges, "Charge Enhanced Contamination and Environmental Degradation of MISSE-6 *SUSpECS* Materials," *IEEE Trans. Plasma Sci.*, **40**(2), 254-261 (2012).
7. JR Dennison and LH Pearson, "Pulse Electro-Acoustic (PEA) Measurements of Embedded Charge Distributions," *Proc. SPIE Optics & Photonics Conf.*, **8876**, 2013, 887612-1-11.
8. JR Dennison, AM Sim, J Brunson, S Hart, JC Gillespie, J Dekany, C Sim D Arnfield, "Engineering Tool for Temperature, Electric Field and Dose Rate Dependence of High Resistivity Spacecraft Materials," AIAA-2009-0562, *Proc. 47th AIAA Meeting on Aerospace Sciences*, 2009.
9. JR Dennison, RC Hoffmann, J Abbott, "Triggering Threshold Spacecraft Charging with Changes in Electron Emission from Materials," AIAA-2007-1098, *Proc. 45th AIAA Meeting on Aerospace Sciences*, 16 pp., 2007.
10. AR Frederickson and JR Dennison, "Measurement of Conductivity and Charge Storage in Insulators Related to Spacecraft Charging," *IEEE Trans. Nuclear Sci.*, **50**(6), 2003 2284-2291.
11. JL. Hodges, AM Sim, J Dekany, G Wilson, A Evans, JR Dennison "*In Situ* Surface Voltage Measurements of Layered Dielectrics," *IEEE Trans. Plasma Sci.*, **42**(1), 2014, 255-265.
12. RC Hoffmann and JR Dennison, "Methods to Determine Total Electron-Induced Electron Yields Over Broad Range of Conductive & Nonconductive Materials," *IEEE Trans. Plasma Sci.*, **40**, 2012, 298.
13. AE Jensen and JR Dennison, "Defects Density of States Model of Cathodoluminescent Intensity and Spectra of Disordered SiO_2," *IEEE Tran. Plasma Sci.*, 2015, **43**(9), 2015, 2925-2932.
14. AE Jensen, G Wilson, J Dekany, AM Sim, JR Dennison "Low Temperature Cathodoluminescence of Space Observatory Materials," *IEEE Trans. Plasma Sci.*, **42**(1), 2014, 305-310.
15. RH Johnson, LD Montierth, JR Dennison, JS Dyer, E Lindstrom, "Small Scale Simulation Chamber for Space Environment Survivability Testing," *IEEE Trans. Plasma Sci.*, **41**, 2013, 3453-3458.
16. AM Sim and JR Dennison, "Comprehensive Theoretical Framework for Modeling Diverse Electron Transport Experiments in Parallel Plate Geometries," AIAA-2013-2827, *5th AIAA Atmosph. & Space Environ. Conf.*, 2013, 31 pp.
17. G Wilson, JR Dennison, AE Jensen, J Dekany, "Electron Energy-Dependent Charging Effects of Multilayered Dielectric Materials," *IEEE Trans. Plasma Sci.*, **41**(12), 2013, 3536-3544.
18. G Wilson and JR Dennison, "Approximation of Range in Materials as a Function of Incident Electron Energy," *IEEE Trans. Plasma Sci.*, **40**(2), 2012, 305-310.
19. J Dekany, RH. Johnson, G Wilson, A Evans and JR Dennison, "Ultrahigh Vacuum Cryostat System for Extended Low Temperature Space Environment Testing," *IEEE Trans. on Plasma Sci.*, **42**(1), 2014, 266-271.
20. JR Dennison, *et al.*, "Absolute Electron Emission Calibration: Round Robin Tests of Au and Polyimide," *Proc. 14th Spacecraft Charging Techn. Conf.*, (ESA/ESTEC), 2016) , 7 p.
21. JR Dennison and LH Pearson, "Pulse Electro-Acoustic (PEA) Measurements of Embedded Charge Distributions," *Proc. SPIE Optics and Photonics Conf.*, 2013, pp. 887612-1-887612-11.

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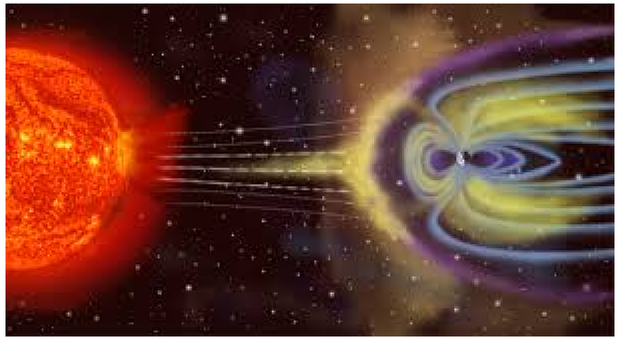
Space Environment Effects Materials Test Facility



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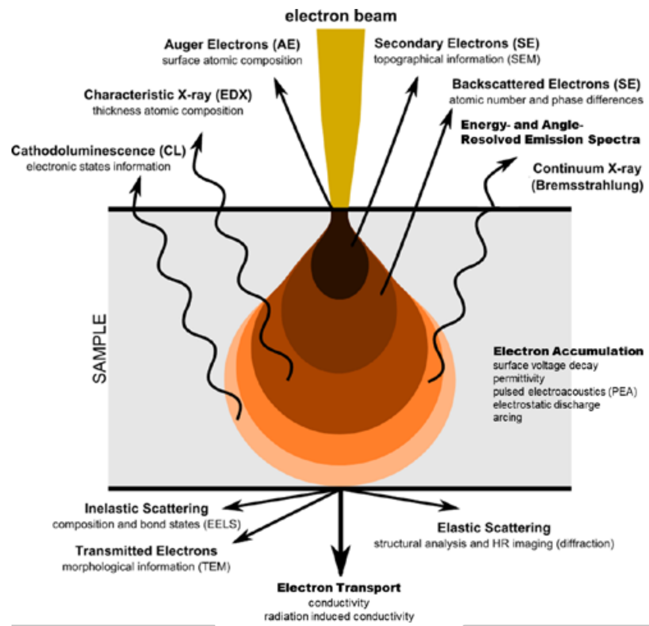

Research Projects & Collaborations

The MPG has been actively involved in more than 50 projects with external funding over the last two decades related to space environment effects. Our interdisciplinary research projects have involved collaborations with numerous space agencies, aerospace corporations and academic institutions, including:

- NASA and Air Force Space Environments Effects Programs.
- NASA Centers (GRC, GSFC, JPL, JSC, LaRC, MSFC),
- Utah NASA Space Grant Consortium.
- AFOSR, AFRL Spacecraft Charging & Instrument Calibration Lab, AFRL Space Weather Center of Excellence, Arnold AFB Engineer Development Center,
- European and Asian Space Agencies (ESA, ESTEC, CNES, ONERA, LAPLACE, ICMM, JAXA, SKLEIPE),
- DOE Centers (Sandia National Laboratory, Idaho National Laboratory Center for Space Nuclear Research),
- Johns Hopkins Applied Physics Laboratory,
- Berkeley Applied Space Laboratory.
- Utah State University Space Dynamics Laboratory,
- Aerospace Companies (Aerospace Corporation, ATK, Ball, Boeing, DPL Science, Electro Magnetic Applications, Lockheed Martin, Northrop Grumman, Orbital, SAIC, Times Microwave, Vanguard Space Technologies, ViaSat),
- SBIR projects (Ashwin, Advanced Scientific, Applied Sciences, Box Elder Innovations, Nokomis, Sienna Technologies).

These ventures have studied both basic science and specific effects and mitigation strategies in a wide variety of extreme environments, each of which present their own unique sets of issues and materials, including:

- Low Earth Orbit (Satellites, CubeSats, FPMU, ISS, *MISSE,* OPAL),
- Geosynchronous Earth Orbit (Communication Satellites, CRRES/IDM, GOES, Landsat LCDM),
- Polar Orbit (DICE, Radiation Belt Space Probes, Communications Satellites, CubeSats),
- L1 and L2 (James Webb Space Telescope, DSCOVR),
- Near-solar (Solar Probe Mission, Parker Solar Probe),
- Lunar and Martian (Dust Mitigation, Orion),
- Jovian (Europa Clipper, Europa Lander, JUNO, Prometheus, Solar Probe Mission, SIRSE),
- Interplanetary (Solar Sails, Solar Probe Mission, Parker Solar Probe, Europa Clipper).

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Utah State University Space Environments Effects Materials (SEEM) Test Facilities

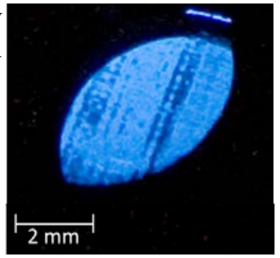
Electron Emission

Electron emission studies for incident electrons, ions and photons, with precision absolute yields of conductors, semiconductors, insulators and extreme insulators [12].

Measurements include:

- **Total / Secondary / Backscattered Electron Emission** using <20 eV to 80 keV monoenergetic pulsed beams with <5% absolute uncertainty [2,12,17,20].
- **Electron Emission Spectra** versus energy (0-5 keV with ~0.1 eV resolution) and angle [12].
- **Ion-Induced Electron Emission** spectra and yields for various <300 eV to 5 keV mono-energetic inert and reactive ions.
- **Photon-Induced Electron Emission** spectra and yields for <0.6 to >6.5 eV (165-2000 nm) mono-chromated photons plus 10 eV near-H Lyman-α source.
- **Surface Voltage** simultaneous measurements of 0-10 kV with <0.2 eV resolution [11,17].
- **Induced Electrostatic Breakdown** simultaneous current, NIR/VIS/UV, & RF measurements [18].
- **Temperature capabilities** from <60 to >450 K [3,19]. (Higher temperatures under development)

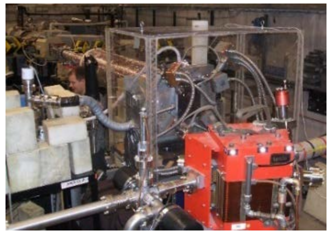
Cathodoluminescence

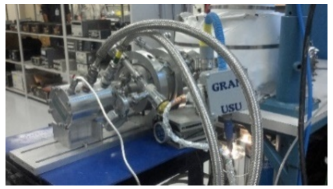


Absolute intensity and low level electron-induced luminescence spectra.

- **Spectra** 0.8-6.0 eV or 200-1700 nm with <0.1 nm resolution [13,14].
- **Temperature capabilities** from <60 K to >450 K [3,14].
- **Charging and Saturation studies** [13,14].

Conductivity & Charge Transport



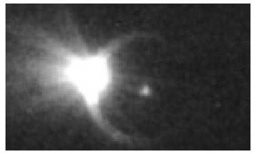


Conductivity and charge transport studies for conductors, semiconductors, insulators and extreme insulators.

Measurements include:

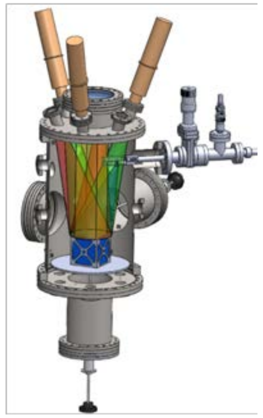
- **Bulk and surface conductivity** using constant voltage and charge storage methods for conductivities as low as 10^{-23} $(\Omega\text{-cm})^{-1}$ [4,8,10].
- **Radiation Induced Conductivity (RIC),** with temperature and temporal dependence [5,8].
- **Photoyield IV curves.**
- **Pulsed Electroacoustics (PEA)** spatial and temporal measurements of internal charge distributions of dielectric layers [21].
- **Surface Voltage** spatial and temporal measurements over 0-10 kV with <0.2 eV resolution [11,17].
- **Temperature capabilities** from <60 K to >450 K [3,19]. (Higher temperatures under development)

Electrostatic Discharge & Arcing



- **Electrostatic Breakdown Field Strength** (<25 kV or <10^9 V/m at 25 μm) [1,18].
- **Temperature and Vacuum capabilities** from <120 K to >350 K at <10^{-3} Pa [1].
- **Electron-Induced Arcing** with current and spatially and temporally resolved optical measurements from <6 K to >350 K at < <10^{-7} Pa [18].

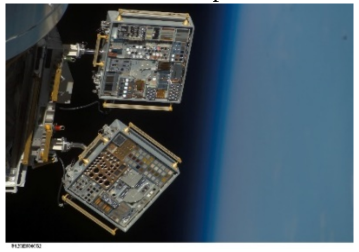
Space Environment Simulation



The **Space Survivability Test (SST) chamber** [15] has unique capabilities for simulating and testing potential environmental-induced modifications of small satellites, components, and devices. It is particularly well suited for cost-effective tests of multiple small scale materials samples over prolonged exposure to simulate critical environmental components including:

- **Electron fluxes** with simultaneous low and high energy electron guns from <20 eV to ~100 keV with ~1 pA/cm^2 to >1 μA/cm^2) fluxes to simulate the solar wind and plasma sheet at more than the 100X cumulative electron flux [9,11,12].
- **Ionizing Radiation** with 100 mCi Sr^{90} broadband (~0.25 to 2.5 MeV) β radiation source at up to 4X GEO equivalent flux [15].
- **NIR/VIS/UVA/UVB radiation** (200 nm to 1700 nm) at up to 4X sun equivalent intensity flux.
- **Far UV** simulation of H Lyman-α with Kr resonance lamps at up to 4X sun intensity.
- **Neutral gas atmosphere/Vacuum** <10^{-7} Pa.
- **Temperatures** 60-450 K with <±2 K [3,19].
- **Custom mounting** of 350 cm^2 area, with extensive cabling and port options for *in situ* monitoring of electrical signals, arcing, video, reflectivity and emissivity.
- **Biological sample** testing of radiation and microgravity effects.

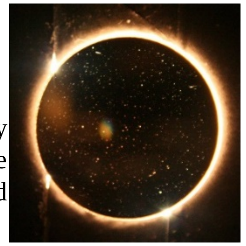
Studies underway will determine how well space degradation of materials can be simulated in the SST. Materials exposed in the SST are compared to 165 samples exposed to the ISS space environment for 18 months on the USU *SUSpECS* project of the AFOSR MISSE-6 mission [6].



Characterization & Preparation

Extensive capabilities for sample preparation and characterization. These include:

- **Bulk Composition** Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES), FTIR and Raman spectroscopy.
- **Surface Composition** Auger Electron Spectroscopy and AES mapping, Energy Dispersive X-ray (EDX) spectroscopy.
- **Surface Morphology** Scanning Electron Microscopy (FE-SEM), Electron Backscatter Diffraction (EBSD), Atomic Force (AFM) and Scanning Tunneling (STM) Microcopies.
- **Vacuum Thermal Ovens** Various ovens down to <10^{-4} Pa and temperatures up to >1500 K.
- **Optical Characterization** Specular/Diffuse NIR/Vis/UV Reflectivity and Transmitivity, Thin-Film Interferometry, T-dependent Emissivity.
- **Luminescence** Optically Stimulated Luminescence (OSL), Thermal Stimulated Luminescence (TSL).



Collaborative Facilities

The MPG collaborates with nearby facilities that extend our capabilities. These include:

- **USU Space Dynamics Laboratory (SDL)** for satellite and sensor development, fabrication and missions.
- **SDL Nano-Satellite Operation Verification and Assessment (NOVA)** test facility for characterization and verification of subsystem and system performance of small satellites.
- **Idaho Accelerator Center** for high energy electron, proton and positron beams and radiation sources to 30 MeV.
- **USU Nanoscale Device Lab** for device and sample fabrication and characterization.
- **USU Core Microscopy Facility** for high resolution electron and optical microscopy.
- **USU Luminescence Lab** for optical and thermal stimulated luminescence testing.