Small Scale Simulation Chamber for Space Environment Survivability Testing

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Simulation Chamber for Space Environment Survivability Testing

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Space Environment Effects

The space environment can significantly impact the performance and durability of spacecraft components. Materials are subjected to a variety of environmental effects that can affect their physical properties and lifetimes.

- Radiation: Ultraviolet, X-rays, and gamma rays can cause damage and degradation of materials.
- Vacuum: Low pressures can cause material issues such as outgassing and evaporation.
- Temperature: Extreme temperature variations can affect material properties and structural integrity.
- Pressure: Changes in pressure can impact fluid flow and gas exchange.
- Humidity: Moisture can penetrate materials, leading to corrosion and degradation.
- Mechanical: Vibrations and shock events can cause wear and fatigue failures.

Space Environment Characteristics

There are certain characteristics of the space environment that are critical for spacecraft survivability. These include:

- Solar radiation: Ultraviolet, X-ray, and gamma rays can cause damage to materials.
- Vacuum: A low pressure environment can affect fluid dynamics and material properties.
- Temperature: Extreme temperature fluctuations can cause thermal stress.
- Pressure: Changes in pressure can impact structural integrity.
- Humidity: Moisture can penetrate materials, leading to corrosion and degradation.
- Mechanical: Vibrations and shock events can cause wear and fatigue failures.

Abstract

A versatile vacuum system for long duration testing of materials modifications due to exposure to simulated space environment conditions has been designed and built. The chamber is particularly well suited for cost-effective tests of multiple small scale materials samples over prolonged exposure. Critical environmental simulators included neutral gas (ultrahigh vacuum, 10⁻⁶ Torr) to ambient, FUV/UV/VIS/NIR solar spectrum, electron plasma fluxes, and temperature. The UV/VIS/NIR solar spectrum is simulated using an external, normally incident and collimated class AAA Solar Simulator source, with standard Air Mass Zero (AM0) filters to shape the incident radiation spectrum. This Xe arc discharge tube has a 200 nm to 2000 nm range with up to four suns light intensity capability. Light intensity feedback is used to maintain the intensity temporally stable during the sample exposure cycle, with standard calibrated solar cells maintained internally on the sample mounting block. Incident radiation flux is continually monitored by Kα discharge line sources, with a primary emission line at 124 nm and secondary emission line at 117 nm with up to four suns intensity. This provides an adequate substitution for the solar FUV spectrum, which is dominated by the Lyman-α emission line at 121.6 nm. An electron flood gun provides a monochromatic (~20 eV to ~15 keV) electron flux. Electron fluxes at the sample surface of <1 pA·cm⁻² to >1 µA·cm⁻² are continuously monitored during the sample exposure cycle, using a standard Faraday cup mounted on the sample block. The chamber maintains 5% uniformity of the electromagnetics and electron radiation exposure over a sample area of ~70 cm². Samples are mounted on a rotatable OFHC Cu sample block with large thermal mass to minimize the differences in temperature between samples and thermal fluctuations during the sample exposure cycle. A controlled, uniform temperature range from 100 K to 450 K is achieved using a cryogenic reservoir and resistance heaters attached to the sample block. The sample carousel is attached to a standard rotational vacuum feedthrough to allow 360° rotation of the samples relative to the incident fluxes. Reflectivity and emissivity are measured by using a compact integrating sphere with a fiber optic connection to an external calibrated commercial UV/VIS/NIR spectrophotometer mounted on a linear translation stage toward the center of the chamber; each sample and in situ calibration standards are rotated under the probes in turn. An automated data acquisition system continuously monitors and records the environmental conditions, UV/VIS/NIR reflectivity, and IR emissivity of the samples in situ during the sample exposure cycle.

In Situ Analysis Capability

UV/VIS/NIR Reflectivity-Two fiber optic spectrometers (F) measure reflectivity of UV/VIS/NIR (200-1000 nm) and 1000-1700 nm ranges with ~1 nm resolution. Integrating Sphere-A 2.5 cm diameter integrating sphere (H) covered with over-the-sample window provides reproducible probe-temperature calibration stage. The sample stage can be rotated to position different samples under the probes. Light from a deuterium/interhalogen calibrated light source enters the integrating sphere through one fiber optic connection; reflected light from the sample exits through another fiber optic to spectrometers. Emissivity-Measured with retroreflective probe (4 µm to 15 µm) focused on probe translation stage. Calibration Samples-in situ high and low reflectivity/emissivity calibration standards (R) are mounted behind the probe translation stage.

Light Flux-Continuously monitored with in situ photodiodes (B) on the sample stage. A low temperature xeon bulb equipped with filters to monitor NIR, VIS, UV intensities. External sensor feedback used to regulate the solar simulator intensity.

Electron Flux-Continuously monitored with in situ Faraday cup (J) on sample stage (H).

Pressure-Absolute pressure monitored with Convectron and Diffusion Pump Gauge (G).

Electrostatics-Spacecraft-like and grounded probe configuration to other SDL/USU chambers.

Legend of Components

- L Samples
- H Integrating Sphere
- A Sample Stage/Stage mount
- M Sample Mount
- J Probe Translation Stage
- R Reflectivity/Emissivity Standards
- Q Temperature Controller
- S Temperature Monitor
- G Air Mass Zero Filter Set
- F FUV/UV/VIS/NIR Solar Simulator Controller
- Y Ion Vacuum Pump
- X Ion Vacuum Pump
- V Magnesium Fluoride Window

Experimental Test Chamber Design

Versatile ultrahigh vacuum test chamber provides controlled temperature and vacuum environment with continuous, long-duration exposure of UV/VIS/NIR fluxes at up to 4 times sun equivalent intensities for accelerated testing for a sample area of 8 cm by 8 cm. Particularly well suited for cost-effective tests of multiple small scale materials samples over prolonged exposure.

Electron Flux-Electron flood gun (A) provides ≤5 × 10¹⁰ electrons/cm²·μs at the sample to avoid more than the 100X cumulative electron flux. Mono-energetic energy range is ≤0.05 to 15 keV. The electron gun provides a broad uniform distribution over the full sample area, with “hot swapable” filament for continuous operation over the entire long duration testing. The electron gun was custom designed at USU after work by Swaminathan [2004].

Infrared/Visible/Ultraviolet Simulated Radiation Chamber: A commercial Class AAA solar simulator (B) provides UV/VIS/NIR fluxes with electronic control of vacuum/pressure, temperature, and solar spectrum. The vacuum ultraviolet (UV) source emits a broad spectrum from the Lyman-alpha (121.6 nm) to 1700 nm at varying flux levels.

Space Simulation Capabilities

- Experiment: Solar simulator with other SDL/USU chambers.
- Analysis: Temperature sensors, spectrometers, reflectivity measurements.
- In situ calibration: Standard samples for continuous monitoring.
- Control: Electron gun for UV/VIS/NIR fluxes.