

Space Environmental testing at GSFC

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Introduction

One critical piece of information needed in the thermal design of all spacecraft are the thermal properties of the coatings and the determination of how those properties change due to the space environmental over the lifetime of a spacecraft. At the Goddard Space Flight Center (GSFC) we have the ability to measure the beginning of life (BOL) thermal properties of thermal control coatings such as solar absorptance, emittance as a function of temperature, conductivity and we can also determine how those properties will change over the lifetime of the spacecraft.

Solar Absorptance measurements (α)

At the GSFC we have several instruments for determining the solar absorptance of thermal control coatings. The primary instrument we use is an AZ-Tek LPSR-300 reflectometer, which can measure the reflectance of 1 inch diameter samples from 250-2800nm and calculate a solar absorptance based on the measured reflectance with an accuracy of ± 0.02 . For a more detailed measurement of reflectance we can also use a Perkin-Elmer Lambda 19 and measure reflectance or transmittance from 250nm to 2500nm with 1nm wavelength precision. The resulting reflectance data at a given angle θ can then be converted to a solar absorptance by the equation¹.

$$\alpha(\theta) = 1 - \rho(\theta)$$

Where the reflectance $\rho(\theta)$ is given by:

$$\rho(\theta) = \frac{\int_0^{\infty} R(\lambda, \theta) S(\lambda) d\lambda}{\int_0^{\infty} S(\lambda) d\lambda}$$

And $S(\lambda)$ is the solar spectrum.

Emittance measurements (ϵ_n ϵ_H)

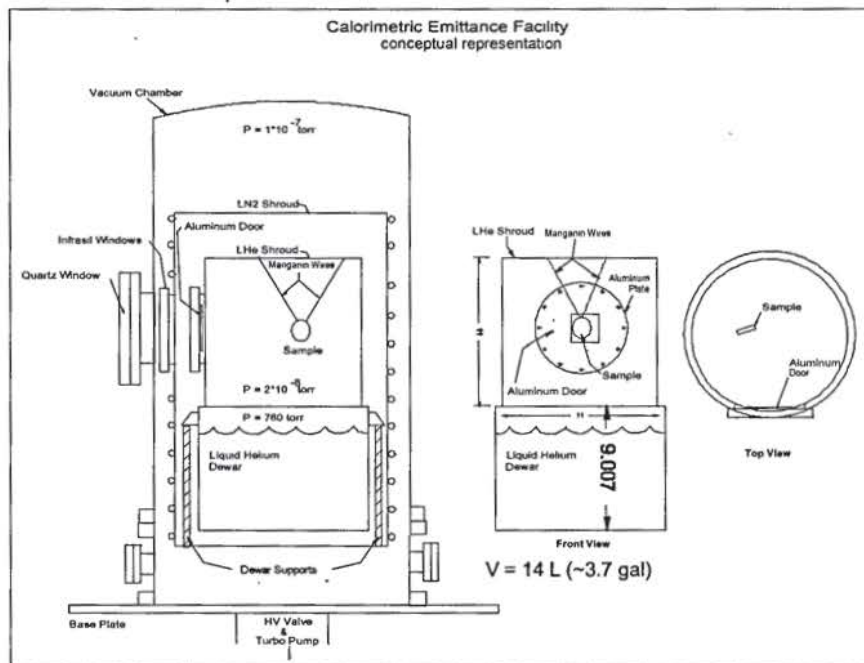
The room temperature emittance of thermal control coatings can be measured easily and quickly measured by a Gier-Dunkel DB100 which covers a wavelength range of 4-40 μ m or about 94 % of a room temperature black body emission. We can also measure the infrared transmittance of samples from 2-20 μ m utilizing a Nicolet FTIR instrument. In the near future we plan to have an ellipsoidal mirror attachment (an SOC 100) which will allow the measurement of the total hemispherical reflectance as a function of angle of incidence from 2-40 μ m. This reflectance data, $\rho(\theta, \phi, \lambda)$, allows for the calculation of the total hemispherical emittance at room temperature and below².

$$\epsilon_T(\theta, \phi, \lambda) = 1 - \frac{\int_0^{\pi/2} \int_0^{\pi/2} \int_0^{\infty} \rho(\theta, \phi, \lambda) \frac{8\pi hc}{\lambda^5 (e^{hc/\lambda T} - 1)} d\lambda d\phi d\theta}{\int_0^{\infty} \frac{8\pi hc}{\lambda^5 (e^{hc/\lambda T} - 1)}$$

$$\varepsilon_h = 2 \int_0^{\pi/2} \varepsilon_t(\theta, \phi, \lambda) \sin(\theta) \cos(\theta) d\theta$$

Cryogenic emittance testing

The Calorimetric Emittance facility at the GSCF is designed to measure the total hemispheric emittance of thermal control surfaces via a transient calorimetric technique over a temperature range of 30°K - 350°K. The test set up consists of the test sample suspended slightly off center within a black painted liquid helium shroud. The liquid helium shroud is contained within an outer shroud of liquid nitrogen and both shrouds are contained within a vacuum chamber that is capable of achieving a base vacuum of $\leq 3 \times 10^{-7}$ torr. The test sample is suspended in the helium shroud by manganin leads which also served as electrical connections to a silicon diode temperature sensor that were epoxied inside an aluminum bolt contained in the substrate. The figure below, gives a schematic representation of the experimental test set up.



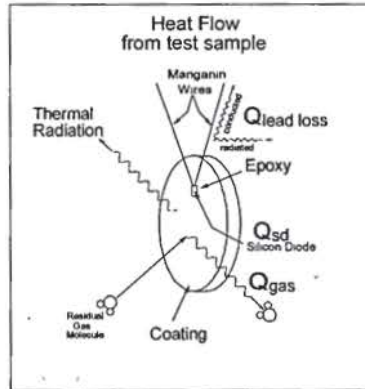
Testing is initiated by evacuating the chamber and cooling both the LN2 & LHe shrouds to their cryogenic operating temperatures. The sample is then heated through the vacuum chamber quartz & infrasil windows via a Spectrolab X25 solar simulator. When a sample temperature of 350°K is reached, the solar simulator is switched off and the vacuum chamber window covered with an aluminum cap and the helium shroud door is closed. The test sample is then allowed to cool by thermal radiation to the liquid helium shroud walls (at ~ 6°K). Monitoring the cool down rate and having knowledge of the specific heat of the substrate as a function of temperature, the sample mass and total radiating area and also knowledge of the parasitic heat losses in the system, allows the total hemispheric emittance to be calculated as a function of temperature. The following equation is used to determine the total hemispheric at each temperature increment.

$$\epsilon_h = \frac{-mC_p \frac{\Delta T}{\Delta t} - m_c C_p \frac{\Delta T}{\Delta t} - Q_{ic} - Q_{gas} - Q_{sd} + a\epsilon(T_s)\sigma T_s^4}{a\sigma T^4}$$

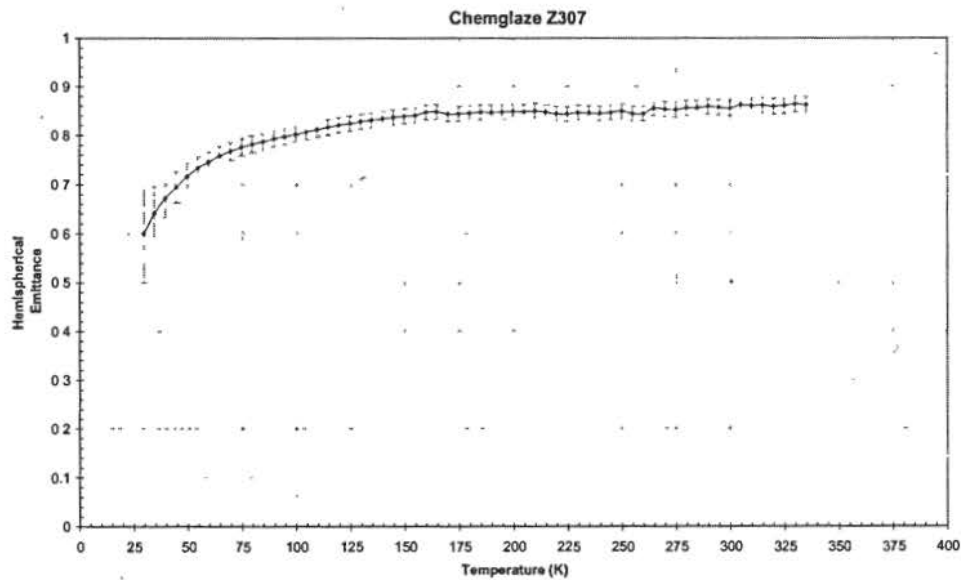
Where:

σ : Stefan-Boltzmann constant
 C_p : specific heat of substrate
 Δt : time increment
 C_p : specific heat of coating
 Q_{ic} : residual gas heat loss
 a : surface area of coating
 T_s : temperature of shroud

m : mass of the Aluminum substrate
 ΔT : temperature increment
 m_c : mass of coating
 Q_{ic} : manganin supports wires heat loss
 Q_{sd} : heat input from silicon diode
 T : temperature of substrate
 $\epsilon(T_s)$: coating emittance at the temperature of the shroud



Results of a typical test:



Electrostatic charge testing

The Electrostatic Charging Facility (ESCF) is a high vacuum apparatus configured to measure the charge level of thermal control coatings when exposed to a simulated on orbit charging environment. A sample is typically a coated (painted) square aluminum substrate six inches on a side and mounted in the vacuum chamber in such a fashion as to be electrically isolated from the vacuum chamber. The charging environment is provided by a Kimball Physics model EFG-9 electron flood gun capable of providing a 1KeV to 25KeV energy electron beam at current densities from $1\text{nA}/\text{cm}^2$ to $10\text{nA}/\text{cm}^2$. The electrical current that is conducted through the sample is measured with a Keithly model 6517A electrometer. The charge build up on the surface of the coating is measured with a Trek model 341 contactless electrostatic probe which can measure charge levels from 0V to 10KV. The electrostatic probe sweeps over the surface of the coating without touching it at a distance of 5mm. The charge potential is thus measured without discharging or disturbing the electrical charge present on the sample surface, from which a coating conductivity can be calculated. The temperature of the sample can also be control from -150°C to $+100^\circ\text{C}$, so that's possible to measure change levels as a function of coating temperature.

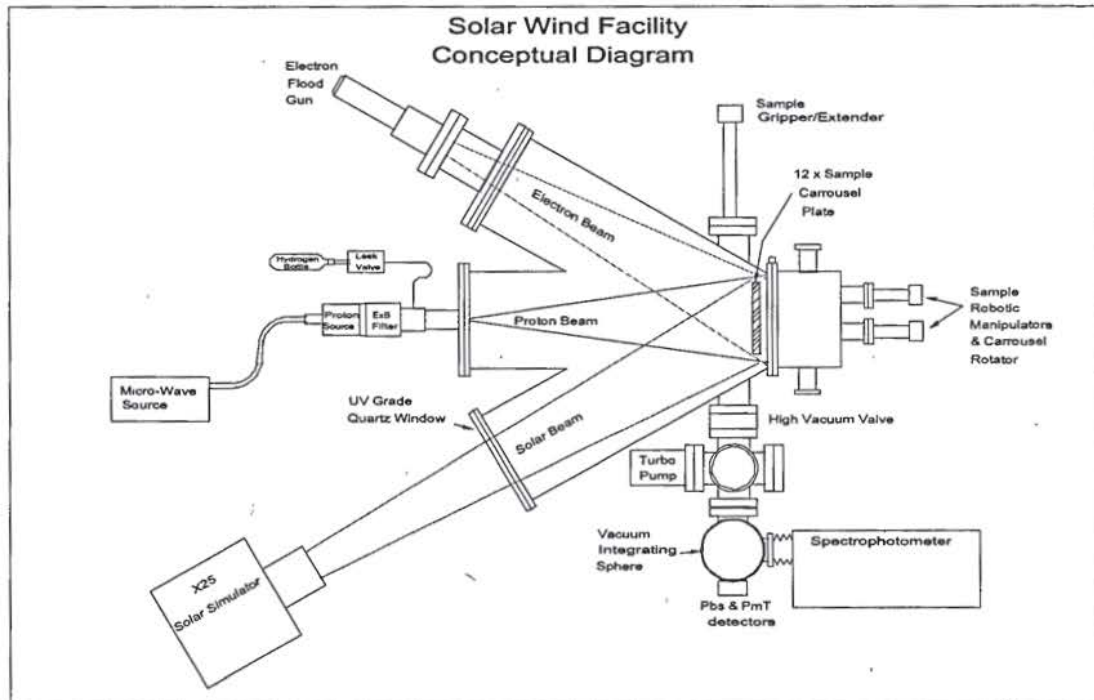
UV degradation testing

The stability of thermal coating properties as a function of long term UV solar exposure is vital to the thermal design of spacecraft. The UV degradation facility at GSFC is designed to provide long term full spectrum solar exposure for 14 thermal control coatings while under vacuum. The samples are mechanically mounted to a water-cooled platen and are normally exposed through 14 individual sapphire window viewports. A dedicated spectrophotometer is capable of measuring the degradation in reflectance of the test samples in-situ from 250nm – 2400nm. The change in solar absorptance as a function of UV exposure can then be easily calculated.

Solar Wind testing

The Goddard Space Flight Center (GSFC) Solar Wind Facility is a combined effects vacuum chamber that simulates the low energy protons and electrons caused by the solar wind, as well as providing simultaneous solar simulation (UV). The proton beam source, a model IMG31 manufactured by Kimball Physics, is created by ionizing hydrogen under low pressure with a 2.455 GHz microwave beam. Electrostatic accelerators and lenses extract and shape the proton beam and an ExB filter removes all ionization species except p^+ , resulting in a pure proton beam that is approximately 0.75cm in diameter at the sample plane. The proton source is differentially pumped by twin turbo pumps that maintain the pressure in the ionization chamber at 4×10^{-5} torr while leaving the main vacuum chamber at a pressure 10^{-7} torr. The proton source is also equipped with X/Y deflection plates and a raster generator that allows the proton beam to be scanned over the entire sample plane with an average current density of approximately $1.0 \text{ nA}/\text{cm}^2\text{-s}$. The Electron beam is generated by a Kimball Physics EFG9 electron flood gun and can be varied from an electron energy of 500eV to 50KeV with current densities up to $20 \text{ nA}/\text{cm}^2$ at the sample plane. The electron beam occupies a leg of the vacuum chamber that is offset 30 degrees to the proton beam. A third section of the chamber allows the solar simulator beam to enter the chamber via a UV grade vacuum quartz window which allows the full spectrum (0.25 μm to 2.5 μm) of the solar simulator to enter the chamber with little loss in intensity. The Spectrolab X25 Solar simulator that resides outside the vacuum chamber provides the full spectrum Solar beam (UV) and is capable of beam intensities from 0.5 to 2.2 equivalent suns with a beam uniformity of 5% over the entire sample plane.

All three beams simultaneously irradiate 12 samples, 2 cm in diameter, which are typically housed in a carousel plate that can be rotated to provide for a uniform irradiation. Typically each of the samples can be removed from the carousel plate and moved into an independently pumped vacuum integrating sphere that is attached to the main vacuum chamber. This provides for absolute in-situ reflectance measurements.



Thermal Coatings Committee

The GSFC thermal coatings committee has the task of estimating the EOL properties of spacecraft thermal control coatings for virtually every GSFC mission. The committee is composed of six seasoned engineers; Jack Triolo, Ted Michelak, Wanda Peters, Mark Hasagawa, Ray Levesque, and my self. Based on flight data, experimental degradation data and many years of collective experience, EOL values are estimated and provided to thermal engineers.

References:

1. John H. Henninger. Solar Absorptance and Thermal Emittance of Some Common Spacecraft Thermal Control Coatings. NASA Reference Publication 1121, April 1984.
2. Lonny Kauder. Spacecraft Thermal Control Coatings References, NASA/TP-2005-212792, December 2005