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PREPRINT

AN IN-SITU FACILITY FOR THE DETERMINATION OF THE EFFECTS OF A SPACE ENVIRONMENT ON THE SOLAR ABSORPTANCE OF MATERIALS

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Abstract

Due to the degradation and subsequent recovery of many spacecraft materials based on the measurement of total solar absorptance in laboratory tests, the facility described in this paper was designed. Use of a vacuum integrating sphere allowing for an absolute absorptance value eliminates difficulties encountered in optical measurements through a window. Four samples can be mounted in the facility at the same time but irradiated individually. The space environment consists of ultra-high vacuum, low energy protons and electrons, from 1 to 30 Kev, and solar electromagnetic radiation. All radiation doses are measured at the sample position. Sample temperatures are controlled and recorded during the pre-irradiation, irradiation, and optical measurement phases. The above facility should allow for an accurate and dependable means of determining the qualifications of thermal control coatings when exposed to a space environment.

Introduction

The ability of a spacecraft to function properly is closely related with the problem of maintaining a tolerable temperature range within which the vehicle operates. Thermal control coatings applied to spacecraft surfaces maintain this temperature balance.

The space environment, consisting of ultraviolet radiation, high vacuum, and energetic particles degrades the optical properties of coatings. To provide more stable coatings, laboratory tests have been going on for some time, which simulate the space environment and study its effect on the solar absorptance of coatings.

It was found that optical reflectance measurements on coatings' surfaces made in vacuum, differed from those made in air.(1) (2) Upon exposure to air following tests, a recovery of degradation occurs in certain types of white thermal control coatings leading to uncertainty as to the actual effects of the simulated space environment. Synergistic effects, where the change in absorptance caused by the sum of each component of the space environment is not the same as that caused by all the components acting together, have been shown to exist.(3) (4) Reflectance measurements should be made at the temperature of the sample at the time of exposure, which necessitates temperature control over the sample during laboratory tests.(5)

The effects of solar electromagnetic radiation on thermal control coatings has been pointed out,(6) therefore simulated tests should approximate as close a match as possible with the ultra-violet portion of the spectrum.

Low energy charged particles, particularly protons, are of great concern in many space missions, and are abundant enough. The integral flux for protons of low energies up to about thirty thousand electron volts is seen to be about 10^8 protons/cm^2-sec.(7)

The above constituents of the space environment, along with the means for measuring their effects on thermal control coatings, have been incorporated in the in-situ facility designed at the Goddard Space Flight Center.

Overall Facility

The facility is shown in Figure 1.

FIGURE 1. OVERALL PHOTOGRAPH OF FACILITY WITHOUT ION SOURCE.

Three stainless steel vacuum chambers make up the facility.

1) An ante-chamber for mounting samples on the main shaft and allowing for outgassing of the samples during pump down.

2) The main irradiation chamber, below the ante-chamber, and separated from it by a metal gate valve.

3) An integrating sphere below the main chamber and open to it except for an optical shutter to allow entry of the samples.

These three chambers along with the sample positioning shaft are illustrated in Figure 2. The

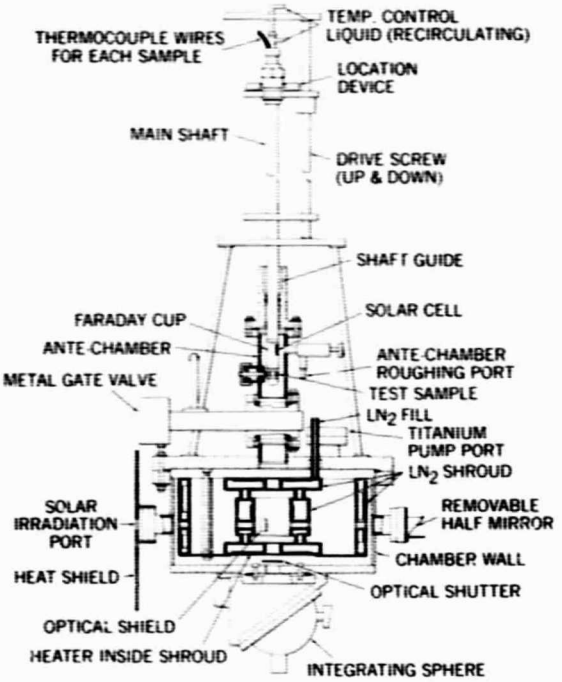

FIGURE 2. CUTAWAY VIEW OF FACILITY SHOWING THE THREE VACUUM CHAMBERS.

shaft permits vertical movement of the samples from one chamber to the next, and rotates so that one sample may be irradiated and measured. Two viton "O" rings, below the shaft guide in Figure 2, provide a vacuum seal in the ante-chamber. The vertical movement of the sample shaft is motor driven with pre-selected stops.

Vacuum System

The main chamber and integrating sphere operate at the same pressure. Once they have been pumped down, they remain under high vacuum, with only the ante-chamber varying from high vacuum to atmospheric pressure.

The ante-chamber, shown in Figure 3, is above the main chamber and separated from it by a gate valve. The top half of the chamber is

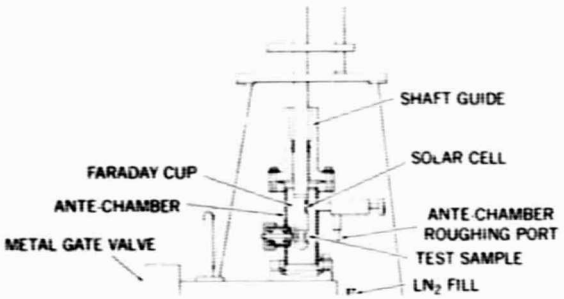

FIGURE 3. ANTE-CHAMBER WITH SAMPLE SHAFT SUPPORT.

unfastened and raised to allow the samples to be mounted on the shaft. A copper seal is replaced each time the chamber is opened.

All three chambers can be rough-pumped through the ante-chamber, using a liquid nitrogen trapped mechanical pump. Once a pressure of 10^{-3} torr has been reached, the ante-chamber can be closed off from the main chamber and each pumped separately.

A 20 liter/sec ion pump is used to achieve high vacuum in the ante-chamber. A strong feature of the facility is thischamber to provide for outgassing of the samples before being moved to the main chamber.

The main irradiation chamber along with the sphere, is closed off from the ante-chamber after having reached a pressure of about 10^{-3} torr. Pumping into the high vacuum region is carried out by a 100 liter/sec ion pump combined with about 2000 liter/sec of titanium sublimation pumping at 10^{-9} torr at LN_2 temperature. With the above pumping capability, pressure in the main chamber should be in the 10^{-9} torr region. The titanium filaments are located between two liquid nitrogen shrouds as shown in Figures 4 and 5. Care has

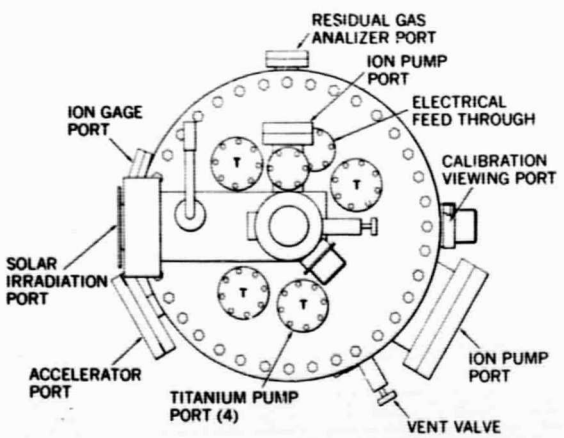

FIGURE 4. TOP VIEW OF MAIN VACUUM CHAMBER.

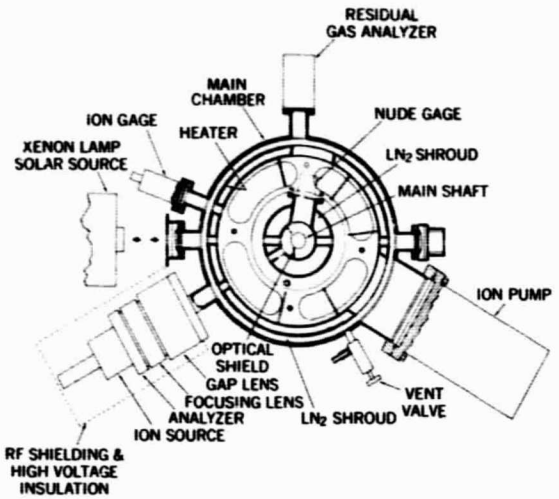

FIGURE 5. BOTTOM VIEW OF MAIN VACUUM CHAMBER SHOWING LN SHROUDS.

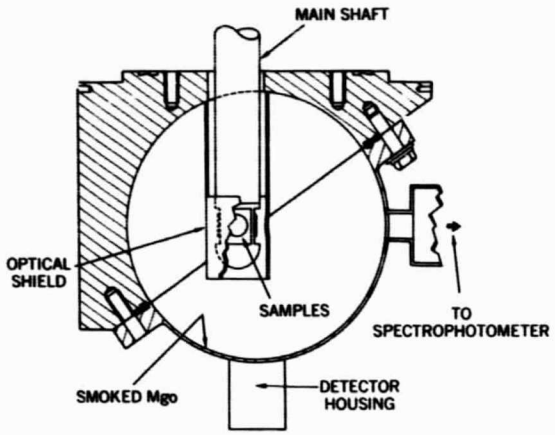

FIGURE 6. SIX INCH VACUUM INTEGRATING SPHERE.

been taken in placing the filaments and shielding the samples from titanium. During operation of the titanium pumps, the samples are in the antechamber. After titanium deposition, the samples are lowered into the main chamber. Two in line one-inch diameter openings exist in both shrouds allowing the passage of particle and light beams. These openeings can be seen in Figure 5. Tantalum apertures on the outside of each shroud are inserted in the opening for the particle beam, to prevent reflection from the shroud walls, thus giving use to a spectrum of particle energies. Actually at the low energies used the aperture material is not of particular importance. Heating elements in both shrouds allow for bake-out.

Pressure in the main chamber is determined by an ion gauge near the outer wall. A Nude ionization gauge, about one inch from the samples, within the inner shroud, measures the pressure in the vicinity of the sample. A residual gas analyzer is also attached to the main chamber. See Figure 5.

The six-inch diameter integrating sphere is open to the main chamber. During sample irradiation, the sphere walls, which are smoked magnesium oxide, are protected from any scattered particles, by an optical shutter. This sphere is a slight modification of the integrating spheres described by Edwards, et al.[8] In Figure 6, a second optical shield can be seen located within the integrating sphere, which prevents the reflected beam from reaching the other samples. The shield is suspended from the upper wall of the sphere and is magnesium-oxide coated. Two detectors, a photoelectric for the ultra-violet and visible, and a lead sulfide for the infra-red are housed at the bottom of the sphere.

Energetic Particle Source

Low energy protons or electrons are obtained from a commercial radio frequency ion source. By changing the polarity of the extractor potential and accelerating voltage either a positive beam or electron beam is obtained. On the particular source and accelerating lens used, beam energies between one and thirty thousand electron volts are attainable. Beam fluxes between 10^9 particles/cm^2-sec and 10^{12} particles/cm^2-sec can be obtained for both proton and electron beams. In the positive mode, the beam needs to be analyzed due to the mixture of molecular hydrogen ions, H_2^+, along with the desired H_1^+ component. For this purpose, an analyzing magnet along with an equipotential lens for beam focusing is used. These elements along with the source and r-f oscillator are seen in Figure 7.

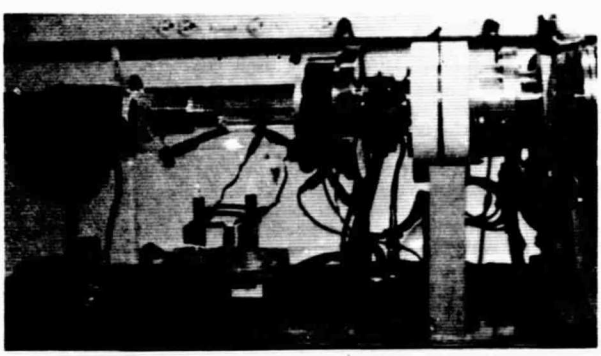

FIGURE 7. CHARGED PARTICLE SOURCE SYSTEM.

The ion source system is to be pumped by an ion pump perpendicular to the beam tube, and following the accelerating lens so that the pump and

vacuum line will be at ground potential. A two-inch gate valve will then be used to open or close off the ion source from the main vacuum chamber. This is advantageous in that, when electrons are wanted, the analyzer element must be removed, and this means opening the ion source to atmosphere. Further, since viton seals are used between the lens elements, differential pumping of the source could prevent unwanted volatiles from reaching the main chamber and adding to the gas load.

In the positive mode the beam is a mixture of protons and molecular hydrogen ions which are separated out by adjustment of the analyzer settings. The beam current picked up at the sample, plotted against the magnet settings produces peaks as shown in Figure 8.[9] The proton peak is greater since this comprises about 85% of the beam before separation.

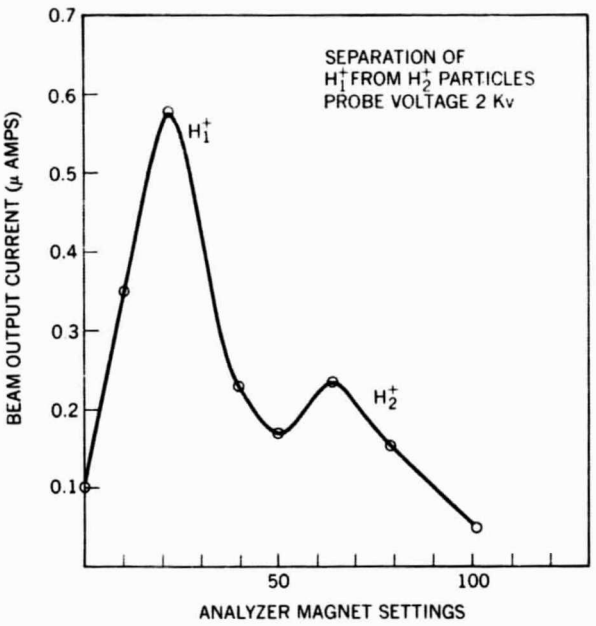

FIGURE 8. SEPARATION OF PROTON BEAM FROM MASS TWO BEAM.

Ultra-Violet Source

A 2500 watt Xenon arc lamp (X-25) is used as the source of ultra-violet radiation. The lamp is located outside the main chamber and can be adjusted to furnish from one to three solar constants. The beam enters the chamber through a one-sixteenth inch thick sapphire window. A comparison of the lamp output against the solar electromagnetic output over the region 250 mμ - 2500 mμ is shown in Figure 9.

Sample Positioning and Temperature Control

The facility can accommodate four one-half inch diameter samples. These are mounted on

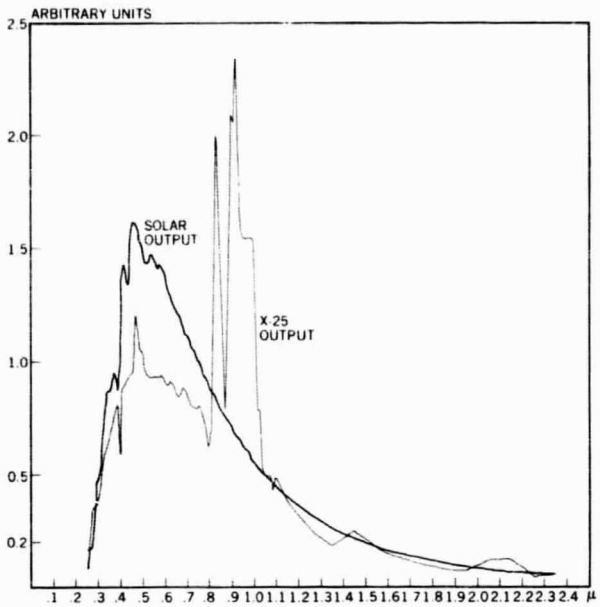

FIGURE 9. COMPARISON OF SIMULATED ELECTROMAGNETIC RADIATION TO SOLAR RADIATION.

the periphery of the bottom end of the sample positioning shaft. See Figure 2. This shaft is double walled, to allow circulation of fluid for controlling sample temperature. The heat exchanger used for this purpose has an output range of from -50°C to +200°C.

Thermocouple leads are carefully insulated, and run from the sample mounting block behind each sample, through the shaft, to a strip chart temperature recorder. This allows substrate temperature of the sample to be controlled to within one centigrade degree.

The shaft is motor driven vertically. Set stops allow the samples to be moved into position for irradiation and measurement. Each of the four samples along with the radiation detectors can be brought into position by rotating the shaft. A location device at the top of the shaft indicates which sample is in position and its angle to the incident beams.

Measurement of Intensities of Particle and Ultra-Violet Beams

The energy of the charged particles is determined from the extractor voltage of the power supply. The particle flux is obtained from the beam current picked up by a Faraday cup. The sixteenth-inch diameter cup is located on the shaft approximately an inch above the samples. By driving the shaft vertically a mapping of the beam along one direction is obtained. The beam current is read-out on a shielded electrometer.

A calibrated solar cell on the shaft, opposite the Faraday cup, monitors the light intensity through the solar region. A second viewing port, on the opposite side of the chamber from the entrance port for the light beam, allows a check on degradation of the sapphire window ports. See Figure 10.

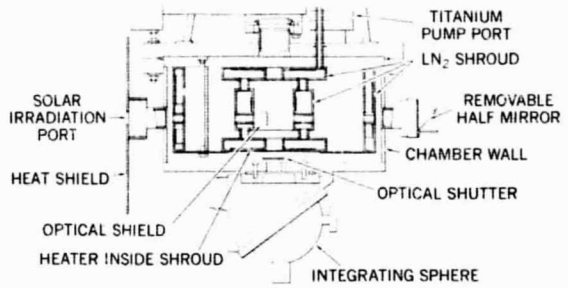

FIGURE 10. CROSS-SECTION OF MAIN CHAMBER WITH VIEWING PORTS.

Measurement of Spectral Reflectance

Spectral reflectance measurements over the wavelength region, 250 mμ to 2500 mμ, are made in the vacuum integrating sphere. The lower part of the shaft, where the samples are mounted and which enters the sphere, is coated with a highly reflective sodium chloride paint, since a smoked magnesium-oxide coating would be too brittle.

A double beam spectrophotometer using a Xenon lamp and with modified transfer optics admits the sample and reference beams through a quartz window into the sphere. All seals in the sphere, including those at the detector are metal.

As noted in Figure 6, the sample surface is at the center of the sphere and affords an absolute value of the solar absorptance of the sample. During measurement, the sample substrate temperature can be controlled, so that it is at the temperature registered during irradiation. Reflectance curves for each sample are recorded in the near ultra-violet, visible, and near infra-red regions, and reduced to furnish a value of the absorptance. The curves also directly show changes in absorptance at any particular wavelength in these regions. Accuracy of the reflectance measurement theoretically is about 1.5% over the range 250 mμ to 2500 mμ.

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