operation of optical instruments by scattering light from the Sun or Earth. The purpose of this paper was to introduce this idea and to review the laboratory evidence that the plasma-dust shedding phenomenon exists.

At this point, it is not possible to quantify the rate of shedding exactly for spacecraft problems. It is likely that the rate of shedding will be $dN/dt=-KN$, as it was in the laboratory experiment, where N is the inventory of dust on the surface. For the dense plasma found in the experiment, $K \approx 10^{-2}\ s^{-1}$. Since the shedding rate was found to increase with plasma density, K would likely be lower by a few orders of magnitude for a spacecraft in the less dense plasma of the ionosphere. It is not possible at this time to specify an exact value for K for various conditions in Earth orbit. This would require further observations of the rate of dust release due to plasma exposure.

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Plasma Current Collection of Z-93 Thermal Paint

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Introduction

A PAINT composed of zinc oxide in a potassium silicate binder, Z-93, has been widely used in the space program as a thermal control coating. Recently, there has been an increased interest in the electrical properties of this paint because of its anticipated use on surfaces which may be at high electrical potentials with respect to the ionospheric plasma.

In particular, the radiators baselined for Space Station Freedom will be coated with Z-93. The measurement of plasma current collection from such surfaces is important because the ground potential of large space structures with respect to the ionosphere can differ significantly from that of the plasma. This occurs as a result of current balance. Because of their large mass and low mobility, ions collected by negatively biased surfaces result in a relatively small plasma current density. The lightweight electrons, on the other hand, are readily collected by positively biased surfaces. Ram and wake effects further complicate the picture. Ram ion energy is considerably higher than ambient thermal energy so ion collection is enhanced on ram facing surfaces relative to surfaces which are oblique to plasma flow. The spacecraft will reach equilibrium at whatever potential results in a net collection current of zero. The most challenging situations occur when the spacecraft power system uses a negative ground as planned for Space Station Freedom. In such a configuration, large surfaces are negative and must collect slow moving ions to balance the current from electron collection which now occurs only from relatively small areas of positive surface. In the worst case, parts of the spacecraft will be biased negatively with respect to the ionosphere to a level very near the maximum voltage used on the solar arrays.

An initial assessment of the implications for Space Station Freedom (SSF) was made by a workshop which included most of the recognized experts in NASA, industry, and academia.[1] That assessment concluded that plasma effects may have considerable impact on the performance and surface properties of SSF. As a result, an ad hoc committee was formed within NASA to comprehensively evaluate all related issues and to recommend any necessary action.[2] This team worked for more than a year to study these issues. Extensive computer modeling and ground-based plasma testing was performed and incorporated into an exhaustive set of trade studies.

The ad hoc committee concluded that major parts of SSF would "float" at about 140-V negative with respect to the ionosphere, close to the 160-V maximum used by its power system. Such large potentials would cause difficulties with arcing and sputtering and cannot be tolerated. To address this problem a plasma contactor will be added to SSF. The plasma contactor will emit a continuous cloud of plasma which will effectively "ground" the structure to the ionosphere. The result will be that as conditions change throughout the orbit, the floating potentials of various parts of the structure will oscillate between positive and negative. The design parameters for the contactor will be chosen to keep the amplitudes of these potentials to within 40 V of plasma ground. To properly design the contactor, it is necessary to model the overall system of "station plus contactor plus ionosphere." This, in turn, requires an understanding of the plasma current collection characteristics of the various surfaces. Because of the large area of the radiators of SSF, which comprise about half the surface area of the entire space station, a moderately conducting coating applied to the radiators would be expected to affect the current balance significantly. In particular, if the Z-93 coated radiators are a good conductor of plasma electrons the plasma contactor will have to be larger to compensate for the resulting current during the positive part of the cycle.

A knowledge of the electrical conductivity of the Z-93 coating is not adequate to determine its impact on the current balance of SSF for two reasons. First, plasma is not a standard electrode for bulk conductivity measurements and a measurement made with metal electrodes cannot be expected to produce the same result. Second, since there is no way of knowing how much of the applied bias "drops" over the thickness of the material, one can not easily calculate the plasma current conduction from a knowledge of the bulk conductivity. A

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direct measurement of the plasma current characteristics of Z-93 was therefore undertaken and is reported here.

Test Facility And Procedures

Testing was done in the plasma interaction facility (PIF) at the NASA Lewis Research Center. The tests were performed in a space simulation chamber that measures 6 ft in diameter by 6 ft long. A 36-in. diffusion pump provides an initial pumpdown to approximately 5×10^{-7} Torr. Plasma is generated by a tungsten filament source with a continuous flow of argon. Pressure in the tank during operation of the plasma source was approximately 5×10^{-5} Torr.

A calibrated laboratory electrometer was used to apply a bias voltage to the test sample and to measure the resulting collected current. The measurements were made from -100 V to $+300$ V in 10-V increments. Ion and electron current sweeps were made separately, always beginning with zero volts and increasing the applied voltage. The negative bias range was restricted to -100 V to avoid arcing and possible damage to the sample. A complete data set consisted of five runs which were averaged to smooth random fluctuations. Additional precautions were necessary to account for systematic drifts in plasma density caused by conditions in the plasma source. Filament sources generally degrade as the tungsten evaporates and the resistance slowly increases. The result is a slow increase in filament temperature and a resulting increase in measured plasma density. To account for this, the plasma density was monitored using a 3/4-in. Langmuir probe with a separate electrometer. At the beginning of each data run, the plasma source was adjusted to produce a current of 800 μA when the Langmuir probe was biased to $+100$ V. It was observed that this current would typically increase by 2% or 3% by the time the run was completed. Plasma conditions corresponding to this value were measured and are shown in Table 1. The procedure effectively normalizes all data to the plasma density indicated. The electrometer used to measure the sample was controlled by a laboratory personal computer whereas the one used for the monitor probe was operated from its front panel controls.

The sample was a disk 2.38 cm (nominally 15/16 in.) in diameter and 0.079 cm (1/32 in.) thick. Z-93 was applied to one face of the disk with a nominal coating thickness of 0.0114 cm (4.5 mil). A single electrical connection was made to the back face and all exposed metal surfaces were sealed with Kapton® tape and a clear silicon sealant.

The Z-93 test was performed in three parts. First, the sample was placed in the tank and a set of measurements taken. This set of data is labeled "initial." It was then allowed to remain in the tank for 6 days. During this time, other work was proceeding intermittently so that the sample saw a plasma environment during much of each day and vacuum conditions the remaining time. At the end of the 6-day period, the test was repeated. This set of data is labeled "intermediate." As discussed subsequently, the measured currents decreased as a result of the extended exposure to tank conditions. The sample was then removed from the tank and hung in a corner of the laboratory for approximately 60 h. It was then returned to the tank and the measurements repeated a third time. This set of data is labeled "final."

Results

To help understand the meaning of the results, a direct comparison was made of Z-93 data with data for a metal sample. The metal sample, made of copper, was constructed to be as close as possible in size, exposed surface, and use of insulating materials on the back and on cable connections. Data from the metal sample is presented along with the Z-93 data.

Table 1 Plasma parameters

Electron density	$3.3 \times 10^5/cm^3$
Electron temp	1.20 eV
Ion temp	0.123 eV
Plasma potential	2.95 eV

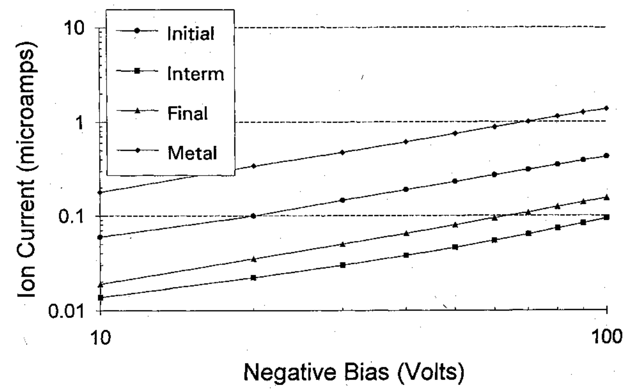

Fig. 1 Ion current vs applied bias.

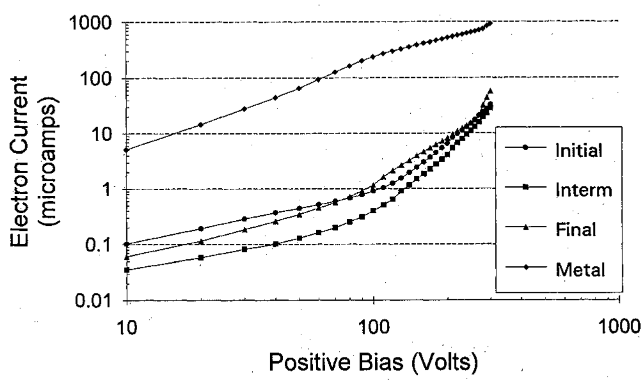

Fig. 2 Electron current vs applied bias.

The ion current data is plotted in Fig. 1. The standard errors are generally in the range of 1% or 2% of mean value. As can be seen, current collection is linear with bias voltage in all cases. Comparison of the initial Z-93 curve with the metal sample shows that the current collection is a factor of three smaller. The intermediate curve is reduced from the initial one by an almost constant factor of five and only partially recovers after 60 h of room air exposure.

The electron current data is plotted in Fig. 2. The initial data shows a nearly linear dependence on bias up to about 100 V followed by a deviation from linearity. Collected current from Z-93 is about 50 times smaller than from the metal sample. For higher voltages, the current collection increases approximately with the third power of applied voltage. This may be due to some sort of snapover[3] effect or to a change in the actual material properties of Z-93. Since the metal sample appears to undergo a change at the same point in the curve, it is likely that this is a plasma sheath effect characteristic of this test geometry. In any event, the Z-93 sample appears to become significantly more conducting at this voltage, an effect that was observed in all five runs comprising this data set.

The intermediate data set, representing 6 days exposure in the chamber, shows a reduction in conductivity similar to what was observed in the ion collection data. Below 100 V this reduction is about a factor of three. At higher voltages the reduction in conductivity is much less than a factor of three.

The curve representing the final data, collected after 60 h of room exposure, indicates a partial recovery up to about 80 V. After this point, the effective conductivity increases rapidly, exceeding even the initial value. The final data and, to a lesser extent the intermediate data, show a pronounced "hump" in the 120–160 V range. The reasons for this behavior are not clear but may involve some sort of breakdown or change in the material properties at high voltages. Within the limited range of interest for the plasma contactor, ± 40 V, the results are consistent for both ion and electron collection.