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PLASMA INTERACTIONS AND SURFACE/MATERIAL EFFECTS

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I. INTRODUCTION

This section is an executive summary of the discussion on plasma interactions and surface/material effects. During the discussion, the panel members unanimously agreed that the key issues in this area were: (1) the lack of data on the material properties of common spacecraft surface materials; (2) lack of understanding of the contamination and decontamination processes; and (3) insufficient analytical tools to model synergistic phenomena related to plasma interactions. Without an adequate database of material properties, accurate system performance predictions cannot be made. The interdisciplinary nature of the surface-plasma interactions area makes it difficult to plan and maintain a coherent theoretical and experimental program. The shuttle glow phenomenon is an excellent example of an unanticipated, complex interaction involving synergism between surface and plasma effects. Building an adequate technology base for understanding and predicting surface-plasma interactions will require the coordinated efforts of engineers, chemists, and physicists. An interdisciplinary R&D program should be organized to deal with similar problems that the space systems of the 21st century may encounter.

II. KEY ISSUES

A. Materials Characterization

A knowledge of the material properties of all spacecraft surfaces is essential to assure the long-term reliability and survivability of future space systems. This knowledge enables modeling of the thermal, electrostatic, and electrodynamic performance of space systems in the space environment in order to optimize design parameters. For example, the electrical properties (surface and bulk conductivity, photoemission, secondary emission) determine the amount of charging that can be caused by the plasma environment. The sputtering coefficients of surface materials determine not only the longevity of those materials, but also the enhanced plasma and chemical environment in the vicinity of the space system. The operation of such space systems as high-voltage solar arrays and RF communications systems are strongly dependent on the plasma environment in the vicinity of the spacecraft. Therefore, the performance of these systems is affected by the behavior of spacecraft surface materials.

The existing data on the electrical properties of common spacecraft materials range from outdated to nonexistent. In particular, there are virtually no data on candidate new and replacement materials. For new classes of materials, such as fluids, composites, and textured materials, the techniques for characterizing such electrical properties as secondary electron-emission coefficients and surface conductivities still remain to be developed. Also, there is little understanding of how various material properties change as a material ages in the space environment.

B. Contamination and Decontamination

The contamination processes to be discussed in this section deal only with those processes induced by plasma interactions or by operation of the space system in the space-plasma environment. At present, contamination has been unavoidable, and there is no proven technique to

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decontaminate a space system. The main present and anticipated sources of contamination are outgassing, attitude control engine burns, manned servicing of spacecraft, water dumps, and spacecraft charging and discharging. The manned space station and other advanced space systems that require frequent servicing or revisitation will be periodically subjected to renewed sources of contaminants. This will drastically increase the need for contamination control.

Contamination can significantly alter the material properties of a surface. Optical mirrors are obviously sensitive to contamination. Contamination has also been observed to change a conductive surface to an insulating surface, or vice versa. Results from experiments on the characterization of electrical properties of exhaust plume contaminants emitted by a bipropellant engine (footnote 1) show that during the first hour of the condensation of the plume exhaust, the contaminant acts like a semiconductor with a resistivity of 10^4 ohm-cm. After exposing the plume condensate to the simulated space environment for several hours, the contaminant becomes an insulating material with a resistivity of 10^{10}ohm-cm. Therefore, contamination can completely alter the plasma interaction processes. Spacecraft charging/discharging can occur unexpectedly. High-voltage surfaces can become electrically shorted, causing an unforeseen failure of space systems. Other plasma-related contamination effects include: (1) errors in science measurements, (2) alteration of the enhanced spacecraft environment due to change in secondary electron-emission coefficients, and (3) degradation of thermal and optical properties.

At the present time, decontamination technology is virtually nonexistent. Innovative active and passive techniques for the dissipation of contaminants need to be developed. The existing models for contamination are crude, and the required data for their use are lacking. There are only isolated R&D efforts to obtain the essential surface material data where needed for a specific mission, e.g., Galileo. A more coherent program is needed.

C. Synergistic Surface Chemical and Physical Processes

The chemical and physical processes that can take place on or near a spacecraft surface affect the enhanced plasma environment in the vicinity of the surface. The glow phenomenon, which is believed to be a synergism between nonlinear plasma interaction processes and chemical reactions of free atomic oxygen with surface materials, is an example of a complex process that can take place in the space environment. The glow has caused unanticipated noise problems for several sensitive optical instruments. Undoubtedly, other space-unique processes will be found requiring synergisms not commonly encountered on the ground, such as reactions involving both atomic oxygen and solar ultraviolet. The unavoidable erosion of surface materials through chemical reaction with free oxygen atoms will definitely reduce the long-term reliability of space systems.

Models to predict space chemistry effects are in a rudimentary stage of development. One of the reasons for the lack of modeling effort is the unavailability of data on the cross-sections for the chemical reactions potentially important in space. Some of the required cross-sections are those for the chemical reactions of ground and excited states of atomic oxygen with spacecraft material (particularly organic materials). The intensity of glow could be related to the presence of a high-density plasma in the vicinity of spacecraft surfaces. The plasma processes responsible for the formation of this high-density plasma are believed to be caused by critical ionization and sheath ionization phenomena. Fundamental knowledge of these processes needs to be improved in order to predict and control the shuttle glow and other synergistic phenomena.

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III. PROPOSED PROGRAM

The key issues discussed above illustrate two common deficiencies:

(1) Lack of experimental data required for modeling system performance.

(2) Nonexistent theory and modeling frameworks for extrapolation of experimental data with respect to geometrical, environmental, and synergistic effects.

In order to prepare the space systems of the next century for possible adverse plasma surface-interaction effects, the following are needed:

(1) A ground-based test program including the following investigations:

(a) Electrical properties (including bulk and surface conductivities, spacecraft surface materials and contaminants.

(b) Outgassing data for new and existing spacecraft materials.

(c) Chemical reaction rates for the ground and excited states of free oxygen atoms with solid materials and outgassed contaminants.

(d) Sticking coefficients of contaminants.

(e) Innovative decontamination techniques.

(f) Space-unique chemical and physical processes.

(2) A space test facility to validate the ground-based measurements.

(3) A program to coordinate phenomenology and modeling development.

(4) A central database for data and phenomenology useful in predicting system performance.

Other space-unique effects, including micrometeoroids and debris, were discussed in the panel meeting. Since these topics are only remotely related to plasma interactions, they are not included in this summary.