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The Dynamic Interplay Between Spacecraft Charging, Space Environment Interaction and Evolving Materials

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Abstract

While the effects on spacecraft charging from varying environmental conditions and from the selection of different constituent materials have been studied extensively, modification of materials properties by the space plasma environment can also have profound effects on spacecraft charging. This presentation focuses on measurement methods and modeling employed to assess the effects of environment-induced material modifications on physical properties relevant to spacecraft charging simulations. It also reviews several specific studies in which environment-induced material modifications have significant impact on predicted spacecraft charging.

Given the increasingly demanding nature of space missions, there is clearly a need to extend our understanding of the dynamic nature of material properties that affect spacecraft charging and to expand our knowledgebase of materials’ responses to specific environmental conditions so that we can more reliably predict the long term response of spacecraft to their environment.

“New Frontiers” from a Materials Perspective

Ferguson’s “New Frontiers in Spacecraft Charging” -C. Purvis

Five Cases of Dynamical Change in Materials:

#1 Non-static Spacecraft Materials Properties
#2 Non-static Spacecraft Charging Models

These result from the complex dynamic interplay between space environment, satellite motion, and materials properties

Case Studies I & II—Contamination & Surface Modification

Case I: Evolution of Contamination & Oxidation

Perhaps the most obvious case of dynamic materials properties in the contamination of materials by the space environment. Evolution of MSSE-6 samples after 18 iron in LEO (shown below).

Before Kapton, IN

After Kapton, IN

Studies of C Contamination Evolution of SE yield as Au contaminated with this disordered C layer. This is an extreme case; Au has very high yield (~1.8 tot yield) and C has very low yield (<1 tot yield).

Before After Black Kapton

Ag coated Mylar with microscratched impact

“All spacecraft surfaces are eventually carbon...” -C. Purvis

Case II: Surface Modification

Surface can be modified in other ways. For example, sputtering or corona can roughen a surface. The optical absorption coefficient, $\alpha$, changes as a function of wavelength for each size of roughening compound used. Increased absorption indicates that charging is increased through the photoelectric effect.

$\alpha = \frac{\sigma}{E}$

$\alpha$ changes reflectivity as a function of particle size.

Successive stages of removal of C

ESD - Electrostatic Discharge

Cases I & II: Reflectivity as Feedback Mechanism

The dynamics of the situation can make the problem even more complex, as changes in one property affect other properties, which can set up feedback loops reusing the same physical quantities.

Consider the interactions possible with the first two cases. Reflectivity changes with surface roughness and contamination

Equilibrium charging potential for a simple material using the time evolution of the secondary electron emission parameters for contaminated gold. Curves are for the 4 September, 1997 (square), worst case (circles), and ATM-5 (triangles) geosynchronous environments in full sunlight (dashed curves) and eclipse (solid curves).

$E = q \cdot V$

$\Delta V$ or $\Delta Q$

Dark conductivity vs $T$

Threshold charging as a result of the change in optical absorption coefficient.

Charge Transport

Conductivity

Di-electric Constant

ESD

RIC factor changes many orders of magnitude in the temperature range typically encountered by spacecraft.

Case III: Radiation Effects

Higher energy radiation causes direct modification of the materials through bond breaking or deposition of energy into conduction electrons.

Large Dose (\textgreater{}10^8 Rad)

Medium Dose (\textless{}10^6 Rad)

Low Dose Rate (\textless{}10^5 Rad)

Charge Transport

Conductivity

Di-electric Constant

ESD

RIC

Conductivity mechanism can change both as a function of temperature and as materials undergo structural phase changes.

Case IV: Temperature Effects

Many material properties can change dramatically over the extreme temperature ranges encountered by spacecraft, from \textless{}30 K to \textgreater{}1800 K. Electron transport properties of insulators are particularly susceptible to temperature.

Charge Transport

Conductivity

Di-electric Constant

ESD

RIC

Uniform Trap Density

Exponential Trap Density

RIC factor changes many orders of magnitude in the temperature range typically encountered by spacecraft.

Case V: Combined Temperature and Dose Effects

The original orbit for the Solar Probe Mission (right) experienced huge extremes in T and dose rate leading to wide variation in materials properties (below). We look for the worst orbit for charging conditions.

Ric vs T

Wide Orbital Range

Earth to Jupiter Flyby

Solar Flyby to 4 Rs

Wide Temperature Range

-10 K to +1600 K

Di-electric Constant vs T

General Trends

Dose rate decreases as $r^{-2}$

$T$ decreases as $e^{-1}$

$\sigma_{acc}$ decreases as $e^{-1}$

$\sigma_{acc}$ decreases as $e^{-1}$ and decreases as $r^{-2}$

A peak in charging at $\sim$0.3 to 2 AU

...Curvature and curvature...

...Alto