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

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Motivation

Complex dynamic interplay between space environment, satellite motion, and materials properties

Abstract

While the effects on spacecraft charging from varying environmental conditions and from the selection of different construction 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”

Five Cases of Dynamical Change in Materials:
- Contamination and Oxidation
- Surface Modification
- Radiation Effects (and t)
- Temperature Effects (and t)
- Radiation and Temperature Effects

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 MSU-6 samples after 18 iron in LEO (shown below).

Case II: Surface Modification
Surface can be modified in other ways. For example, sputtering or corrosion can roughen a surface. The optical absorption coefficient, \(\alpha\), changes as a function of wavelength for each size of roughening compound used.

Cases I & II: Reflectivity as Feedback Mechanism

Conclusions

- Satellites are complex and require:  
  - Complex materials configurations
  - More power
  - Smaller, more sensitive devices
  - More demanding environments
  - There are numerous clear examples where accurate dynamic charging models require accurate dynamic materials properties
  - It is not sufficient to use static (BOL or EOL) materials properties
  - Environment/Materials Modification feedback mechanisms can numerous new problems

Experimental

What do you need to know about the materials properties?

- Charge Accumulation
  - Electron yield
  - Ion yield
  - Photoyield

- Charge Transport
  - Conductivity
  - RIC
  - Dielectric Constant
  - ESD

All as functions of materials species, flux, and energy.

Instrumentation at USU for study of electron emission and electron transport properties applicable to spacecraft charging (left) USU Electron Emission Test Chamber. (Right) Constant Voltage Resistivity Test Chamber.

Reference:
Donegan, 1991  
Charging Study

Case Studies III, IV & V

Case III: Radiation Effects

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

Large Dose (>107 Rad)
Mechanical and Optical Materials Damage
Medium Dose (>106 Rad)
Mechanical Modification of Electron Transport and Emission Properties
Low Dose Rate (>104 Rad)
Radiation Induced Conductivity (RIC) Temperature dependent

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

Charge Transport
- Conductivity
- RIC
- Dielectric Constant
- ESD

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

Case IV: Temperature Effects

Many materials properties can change dramatically over the extreme temperature ranges encountered by spacecraft, from ~30 K to ~1000 K. Electron transport properties of insulators are particularly susceptible to temperature.

“…Curiouser and curiouser…” – Alice

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

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 requiring complex dynamic magnitudes and complex dynamic modifications.

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

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