Overview on Spacecraft Charging Study in Japan

Mengu Cho
Laboratory of Spacecraft Environment Interaction Engineering
Kyushu Institute of Technology

Koga Kiyokazu Koga, Hideki Koshiishi and Kumi Nitta
Japan Aerospace Exploration Exploration Agency

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Contents

• Simulation study
• Electrostatic discharge research in laboratory
• Characterization of charging properties
• Preparation for flight experiment and demonstration
• In-orbit space environment measurement
• Guideline
MUSCAT Improvement

- Fast & Stabilized Computation
- Internal Charging Simulation
- Plasma Environment Data
- Auroral Electron Energy Distribution
- Linux Stand Alone
- Simulation of Charging Mitigation by Neutralizer
- & etc.
Charging Analysis of a Solar Sail

For the Next-generation, Interplanetary-Flight Spacecraft

Membrane: Al-coated Polyimide
Area: 14x14(m²), Thickness: ~10⁻⁶(m)

S/C Charging & Charged Particle Profiles:
For S/C & Payload Design

Paper on Wednesday
Charging Analysis of a Solar Sail

Solar Flux & Plasma flow: left to right, dx=0.5m, Plasma environment@1.0AU

Paper on Wednesday
Application of space plasma PIC simulation to the analysis of time-dependent electromagnetic environment of scientific spacecraft

**EMSES Code (Electro-Magnetic Spacecraft Environment Simulator)**

[Miyake and Usui, *Phys. of Plasmas*, 16, 062904, 2009]

- **Full PIC electromagnetic code**
- **Modeling of spacecraft immersed in space plasma**
- **Time-dependent spacecraft-plasma interactions including EM-field evolution**
  - Spacecraft charging, Plasma and **EM-field environment around S/C**
- **Rectangular, uniform grid system**
- **High performance computing by parallelization with domain decomposition using MPI**

Displacement relation of EM sheath wave propagating along S/C surface
Application of EMSES to simulations of a double-probe electric field sensor

BepiColombo/MMO to Mercury

MEFISTO: Electric field sensor

Guard electrode (negatively charged by reference to s/c)

Structure of MEFISTO

Density plot of photoelectrons emitted by the s/c body

- PIC simulations with EMSES
  - Demonstration of the guard electrode to repel PEs coming from the s/c body.
  - PE behavior around the sensor
  - Study on the conditions for the guard electrode operation to repel the PEs effectively

Application to scientific payload design and data calibration
Electrostatic discharge research in laboratory
ESD test on solar array

- ESD tests on solar array continues at KIT based on ISO-11221
Flashover propagation experiment

2 solar array panels with 2m x 1.2m

gap: 6cm

Propagate to 3m

Discharge point

Flashover jumped the gap

Joint experiment by KIT and JAXA
Solar array ESD researches at KIT

• Effect of temperature on arc rate
• Effect of water molecule adsorption on arc rate
• Aging effect
• Arc initiation method
• Secondary arc mitigation by current oscillation with capacitor and inductor
• Flashover simulator
• Orbital demonstration of high voltage solar array technology

Papers in this conference
ESD from electrically floating electrodes due to internal charging

0.1 mm thick poly-imide substrates with floating electrodes

Electrodes

#2, #3: electrically floating
#1, #5: grounded through electrometer
#4, backing: grounded

Shape of sample

Time dependences of surface potentials of floating electrodes irradiated with electron energy of 7keV and beam current density of 0.1 nA/cm²
Characterization of charging properties
Internal charge measurement in bulks using Pulsed Electro-Acoustic (PEA) method at TCU

- The internal charge accumulation and distribution in dielectrics can be observed using PEA method.
- Observed charge accumulation in the bulks of PI films irradiated by the beams.

[Diagram showing charge distribution in PI films irradiated by electron and proton beams]

Now, Developing the new internal & surface charge measurement system using improved PEA method.

Paper on Thursday
Electron beam induced charging of insulating materials at Nara National College of Technology

125μm silvered Teflon FEP

Electron energy dependence of surface potential in case of beam current density $J_b = 0.1 \text{ nA/cm}^2$ for 60 minutes

Surface potential dependence of volume resistivity obtained from the charge decay characteristics after electron irradiation.
Characterization of charging properties of degraded material at KIT

- Secondary-electron
- Photo-electron
- Volume and surface conductivity by charge storage method

Papers in this conference

[Image of experimental setup]

AO generation chamber

Electron beam source

Moveable stage

Beam modifier plate

Surface potential meter

Reference Plate

Test sample

CO₂ Laser  RGA  O₂ Gas  Nozzle

PV

AO

UV

SEE & PEE
Characterization campaign of charging properties of degraded material sponsored by JAXA

Framework for the Measurements of Materials Properties Parameter

<table>
<thead>
<tr>
<th>Material property</th>
<th>The range of primary energy</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary electron emission (SEE)</td>
<td>Accelerating voltage: 600V-5kV</td>
<td>The High Energy Accelerator Research Organization (KEK)</td>
</tr>
<tr>
<td></td>
<td>Accelerating voltage: 200V-1kV</td>
<td>JAXA &amp; Tokyo City university</td>
</tr>
<tr>
<td>Photoelectron emission (PE)</td>
<td>Wavelength 30 to 250 nm</td>
<td>KEK</td>
</tr>
<tr>
<td></td>
<td>Wavelength 110 to 400 nm</td>
<td>Tokyo City university</td>
</tr>
<tr>
<td>Bulk resistivity, Surface resistivity</td>
<td>ASTM D-257, JIS C2139</td>
<td>Saitama University</td>
</tr>
<tr>
<td>Bulk resistivity</td>
<td>Charge storage method</td>
<td>Saitama University</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td></td>
<td>Sumitomo Metal Technology Inc.</td>
</tr>
</tbody>
</table>
Charging/discharging properties of many materials were studied through collaboration of JAXA and Kobe University. Well-characterized 8 km/s atomic oxygen beam was used for simulating LEO space environment at Kobe University. Charging/discharging properties of the simulated EOL samples were analyzed by JAXA and Saitama University.
Charge Storage Method for Volume Resistivity in Space Environment at TCU

- Vacuum and E-beam
- Volume resistivity is calculated from the dark current decay constant in week long surface potential history

\[ V(t) = V_0 e^{-t/\tau_d} \]

\[ \rho \propto \exp\left( T^{-1} \right) \]

Test parameters
- Temperature → charge residual at cryogenic temperature
- Electron energy and flux → range and dose effect (RIC)
- Sample thickness → E-field enhancement

Conductivity Measurement in Vacuum using Conventional Method at TCU

- The conductivity of dielectrics for spacecraft is observed using the conventional method (ASTM D257, JIS K6911).
- We confirm that the PI’s conductivity decrease in vacuum condition.
Lunar Dust Charging

- Experiment on dust charging and subsequent levitation

Joint work of KIT and USC

*Poster in this conference*
Preparation for flight experiment and demonstration
Development of surface charging sensor

- Application of COTS potential monitor to satellite surface potential monitor

Trek 820 potential meter

- Conversion of ultra-high impedance contact-type
- Sensor head as small as 1mm or less
- Multiple-sensor head to measure deep dielectric charging

Poster in this conference
Spacecraft Charging Mitigation

• Electron-emitting Film for Spacecraft Charging Mitigation (Elf’s CHARM)
  – To be launched in as early as Nov. 2011

• Semi-conductive transparent coating

![Image of ELF/GEO and ELF/PEO films]

**Paper in this conference**
Electrodynamic bare tether

- Preparation for orbital demonstration on a small satellite
  - Field Emission Cathodes using Carbon Nanotube (Paper on Thursday)
  - Arc suppression (poster in this conference)
PASCAL (Primary Arcing effects on Solar Cells at LEO)

- To be launched to ISS in February 2011
  - Characterize solar cell degradation due to arcing
  - Active experiment with COTS-based electronics for biasing cells and collecting data

In-orbit space environment measurement
Instruments onboard (LEO)

ISS
Space environment data acquisition instruments (SEDA-AP)

GOSAT
Space radiation environment detectors (TEDA/ LPT)

ALOS
Space radiation environment detectors (TEDA/ SDOM)

JASON-2
Space radiation environment detectors (TEDA/ LPT)
Instruments onboard (GEO)

Space environment monitors (TEDA/MAM, POM)

Space radiation environment detectors (TEDA/SDOM)

Space environmental monitors (TEDA/LPT, MAM, POM)
Spacecraft charging design guideline

- JERG-2-211 “Satellite Design Guideline for Charging and Discharge”
  - Published in 2009
  - Characterization Campaign
    - Material data for charging simulation
    - Solar array secondary arc