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 Agency

Acknowledgement: Colleagues in Japan

September 20, 2010

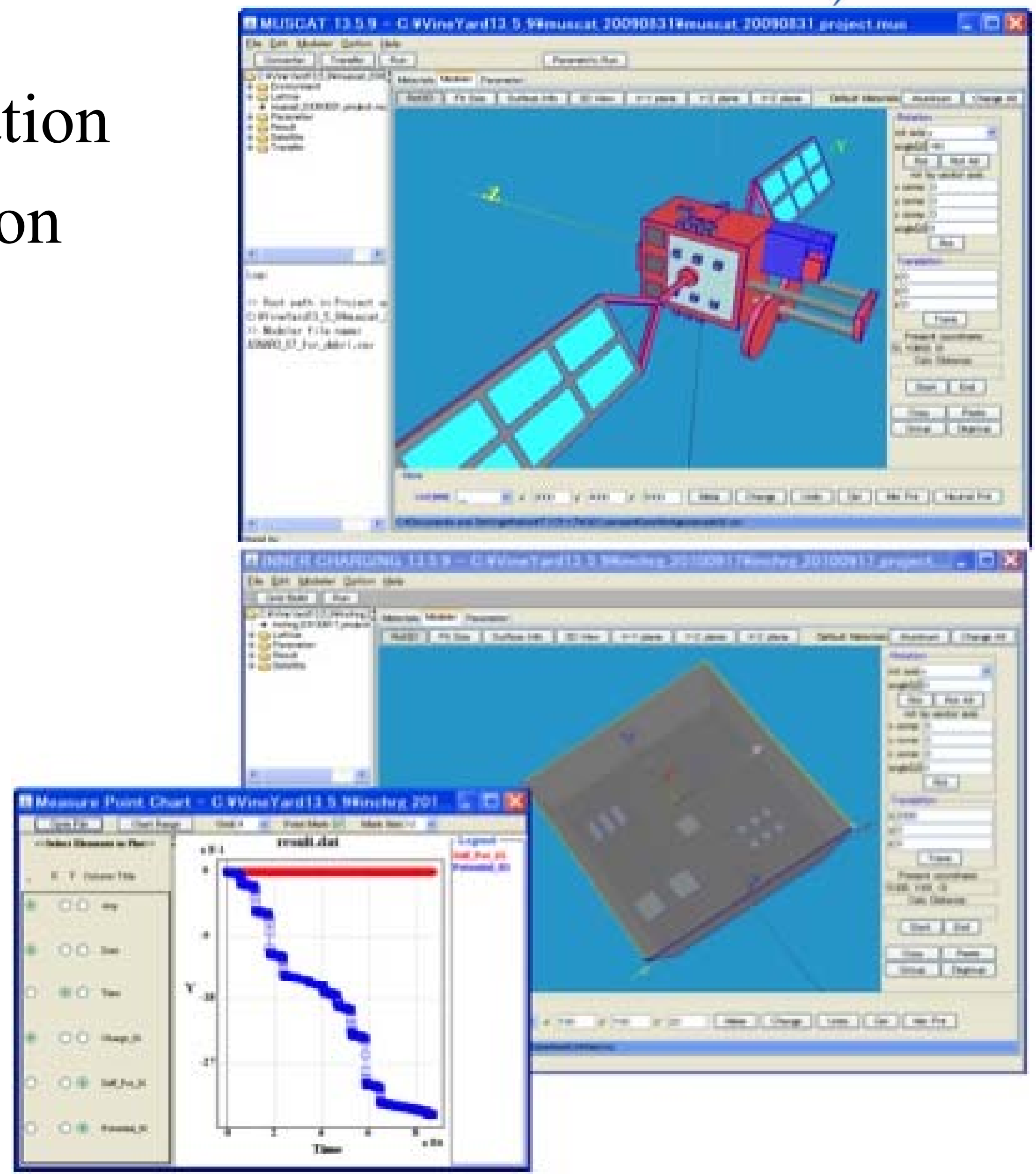
11th Spacecraft Charging Technology Conference, Albuquerque, NM, USA

Contents

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

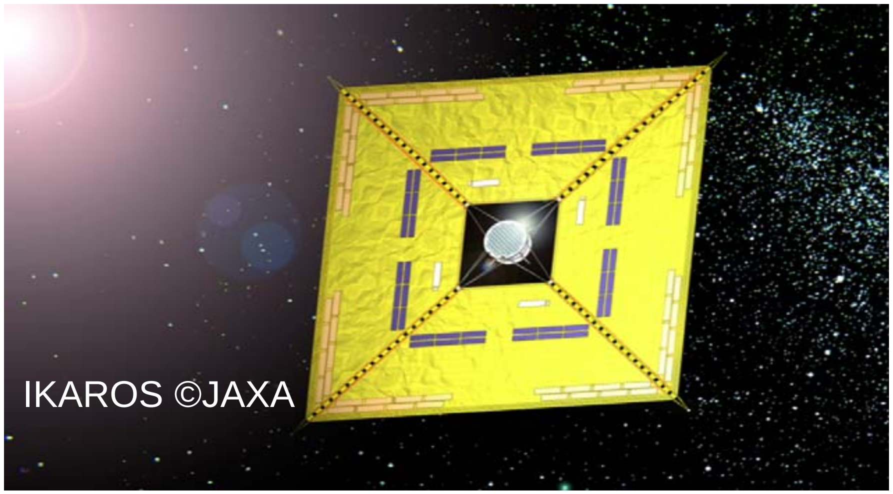
MUSCAT Improvement

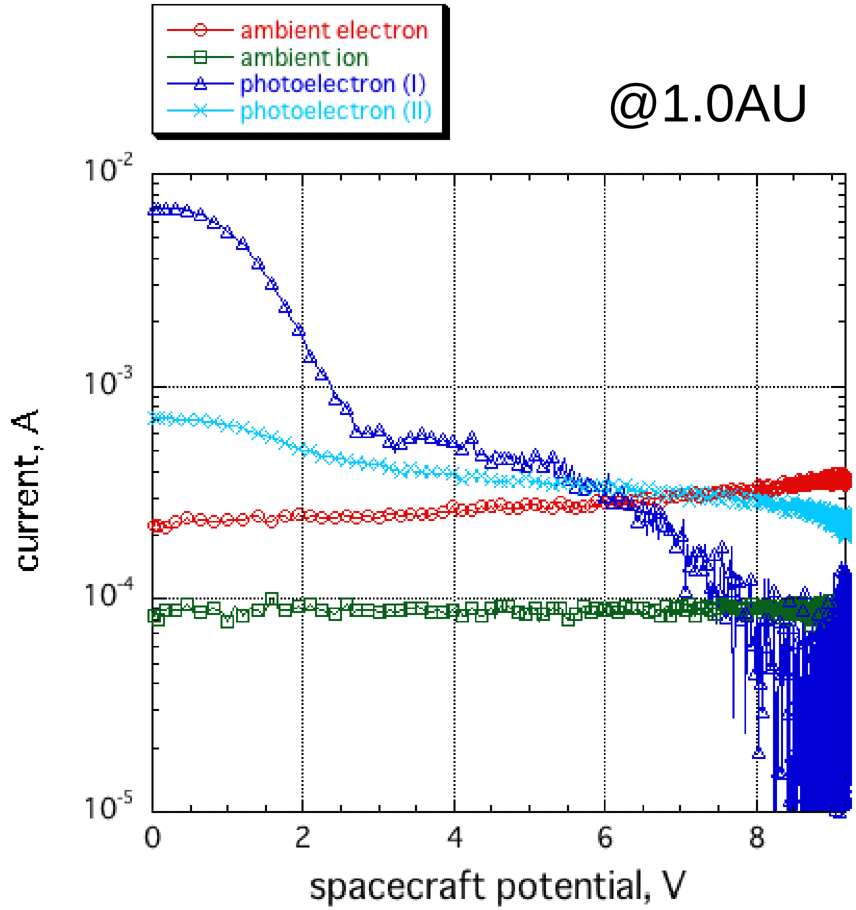
- Fast & Stabilized Computation
- Internal Charging Simulation
- Plasma Environment Data
- Auroral Electron Energy Distribution
- Linux Stand Alone
- Simulation of Charging Mitigation by Neutralizer
- & etc.



Charging Analysis of a Solar Sail

For the Next-generation, Interplanetary-Flight Spacecraft





Membrane: Al-coated Polyimide
Area: 14x14(m^2), Thickness: ~10^{-6}(m)

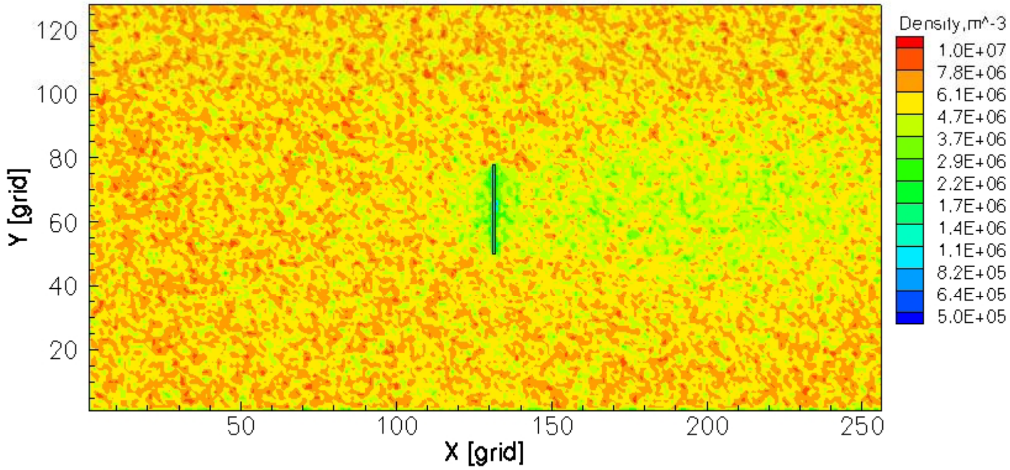
S/C Charging & Charged Particle Profiles:
For S/C & Payload Design

Paper on Wednesday

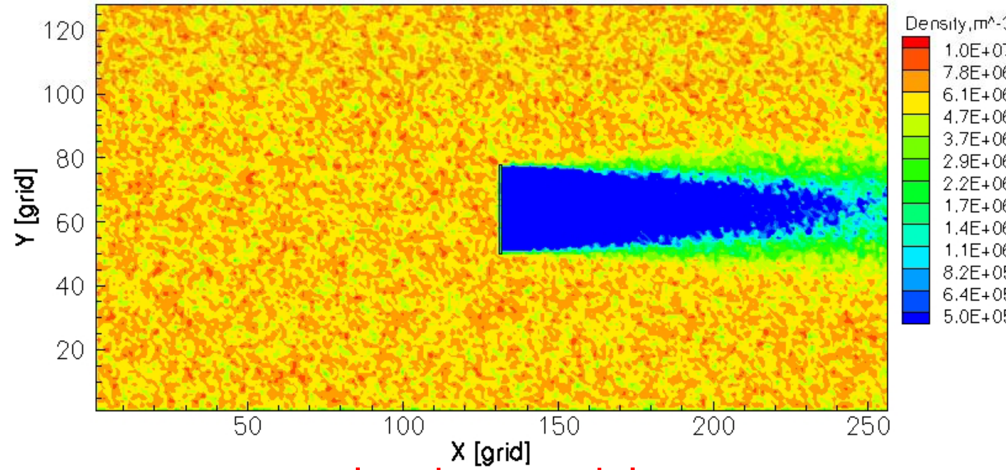
Charging Analysis of a Solar Sail

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

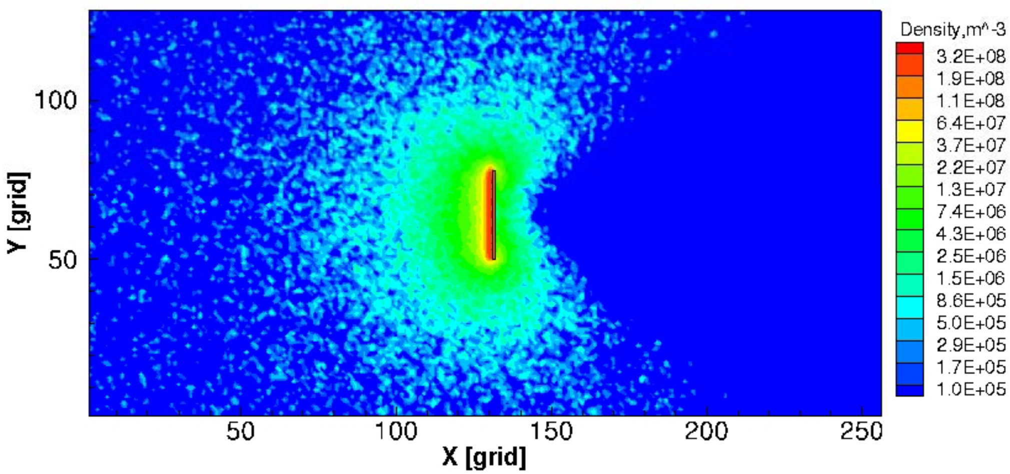
ambient electron



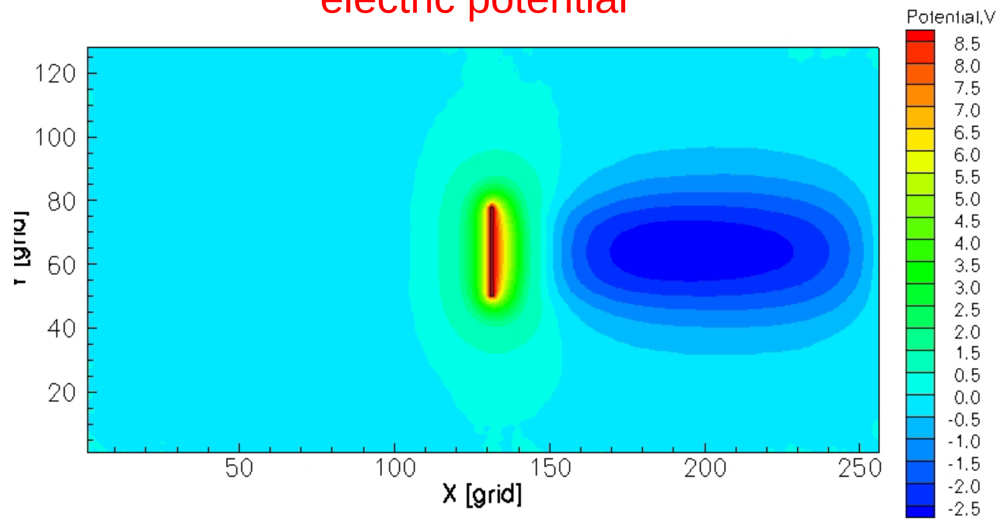
ambient ion



photoelectron



electric potential



Paper on Wednesday

PIC Simulations of a Double-Probe Electric Field Sensor onboard Scientific Spacecraft Using the EMSES Code

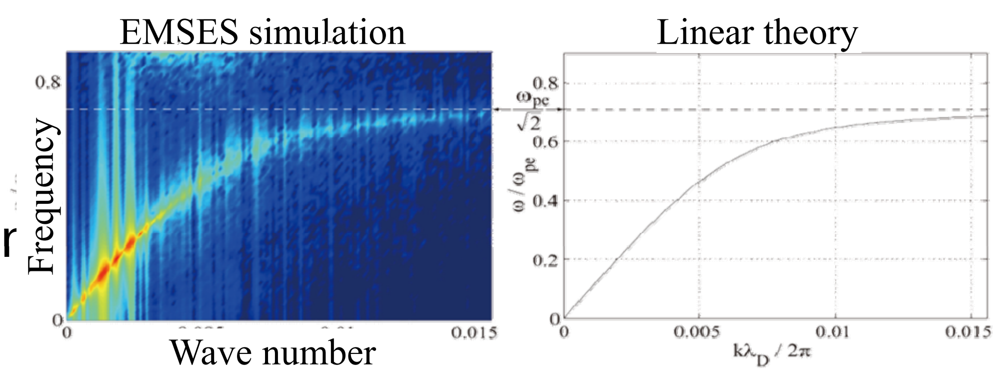
Miyake, Y. (Kyoto Univ.), H. Usui (Kobe Univ.), and H. Kojima (Kyoto Univ.)

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]

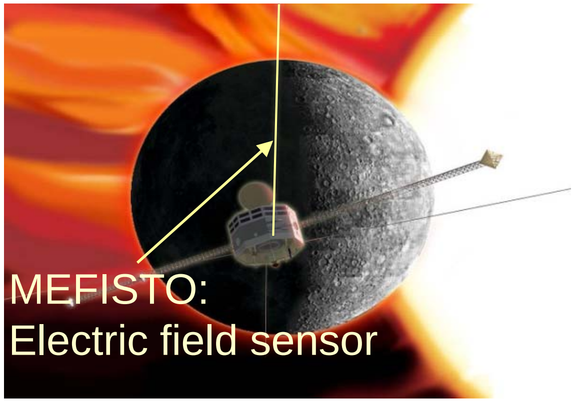
- Full PIC electromagnetic code
- Modeling of spacecraft immersed in space plasma
- Time-dependent spacecraft-plasma interactions including EM-field evolution
  - Spacecraft charging, Plasma and EM-field environment around S/C
- Rectangular, uniform grid system
- High performance computing by parallelization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

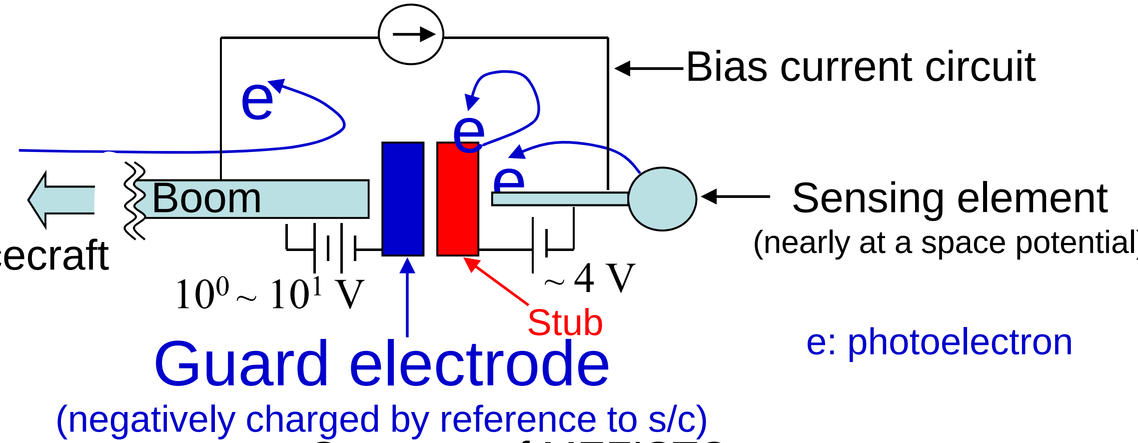


Dispersion relation of EM sheath wave propagating along S/C surface

■ Application of EMSES to simulations of a double-probe electric field sensor

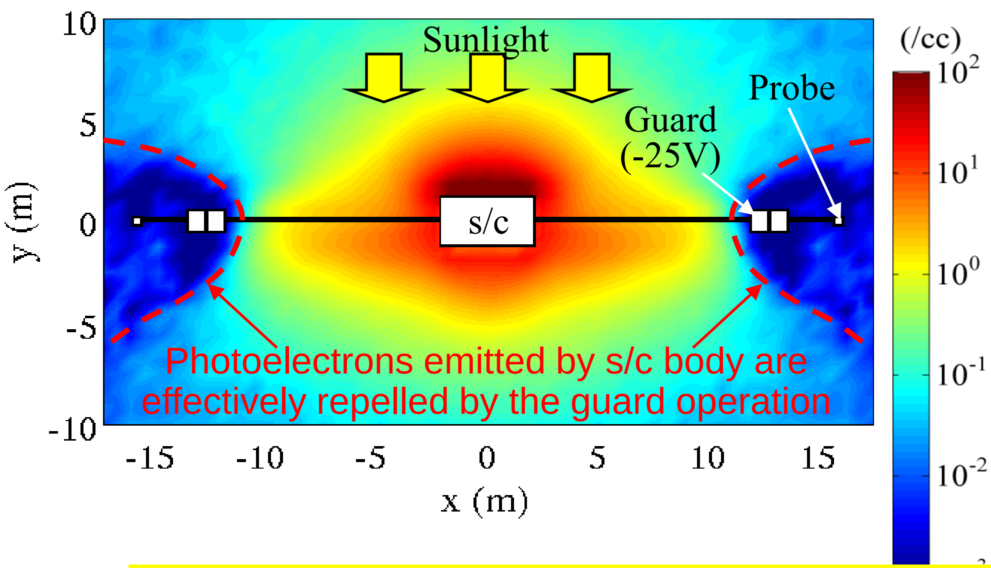
BepiColombo/MMO to Mercury





Structure of MEFISTO

Density plot of photoelectrons emitted by the s/c body



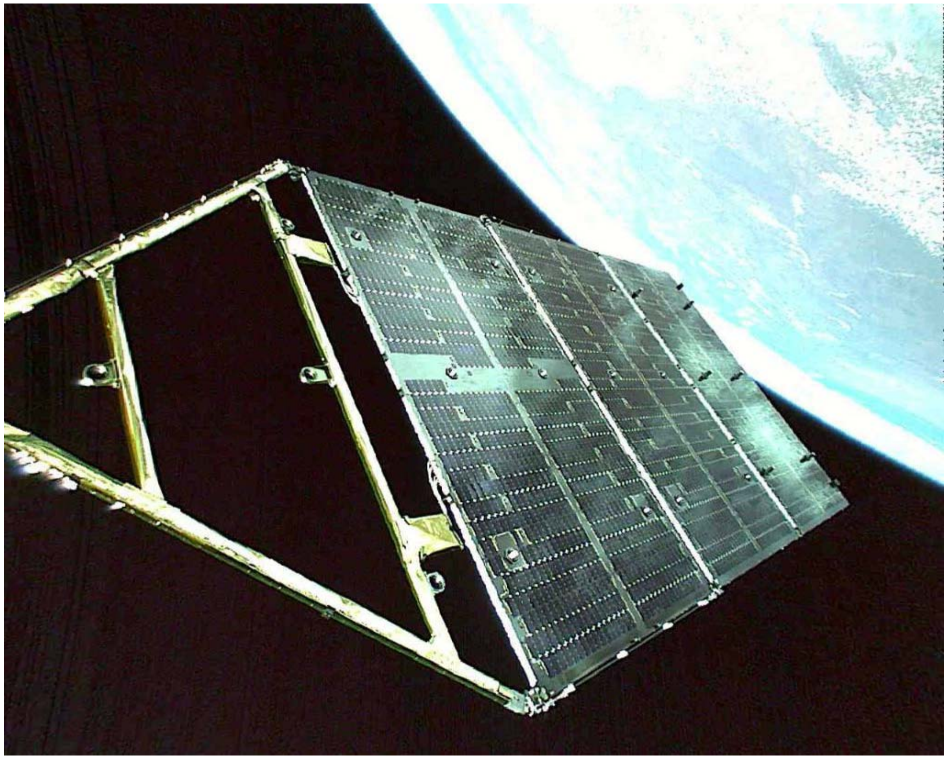
•PIC simulations with EMSES

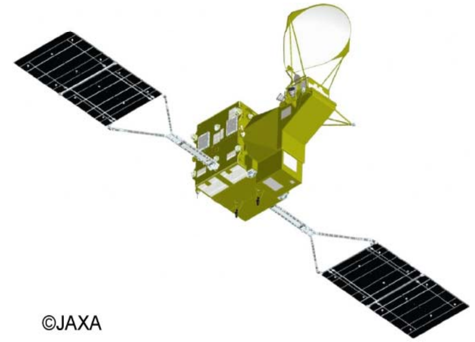
- Demonstration of the guard electrode to repel PEs coming from the s/c body.
- PE behavior around the sensor
- Study on the conditions for the guard electrode operation to repel the PEs effectively

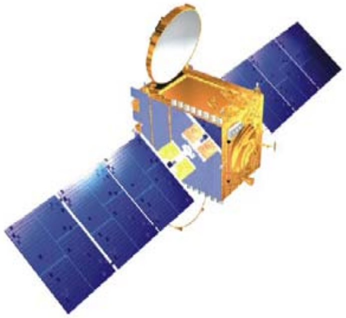
Application to scientific payload design and data calibration

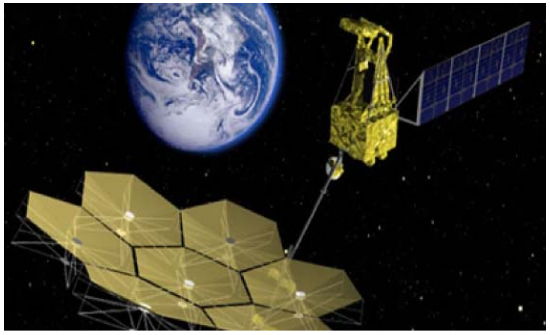
Electrostatic discharge research in laboratory

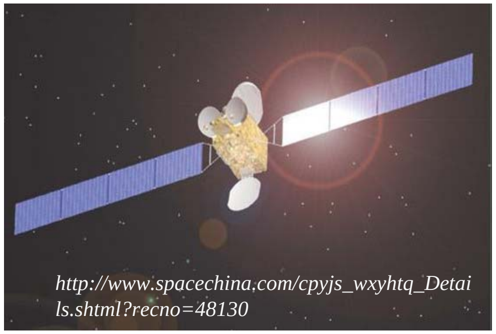
ESD test on solar array

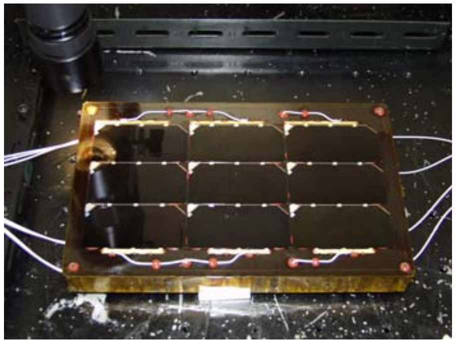


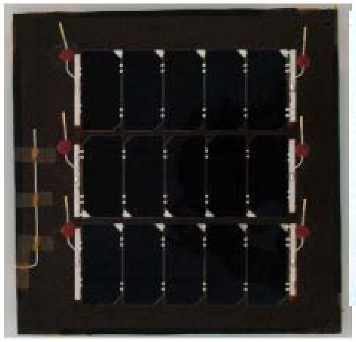


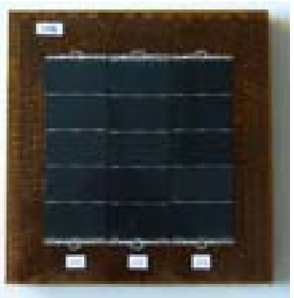


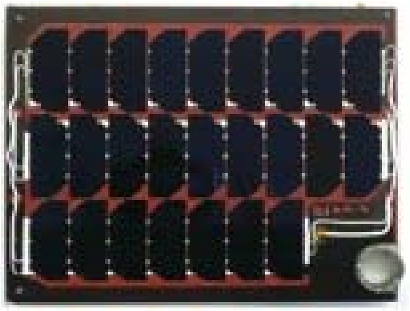








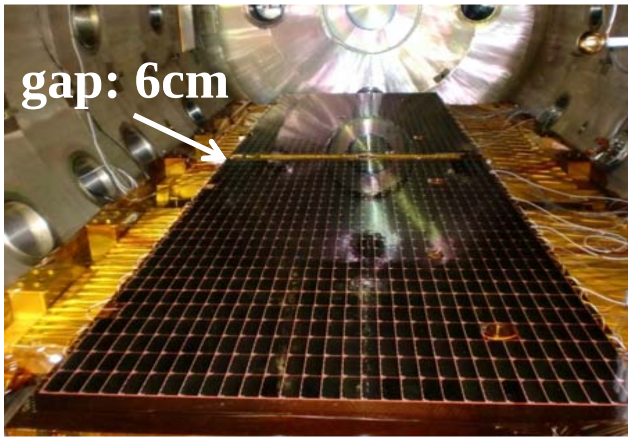


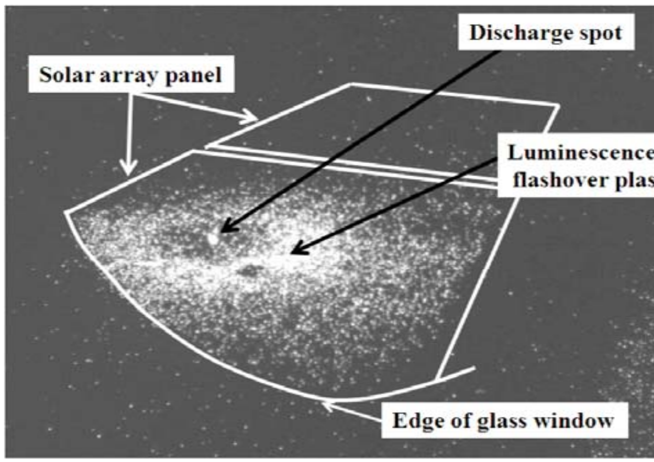


- ESD tests on solar array continues at KIT based on ISO-11221

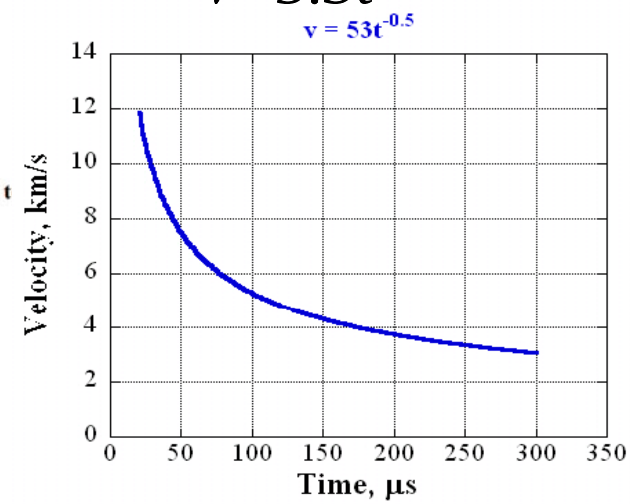
Flashover propagation experiment

2 solar array panels with 2m x 1.2m



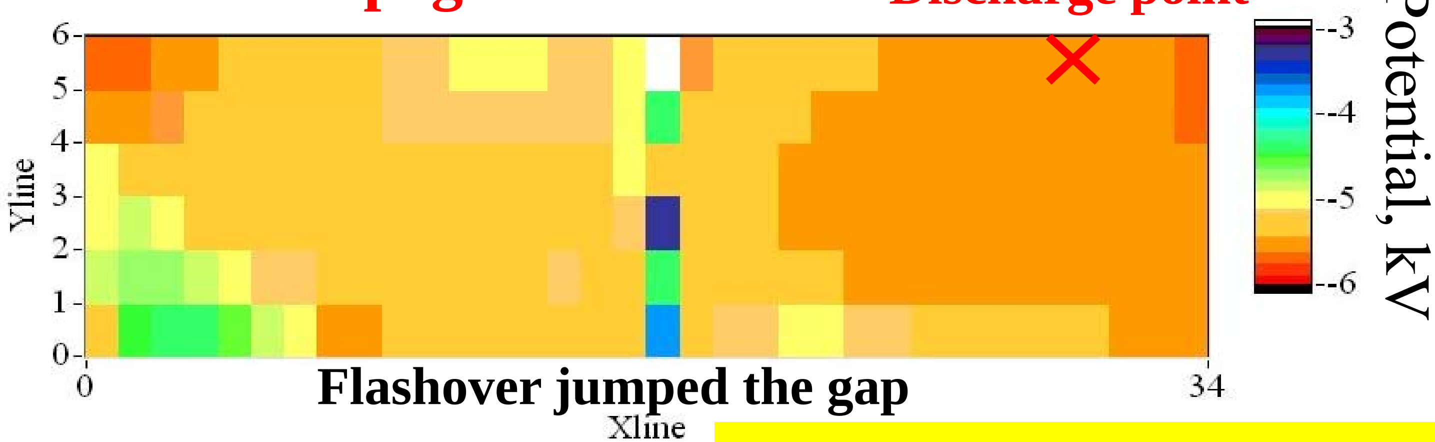


$v=5.3t^{-0.5}$



Propagate to 3m

Discharge point



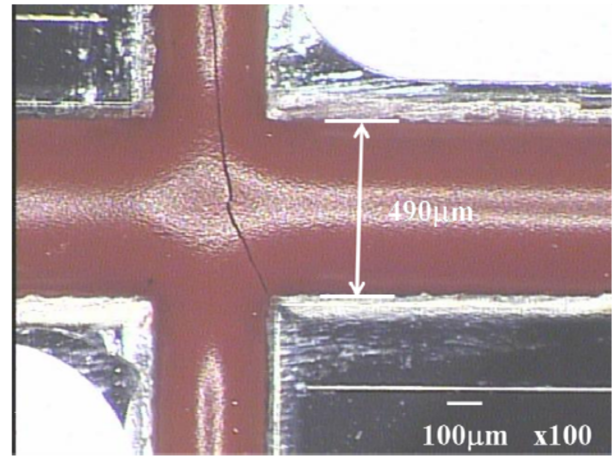
Flashover jumped the gap

Joint experiment by KIT and JAXA

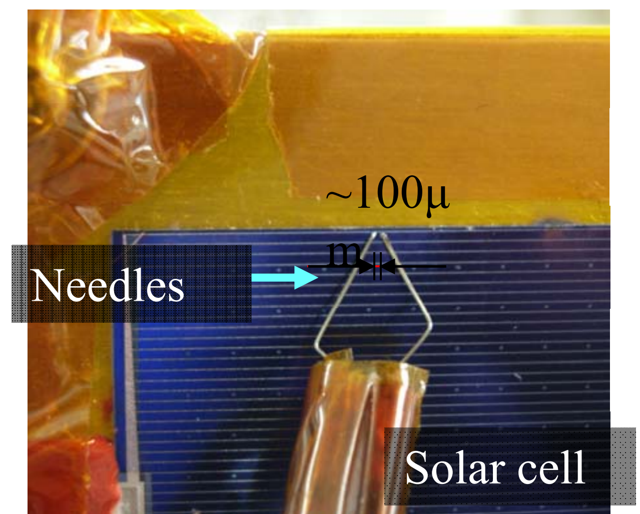
Solar array ESD researches at KIT

- 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



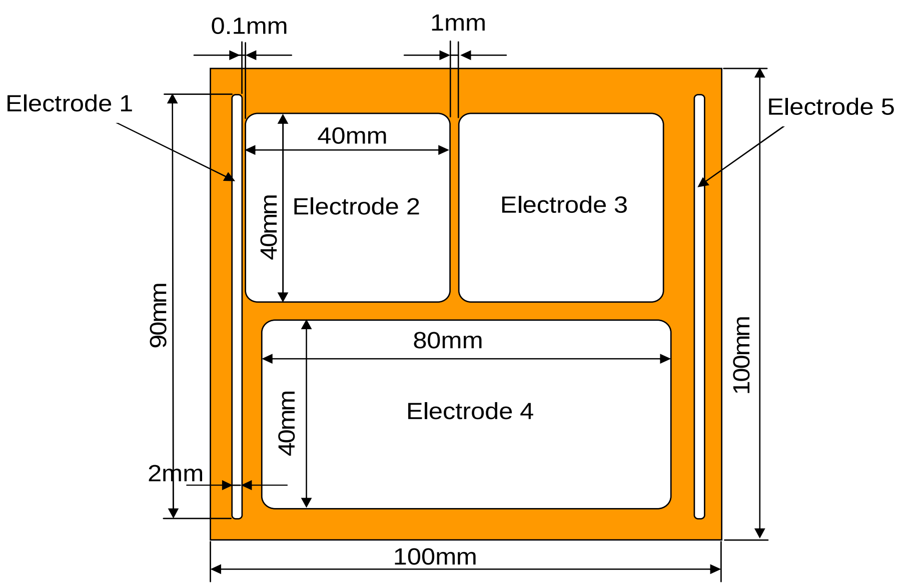
Cracks observed in grouting after aging



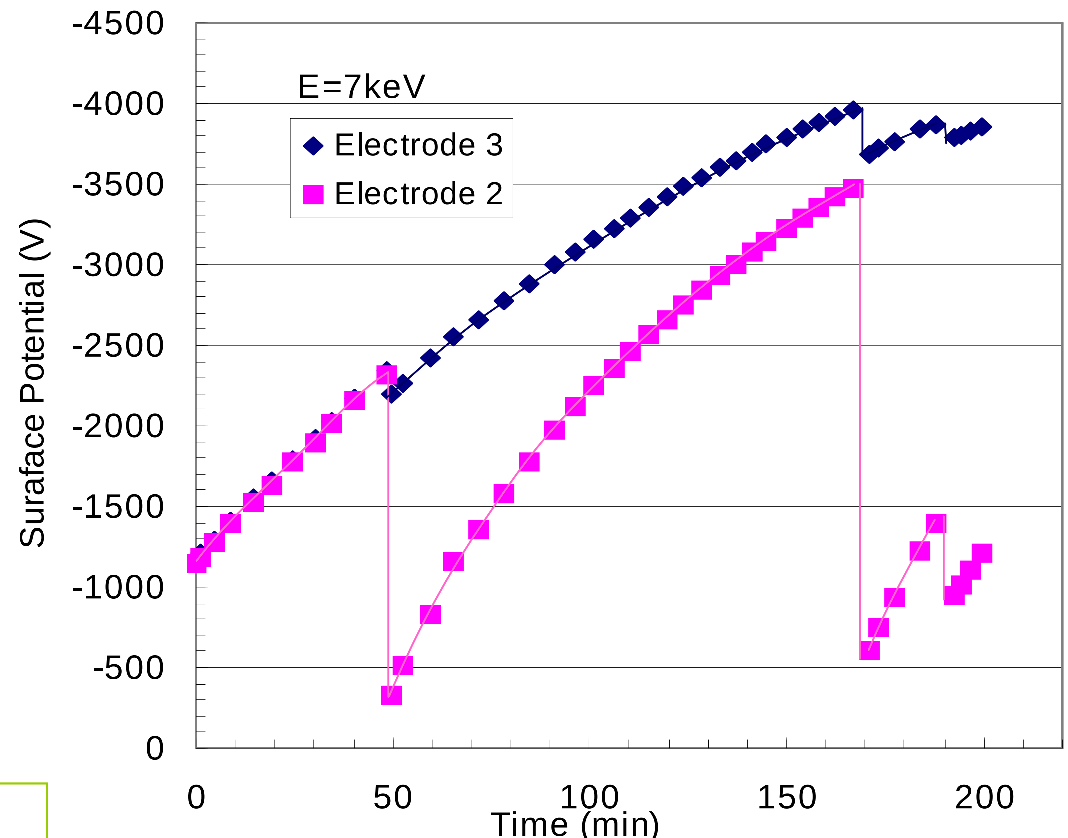
Primary arc trigger

ESD from electrically floating electrodes due to internal charging

0.1 mm thick poly-imide substrates with floating electrodes



Shape of sample



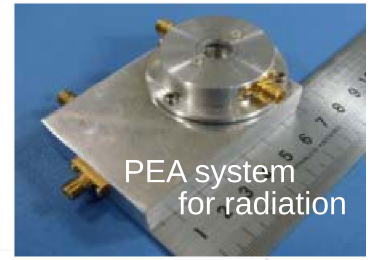
Electrodes

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

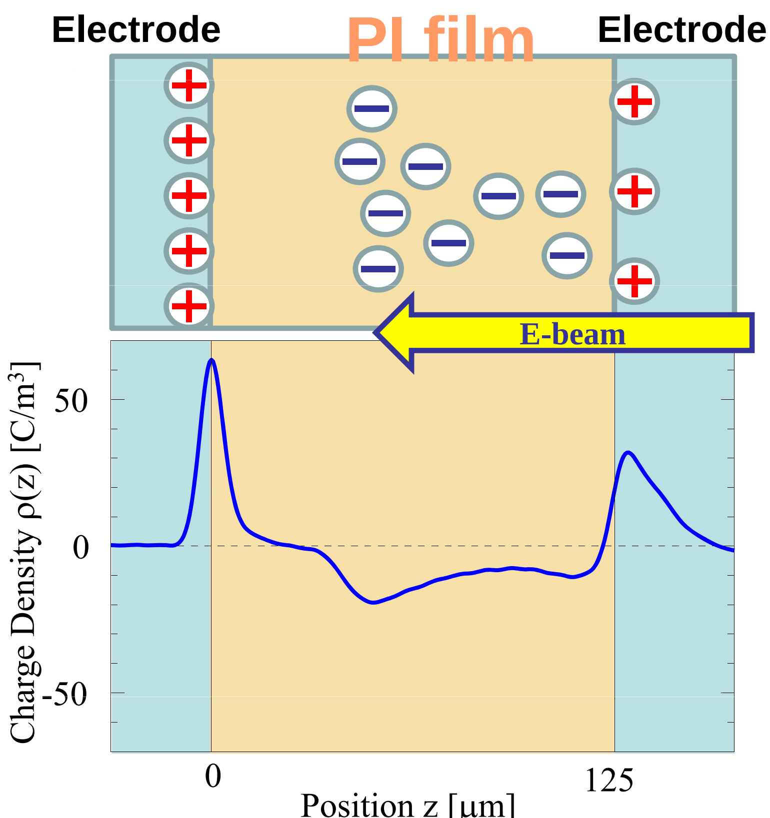
Time dependences of surface potentials of floating electrodes irradiated with electron energy of 7keV and beam current density of 0.1 nA/cm^2

Characterization of charging properties

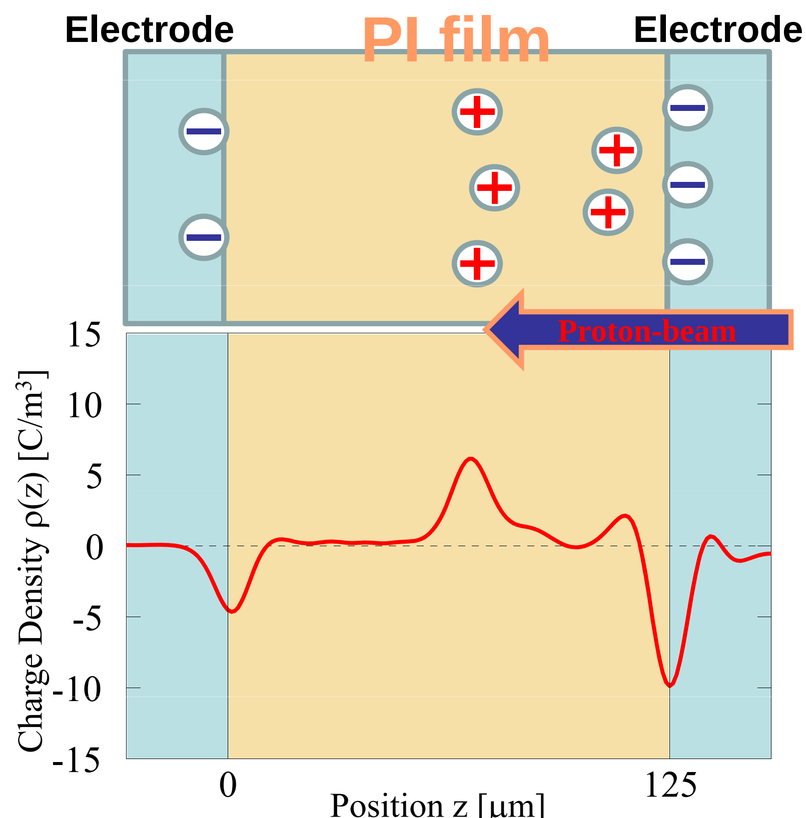
Internal charge measurement in bulks using Pulsed Electro-Acoustic(PEA) method at TCU



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



Electron beam irradiation(80keV)



Proton beam irradiation(2MeV)

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

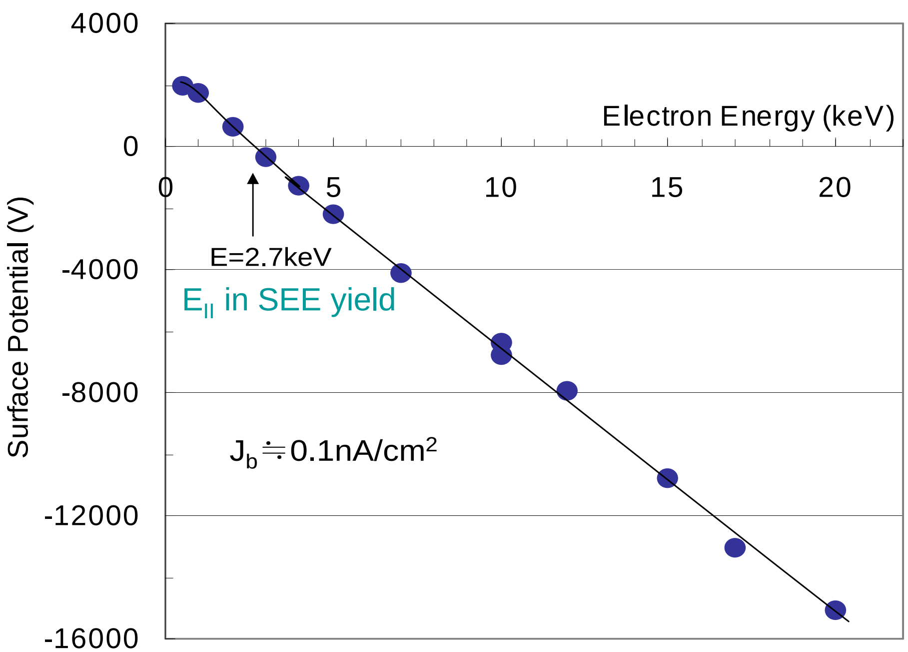
TOKYO CITY UNIVERSITY

Paper on Thursday

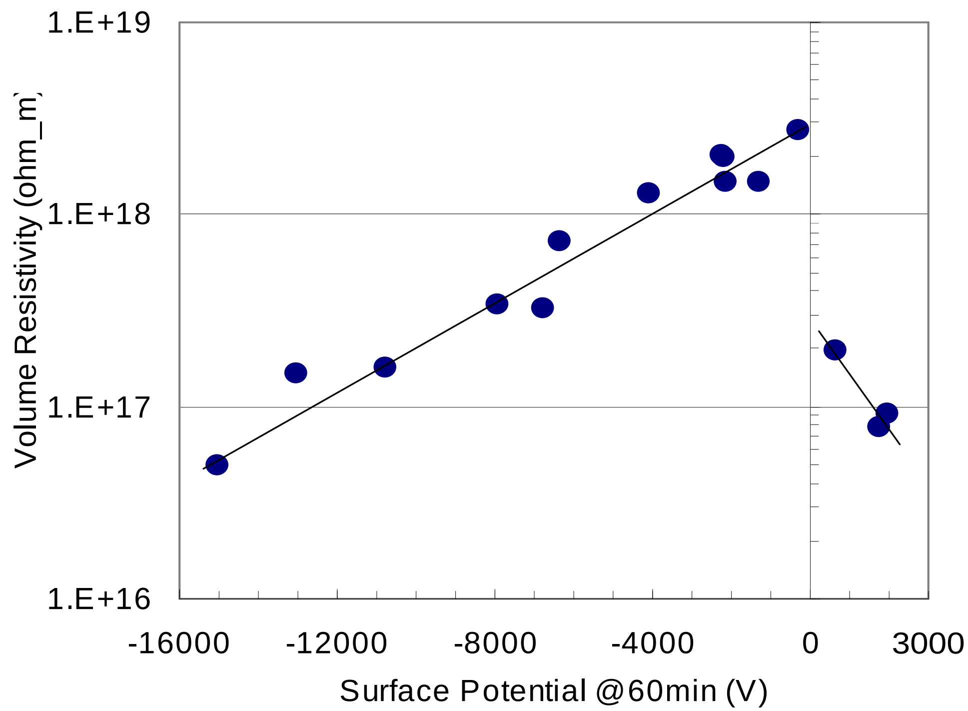
Electron beam induced charging of insulating materials at Nara National College of Technology

奈良高専
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 nA/cm^2 for 60 minutes

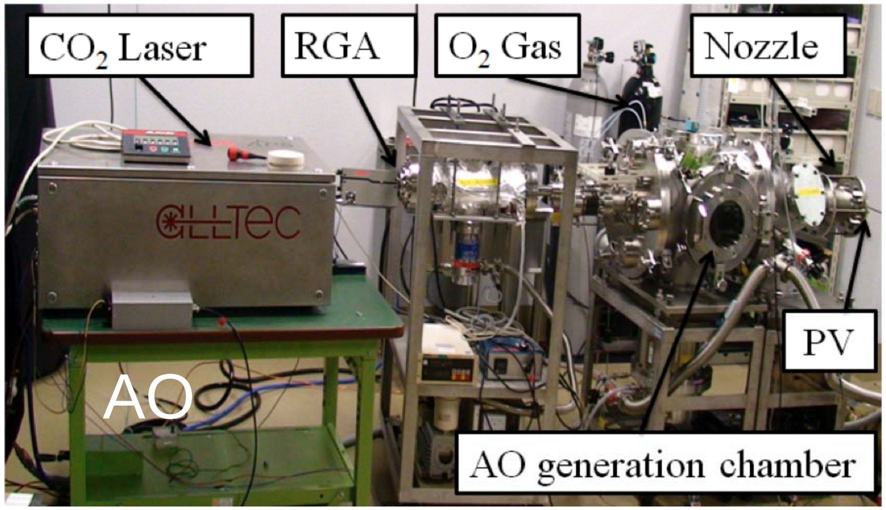


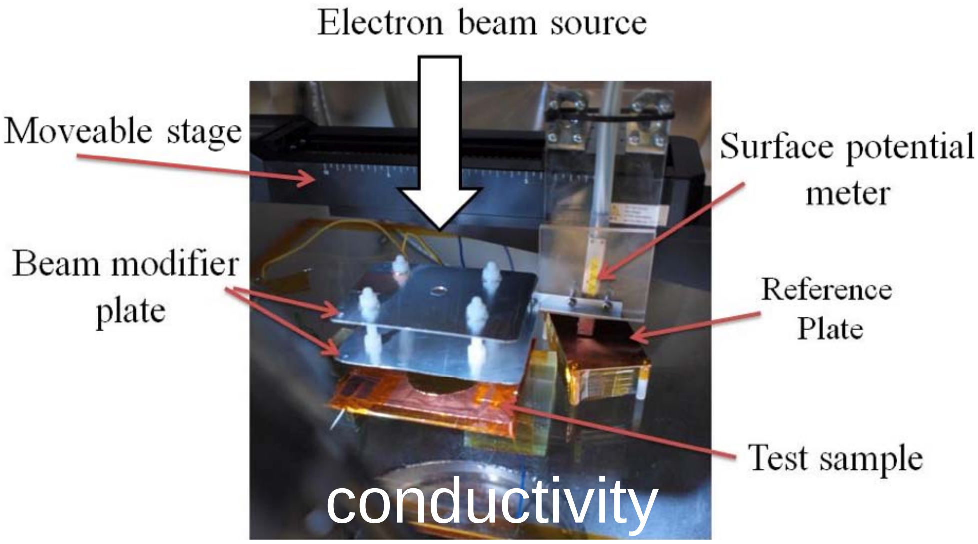
Surface potential dependence of volume resistivity obtained from the charge decay characteristics after electron irradiation.

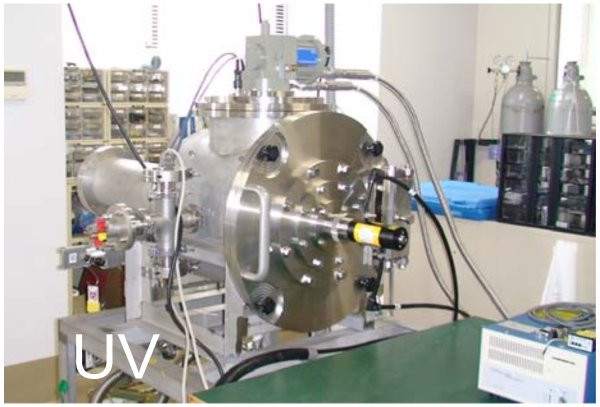
Characterization of charging properties of degraded material at KIT

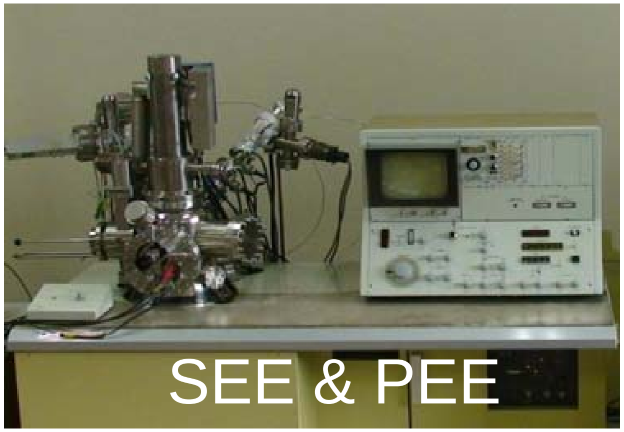
- *Secondary-electron*
- *Photo-electron*
- Volume and surface conductivity by charge storage method

Papers in this conference







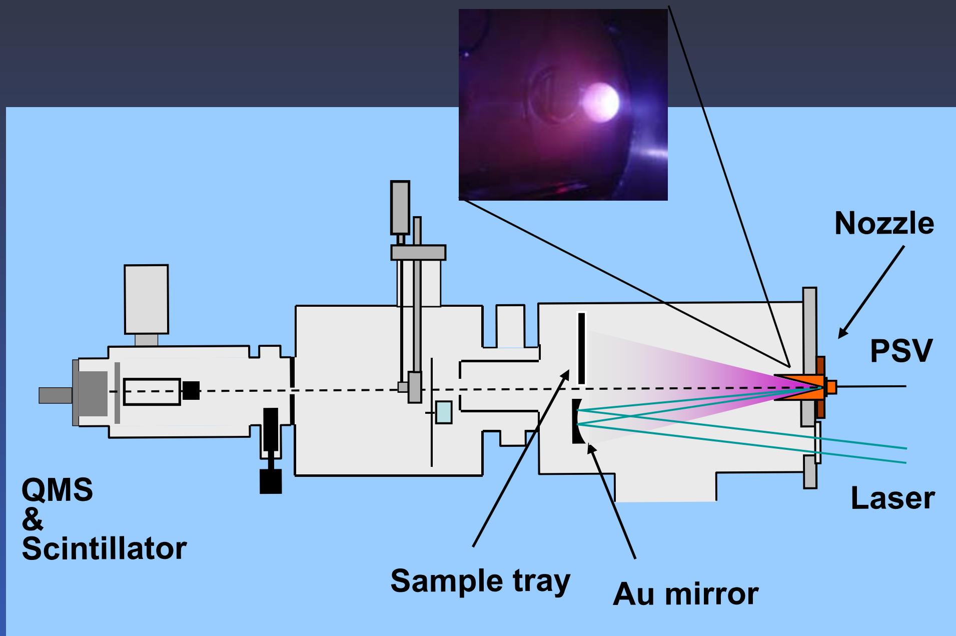


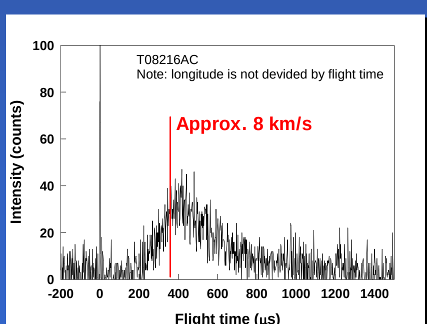
Characterization campaign of charging properties of degraded material sponsored by JAXA

Framework for the Measurements of Materials Properties Parameter

Material property	The range of primary energy	Place
Secondary electron emission (SEE)	Accelerating voltage : 600V-5kV	The High Energy Accelerator Research Organization (KEK)
	Accelerating voltage : 200V-1kV	JAXA & Tokyo City university
Photoelectron emission (PE)	Wavelength 30 to 250 nm	KEK
	Wavelength 110 to 400 nm	Tokyo City university
Bulk resistivity, Surface resistivity	ASTM D-257, JIS C2139	Saitama University
Bulk resistivity	Charge storage method	Saitama University
Dielectric Constant		Sumitomo Metal Technology Inc.

Charging/discharging properties at EOL



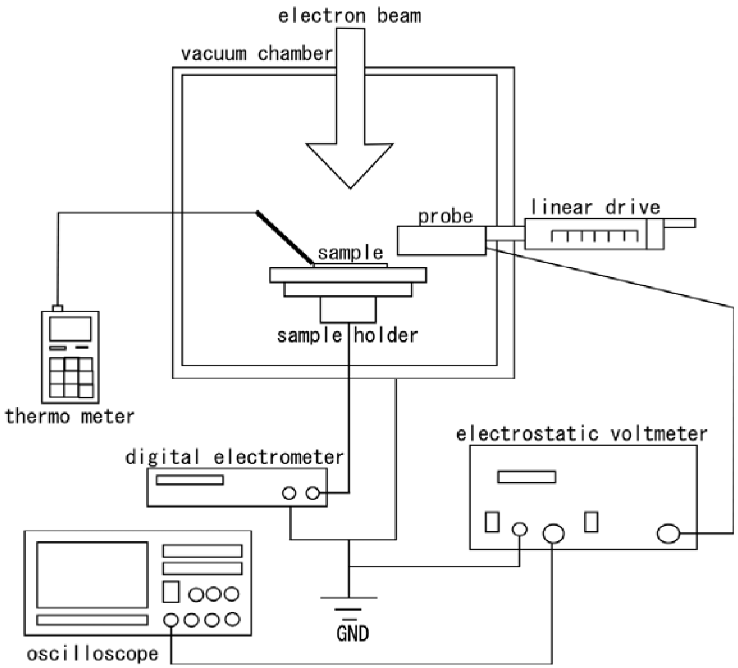


TOF distribution of oxygen atom

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

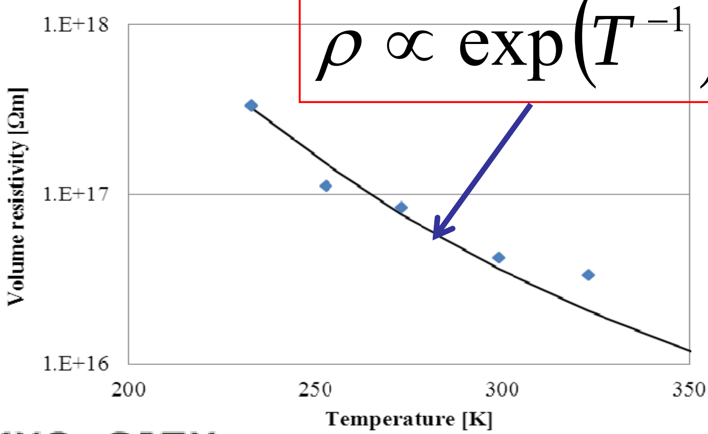
$$V(t) = V_0 e^{-t/\tau_d}$$



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

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

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



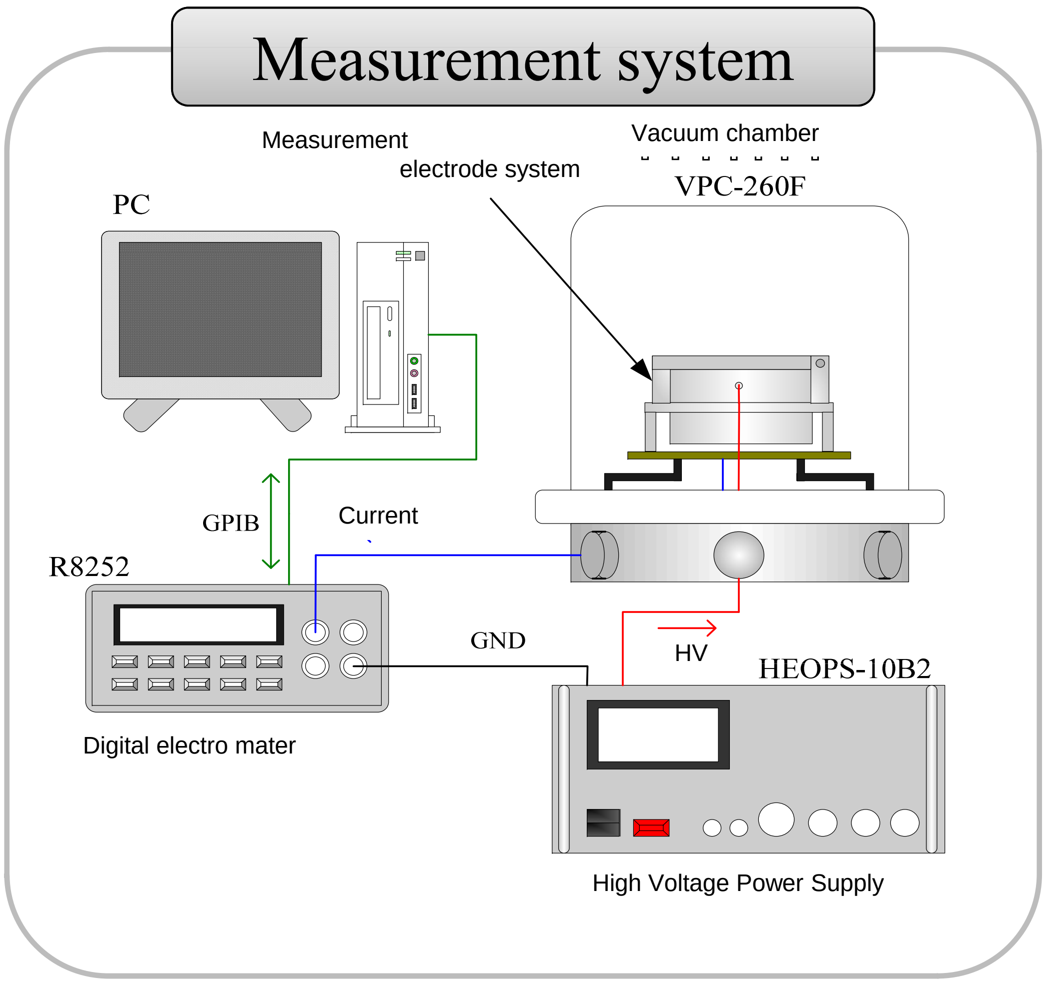
*A.R. Frederickson and J.R. Dennison, IEEE Trans. on Nuc. Sci., Vol. 50, No. 6(2003)

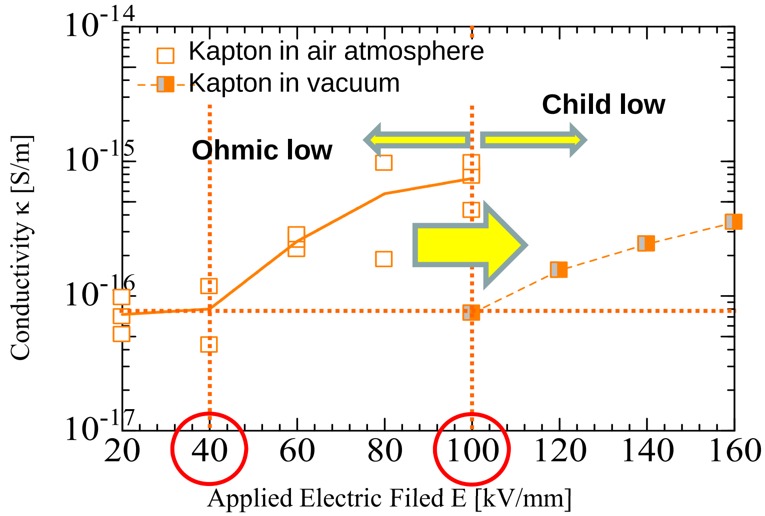
TOKYO CITY UNIVERSITY

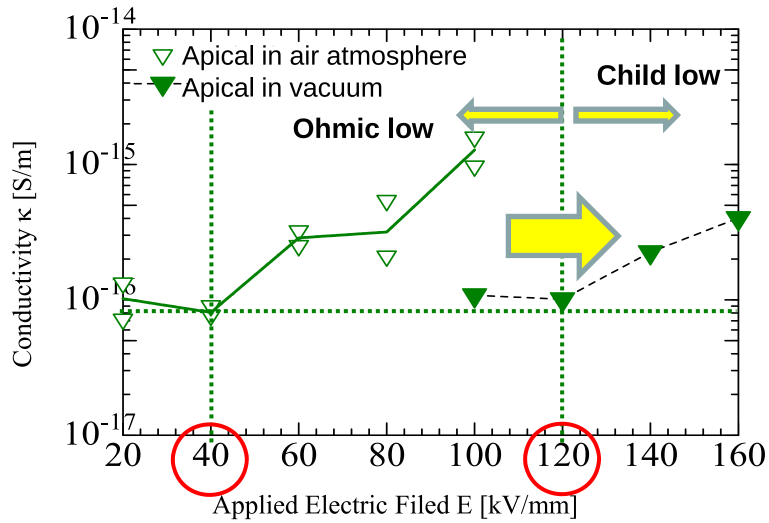
Conductivity Measurement in Vacuum using Conventional Method at TCU

・ 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.



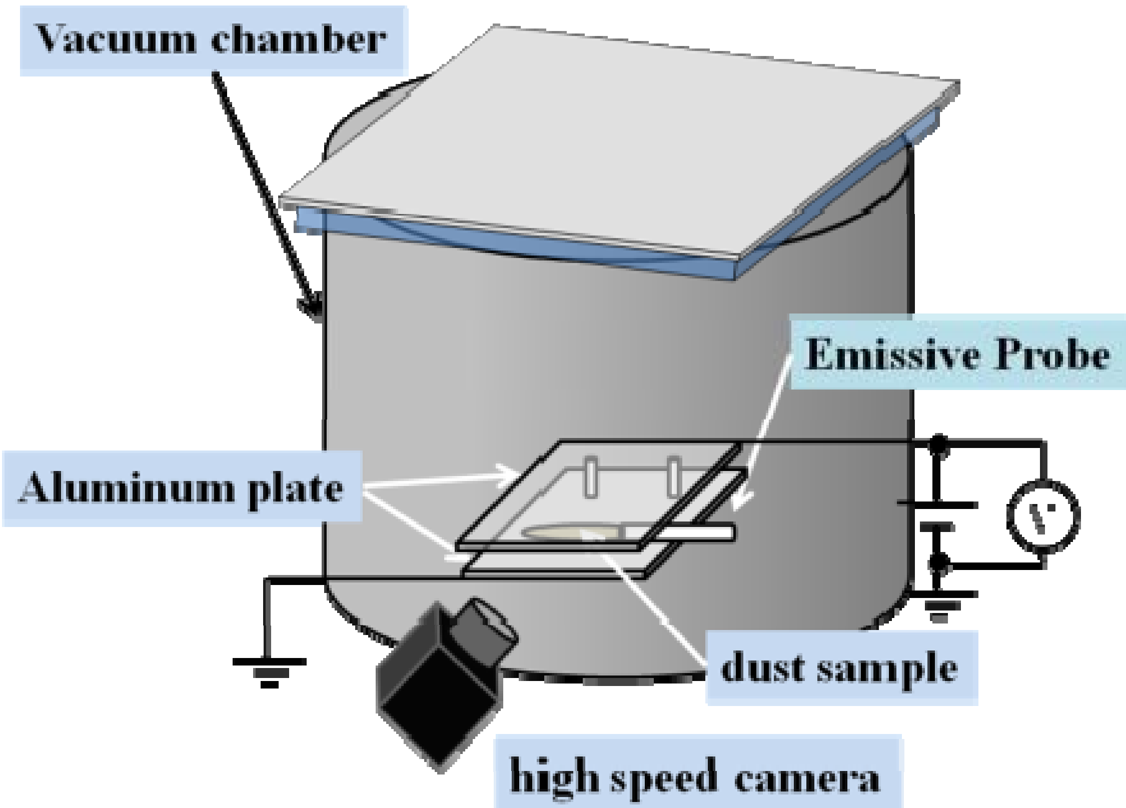


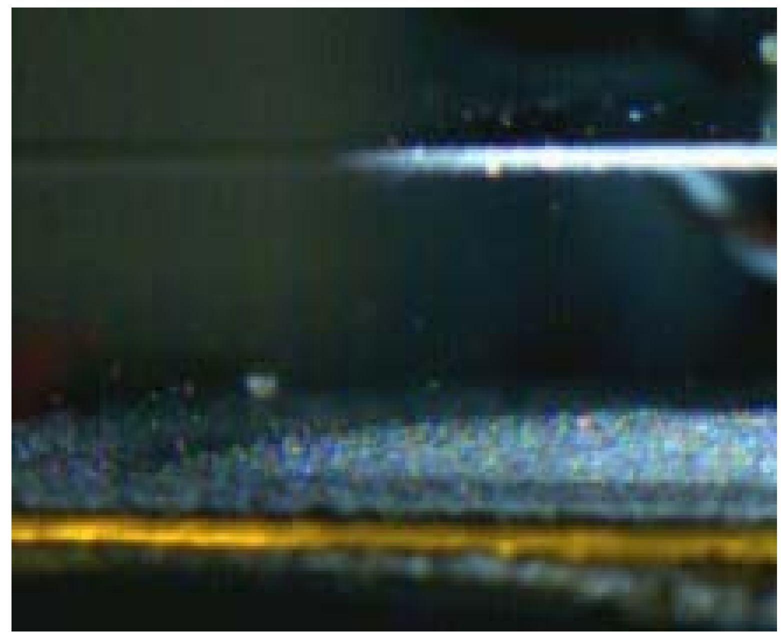


TOKYO CITY UNIVERSITY

Lunar Dust Charging

- Experiment on dust charging and subsequent levitation





Joint work of KIT and USC

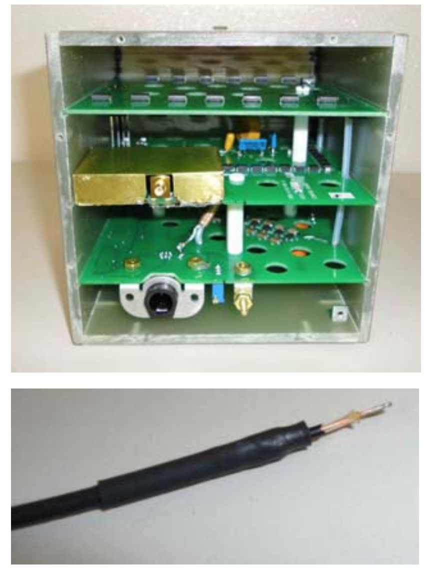
Poster in this conference

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



Environment test model

•Conversion of ultra-high impedance contact-type

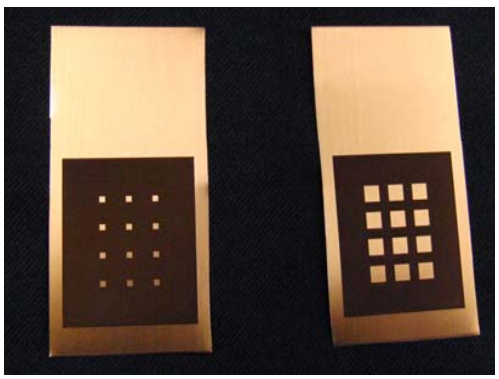
•Sensor head as small as 1mm or less

•Mulitple-sensor head to measure deep dielectric charging

Poster in this conference

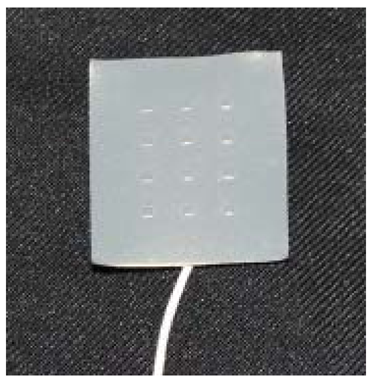
Spacecraft Charging Mitigation

- Electron-emitting Film for Spacecraft Charging Mitigation (Elf's CHARM)
  - *To be launched in as early as Nov. 2011*
- Semi-conductive transparent coating



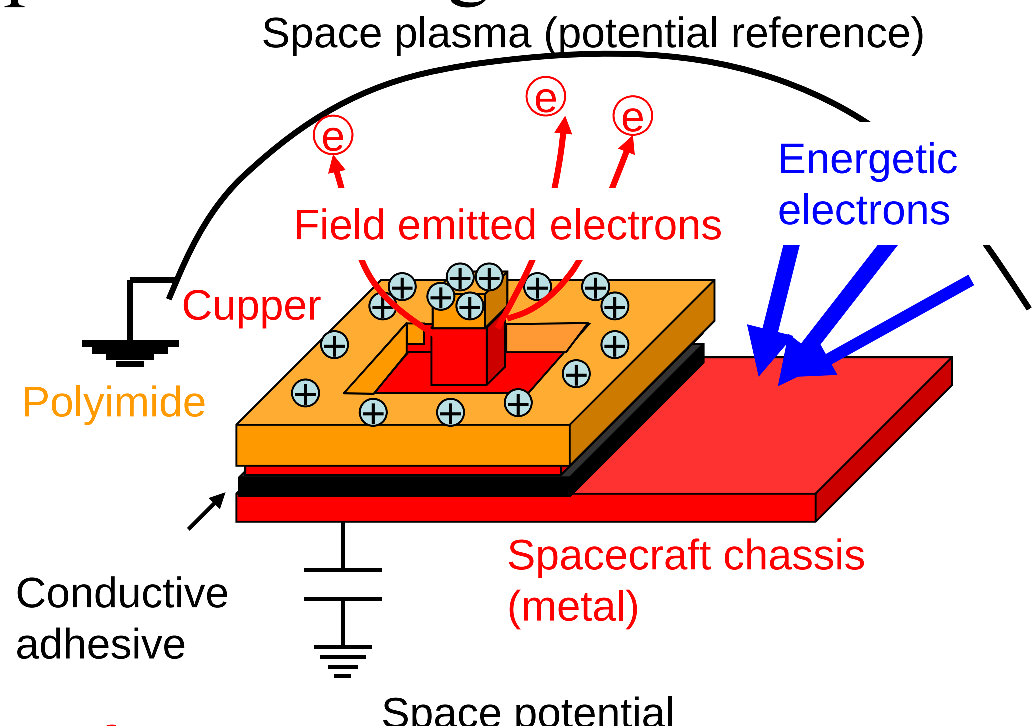
ELF/GEO

Polyimide/Copper



ELF/PEO

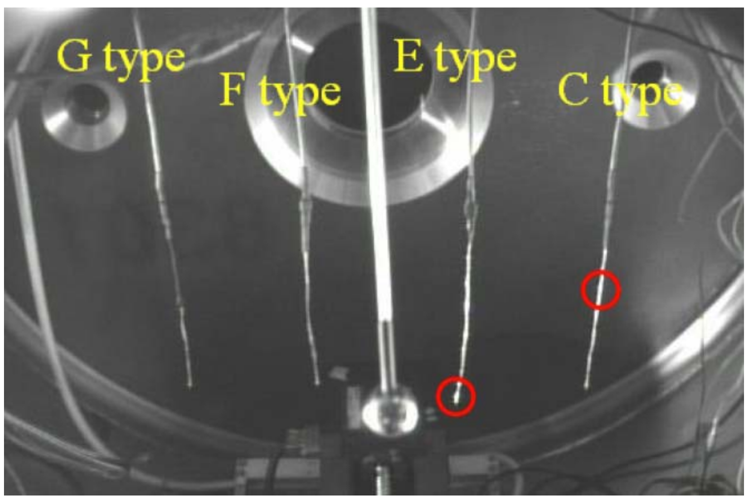
Fluorine Polymer/Copper



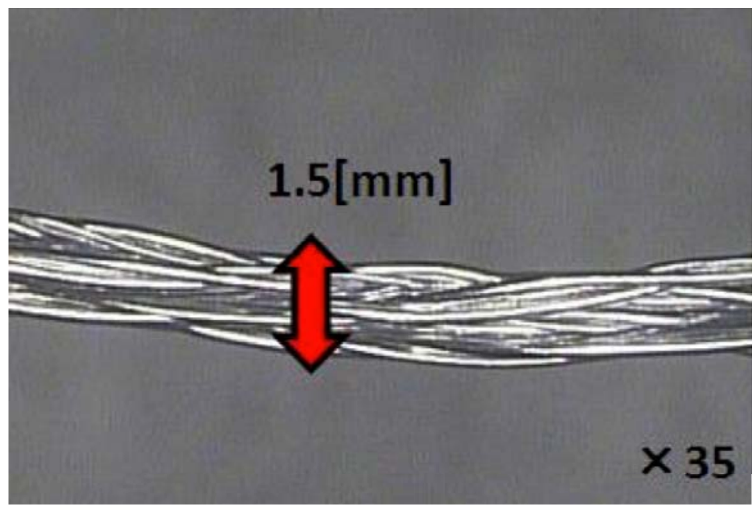
Paper in this conference

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)



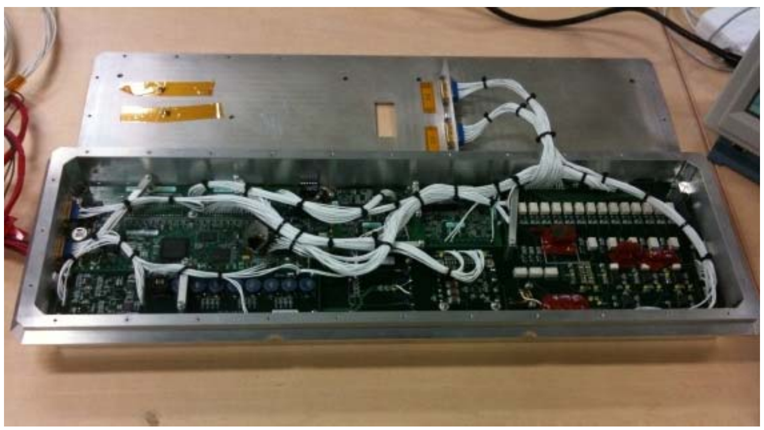
EDT Discharge positions



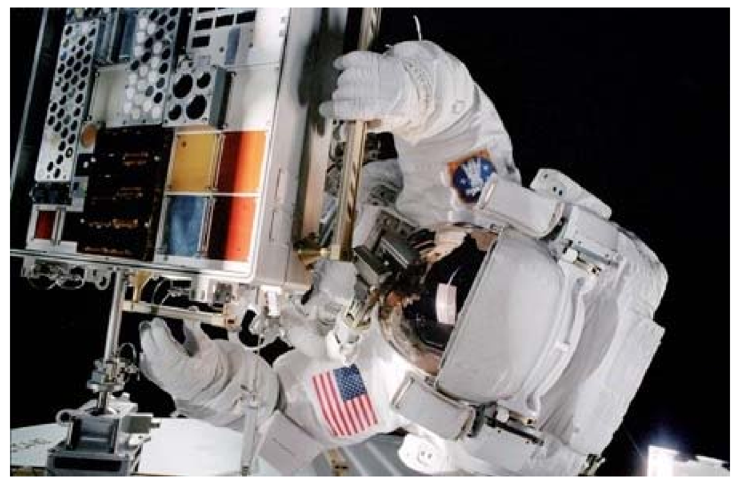
Bare tether sample

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



PASCAL electronics box



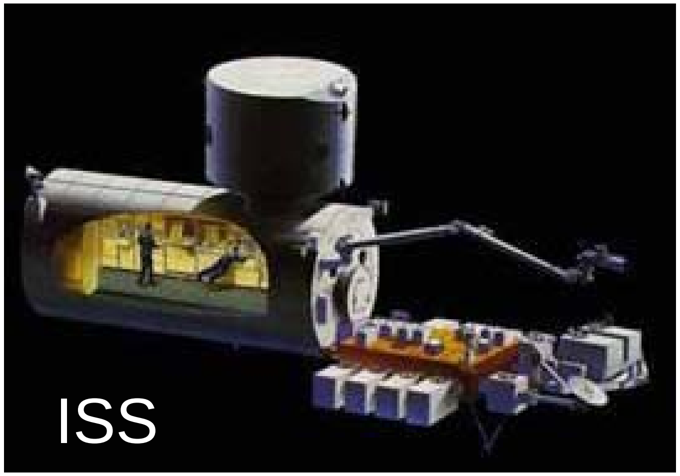
http://iss.jaxa.jp/iss/ulf3/mission/overview/eva/eva3/

La SEINE

Japan Aerospace Exploration Agency

In-orbit space environment measurement

Instruments onboard (LEO)



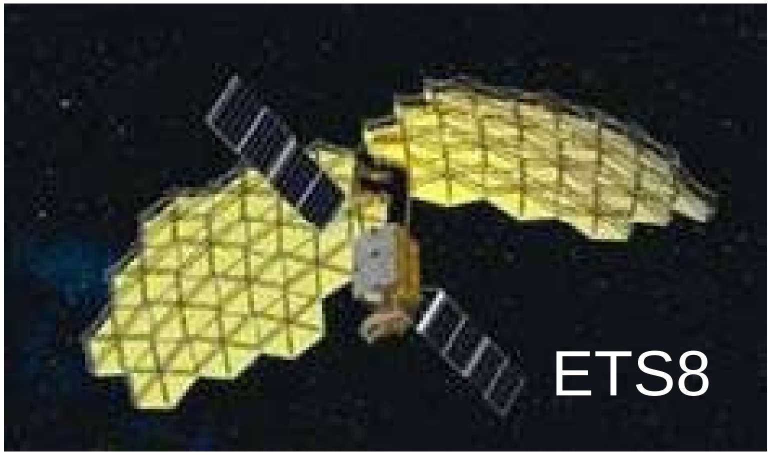
Space environment data acquisition instruments (SEDA-AP)

Space radiation environment detectors (TEDA/ LPT)

Space radiation environment detectors (TEDA/ SDOM)

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