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Measurement of Conductivity and Charge Storage in Insulators Related to Spacecraft Charging

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ASTM and IEC Conductivity Test Method

\[ V = \int_{0}^{a} \vec{E} \cdot d\vec{x} \]

\[ \oint \vec{D} \cdot d\vec{s} = Q \]

\[ \vec{D} = \sigma \vec{x} = \varepsilon_0 \vec{E} + \vec{P} \]

\[ \vec{J}_i = \frac{d}{dt} (\sigma \vec{x}) = \frac{d}{dt} (\varepsilon_0 \vec{E} + \vec{P}) = \frac{d}{dt} \vec{P}. \]

Current consists of charge injected at electrodes and time-dependent polarization.
Alternative Method: Surface Voltage Measurement

\[ V = V_0 \exp \left(\frac{-t}{\tau}\right) \]

\[ \tau = RC = \rho \varepsilon \]

\[ \rho = \text{resistivity} \]
For measurements on same sample of polyimide

\[ \rho = 1 \times 10^{16} \text{ (ohm-cm)} \quad \rho > 5 \times 10^{20} \]
A Typical Surface Voltage Measurement

Polyimide Surface Voltage

Days Since First Charge Established

(negative) Volts on Surface

LaRC-SI-001
Kapton-001
The Spacecraft Charging Issues

- Polyimides, Mylar, Circuit Board, Teflon, Glass and etc. store charge >>longer than ASTM indicates.
- Charge accumulates from many orbits. How many volts are developed?
- What are the real mechanisms of charge storage and loss?
- How do we qualify a material for space flight?
- What are the proper test procedures?
Improved Measurement Capability

Electrostatic Voltmeter Dies in This Environment
Some Measurement Features
Sample Measurements Chamber
Surface Voltage Probe and 5-sample Carousel
Sample Capacitance Measurement
Typical Capacitance Data

Open Mount vs Closed Mount

Electron Beam Charging
Open Mount Only
Electron Beam Charging Physics

\[ \text{Div } D = Q \quad D = \varepsilon E \]
Elementary Conductivity Physics

Diagram:

- Electron density (se^-)
- Drift left: \( \vec{E}^+ \)
- Drift right: \( \vec{E}^- \)
- Electron range

Energy Levels:

- \( E_C \) - Conduction Band
- \( E_v \) - Valence Band
- \( E_f \) - Fermi Level

Processes:

- Visible light empties these traps
- UV light empties these traps
- UV light, X-ray, keV e^- empty these filled states
Conduction Physics After Irradiation
Evolution of Conduction During Irradiation

Time = 0, $e^-$ beam turned on...

Time = 1

Time = 2

Time = 3
Evolution of Conduction, continued

Time = 4

Thermal Emission

Tunneling

e⁻ range

Time = 5

Thermal Emission

Tunneling

e⁻ range
Emission of Electrons from Floating Surface of Sample

Electrons on Sensor Plate

Electrons, nanoCoulombs

Minutes
CONCLUSIONS

• New apparatus for measuring charge storage and resistivity has been designed and proven.
• Charge Storage measurements superior to ASTM
• Can monitor electron thermal emission from traps
• Monitor high-field tunneling currents from traps
• Monitor photon-assisted (lamp) conductivity
• In-situ comparison of multiple samples
• In-Situ characterization of pulsed discharges
• Electron and/or Ion Charging
• Measure sample capacitance or dielectric constant