In Situ Surface Voltage Measurements of Dielectrics Under Electron Beam Irradiation

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New instrumentation has been developed for non-contact, in vacuo measurements of the electron beam-induced surface voltage as a function of time and position for dielectric spacecraft materials in a simulated space environment. Used in conjunction with the capabilities of an existing ultrahigh vacuum electron emission analysis chamber, the new instrumentation facilitates measurements of charge accumulation, bulk reactivity, effects of charge depletion and accumulation on yield measurements, electron induced electrostatic breakdown potentials, radiation induced conductivity effects, and the radial dispersion of surface voltage.

The novel system uses two movable capacitive sensor electrodes that can be swept across the sample to measure surface voltage distributions on samples, using a non-contact method that does not dissipate sample charge. Design details, calibration and characterization measurements of the system are presented, for a surface voltage range from <1 V to >30 kV, voltage resolution <1 V, and spatial resolution <1.5 mm. Extensive characterization tests with externally biased conductors were performed to calibrate the system and determine the instrument stability, sensitivity, accuracy, range, spatial resolution and temporal response.

Two types of measurements have been made on two prototypical polymeric spacecraft materials, low density polyethylene (LDPE) and polyimide (Kapton HNTM) to illustrate the research capabilities of the new system. First, surface voltage measurements were made using a pulsed electron beam, while periodically measuring the surface voltage. Second, post charging measurements of the surface voltage were conducted, as deposited charge dissipated to a grounded substrate. Theoretical models for sample charging and discharge are outlined to predict the time, temperature, and electric field dependence of the sample net surface voltage. The good agreement between the fitting parameters of the model is discussed and the corresponding physical parameters determined from the literature and measurements by related techniques.

### Design Goals

When designing an instrument, the physical parameters of the measurements being made drive the design of the apparatus. The constraints on these parameters (actual values shown in green) are based on typical insulator/semiconductor decay times which are usually of the order of ~103 to 108 s.

- Input Signal: 0 to 5 V
- Charge Measurement System: 0 to 10 V
- Resolution: ~10-8 C
- Response Speed: ~10-5 m/s
- Stability: ~10-8 V
- Linearity: ~10-9 V
- Range: ~1 V
- Voltage resolution: ~10-9 V
- Spatial resolution: ~10-7 m
- Time constant of exponential fit to drift data: ~10-4 s

### Characterization and Calibration

Extensive testing helped develop an understanding of all effects factoring into Eq. (1), that converts probe voltage to a sample voltage.

\[
V_{\text{sample}} = \frac{V_{\text{probe}} - V_{\text{offset}}}{(1 + V_{\text{probe}} + (1 - t_g) - \left(1 - e^{-\tau_{\text{offset}}} \right)} - \frac{1}{(1 - e^{-\tau_{\text{probe}}})}
\]

### Design of the Instrumentation

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### Experimental Applications

**Charge Accumulation from Incident Electron Flux.**

\[ E(t) = \int_{0}^{t} F \cdot \sigma \cdot dt \]

**Charge Dissipation of Highly Insulating Materials.**

Radial Distribution of Stored Charge and Lateral Charge Dissipation.

Experiment examined the radial distribution of charge, and the possibility of lateral charge dispersion over time (TOP). The three figures at left show the normalized spatial profile of the charge for successive discharge times (red) at 50 μm, 1 and 2 days after deposition and the exponential profile of a Gaussian beam with a 1.5 mm FWHM (bottom). The peak voltage was monitored over time: the amplitude decayed at a rate very similar to that observed in the charge dissipation experiment above. These results suggest dissipation through the film and no appreciable lateral diffusion of charge.

### References