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Pulsed Electro-Acoustic Measurements of Charging and Relaxation in Low Density Polyethylene

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Pulsed Electro-Acoustic Measurements of Charging and Relaxation in Low Density Polyethylene

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Overview

• Pulsed Electro-Acoustic (PEA) method
• Importance of PEA
• Our PEA system
• Measurements of Low Density Polyethylene
• Conclusions
• Future work
What is PEA?

How it works:
- Measures charge layers
- Charge is injected through electrodes or electron beam
- Pulsed voltage “bumps” charge in material
- Signal is processed to show charge in material

Benefits:
- Nondestructive measurement
- Low cost
- High resolution

Limitations:
- Instrumentation bandwidth
- Electronics for higher resolution are costly

L. Pearson (2017)
Importance

The majority of space environment-induced anomalies (failures) are attributed to spacecraft charging, therefore understanding the accumulation and mitigation of charge is critical.

• Space plasma fluxes are typically ~10’s of keV, which means penetration depths of ~1-100 µm
• Spacecraft materials typically ~10’s – 100’s of µm thick
• Funding for our group and this project is for spacecraft charging

Also useful for many other applications:

• High voltage power cabling insulation
• High voltage devices and switches
• Electrostatic charging in accelerators and plasma chambers
• Plasma deposition
• Thin film dielectrics in semiconductors and sensors
• Electron microscopy and spectroscopy
• Photoconductive devices/sensors
• Inferring defect states in materials
Our PEA System

Specs:
• 0-10 kV DC voltage
• ~100 MHz
• 0-1000 V reference voltage
• ~2-5 μm resolution
Proposed PEA Measurements

### Resistivity and Decay Time of Common Spacecraft Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity (Ω·cm)</th>
<th>Thickness (µm)</th>
<th>Decay Times (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDPE (ambient)</td>
<td>$10^{15}$</td>
<td>125</td>
<td>~200 (minutes)</td>
</tr>
<tr>
<td>LDPE (baked out)</td>
<td>$10^{18}$</td>
<td>125</td>
<td>~$2 \times 10^5$ (days)</td>
</tr>
<tr>
<td>Kapton</td>
<td>$10^{19}$</td>
<td>125</td>
<td>~$5 \times 10^6$ (month)</td>
</tr>
<tr>
<td>Teflon</td>
<td>$10^{20}$</td>
<td>125</td>
<td>~$5 \times 10^7$ (year)</td>
</tr>
</tbody>
</table>

#### Charging up of Uncharged LDPE

#### Charge Dissipation of Charged LDPE
Measurements: Set-Up

- Sample is 4 mil (100 μm) thick LDPE
- Measured charging at ~40 kV/mm with an applied DC voltage of 4.4 kV for 30 minutes
- Measured discharging/relaxation for 30 minutes at 0 V applied voltage
- Reference voltage for pulsed electro acoustic measurement was ~800 V
- 100 MHz
- Silicone Oil used for acoustic coupling for sensor-electrode, and electrode-sample interfaces
• At first pass it looks to be charging up
• Ringing is due to multiple reflections within the materials as shown to the right
Measurements: Signal Processing

Still in progress

Example of Signal Processing:

• Remove DC offset
• Apply bandpass filter
• Deconvolve waveform using response of charge on front electrode to remove “ringing”
Conclusions

• Our system works ... perhaps
• Raw data seem to corroborate previous studies
• Signal processed data seems to imply little to no charging in the bulk of the material
• More work is needed
Future Work

• Better measurements
• Improve data-analysis
• Improve spatial resolution of ambient system to limit
• Develop in-situ system with resolution of ~1 µm
• Measure charging, transit, decay times and rates for many dielectrics and highly disordered materials in different environments by varying temperature, irradiation, applied voltage, etc.
Questions?
References


Decay Time Based on Resistivity

Decay time vs. resistivity base on simple capacitor model.

\[ \tau = \rho \varepsilon_r \varepsilon_o \]

Corresponding Decay Times (\(\varepsilon=1\))

- \(\rho \sim 1\times10^{23} \text{ } \Omega\text{-cm} \rightarrow 500 \text{ } \text{yr} \)
- \(\rho \sim 5\times10^{21} \text{ } \Omega\text{-cm} \rightarrow 15 \text{ } \text{yr} \)
- \(\rho \sim 4\times10^{20} \text{ } \Omega\text{-cm} \rightarrow 1 \text{ } \text{yr} \)
- \(\rho \sim 1\times10^{18} \text{ } \Omega\text{-cm} \rightarrow 1 \text{ } \text{day} \)
- \(\rho \sim 4\times10^{16} \text{ } \Omega\text{-cm} \rightarrow 1 \text{ } \text{hr} \)
- \(\rho \sim 1\times10^{15} \text{ } \Omega\text{-cm} \rightarrow 1 \text{ } \text{min} \)