10-9-2021

Embedded Charge Distributions in Electron Irradiated Polymers – Pulsed Electroacoustic Method Reproducibility and Calibration

Zachary Gibson  
Utah State University

JR Dennison  
Utah State University

Ryan Hoffmann  
Air Force Research Lab

Follow this and additional works at: https://digitalcommons.usu.edu/phys_stures

Part of the Physics Commons

Recommended Citation
Embedded Charge Distributions in Electron Irradiated Polymers – Pulsed Electroacoustic Method Reproducibility and Calibration

Zachary Gibson, JR Dennison, and Ryan Hoffmann
APS 4CS Virtual Meeting
October 9th, 2021
Outline

• Motivation
• Pulsed Electroacoustic (PEA) Method
  — Signal Processing
• The Experiment
• Uncertainties
  — Relative
  — Absolute
• Conclusions
Defining the Problem – Charging of Insulators

Charge accumulation is a problem in many areas
• HV power cabling insulation
• HV devices and switches
• Electrostatic charging in accelerators and plasma chambers
• Plasma deposition
• Thin film dielectrics
• Electron microscopy and spectroscopy
• Photoconductive devices/sensors
• Inferring defect states in materials
• Spacecraft charging

Spacecraft Charging
• A majority of space environment-induced failures are due to spacecraft charging
• Length scales from 1-100’s of µm
The Experimental Set-up: What is PEA?

How it works:
• Pulsed voltage probes embedded charge
• Time of flight indicates position of charge

Benefits:
• Nondestructive measurement
• Low cost

Limitations:
• Hard to increase resolution
  • High cost electronics
  • Difficult sensor fabrication

L. Pearson (2017)
Measuring Charge Distributions – An Example

Preliminary Data

PEEK 125 um 50 keV Irradiation (incident right)

Volume Charge Density (C/m³)

Thicknss (um)

Sample (PEEK)
Signal Processing

Processing Steps:
• Compute FFT to determine filter
• Bandpass filter data
• Take difference of DC on – DC off
• Use system response to perform deconvolution

Calibration
• Multiply by calibration factor
  • Determined by amplitude of response to DC bias
• Convert time to distance using thickness of material
  • x axis = thickness / time
The Experiment – Electron Irradiation of Polymers

Samples
• Polyether-etherketone (PEEK)
• Polytetrafluoroethylene (PTFE)

Thicknesses
• 125 µm
• 250 µm

Irradiation Energy
• 50 keV
• 80 keV
The Experiment – Details

Average Flux
• For 80 keV, 210 pA/cm²
• For 50 keV, 220 pA/cm²

Irradiation time
• 150 s
• 75 s in beam
• 75 s out of beam
• 30 s per rotation (2 RPM)

High spike of flux
• Higher than baseline for ~15 s
• Highest flux for ~5 s
• ~1/2 of samples received higher than baseline irradiation (6 samples)
• ~1/6 of samples received highest flux (2 samples)
The Mystery – Is there a difference?

Can you tell the difference between the two dose rates?

PTFE Sample Comparison - 125 um 50 keV

Sample (PTFE)
Uncertainty from PEA System – Relative Error

Reproducibility Measurements
- “No touching”
- Removing and replacing sample
- Pulse width and amplitude
- # of measurements averaged

Relative error ± 1-3% of the peak amplitude
- For typical settings
  - 0.5 ns 1 kV pulse
  - 1000 waves averaged
Uncertainty from PEA System – Relative Error

3 Peak Positions found
  • Interfaces (2)
  • Deposited charge

Calculations
  • Compute average
  • Compute standard deviation

Relative error $\pm 0.5 \, \mu m$ for peak position
Uncertainty in the calibration are introduced from errors in:

- Sample thickness
  - For each sample ± 0.5-1 μm
  - Sample uniformity ± 1-3 μm
- Speed of sound ± 5-10% ?
- Resistance of sample
- Resistance of acoustic coupling layers
- Thickness of acoustic coupling layers ± 1-3 ? μm
- HVDC Source
- Reflections of pulsed voltage (electrical impedance mismatches)
- Pulse shape

Determination of uncertainty from these sources is still in progress

Calibrated Signal = IFFT[R(f)]

\[ R(f) = \frac{V_{DC} \varepsilon_r \varepsilon_o}{d \nu_{sample} \tau} \left( \frac{V_{meas}(f)}{V_{response}(f)} \right) \]

R(f) is FFT of space charge distribution, \(V_{DC}\) is DC bias, \(\varepsilon_r\) is relative permittivity of sample, \(\varepsilon_o\) is permittivity of free space, \(\nu_{sample}\) is speed of sound in sample, \(d\) is thickness, \(\tau\) is sampling rate, \(V_{meas}\) is the PEA measurement, and \(V_{response}\) is the response function of the PEA system. First term is calibration factor and second term is deconvolution.

Calibrate (DC On – DC off) and use that to calibrate the original signal.
Conclusions

- With settings of 0.5 ns 1 kV pulse and 1000 waves averaged, the relative error is:
  - ± 1-3% of peak amplitude
  - ± 0.5 um in spatial dimension
- Uncertainty in calibration (absolute error) still needs to be determined
- More work needs to be done to determine if difference in deposition depth is significant
Future Work

• Identify and quantify errors from
  • Sample thickness
  • Resistance of sample
  • Resistance of acoustic coupling layers
  • Thickness of acoustic coupling layers
  • HVDC Source
  • Reflections of pulsed voltage (electrical impedance mismatches)

• Solve the mystery!
Back up slides
All Waves Normalized and Aligned for Comparison
Avergs 100-5000, pulse 0.5 - 5 ns, amplitude 1 - 2 kV