7-2022

Uncertainties of the Pulsed Electroacoustic Method: Peak Positions of Embedded Charge Distributions

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ICD 2022

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Motivation

Understanding the accumulation and dynamics of embedded charge in insulating materials is paramount for myriad of applications from HVDC power transmission to spacecraft charging [1,2].

PEA systems allow for nondestructive measurements of embedded charge distributions. The spatial resolution of PEA measurements are typically defined as the FWHM of the leading interfacial peak, ~10 µm is typical. However, this is only one moment of the charge distribution. There are also the magnitude, peak position, and skewness of the charge distribution.

Precise knowledge of the peak position of embedded charge distributions is important for understanding the electrical properties of insulators such as conductivity (slow charge migration), radiation induced conductivity (and delayed radiation induced conductivity), and electron range/penetration depth (as a function of dose and incident energy).

This study focuses on the resolution of the peak position of embedded charge distributions measured via the PEA method.

Experiment

50 keV Electron Beam Flux

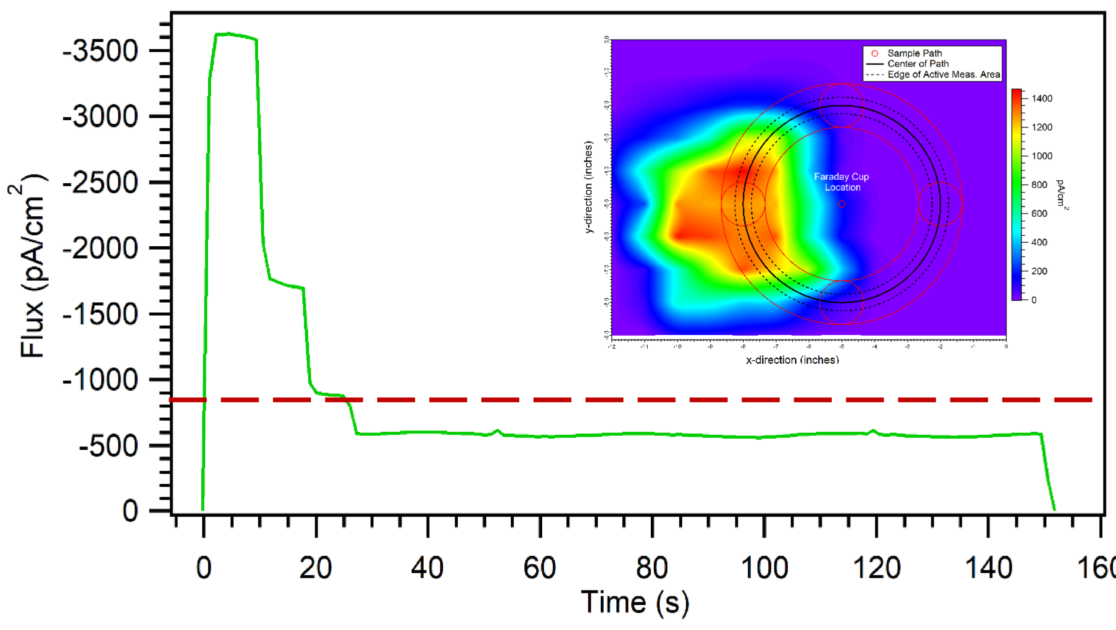

Figure 1: Electron beam flux during the 50 keV irradiation. Red dashed line indicates the average. Inset shows beam profile and sample path during irradiation.

Experiments:

1. Repeated measurements to determine experimental precision
2. Irradiation with differing electron doses to achieve slightly different peak positions of embedded charge
3. Long duration charge migration of embedded charge

Samples:

PEEK 125 µm thick, 50 keV higher dose (K4A, K6A)

PEEK 250 µm thick, 50 keV lower dose (K4B, K6B)

PEEK 125 µm thick, 80 keV

The samples with differing total doses are compared. The samples were then stored (without grounding either surface) for 229 days before being measured again.

Further experimental details in [3].

Reproducibility

Uncertainty: 80 keV Irradiated PEEK

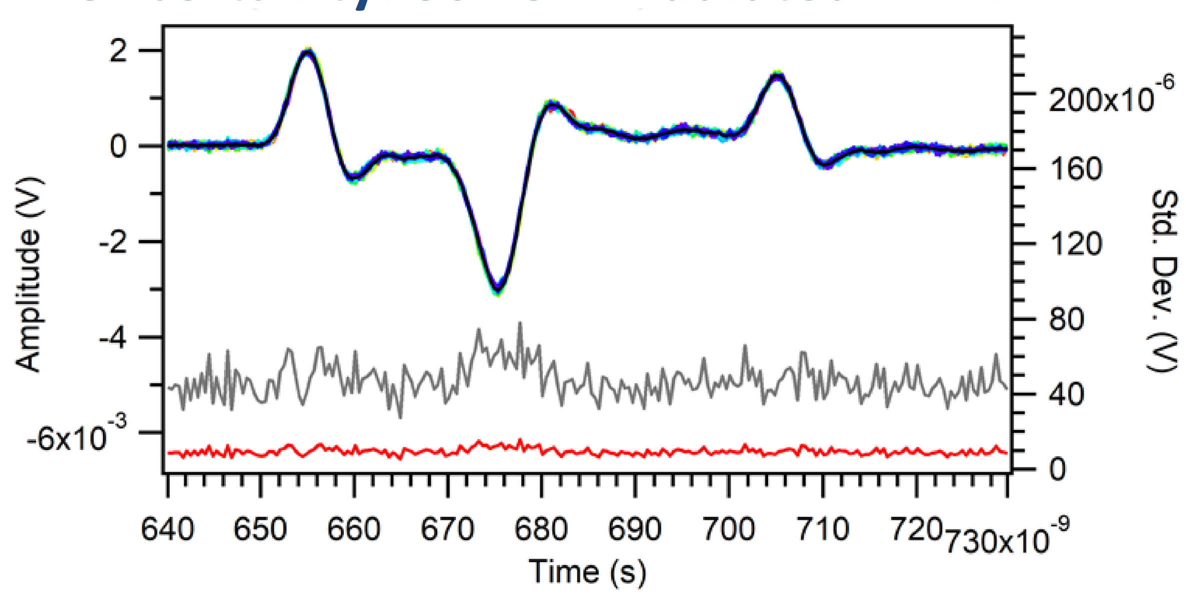

Figure 2: Repeated PEA measurements without removing sample from PEA fixture. Standard deviation (grey) and standard error (red) are also plotted.

The experimental precision was determined by repeating measurements 25 times. The standard deviation of the magnitude of the leading interfacial peak is ≤3%.

The distribution of the deviation from the mean (point by point) was found to be normally distributed, indicating random error. A reduced chi-square test (0.97±0.09) confirmed the standard deviation to be an appropriate measure of error.

The uncertainty in peak positions was found to be ≤0.2 µm for the leading and trailing interfacial charge peaks and the embedded charge peak.

Differing Doses

The difference in peak position between the two sets of samples is 3.5±0.4 µm.

This shows that the determination of peak position is better than the spatial resolution as defined by the FWHM (~10 µm).

50 keV Irradiated PEEK

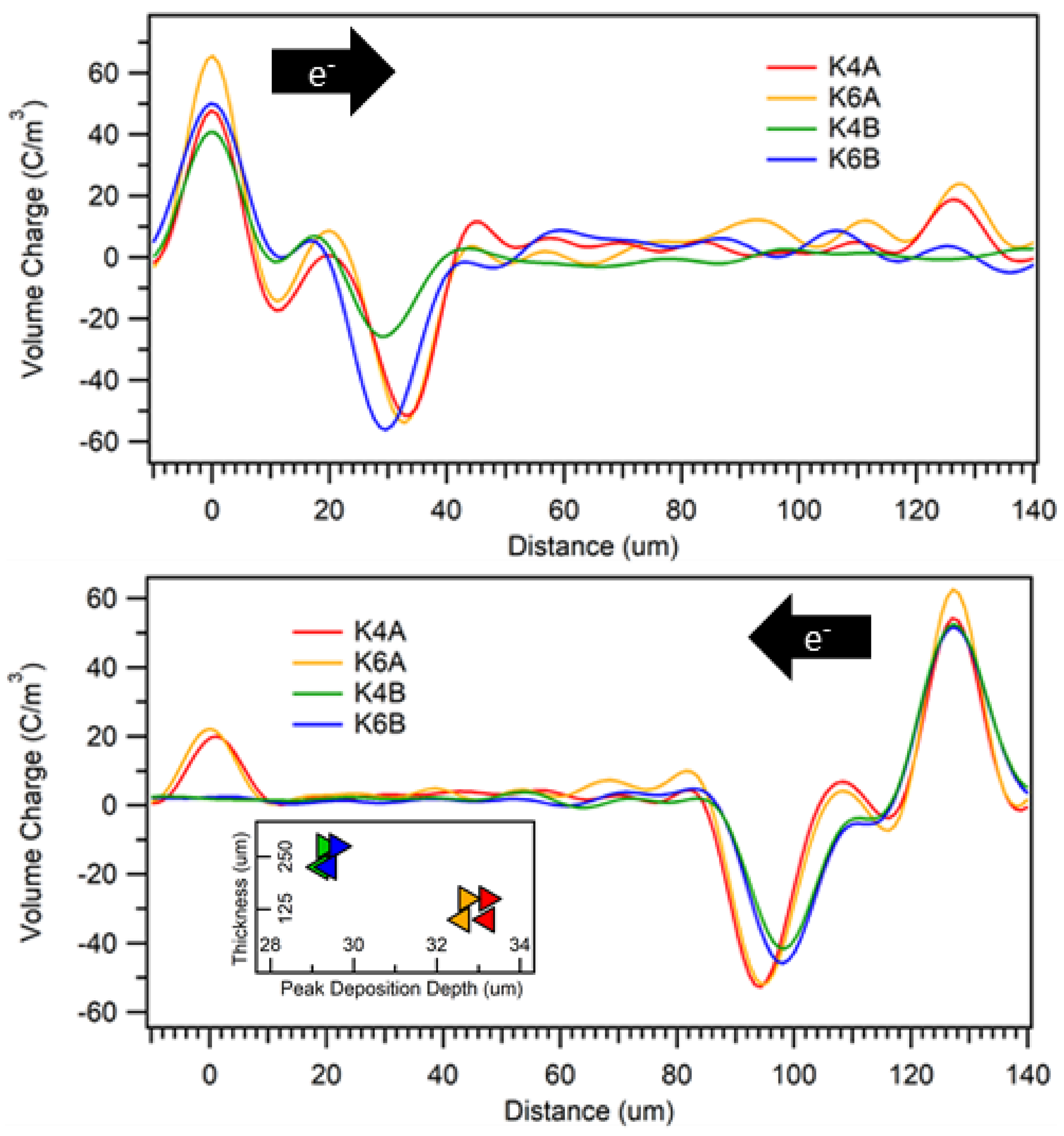

Figure 3: Results of slightly differing doses. Inset indicates deposition depths with direction of arrow indicating irradiation direction.

Slow Charge Migration

The charge migration was measured after 229 days of storage. The shift in peak position is expected to be up to several tens of microns if either surface was grounded. These samples were not grounded.

Charge Migration Distance:

0.8±0.2 µm for K4A

0.65±0.2 µm for K6A

50 keV Irradiated PEEK Charge Migration

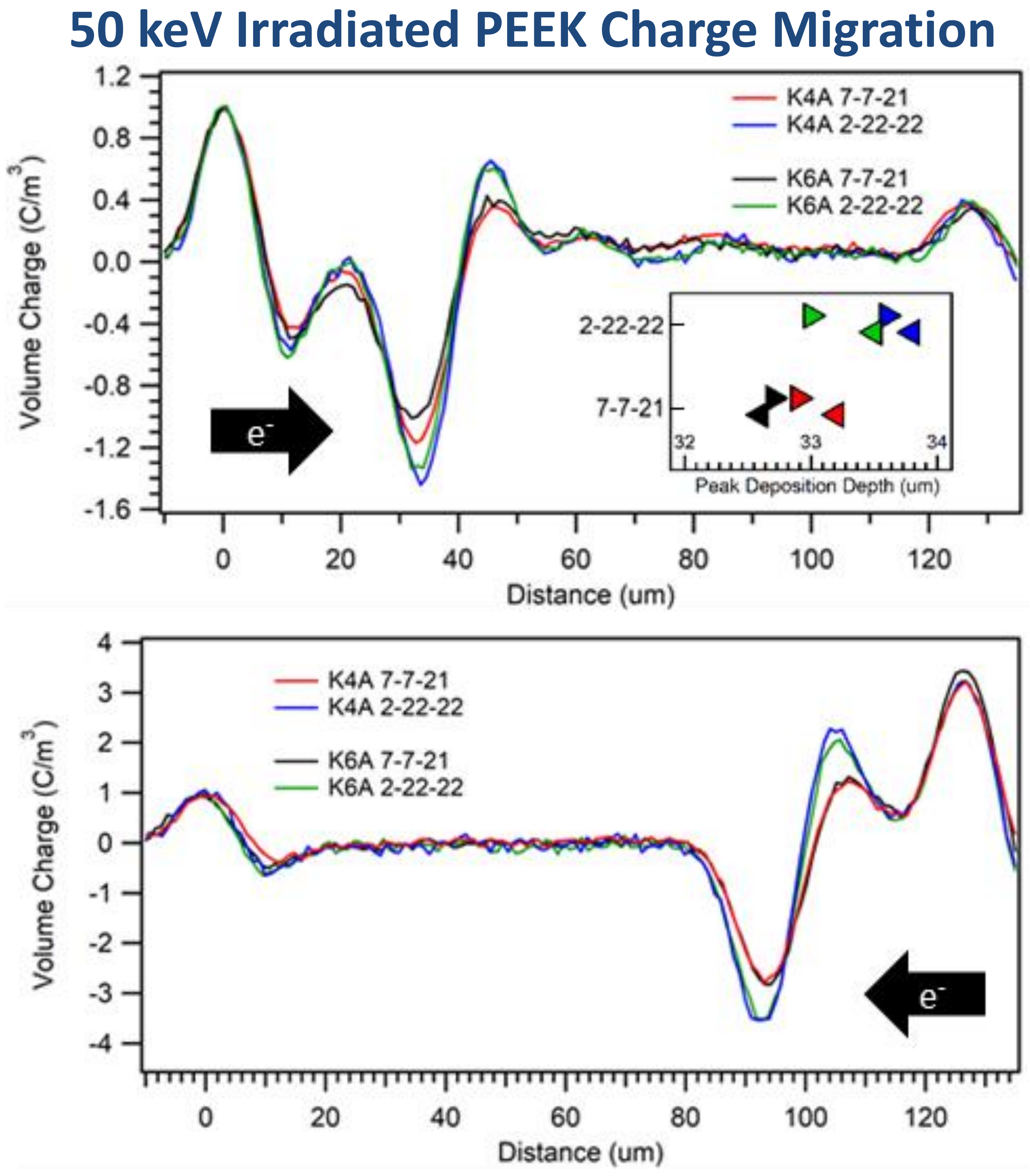

Figure 4: Results of slow charge migration in PEEK. The inset indicates the deposition depth with the direction of the arrow indicating the irradiation direction.

Conclusion

The PEA measurements presented demonstrate the experimental uncertainty in peak position of the system to be ≤1 µm.

The appropriate choice of measure of the PEA system spatial resolution depends on the context of the measurements. While the FWHM may be a good measure of resolution when differentiating multiple embedded charge distributions, the uncertainty in peak position for a single charge distribution is much higher.

Future work includes determining the proper alignment of PEA measurements (rising edge, peak position, etc.) and the uncertainty in the other moments of the embedded charge distributions, and more measurements of the slow migration of the embedded charge to provide more confidence that there is a trend of the charge migrating deeper into the sample over time.

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Acknowledgments:
Research partially supported by an AFRL STTR award through Box Elder Innovations. Gibson acknowledges support from USU Presidential Doctoral Research Fellowship. We thank Ryan Hoffmann at AFRL-RVBX for irradiating the PEEK samples in their facilities.

References:
[1] G. Rizzo, P. Romano, A. Imburgia, and G. Ala, "Review of the PEA method for space charge measurements on HVDC cables and mini-cables," Energies, vol. 12, p. 3512, 2019.
[2] J.R. Dennison and L. H. Pearson, "Pulsed electro-acoustic (PEA) measurements of embedded charge distributions," in Nanophotonics and Macrophotonics for Space Environments VII, 2013, p. 887612.
[3] Z. Gibson and J. R. Dennison, "Comparison of Charge Deposition Profiles in Polymers Irradiated with Monoenergetic Electrons: Pulsed Electroacoustic Measurements and AF-NUMIT3 Modeling," Journal of Spacecraft and Rockets, Unpublished.