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High-Frequency Pulsed-Electro-Acoustic (PEA) Measurements for Mapping Charge Distribution

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Content

• Objective
• Approach
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  • Theory
• Measurement System
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• Discussion
• Conclusion
Objective

- Use high-frequency pulsed-electro-acoustic (PEA) measurements as a non-destructive method to investigate internal charge distribution in dielectric materials

Figure 1. Electron range calculations
Figure 2. Ex situ PEA profiles showing charge dissipation and migration at different times after electron irradiation
Approach

• Thin dielectric positioned between two conducting electrodes
• Voltage signal on the two electrodes to generate an electric field across the dielectric
• Force on embedded charge creates a pressure wave that propagates within the capacitor
• Coupled acoustic sensor measures the ensuing pressure pulse response
• Spatial distributions of the charge profile are obtained from the resultant pressure waveform
Model

![Diagram of a model with a piezoelectric sensor, electrodes, and a digital oscilloscope. The diagram shows the voltage $E(t)$ and the dielectric layer with labels $P_{31}, P_{30}, P_{22}, P_{21}, P_{20}, P_{12}, P_{11}, P_{10}$. The electrodes are labeled as $h_s, h_{a1}, h_d, h_{a2}$.](image)
Theorem

\[ \Delta f(z, t) = \rho(z) \cdot \Delta z \cdot E(t) \]
\[ \Delta f(\omega, z) = \rho(z) \cdot \Delta z \cdot E(\omega) \]
\[ \Delta p(\omega, z) = p_0(\omega) \cdot \rho(z) \cdot \Delta z \cdot E(\omega) \cdot e^{i k_d z} \cdot e^{i k_a h_{a1}} \cdot t_{43} \cdot t_{32} \]
\[ z = t \cdot c_d \quad \Delta z = c_d \Delta t \quad k_d = \frac{\omega}{c_d} \]
\[ \Delta p(\omega, t) = p_0(\omega) \cdot E(\omega) \cdot c_d \cdot e^{i k_a h_{a1}} \cdot t_{43} \cdot t_{32} \cdot \rho(c_d t) \cdot e^{i \omega t} \Delta t \]
\[ p(\omega) = p_0(\omega) \cdot E(\omega) \cdot c_d \cdot e^{i k_a h_{a1}} \cdot t_{43} \cdot t_{32} \cdot \int_0^t \rho(c_d t) \cdot e^{i \omega t} dt \]
\[ p(t) = \text{Re}[\text{fft}[p(\omega)]] \]
\[ \rho(c_d \omega) = \frac{p(\omega) \cdot e^{-i k_a h_{a1}}}{p_0(\omega) \cdot E(\omega) \cdot c_d \cdot t_{43} \cdot t_{32}} \]
\[ p_{10}(\omega) = p_0(\omega) \cdot E(\omega) \cdot e^{i k_a h_{a1}} \cdot t_{32} \]
\[ p_{20}(\omega) = p_0(\omega) \cdot E(\omega) \cdot c_d \cdot \rho(c_d \omega) \cdot e^{i k_a h_{a1}} \cdot t_{43} \cdot t_{32} \]

- Calculate Force on Electrons due to Applied Electric Field
- Change to Frequency Domain
- Account for Reflection and Transmission Coefficients
- Compute Inverse Fourier Transform
- Extract Waveform
Measurement System

- Purpose: study of charge migration under external fields

3.

- Generation of a 0-5kV input from a DC field
- Electric field impulse created from 350V pulse generator
- Superimposition of impulse on 5kVDC input produces pressure wave

Figure 3. Schematic diagram and of the measurement apparatus. (Miyake 2010)
Experimental Procedure

- PULSE/REC
- RECEIVER
- RF OUT
- EXT TRIG
- SYNC OUT

Dell Notebook Computer

LabVIEW Data Acquisition

Digital Storage Oscilloscope, 500 MHz, 1 Gs/s
Hewlett-Packard, HP 54522A

Dell Notebook Computer

USB
GPIB to USB Interface Cable

USB
GPIB

CH 1
CH 2
EXT TRIG
In Vacuo Experimental Set-up

- Programmable Function Generator
- High Voltage Amplifier
- High Speed Waveform Digitizer

Vacuum

Electron Beam
Signal Processing

Split-Spectrum Processing + Gaussian Filter
+ Synthetic Aperture + Envelop
• **Intent:** increase the signal-to-noise ratio
Discussion

• Validating existing PEA models requires
  • Understanding of wave propagation inside the PEA cell
  • Analysis of transducer geometry on the quality of output voltage signal
• Very thin (1-10µm) PVDF piezoelectric transducers necessary to improve spatial resolution
• Signal-processing may improve the signal-to-noise
• High vacuum and low energy conditions are allow direct electron beam irradiation
Measurement and analysis of volume charge distribution in thin dielectrics using high-frequency (ultrasonic) waveforms will improve the prediction of charge distribution while seeking to validate and improve existing PEA models and theories.

**Figure 4**: Relationship between distributed charge density $\rho(x)$ in the sample and the output signal voltage $v_s(t)$ from the transducer of the piezoelectric device.
Citations


**Questions?**

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