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

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Content

- Objective
- Approach
  - Model
  - Theory
- Measurement System
  - Data Acquisition
  - Signal Processing
- 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

1.

2.
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

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

- 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

Digital Storage Oscilloscope, 500 MHz, 1 Gs/s
Hewlett-Packard, HP 54522A
Dell Notebook Computer
LabVIEW Data Acquisition
USB
GPIB to USB Interface Cable
GPIB
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
Band Pass Filter and Envelope

- **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
Conclusion

- 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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