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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

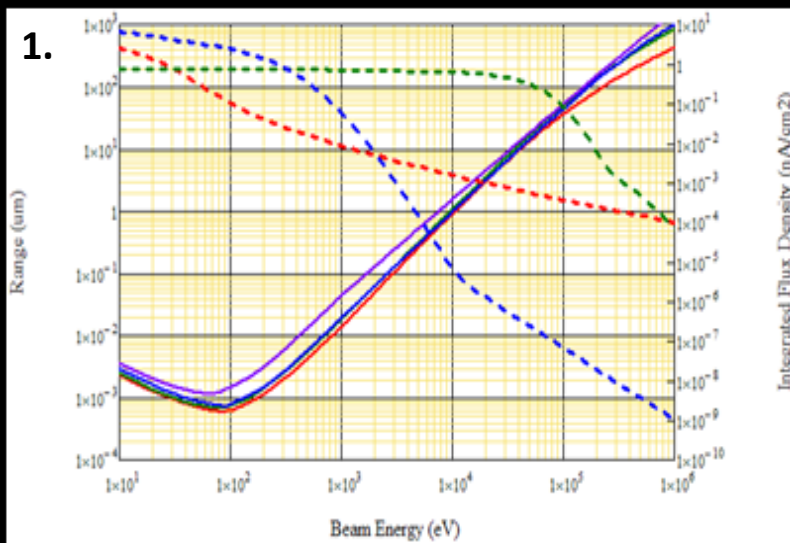
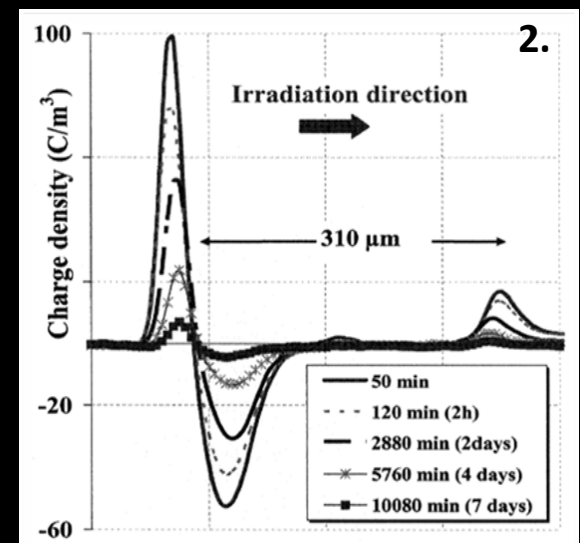


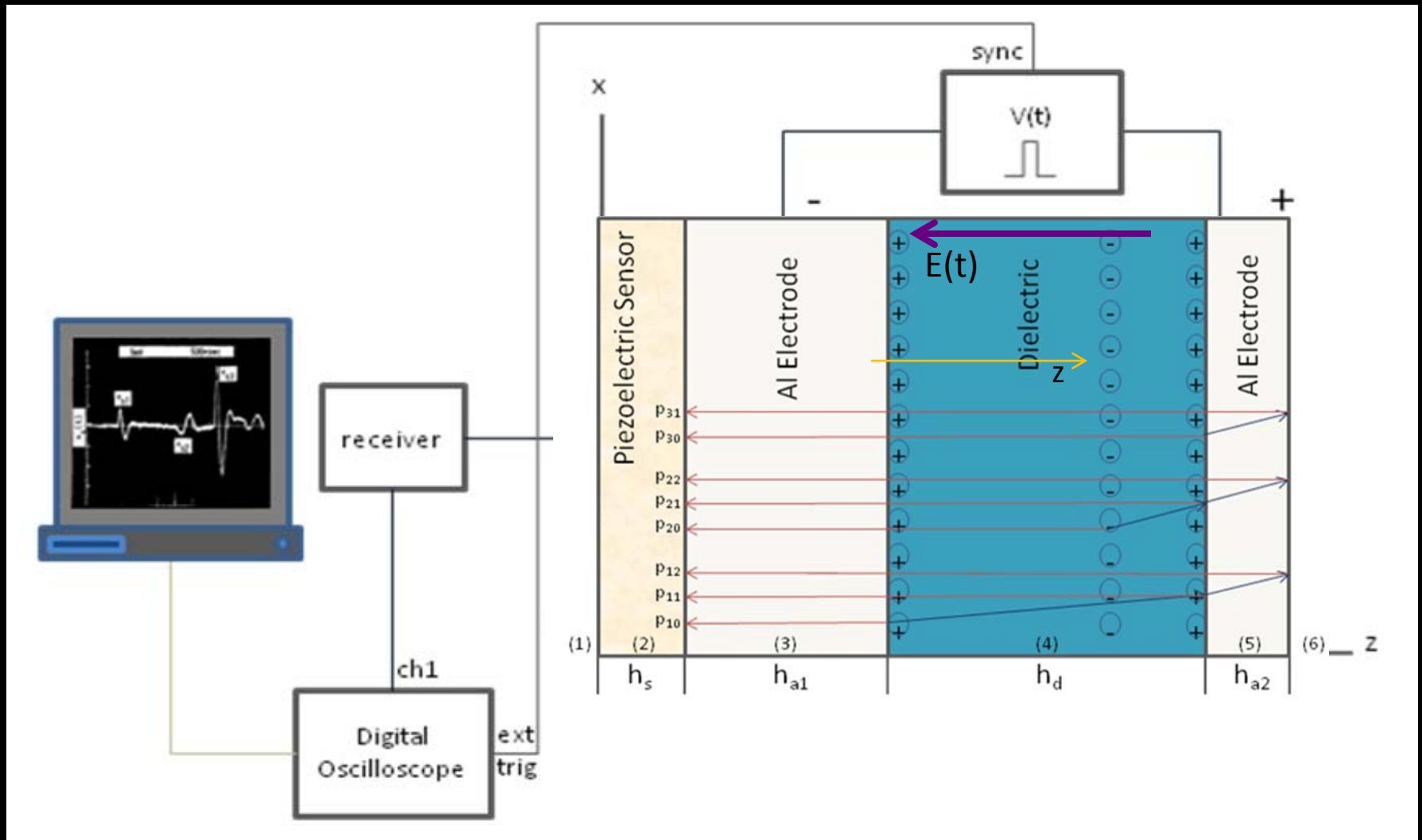
Figure 1. Electron range calculations
Figure 2. Ex situ PEA profiles showing charge dissipation and migration at different times after electron irradiation



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



Theory

$$\Delta f(z, t) = \rho(z) \cdot \Delta z \cdot E(t)$$

$$\Delta f(\omega, z) = \rho(z) \cdot \Delta z \cdot E(\omega)$$

$$\Delta p(\omega, z) = p_0(\omega) \cdot \rho(z) \cdot \Delta z \cdot E(\omega) \cdot e^{ik_d z} \cdot e^{ik_a h_{a1}} \cdot t_{43} \cdot t_{32}$$

$$z = t \cdot c_d ; \Delta z = c_d \Delta t ; k_d = \frac{\omega}{c_d}$$

$$\Delta p(\omega, t) = p_0(\omega) \cdot E(\omega) \cdot c_d \cdot e^{ik_a h_{a1}} \cdot t_{43} \cdot t_{32} \cdot \rho(c_d t) \cdot e^{i\omega t} \Delta t$$

$$p(\omega) = p_0(\omega) \cdot E(\omega) \cdot c_d \cdot e^{ik_a h_{a1}} \cdot t_{43} \cdot t_{32} \cdot \int_0^t \rho(c_d t) \cdot e^{i\omega t} \cdot dt$$

$$p(\omega) = p_0(\omega) \cdot E(\omega) \cdot c_d \cdot e^{ik_a h_{a1}} \cdot t_{43} \cdot t_{32} \cdot \rho(c_d \omega)$$

$$p(t) = \text{Re}[icfft[p(\omega)]]$$

$$\rho(c_d \omega) = \frac{p(\omega) \cdot e^{-ik_a h_{a1}}}{p_0(\omega) \cdot E(\omega) \cdot c_d \cdot t_{43} \cdot t_{32}}$$

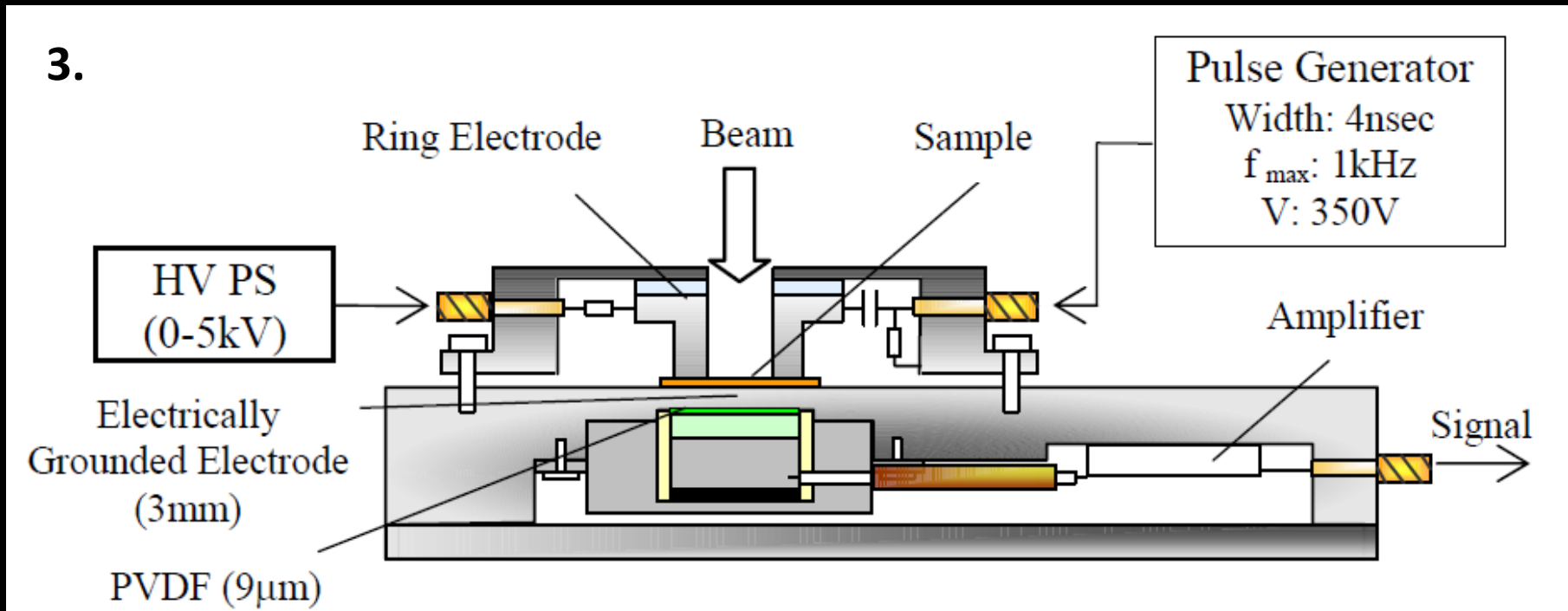
$$p_{10}(\omega) = p_0(\omega) \cdot E(\omega) \cdot e^{ik_a h_{a1}} \cdot t_{32}$$

$$p_{20}(\omega) = p_0(\omega) \cdot E(\omega) \cdot c_d \cdot \rho(c_d \omega) \cdot e^{ik_a h_{a1}} \cdot t_{43} \cdot t_{32}$$

- 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

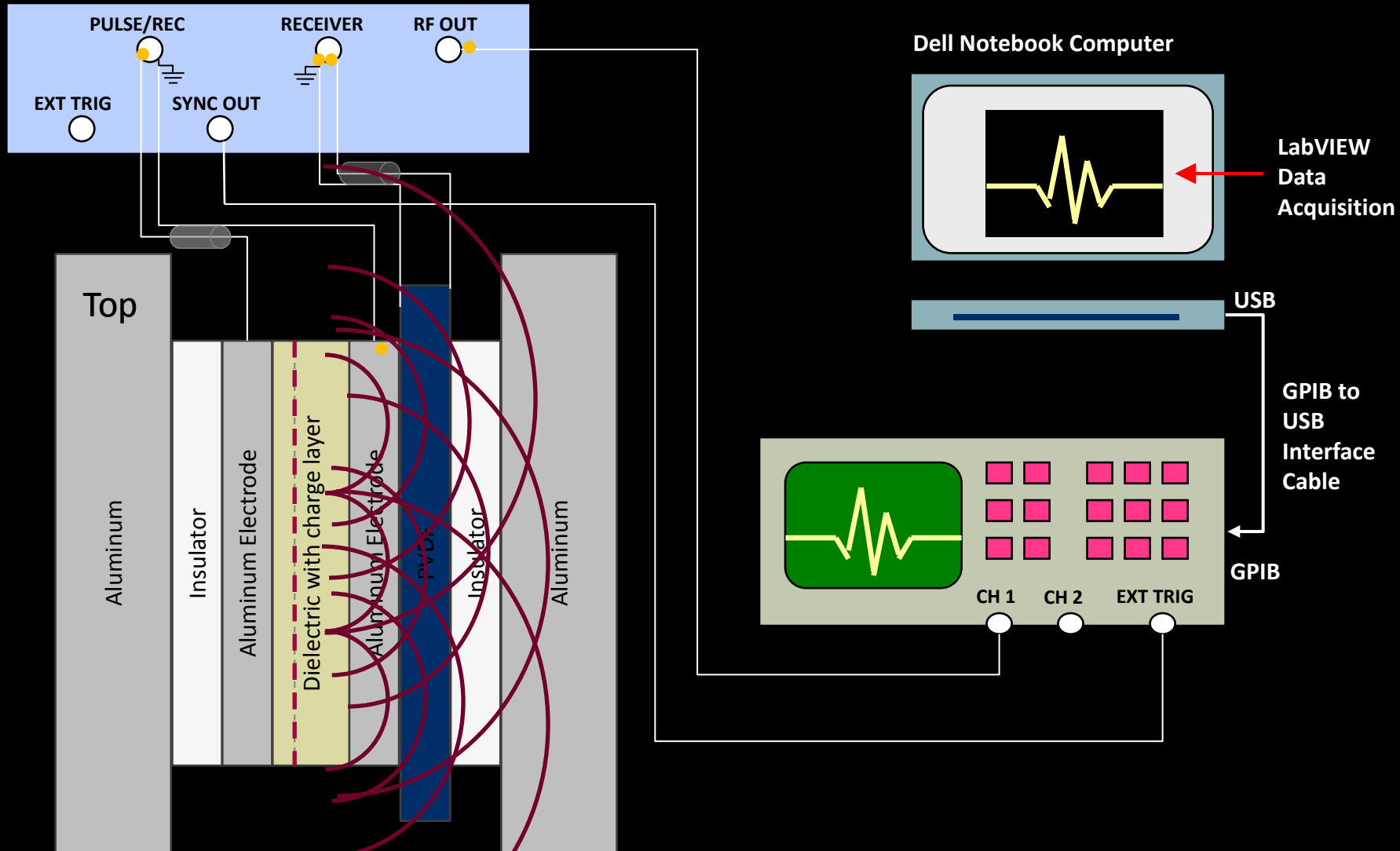
- Purpose: study of charge migration under external fields



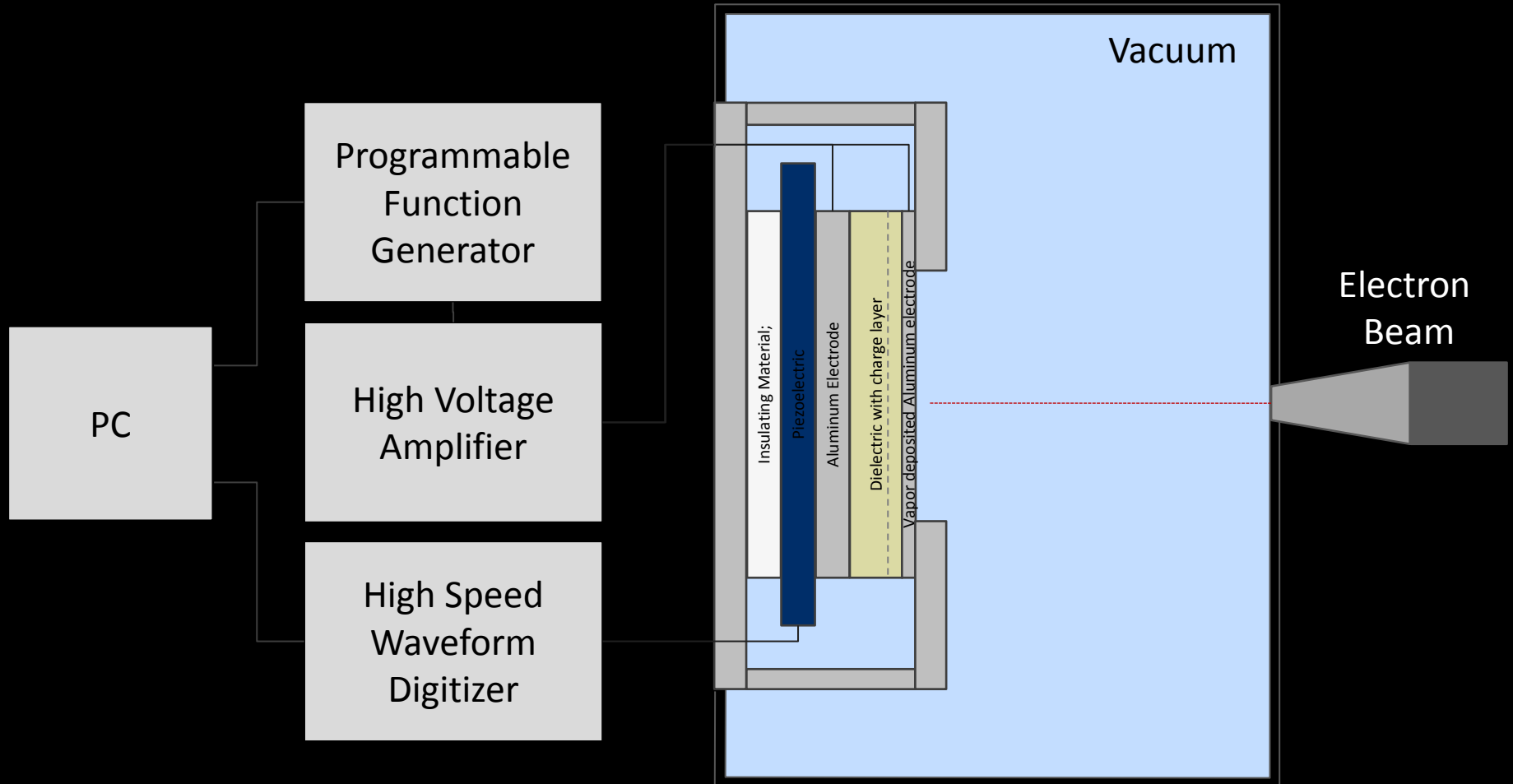
- Generation of a 0-5kV input from a DC field
- Electric field impulse created from 350V pulse generator
- Superimposition of impulse on 5kVDC input produces pressure wave

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

Experimental Procedure

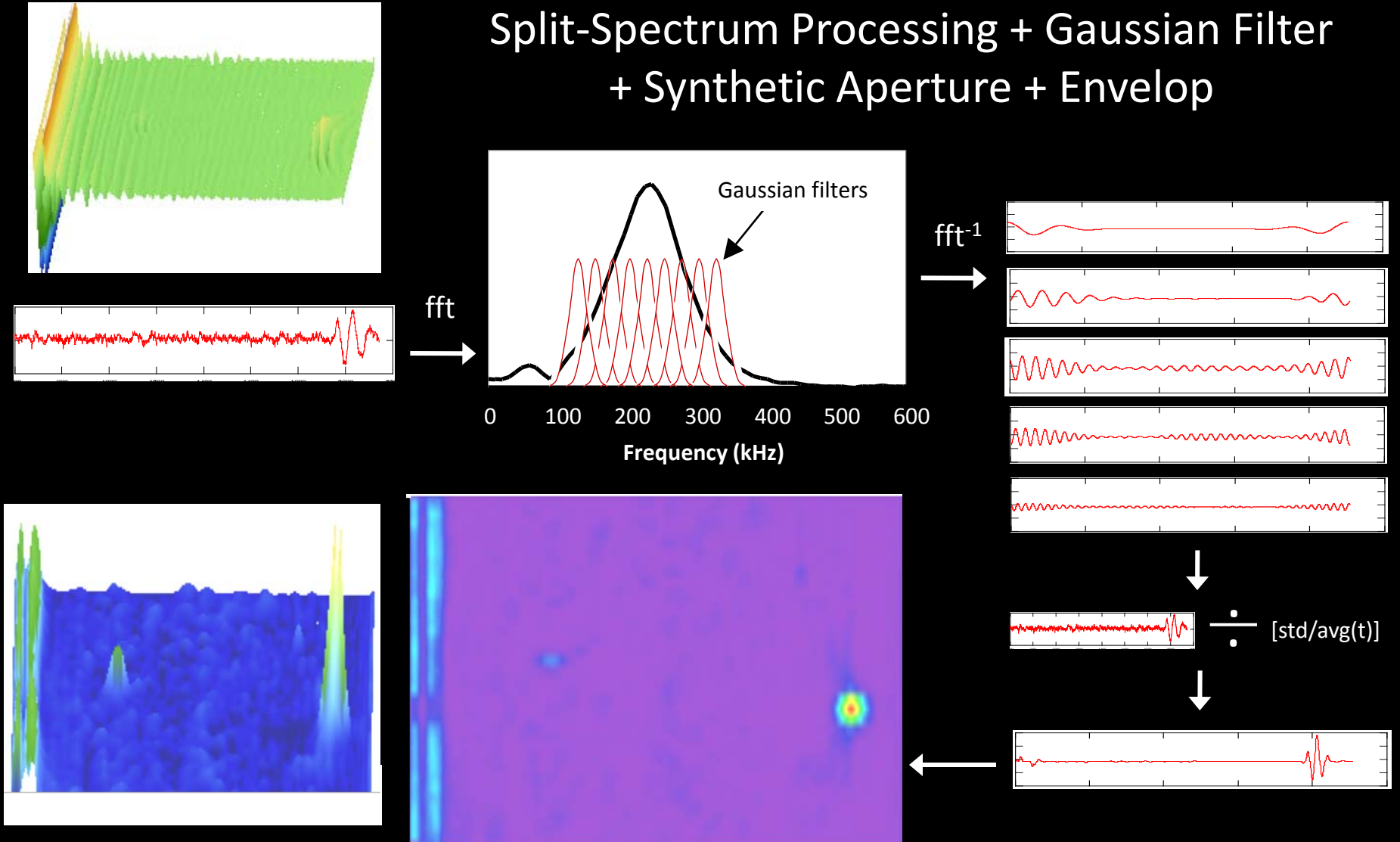


In Vacuo Experimental Set-up

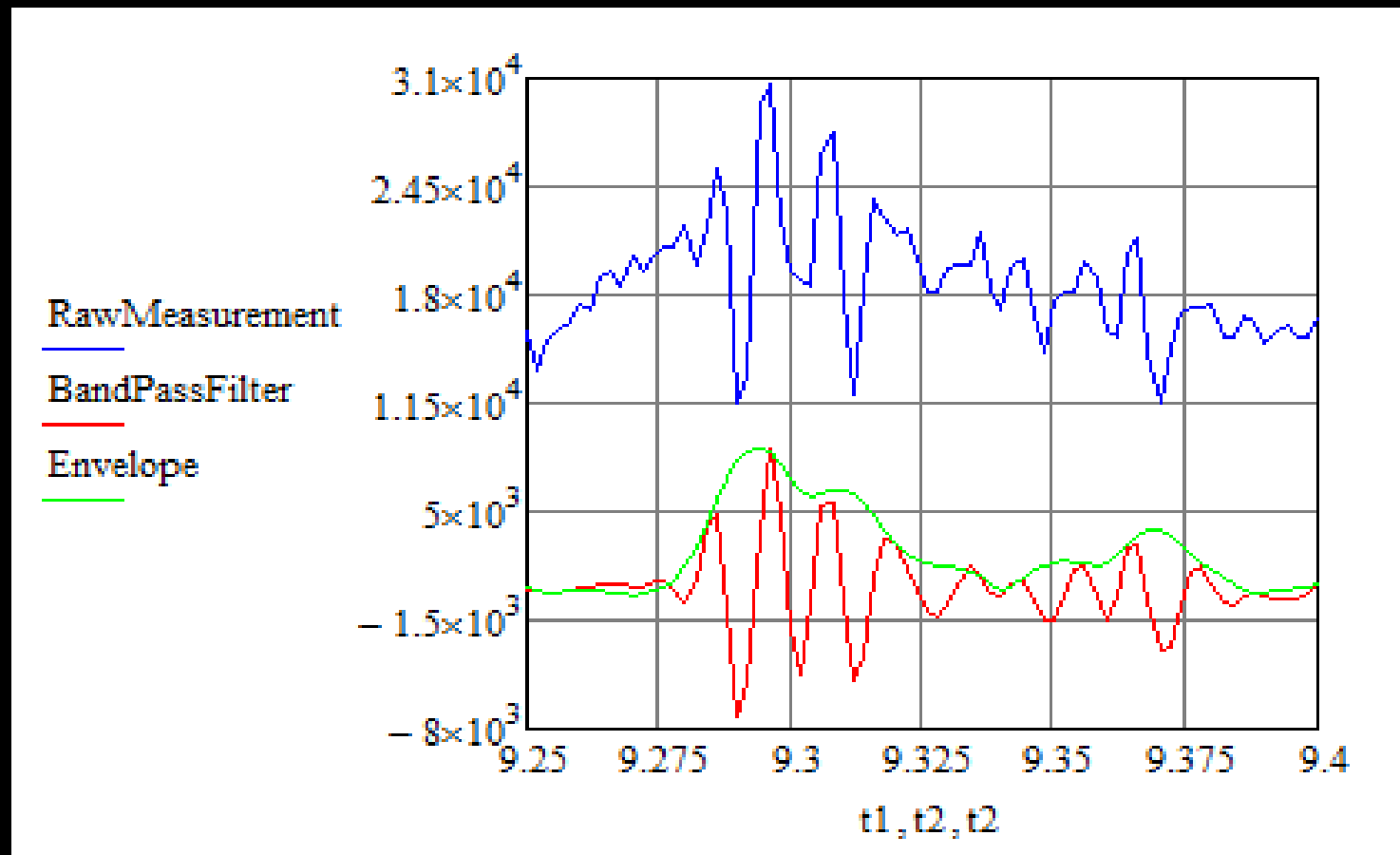


Signal Processing

Split-Spectrum Processing + Gaussian Filter + Synthetic Aperture + Envelop



Band Pass Filter and Envelope

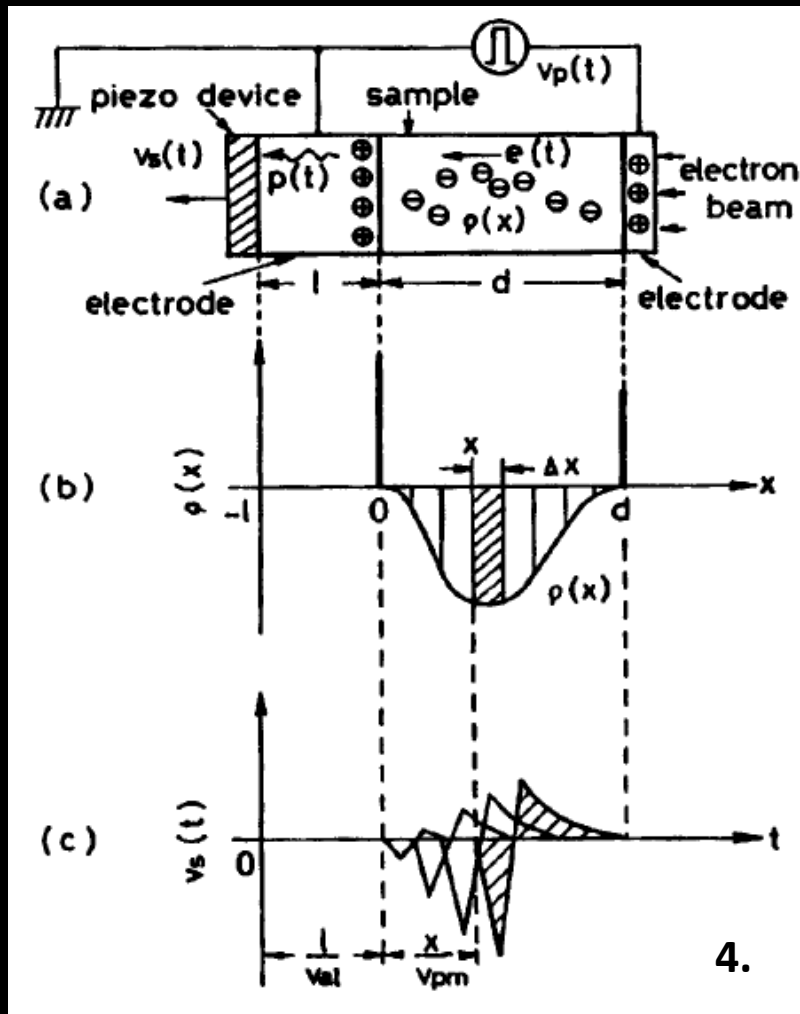


- Intent: increase the signal-to-noise ratio

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 (1-10 μm) 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, Acknowledgements

Citations

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Questions?

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