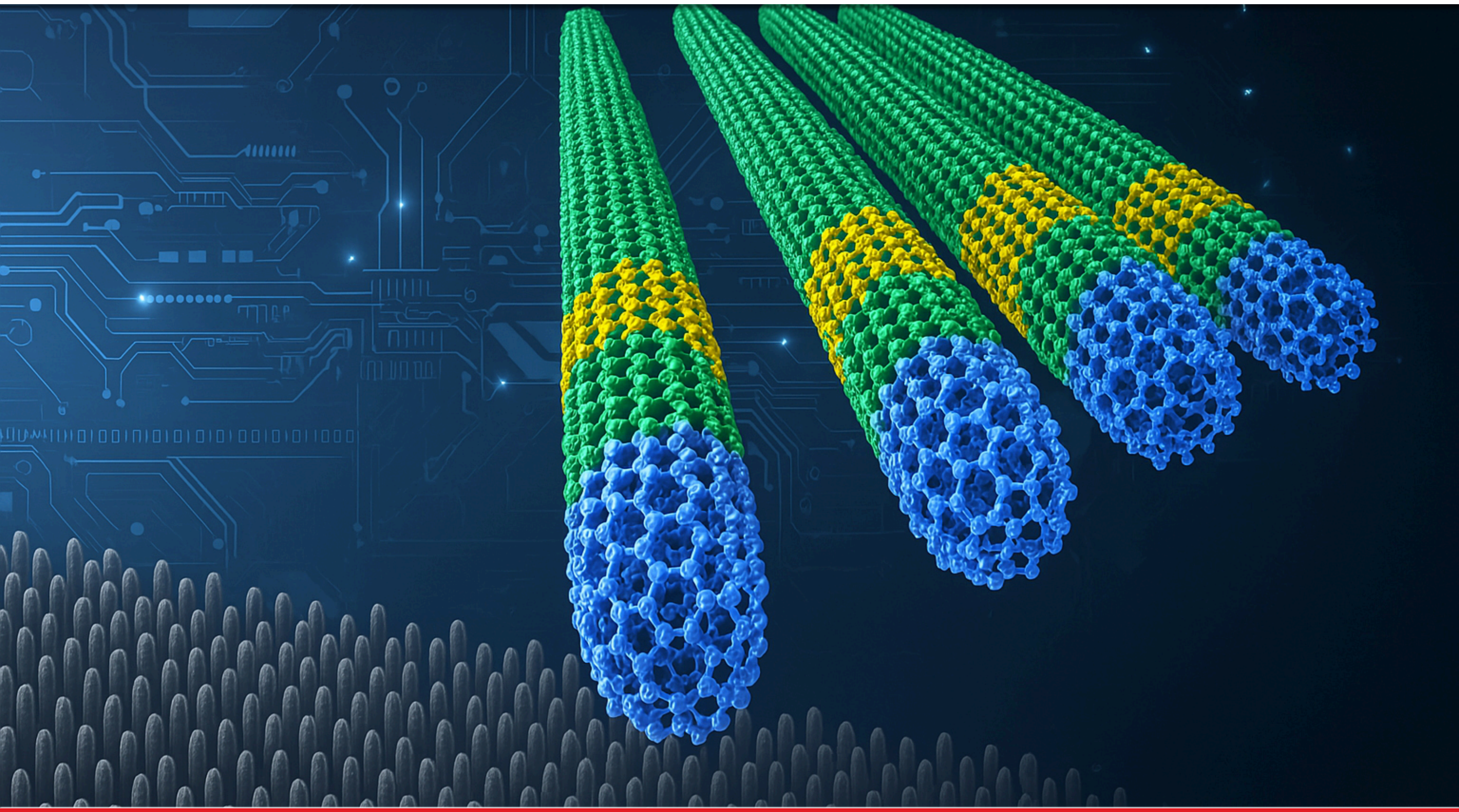

Precision Measurement of Piezoelectric Coefficients in ZnO Nanowires Using ESPY33

Reliable, SI-traceable direct d_{33} measurements enabling detection of ultra-weak piezoelectric activity in nanowires, overcoming charge leakage and mechanical instabilities.

The Challenge

The push for miniaturized, self-sustaining electronics has driven interest in piezoelectric ZnO nanowires (NWs). The d_{33} coefficient is a standard metric for evaluating application-relevant piezoelectric performance, and commercial tools exist to measure it. However, these systems often struggle due to:

- High Compliance: nanostructures like ZnO NWs are extreme flexible, making them prone to deformation under measurement forces, distorting true d_{33} values.
- Charge Leakage & Instrumentation Artifacts: Conventional methods suffer from actuator misalignment, parasitic vibrations, and suboptimal electrode configurations, leading to charge dissipation and distorted piezoelectric response.
- Instrumentation Artifacts: mechanical stress can cause bending or torsional forces, especially detrimental when assessing flexing and thin materials. Actuator misalignment, parasitic vibrations, and suboptimal electrode configurations induce measurement artifacts, distorting true piezoelectric response.
- Raw Measurement Data: Fitting distorted charge/force curve will still yield d_{33} value, which contains measurement artifacts. Raw data access is essential for confidence in data.
- Parameter Control and Accuracy: broad flexibility to adjust measurement parameters with high accuracy is essential.

Overcoming these challenges requires a high-precision system capable of suppressing charge leakage, eliminating mechanical instability, and capturing ultra-weak piezoelectric signals with SI-traceable accuracy.

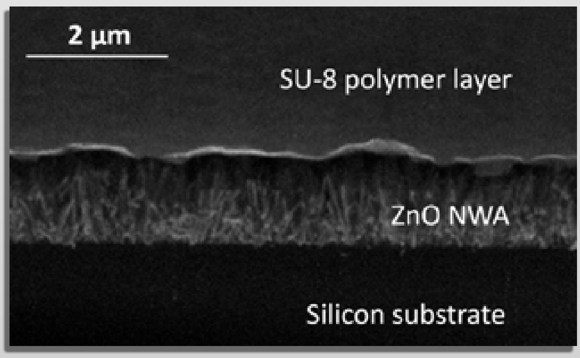

Fig 1: SEM images of SU-8 spin-coated on a ZnO NWA, inclined view on the edge of a ZnO

The Solution

- **Force Measurement:**
  Aligned force measurement cell ensures uniform on-axis loads, eliminating bending and torsional artifacts.
- **High Measurement Precision:**Transimpedance virtual earth amplifier enables 100 fA current resolution and sub-pC charge accuracy.
- **Load Application:**
  Static pre-loads from 0.1 N to 10 N, dynamic loads up to 1000 mN, spanning 10 mHz–500 Hz ensure consistent contact between instrument and sample, minimizing mechanical instabilities.
- **Load Accuracy:**
  100 µN precision prevents mechanical deformation of ZnO nanowires, preserving their intrinsic piezoelectric properties.
- **SI-Traceability:**
  Force and charge measurements are SI-traceable (International System of Units), ensuring reproducibility and cross-study comparability.
- **Automation:**
  Supports parameter sweeps (frequency, static/dynamic load, duration) for fully automated experiments.

These capabilities make ESPY33 a high-precision solution for d33 measurements in soft and nanoscale materials, overcoming limitations of conventional methods.

Experimental

A silicon wafer with four lithographically patterned ZnO NW arrays (200 nm diameter, 1.8 µm length) was modified to connect bottom electrode vias to the ESPY33 probe. A thin polymer SU-8 infill enabled Cr/Au top electrode deposition. The sample was loaded with the applied force aligned along the NW axes, ensuring precise top and bottom probe contact.

The d_{33} coefficient, relating polarization to applied stress, was determined using an instrumented load cell for force measurement and a transimpedance virtual earth amplifier for charge detection.

Identical 0.1 N pre-loads were applied, with small-signal forces of 100 mN incremented by 10 mN to assess load dependence of the piezoelectric response.

Results

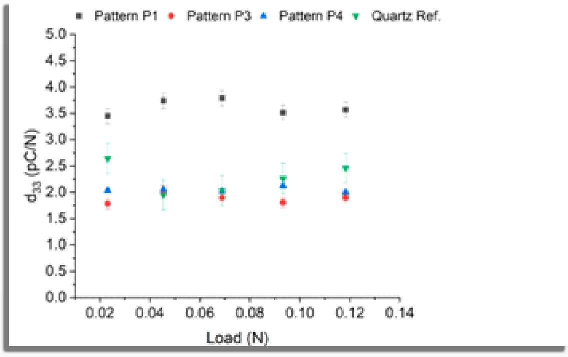

Fig 2: Effective bulk piezoelectric charge coefficients measured using the EPSY33.

Figure 2 presents the measured d_{33} values for three ZnO nanowire patterns. Three patterns (P1, P3, P4) exhibited extremely weak but reliably quantified bulk piezoelectric response, with nominal values of 1.9, 2.1, and 3.6 ± 0.5 pC/N. Such low activity levels are typically impossible to measure with conventional methods due to charge leakage and mechanical instabilities.

The ESPY33 overcomes these limitations, enabling artifact-free, high-precision measurement by:

- Eliminating Charge Leakage: Enhanced electrical isolation and minimized stray capacitance ensured complete charge collection.

- Ensuring Perfect Electromechanical Contact: Optimized probe design prevented interface-induced charge dissipation.

- Delivering Unmatched Load Precision: High-accuracy static and dynamic force control mitigated deformation effects.

These advancements establish ESPY33 as a breakthrough tool for detecting even the weakest piezoelectric signals, pushing the boundaries of what's measurable in nanoscale materials.

Acknowledgement

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All images are from published literature sources below.

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Links

Case study: https://www.euramet.org/ casestudies/ casestudiesdetails/news/ accurately-determining-the-piezoelectriccoefficient-of-nanowires

Area-Selective Growth of Zinc Oxide Nanowire Arrays for Piezoelectric Energy Harvesting, DOI: https://doi.org/10.3390/ mi15020261

Thermo-Convective Solution Growth of Vertically Aligned Zinc Oxide Nanowire Arrays for Piezoelectric Energy Harvesting, DOI: https://doi.org/10.3390/ mi15101179

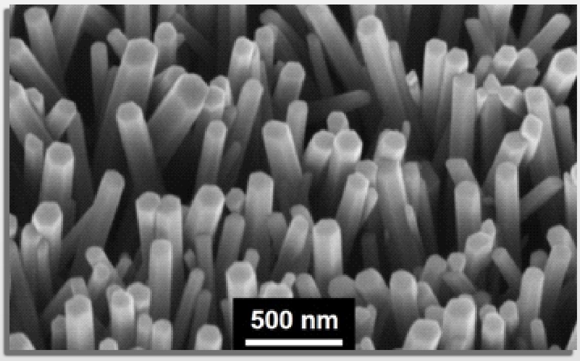

Fig 3: SEM images ZnO on silicon substrate

Fig 4: ESPY 33 instrument