Piezoelectric and Electrical Properties of ZnO Nanorods for sensor applications

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories
David A. Scrymgeour & Julia W.P. Hsu

Statement of Problem

Nanostructured zinc oxide, with its high surface area to volume ratio and unique piezoelectric and semiconducting properties, is a key material for the development of next-generation sensor arrays. The motivating idea behind this research is to utilize the combination of piezoelectric effect and the small geometries of nanostructures, which together give an intrinsically high-frequency resonant behavior. These features can be exploited to create sensors analogous to the quartz crystal microbalance, but have the advantage of enhanced sensitivity due to higher operating frequency and smaller surface area. However, the basic properties of nanoscale piezoelectric structures must first be understood to implement such devices. This work characterizes the piezoelectric and electrical properties of individual nanostructures and the measurement of high-frequency impedance characteristics of both arrays and individual nanostructures.

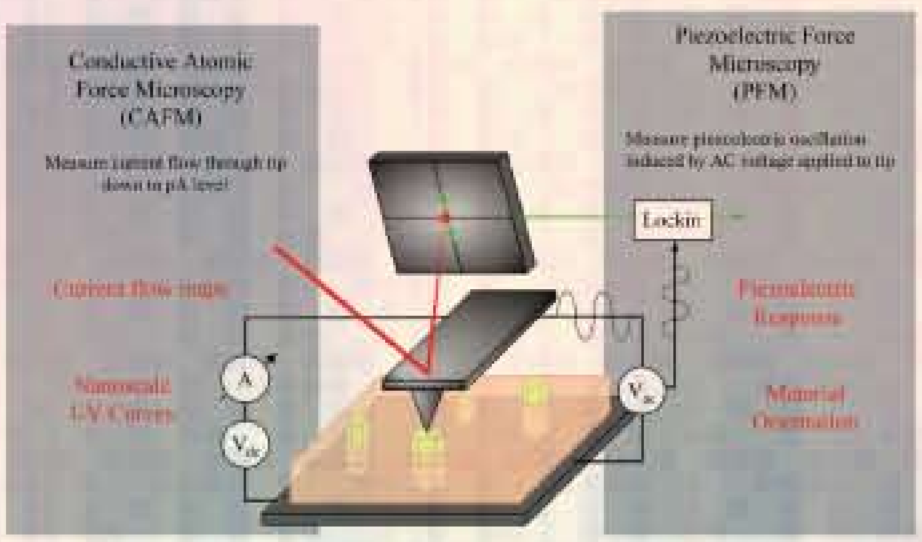
Approach

Individual piezoelectric and electrical properties of nanorods:

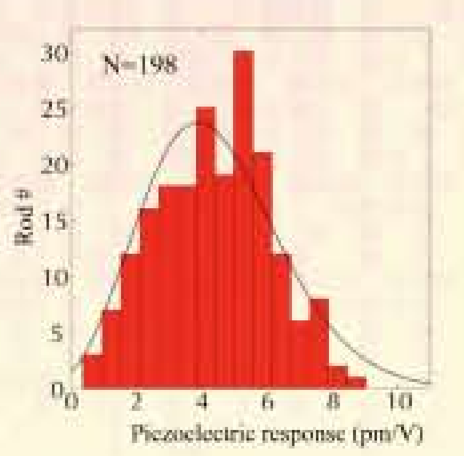
- Built and calibrated piezoelectric force microscope (PFM) capable of measuring piezoelectric distortions to ~1 pm
- Integrated PFM with conductive atomic force microscopy (CAFM)
- Allowed sequential property measurements on individual nanorods

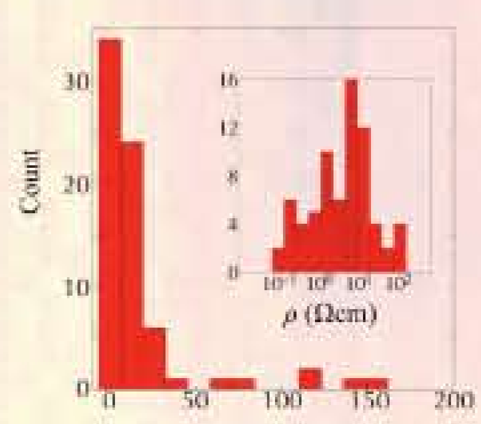
High frequency impedance spectroscopy of arrays and individual nanorods:

- Dielectrophoretic assembly of suspended nanorods onto coplanar waveguide structures
- Measure transmission and reflection scattering parameters from 0.1 to 50 GHz using network analyzer
- Examine both arrays and individual nanorods and look for high frequency resonances

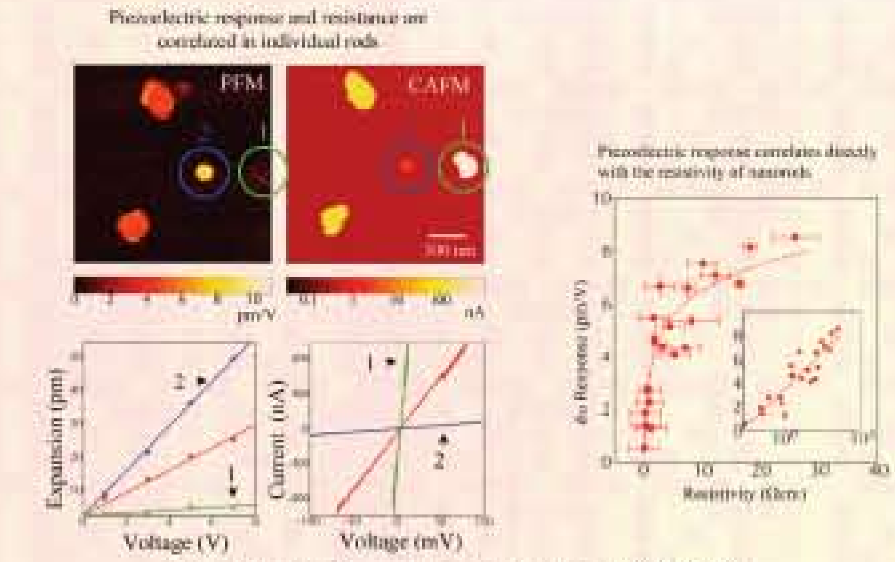


Piezoelectric response and electrical resistivity show much variation within a single population of ZnO nanorods. Piezoelectric response varies widely, very surprising considering that it depends on crystal structure. Likewise, the electrical resistivity varies by over 3 orders of magnitude. This distribution would not be evident using ensemble measurements, indicating that individual measurements of nanorod properties is necessary.





- Wide variation in resistivity due to unintentional impurity of defect incorporation during synthesis
- Direct correlation between electrical and piezoelectric properties in individual ZnO nanostructures
- Lower-resistivity rods have higher free carrier concentration that reduces piezoelectric response
- Distribution of resistivities explains range of piezoelectric response



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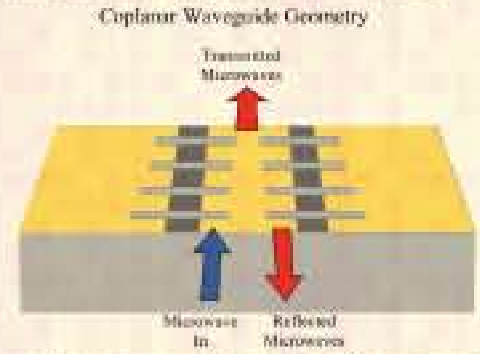
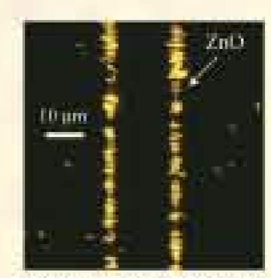
High-frequency Impedance Spectroscopy

Collaboration with Clark Highstrete and Mark Lee

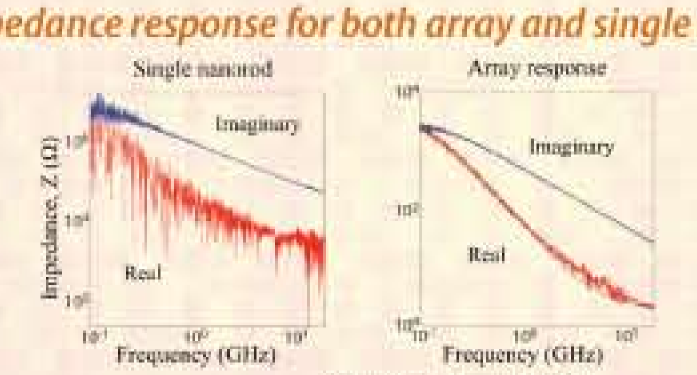




Dielectrophoretic assembly of ZnO nanowires on waveguide structure

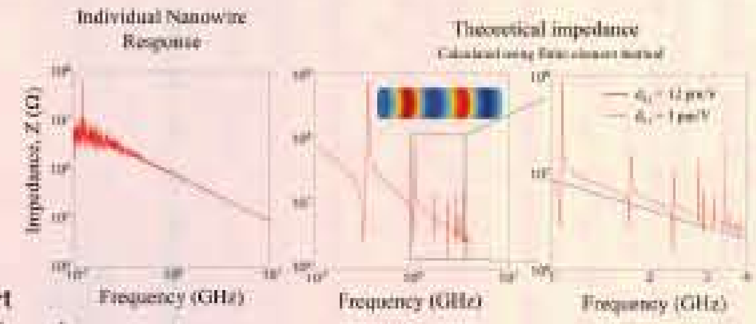
- Probe impedance properties at high frequency (0.1-50 GHz)
- Characterize high-frequency electrical properties
- Look for high-frequency piezoelectric resonances of nanorods

Extract impedance response for both array and single nanowires



Both arrays and single nanorod modeled as 3 element circuit with typical values

No resonances observed in either nanorod arrays or individual nanorods



- Lack of resonance at high frequency due to low resistivity/low piezoelectric rods
- Low-piezoelectric-coefficient rods cannot effectively convert electrical signal to mechanical motion
- Higher-resistivity rods required to observe resonances

Significance

Individual Properties of ZnO nanorods

- Large variation of resistivity (0.1 - 155 Ωcm)
- Surprising wide variation of piezoelectric coefficient (0.7 - 8.8 pm/V)
- Piezoelectric response and electrical resistivity is coupled in ZnO nanorods
- Low-resistivity rods have low piezoelectric response
- Lack of control of synthesis leads to uncontrollable properties

High-frequency impedance properties of ZnO nanorods

- Sucessfully measured impedance properties of arrays and single ZnO nanorods
- Modeled as 3-element circuit model with low nanorod resistivity
- High-frequency resonances not observed
- Better control of properties needed to observe high-frequency resonances

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