Abstract:

Materials exhibit unique electrical and mechanical properties at the nanoscale such as quantized conductance and high elastic modulus, which make them ideal for next-generation sensors, actuators and nano-electronics. To study these properties, we have developed MEMS-based nano-Newton force and nanometer displacement resolution sensors. The design philosophy exploits the amplification of displacement and attenuation of structural stiffness in the post-buckling deformation of slender columns. The research experience aims to: (a) explore reliable methods for placing a nanowire or nanotube on the device or co-fabrication, and (b) study the electromechanical coupling in ZnO nanowires. The devices have been patterned on silicon-on-insulator (SOI) wafers using UV photolithography and DRIE. The movable silicon beams were made freestanding using vapor-phase HF etching. Dispersion for ZnO nanowires has been characterized and a focused ion beam (FIB) with a tungsten probe (capable of nanometer level positioning) was used to place the nanowires on the device. An upper bound of 5 GPa for the Young’s modulus of ZnO nanowires has been observed. Stress-strain curves for these nanowires have been computed. The experimental setup has also been extended to include electromechanical characterization, and experiments are being conducted to determine strain-conductance relations.

Introduction:

Nanotubes and nanowires are expected to have superior thermal, electrical, and mechanical properties that promise breakthroughs in the development of super-strong composite materials and ultra-high resolution sensors. There has been extensive research on the mechanical, electrical and thermal properties but very little effort is evident on determining these properties under coupled (and not individual) domains. This is mainly due to the high measurement resolution requirements and challenges in experimentation at the nanoscale. Existing technologies for obtaining nanostructure stress-strain and strain-conductance data, such as nanoindentation and mechanically-controllable break junction (MCBJ) do not provide for in situ experimentation and do not work for nanowires and nanotubes with large variations in structure and chemistry.

We therefore have designed and fabricated a MEMS-based tensilometer based on post-buckling deformation of thin silicon cantilevers, for studying the mechanical and electro-mechanical coupling of nanowires and nanostructures.

Figure 1: SEM image of the buckling beam device.

Figure 2. Buckling beam with labeled axial load (P), axial displacement (δ), lateral displacement (D), and initial imperfection (ε).
axial force \( P \) in Figure 2) can also be computed as a function of lateral displacement. The post-buckling deformation mechanics results in reduction of stiffness with increasing lateral displacement and hence the force resolution increases.

The device design consists of two pairs of beams (as shown in Figure 3). One end of the specimen is fixed and the other end is attached to the movable middle rib, as shown in Figure 3. On loading the device, the middle rib moves to the right and applies very small forces and displacements on the specimen. The tensiometer can achieve much higher resolution than a single set of buckling beams by exploiting the small difference in axial displacement and load for each set of beams \( (\delta_1 - \delta_2 \text{ and } P_2 - P_1) \). The average lateral displacements, \( D_1 \) and \( D_2 \) are on the order of microns, and can be measured using a high-power optical microscope.

**Results and Progress-to-Date:**

The characterization of dispersion of ZnO nanowires made it possible to successfully prepare samples. Preliminary results for the Young’s modulus for ZnO nanowires were estimated to 5 MPa using the aforementioned method. Electrical measurements were not possible due to the lack of a reliable conductive path between the device and the specimen, possibly due to the low conductivity of FIB deposited Pt. Chemical vapor deposited growth of nanotubes directly onto the jaws of the device is also being explored for nanotube measurements.

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**References:**


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**Fabrication and Preparation:**

The devices were fabricated on a silicon-on-insulator wafer with a 20 µm Si layer on a 1 µm oxide layer. The device was patterned using Shipley 3012 resist, and the Si layer was etched using deep reactive ion etching with \( SF_6 \). The oxide layer was then etched with a 3 µm undercut using a vapor-phased HF tool. The photoresist was then stripped and the devices were sputtered with 100 nm of gold for improved conductivity and imaging.

Nanowires were dispersed on a thin but stiff oxide grid with a 75 nm gold layer for conductivity. The focused ion beam (FIB) was used to deposit an adhesive Pt compound on the ends of the nanowire. A grid with a freestanding nanowire was then cut using the FIB, and picked up using the OmniProbe® nanomanipulator. The FIB was then used to etch posts onto the jaws of the device, and the nanomanipulator was used to place the grid onto the posts (see Figure 3). The ends of the grid were cut so that the sample was the only conductive path between the two jaws.