One Dimensional Materials Testing

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Nanowires are one-dimensional solids with potential applications in future nanoscale sensors and actuators. Due to their unique length scale, they exhibit superior mechanical properties and other length-scale dependent phenomena. To fully utilize the basic and technological advantages offered by the small length scale, it is essential to investigate their unique characteristics, like mechanical and electromechanical properties, of individual nanowires.

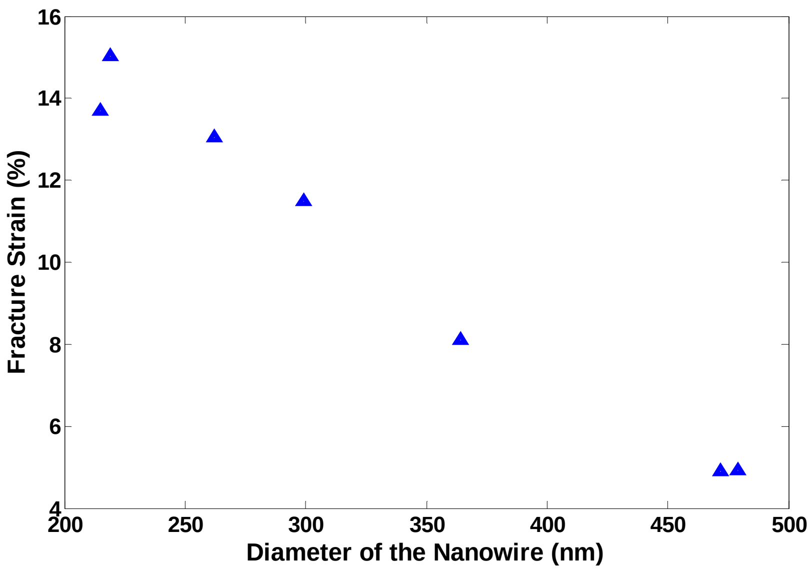
Zinc oxide is a unique materials for nanoelectronics, piezoelectric devices, opto-electronics, chemical sensors and AFM tips because it is a wide bandgap semiconductor with large piezoelectric coefficients and is also biocompatible. Very few experiments have been performed on ZnO nanowires due to the challenges with nano-scale experimentation like specimen preparation and manipulation, high resolution force and displacement sensing and ability to perform in-situ experimentation. It has been reported in literature that the bending modulus of ZnO nanobelt is 52 GPa, the elastic modulus of ZnO nanowires is 29 ± 8 GPa and that the piezoelectric coefficient of ZnO nanobelt is between 14.3 and 26.7 pm/V. In this paper we present experimental results on the elastic modulus and fracture strain of zinc oxide nanowires.

In this paper we report a MEMS test-bed for mechanical characterization of nanowires. We present a micro scale version of the pick-and-place technique for manipulating individual nanowires and preparing free-standing nanowire specimens. We performed experiments on zinc oxide nanowires to determine the fracture strain and Young’s modulus. We observed size effect (diameter dependence) on the fracture strains for zinc oxide nanowires (varied from 5 to 15 %) and also that the fracture strain is very high, considering zinc oxide is a ceramic material at the bulk scale. The high fracture strain property of zinc oxide nanowires might make them a very viable and potential material for nanoscale sensors and actuators. We estimated the Young’s modulus of the zinc oxide nanowires to be about 21 GPa which is significantly less than modulus at the bulk scale. We are designing experiments for in-situ mechanical characterization inside a TEM and also for studying electro-mechanical coupling in zinc oxide nanowires.

Our MEMS-based experimental setup exploits the mechanics of post-buckling deformation of slender beams to address the challenges in nanoscale specimen preparation and force and displacment resolution. Amplification of displacement and attenuation of structural stiffness (spring constant) of micro-scale columns in the direction of axial loading is used to obtain high force and displacement resolution, without transduction of any signal. The details of the design, working and fabrication of the device will be presented. The devices were fabricated on silicon-on-insulator wafers using photolithography, deep reactive ion etching and hydro-fluoric acid vapor oxide etching. The specimen is placed on the device using a microscale pick and place technique using a Focused Ion Beam equipment with Omniprobe manupulator. We present the calibration of the device prior to its use and the error estimates.

When the device is loaded, the middle section of the device moves to the right and subsequently applies uniaxial tensile load on the specimen. The force and displacement on the specimen can be calculated using the lateral displacement of the buckling beams (slender columns).

Experimental results show completely elastic deformation of the nanowires accompanied by brittle fracture. The Young's modulus and fracture strain are found to be diameter dependent. The average Young's modulus for nanometers with diameter 250-300 nm is about 20 Gpa. Fracture strain increases from 5% to 15% as diameter decreases from 450 nm to 200 nm. It is interesting to note that zinc oxide, which is a ceramic material (fracture strain less than 1 %) on the bulk scale, exhibits high fracture strains as one-dimensional nanowires. This fact corroborates with a molecular dynamic simulation study on zinc oxide nanobelts, where fracture strain was observed to be as high as 8 %. These results cannot be compared with existing findings due to absence of relevant experimental data on zinc oxide nanowires and only theoretical estimates are available.



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