IN-SITU MECHANICAL TESTING OF NANOWIRES AND NANODOTS

J. Michler, L. Philippe, D. Zhang, Z. Wang, W. Mook, V. Friedli, I. Utke,
EMPA, Materials Science and Technology, Thun, Switzerland
zhao.wang@empa.ch

Nanowires are among the most exciting one-dimensional nanomaterials because of their potential use as building blocks for future nanoelectronic devices or as nanoelectromechanical systems in artificial human nose and ear implants. These applications require an in depth understanding of mechanical integrity issues like the dependence of electronic and optical properties under mechanical strain or a precise knowledge of mechanical material properties for device design, respectively. The integration of nanomechanical testing equipment inside a scanning electron microscope allows for the handling of nanowires and to observe failure mechanisms under load.

We developed recently several instruments for nanomechanical testing of nanowires in the SEM: an atomic force microscope (AFM) in SEM for resonance testing and nanobending experiments, a MEMS-based nanotensile testing device, a nanoindentation device for nanocompression and nanoindentation experiments, and a femptogramm mass sensor to measure density. These instruments were used to measure mechanical properties of metal and semiconductor nanowires.

The fracture strength of epitaxial silicon nanowires grown on a [111] silicon substrate by the vapor-liquid-solid process was measured by AFM. The average strength calculated from the maximum nanowire deflection before fracture was around 12 GPa, which is 6% of the Young's modulus of silicon along the nanowire direction. This value is close to the theoretical fracture strength, which indicates that surface or volume defects, if present, play only a minor role in fracture initiation. Similarly, the fracture strength of ZnO nanowires vertically grown on sapphire substrates was measured in tensile and bending experiments. The fracture strain of 7.7 % measured in the bending test was found to be close to the theoretical limit of 10% and revealed a strength about twice as high as in the tensile test. From the tensile experiments, the Young's modulus could be measured to be within 30% of that of bulk ZnO, contrary to the lower values found in the literature.

Electrodeposited nanocrystalline cobalt nanowires were loaded in tension and revealed surprisingly low Young’s modulus values of 64 GPa. An independent measure of the Young’s modulus by nanoindentation along the wire axis revealed similar values. Coupling these values with a resonance excitation technique revealed the low nanowire modulus was due to a low mass density.

Nanocompression tests on single crystal gold nanodots will also be presented. These structures yielded in a stochastic manner which was followed by repeatable plastic flow which, very similar to nanoindentation results of flat single crystals. However yielding of these freestanding structures was accompanied by large displacement bursts between 5-50% engineering strain which were analysed by in-situ SEM observations.