Mechanical Metrology for Small-Scale Structures

Myriad industrial and biological systems are composed of small-scale structures for which the mechanical behavior is not accurately known. Optimizing the performance and reliability of these systems requires either mechanical property measurements on specimens of these structures harvested from the appropriate phases or interfaces of the system, or the ability to test these structures in situ. We are developing standardized testing configurations and methodologies for localized measurements of strength and fracture toughness of materials and interfaces at the micro- to nanometer-length scale.

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This project aims to: (1) measure mechanical properties of microstructures for myriad industrial and biological systems that cannot be fabricated in bulk samples; (2) study small-scale phenomena that may be controlled by surface effects, *e.g.*, the influence of surface stresses on crack nucleation and extension; and (3) obtain quantitative mechanical property data of materials and interfaces for designing small-scale structures and components and for assessing their mechanical reliability. To address these goals, well-characterized testing configurations must be developed for small-scale measurements of strength and crack extension. We are pursuing four tasks: (1) configuration design and finite element analysis; (2) specimen fabrication; (3) mechanical testing and fracture analysis (fractography); and (4) length and force metrology. Work in the Ceramics Division this year has focused on the first and third areas. Two collaborations were established in the fabrication task: one with James A. Beall of the Quantum Electrical Metrology Division (817) in NIST Boulder, and one with Northwestern University. Work in the fourth task will come in subsequent years, most likely in collaboration with the Manufacturing Engineering Laboratory. Significant progress has been made in the design of a compressively loaded test configuration with a well-defined, tensile gage section. Such a specimen can be loaded using a depth-sensing nanoindenter as a universal testing machine, thereby giving a record of both applied load and load-point displacement. One of these specimens, fabricated by James Beall from a silicon wafer by deep reactive ion etching, is shown in the right-side of Figure 1. The configuration is similar to a theta specimen, except that the geometry is hexagonal. When a load (per unit thickness) is applied to the top beam, a uniform uniaxial tensile stress results in the middle gage section. Finite element analysis gives (horizontal) gage section stresses on the order of 1.25 GPa for 50 mN/µm of applied load. For a 2 N applied load, these 100 mm-thick specimens generate 500 MPa of tensile stress in the gage section. The left-side of Figure 1 shows a reconstructed failed specimen. The insert shows the fracture surface of the gage section, and the two [111] cleavage facets that were formed. Alternate geometries, including a round theta specimen, are also being considered.

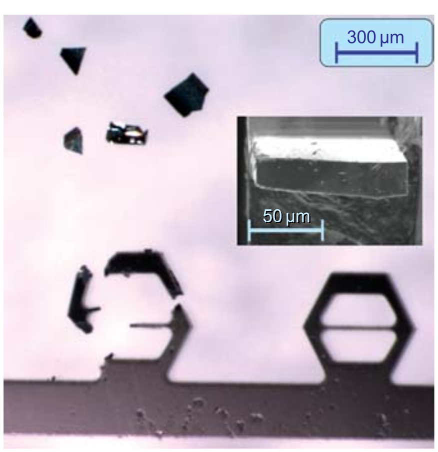

***Figure 1:** Prototype specimen design.*

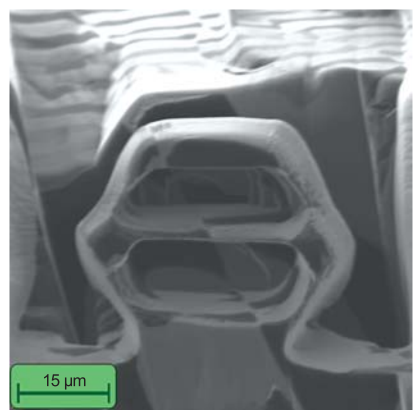

***Figure 2:** Hexagonal theta specimen by FIBing.*

To extend this technique to a wide variety of materials and systems, general fabrication procedures need to be developed. Towards this objective, focused-ion-beam (FIB) milling is being explored in collaboration with Northwestern University. Figure 2 shows our first attempt at producing a hexagonal theta specimen by FIBing. It has been scaled-down by about a factor of 10, and is fabricated from a lamellar directionally solidified eutectic of $Ni_{0.5}Co_{0.5}O$ and ZrO_2.

Contributors and Collaborators

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