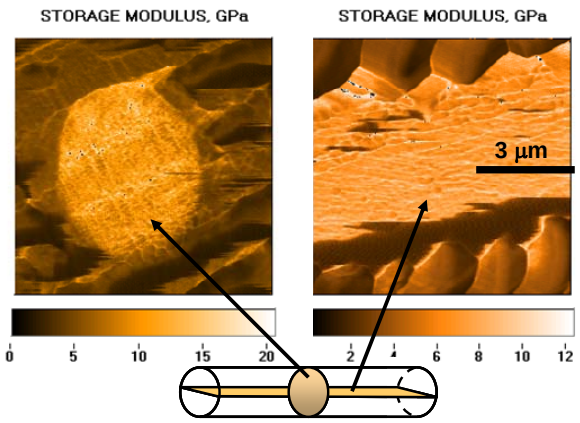
Scientific Accomplishments: Fundamental Nanoscale Phenomena and Processes (PCA 1)

Imaging the Mechanical Properties of Spider Silk Fibers

Spider silk is one of nature's amazing materials – a strong, stretchable fiber drawn through a natural spinning process that humans have yet to match. The fibers that support a spider's weight as it hangs in midair and form the framework for orb webs, known as dragline silk, have evolved remarkable properties. These fibers have a hierarchical structure – being composed of small fibrils imparting strength to the fiber as a whole. The spinning and drawing process, like for human-processed fibers, is known to result in materials with orientation-dependent, or anisotropic, mechanical properties. The small diameter of spider dragline silk (about 1/10 the thickness of a human hair) makes measuring the orientation dependent mechanical properties challenging.

Researchers at the Naval Research Laboratory have developed an instrument that can image the mechanical properties of nanostructured materials and fibers. Measurements are made by combining the imaging capability of scanning probe microscopy (SPM) and the nanomechanical measurement capabilities of instrumented indentation. While the imaging tip is scanned along the surface, a small repetitive deflection is applied to the tip and the relative stiffness of the tip-sample contact is measured at each point. The result is an image of the variation in mechanical properties within the test material, as well as topographic information about the surface texture.



The two figures to the left show cross-sectional images of spider dragline silk after embedding in a polymer and slicing to reveal morphology across (left) and along (right) the fiber. The color gradient in the images (from dark to light) corresponds directly to mechanical properties of the fiber and surrounding polymer. The fiber was found to be 25-35% stiffer across rather than along the fiber. This results from orientation of protein structures during the silk spinning process.

NRL's imaging technique revealed an oriented, fibrillar microstructure within the spider silk fibers, aligned with the drawing axis of the fiber. The images demonstrated anisotropy in both structure and mechanical properties of the silk fibers. In the past, such mechanical properties information would have required hundreds of individual measurements. This new technique allows scientists to develop an image of the mechanical properties of nanostructured materials like fibers, as well as other biomaterials like bone, teeth, and shells.

D.M. Ebenstein and K.J. Wahl, "Anisotropic Nanomechanical Properties of *Nephila clavipes* Dragline Silk," *J. Mater. Res.* **21**, 2035-2044 (2006).

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