A variety of emergent phenomena in mechanical behavior, heat conduction, and electronic charge transport arise in materials when length scales associated with the physical dimensions or intrinsic structure approach the nanoscale. For instance, defect ensemble interactions and poor mechanical strength give way to discrete plasticity and ultra-high strength in elemental nanostructures; facile thermal transport gives way to abundant phonon scattering in nanomaterials; and electronic band structure becomes altered in quantum-confined systems. Rational exploration of the interconnections between these various fields to exploit unprecedented property enhancements and tunable transport behavior relevant to next-generation computing, sensing, and efficient energy conversion hinge on elucidation of nanoscale deformation mechanisms.

This talk will present experiments on metallic nanostructures, which have the capability of withstanding specimen-wide mechanical stresses that approach the theoretical limit. In the case of single crystals, nanoscale synthesis creates small volumes of materials with minimal to nominally zero defects that allow for these mechanically extreme environments. Nanocrystalline materials exhibit an impressive suite of properties owing to confinement by planar defects such as grain boundaries. However, the large fraction of interfacial material in nanostructured materials is responsible for both high strength as well as a propensity for instabilities.

Recent progress in the area of in situ electron microscopy has allowed for quantitative interrogations of the deformation of nanoscale materials and has been an enabling technology. Selected experiments on submicron metallic nanostructures in both amorphous and crystalline states will be presented to illustrate how these approaches can correlate underlying physical phenomena with measured properties. Our findings suggest that while high strengths are achieved in such various nanostructured metals, the ensuing plastic deformation is often not deterministic, and hinges on the initial structure and defect density of the material. Somewhat paradoxically, we find that nanostructures with disordered atomic structures display near-deterministic strengths, whereas those with near-perfect order and a scarcity of defects exhibit a pronounced probabilistic onset of yielding.