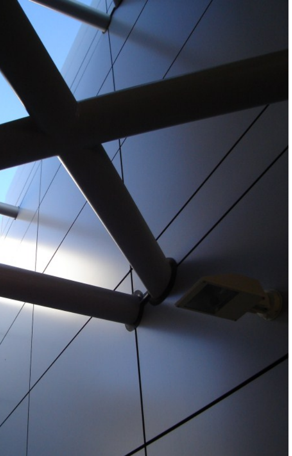

Colloquium
Mechanical Engineering

The Department of Mechanical Engineering presents:

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Friday, May 20, 2011 - 11:10AM-12:00PM - Bourns Hall A265

SIZE MATTERS: Mechanical Properties of Nano-sized Solids

Abstract: A key focus in J.R.Greer's research is the development of innovative experimental approaches to assess mechanical properties, microstructure evolution, and deformation mechanisms in materials whose dimensions have been reduced to nano-scale not only vertically but also laterally. One such approach involves the fabrication of surface dominated metallic specimens (i.e. nano-pillars) with different homogeneous initial microstructures: single crystalline and amorphous; or containing boundaries: nano-twinned, nano-crystalline, and amorphous/crystalline. These samples range in diameter from below 100 nm to 1 micron and are created by using both the Focused Ion Beam (FIB)- based and other novel micro-fabrication approaches. In addition, we study the deformation of carbon nanotube (CNT) foam 50 micron-diameter cylinders, while individual CNT diameters are ~ 20-50nm. Their mechanical response under uniaxial tension and compression is subsequently measured in a one-of-a-kind *in-situ* mechanical deformation instrument, SEMentor, comprised of SEM and Nanoindenter, which allow for precise control of displacement and loading rates, as well as for simultaneous video capture. Post-deformation microstructure is analyzed by high-resolution, sitespecific TEM. In this talk we will discuss the differences in mechanical behavior observed in these nano-sized metallic systems: single crystals, nano-crystalline metals, and amorphous metallic alloys (metallic glasses), as well as in CNT foams. In a striking deviation from classical mechanics, we observe a SMALLER is STRONGER phenomenon in all single crystals manifested by a significant (~50x) increase in strength as material size is reduced to below 100nm. This size-dependent strengthening, as well as tension-compression asymmetry, is different for face-centered (fcc) and body-centered (bcc) metals. Further, unlike in bulk where plasticity commences in a smooth fashion, all of these metals exhibit a discrete strtess-strain response of highly stochastic nature due to dislocation avalanches. To the contrary, nano-crystalline materials tend to exhibit the opposite trend: SMALLER is WEAKER. We attribute this phenomenon to a transition in deformation mechanism: from Hall-Petch like to grain boundary-assisted. Metallic glasses, whose Achilles' heel has always been the occurrence of catastrophic failure at very small tensile strains, appear to exhibit non-trivial ductility (~20% tensile strain) and a slight increase in strength when reduced to nano-scale. These remarkable differences in the mechanical response of nano-scale metallic systems subjected to uniaxial deformation challenge the applicability of conventional plasticity models at the nano-scale. We postulate that they arise from the effects of free surfaces, leading to the significant differences in dislocation behavior for the case of crystals, grain-boundary activity for the case of nano-crystalline solids, and shear transformation zones in metallic glasses, and serve as the fundamental reason for the observed differences in their plastic deformation. We also show that complex hierarchical materials like 50 micron-diameter cylindrical CNT form bundles deform via a series of localized folding events originating near the bundle base, upon which they sequentially propagate laterally and collapse from bottom to top. This unusual deformation mechanism accompanies a foam-like stress-strain relation having elastic, plateau, and densification regimes with the added feature of undulations in the stress throughout the plateau regime that correspond to the sequential folding events. These mechanisms and their effect on the evolved microstructure and the overall mechanical properties will be discussed.

Biography: A key focus in Professor J.R.Greer's research is the development of innovative experimental approaches to assess mechanical properties and deformation mechanisms in nano structures. Greer received her S.B. degree in Chemical Engineering with a minor in Advanced Music Performance from Massachusetts Institute of Technology (1997) and Ph.D. degree in Materials Science and Engineering from Stanford University, working on nano-scale plasticity of gold (2005). She has also worked at Intel Corporation in a mask micro-fabrication facility (2000-03) and was a post-doctoral fellow at the Palo Alto Research Center, PARC (2005-07), where she studied organic flexible electronics. Greer is a recipient of the WTN's World Technology Award in Materials (2010), TMS's Young Leaders award in structural materials division (2010), NASA's Tech Briefs award (2010), DARPA's Young Faculty Award (2009), one of 100 invited participants in the National Academy of Engineering's Frontiers of Engineering Symposium (2009), Technology Review's Top Young Innovator Under 35 award (TR-35, 2008), the NSF's CAREER Award (2007), and the Gold Materials Research Society's Graduate Student Award (2004) and was recently featured as a "Rising Star" in Advanced Functional Materials (2009). Julia joined the Materials Science and Mechanical Engineering departments of California Institute of Technology (Caltech) in 2007. She is also a concert pianist, with most recent performances of a solo piano recital at Caltech (2011), a violin-piano recital in the Lagerstrom Chamber Series (2009), and as a soloist of the Brahms Concerto No. 2 with the Redwood Symphony (2006).