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Size Matters: size-dependent strength and nucleation-governed deformation mechanisms in nano-scale Cu pillars

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Uniaxial compression and tension tests on single crystalline micro and nanopillars have revealed a strong size effect. For face-centered cubic metals, this size effect is characterized by a power-law: where n is between .5 - .7. The majority of these micro-mechanical tests have been performed on pillars produced by the focused-ion-beam (FIB), a process known to introduce surface damage into the material and to limit the smallest attained pillar diameter to $\sim$150nm while maintaining its shape integrity. In order to overcome these detriments, we developed a new technique combining electroplating and electron beam lithography to create single crystalline Cu nano-pillars with diameters down to 50 nm. We find the mechanical response of these samples to exhibit the same power-law strengthening behavior as other fcc metals down to the diameter of 100nm, as revealed by *in-situ* uniaxial compression and tension tests conducted in a custom-built in-situ mechanical deformation instrument, SEMentor. TEM investigations of the microstructure of pillars produced by the FIB and by electroplating show similar initial dislocation densities of $\sim 10^{14}$ m^{-2} implying that size-dependent strength at the nano-scale is a strong function of initial microstructure and not of fabrication method. We examine the limits of this power-law trend down to diameters of 50nm, as at these small sizes, deformation behavior has been theoretically predicted to change due to the activation of surface dislocation sources and the increasing influence of the surface stress. Furthermore, we find that these single crystalline Cu nano-pillars show a remarkable strain-rate dependence that increases with decreasing diameter further revealing the thermally activated nature of dislocation sources and corresponding changes in activation volume. HRTEM investigations of post-mortem structures will be presented in the context of dislocation-based phenomenological modeling.