In-situ TEM investigation of toughening in Silicon at small scales

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We present quantitative in-situ Transmission Electron Microscopy (TEM) fracture experiments on single crystal Silicon at room temperature. Findings consist of a brittle bulk fracture behavior of large samples at a stress intensity K_{IC}~1 MPa.m$_{1/2}$. However, below characteristic dimensions of about 250 nm, the fracture toughness strikingly increases inversely with size to at least triple.

Advanced in-situ TEM nanoscale strain mapping reveal the stresses at the crack tip approach the theoretical strength in small specimens. Strain mapping represents the tensile strain in the notch area in the opening direction of the crack, which reaches ~ 8% at a distance of ~5 nm from the notch tip in a specimen with thickness 136 nm thickness. For validation, FEM elastic tensile strain map of a computational digital twin with identical dimensions loaded to the same point is calculated and show excellent agreement and validating the plane strain condition and respective data analysis. Moreover, taking the average instantaneous force F_i applied during strain mapping, the von Mises stress tensor, is calculated. Latter show that the Peierls stresses estimated as [4.6–5.77] GPa for Si are easily overpassed in the tip singularity region of small specimens. Thus, after dislocations nucleated, they can also propagate. TEM observations show that below this critical transition length, nucleation and propagation of dislocations occur, shielding the crack tip and enabling the unprecedented rise in fracture toughness.