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Transition of Deformation Mechanism in Single Crystalline Metallic Nanowires

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Metallic nanowires (NWs) usually exhibit ultrahigh mechanical strength and are ideal candidates for studying fundamental deformation mechanisms at the nanoscale [1-5]. Different from bulk materials, surface dislocation nucleation has been identified as a dominant deformation mechanism in NWs. Extensive research has been performed on defect-free, single-crystalline metallic NWs where surface-nucleated dislocations tend to slip across the NW, as a result of two competitive deformation mechanisms, twinning and localized dislocation slip. The former leads to large plasticity, while the latter results in limited plasticity. Thus, it is of interest to study how the two deformation mechanisms compete with each other in face-centered cubic (FCC) metallic NWs and what the underlying factors are.

Here, using in situ transmission electron microscopy tensile tests, we report an additional factor, cross-sectional shape, that can affect the competition between the deformation mechanisms in single-crystalline FCC metallic NWs. In situ TEM tensile testing of NWs was performed on a microelectromechanical system (MEMS)-based tensile testing stage [5, 6]. The load and displacement can be accurately measured using this MEMS device, along with concurrent, real-time imaging of microstructure evolution during deformation (no beam damage issue [7]). Figure 1 showed stress–strain curves and snapshots of microstructure changes for tensile tests of two single-crystalline Ag NWs. Insets in Figures 1a,b are the corresponding cross-sectional TEM images of the tested NWs, taken from the undeformed part (beyond the clamps). For a truncated rhombic cross-section, the extent of truncation determines the competition. Specifically, a transition from twinning to localized dislocation slip occurs with increasing extent of truncation. Theoretical and simulation results indicate that the energy barriers for twinning and dislocation slip depend on the cross-sectional shape of the NW. The energy barrier for twinning is proportional to the change of surface energy associated with the twinning. Thus, the transition of deformation modes can be attributed to the change of surface energy as a function of the cross-sectional shape [8].

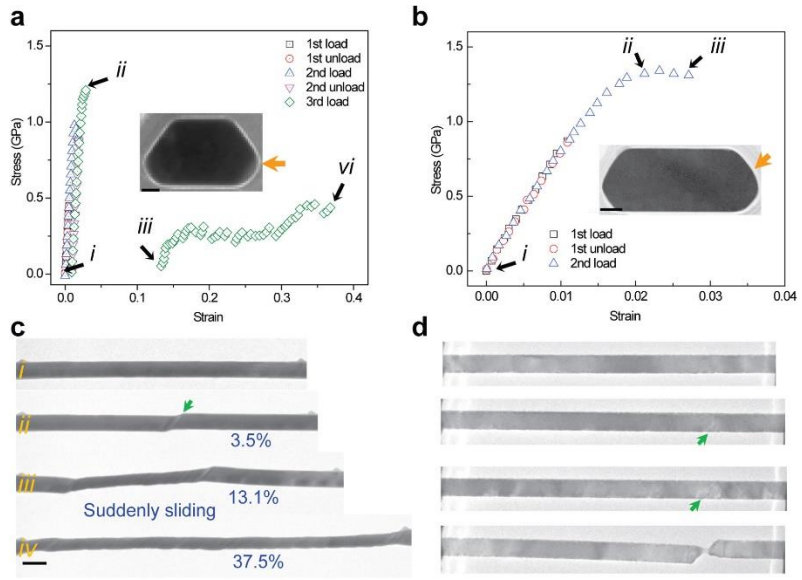

Figure 1. Mechanical behaviors and microstructure evolutions of single-crystalline Ag NWs under in situ TEM tensile tests. (a, b) Engineering stress–strain curves of two single-crystalline Ag NWs with different aspect ratios. Insets in (a) and (b) are the corresponding cross-sectional images of the tested NWs (sectioned from the undeformed part after the test). Scale bar: 20 nm. (c, d) Snapshots of microstructure evolutions corresponding to (a) and (b). The four snapshots in each case correspond to the stresses and strains marked in (a) and (b). Planar sliding is labeled by green arrows. Scale bars: 100 nm. The viewing directions in (a) and (b), marked by the yellow arrows in the insets, are from the $\langle 1\bar{1}0 \rangle$ and $\langle 111 \rangle$ zone axes, respectively.

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