In-situ TEM Study of Dislocation Plasticity of a Single Crystal FeCoCrMnNi HEA

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Dislocation-based deformation mechanisms of high entropy alloys (HEAs) remain elusive and require a fundamental understanding in order to tailor their mechanical properties. Since HEAs have five or more constituent elements close to the equiatomic ratio with a stable single phase [1,2], their plastic deformation is expected to be different compared to conventional alloys. Several key effects are suggested which may influence microstructure evolution and mechanical properties of HEAs such as sluggish diffusion, severe lattice distortion, and cocktail effects [3]. Also, the reported high lattice friction stress of 125 MPa for the FCC FeCrCoMnNi alloy [4] suggests that atomic scale hardening mechanism contribute the mechanical properties, for example, short-range ordering or solid solution hardening. To reveal the hardening mechanism, direct observation of dislocation plasticity and deformation dynamics is required.

Here, we present a study correlating the microstructure and dislocation plasticity of a single crystalline FeCrCoMnNi FCC single phase HEA by employing in-situ transmission electron microscope (TEM) compression and tensile deformation. Moreover, an atomic-scale chemical analysis is conducted by aberration-corrected scanning TEM energy dispersive X-ray spectroscopy (STEM-EDS) and atom probe tomography to investigate chemical inhomogeneity, for example, precipitate formation or local inhomogeneity. The aims of the study are 1) understanding of dislocation plasticity in a FCC HEA, 2) investigation of nanometer-scale elemental distribution and 3) measurement of mechanical properties of FCC HEA submicron pillars.

Compression tests with sub-micron pillars with 250 and 120 nm diameter show the size effects on yield stress with a size exponent of 0.42, which is small compared to typical FCC metals. It suggests that relatively strong inherent hardening processes are present which attenuate the FCC reported size scaling exponent, which is typically 0.6 for pure FCC metals. Dislocation dynamics investigated by in-situ TEM straining suggested the planar slip is the dominating deformation mechanism, probably due to restricted cross-slip by low stacking fault energy which was measured by high resolution TEM to ca. 20 mJ/m^2. Fig. 1 show the dislocation structure after deformation with high density of dislocation array and pile up supporting the planar slip. Moreover, dissociated dislocations with stacking faults and extended partial dislocations also contribute to the dislocation plasticity, especially at small strain. However, atomic scale chemical analysis by both STEM-EDS and atom probe tomography show a homogeneous distribution of constituent elements (Fig. 2). Therefore, the mechanical properties of HEA are expected to originate from solid solution hardening or short-range ordering which can hinder dislocation glide increasing internal lattice friction stress. The presence of planar glide indicates that short-range ordering may be the main reason.

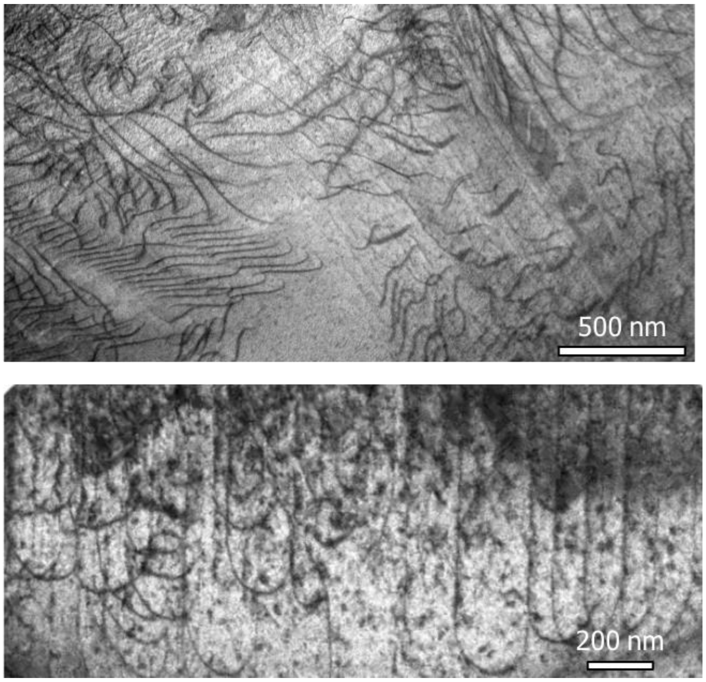

Figure 1 Dislocation structure after in-situ TEM tensile test

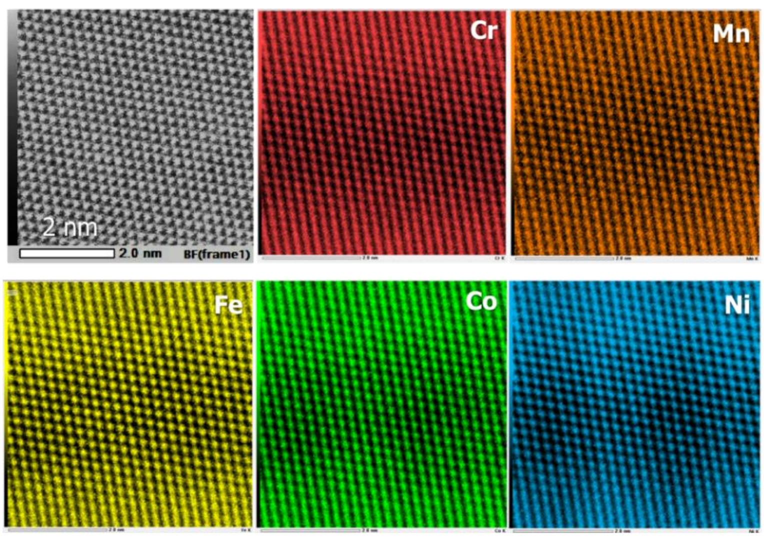

Figure 2 Atomic-scale STEM-EDS elemental mapping

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