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Interfaces, inclusions, and impurities in nanolaminate metallic structures

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ABSTRACT

The use of thin metal structures to add strength to metallic systems due to dislocation interactions with interfaces has been well documented in laminate blanket bilayer composites such as Cu–Nb or Cu–Ni thin films. Adding a third layer, such as Cu–Ni–Nb, alters the landscape for dislocation motion and results in added strain hardening which is not possible in bimetallic systems. This study extends the impact of heterogeneities into three different systems of reduced dimension: one of adding impurities and solid solution elements to the systems, and two where the defects of hard second-phase structures are deposited and precipitated within a softer FCC layers. Cu–Ni alloying is used in the Cu–Ni–Nb system to examine solid solution strengthening, whereas Cr in a bilayer of Cr–CuCr is used to examine precipitate effects on strengthening. A third system, ZnO in Au is used to compare the combined effects of solute Zn and precipitated ZnO to separate the effects of the impurities from the interfacially dominated behavior of the multilayer systems. A combination of nanoindentation and microcompression testing are used to demonstrate hardening effects as a function of layer thickness, and the strength enhancement beyond what would be expected using a classical Hall–Petch model is described in terms of the confined layer slip model. Testing has been carried out at room temperature and elevated temperatures (up to 600K) to examine any changes in mechanisms which may occur in these cases. The ability to strain harden in the trilayer structures is well beyond that of the bilayer films both with and without additional impurities that increase strength. The addition of harder precipitates of Cr in the FCC layers, adding an additional obstacle to dislocation motion, is shown both through simulation and experiment to add significant strength to these new structures. The size of the defects also controls the behavior at elevated temperatures and after extended annealing, leading to films which strengthen after annealing. Finally, solute Zn and precipitated ZnO demonstrates how these strengthening methods, used in conventional bulk systems, need to be balanced versus grain size strengthening if composition, rather than only structural features, is to become a parameter to open new design windows in metallic thin films for electronic and MEMS applications.