Measuring Interfacial Shear Strength of Cu₃Ni-Nb Alloys

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Multilayer nanolaminates composed of immiscible alloys provide high-strength, good thermal stability, and a high-density of stable interfacial sinks for point defect recombination under irradiation.[1-3] A number of recent reports have focused on understanding the structure of these interfaces, their efficiency in promoting point defect recombination, and their effect on mechanical properties.[4-6] Interfacial shear strength has been shown to underlie bulk mechanical response[3] and recent efforts have focused on predicting and characterizing their properties both in the pristine state[4] and after exposure to irradiation.[6] It is anticipated that interfacial shear strength should relate to both the density of constitutional interfacial dislocations[1] and the heat of mixing of the alloy components (i.e. the bond strength at the interface). While simulations can simply vary these parameters in isolation[7] performing analogous experiments is challenging given restrictions imposed by the periodic table.

In this work, we attempt to quantify the interfacial shear strengths of Cu-Nb, Ni-Nb, and Cu₃Ni-Nb, where Cu₃Ni indicates solid-solution alloys of different compositions (x=1 or 3). Cu-Nb is relatively immiscible with a large heat of mixing while Ni-Nb has a negative heat of mixing. Cu and Ni mix almost ideally and have very similar atomic radii. By interfacing Nb with solid-solution Cu-Ni alloys, it is possible to tailor the average bond strength at the interface and characterize how the shear strength varies with this parameter with little change in the average atomic misfit. Cu-Nb and Ni-Nb both grow with strong preference for the Kurdjumov-Sachs misorientation relationship. This allows the effect of chemistry to be probed for interfaces of the same crystallographic character.

We prepared 45° pre-tilt pillars on Si wedge-shaped substrates (Hysitron) by focused ion beam (FIB, FEI Company, Helios 600i) milling. This pre-tilt angle maximizes the resolve shear stress on the interface. Prior experiments indicate that the properties of these multilayers are neither pillar diameter nor pre-tilt angle dependent.[6] Multilayers were then grown from elemental targets by magnetron sputtering in 2x10⁻³ torr Ar in a chamber with a base pressure of ≈10⁻⁸ torr. Each layer was grown to be ≈50 nm thick. Nanocompression experiments were performed in-situ in a 200 kV JEOL 2010LaB₆ TEM using a Hysitron PI-95 picoindenter. Performing such experiments in-situ is useful for determining the stress associated with the onset of interfacial shearing and to observe any non-ideal deformation modes.

Figure 1 shows example images of Cu-Nb and Ni-Nb samples before and during compression testing that demonstrate how Cu-Nb interfaces shear, while Ni-Nb interfaces do not. In the Ni-Nb samples, a large dislocation content develops in the lattice. Notably, the Cu-Nb interfaces exhibit interfacial shear strengths of 0.60 ± 0.05 GPa, while Ni-Nb interfaces that do not shear and experience a maximum shear stress of 1.97 ± 0.63 GPa. The negative heat of mixing in Ni-Nb must strongly affect the interfacial shear strength causing it to be more than a factor of three greater than in Cu-Nb. Interfacial shearing also did not occur in the Cu₃Ni-Nb and CuNi-Nb samples, where the maximum shear stress was 0.81 ± 0.09 GPa and 0.51 ± 0.06 GPa, respectively. Again, these values represent lower bounds since interfacial shearing did not occur in any of the 7 alloy samples tested.
References:

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Figure 1. Time-lapse images of Cu-Nb (a) before and (b) after yield and Ni-Nb (c) before and (d) after yield. Note that Cu-Nb multilayers shear along the interface, while Ni-Nb multilayers do not.