Nanoscale metallic multilayers (NMMs) have been the subject of an increasing number of studies due to their exceptional mechanical properties. Their unique properties are a result of the high density of interfaces, which change the conventional mechanisms of plastic deformation when the individual layer thickness is below 100 nm. The strength of NMMs depends on the modulation periodicity and several mechanisms have been proposed to explain their ultra-high strength, such as: (1) coherency strain hardening, (2) structure barrier strengthening, (3) modulus mismatch, and (4) intermixing at the interface.

Three sets of Cu/W multilayers about 1 μm thick were deposited with different modulation periodicity (λ = 5/5 nm, 15/15 nm and 30/30 nm) on single crystal (100) Si wafers by a balanced magnetron sputtering apparatus using 2’’ targets of W (99.99% purity) and Cu (99.99% purity). Cross-sectional samples were cut from 3 mm x 5 mm sandwich, mechanically thinned to 20 μm, dimple polished, and ion-beam milled in Gatan PIPS 691 device. Their observation was carried out at 200 kV using FEI Tecnai G2 F20 XT microscope.

The layering structure was well defined in all cases, but the layers, that were initially flat close to the substrate, quickly became wavy as deposition progressed. The waviness in the layers triggered earlier (after the 2nd layer) for Cu/W 5/5 nm than for Cu/W 30/30 nm (after the 5th layer). The transition from planar to wavy layers seemed to be a consequence of the cumulative layer waviness developed in the multilayers and the shadowing effects inherent to sputtering processes. As a result, the multilayers developed a columnar structure, with a column width between 20 and 100 nm, and a high porosity level at the columnar boundaries. The layer waviness amplitude was large enough to break up the layers for the 5/5 nm multilayer, as shown in Fig. 1, but not for the 30/30 nm multilayer (Fig. 2). The selected area electron diffraction (SAED) patterns (inserts in Figs. 1, 2) indicate that Cu and W layers display a nanocrystalline structure, with no clear preferred growth orientation. The W diffraction rings were practically continuous, while the Cu rings were formed by discrete spots. Therefore, the W nanograins were on average much finer than the Cu ones.

From high magnification phase contrast micrographs it can be seen that that Cu layers in the 5/5 nm multilayer are formed of grains 5 nm thick and about 15 nm wide (Fig. 3) and that Cu/W interfaces are smoother than W/Cu, which are rather rugged. Fig. 4 shows local continuity of atomic planes (coherence) across Cu/W interface in the 30/30 nm multilayer and deformed atomic planes with edge dislocations in the W layer.

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Fig. 1: STEM – HAADF micrograph of the 5/5 nm W/Cu multilayer and corresponding SAED pattern.

Fig. 2: STEM – HAADF micrograph of the 30/30 nm W/Cu multilayer and corresponding SAED pattern.

Fig. 3: Cu/W interfaces in the 5/5 nm multilayer are smoother, the W/Cu more rugged.

Fig. 4: Deformed atomic planes in W close to the Cu-W 30/30 nm interface; the arrows point out edge dislocations.