**Society of Engineering Science 51st Annual Technical Meeting**

**1–3 October 2014**

**Purdue University, West Lafayette, Indiana, USA**

# Enhancing ductility of ultrahigh strength metal-ceramic nanolayered composites

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## ABSTRACT

In recent years, two-phase nanolayered composites (also referred to as nanolaminated or nanoscale multilayers) with individual layer thicknesses varying from 200—300 nm down to 1–2 nm have been the subject of intensive study because of their unusual physical, chemical, and mechanical properties. For instance, with decreasing layer thicknesses (down to nanometer length scales), the mechanical response of these nanocomposites becomes increasingly interface dominated, and they exhibit ultrahigh strengths approaching the theoretical limit for ideal crystals. Moreover, if the constituent phases present large differences in strength, elastic modulus, and ductility, these multilayers give rise to new possibilities for the deformation mechanisms and properties of the composite as a whole. In this study we explore the possibility of synthesizing multilayered composites where one constituent phase has a low ductility, with a final goal of enhancing both the strength and ductility of the system. Using physical vapor deposition (PVD) techniques we synthesized two multilayered systems: a metal–ceramic Cu–TiN nanocomposite (where the ceramic is the brittle phase) and a hitherto unstudied hexagonal close-packed (HCP) – body-centered cubic (BCC) Mg–Nb system (where twinning in Mg leads to its lack of ductility), over a range of layer thicknesses ranging from 5 nm to 200 nm. Testing of such miniaturized systems poses significant challenges. We demonstrate the utility of both nanoindentation and compression testing of micropillars containing these multilayered nanocomposites to evaluate their deformation mechanisms. We utilize a novel lithographic polymer photomasking technique during the PVD synthesis of these multilayers to enable faster fabrication of the micropillars using focused ion beam technique. Micropillars were fabricated for three different orientations, with the interfaces oriented normal, parallel, and oblique (45°) to the compression axis, to explore the anisotropy in the mechanical response of the multilayer system. In the metal–ceramic system compression tests normal and parallel to the interface allow a complete understanding of the co-deformation response of the ceramic with its metallic counterpart, which is critical to the ductility of the system. The tests with the interfaces loaded obliquely provide a unique measure of interfacial shear strength. For the HCP–BCC system, these three orientations allow a detailed exploration of the propensity for twin formations in Mg as a function of their interface orientation. These results are compared for varying layer thicknesses and the results analyzed using the concepts of dislocation motion and interactions within the confined nanoscale layers.