Frontiers in Nanostructured Materials and their Composites (Keynote Lecture ICCE-18)

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Nanoscience and nanotechnology hold a great promise as envisioned by Richard Feynman by his famous statement in 1959 Lecture "there is a plenty of room at the bottom." In 2004, Richard Smalley saw future energy security with nanotechnology and nanomaterials as we can do more with lot less. Present author wondered if there is fundamental advantage in going to nanoscale materials (1). It turns out there is a fundamental advantage because there is critical size below which materials can be defect-free. Thus, we have an opportunity to realize the property and performance of a perfect material with sizes in nanometer range. We have designed nanomaterials of uniform as this structure is critical to develop a fundamental understanding of these materials. Dependence of hardness and strength with grain size represents a critical issue. The question of critical size at which materials become softer is one critical issue which needs to be resolved. To address this fundamental issue and design novel materials with improved properties, materials of uniform grain size are needed for careful measurements and evaluation. In this review paper, we address self-assembly processing techniques to create nanostructured materials of control size and uniformity. More importantly, it is possible to alloy the interfaces and create more stabilized structures against coarsening. This interface engineering can create stable nanostructures to maintain naneness and preserve unique advantages of nanostructured materials. There is a critical size below which nanograins can be defect-free and dislocation mobility can be frozen to enhance yield strength. For these materials interface shear or deformation plays a critical role in maintaining toughness and ductility of these materials. We have created novel nanostructured WC-NiAl composites where grain size of WC is systematically varied from 5-100nm with a couple of monolayers of NIAl binder, instead of normal Co binder. The WC composites with traditional Co binder lose strength with temperature, whereas these nanocomposites are stronger and maintain their strength with temperature. Fig. 1 shows WC-NiAl nanocomposte, where WC is of uniform grain size of 11nm with a couple of monolayers of NiAl. The corresponding selected-area diffraction pattern shows only WC lines. The grain size of WC is remarkably uniform. Fig 2 shows similar results with uniform grain size of WC as 6nm. The hardness as function of inverse root of grain size was measured from these samples of uniform grain size. The results are shown in Fig. 3, which clearly demonstrate that there is a critical size below which there is softening. We have modeled this softening based upon grain boundary shear and found an excellent agreement with experimental results.

In the second part, we discuss metal-ceramic nanocomposites where nanocrystals of metals are embedded into strong but brittle ceramic matrix. In these materials, the size of the nanoparticles can be controlled to improve optical, mechanical and magnetic properties. He optical properties can be manipulated by changing the average size and size distribution, where absorption edge can be suitably shifted to match the needs of various applications. Mechanical properties such as strength and toughness of ceramics can be improved suitably by providing sources of dislocations through the metallic nanoparticles embedded inside the ceramic matrix. Magnetic properties of these nanocomposites can be manipulated by changing the size distribution, where size can be controlled to transition from superparamagnetic to ferromagnetic properties (2).

References:

1. J. Narayan, “Critical size for defects in nanostructured materials,”J. Appl. Phys. 100, 034309 (2006).

2. J. Narayan, “New frontier in thin film epitaxy and nanostructured materials,” Int. J. Nanotechnol. 6, 5/6 (2009) and references therein; Us Patent # 7,105,118 (2005).

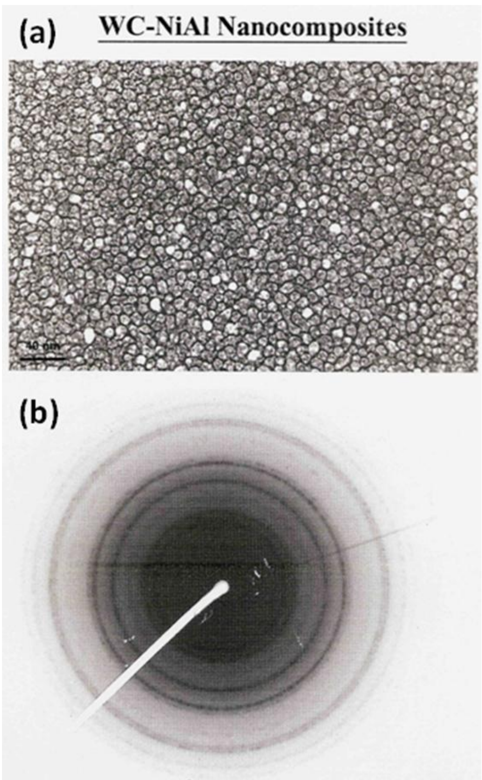

Fig. 1: WC-NiAl nanocomposites: (a) TEM micrograph showing uniform grain size 11nm (b) selected area electron diffraction pattern

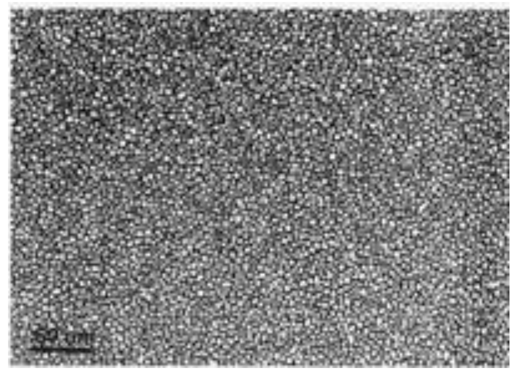

Fig. 2: TEM Micrograph of WC nanocomposites with NiAL at the grain boundaries. Average grain size = 6nm.

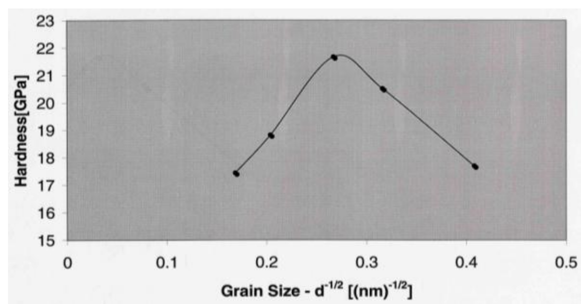

Fig. 3: Hardness vs grain size ($d^{-1/2}$) – Tungsten Carbide Nanocrystals

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