Nanomaterials and Surfaces: Processing, Characterization, and Applications*

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Nanomaterials, with their unique physical and chemical properties, hold promise for technologically important applications in a wide range of sectors including electronics, photonics, telecommunications, biotechnology, medicine, aerospace, and energy. In comparison with their bulk counterparts, nanomaterials are unique due to their quantum confinement and large surface-to-volume ratio. Most nanostructures are primarily surface rearrangements of atoms. In light of this, the characterization of the surfaces and interfaces of nanomaterials is paramount for understanding their properties and functionalities. In recent years, significant developments have taken place in the design of new experimental and theoretical approaches at the atomic to molecular level for understanding of the surface and/or interfacial properties of nanomaterials. These developments have further fueled a quest for exploration of new applications of nanomaterials on surfaces and at interfaces.

The rapid growth and widespread applications of nanomaterials and nanotechnology correlates well with the projected average annual growth of 33% in the U.S. nanomaterials market between 2002 and 2020 (*http://pubs.acs.org/cen/coverstory/8135/8135nanotechnology.html*). However, activities related to nanomaterials research and applications are concentrated in the hands of a few players, primarily start-ups or small companies (40%), followed by research institutes and universities (32%), large companies (10%), subsidiaries and joint ventures (7%), and other interested organizations (11%). Although widespread applications of nanomaterials are envisioned, the start-ups and small companies have focused on materials and production processes (31%), medicine/pharmaceuticals (21%), research (14%), electronics (11%), consumer products (7%), and other (16%). From these data, it is evident that the development of science and technology related to nanotechnology will continue in years ahead. Therefore, this issue of *JOM* presents articles on the topic of nanomaterials and surfaces. The articles deal with a broad spectrum of subjects ranging from processing and characterization to applications of nanomaterials and their associated surface properties. In addition to five articles in this issue, two more will appear in the March 2005 issue.

Research is important, and the quest for funding continues. The first article by Y.W. Chung and K. Chong of the U.S. National Science Foundation (NSF) emphasizes the potential of nanomaterials and surfaces/interfaces and the need for research into nanomechanics and surface engineering, including thermomechanical instabilities, mechanical properties of living cells, and surface engineering of metallic implants. The article also points out NSF-wide initiatives on nanoscale science and engineering, which focus funding on four major areas: science and engineering centers, interdisciplinary research teams, exploratory research, and undergraduate education. Most importantly, some advice for the preparation of winning proposals is provided.

The next paper, by R.J. Narayan et al., presents a review on several classes of nanostructured ceramics with unique biological functionalities that hold tremendous potential for use in medical devices. Nanostructured materials such as calcium phosphate nanoparticles (nanoCaPs™) and diamond-like carbon-metal nanocomposite films possess unique capabilities for specific interactions with cells, proteins, and DNA, and their properties are described in detail. Future prospects for nanostructured ceramics in medicine are reviewed.

Pulse-thermal processing (PTP) utilizing high-density infrared heating has the ability to revolutionize processing methods of functional materials. The high temperature and short exposure times associated with PTP make it possible to rapidly process functional materials, such as amorphous silicon, poly-silicon, and other thin-films and nanoparticles, on a broad range of substrates in a fraction of a second to seconds. An article by R.D. Ott et al. describes a revolutionary PTP utilizing high-energy-density infrared plasma arc lamp technology for large surfaces that can provide heating rates up to 600,000°C/s, which is orders of magnitude larger than current state-of-the-art rapid thermal annealing systems. Under such rapid heating rates it is possible to control diffusion on the nanoscale, which permits processing of thin-films and nanoparticles on temperature-sensitive substrates such as polymers.

The final two articles deal with nanoscale characterization. R.W. Carpick et al. have studied contact, adhesion, and friction for nano-asperities using atomic force microscopy. The continuum models were used to determine the fundamental tribological parameters of nanoscale interfaces: the interfacial shear strength and the work of adhesion. This study indicated that fracture mechanics can provide a useful formalism for describing the relationship between contact area and load and insight into the mechanics of nanoscale friction. Such an approach can now be applied to the more challenging study of real, multi-asperity contacting interfaces present in micromachine devices or macroscopic systems. The next paper by Y-h. Sohn et al. describes the use of relatively conventional non-destructive evaluation techniques such as photostimulated luminescence spectroscopy and electrochemical impedance spectroscopy in complement with focused-ion-beam in-situ lift-out, transmission and scanning transmission electron microscopy (TEM) for studying detailed nano- and microstructural developments during quality control and life-remaining assessment of thermal barrier coatings.

The following papers under the same topic have been scheduled to appear in the March 2005 issue of *JOM* issue. “Nanoporous Ni-based Superalloy Membranes by Selective Phase Dissolution” by J. Rösler et al., and “Assessment of the Phase Diagrams of Nanometer-sized Particles in Binary Systems: Experimental and Theoretical Approach” by J. Lee et al. The article by J. Rösler focuses on single-crystalline based materials that lead to products with particularly high quality due to the uniformity of the single-crystal microstructure. J. Lee et al., describe the use of in-situ TEM to examine the phase equilibrium of an isolated nanometer-sized alloy particle.

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