Nanotechnology and Biomedicine at the Cross Roads
Thomas Tsakalakos, E. Koray Akdogan, M. Muhammed
Department of Materials Science & Engineering, Rutgers-The State University of New Jersey
Piscataway, New Jersey, U.S.A.

ABSTRACT
Nanostructured materials can be tailor-made by controlled assembly of an array of nano-scale building blocks in principle. While the physical properties of materials are chiefly controlled by their atomic and molecular constitution, their novel functionalities emerge when the scale of the microstructure reaches down to the nanometer regime. The properties and functionalities of such nano-ensembles should be expected to be substantially different as the scale evolves from the nano-regime to the micron regime and bulk the bulk regime. Nanotechnology in general and nanomaterials in particular offer new possibilities to design unique properties from which new applications may emerge. Nanotechnology, therefore, may be considered as an enabling technology for new technologies. Nanomaterials technologies whose inspiration and understanding comes from the biological world, have a high chance of finding implementation in biomedical applications if the lessons learned from nature can be intelligently used to manipulate processes in nature for the better good of mankind.

KEY WORDS: Nanotechnology, nanomaterials, processing, biomedical, biomedicine.

INTRODUCTION
The main goals of nanotechnology are enunciated very clearly. However, the need for systematic and comprehensive blueprint (Gleitner, 2000; Zarur et al., 2000; Fokema et al., 2000; Wang et al., 1999; Kear et al., 1999; Muhammed et al., 2003) of the effects of processing and the resultant evolution of nanostructure and its ramification on the physical and chemical properties of nanomaterials remain as a formidable challenge. The challenge in hand is formidable because standardized procedures, which are imperative for the design and synthesis of nanomaterials for novel applications, do not exist for the testing and analyses, especially in the <100 nm size range. In this brief report, we will overview the general topography of the nanotechnology field as applied to nanomaterials first and then exemplify its potential use in biomedical applications. Of all the challenges that lie ahead, one of the most important is the ability to access the extremely high information density of nanostructured systems, which can possibly be accomplished by bio-inspired processing methodologies. This approach leads naturally to the development of multifunctional nanomaterials for use in applications through basic research on bio-inspired nanostructured materials which act as a roadmap. Such an approach is most likely to pave the way for natural sensing, information processing, and actuation of responses to the physical environments. The potential to fit these candidate systems to a wide range of societal applications seems to be of necessity in the 21st century.

Nanotechnology is inherently a multi-disciplinary endeavor, and rests on a variety of mature science and engineering disciplines that need to be harmonized in the nano-realm. Here, we will evaluate the potential of some processing schemes to assess its potential use in synthesizing materials tailored for a great variety of special applications. Synthesis and processing methods include recent advances in preparation of nanostructured powders by rapid condensation and quenching of ceramic melt to form metastable powders. On the other hand, biomimetic, or bio-inspired materials, is a blueprint by which we can study nature's way of handling environmental challenges as a function of temperature, pressure etc. While the same materials used in nature may not be useful in engineering applications, one can learn from them and synthesize advanced nanostructured materials for a range of novel applications.

New materials, such as carbon nanotubes, have been investigated with promising characteristics as structural materials of the future, however, many biomaterials are similar to carbon nanotubes, possessing strength, low density, and resistance to irradiation damage. Keratin, the major protein in hair, is one example withstanding well over 5-6.5 Gy without significant damage. Moreover, bio-nano-materials are typically evaluated for strength, stiffness, fracture toughness, and erosion resistance. The fundamental understanding derived from such studies are usually used to develop general constitutive models which will form the basis for multi-scale modeling of deformation and failure, spanning the atomistic to the continuum length scales and for formulating life prediction methodologies. Models of structural and functional performance have been also developed to provide basic insights about the ultimate potential of these new materials for a number of applications. Another major effort has been recently dedicated to the goal of establishing the limits and promise of inorganic and bio-inspired functional nanomaterials in a device environment for magnetic, electronic, and optical applications. Manifestations include: optical materials with tunable Bragg gratings, magnetic composites for absorbing aerospace materials and sophisticated self-assembled piezoelectric devices synthesized to monitor multi-function operation in electronic industries. Mechanically-linked actuation is another desirable property for nanomaterials. From the example of Micro-Electro-Mechanical Systems (MEMS), one can extrapolate to postulate Nano-Electro-Mechanical Systems (NEMS). Most of these efforts consist of a two-fold approach to the implementation of NEMS-type capabilities in nanomaterials: a "top-down" approach in which the idea is to push the state of the art in MF-MS to understand scaling limits in signal to noise and system integration and a "bottom-up" approach to investigate new materials with desirable nanomechanical properties, characterizing their performance and developing methods for integration.

As concisely elaborated on in this prelude, nanotechnology is expected to remain an active field of research in the foreseeable future, and become one of the critical areas for economic growth. This field should