Structural Nanocrystalline Materials

Nanocrystalline materials exhibit exceptional mechanical properties, representing an exciting new class of structural materials for technological applications. The advancement of this important field depends on the development of new fabrication methods, and an appreciation of the underlying nanoscale and interface effects. This authored book addresses these essential issues, presenting a fundamental, coherent, and current account at the theoretical and practical level of nanocrystalline and nanocomposite bulk materials and coatings. The subject is approached systematically, covering processing methods, key structural and mechanical properties, and a wealth of applications. This is a valuable resource for graduate students studying nanomaterials science and nanotechnologies, as well as researchers and practitioners in materials science and engineering.

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Fundamentals and Applications

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Preface

Nanoscience and nanotechnology has become an identifiable, if very large, diverse, and multidisciplinary field of research and emerging applications. It is one of the most visible and growing research areas in science and technology. Government research funding agencies throughout the world have recognized its potential importance with substantial special initiatives to support its growth and development. The realms of nanotechnology applications are being explored not only of chemistry, materials, and engineering, but the frontiers of medicine as well. This on-going research is what enables the continuing expansions in nanotechnology. Over the past two decades there has been a revolution in the material-science field that has sparked great interest and research in all areas of science and engineering. Nanotechnology and nanoscience are leading this revolution fueled by the industrial progress, the scientific ability to fabricate, model and manipulate objects (things) with a small numbers of atoms, and the almost daily discovery of new phenomena of the nanoscale.

Nanostructured materials include atomic clusters, layered (lamellar) films, filamentary structures, and bulk nanostructured materials. The common thread to these various material forms is the nanoscale dimensionality, i.e. at least one dimension less than 100 nm (more typically less than 50 nm), often less than 10 nm.[1] While this dimension requirement may appear to be arbitrary, it is usually at these length scales that the "physics" often changes and leads to very different properties, often superior, than those of conventional materials. Typical manifestations of nanoscale effects in solids are the dislocation instability in nanoscale crystallites and the quantum confinement of charge carriers in semiconductor quantum dots. Nanoparticles can be considered to be of "zero" dimensionality and examples include a large range of nanoscale powders of interest for diverse applications such as dispersions in cosmetics and pharmaceuticals. Quantum dots for optoelectronic applications may also fall into this category. A layered or lamellar structure is a one-dimensional nanostructure in which the magnitudes of length and width are much greater than the thickness that is nanoscale. Thin films with quantum well structures for electronic device applications are examples of this category. Two-dimensional nanostructures have the length much larger than the width or diameter and nanowires or nanotubes may fit this division. The nanostructures that contain the "bulk" definition relevant to this book are three-dimensional and consist of crystallites, or in certain cases quasicrystals and/or amorphous material, that are

[1] This applies for optoelectronic materials, catalysts, superhard nanocomposites, etc.

nanoscale in dimension. Structural geometry of nanostructures becomes more complicated in the case of composite materials. Categories of nanocomposites consisting of at least two phases, with at least one phase having characteristic sizes less than 100 nm, are specified by size scales and geometry of constituent phases.

Surfaces and interfaces are also important in explaining nanomaterial behavior. In bulk materials, only a relatively small percentage of atoms will be at or near a surface or interface. In nanomaterials, the small feature size ensures that many atoms, perhaps half or more in some cases, will be near interfaces. Surface properties such as energy levels, electronic structure, and reactivity can be quite different from interior states, and give rise to quite different material properties.

Structural nanomaterial can exist in various forms, such as, nanometals, nano-oxides and nanocomposites. Each type exhibits different properties, thus having an immense potential for many applications in every field of science and engineering. These materials can find applications in mechanical, aerospace and electronics engineering. For example, aerospace is in constant search of lighter, more flexible and stronger materials; higher efficiency fuels and more powerful engines among others. Electronics are ruled by Moore's law,[2] and the need for smaller yet more powerful integrated circuits makes, nanomaterials the holy grail of the electronics field. Other fields that are worth mentioning owing to their large interest and research into the materials are medical science, forensic science, civil engineering, and cosmetology.

As the field of nanoscience/nanotechnology has developed, new journals, books, and topical conferences have been devoted to the dissemination of the research results that are increasing at a rapid rate. However, often "nano" refers to the size of a component rather than the dimensions of the internal microstructure of a bulk material. In many cases, the specialized nanomaterials journals and books leave out bulk nanostructured materials.

This book takes for its theme *Structural Nanocrystalline Materials: Fundamentals and Applications*. Since structural materials are typically "bulk" or coatings the book will focus mainly on these categories although the two-dimensional nanotubes are also briefly addressed. Since many books on nanostructured materials have already been published we must justify another book in this area. First, since the field is moving so rapidly owing to its novelty and the huge number of researchers working in the area, many concepts only a few years old have become obsolete and another "snap-shot" of the state-of-the-art of the field is worthwhile. Secondly, the area of structural nanomaterials has been relatively neglected although several excellent reviews of the mechanical behavior of nanocrystalline materials have been published. This book aims to cover the complete cycle of structural nanomaterials from their processing, characterization, stability, mechanical behavior, corrosion, and applications.

The introductory chapter briefly covers the need for structural nanocrystalline materials. Chapter 2 covers the variety of processing methods that have been used to make nanomaterials for bulk or thin-film structural applications. Chapter 3 describes the stability of nanocrystalline microstructures and also covers the various methods used to characterize the

[2] Moore's law means that the number of transistors on a chip doubles, their size shrinks and speed increases by a factor of 2 every 18–24 months.

nanocrystalline structure. Chapter 4 reviews the experimental evidence for the mechanical behavior of bulk and thin film nanocrystalline materials. Chapter 5 covers the theoretical understanding of the mechanical properties of nanomaterials. Chapter 6 reviews the limited knowledge regarding the corrosion behavior of nanocrystalline materials that is important for structural applications. Chapter 7 presents existing and potential applications for structural materials.

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