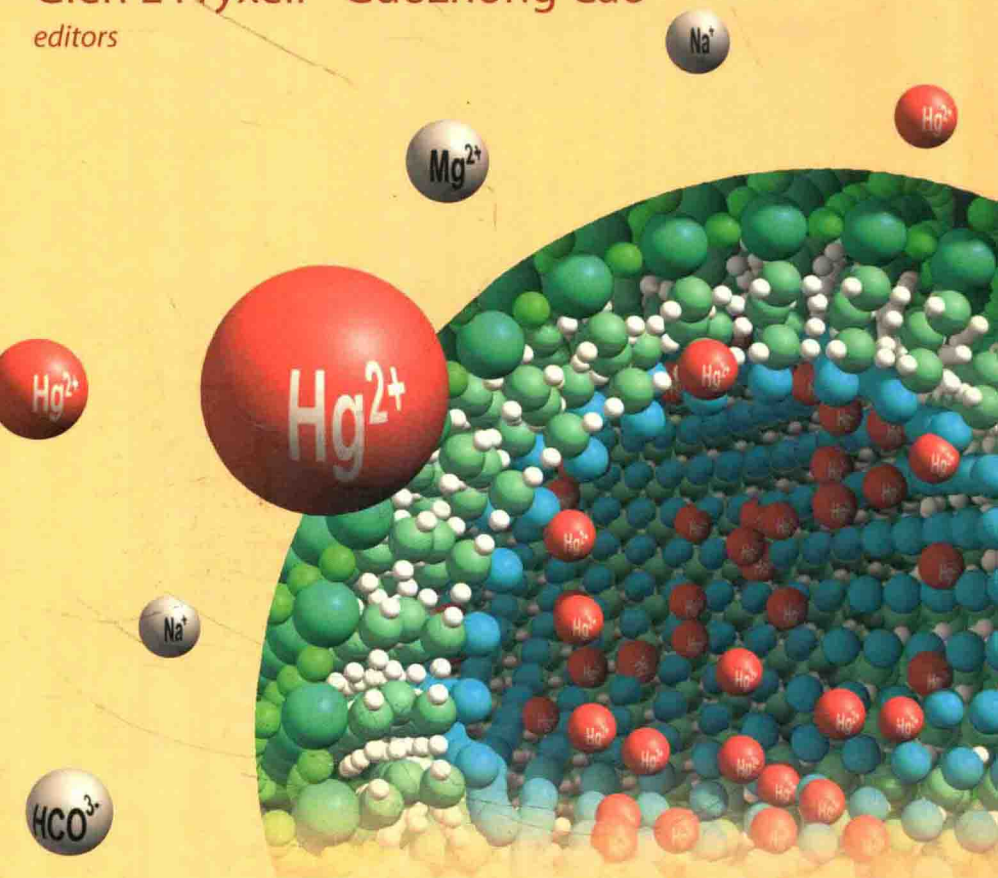
Environmental Applications of Nanomaterials

Synthesis, Sorbents and Sensors

2nd Edition

Glen E Fryxell • Guozhong Cao
editors



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Preface to the First Edition

Nanotechnology has attracted a lot of attention recently, particularly in the research and industrial communities. It offers many unprecedented opportunities for advancing our ability to influence not only our day-to-day lives, but also the very environment in which we live. The ability to design, synthesize and manipulate specific nanostructured materials lies at the very heart of the future promise of nanotechnology. Nanomaterials may have unique physical and chemical properties not found in their bulk counterparts, such as unusually large surface-area-to-volume ratios or high interfacial reactivity. Such properties give hope for new chemical capabilities arising from exciting new classes of nanomaterials. Indeed, as this book summarizes, nanomaterials have been developed for specific applications that involve interfacial reactions and/or molecular transport processes.

The industrial revolution of the late 19th and early 20th century led to unprecedented economic growth in Europe and the United States. However, it also produced unprecedented environmental pollution. In those simpler, more naive times, contamination of the environment was largely ignored, a common sentiment being simply that "dilution is the solution to pollution". The economic benefits of increased industrial production outweighed the emerging environmental problems, and the vastness of the wilderness and ocean (along with the lower populations of the day) allowed this industrial contamination to dissipate to levels that made it relatively easy to ignore... for a while. Today, we see other countries (e.g. China) going through similar growing pains, and experiencing similar environmental damage.

The 20th century also brought an unprecedented arms race, which in turn brought its own unique set of environmental concerns and needs. Of particular importance to the environment are the legacy wastes arising from 40 years of nuclear weapons production, as well as the vast stockpiles of chemical weapons, throughout the globe. Our parents devised and built

these devastating weapons in order to fight back against the ruthless tyrants that threatened their world. They did not have the luxury of planning ahead for the eventual disposal of these deadly materials; they needed to fight, and they needed to fight NOW. Their success ultimately led to improved standards of living throughout much of Europe and the United States (eventually spreading to other parts of the world, as well). However, the issues raised by the presence of these difficult waste materials are still unresolved.

This new-found quality of life was starting to be threatened by industrial pollution in the 1960s and early 1970s, and society quickly realized that we must take a more active stance in terms of pollution management and prevention. In the years since, governments and industry have learned to work together (albeit awkwardly at times), monitoring industrial effluents and limiting new releases of toxic materials into the environment. Remediation methods have been developed to repair some of the damage that previously took place. We are learning. We have a responsibility, both to future generations, and to our global neighbors, to share these insights — both regulatory and remediatory.

The last 10 to 15 years have seen a remarkable explosion of research in the design and synthesis of nanostructured materials — nanoparticles, nanotubes, nanorods, etc. Early work largely focused on making different shapes, or different sizes; then work started to focus on making a variety of compositions, and multicomponent materials. Tailoring the composition or interface of a nanomaterial is a key step in making it *functional*. This book is concerned with functional nanomaterials — materials containing specific, predictable nanostructure whose chemical composition or interfacial structure enable them to perform a specific job — destroy, sequester or detect some material that constitutes an environmental threat. Nanomaterials have a number of features that make them ideally suited for this job — high surface area, high reactivity, easy dispersability, rapid diffusion, etc. The purpose of this book is to showcase how these features can be tailored to address some of the environmental remediation and sensing/detection problems faced by mankind today. A number of leading researchers have contributed to this volume, painting a picture of diverse synthetic strategies, structures, materials and methods. The intent of this book is to showcase the current state of environmental nanomaterials in such a way as to be useful either as a research resource, or as a graduate-level textbook. We have organized this book into sections on nanoparticle-based remediation strategies, nanostructured inorganic materials (e.g. layered materials like the apatites), nanostructured organic/inorganic hybrid materials,

and the use of nanomaterials to enhance the performance of sensors. The materials and methods described herein offer exciting new possibilities in the remediation and/or detection of chemical warfare agents, dense non-aqueous-phase liquids (DNAPLs), heavy metals, radionuclides, biological threats, CO_2, CO and more. The chemistries captured by these authors form a rich and colorful tapestry. We hope the final result is both valuable and enjoyable to the reader.

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March 2006

Preface to the Second Edition

Recent years have seen a number of exciting advancements in the field of functional nanomaterials and their use to address issues related to the environment. Generally speaking, these nanomaterial-based strategies can be grouped into three broad categories: nanomaterials designed to capture chemical species of concern from the environment (or prevent their release into the environment), nanomaterial-enhanced sensors for making more sensitive measurements of chemical species in the environment, and nanomaterial-enhanced biomedical technologies (i.e. technologies to deal with the results of environmental exposure). Specific examples of nanomaterials for capture would include: the use of crystalline silicotitanates to sequester cesium from nuclear waste, the use of hybrid nanomaterials to remove toxic anions from water, new classes of nanostructured polysilsesquioxanes that capture toxic metal ions, and hybrid nanoporous materials tailored for the selective and efficient capture of CO_2 (a major global warming concern). Recent examples of the nanomaterial-enhanced sensors would include work with carbon nanotube and graphene-based sensors tailored for detecting organophosphate pesticides, semiconductor oxide nanotubes for gas sensors for toxic gases (e.g. CO, NO_2, etc.), as well as electrochemical sensors based on TiO_2 nanotube arrays. Functional nanomaterials are also being evaluated for a variety of biomedical applications, examples of this would include: the use of functional nanomaterials as an orally administered alternative to chelation therapy, and electrochemical sensor systems designed to perform heavy metal determinations in biological fluids like urine and blood. We felt that the readers would benefit from discussion of these exciting results, so the second edition of this book has been expanded to include these topics and we believe that the readers will find this expanded second edition to be both a valuable research reference, as well as a useful teaching tool.

We thank the authors for their excellent contributions.

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