Nanomaterials for the Life Sciences

Edited by Challa Kumar

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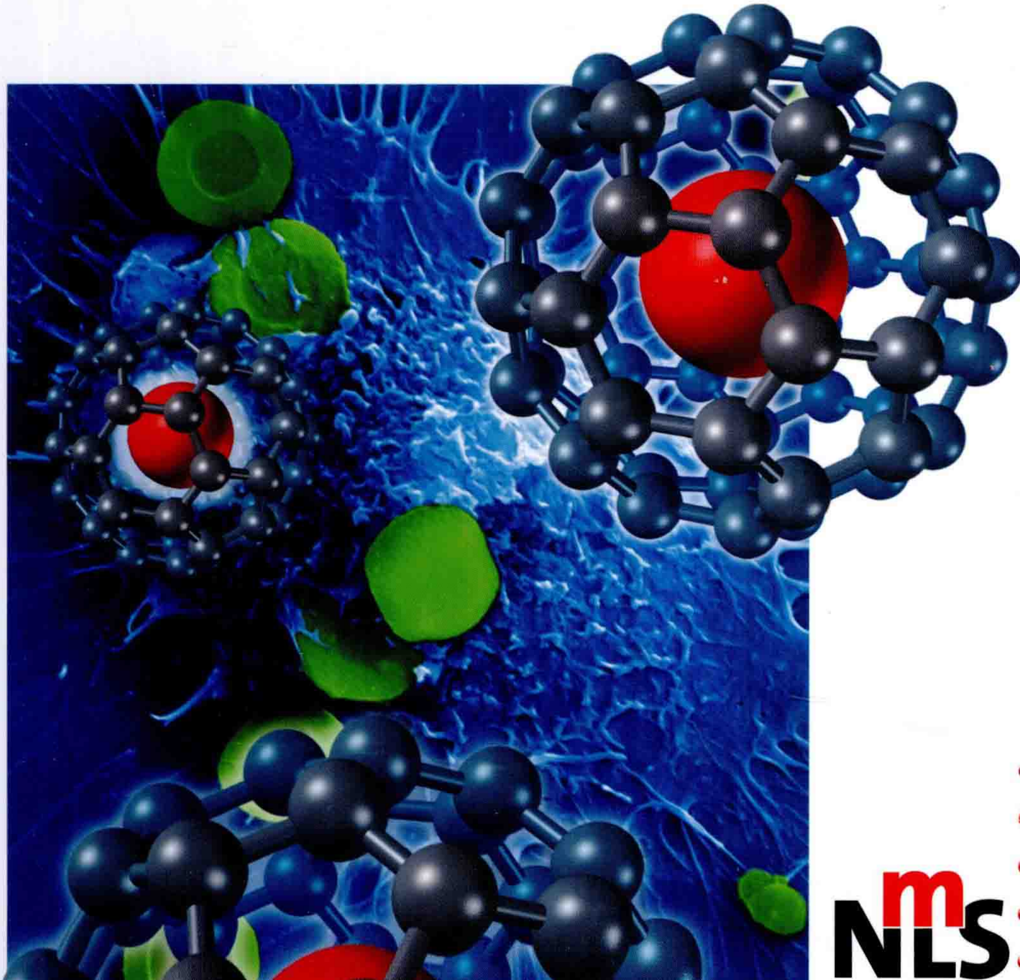
Biomimetic and Bioinspired Nanomaterials



NLS

Nanomaterials for the Life Sciences
Volume 7

Biomimetic and Bioinspired Nanomaterials

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Cover Picture
As we all know, science is developing step-wise – periods of steady-state growth are interrupted by fast transformations caused by new experimental evidence or/and NEW IDEAS. Truly new ideas use to emerge as some "unlogical" steps related to "cross-terms" with other fields of science and even art. Each researcher always has his own "picture" behind any new model or theory. To have such ideas one should go beyond common way of thinking for a while.

Science for authors (and we believe, for many others) is fun, and they would like to share this fun with readers! Working over our simple models of complex phenomena, we sometimes managed to find reasonable solutions by using the analogies between reactions in solid state and in surrounding nature and art. May be naively, we decided to illustrate this principle from the very beginning – at the cover picture, using kind permission of their international authors – King Ning Tu (USA), Chen Zhong (Singapore), Oksana Bortz (Russia), Juern Schmelzer (Germany). In remaining photos the principle of analogy is applied:

Tin-lead solder bump – sun "bump",

Cu_6Sn_5 scallops in Flux Driven Ripening – natural rocks "scallops",

Morphology of reaction zone between electroless nickel and solder – "reaction zone" of waterfall,

Diffusion zone with emerging intermediate phases layers and islands in MC simulation – diffused transition zone between night and day with emerging intermediate foggy "phases".

Unexpected nucleation of rainbow between clouds and earth is actually of the same type, but it is simultaneously a logical center of all collection, analogical couples going clockwise.

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Preface

Nature continues to teach us and inspire us. It is therefore not surprising that Nature is far advanced in utilizing Nanomaterials and nanotechnology principles than us. It is awe inspiring to learn these tools from Nature and to apply them to build materials that are useful in our day to day life. We have seen a dramatic increase in the number of investigation focusing on these approaches aptly termed as "biomimetic" or "bioinspired." The concept of biomimetics, though, emerged only in the 1960s, it has been developing rapidly in enhancing the functions of materials and devices ranging from biomedicine to energy. This advancement came about mainly due to progress in nano- and biotechnologies. Here within this book we have the first opportunity to summarize these advances with special reference to life sciences. I am pleased to present to you the seventh volume in the NmLS series that is dedicated to capturing these investigations and organizing them in such a way as to provide information in an easy and free flowing manner. The book is aptly titled, Biomimetic and Bioinspired Nanomaterials for Life Sciences, and has fourteen chapters describing in depth various aspects of nanomaterials derived from or inspired by Nature ranging from plant and animal kingdom. This is judiciously interspersed with chapters covering tools developed for understanding the nanoscale phenomenon in nature and applying the lessons to design materials in the laboratory.

Who have not heard of Geckos, small to average sized lizards belonging to the family Gekkonidae, and well known for their adhesion? The book begins with a chapter on Gecko-inspired Nanomaterials by Christian Greiner. It discusses the physical origin of gecko adhesion and how to mimic its abilities. Moving from Gecko to humans, the second chapter offers a brief review of teeth with reference to bio-mineralization systems and in vitro strategies to synthesize similar materials. The chapter by Janet Moradian-Oldak zeroes in on enamel and dentin as nanocomposite materials, their unique structures and common molecular mechanisms involved in their formation. From more specific nanocomposites to general tissue engineering, the third chapter by Peter Ma describes extracellular matrix (ECM) scaffold for tissue regeneration and explains fabrication techniques viz electro spinning, self-assembly, and phase separation for nano-fibrous scaffolds and their applications to tissue engineering. Such ECM-mimicking nanostructured biomaterials have been shown to actively regulate many biological

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effects and cellular responses including adhesion, proliferation, and differentiation thereby demonstrating the significance of biomimetic nanomaterials for tissue engineering and regeneration. In the next chapter, nature-inspired nanomachines and their significance with respect to Nano-Electro-Mechanical-Systems are presented. Covering several biological molecular machines, including Myosin, Kinesin, ATPase, and DNA, the author Tony Jun Huang continues the discussion to include several biomimetic molecular machines, such as rotaxanes, catenanes, pseudorotaxanes, nanocars, polyelectrolyte brushes, and light-driven molecular motors. This chapter in combination with chapter eight provides a comprehensive review on nature inspired nanomachines. Unlike the chapter four, the chapter eight covers advances in biomimetic distributed nanosensos and nanoactuators (BNN) made with nanocomposites of ion-containing polymers, polyelectrolytes and conductive materials and networks. In addition, the chapter by Mohsen Shahinpoor shares phenomenological model of the underlying sensing and actuation mechanisms in these sensors.

The peptide nanostructures have remarkable features such as rigidity, thermal stability, chemical stability and high versatility that allow tailor-made chemical and biological modifications. In the fifth chapter, Francesco Pampaloni's commentary on Biomimetic and Bio-inspired Self-assembled Peptide Nanostructures reiterates the importance of several types of peptide nanostructures ranging from nanotubes, wires, rods, particles to thin films in a number of applications related to life sciences. In the sixth chapter entitled, Bio-inspired Layered Nanomaterials in Medical Therapy, Jin-Ho Choy introduces structure and chemical features of biocompatible layered nanomaterials and the intercalative hybrid nanomaterials for medical therapy. The chapter is also valuable as it presents information from the point of view of clinical toxicology. Offering the possibility for drugs to be intercalated into layered materials, these nanostructures act as biomolecular reservoirs or drug delivery systems with superior drug pharmacokinetics.

While biomimetic nanostructures are intriguing and provide new opportunities for designing novel nanomaterials with unique properties and applications, a different line of investigations is related to the increasing interest and emphasis on developing cleaner and more sophisticated methods for preparation of nanomaterials using bio-templates by mimicking biological processes. In the seventh chapter, Jim Yang Lee argues that the synthesis of nanoparticles by organisms or biomolecules is ideal from the viewpoint of a reduced environmental footprint. Substantiating this point of view, the chapter summarizes the current progress in biological and biomimetic synthesis of metal nanoparticles (using nanogold and nanosilver as examples), emphasizing on their major differentiating features from conventional chemical synthesis and some understanding of the fundamental principles involved. The chapter "Biomimetic Nanotechnology" reviews current status on bio-mineralization processes; covering the growth of bio-crystals, their morphological control and site-selective immobilization using bio-mimetic approaches. The role of molecular recognition is also stressed. In this chapter by Takahiro Ishizaki, the emphasis is on the products of bio-mineralization, that is, bio-minerals, controlling their crystallo-chemical properties through molecular recognition at an inorganic-organic interface.

Self-assembly is the most sought after and reliable approach that Nature has been using from the time immemorial. We have learnt a lot about self-assembly from Nature and bio molecular and bio mimetic self-assembly has emerged as an appealing and promising route for fabrication of materials and devices with most desirable functions. In the tenth chapter by Bo Liedberg, an overview of current progress on bio mimetic approaches for self-assembly of nanomaterials, with a particular focus on *de novo* designed polypeptides and their uses as scaffolds and tools for self-assembly of functional nano-architectures and hybrid materials is presented. This analysis reveals that bio mimetic self-assembly designs from Nature are far more advanced than most manmade materials and possess many attractive physical and chemical properties. With specific reference to self assembly related to surfaces, the next chapter teaches the reader about artificial nanostructured surfaces resulting from both mimicking and being inspired by nature. The chapter by Emmanuel Stratakis also reviews different approaches that have been employed so far for the fabrication of bio-inspired artificial nano structured surfaces in addition to delineating existing limitations and discussing emerging possibilities and future prospects. The twelfth chapter, Natural and Modified Nanomaterials for Environmental Applications, is a contribution from Guodong Yuan. In this chapter, the author describes natural aluminosilicate nanomaterials and more specifically the actual and potential applications of two well-studied nanosize aluminosilicates, notably montmorillonite and allophane, and their modified forms. The chapter provides an overview of various facets of environmental functions of natural nanomaterials ranging from adsorbents, filters, membranes, catalysts, antimicrobial agents, sensors, and finally as carriers of chemicals.

Among the biopolymers, S-layer proteins are one of the most common and their structure, genetics, chemistry, morphogenesis and function have been under investigations for more than 30 years. Pointing out the importance of scanning force microscopy as an important tool for imaging and probing the surface properties of native and genetically modified S-layer proteins, the thirteenth chapter provides an overall description of native and genetically modified S-layer proteins, their reassembly on solid surfaces and patterning by lithographical methods and their structural investigations using single molecule recognition force spectroscopy. The author Dietmar Pum focused the discussion towards rendering silicon surfaces hydrophilic or hydrophobic utilizing S-layer proteins. The final chapter contributed by Himadri S. Gupta is entitled, Nanoscale Deformation Mechanisms in Biological Tissues. In this chapter, the author highlights the importance of cooperative and multi-scale processes activated during deformation of biological materials and highlights some unifying common principles in nanoscale deformation behavior that emerge, when considering a whole range of materials. The author also recommends utilization of high resolution experimental tools like in-situ synchrotron testing and single molecule mechanical spectroscopy for discovering and discriminating between the relevant deformation mechanisms.

I do hope that the information that has been painstakingly accumulated by several researchers in this book will help in furthering better understanding of the nanosystems derived from Nature leading to newer biomimetic materials with never foreseen applications. I am very grateful to all the authors for their excellent presentations of their topics, providing timely inputs and corrections in making this unique book a reality. I am always thankful to my employer, family, friends and Wiley VCH publishers for their continued support and encouragement. Finally, my special thanks to you, the readers, for making attempts to utilize the knowledge base provided in this book. I look forward to receiving your comments and suggestions.

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