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Book Review

NANOTECHNOLOGY
Volume I: Principles and Fundamentals

Günter Schmid (Ed.)
WILEY-VCH Verlag GmbH&Co. KGaA, Weinheim, Germany
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The book deals with the principals and fundamentals of nanotechnology, explaining what nanoscience and nanotechnology really means and what it does not mean. Furthermore, this book contains philosophical and ethical aspects, since any new technology opens up questions concerning social consequences.

After a short introduction, where some new findings in the field of nanotechnology are briefly discussed, Chapter 2, "The Nature of Nanotechnology", author Günter Schmid starts with various definitions of nanotechnology.

Then, the transition from nanoscience to nanotechnology is considered in a short analysis.

Nanoscience, nanoengineering and nanotechnology are represented by three steps following each other. Each step contains several of many possible examples, which will help to realize how nanoscience develops into nanotechnology. Some of the areas are still only to be found in "nanoscience", others have already developed into the "nanoengineering" step or even into "nanotechnology"; some are present in all three fields, indicating that there is still a further need for basic research to improve or to extend existing technologies.

Also, in Chapter 2, some aspects regarding molecular motors and machines, molecular switches, single-electron memories, drug delivery, gene chips, hyperthermia, gas sensors, technologies on the nanoscale and structured surfaces are highlighted in order to demonstrate the enormous diversity of nanoscience and nanotechnology. It is shown that nano-effects can occur everywhere, both in simple materials and in complex biological structures. This makes nanoscience and nanotechnology a unique field of development. The examples discussed illustrate the universality of this future-determining technology, which in many of the most attractive fields is still at the very beginning. Distinct fields that are still part of basic research will develop into techniques which will influence daily life dramatically. Others, usually those of easier and faster research and development, have already become routine techniques.

In Chapter 3, "Top-Down Versus Bottom-Up", authors W.J. Parak, F.C. Simmel and A.W. Holleitner evidence, in the introductory part, that nanotechnology has evolved from different scientific fields such as physics, chemistry, molecular biology, microelectronics and material sciences. Generally, nanotechnology aims to study and to manipulate real-world structures with sizes ranging between 1 nm, which is one millionth parts of a millimeter, and up to 100 nm. The set of typical "nano"-objects includes colloidal crystals, molecules, DNA-based structures and integrated semiconductor circuits. Also, complex biological organisms, such as a human body, can be subdivided into smaller and smaller subunits.

The "top-down" strategy is introduced as to take processes known from the macroscopic world and to adopt them in such a way that they can be used for doing the same thing on a smaller scale. At present, there are several possible successor top-down nanotechnologies for industry, for example extreme ultraviolet light lithography (EUV), electron beam lithography with multicolumn processing facilities; the focused ion beam (FIB) technique and the ultraviolet nano-imprinting technique. The implementation of each of these techniques requires enormous technical challenges to be overcome.

The antipode of the top-down approach is the so-called bottom-up technique. Here a complex structure is assembled from small building blocks. These building blocks possess specific binding capabilities – often termed "molecular recognition properties" – which allow them to arrange automatically in the correct way. Self-assembly is an essential component of bottom-up approaches. The ultimate examples of molecular recognition are biological receptor-ligand pairs: molecules that recognize and bind to each other with very high specificity. Prominent examples of such pairs are antibodies and their corresponding antigens and complementary strands of deoxyribonucleic acid (DNA).

Generally, bottom-up assembly techniques seek to fabricate composite materials comprising nanoscale objects which are spatially ordered via molecular recognition. The prime examples of the technique are self-assembled monolayers (SAMs) of molecules. A substrate is immersed in a dilute solution of a surface-active organic material that adsorbs on the surface and organizes via a self-assembly process. The result is a highly ordered and well packed molecular monolayer. The method can be extended towards layer-by-layer (LBL) assembly, by which polymer light-emitting devices (LEDs) have already been fabricated. The self-assembly technique also allows positioning of single molecules between two metal electrodes and subsequently into an experimental circuit. By this set-up, quantum mechanical transport characteristics of single molecules, such as photochromic switching behavior, can be studied in order to build electronic devices with new functionalities.

A typical application of this technique is the formation of networks of metallic nanowires, that is, metals are vapor deposited on to a preformed template matrix made out of copolymers. The polymer networks can be used as two- or even three-dimensional templates. Generally, there is a wide range of materials which can be engineered by bottom-up techniques, such as: nanotweezers, nanomorors, patterning, quantum dots.

Chapter 4, "Fundamental principles of Quantum Dots", authors W.J. Parak, L. Manna, T. Nann, analyses some considerations on these new trends which involve the ability to fabricate, characterize, and manipulate artificial structures, whose features are controlled at the lower nanometer scale, in areas of research as diverse as engineering, physics, chemistry, materials science and molecular biology. Research in this direction has been triggered by the recent availability of revolutionary instruments and approaches that allow the investigation of material properties with a resolution close to the atomic level. Strongly connected to such technological advances are pioneering studies that have revealed new physical properties of matter at a level which is intermediate between the atomic and molecular level and bulk.

Nanoscale materials are presented as intermediates between atomic and bulk matter.

A few examples are given to explain why the behavior of nanoscale materials can be very different from that of their bulk and from their atomic counterparts and how quantum mechanics can help us in rationalizing this. A bottom-up approach and a simplified picture of a solid are given as being a very large molecule, where the energy levels of each individual atomic component have merged to form bands. The electronic structure of a quantum dot being intermediate between the two extreme cases of single atoms and the bulk, will then be an easier concept to grasp. The mole of a free electron gas and the concept of quantum confinement are used to explain what happens to a solid when its dimensions shrink one by one. This leads to a more accurate definition of quantum wells, quantum wires and quantum dots. The electronic structure of quantum dots is examined in more detail.

In Chapter 5, "Fundamentals and Functionality of Inorganic Wires, Rods and Tubes", authors J.J. Schneider, A. Popp and J. Engstler, the physical properties of 1D inorganic structures are discussed first, followed by a section devoted to general techniques for the synthesis of inorganic wires, rods and tubes. The chapter then highlights some of the material developments made over the last few years in the very active area of nanostructured inorganic rods, wires and tubes with respect to their scientific materials functionality. The field carbon nanotubes (CNTs) is touched upon in this chapter as far as sensing and nano-micro integration in functional devices are concerned.

The interest in nanostructured materials often arises from the fact that the small size connected with nanoscaled matter creates new chemistry. For example, the extremely high number of interfaces connected with small-scale matter, be it in 0D (particles), 1D (wires, rods, tubes), 2D (films), dimensions create high chemical reactivity. Interfaces control important material properties such as catalytic activity or analytical sensing behavior in addition to electronic properties of nanomaterials, which are highly dependent on such interfacial contacts of individual nano-building blocks and also on the individual QSE of the nano-building blocks. Besides such effects connected with the nanoscale regime, morphological properties of assembled nanomaterials such as habit (size, shape) and surface structure are also important for new and desired materials properties arising from the sequential build-up of larger structures from nano-building blocks.

Chapter 6, "Biomolecule-Nanoparticle Hybrid Systems", authors M. Zayats, I. Willner, is aimed at summarizing the different venues where the unique optical and electronic properties of biomolecule-NP hybrid systems have been applied and to discuss future opportunities in the area. The discussions include issues such as metal nanoparticles for electrical contacting of redox proteins, metal nanoparticles as electrochemical and catalytic labels, metal nanoparticles as microgravimetric labels, semiconductor nanoparticles as electrochemical labels for biorecognition events, metal nanoparticles as optical labels for biorecognition events, semiconductor nanoparticles as optical labels, semiconductor nanoparticles for photoelectrochemical applications, biomolecules as catalysts for the synthesis of nanoparticles, biomolecule growth of metal nanowires.

The analytical applications of biomolecule-NP hybrid systems have seen tremendous advances in the last decade. The electronic properties of metallic NPs were used to electrically communicate redox proteins with electrodes and to develop amperometric biosensors. The catalytic functions of metallic NPs were broadly applied to develop amplification methods for biosensing events, and the localized plasmonic features of NPs were extensively used to develop new optical methods that probe biorecognition events and design novel biosensor configurations. Optical phenomena such as the surface-enhanced fluorescence are Raman signals by dye-modified metallic NPs, the coupling of the localized plasmon of metallic NPs with surface plasmonic waves, the interparticle plasmon coupling in metallic NP aggregates and the reflectance of NPs were creatively used to image biorecognitionevents and to develop optical biosensors. Similarly, the coupling of biomolecules to semiconductor NPs (quantum dots) demonstrated the utility of these systems to assemble new optical and photoelectrochemical biosensor systems. The size-controlled emission properties of semiconductor QDs, as a result of the quantum confinement of the electronic levels in the nanoparticles, allow the multiplexed analysis of different targets and the design of high throughput analyses in array formats. The development of photoelectrochemically based biosensors by the use of biomolecule-semiconductor hybrid systems highlights the bridge between the optical and electronic applications of biomolecule-NP hybrids for biosensing.

The development of biomolecule-NP-based sensors reached the level of practical applicability, and various analytical systems for clinical diagnostics, the analysis of food products, environmental pollutants and homeland security biosensors are expected to emerge from these hybrid nanocomposites.

Chapter 7, “Philosophy of Nanosciences”, author A. Nordmann, addresses some aspects of philosophy of technoscience, which asks for nanotechnological, biomedical or semiconductor research the four questions that were identified above: what is the role of theory and theory-development in nanoscale research and what kinds of theories are needed for nanotechnological development?; what are the preferred methods and tools and the associated modes of reasoning in nanoscientific research?; what is nanoscience and how are its objects constituted?; and what kind of knowledge do technoscientific researchers typically produce and communicate? The four main sections of this chapter will address these questions – and in all four cases, strictly philosophical considerations will shade into societal dimensions and questions of value. Other problems, such as applying theory to the nanoscale: fitting versus stretching, mute complexity, from successful methods to the power of images, technoscientific methodology: quantitative versus qualitative, “ontological indifference”: representation versus substitution, images as the beginning and end of nanotechnologies represent an important part of this chapter. This chapter did not survey a revolutionary development, but pragmatic and problematic integrations of pre-existing scientific knowledge with the novel discoveries at the nanoscale.

Chapter 8, “Ethics of nanotechnology. State of the Art and Challenges Ahead”, author A. Brunwald, is a study on current and foreseeable developments in nanotechnology from the viewpoint of philosophical ethics. This overview is complemented by two in-depth case-studies of ethical aspects in nanotechnology: the challenge of dealing with possible risks of nanoparticles and the role of the precautionary principle and the human enhancement case, which is directly related to nanotechnology via the debate on “converging technologies”. Dealing constructively and in a rational way with these ethical challenges requires specific conceptual and methodical developments. In particular, some effort has to be invested into handling the dimension of the future in normative as well as epistemological regard in a non-partisan way.

The last Chapter, 9, “Outlook and Consequences”, author Günter Schmid, summarizes the main findings and ideas from the whole book, in order to demonstrate the innovative power of nanoscience and technology. The conclusion at the end is that there is no doubt that nanotechnology will change our lives, but it depends on us what this change will look like.

This is considered to be one of the first books which deals with the various fields on nanotechnology. In addition to the principles and fundamentals, treated in this volume, information technology, medicine, energy, tools and analytics as well as toxicity could be the subjects of subsequent other books. Developed fields of nanotechnology and future areas of nanotechnological applications are described and discussed.

The book addresses scientists, teachers/professors and students involved in this important and advanced field of fundamental and applicative science.

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