Preface

This is the first book on bionanoelectronics which deals with the applications of nanoelectronics in biology and medicine. Nanoelectronics is the most advanced area of nanotechnologies having huge applications in daily life. The mobile phones at which we are communicating every day as well as the desktop and laptop computers and iPhones are all results of the development of nanoelectronics, which is now able to fabricate with high reproducibility trillions of very large scale integrated circuits, integrating a huge number of transistors in a single chip. The nanoelectronics technologies are so effective that even 10 years ago the number of transistors contained in DRAM memories was greater than the number of grains of rice produced in the same year, and the price of a transistor was significantly lower than that of a grain of rice. These nanoscaled chips contain one billion transistors, which act as Boolean switches, connected in complicated paths, with a total length of 20 km, but confined and packed in an area of few cm^2. The nanoelectronics technology has developed so significantly according to the Moore law, which states that the dimensions of transistors reduce with 30% every 3 years, such that today the software of any iPhone is more powerful than that of the Apollo 11 lunar module, which landed on the Moon 30 years ago.

After publishing the second edition of the book *Nanoelectronics. Principles and Devices*, at Artech House, in 2009, which followed the first edition after only 3 years, we started to think that the last chapter of this book, called "Molecular and biological nanodevices," must be extended into a separate book, taking into account the amazing applications of bionanoelectronics in rapid DNA sequencing, tissue engineering, controlled drug delivery, bioinspired devices, targeted cancer therapy, or even nanoelectronic artificial organs such as the nose, liver, or lung. More than 20 therapy products based on nanotechnologies are already in use, with very promising results, and other hundreds of nanomedicine-related devices are researched and are under clinical tests. However, we were a bit reluctant to start such an endeavor. We have known that nanoelectronic devices are governed by the rules of quantum mechanics, which prevail for any nanoscale device, and are accompanied by other fundamental laws of physics that cannot be easily adapted to the complex systems of biology. While physics uses a reductive approach to get relatively simple equations

with a universal character, also applicable in nanodevices, biology, and medicine are mainly observational science, since life manifestations are extremely complex. For example, in a human body, there are 10^{14} cells and, due to cell divisions, 25 millions of new cells are generated every second; a cell has an average dimension of 10 μm and weighs 1 ng; each cell contains the human genome having 3×10^9 base pairs, which means 750 MB of information; the human genome is 1 m long but is folded and packed in few microns and weighs 3 pg. Indeed, our nanoelectronics chips are simple toys compared to what nature has created. We have to recognize that human body is in itself a universe having at least a similar complexity to the cosmological universe from which we originate.

So we have thought how to make accessible to the engineering and physical community the amazing accomplishments of nanoelectronic devices and nanotechnologies applied in various areas of biology and medicine. The reason of such important steps forward in bionanoelectronics are due to the fact that the size of nanodevices and nanomaterials are similar to that of cells, and even of the DNA. The result of our efforts is the present book. The book is not focused on complicated biological, medical, or chemical considerations, although we inevitably use terms from these sciences, briefly explained in the text.

The main idea of the book is to provide to the reader the basic knowledge of nanosciences, i.e., the theoretical concepts and the basic technologies, as well as their applications in biosensing, imaging, bioarchitectures, molecular devices, bioinspired devices, controlled drug delivery, implants, biochips, etc. Thus, the book has achieved an internal coherence reflecting the dual interaction between nanoelectronics on one side and biology and medicine on the other, manifested by bioinquiring devices, when nanotechnologies are used to sense, control, or heal biological systems, and by bioinspired devices, when innovative nanoelectronic devices mimic the function of biological systems.

The first chapter of the book contains the basic principles and theoretical concepts of nanosciences and nanotechnologies, which are further used in the entire book. The second chapter is dedicated to the sensing of biomolecules, including single biomolecules such as DNA, using various techniques, for example, nanoelectronic devices based on nanowires, carbon nanotubes, or graphene, nanocantilevers, or plamonic devices. An artificial nose, which is able to sense various gases in very small quantities, of even few molecules, and to detect the gases associated with diseases such as lung cancer ends this chapter. Chapter 3 is dealing with the imaging tools used in nanotechnologies, such as atomic force microscopy (AFM), which are applied to determine important parameters of various biological systems. The manipulation of biomolecules using optical tweezers and dielectrophoresis is also described in this chapter. These three chapters form the basis for understating the bioinquiring nanodevices. Chapter 4 is focused on the applications in medicine of nanoelectronic devices, which perform complex tasks such as controlled drug delivery monitored by external signals, targeted cancer cell therapy, and mimicking organs such as lung.

Chapters 5, 6, and 7 are dedicated, respectively, to biomolecular architectures, molecular devices, and biocomputing. These chapters present biological

devices that perform mechanical, optical, or electrical actions usually associated to nonbiological devices. On the contrary, Chap. 8 gathers examples of bioinspired devices, which refer to mechanical, optical, or electrical devices designed based on nature's lessons. The book ends with Chap. 9, which deals with nano-bio integration, a subject that could prove invaluable in the future innovative nanodevices. The applications of nanotechnologies in biology and medicine will produce soon a revolution similar to that of communications and computers, which made possible the occurrence of the internet, mobile phones, and laptops. In the case of bionanoelectronics and nanomedicine, we hope that the final result will be a better and healthier life, in a cleaner environment, the nanotechnologies contributing to the diagnosis and therapy of serious diseases as well as to the development of environmental-friendly technological processes.

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