Nanotechnologies for the Life Sciences

Edited by Challa Kumar

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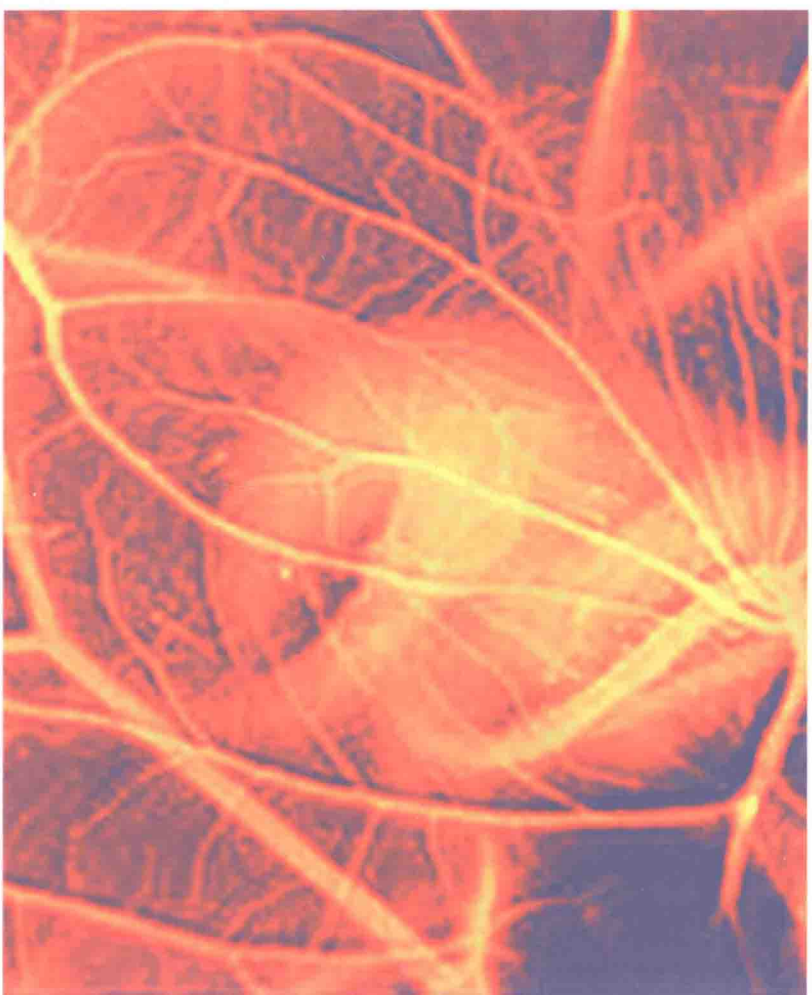
# Nanomaterials for Biosensors



NtLS

*Nanotechnologies for the Life Sciences*
*Volume 8*

# Nanomaterials for Biosensors

*Edited by*
*Challa S. S. R. Kumar*


WILEY-VCH Verlag GmbH & Co. KGaA

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**Cover**
Cover design by G. Schulz based on Micrograph Courtesy of Quantum Dot Corporation.



**Library of Congress Card No.:** applied for
**British Library Cataloguing-in-Publication Data**
A catalogue record for this book is available from the British Library.

**Bibliographic information published by the Deutsche Nationalbibliothek**
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at ⟨http://dnb.d-nb.de⟩.



Printed in the Federal Republic of Germany
Printed on acid-free paper

**Typesetting** Asco Typesetters, Hongkong
**Printing and bookbinding** buch bücher dd ag, Birkach
**Cover Design** Grafik-Design Schulz, Fußgönheim

**ISBN** 978-3-527-31388-4

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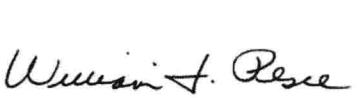

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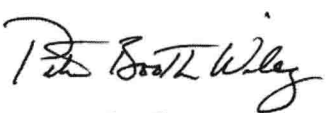

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Kumar, C. S. S. R. (ed.)

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# Preface

As we come closer to the completion of the ten-volume series on *Nanotechnologies for the Life Sciences*, I am reminded of a statement by the great scientist Arthur C Clarke who said: "Any sufficiently advanced technology is indistinguishable from magic." This statement is particularly true in molecular biosensing based on nanomaterials where the detection limits are 'magically' becoming smaller and smaller, even reaching zeptomolar concentrations in addition to opening up possibilities for ultra-sensitive multiplexed detection. Thanks to the development of novel concepts such as bio-bar-code assays, nanomaterials-based companies are revolutionizing the commercialization of molecular diagnostics at breathtaking speeds. Therefore, on behalf of a great team of nano researchers who have been involved in the development of nanomaterials for biosensing and particularly those who have contributed to this specific volume, I am pleased to introduce you the 8$^{th}$ volume of the series, *Nanomaterials for Biosensors*. We have come a long way in our journey since the publication of the first volume of the series, *Biofunctionalization of Nanomaterials*, into bringing the existing knowledge base of applications of nanotechnologies in biology, biotechnology and medicine on a single platform. The eigth volume has thirteen chapters covering various aspects of biomolecular sensing using a variety of nanomaterials such as carbon nanotubes, nanowires, nanocantilevers, fullerenes, denrimers in addition to metallic and quantum dot nanoparticles. The most exciting and unique aspect of the book is that it deals with the utilization of nanomaterials not only for enhancing the capabilities in conventional biosensing platforms, but also brings out newer approaches such as biomimetic and reagent-less biosensing.

The first four chapters of the book are dedicated to various modes of biosensing using carbon-based nanomaterials. The first chapter by Padmakar D. Kichambare and Alexander Star from the University of Pittsburgh, USA, provides an overview of recent advances in biodetection using single-walled carbon nanotube field-effect transistors (NTFETs) focusing primarily on fabrication of NTFET devices and how carbon nanotubes can be effectively integrated into conventional electronics for biosensor applications, for example, antibody–antigen interactions, DNA hybridization, glucose detection and enzymatic reactions. The chapter entitled *Biosensing using Carbon Nanotube Field-effect Transistors* provides a promising outlook for novel sensing applications of carbon nanotubes in living systems as

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ISBN: 978-3-527-31388-4

well as new opportunities for CNT-based bioelectronics. In addition to the utility of CNTs as field effect transistors, they can also be used as material of construction as nanoelectrodes, which can be utilized as electrochemical sensing systems. The second chapter, *Carbon Nanotube-based Sensors*, contributed by Jian-Shan Ye and Fwu-Shan Sheu from the National University of Singapore, brings out the importance of various methods utilized for preparing CNT electrodes and different ways to functionalize them for biosensing applications. Particularly interesting in this chapter is the discussion on mechanistic aspects of electrocatalysis by CNTs. The chapter will be very useful for those who are interested in exploiting the electrochemistry of CNTs in molecular diagnostics. Though CNTs are the most well-studied amongst one-dimensional nanomaterials, there are a considerable number of research investigations into exploiting the potential of other 1D nanomaterials like semiconducting nanowires and cantilevers. The third chapter, therefore, is a comprehensive review on silicon nanowires, conducting polymer nanowires, metal oxide nanowires, and nanocantilevers with reference to carbon nanotubes. The chapter, *Nanotubes, Nanowires, and Nanocantilevers in Biosensor Development*, contributed by Jun Wang, Guodong Liu, and Yuehe Lin from Pacific Northwest National Laboratory in Richland, USA, provides up to date information on the development of 1D-nanomaterial-based biosensors. The fourth and final chapter on carbon nanomaterials for biosensing is *Fullerene-based Electrochemical Detection Methods for Biosensing* presented by Nikos Chaniotakis from the University of Crete, Greece. Fullerenes have not received as much attention as CNTs as suitable materials for biosensing, mainly because their physicochemical characteristics are still not very well understood. However, the chapter provides a complete picture on several possibilities for fullerenes to offer new and powerful tools as electrochemical biosensors especially in signal mediation, protein and enzyme functionalization, and light-induced switching.

Nanomaterials also offer opportunities for ultra-sensitive biomolecular sensing through their local field optical effects, which are several orders of magnitude higher than the corresponding bulk effects. Optically active metallic and quantum dot nanomaterials have opened up avenues for newer techniques such as local surface plasmon resonance (LSPR), surface-enhanced Raman scattering (SERS), surface-enhanced fluorescence (SEF), fluorescence resonance energy transfer (FRET), time-resolved fluorimetry, and others. The next two chapters in the book provide an overview of these technologies. The fifth chapter, *Optical Biosensing Based on Metal and Semiconductor Colloidal Nanocrystals* by R. Comparelli, L. Curri, P. D. Cozzoli, and M. Striccoli from the Italian National Research Council's Institute of Physicochemical Processes of CNR in Bari, focuses in general on metal and quantum dot-based optical biosensing, providing a comparative assessment of recent developments categorized into various novel and/or improved optical techniques with traditional methods. The sixth chapter is exclusively dedicated to optical biosensing by quantum dots. Authors Rumiana Bakalova, Zhivko Zhelev, Hideki Ohba, and Yoshinobu Baba from the AIST-Kyushu National Institute of Advanced Science and Technology in Saga and Nagoya University, both in Japan, present an overview on the current status and future trends of QD-based biosensor develop-

ment. The chapter, *Quantum Dot-based Nanobiohybrids for Fluorescent Detection of Molecular and Cellular Biological Targets*, covers not only the basic principles of design and synthesis of highly fluorescent QDs, but also intricacies of *in vitro* and *in vivo* cellular and deep-tissue imaging.

The utility of gold nanoparticles in optical biosensing is very well known and already finding several commercial applications. However, the application of gold nanomaterials' capability as amperometric sensor is only recently being recognized as very promising and powerful tools in bio-fluid or biomaterial investigations and their associated clinical studies. The seventh chapter, *Detection of Biological Materials by Gold Nano-biosensor-based Electrochemical Methods*, provides a review on gold nanowire arrays and their utility as biosensors in bacterial detection. The authors, Juan Jiang, Manju Basu, Sara Seggerson, Albert Miller, Michael Pugia, and Subhash Basu from the university of Notre Dame in Indiana, USA, provides an in-depth analysis of the application of electrochemical impedance spectroscopy (EIS) in gold nanomaterial-based biosensing and demonstrates the technique's potential in clinical laboratories, environmental monitoring and the food industry to achieve rapid and sensitive detection. Continuing on a similar theme related to electrochemical sensing but utilizing dendrimeric nanomaterials, authors Hak-Sung Kim and Hyun C. Yoon from KAIST at Daejeon, Korea, cover various facets of bioelectrocatalytic enzyme sensors in the eighth chapter. *Dendrimer-based Electrochemical Detection Methods* is a must for readers interested in the fabrication of dendrimer-based biocomposite mono-/multilayers and their biosensing applications.

Each of the last five chapters in the book brings out several fascinating facets of nanomaterial-based biosensing very different from what we have seen so far in the first eight chapters. The author of the ninth chapter, *Coordination Biosensors: Integrated Systems for Ultrasensitive Detection of Biomarkers*, Joanne Yeh from the University of Pittsburgh Medical School, USA, presents altogether a different approach to biosensing, utilizing newer concepts to align the signal transduction centers to enhance the kinetics of reactions leading to improved sensitivity of detection. It has been observed that there is a direct electrochemical and catalytic activity of many proteins at electrodes modified with various nanomaterials such as $TiO_2$, $ZrO_2$, $SiO_2$ , $Fe_3O_4$, metal nanoparticles and carbon nanotubes. In the tenth chapter, the author Genxi Li from Nanjing University in China reviews the literature to demonstrate that nanomaterials can not only provide a friendly platform for the assembly of protein molecules but also enhance the electron-transfer process between protein molecules and the electrode. The chapter entitled *Protein-based Biosensors using Nanomaterials* brings out the advantages of combining proteins and nanomaterials to develop sensitive biosensor elements. Proteins and in general various nano-size structures in the field of life sciences provide testimony to the endless possibilities and elegant applications in our day to day world. Therefore, it is not very surprising that a new branch of science, 'Biomimetics', has roots in a variety of scientific disciplines, and the field of biosensors is not an exception. In the eleventh chapter, authors Raz Jelinek and Sofiya Kolusheva from Ben Gurion University of the Negev in Beer-Sheva, Israel, brings out the utility of concepts and methodologies from the biological world into the laboratory. The

chapter, *Biomimetic Nanosensors*, provides a broader perspective on bio-inspired devices and applications related to nanomaterial-based biosensing.

As the title indicates, the twelfth chapter, *Reagentless Biosensors Based on Nanoparticles*, provides the readers with yet another novel concept in biosensing, where sensing tools are being developed based on perturbation of nanoparticle properties, without the need for reagents, in order to produce unique yet sensitive signals for biomeoclecular sensing. The author, David Benson from Wayne State University in Detroit, USA, provides a strong case for adaptation of reagentless concepts that provide sensors that can be adapted to various detection platforms. The book concludes with its thirteenth chapter, wherein the authors, Shohei Yamamura, Sathuluri Ramachandra Rao, and Eiichi Tamiya from Japan Advanced Institute of Science and Technology at Nomi, Japan, bring us closer to biosensing devices incorporating highly integrated microarray systems that can perform assays at pico- and nano-liter volume level. In this chapter, *Pico/Nanoliter Chamber Array Chips for Single-cell, DNA and Protein Analyses*, the authors discuss three very important topics – novel multiplexed PCR, cell-free protein synthesis, and high-throughput single-cell analysis systems using nanolitre microarray platforms.

Nanotechnology embodies the spirit of interdisciplinary approaches and teams. I am, therefore, very grateful to all the authors who have shared my enthusiasm and vision by contributing high-quality manuscripts keeping in tune with the theme of this volume. It is primarily due to their scholarly contributions that this book comes into existence. I am thankful to my employer, the Center for Advanced Microstructures and Devices (CAMD), for providing me with an opportunity to undertake this enormous project. No words can express the understanding of my family, friends, mentors and most importantly the readers who are now an integral part of my existence and continue to shape my life and I am indebted to them. Finally, Wiley-VCH publishers have done a remarkable job and I am grateful for their support.

September 2006
Baton Rouge

*Challa S. S. R. Kumar*

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# Contents



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ISBN: 978-3-527-31388-4