

Edited by Challa Kumar

WILEY-VCH

Nanomaterials for Biosensors



NtLS

Contents

Preface XV

List of Authors XIX

1 Biosensing using Carbon Nanotube Field-effect Transistors 1

Padmakar D. Kichambare and Alexander Star

- 1.1 Overview 1
- 1.2 Introduction 1
- 1.3 Carbon Nanotube Field-effect Transistors (NTFETs) 3
 - 1.3.1 Carbon Nanotubes 3
 - 1.3.2 Nanotube Synthesis 4
 - 1.3.3 Fabrication of NTFETs 6
- 1.4 Sensor Applications of NTFETs 9
 - 1.4.1 Sensitivity of NTFETs to Chemical Environment 9
 - 1.4.2 Bioconjugates of Carbon Nanotubes 12
 - 1.4.3 Protein Detection 14
 - 1.4.4 Detection of Antibody–Antigen Interactions 15
 - 1.4.5 DNA Detection 17
 - 1.4.6 Enzymatic Reactions 19
 - 1.4.7 Glucose Detection 20
- 1.5 Conclusion and Outlook 21
- References 21

2 Carbon Nanotube-based Sensor 27

Jian-Shan Ye and Fu-wu Shan Sheu

- 2.1 Overview 27
- 2.2 Introduction of Carbon Nanotubes 27
- 2.3 Growth of Carbon Nanotubes 29
- 2.4 Methods to Prepare CNTs-based Sensors and Biosensors 29
 - 2.4.1 Individual MWCNTs as Nanoelectrodes 29
 - 2.4.2 Randomly Distributed CNT Electrodes 30
 - 2.4.3 Well-aligned Carbon Nanotube Electrodes 30
 - 2.4.4 Carbon Nanotube Paste Electrodes 31

2.4.5	Screen-printing Carbon Nanotubes	32
2.4.6	Self-assembly of Carbon Nanotubes	33
2.4.7	Carbon Nanotube-packaged Microelectrodes	34
2.5	Application of CNTs-based Electrochemical Sensors and Biosensors	34
2.5.1	Electrochemical and Electrocatalytical Properties of Carbon Nanotubes	34
2.5.2	CNTs-based Electrochemical Biosensors	37
2.6	Functionalization of CNTs	39
2.6.1	Biological Functionalization of CNTs	39
2.6.2	Self-assembly of Surfactant and Lipid Molecules at CNTs	39
2.6.3	Electrochemical Functionalization of CNTs	42
2.6.4	Electrochemical Application of Functionalized CNTs	43
2.6.4.1	Application of Lipid–CNT Nanomaterials in Electrochemical Sensors	43
2.6.4.2	Achieving direct Electron Transfer to Redox Proteins by Functional CNTs	44
2.6.4.3	Biomolecule-functionalized CNTs for Electrochemical Sensors and Biosensors	45
2.7	Conclusions and Future Prospects	48
	Acknowledgments	49
	References	49
3	Nanotubes, Nanowires, and Nanocantilevers in Biosensor Development	56
	<i>Jun Wang, Cuodong Liu, and Yuehe Lin</i>	
3.1	Introduction	56
3.2	Carbon Nanotubes in Biosensor Development	57
3.2.1	Preparation and Purification of CNTs	58
3.2.2	Construction of CNT-based Biosensors	60
3.2.2.1	Dispersion and Stabilization by Oxidative Acids	60
3.2.2.2	Dispersion by Surfactant Interaction	61
3.2.2.3	Polymer-assisted Solubilization	61
3.2.2.4	CNT Adsorption on the Transducer Substrate	61
3.2.2.5	Surface Functionalization of CNTs	62
3.2.2.6	Composite Entrapment and CNTs Bulky Electrode Material	63
3.2.2.7	More Sophisticated Surface Tailoring Based on Combination of Co-adsorption, Integration, Prohibition, Spacing, Linkage, Sandwich, Tagging, and other Anchoring Approaches	66
3.2.3	CNT-based Electrochemical Biosensors	69
3.2.3.1	Direct Electrochemistry of Biomolecules on Carbon Nanotubes	69
3.2.3.2	Enzyme/CNTs Biosensors	72
3.2.3.3	DNA and Protein Biosensors	73
3.2.3.4	Immunosensors	74
3.2.4	Flow-injection Analysis	75
3.2.5	Carbon Nanotube Array-based Biosensors	76
3.2.6	Chemiluminescence	80

3.2.7	Field-effect Transistor and Bioelectronics	81
3.3	Nanowires in Biosensor Development	84
3.3.1	Silicon Nanowire-based Biosensors	84
3.3.2	Conducting Polymer Nanowire-based Biosensors	86
3.3.3	Metal Oxide Nanowire-based Biosensors	89
3.4	Nanocantilevers for Biosensors	89
3.5	Summary	90
	Acknowledgments	91
	Glossary	91
	Abbreviations	92
	References	93
4	Fullerene-based Electrochemical Detection Methods for Biosensing	101
	<i>Nikos Chaniotakis</i>	
4.1	Introduction	101
4.2	Aims of the Chapter	101
4.3	Electrochemical Biosensing	103
4.3.1	Making a Biosensor	105
4.4	Evolution of Biosensors	105
4.5	Mediation Process in Biosensors	106
4.5.1	Case A: Non-mediated Biosensor	107
4.5.2	Case B: Mediated Biosensor	108
4.6	Fullerenes	109
4.6.1	Synthesis of Fullerenes	109
4.6.2	Biofunctionalization of Fullerenes	109
4.6.3	Electrochemistry of Fullerenes	113
4.7	Fullerene-mediated Biosensing	114
4.8	Conclusions	118
	References	118
5	Optical Biosensing Based on Metal and Semiconductor Colloidal Nanocrystals	123
	<i>Roberto Comparelli, Maria Lucia Curri, Pantaleo Davide Cozzoli, and Marinella Striccoli</i>	
5.1	Overview	123
5.2	Introduction	123
5.3	Colloidal Nanocrystals	127
5.3.1	Size-dependent Optical Properties	127
5.3.2	Chemical Synthesis	131
5.4	Nanocrystal Functionalization for Biosensing	134
5.4.1	Surface Capping Exchange	135
5.4.2	Coating with a Silica Shell	137
5.4.3	Surface Modification through Hydrophobic Interactions	137
5.5	Optical Techniques	139
5.5.1	Colorimetric Tests	139

5.5.2	Fluorescence	139
5.5.3	Fluorescence Resonance Energy Transfer	141
5.5.4	Fluorescence Lifetime	142
5.5.5	Multiphoton Techniques	145
5.5.6	Metal-enhanced Fluorescence	145
5.5.7	Surface Plasmon Resonance	146
5.5.8	Surface-enhanced Resonance Spectroscopy	149
5.6	Advantages and Disadvantages of Nanocrystals in Optical Detection	152
5.7	Applications	153
5.7.1	Biosensing with Semiconductor Nanocrystals	153
5.7.2	Biosensing with Metallic Nanoparticles	157
5.8	Towards Marketing	162
5.9	Conclusions	164
	References	164
6	Quantum Dot-based Nanobiohybrids for Fluorescent Detection of Molecular and Cellular Biological Targets	<i>175</i>
	Zhivko Zhelev, Rumiana Bakalova, Hideki Ohba, and Yoshinobu Baba	
6.1	Introduction	175
6.2	Quantum Dots – Basic Principles of Design and Synthesis, Optical Properties, and Advantages over Classical Fluorophores	176
6.2.1	Basic Principles of Design and Synthesis of Quantum Dots	176
6.2.2	Optical and Chemical Properties – Advantages Compared with Classical Fluorophores	178
6.3	Quantum Dots for Fluorescent Labeling and Imaging	181
6.3.1	Structure of Quantum Dot Nanobiohybrids for Fluorescent Microscopic Imaging	181
6.3.2	Quantum Dots for Fluorescent Cell Imaging	182
6.3.3	Quantum Dots for Fluorescent Deep-tissue Imaging <i>In Vivo</i>	184
6.3.4	Potential of Quantum Dots for Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI)	191
6.4	Quantum Dots for Immunoblot Analysis with Fluorescent Detection	192
6.4.1	Basic Principles of Classical and QD-based Immunoblot Analyses	192
6.4.2	QD-based Immunoblot Analysis of “tracer” Proteins – Privileges over Classical Immunoblot Analysis	194
6.5	Quantum Dots for FRET Analyses, Time-resolved Fluorimetry, and Development of Optical Recognition-based Biosensors	196
6.5.1	Quantum Dots for FRET-based Bioanalyses	196
6.5.2	Quantum Dots for Time-resolved Fluorimetry	197
6.5.3	Quantum Dots for development of New Generation Optical Recognition-based Biosensors	197
6.6	Quantum Dots as New Fluorescent Standards for the Thin Calibration of Fluorescent Instrumentation	201
	References	201

7	Detection of Biological Materials by Gold Nano-biosensor-based Electrochemical Method	208
	<i>Juan Jiang, Manju Basu, Sara Seggerson, Albert Miller, Michael Pugia, and Subhash Basu</i>	
7.1	Introduction	208
7.2	Template Synthesis of Gold Nano-wire Arrays for Biosensor Applications	209
7.2.1	General Template Synthesis	209
7.2.2	Template Formation	212
7.2.3	Fabrication of Gold Nano-wire Arrays (GNW)	214
7.3	Synthesis of a Linker and its Attachment to Gold Posts of GNW followed by Binding to Specific Antibodies	220
7.4	Development of Electrochemical Nano-biosensor for Bacteria Detection	224
7.4.1	General Detections for Biosensors	224
7.4.2	Experimental Conditions	226
7.4.3	Electrochemical Impedance (EIS) Detection of <i>E. coli</i>	227
7.4.3.1	EIS on Flat Gold Surfaces	228
7.4.3.2	EIS on GNW	230
7.4.3.3	EIS on GNW with Al ₂ O ₃	230
7.4.4	Summary of EIS Detection of <i>E. coli</i> Bacteria	233
7.5	Conclusions	235
	Acknowledgments	235
	References	236
8	Dendrimer-based Electrochemical Detection Methods	240
	<i>Hak-Sung Kim and Hyun C. Yoon</i>	
8.1	Overview	240
8.2	Introduction	240
8.2.1	Background	240
8.2.2	Dendrimers as a new Constituent of Biocomposite Structures	241
8.3	Applications for Biosensors	242
8.3.1	Bioelectrocatalytic Enzyme Electrodes based on LBL (layer-by-layer) Assembly with Dendrimers	243
8.3.2	Bioelectrocatalytic Immunosensors based on the Dendrimer-associated SAMs	244
8.3.2.1	Affinity Recognition Surface based on the Dendrimer-associated SAMs	244
8.3.2.2	Electrochemical Signaling from Affinity Recognition Reactions	248
8.3.3	Protein Micropatterning on Sensor Surfaces for Multiplexed Analysis	253
8.4	Conclusions	256
	Acknowledgments	256
	References	256

9	Coordinated Biosensors: Integrated Systems for Ultrasensitive Detection of Biomarkers	259
	<i>Joanne I. Yeh</i>	
9.1	Overview	259
9.2	Introduction	260
9.3	Elements of a Nanobiosensor	262
9.3.1	Biomolecular Components	262
9.3.2	Nanoparticles	263
9.3.3	Nanoelectrodes	264
9.4	Coordinated Biosensors	265
9.4.1	Biomolecular Conduits: Signal Transducing Mediators	265
9.4.2	NADH Peroxidase: the Biocatalytic Element	267
9.4.3	Undecagold Nanoparticle: Role in Alignment and Directing Electron Flow	270
9.4.4	Integrated Signals	270
9.5	Conclusion	272
	Acknowledgments	274
	References	274
10	Protein-based Biosensors using Nanomaterials	278
	<i>Genxi Li</i>	
10.1	Introduction	278
10.2	Metal Nanoparticles	279
10.2.1	Gold Nanoparticles	279
10.2.2	Silver Nanoparticles	284
10.2.3	Other Metal Nanomaterials	285
10.3	Metallic Oxide Nanoparticles	285
10.4	Carbon Nanotubes	286
10.5	Nanocomposite Materials	292
10.6	Nanoparticles with Special Functions	293
10.6.1	Semiconductor Nanoparticles	293
10.6.2	Magnetic Nanoparticles	295
10.7	Other Nanomaterials	295
10.8	Conclusion	297
	References	297
11	Biomimetic Nanosensors	311
	<i>Raz Jelinek and Sofiya Kolusheva</i>	
11.1	Introduction	311
11.2	Nanostructures in Biosensor Design	312
11.3	Nanosensors for Probing Biological and Cellular Systems	317
11.4	Biological Components in Nanosensors	323
11.5	Nano-biotechnology and Biomedical Diagnosis	327
11.6	Conclusions and Future Directions	329
	Abbreviations	330
	References	330

12	Reagentless Biosensors Based on Nanoparticles	337
	<i>David E. Benson</i>	
12.1	Introduction	337
12.2	Surface Dielectric Enhancement	339
12.2.1	Gold Nanoparticle Enhanced Surface Plasmon Resonance	340
12.2.2	Carbon Nanotube and Silicon Nanowire Enhanced Conductivity	343
12.2.3	Advantages and Caveats	346
12.3	Catalytic Activation	346
12.3.1	Electrocatalytic Detection	347
12.3.2	Catalytically Enabled Optical and Magnetic Detection	349
12.3.3	Advantages and Caveats	350
12.4	Biomolecule Conformational Modulated Effects	351
12.4.1	Biosensors Based on DNA Conformation Changes	352
12.4.2	Biosensors Based on Protein Conformation Changes	355
12.5	Conclusion	361
	Acknowledgments	362
	References	362
13	Pico/Nanoliter Chamber Array Chips for Single-cell, DNA and Protein Analyses	368
	<i>Shohei Yamamura, Ramachandra Rao Sathuluri, and Eiichi Tamiya</i>	
13.1	Introduction	368
13.2	Multiplexed Polymerase Chain Reaction from A Single Copy DNA using Nanoliter-volume Microchamber Array	369
13.2.1	PCR Microchamber Array Chip System	371
13.2.1.1	Microchamber Array Chip Fabrication	371
13.2.1.2	Sample Loading with a Nanoliter Dispenser	372
13.2.2	Multiplexed Detection of Different Target DNA on a Single Chip	373
13.2.3	On-chip Quantification of Amplified DNA	376
13.3	On-chip Cell-free Protein Synthesis using A Picoliter Chamber Array	378
13.3.1	Cell-free Protein Synthesis Chip Fabrication	379
13.3.2	Cell-free Protein Synthesis using a Microchamber Array	381
13.4	High-throughput Single-cell Analysis System using Pico-liter Microarray	384
13.4.1	Single-cell Microarray Chip Fabrication	386
13.4.2	Pico-liter Microarray for Single-cell Studies	388
13.4.3	Single-cell Microarray System for Analysis of Antigen-specific Single B-cells	389
13.5	Conclusions	392
	Acknowledgments	393
	References	393
	Index	398