

Contents

1 Stem Cells and Nanostructured Materials.....	1
1.1 Introduction.....	1
1.2 Interaction of Stem Cells with Nanotopographic Substrates.....	3
1.2.1 Cell Shape and the Cytoskeleton.....	4
1.2.2 Morphology, Attachment and Proliferation.....	5
1.2.3 Differentiation.....	6
1.2.4 Self-Assembling Peptide Nanofibers.....	8
1.2.5 Summary.....	8
1.3 Stem Cell Interactions with Nanoparticles.....	9
1.3.1 Nanoparticles as Contrast Agents.....	10
1.3.2 Nanoparticles as Vehicles.....	10
1.3.3 Effect of Internalized Nanoparticles.....	11
1.3.4 Summary.....	17
1.4 Conclusions.....	17
Acknowledgements.....	18
References.....	18
2 Biomedical Polymer Nanofibers for Emerging Technology.....	21
2.1 Introduction.....	21
2.2 Electrospinning Technology-History, Principle, Parameter.....	23
2.3 Functionalization of Nanofibers.....	25
2.3.1 Bulk Modification.....	25
2.3.2 Surface Modification.....	27
2.4 Biomedical Applications.....	29
2.4.1 Tissue-Engineered Scaffolds.....	29
2.4.2 Wound Dressing.....	35
2.4.3 Biomedical Devices and Implants.....	36
2.4.4 Drug Delivery System.....	37
2.4.5 Other Applications.....	38
2.5 Concluding Remark.....	39
Acknowledgement.....	39
References.....	40
3 Nanoscale Mechanisms for Assembly of Biomaterials.....	43
3.1 Introduction.....	43

3.2	Non-Covalent Intermolecular Interaction	45
3.2.1	Electrostatic Interaction.....	46
3.2.2	Hydrogen Bonding	50
3.2.3	Hydrophobic Interactions	50
3.2.4	Non-Covalent Interactions in Biological Systems.....	51
3.2.5	Summary	52
3.3	Approaches for Bioinspired Nanoscale Assembly of Biomaterials	52
3.3.1	Supramolecular Assembly Based Primarily on Ion-Ion Interactions.....	53
3.3.2	Assembly of Amphiphilic Biomaterials	55
3.3.3	Biomimetic Supramolecular Assembly Based on Hydrogen Bonding.....	57
3.3.4	Biomimetic Assembly Based on Affinity-Based Interactions....	58
3.3.5	Summary	59
3.4	Development of Biomaterials That Mimic The Natural ECM	59
3.4.1	Introduction	59
3.4.2	Non-Covalent Interactions in Natural Extracellular Matrices.....	60
3.4.3	Biomaterials That Mimic ECM Structures and Properties	61
3.5	Concluding remarks	70
	Acknowledgements	71
	References	71
4	Fabrication and Assembly of Nanomaterials and Nanostructures for Biological Detections	76
4.1	Introduction.....	76
4.2	Semiconductor Quantum Dots and Metal Nanoparticles	77
4.2.1	Principles of Semiconductor QDs and Metal Nanoparticle Biosensors.....	77
4.2.2	Fabrication of semiconductor QDs and metal nanoparticles for biosensors	80
4.2.3	Assembly of QD and Metal Nanoparticle Arrays for Biosensor Applications	81
4.3	Field Effect Sensors Based on Nanowires and Nanotubes.....	82
4.3.1	Detection Principles of 1-D Nanowire and Nanotube-Based Biosensors.....	82
4.3.2	Fabrication of 1-D Nanowires and Nanotubes	83
4.3.3	Assembly of Ordered Nanowire and Nanotube Arrays	85
4.3.4	Horizontally-Aligned Growth of Single-Walled Nanotubes (SWNTs) on Substrates.....	86
4.4	Micro-cantilever sensors	89
4.4.1	Detection Principle of Micro-Cantilever Sensors.....	89

4.4.2	Fabrication of the array of micro-cantilever sensors	90
4.5	Summary	91
	References	92
5	Nanostructured Materials Constructed from Polypeptides	96
5.1	Introduction	96
5.2	Amino Acids and Their Derivatives: Building Blocks for Nanostructured Materials	97
5.2.1	Canonical Amino Acids	97
5.2.2	Non-canonical Amino Acids	99
5.2.3	Peptidomimetics and Peptide Derivatives	100
5.3	Secondary, Tertiary, and Quaternary Structures in Nanomaterials	102
5.3.1	β -Sheet Fibrils	102
5.3.2	α -Helices and Coiled Coils	107
5.4	Materials Properties Arising from Peptide Construction	114
5.4.1	Stimulus-Responsiveness	114
5.4.2	Multifunctionality and Modularity	116
5.5	Technological Applications of Nanoscale Peptide Materials	119
5.5.1	Tissue Engineering and Regenerative Medicine	119
5.5.2	Antimicrobials	121
5.5.3	Controlled Drug Release	121
5.5.4	Nanoscale Electronics	122
5.6	Concluding Remarks	122
	References	123
6	Photoluminescent Carbon Nanomaterials: Properties and Potential Applications	128
6.1	Introduction	128
6.2	Photoluminescent Carbon Particles-Carbon Quantum Dots	130
6.3	Photoluminescent Carbon Nanotubes	135
6.3.1	A Consequence of Functionalization	136
6.3.2	Photoluminescence Features and Properties	137
6.3.3	Defect-Derived vs Band-Gap Emissions	143
6.4	Dots vs Tubes—Luminescence Polarization	144
6.5	Potential Applications	147
	Acknowledgement	150
	References	150
7	Microwave-assisted Synthesis and Processing of Biomaterials	154
7.1	Introduction	154
7.2	Synthesis of Hydroxyapatite	156
7.2.1	Synthesis in Aqueous Solution	157
7.2.2	Microwave-Hydrothermal Synthesis	162

7.2.3	Synthesis of HA by the Conversion of Precursor Monetite Prepared in Mixed Solvents	163
7.2.4	Preparation of HA Thin Film.....	165
7.2.5	Synthesis by Solid State Reaction	166
7.3	Synthesis of β -Tricalcium Phosphate (β -Ca ₃ (PO ₄) ₂).....	166
7.4	Synthesis of Calcium Carbonate (CaCO ₃)	167
7.5	Synthesis of Composite Biomaterials	171
7.6	Synthesis of Functionally Graded Bioactive Materials	173
7.7	Microwave Sintering of Biomaterials	174
	References.....	176
8	Characterizing Biointerfaces and Biosurfaces in Biomaterials Design.....	178
8.1	Introduction	178
8.2	Characterization of Biointerfaces.....	181
8.2.1	Surface and Interface Analysis Using Fourier Transform Infrared Spectroscopy	181
8.2.2	Surface and Interface Analysis Using Atomic Force Microscopy	183
8.2.3	X-ray Photoelectron Spectroscopy	187
8.2.4	Contact Angle.....	188
8.2.5	Time-of-Flight Secondary Ions Mass Spectrometry (ToF-SIMS).....	189
8.3	Nano-Structuring Surfaces	190
8.3.1	Nanotopology.....	191
8.3.2	Nanopatterning Surfaces with Biomolecules.....	192
8.4	Conclusions	195
	References.....	196
9	Carbon Nanotubes for Electrochemical and Electronic Biosensing Applications.....	205
9.1	Introduction	205
9.2	Design Principles of CNT-Based Biosensors	206
9.2.1	CNTs as Modifiers of Electrode Surfaces	206
9.2.2	CNT-Based Composite Electrodes	209
9.2.3	Nanoparticles Decorated CNT-Based Electrodes	210
9.2.4	CNTs as Key Sensing Elements	211
9.2.5	CNT-Based Biosensors with Immobilized Biological Molecules.....	212
9.3	Electrochemical Detection of Biomolecules	218
9.3.1	Assessment Criteria of Sensors	224
9.3.2	Electrochemical Biosensors.....	224
9.4	Field-Effect Transistors Based on SWNTs.....	236

9.4.1	Protein Recognition.....	237
9.4.2	DNA Hybridization	239
9.4.3	Enzymatic Study.....	240
9.4.4	Protein Adsorption.....	240
9.4.5	Others	241
9.5	Conclusions and Future Prospects.....	241
	Acknowledgement.....	242
	Reference	242
10	Heparin-Conjugated Nanointerfaces for Biomedical Applications....	247
10.1	Introduction.....	247
10.2	Heparin-Bound Biodegradable Polymers for Biocompatible Interfaces	249
10.2.1	Heparin-Conjugated Polylactide (PLA-Hep)	249
10.2.2	Heparin-Conjugated Star-Shaped PLA (sPLA-Hep)	254
10.3	Heparin-Conjugated Polymeric Micelles.....	260
10.3.1	Synthesis of Tetronic®-PCL-Heparin Conjugate	260
10.3.2	Preparation of bFGF Loaded Polymeric Micelle	262
10.3.3	bFGF Release Study.....	264
10.3.4	Bioactivity of the Released bFGF	266
10.4	Heparin-Immobilized Small Intestinal Submucosa (SIS)	266
10.4.1	Preparation of Heparin-Immobilized SIS	266
10.4.2	Blood Compatibility Test	267
10.4.3	In Vitro Fibroblast Attachment.....	268
10.4.4	In Vivo Calcification	269
10.5	Conclusions.....	270
	References.....	270
11	Inorganic Nanoparticles for Biomedical Applications.....	272
11.1	Introduction.....	272
11.2	Unguided Drug Delivery Systems.....	274
11.2.1	Chemical Synthesis of Ceramic Nanomaterials	275
11.2.2	Functionalization of Ceramic Nanomaterials	276
11.3	Magnetically-Guided Drug Delivery Systems	277
11.3.1	Magnetic Guiding.....	277
11.3.2	Chemical Synthesis and Properties of Magnetic Nanostructures.....	277
11.3.3	Functionalization of Magnetic Nanoparticles.....	279
11.3.4	Biocompatibility of Magnetic Nanoparticles for Drug Delivery.....	280
11.4	Optically-Triggered Drug Delivery Systems.....	280
11.4.1	Chemical Synthesis and Properties of NIR-Sensitive Nanoparticles.....	281

11.4.2	Functionalization of NIR-Sensitive Nanoparticles	282
11.4.3	Biocompatibility of NIR-Sensitive Nanoparticles for Drug Delivery.....	282
11.5	Summary	284
	References.....	284
12	Nano Metal Particles for Biomedical Applications	290
12.1	NMPs as Contrast Agents for Bioimaging	290
12.2	Fluorescing NMPs.....	292
12.3	NMPs with High Plamon Field for Fluorescence Manipulation....	293
12.3.1	NMPs Used for Fluorescence Quenching	294
12.3.2	NMP for Fluorescence Enhancement in Biosensing	295
12.3.3	NMP for Fluorescence Enhancement in Bioimaging	301
12.4	Magnetic NMPs for Bioseparation.....	302
12.5	Magnetic NMPs for Biosensing	303
12.6	Magnetic NMPs for Cancer Hyperthermia	305
12.7	MultiFunctional NMPs	308
12.8	Conclusions.....	310
	Acknowledgements.....	310
	References.....	310
13	Micro- and Nanoscale Technologies in High- Throughput Biomedical Experimentation	314
13.1	Introduction.....	315
13.2	Microarray Technologies	316
13.2.1	Evolution of Microarrays	317
13.2.2	Microarray Fabrication and Applications.....	318
13.2.3	DNA and cDNA Microarrays	321
13.2.4	Protein and Antibody-Based Microarrays	323
13.2.5	Cell-Based Microarrays.....	325
13.2.6	Other Microarrays and Microarray-Based Diagnostics....	326
13.3	Micro- and Nanoengineering for Biomedical Experimentation.....	327
13.4	Microfluidics.....	329
13.5	Other Micro- and Nanoscale Technologies for Biological and Chemical Detection.....	333
13.6	Conclusions.....	336
	Acknowledgements.....	336
	References.....	337
14	Delivery System of Bioactive Molecules for Regenerative Medicine	347
14.1	Introduction.....	347
14.2	Delivery Systems of Bioactive Molecules	348

14.2.1	Importance of Bioactive Molecules Release System for the Regenerative Medicine.....	348
14.2.2	Scaffold System.....	353
14.2.3	Injectable Hydrogel System	356
14.2.4	Microspheres System	357
14.2.5	Nanofiber Scaffold System	358
14.3	Differentiation of Adult Stem Cells Using Delivery System of Bioactive Molecules	359
14.3.1	Osteoogenesis of MSC	359
14.3.2	Chondrogenesis of MSCs.....	360
14.4	Repair of Diaphyseal Long Bone Defect with Calcitriol Released Delivery Vehicle and MSCs.....	361
14.5	Future Directions	364
14.6	Conclusion	365
	Acknowledgements.....	365
	References.....	365
15	Modification of Nano-sized Materials for Drug Delivery	369
15.1	Introduction.....	369
15.2	Available Methods to Modify Nano-Sized Materials for Drug Delivery	371
15.2.1	Surface Modification.....	371
15.2.2	Shell-Core Modification.....	374
15.2.3	Bulk Modifications.....	374
15.3	Applications for Drug Delivery of Modified Nano Sized Biomaterials.....	375
15.3.1	Long Circulating Delivery.....	375
15.3.2	Targeting Delivery.....	378
15.3.3	New Therapy and Drug Carriers	382
15.4	Conclusions.....	384
	Acknowledgements.....	384
	References.....	384
16	Polymeric Nano Micelles as a Drug Carrier	388
16.1	Introduction.....	388
16.2	Self-Assembly and Micellization of Amphiphilic Block Copolymers.....	389
16.2.1	Amphiphilic Block Copolymers.....	389
16.2.2	Micellization of Amphiphilic Block Copolymers	390
16.2.3	Polymeric Micelle Shape.....	391
16.2.4	Characterization of Polymeric Micelle Size.....	392
16.2.5	CMC Determination of Polymeric Micelles.....	393

16.3	Drug Loaded Polymeric Micelles	395
16.3.1	Drug Incorporation in Polymeric Micelles.....	395
16.3.2	Drug Solubilization Capacity of the Polymeric Micelles.....	396
16.3.3	Drug Partitioning in Polymeric Micelles.....	396
16.3.4	Drug Release from Polymeric Micelles	397
16.4	Biological Applications of Polymeric Micelles	398
16.4.1	Biodistribution.....	398
16.4.2	Accumulation in Target Solid Tumors.....	399
16.5	Conclusions and Outlook.....	399
	References.....	400
17	DNA Nanotechnology	405
17.1	Introduction.....	405
17.2	Basic Features of DNA	406
17.3	Self-Assembly of DNA Nanostructures	407
17.3.1	Basic Concepts	407
17.3.2	Two-Dimensional DNA Array Structures.....	408
17.3.3	Three-Dimensional DNA Nanostructures	413
17.4	Self-Assembly Properties of DNA Nanostructures.....	414
17.4.1	DNA Templated Self-Assembly of Biological Molecules.....	415
17.4.2	DNA-Templated Self-Assembly of Nanoscale Devices	419
17.5	Application of DNA-Based Nanotechnology	419
17.6	Conclusions and Outlook.....	423
	References.....	424
18	Nanoscale Bioactive Surfaces and Endosseous Implantology.....	428
18.1	Introduction.....	428
18.2	Peri-implant Endosseous Healing and Osseointegration.....	429
18.2.1	Peri-Implant Endosseous Healing	429
18.2.2	Effect of Implant Surface Characteristics on Osseointegration.....	431
18.2.3	Potential Advantage of Nanoscale Surfaces	432
18.3	Nanoscale Bioactive Surfaces.....	434
18.3.1	Nanoscale Textured Surface.....	434
18.3.2	Nanoscale Biological Molecules.....	439
18.3.3	Nanoscale Bioactive Calcium Phosphate Coating.....	440
18.4	Summary	444
	Acknowledgements.....	444
	References.....	444

19	Carbon Nanotube Smart Materials for Biology and Medicine.....	451
19.1	Introduction.....	451
19.2	Carbon Nanotube Array Synthesis.....	453
19.2.1	Array Synthesis.....	453
19.2.2	Synthesis of Carbon Nanotube Towers.....	454
19.2.3	CNT Array Nanoskin and Nanostrands.....	455
19.3	Properties of Carbon Nanotube Arrays.....	457
19.3.1	Hydrophobic Property.....	457
19.3.2	Electrowetting Property.....	458
19.3.3	Capillarity Property.....	459
19.3.4	Nanotube Array Actuator.....	460
19.4	Potential Applications of Nanotube Arrays In Biology and Medicine.....	463
19.4.1	Electronic Biosensors.....	464
19.4.2	Nanotube Electrodes for Biovoltage and Chemical Sensing.....	467
19.4.3	Carbon Nanotube Sensor Film for Environmental Monitoring.....	468
19.4.4	Nanocomposite Materials for Biological Applications.....	469
19.4.5	In-Body Biosensors: Optimistic Hopes and Wildest Outlook.....	472
19.4.6	Investigating Neuronal Activity and Function Using Nanotubes.....	475
19.5	Conclusions.....	480
	Acknowledgement.....	480
	References.....	480
20	Microscopic Modeling of Phonon Modes in Semiconductor Nanocrystals.....	485
20.1	Introduction.....	485
20.2	Theory.....	488
20.2.1	The Valence Force Field Model.....	488
20.2.2	Application of Group Theory to the Study of Nanocrystals.....	490
20.2.3	The Bond Charge Approximation.....	496
20.2.4	Lamb Modes.....	498
20.3	Results and Discussion.....	501
20.3.1	Phonon Density of States for Nanocrystals.....	501
20.3.2	Raman Intensities.....	504
20.3.3	Size Effects on the Highest Phonon Frequencies of Si.....	505

20.3.4	Size Effects on the Lowest Frequencies Phonon for Si.....	508
20.3.5	Folding of Acoustic Phonons	509
20.3.6	Size Effects on Si Raman Peaks.....	510
20.3.7	Size Effects on Mode Mixing.....	511
20.3.8	Size Effects on the Intensities of Ge Raman Peaks	511
20.3.9	Size Effects on the Highest Raman Frequencies for Ge with Fixed or Free Surfaces.....	513
20.3.10	Existence of Interface Modes for Nanocrystals with Fixed Surfaces	515
20.4	Correspondence between the Microscopic and Macroscopic Active Raman Modes.....	516
20.4.1	Projection of the Lamb Modes	516
20.4.2	Group Theory Prediction of the Raman Intensities of the Lamb Modes.....	518
20.4.3	Identifying Lamb Modes within the VFFM-Determined Modes.....	518
20.4.4	The Radial Distribution Function of Ge Nanocrystals	523
20.4.5	Raman Intensities for Ge NC and Lamb modes.....	523
20.5	Conclusions.....	527
	Acknowledgements.....	528
	Appendices.....	528
A.1	The Irreducible Matrices of the T_d Group Used in Our Calculations are as Follows.	528
A.2	Displacements for the $l = 1$ Spheroidal Lamb Modes	529
A.3	Displacements for $l = 2$ Spheroidal Lamb Modes.	530
A.4	Displacements for the $l = 2$ Torsional Lamb Modes.....	532
A.5	Displacements for the $l = 3$ Torsional Lamb Modes.....	533
A.6	Displacements for the $l = 4$ Torsional Lamb Modes.....	534
	References.....	535

21 Fracture Processes in Advanced Nanocrystalline

	and Nanocomposite Materials	537
21.1	Introduction.....	537
21.2	Specific Structural Features and Plastic Deformation Behavior of Nanomaterials.....	538
21.3	Brittle and Ductile Fracture Processes in Nanomaterials.....	543
21.4	Nucleation of Nanocracks at Grain Boundaries and Their Triple Junctions.....	547
21.5	Intergranular Brittle Fracture Through Nucleation and Convergence of Nanocracks in Nanomaterials	555
21.6	Crack Growth in Nanomaterials. Toughening Mechanisms.....	558
21.7	Concluding Remarks.....	563

Acknowledgements.....	564
References.....	564
22 Synthesis, Properties and Application of Conducting PPY Nanoparticles	568
22.1 Introduction.....	569
22.1.1 Synthesis of PPY Nanoparticles	569
22.1.2 Properties and Application of PPY Nanoparticles.....	573
22.2 Experimental	580
22.2.1 Materials.....	580
22.2.2 Polymerization	580
22.2.3 Characterization	580
22.3 Results and Discussion.....	581
22.3.1 The Effect of Polymerization Temperature on the Yield of the Nanoparticles	581
22.3.2 Size and Its Distribution of the PY/SD Copolymer Nanoparticles.....	582
22.3.3 Morphology of the PY/SD Copolymer Nanoparticles	583
22.3.4 Mechanism of the Formation and Self-Stabilization of the Nanoparticles.....	584
22.3.5 Bulk Electrical Conductivity	584
22.4 Conclusions.....	584
Acknowledgements.....	585
References.....	585
23 Field Emission of Carbon Nanotubes	588
23.1 Introduction.....	588
23.2 Field Emission	589
23.3 Carbon Nanotube Growth Technologies	592
23.4 Characterization of Field Emission From CNTs	599
23.4.1 Effect of Structure on Field Emission	600
23.4.2 Effect of Length and Space	601
23.4.3 Method of field emission enhancement.....	606
23.4.4 Gated Field-Emission Arrays with Carbon Nanotubes.....	610
23.5 Summary	614
Acknowledgement	614
References.....	614
24 Flexible Dye-Sensitized Nano-Porous Films Soar Cells.....	618
24.1 Introduction.....	618
24.2 Flexible DSSCs and Low Temperature Preparation.....	622

24.3	Electron Transport and Back Reaction at the TiO_2 /Electrolyte Interface	629
24.3.1	Factors that Determine Efficiency	629
24.3.2	Techniques for Measuring Electron Transport and Back Reaction	631
24.3.3	Results Obtained with Low-Temperature Films	634
24.3.4	Recent Developments and Outlook	638
24.4	Interfacial Electron Transfer, Charge Separation and Recombination	639
24.4.1	Heterogeneous Electron Transfer	641
24.4.2	Charge Separation at the Film/Dye Interface	644
24.4.3	Charge Recombination at the Film/Redox/Dye Interface	645
24.5	Summary	646
	References	646
25	Magnetic Nanofluids: Synthesis and Structure	650
25.1	Introduction	651
25.1.1	Ferrofluids—Magnetically Controllable Nanofluids	651
25.1.2	Early History of Magnetic Fluids (A Short Review)	651
25.1.3	Composition, Structure and Macroscopic Behavior	653
25.2	Synthesis of Magnetic Nanofluids	656
25.2.1	Generalities	656
25.2.2	Synthesis of Nanosized Magnetic Particles	656
25.2.3	Magnetic Nanofluids with Organic Carriers	661
25.2.4	Water Based Magnetic Nanofluids	666
25.2.5	Long-Term Colloidal Stability of Magnetic Nanofluids	673
25.2.6	Dilution Stability	679
25.3	Structure Investigations	684
25.3.1	Particle Structure	684
25.3.2	Interaction	699
	Acknowledgements	703
	References	704