

---

# Contents

---

<b>Introduction</b> . . . . .	ix
<b>Part 1. Nanomaterials and Nanotechnologies.</b> . . . . .	1
<b>Chapter 1. Carbon-based Nanomaterials</b> . . . . .	3
1.1. Fullerenes . . . . .	4
1.1.1. Properties of fullerenes . . . . .	5
1.2. Carbon nanodiamonds . . . . .	11
1.2.1. Principal techniques used in creating nanodiamonds . . . . .	11
1.2.2. Key properties of nanodiamonds . . . . .	13
1.3. Carbon dots or carbon quantum dots . . . . .	16
1.3.1. CQD production methods . . . . .	16
1.3.2. Fluorescence properties of CQDs . . . . .	18
1.3.3. CQD applications . . . . .	21
1.4. Carbon nanotubes . . . . .	21
1.4.1. Chirality of carbon nanotubes . . . . .	24
1.4.2. Mechanistic models of CNT growth. . . . .	26
1.4.3. CNT arrays aligned horizontally or perpendicularly to a planar substrate . . . . .	31
1.4.4. Key properties and applications of CNTs. . . . .	34
1.4.5. Conclusion. . . . .	37
1.5. Graphene . . . . .	37
1.5.1. Electrical properties of exfoliated graphene . . . . .	38
1.5.2. Graphene production techniques . . . . .	41
1.5.3. Applications of graphene and graphene derivatives. . . . .	51
1.5.4. Conclusion. . . . .	62

---

1.6. Graphene quantum dots. . . . .	63
1.6.1. GQD production methods. . . . .	63
1.6.2. Properties and applications of GQDs . . . . .	66
1.6.3. Graphdiyne: a new alternative to graphene. . . . .	72
1.7. Conclusions and perspectives of carbon-based nanomaterials . . . . .	77
<b>Chapter 2. Inorganic Nanomaterials . . . . .</b>	<b>79</b>
2.1. Metallic nanoparticles. . . . .	80
2.1.1. Gold nanoparticles (Au NPs) . . . . .	81
2.1.2. Core-shell type bimetallic nanoparticles . . . . .	83
2.2. Metal nanoclusters. . . . .	87
2.2.1. Production methods for gold nanoclusters . . . . .	88
2.2.2. Structure and stability criteria of Au NC . . . . .	90
2.2.3. Luminescence properties of Au NCs . . . . .	91
2.2.4. Applications using the luminescent properties of Au NCs. . . . .	95
2.2.5. Conclusion. . . . .	97
2.3. Semiconductor quantum dots . . . . .	97
2.3.1. Development of colloidal QDs . . . . .	98
2.4. Two-dimensional inorganic lamellar nanosheets. . . . .	103
2.4.1. Transition metal dichalcogenides . . . . .	104
2.4.2. Conclusion. . . . .	113
2.5. Hybrid metal-organic frameworks . . . . .	113
2.5.1. MOF production . . . . .	113
2.5.2. Potential applications of MOFs. . . . .	119
2.5.3. Conclusions . . . . .	128
2.6. Conclusions on inorganic nanomaterials. . . . .	129
<b>Part 2. Nanotechnology and Nanomaterials for Energy . . . . .</b>	<b>131</b>
<b>Chapter 3. Energy Storage . . . . .</b>	<b>133</b>
3.1. Worldwide energy use . . . . .	133
3.2. Energy storage systems. . . . .	135
3.2.1. Non-chemical/electrochemical storage . . . . .	135
3.2.2. Chemical and electrochemical storage systems . . . . .	136
3.2.3. Rechargeable batteries . . . . .	139
3.2.4. Supercapacitors . . . . .	184
3.2.5. Pseudocapacitors . . . . .	189
3.3. Conclusions on energy storage . . . . .	193

---

<b>Chapter 4. Energy Conversion</b> . . . . .	195
4.1. Photovoltaics . . . . .	196
4.1.1. General principles of the photovoltaic process. . . . .	197
4.1.2. Photovoltaic technologies . . . . .	200
4.2. Electroluminescence, lighting and display. . . . .	225
4.2.1. Inorganic light-emitting diodes. . . . .	226
4.2.2. Organic light-emitting diodes. . . . .	233
4.2.3. QDot light-emitting diodes . . . . .	244
4.3. Conclusions on energy conversion . . . . .	249
<b>Chapter 5. Electro- and Photocatalysis</b> . . . . .	251
5.1. Water splitting . . . . .	252
5.2. Electrolysis techniques . . . . .	253
5.3. HER and OER processes in water splitting . . . . .	257
5.3.1. HER in an acidic medium . . . . .	257
5.3.2. HER in alkaline media . . . . .	274
5.3.3. Conclusions on HER reactions . . . . .	279
5.3.4. Catalysts for oxygen evolution reaction. . . . .	279
5.4. Photoelectrochemical water splitting. . . . .	294
5.4.1. Heterogeneous photocatalysts . . . . .	297
5.4.2. Photocatalytic systems with two SC heterojunctions . . . . .	298
5.4.3. Conclusions . . . . .	302
5.5. Fuel cells . . . . .	302
5.5.1. Operating principle of a fuel cell. . . . .	303
5.5.2. Choice of O <sub>2</sub> reduction catalysts . . . . .	306
5.5.3. Conclusions on electrocatalysis and photocatalysis. . . . .	310
<b>Conclusion</b> . . . . .	313
<b>References</b> . . . . .	317
<b>Index</b> . . . . .	359