

# Contents

## List of Contributors IX

<b>1</b>	<b>Graphene Technology: The Nanomaterials Road Ahead</b>	<b>1</b>
	<i>Stephen R. Waite and Soroush Nazarpour</i>	
1.1	Newly Discovered 2D Materials	1
1.2	Wonder Materials	2
1.3	The Rise of MPM	5
1.4	Addressing the Environment, Health, and Safety	7
1.5	The Nanomaterials Road Ahead	7
1.6	Can Graphene Survive the “Disillusionment” Downturn?	9
1.6.1	Gartner’s Hype Cycle	9
1.6.2	Surviving the Trough of Disillusionment	10
1.6.3	Graphene and Batteries	11
1.6.4	Heat Management with Graphene	13
1.6.5	How Graphene Could Revolutionize 3D Printing	14
<b>2</b>	<b>Graphene Synthesis</b>	<b>19</b>
	<i>Siegfried Eigler</i>	
2.1	Introduction	19
2.2	Definitions	20
2.2.1	Nomenclature and Structure	20
2.2.2	Polydispersity of Graphene	20
2.3	Characterization of Graphene by Raman Spectroscopy	22
2.4	Epitaxial Growth of Graphene from SiC	26
2.5	Graphene by Chemical-Vapor-Deposition	27
2.6	Delamination of Graphene from Graphite	31
2.6.1	Mechanical Cleavage of Graphite	32
2.6.2	Liquid Phase Exfoliation of Graphite – Stirred Media Mills	33
2.6.3	Liquid Phase Exfoliation of Graphite – Sonication	35
2.6.4	Liquid Phase Exfoliation of Graphite – Shear Mixing	36
2.6.5	Liquid Phase Exfoliation of Graphite Using Smart Surfactants	38
2.6.6	Electrochemical Exfoliation of Graphite	38
2.7	Wet-Chemical Functionalization and Defunctionalization	40

2.7.1	Reductive Functionalization of Graphene	40
2.7.2	Oxidative Functionalization of Graphene	43
2.7.2.1	Generalized Synthesis of GO	45
2.7.2.2	Historical Development of the Synthesis of GrO	46
2.7.2.3	Structure of GO	48
2.7.2.4	GO as Precursor for Graphene	49
2.8	Synthesis of Nanographene from Small Molecules	52
	References	57

### 3 Graphene Composites 63

*Suman Chhetri, Tapas Kuila, and Naresh Chandra Murmu*

3.1	Introduction	63
3.2	Preparation and Properties of Graphene	65
3.3	Functionalization of Graphene	66
3.3.1	Covalent Modification	67
3.3.2	Non-Covalent Modification	70
3.4	Preparation of Graphene Polymer Composites	71
3.4.1	In Situ Polymerization	71
3.4.2	Solution Mixing	72
3.4.3	Melt Mixing	72
3.4.4	Other Preparative Technique	73
3.5	Characterization of Graphene-Polymer Composites	74
3.6	Properties of Graphene/Polymer Composites	77
3.6.1	Mechanical Properties	77
3.6.2	Thermal Properties	84
3.6.3	Electrical Properties	88
3.6.4	Dynamic Mechanical Properties	93
3.7	Application of Graphene Based Polymer Composites	94
3.7.1	Gas Barrier	95
3.7.2	Sensor	97
3.7.3	EMI Shielding	97
3.7.4	Flammability Reduction	99
3.7.5	Automotive and Aircrafts	99
3.7.6	Turbine Blades	100
3.7.7	Others	100
3.8	Conclusions and Outlook	101
	References	102

### 4 Graphene in Lithium-ion Batteries 113

*Cyrus Zamani*

4.1	Introduction	113
4.2	Renewable Energies	114
4.3	Batteries, What are They?	115
4.4	Lithium-ion Batteries	116
4.5	Anodes, Cathodes, and Electrolytes	117

4.6	Carbon Materials	118
4.7	Graphite	119
4.8	Graphene	120
4.9	Graphene in Lithium-Ion Batteries	121
4.10	Graphene in Anodes	122
4.11	Graphene in Cathodes	126
4.12	Graphene in Other Types of Lithium Batteries	127
	Summary	127
	References	128
<b>5</b>	<b>Graphene-Based Membranes for Separation Engineering</b>	<b>133</b>
	<i>Luisa M. Pastrana-Martínez, Sergio Morales-Torres, José L. Figueiredo, and Adrián M.T. Silva</i>	
5.1	Introduction	133
5.2	Preparation of Graphene-Based Membranes	134
5.3	Graphene-based Membranes for Separation Applications	140
5.3.1	Gas Separation	140
5.3.2	Water Treatment	142
5.4	Conclusions	149
	Acknowledgments	150
	References	150
<b>6</b>	<b>Graphene Coatings for the Corrosion Protection of Base Metals</b>	<b>155</b>
	<i>Robert V. Dennis, Nathan A. Fler, Rachel D. Davidson, and Sarbajit Banerjee</i>	
6.1	Introduction to Corrosion	155
6.2	Bare Graphene as a Protective Barrier	159
6.2.1	Some Electronic Structure Considerations at Graphene/Metal Interfaces	159
6.2.2	Graphene as a Standalone Corrosion-Resistant Coating and Some Mechanistic Considerations	162
6.3	Graphene Nanocomposites for Corrosion Inhibition	164
6.4	Graphene/Metal Nanocomposites for Corrosion Inhibition	168
6.5	Graphene/Ceramic Nanocomposites for Corrosion Inhibition	171
6.6	Summary and Future Outlook	172
	Acknowledgments	173
	References	174
<b>7</b>	<b>Graphene Market Review</b>	<b>177</b>
	<i>Marko Spasenovic</i>	
7.1	Introduction	177
7.2	Graphene Market: Past and Present	178
7.3	Co-ordinated Market Initiatives	184
7.4	Market and Application Projections	185
7.5	Conclusion	186
	References	187

<b>8</b>	<b>Financing Graphene Ventures</b>	<b>189</b>
	<i>Stephen R. Waite</i>	
8.1	Graphene Start-ups	190
8.2	The Art of Raising Capital	191
8.3	Shifting Financial Landscape for Graphene Ventures	199
8.4	The Graphene Financing Road Ahead	203
	Summary	205
	Appendix Nantero Case Study – The Funding and Evolution of a Nanomaterials Start-up	206
	The Founding of Nantero	207
	Series A: Financing Round	207
	Post-Series A: Funding Evolution	208
	Series B: Financing Round	208
	Post-Series B: Funding Evolution	209
	Series C: Financing Round	210
	Post-Series C: Funding Evolution	210
	Series D: Financing Round	212
	Post-Series D: Funding Evolution	212
	Series E: Financing Round	212
	Summary	213
	<b>Index</b>	<b>215</b>