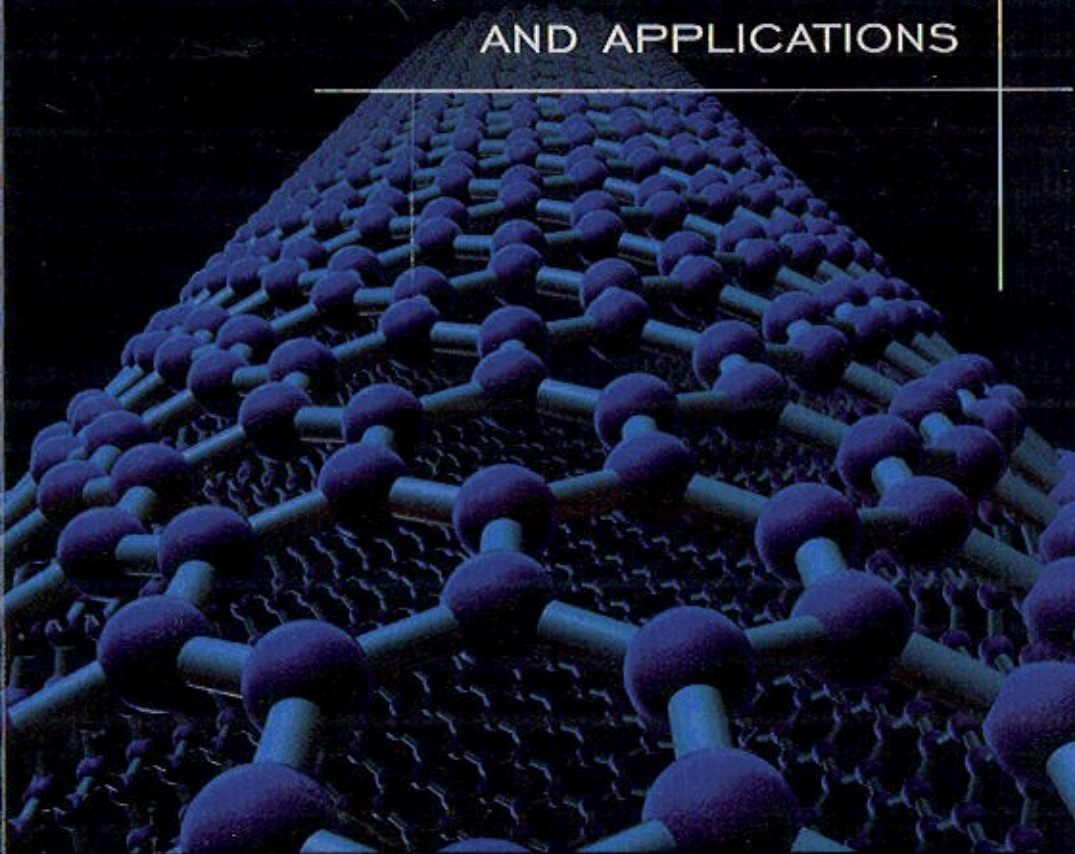


McGraw-Hill Nanoscience and Technology Series

POLYMER NANOCOMPOSITES

PROCESSING, CHARACTERIZATION,
AND APPLICATIONS



JOSEPH H. KOO

Contents

Preface	xi
Chapter 1. Introduction	1
1.1 What Is Nanotechnology?	1
1.2 Why Is This Length Scale So Important?	2
1.3 What Does <i>Nano</i> Really Mean?	2
1.4 Uniqueness of Nanostructured Materials	3
1.5 Polymer Nanomaterials	4
1.6 Scope of the Book	5
References	7
Chapter 2. An Overview of Nanoparticles	9
2.1 Current Polymer Nanocomposite Technology	9
2.2 Different Types of Nanoparticles	9
2.2.1 Montmorillonite nanoclays	10
2.2.2 Carbon nanofibers (CNFs)—vapor-grown carbon fibers (VGCFs)	19
2.2.3 Polyhedral oligomeric silsesquioxane (POSS)	26
2.2.4 Carbon nanotubes	29
2.2.5 Nanosilica	38
2.2.6 Nanoaluminum oxide	44
2.2.7 Nanotitanium oxide	46
2.2.8 Others	47
2.3 Summary	48
References	48
Chapter 3. Selecting Resin Matrix and Nanoparticles for Applications	51
3.1 Characteristics of Polymer Nanostructured Materials	51
3.2 Polymer Matrices	52
3.2.1 Thermoplastic-based nanocomposites	52
3.2.2 Thermoset-based nanocomposites	53
3.2.3 Elastomer-based nanocomposites	55
3.3 Summary	56
References	56

Chapter 4. Processing of Nanomaterials	61
4.1 Synthesis Methods	61
4.2 Solution Intercalation	64
4.2.1 Solution intercalation from polymers in solution	64
4.2.2 Solution intercalation from prepolymers in solution	65
4.3 Melt Intercalation	66
4.3.1 Thermoplastic nanocomposites	66
4.3.2 Elastomer nanocomposites	67
4.4 Roll Milling	67
4.5 Emulsion Polymerization	68
4.6 In-Situ Polymerization	69
4.6.1 Thermoplastic nanocomposites	70
4.6.2 Thermoset nanocomposites	71
4.6.3 Rubber modified epoxy nanocomposites	71
4.7 High-Shear Mixing	72
4.8 Summary	74
References	74
Chapter 5. Characterization of Polymer Nanomaterials	79
5.1 Characterization Methods	79
5.2 X-Ray Diffraction	80
5.3 Transmission Electron Microscopy and Spectroscopy	81
5.3.1 Transmission electron microscopy (TEM)	81
5.3.2 Energy-dispersive x-ray spectroscopy (EDS)	86
5.4 Small-Angle X-Ray Scattering (SAXS)	86
5.5 The Cone Calorimeter (CC)	88
5.6 The Mass Loss Calorimeter (MLC)	91
5.7 Summary, Future Needs, and Assessments	92
References	93
Chapter 6. Properties of Polymer Nanostructured Materials	95
6.1 Materials Properties	95
6.2 Thermoplastic Nanocomposites	95
6.2.1 Nylon 6 nanocomposites	95
6.3 Thermoset Nanocomposites	103
6.3.1 Epoxy nanocomposites	104
6.4 Elastomer Nanocomposites	118
6.4.1 TPO nanocomposites	118
6.5 Summary	122
References	122
Chapter 7. Polymer Nanostructured Materials for High-Temperature Applications	125
7.1 Thermoplastic Nanocomposites	125

7.1.1	Nonhalogenated, flame-retardant polymers for cabling jackets	126
7.1.2	Waterborne fire-retardant nanocomposite coating	132
7.1.3	Flame-retardant polymer nanocomposites for rapid manufacturing	138
7.2	Thermoset Nanocomposites	159
7.2.1	Nanocomposites for rocket ablative materials (NRAMs)	159
7.2.2	Flammability properties of polymer nanostructured materials	176
7.2.3	Nanomodified carbon/carbon composites (NCCCs)	182
7.2.4	Nanocomposites for carbon-fiber reinforced polymer matrix composites (NCPMCs)	198
7.3	Thermoplastic Elastomer Nanocomposites	214
7.3.1	Elastomer nanocomposites for propulsion systems	215
7.3.2	Thermoplastic elastomer nanocomposites for propulsion systems	217
7.3.3	Flame-retardant thermoplastic polyurethane nanocomposites	220
7.4	Summary	228
	References	228

Chapter 8. Current Status, Trends, Future Directions, and Opportunities 235

8.1	Nanotechnology Research Funding	235
8.1.1	Government R&D investments	235
8.2	Nanotechnology Research Output	237
8.2.1	Publication output	237
8.2.2	Patent output	238
8.2.3	Research areas of focus	238
8.2.4	Private sector activity	239
8.3	Nanotechnology Commercialization Prospects	239
8.4	Economics of Nanoparticles	242
8.5	Current Nanotechnology Commercial Applications	243
8.5.1	Hybrid compounds for cosmetics	245
8.5.2	Hybrid materials for protective and decorative coatings	246
8.5.3	Hybrid materials for dental applications	247
8.5.4	Hybrid materials (polymer-clay nanocomposites - PCNs) with structural properties	248
8.5.5	Hybrid materials (PCNs) with gas barrier properties	249
8.5.6	Hybrid materials (PCNs) with flame-retardant properties	251
8.5.7	Hybrid materials (PCNs) with other properties	252
8.6	Future Directions of the National Nanotechnology Initiative	253
8.6.1	Budget summary	255
8.7	Identified Areas of Opportunity	257
8.7.1	Near-term (1 to 5 years)	257
8.7.2	Mid-term (5 to 10 years)	257
8.7.3	Long-term (20+ years)	258
8.8	Nanotech's Safety Risks	258
8.9	Summary	260
	References	260