

Contents

1	Introduction to Thermal Properties of Materials	1
	<i>Rui Feng and Chengyi Song</i>	
1.1	Conventional Macroscale Heat Transfer	1
1.1.1	Normalization	2
1.1.2	Thermal Equilibrium and Nonequilibrium	2
1.1.3	Integral Structural Heat Transfer	3
1.1.4	Control Volume and Interface	4
1.1.5	Conduction in Single and Multiphase Medium	6
1.1.5.1	Single-phase Medium	6
1.1.5.2	Multiphase Composite Medium	6
1.1.6	Heat Capacity	8
1.1.7	Phase Change	9
1.2	Micro/Nanoscale Heat Transfer	10
1.2.1	Micro/Nanoscale Heat Carriers	10
1.2.2	Nanoscale Thermal Dynamic Theory via Boltzmann Equation	13
1.2.3	Molecular Dynamics Calculation	15
1.2.4	Photothermal Effect via SPR Heating	16
1.3	Bioinspired Thermal Materials	17
1.3.1	Bioinspired Thermal Materials for Heat Conduction	17
1.3.2	Bioinspired Materials for Thermal Storage	18
1.3.3	Bioinspired Thermal Detection	19
1.3.4	Bioinspired Materials for Energy Conversion	19
1.4	Perspective and Outlook	20
	Acknowledgments	21
	References	21
2	The Engineering History of Thermal Materials	25
	<i>Mohammed T. Ababneh</i>	
2.1	Introduction	25
2.2	Engineering History of Thermal Materials	25
2.2.1	Thermal Conductivity	25
2.2.2	Development of Materials with High Thermal Conductivity	27
2.3	Engineering Applications with Bioinspired Thermal Materials	33
2.3.1	Hydrophilic and Hydrophobic Surfaces	33

2.3.2	Dropwise Condensation	34
2.3.3	Heat Pipes	37
2.4	Bioinspired Multiscale Wicks	38
2.5	Hybrid Superhydrophilic/Superhydrophobic Wicks	40
2.6	Flexible Heat Pipes with Integrated Bioinspired Design	42
	References	44
3	Bioinspired Surfaces for Enhanced Boiling	47
	<i>Yangying Zhu, Dion S. Antao, and Evelyn N. Wang</i>	
3.1	Introduction	47
3.2	Bioinspired Surfaces for Boiling	49
3.3	Surface-Structure-Enhanced Pool Boiling	52
3.4	Biphilic and Biconductive Surface-Enhanced Boiling	55
3.5	Surfactant-Enhanced Pool Boiling	59
3.6	Flow Boiling	62
3.7	Conclusions and Outlook	66
	Acknowledgments	67
	References	67
4	Bioinspired Materials in Evaporation	73
	<i>Yanming Liu and Chengyi Song</i>	
4.1	Introduction	73
4.2	What Is Evaporation?	74
4.2.1	Theoretical Models of Evaporation via Bulk Heating or Interfacial Heating	74
4.2.2	Examples of Bulk Heating and Interfacial Heating	76
4.3	Bioinspired Materials in Evaporation	80
4.3.1	Bioinspired Enhancing of Evaporation Rate via Interfacial Localized Heating	81
4.3.2	Skin-Mimic Evaporative Cooling System	86
4.3.3	Application of Bioinspired Materials in Evaporation	88
4.3.3.1	Distillation	88
4.3.3.2	Sterilization	89
4.3.3.3	Desalination	91
4.3.3.4	Wastewater Treatment	92
4.3.3.5	Electronics Cooling System	94
4.4	Summary and Perspectives	95
	Acknowledgments	96
	References	96
5	Bioinspired Engineering of Photothermal Materials	99
	<i>Wang Zhang and Junlong Tian</i>	
5.1	Antireflection and Photothermal Biomaterials	99
5.1.1	Nipple Arrays Antireflection Biomaterials	100
5.1.2	Protuberances Arrays Antireflection Biomaterials	101
5.1.3	Triangular Roof-Type Antireflection and Photothermal Materials	103
5.2	Bioinspired Photothermal Materials	105

5.2.1	Bioinspired Photothermal Materials Synthesis Approach	106
5.2.2	Bioinspired Metal–Semiconductor Photothermal Materials	106
5.2.3	Bioinspired Carbon-Matrix Metal Functional Materials	116
	References	122
6	Bioinspired Microfluidic Cooling	129
	<i>Charlie Wasyl Katrycz and Benjamin D. Hatton</i>	
6.1	Introduction	129
6.2	Biological Heat Exchange	131
6.3	Wearable Fluidics	132
6.3.1	Liquid Cooling Garments	132
6.3.2	Head Cooling	134
6.3.3	Wearable Microfluidics	136
6.4	Fluidic-Based Windows and Facades for Buildings	136
6.4.1	Thermal Storage in Fluidic Layers	139
6.4.2	Forced Convection for Thermal Control	140
6.4.3	One-Dimensional Steady-State Heat Transfer Model	142
6.4.4	Fluidic Networks for Adaptive Windows	143
6.5	Fabrication Methods for Large-Area Fluidic Networks	145
6.5.1	3D Printing	145
6.5.2	Radio Frequency Welding	147
6.5.3	CNC Milling	148
6.5.4	Micro Molding	148
6.5.5	Viscous Fingering	150
6.6	Summary	153
	References	153
7	Thermal Emissivity: Basics, Measurement, and Biological Examples	159
	<i>Lars Olof Björn and Annica M. Nilsson</i>	
7.1	Terminology	159
7.2	Basic Radiation Laws	160
7.3	Direct Emissivity Measurements	160
7.4	Kirchhoff’s Law	161
7.5	Measurements Using Kirchhoff’s Law	162
7.6	Attenuated Total Reflectance	164
7.7	Ways to Determine Hemispherical Emissivity	165
7.8	Specular and Diffuse Reflectance	166
7.9	Problems with Sample Shape	168
7.10	Remote Sensing from Aircraft or Satellites	168
7.11	Examples of Emissivity Determinations of Biological Samples	168
	References	171
8	Bioinspired Thermal Detection	175
	<i>Zhen Luo and Wen Shang</i>	
8.1	Introduction	175

8.2	Thermal Detection	176
8.2.1	Invasive Thermal Detection	177
8.2.1.1	Thermometers	177
8.2.1.2	Thermocouple	178
8.2.1.3	Thermistors	179
8.2.2	Noninvasive Thermal Detection	179
8.2.2.1	Electron or Molecule Excitation-Based Noninvasive Thermal Detection	179
8.2.2.2	Noninvasive Thermal Detection Based on the Change of Other Physical Properties	180
8.3	Bioinspired Thermal Detection	181
8.3.1	Thermal Detection by Direct Use of Biological Materials	181
8.3.1.1	Bimaterials Combining Biological Materials and Thermal Materials	181
8.3.1.2	Temperature-Dependent Photoluminescence (PL) Sensor	182
8.3.1.3	Biomolecule Thermosensors	183
8.3.2	Thermal Detection Inspired by Biological Structures that Might Not Be Related to Thermal Function of Biological Systems	187
8.3.3	Thermal Detection Inspired by the Thermal Function of Biological Systems	189
8.3.3.1	Thermosensitive Biological Polymers	189
8.3.3.2	Thermal Detection Inspired by Skin	189
8.3.4	Application of Bioinspired Thermal Detection	193
8.4	Perspectives	195
	References	197
9	Bioinspired Thermal Insulation and Storage Materials	201
	<i>Peng Tao and Dominic J. McCafferty</i>	
9.1	Introduction to Thermal Insulation Materials	201
9.1.1	Introduction	201
9.1.2	Fundamentals of Thermal Insulation	202
9.2	Engineering of Thermal Insulation Materials	204
9.2.1	Conventional Thermal Insulation Materials	204
9.2.2	Advanced Thermal Insulation Materials	206
9.2.3	Application of Thermal Insulation Materials	208
9.2.3.1	Thermal Insulation for Buildings	208
9.2.3.2	Thermal Insulation for Spacecraft	208
9.2.3.3	Thermal Insulation for Mechanical Systems	210
9.2.3.4	Thermal Insulation for Textile Industries	210
9.3	Bioinspired Thermal Insulation and Storage Materials	211
9.3.1	Biological Thermal Insulation	211
9.3.1.1	Fat and Blubber	211
9.3.1.2	Feathers and Plumage	212
9.3.1.3	Hair, Fur and Wool	212
9.3.1.4	Heat Transfer Processes in Animal Coats	212
9.3.2	Advanced Thermal Insulation Materials Inspired by Animals	214
9.3.3	Thermal Storage Inspired by Black Butterflies	216

9.4	Summary and Outlook	219
	Acknowledgments	219
	References	219
10	Bioinspired Icephobicity	225
	<i>Ri Li</i>	
10.1	Icing Nucleation of Sessile Drops	226
10.2	Literature Review – Icing of Water Drops on Surfaces	230
10.3	Icing of Stationary Water Drops	231
10.4	Icing of Water Drops Impacting Surfaces	235
	References	238
	Index	241

