

Contents

Preface	ix
Hiroyuki AKINAGA, Atsuko KOSUGA and Takao MORI	
Introduction	xiii
Hiroyuki AKINAGA, Atsuko KOSUGA and Takao MORI	
Part 1. Material Challenges and Novel Effects	1
Chapter 1. Reliability and Durability of Thermoelectric Materials and Devices: Present Status and Strategies for Improvement	3
Congcong XU, Hongjing SHANG, Zhongxin LIANG, Fazhu DING and Zhifeng REN	
1.1. Introduction	3
1.2. Thermoelectric material stability	5
1.3. $Mg_3(Sb, Bi)_2$	5
1.4. Zn_4Sb_3	7
1.5. Skutterudites	8
1.6. $Cu_{2-x}X$ ($X = S, Se, Te$)	9
1.7. GeTe	11
1.8. Outlook on thermoelectric materials stability	12
1.9. Thermoelectric device design analysis	13
1.9.1. Thermal stress analysis	13
1.9.2. Interface analysis, design and fabrication	21
1.10. Advanced thermoelectric module case studies	33
1.10.1. Bi_2Te_3	33
1.10.2. $Mg_3(Sb, Bi)_2$	35
1.10.3. GeTe	37
1.10.4. Skutterudites	39
1.11. Summary and outlook	40
1.12. References	41

Chapter 2. Effect of Microstructure in Understanding the Electronic Properties of Complex Materials	53
Chenguang FU, Chaoliang HU, Qi ZHANG, Airan LI and Tiejun ZHU	
2.1. Introduction	53
2.2. Basic principles of electronic transport parameters	54
2.2.1. Solid solutions	59
2.2.2. Intrinsic defects	60
2.2.3. Grain boundary	62
2.2.4. Texture	65
2.3. Summary	67
2.4. References	67
Chapter 3. Thermoelectric Nanowires	73
Olga CABALLERO-CALERO and Marisol MARTÍN-GONZÁLEZ	
3.1. Introduction	73
3.2. Nanowires: a way to enhance thermoelectric efficiency	74
3.3. Fabrication of thermoelectric nanowires	77
3.4. Measurement of thermoelectric properties in nanowires	79
3.5. Nanowire-based thermoelectric devices	86
3.6. Interconnected 3D nanowire networks	87
3.7. Summary and outlook	89
3.8. References	89
Chapter 4. Impact of Chemical Doping or Magnetism in Model Thermoelectric Sulfides	99
Sylvie HÉBERT, Ramzy DAOU and Antoine MAIGNAN	
4.1. Introduction	100
4.2. TiS ₂ : intercalation chemistry to combine power factor optimization and lattice thermal conductivity degradation	101
4.3. Magnetism and thermoelectricity in sulfides	104
4.4. Conclusion	110
4.5. References	110
Chapter 5. Thermoelectric Generation Using the Anomalous Nernst Effect	117
Akito SAKAI and Satoru NAKATSUJI	
5.1. Thermoelectric conversion – Seebeck effect and anomalous Nernst effect (ANE)	117
5.2. Physics of topological magnets	120
5.2.1. Transverse electrical and thermal conductivity driven by Berry curvature	120
5.2.2. Magnetic Weyl semimetals, Weyl magnets	121

5.2.3. Type-II Weyl semimetals	122
5.2.4. Nodal line magnets	123
5.3. Experimental realization of the giant anomalous Nernst effect	124
5.3.1. Weyl antiferromagnets Mn_3X ($X = Sn, Ge$)	124
5.3.2. Weyl ferromagnet Co_2MnGa	124
5.3.3. Nodal-web ferromagnets Fe_3X ($X = Ga, Al$)	125
5.4. Summary and prospects	127
5.5. Acknowledgment	127
5.6. References	127
Chapter 6. A Comprehensive Review of Phonon Engineering	131
Bin XU, Harsh CHANDRA, and Junichiro SHIOMI	
6.1. Introduction	131
6.1.1. Thermal conductivity	133
6.1.2. Phonons in thermal transport	133
6.2. Methodology of phonon engineering	142
6.2.1. Computational method for thermal conduction and phonon properties	142
6.2.2. Experimental method for nano-/micro-scale heat conduction characterization	144
6.2.3. Direct measurement of phonon properties through phonon scattering	149
6.2.4. Phonon engineering for low thermal conductivity	152
6.2.5. Intrinsic low thermal conductivity in complex lattice structure	153
6.2.6. Low thermal conductivity by nanostructures	155
6.2.7. Coherent phonon engineering in superlattice	158
6.3. Summary and future prospects	162
6.4. References	164
Part 2. Toward Device Applications	171
Chapter 7. The Current State of Thermoelectric Technologies and Applications with Prospects	173
Slavko BERNIK	
7.1. Introduction	173
7.2. Thermoelectric materials	180
7.3. Thermoelectric devices – structure, materials, fabrication technology	189
7.4. Summary	198
7.5. References	199

Chapter 8. Processing of Thermoelectric Transition Metal Silicides Towards Module Development	213
Sylvain LE TONQUESSE, Mathieu PASTUREL, Franck GASCOIN and David BERTHEBAUD	
8.1. Introduction	213
8.2. Recent progress on the process of thermoelectric transition metals silicide	214
8.2.1. Synthesis of mesostructured silicides through magnesiothermic reduction	214
8.2.2. Synthesis of higher manganese silicide through wet ball milling.	218
8.2.3. Issues of MnSi striations and thermal stability on thermoelectric performance of doped higher manganese silicide	219
8.2.4. Upscaling processes, the examples of additive manufacturing and RGS process	223
8.3. Towards contacts and device developments.	225
8.4. References	226
Chapter 9. Application of the Thermoelectrics; Past, Present and Future	229
Hirokuni HACHIUMA	
9.1. Introduction	229
9.2. Thermoelectric module	230
9.3. TEC application for refrigerator and cooler	231
9.4. TEC for electronic components.	234
9.4.1. TEC for optical communication	234
9.4.2. Multi-stage TEC for optical sensors.	236
9.5. TEC for semiconductor manufacturing	239
9.6. TEG application	241
9.6.1. TEG for energy harvesting (EH).	242
9.6.2. TEG for stand-alone power source	244
9.6.3. TEG for waste heat recovery.	245
9.7. Conclusion	247
9.8. References	247
List of Authors	249
Index.	253
Summary of Volume 1	255