

Contents

Abstract	i
Zusammenfassung	iii
Acknowledgements	v
List of Symbols	vii
List of Abbreviations	ix
List of Figures	xv
List of Tables	xix
1 Introduction	1
1.1 Material synthesis and properties of Bi ₂ Se ₃	4
1.1.1 Thermoelectric and thermoresistive properties	5
1.1.2 Memristive properties	8
1.1.3 Bi ₂ Se ₃	9
1.2 Research objectives	12
1.3 Thesis overview	14
2 Bi₂Se₃: electrodeposition and material characterization	15
2.1 Introduction & motivation	15
2.2 Experimental	15
2.2.1 Electrodeposition	15
2.2.2 Design and fabrication of templates	17
2.2.3 Characterization	20
2.2.3.1 Structural properties	20
2.2.3.2 Electrical, thermal and thermoelectric characteriza-tion	23

2.3	Results	28
2.3.1	Electrodeposition studies	28
2.3.1.1	Electrolyte concentrations	28
2.3.1.2	Effect of KCl	30
2.3.1.3	Influence of pulsed plating	33
2.3.2	Structural properties	35
2.3.2.1	Cross-sectional morphology and stoichiometry	35
2.3.2.2	Analysis of the crystal structure	37
2.3.3	Electronic properties	40
2.3.3.1	Thermoelectric properties	40
2.3.3.2	Electrical and thermoresistive properties . . .	42
2.3.3.3	Thermal properties	48
2.4	Chapter summary	50
3	Bi₂Se₃ thermoelectric & thermoresistive devices: design, fabrication & characterization	53
3.1	Introduction & motivation	53
3.2	Sensor design considerations	53
3.2.1	Choice of substrate	53
3.2.2	Choice of matrix material	54
3.2.3	Bottom contacts	54
3.2.4	n-type and p-type	56
3.2.4.1	Electrodeposition of copper	57
3.2.4.2	Electrical characterization of copper	57
3.2.5	Selective electroplating	59
3.2.6	Top contacts	59
3.3	Demonstration of process flow	60
3.3.1	Bottom contact structuring	60
3.3.2	Oxide structuring	61
3.3.3	SU-8 processing	61
3.3.4	Bi ₂ Se ₃ plating	62
3.3.5	Planarization	62
3.3.6	Temporary photoresist & oxide removal	62
3.3.7	Copper plating & planarization	64
3.3.8	Temporary photoresist & oxide/metal removal . . .	64
3.3.9	Top contact evaporation	64

3.4	Sensor characterization	64
3.4.1	Sensor performance	66
3.4.1.1	Temperature sensitivity	66
3.4.1.2	Heatflux sensitivity	69
3.4.1.3	Temperature accuracy	70
3.4.1.4	Heatflux accuracy	73
3.4.1.5	Resolution	73
3.5	Chapter summary	75
4	Bi₂Se₃ based sensor systems: integration aspects	77
4.1	Introduction and motivation	77
4.1.1	Energy harvester	78
4.1.2	Dual-mode sensor	79
4.1.3	Sense-log device	80
4.2	Bi ₂ Se ₃ memristors: fabrication	81
4.2.1	Top contact	82
4.2.2	Implication for integration	84
4.3	Bi ₂ Se ₃ memristors: characterization framework	85
4.3.1	Framework theory	86
4.3.2	Framework application	88
4.3.2.1	IV & RV characteristics	88
4.3.2.2	WE-measurements	90
4.3.2.3	WRER-measurements	92
4.3.2.4	Conclusion on the framework	95
4.4	Bi ₂ Se ₃ sense-log systems	96
4.4.1	Bi ₂ Se ₃ modelling	96
4.4.2	Bi ₂ Se ₃ measurements	99
4.5	Low resistance TEG sense-log systems	102
4.6	Discussion and sense-log opportunities	108
4.6.0.1	Sensing complexity	109
4.6.0.2	Directionality	109
4.6.0.3	Reversibility	109
4.6.0.4	Heatflux sensing capability	110
4.6.0.5	Temperature sensing capability	110
4.7	Chapter summary	110
5	Conclusion	113

6 Outlook	115
6.1 n-type legs	115
6.2 Memristor tuning	115
6.3 Indirect probing & device integration	116
A Appendix A - Error propagation	117
A.1 General gaussian formula for error propagation	117
A.2 Simplification for case of multiplication by a constant	117
A.3 Simplification for case of addition and subtraction	117
A.4 Simplification for case of multiplication and division	118
B Appendix B - Electrochemistry and characterization	119
B.1 Thermoelectric setup	119
B.2 Deposition regime	120
B.3 Determination of the faraday efficiency	122
B.4 Chemical diagrams from medusa	122
B.5 Raman and XRD measurements	124
C Appendix C - Device processing	127
C.1 Electrochemical experiments	127
C.2 Electrolyte mixing	127
C.3 Electrochemical deposition of thermoelectric pillars	128
C.4 TEG pillar processing	128
C.5 TEG chain processing	129
C.6 Top contact of thermoelectric pillars and devices	132
C.7 Electrochemical deposition of memristors	133
C.8 Top contact of memristors	133
C.9 Processing comparison of TEGs and memristors	134
C.10 Electrodeposition experiment with Sb_2Te_3 & Bi_2Te_3	136
C.11 Thermal computations	138
D Appendix D - Thermoelectric thermoresistive device B	141
E Appendix E - List of samples	143
Bibliography	149
Publications	167
Curriculum Vitae	169