

Contents

Preface	xi
List of Symbols	xv
List of Abbreviations	xxi
1 Introduction	1
1.1 What is a Microsystem?	3
1.2 Microelectronics and Microsystem Technology	6
1.3 Areas of Application and Trends of Development	8
1.4 Example: Yaw Rate Sensor	9
1.4.1 Structure and Function	10
1.4.2 Function Components and Elements	10
Exercises	15
References	15
2 Scaling and Similarity	17
2.1 Scaling	17
2.2 Similarity and Dimensionless Numbers	22
Exercises	25
References	26
3 Materials	27
3.1 Overview	27
3.2 Single Crystalline Silicon	29
3.2.1 Description of the Orientation of Planes and Directions in a Crystal	31
3.2.2 Surface Characteristics at Different Orientations	37
3.2.3 Anisotropic Elastic Characteristics	38
3.2.4 Mechanical Strength	41
3.2.5 Silicon Wafer	44
3.3 Glasses	47
3.3.1 General Characteristics of Glass	47
3.3.2 Visco-elastic Behavior	49
3.3.3 Glasses in Microsystem Technology	52
3.4 Polymers	53

3.4.1	Thermoplastic Materials in Microsystem Technology	54
3.4.2	Photoresists	55
3.5	Thin Films	58
3.5.1	Silicon Dioxide, Silicon Nitride	61
3.5.2	Conducting Layers	62
3.5.3	Polysilicon Layers	63
3.6	Comparison of Material Characteristics	63
	Exercises	64
	References	64
4	Microfabrication	67
4.1	Overview	67
4.2	Cleanliness During Production	72
4.2.1	Clean Room Technology	72
4.2.2	Wafer Cleaning	77
4.3	Lithography	78
4.3.1	Principle	78
4.3.2	Lithographic Process	79
4.3.3	Minimum Structurable Line Width	81
4.3.4	Double-sided Lithography	82
4.3.5	Lithography in Structures with Deep Profiles	83
4.4	Thin-film Formation	83
4.4.1	Overview	83
4.4.2	Layer Conformity	84
4.4.3	Thermal Oxidation	85
4.4.4	Evaporation	86
4.4.5	Sputtering	88
4.4.6	Chemical Vapor Deposition	89
4.4.7	Comparison	92
4.5	Layer Patterning	93
4.5.1	Basics	93
4.5.2	Wet Etching	94
4.5.3	Dry Etching	94
4.5.4	Lift-off Process	97
4.6	Anisotropic Wet Chemical Deep Etching	97
4.6.1	Principle	97
4.6.2	Anisotropic Etching Solutions	98
4.6.3	Etch Rates	100
4.6.4	Etch Stop Techniques	103
4.6.5	Etch Figures	105
4.6.6	Design of Etch Masks	112
4.7	Doping	114
4.7.1	Diffusion	114
4.7.2	Ion Implantation	117
4.7.3	Comparison of Doping Techniques	119
4.8	Bonding Techniques	120
4.8.1	Eutectic Bonding	121

4.8.2	Anodic Bonding	121
4.8.3	Silicon Direct Bonding	122
4.8.4	Comparison of Bonding Techniques	123
4.9	Insulation Techniques	124
4.9.1	SIMOX Technique	124
4.9.2	BESOI Technique	125
4.9.3	Smart-cut Technique	127
4.10	Surface Micromachining	128
4.10.1	Principle	128
4.10.2	Production of Hollow Spaces	130
4.10.3	Adhesion of Movable Structures	133
4.10.4	Comparison of Bulk and Surface Micromachining	135
4.11	Near-surface Micromachining	136
4.11.1	Principle	136
4.11.2	Techniques	137
4.12	HARMST	139
4.12.1	Definition	139
4.12.2	LIGA Technique	139
4.13	Miniaturized Classical Techniques	141
4.13.1	Micro Injection Molding	142
4.13.2	Micro Hot Embossing	145
4.13.3	Micro Cutting	146
4.14	Selection of Microtechnical Manufacturing Techniques	148
	Exercises	151
	References	153
5	Packaging	155
5.1	Tasks and Requirements	155
5.1.1	Tasks	155
5.1.2	Packaging for Reliability	159
5.2	Functions of Packaging	159
5.2.1	Mechanical Links	159
5.2.2	Electrical Connections	164
5.2.3	Heat Dissipation	165
5.2.4	Encapsulation and Packaging	166
	Exercises	170
	References	170
6	Function and Form Elements in Microsystem Technology	171
6.1	Mechanical Elements	171
6.1.1	Sensitivity in Surface Normal Direction	174
6.1.2	Transverse Sensitivity	176
6.1.3	Eigenfrequency	177
6.1.4	Damping	177
6.1.5	Quality Factor	179
6.1.6	Amplitude Response	179
6.1.7	Stress at the Fixation Point	180

6.2	Fluidic Elements	184
6.2.1	Parameters and Model Systems	184
6.2.2	Element Types	187
6.2.3	Fluidic Interfaces	189
6.2.4	Design of Microfluidic Elements and Components	190
6.3	Thermal Elements	194
6.3.1	Thermal-electric Analogies	194
6.3.2	Basic Equations for Heat Transport	195
6.3.3	Equivalent Circuits	199
	Exercises	203
	References	205
7	Sensors and Actuators	207
7.1	Reversible and Parametric Transducers	208
7.1.1	Reversible Transducers	208
7.1.2	Parametric Transducers	214
7.1.3	Stationary Reversible Transducers	216
7.2	Transducers for Sensors and Actuators	218
7.2.1	Electrostatic Transducers	219
7.2.2	Piezoelectric Transducers	224
7.2.3	Electrodynamic Transducers	228
7.2.4	Thermomechanical Transducers	231
7.2.5	Piezoresistive Transducers	238
	Exercises	247
	References	254
8	Design of Microsystems	255
8.1	Design Methods and Tools	255
8.2	Systems with Lumped Parameters	261
8.2.1	Behavioral Description of Electromechanical Systems	261
8.2.2	Analysis of the Static Behavior of Electromechanical Systems	261
8.2.3	Analysis of Electromechanical Systems for Harmonic Loads	264
8.2.4	Transient Analysis of Electromechanical Systems	267
8.3	Systems with Distributed Parameters	269
8.3.1	Behavioral Description Based on Analytical Models	269
8.3.2	Numerical Methods Based on the Finite Element Method	272
8.3.3	Macro-modelling of Complex Systems by Order Reduction	273
	References	282
9	Effect of Technological Processes on Microsystem Properties	283
9.1	Parameter-based Microsystem Design	283
9.2	Robust Microsystem Design	286
	Exercises	293
	Reference	293
10	The Future of Microsystems	295
10.1	Status and Trends in Microsystem Technology	295
10.2	Microoptical Applications	300

10.2.1 Displays and Light Modulators	300
10.2.2 Infrared Sensor Arrays	301
10.2.3 Spectrometers	307
10.3 Probe Tips	307
10.4 RF Microsystems	310
10.5 Actuators	312
10.6 Microfluidic Systems	316
10.6.1 Micropumps and Microvalves	317
10.6.2 Inkjet Print Heads	318
10.7 Chemical, Biological and Medical Systems	319
10.7.1 Microreactors	319
10.7.2 Lab on a Chip	320
10.8 Energy Harvesting and Wireless Communications	320
10.9 Micro Fuel Cells	326
References	329
Appendix A Physical Constants	331
Appendix B Coordinate Transformation	333
B.1 Elastic Coefficients	334
B.2 Piezoresistive Coefficients	336
References	338
Appendix C Properties of Silicon Dioxide and Silicon Nitride Layers	339
References	340
Appendix D Nomenclature of Thin-film Processes	341
Reference	342
Appendix E Adhesion of Surface Micromechanical Structures	343
E.1 Capillary Forces	343
E.2 Critical Length of Cantilever Springs	344
Reference	345
Index	347

