

Contents

1. Introduction	1
2. MEMS	5
2.1 Miniaturisation and Systems	5
2.2 Examples for MEMS.....	6
2.2.1 Bubble Jet	7
2.2.2 Actuators.....	9
2.2.3 Micropumps.....	10
2.3 Small and Large: Scaling	13
2.3.1 Electromagnetic Forces.....	13
2.3.2 Coulomb Friction.....	16
2.3.3 Mechanical Strength	16
2.3.4 Dynamic Properties.....	17
2.4 Available Fabrication Technology	20
2.4.1 Technologies Based on Lithography	20
2.4.1.1 Silicon Micromachining	21
2.4.1.2 LIGA.....	22
2.4.2 Miniaturisation of Conventional Technologies	23
3. Introduction into Silicon Micromachining	24
3.1 Photolithography	24
3.2 Thin Film Deposition and Doping	25
3.2.1 Silicon Dioxide	26
3.2.2 Chemical Vapour Deposition.....	27
3.2.3 Evaporation.....	29
3.2.4 Sputterdeposition	31
3.2.5 Doping	31
3.3 Wet Chemical Etching	32
3.3.1 Isotropic Etching.....	32
3.3.2 Anisotropic Etching	34
3.3.3 Etch Stop.....	36
3.4 Waferbonding	40
3.4.1 Anodic Bonding.....	41
3.4.2 Silicon Fusion Bonding	43

3.5	Plasma Etching	45
3.5.1	Plasma	45
3.5.2	Anisotropic Plasma Etching Modes	47
3.5.3	Configurations	48
3.5.4	Black Silicon Method	53
3.6	Surface Micromachining	55
3.6.1	Thin Film Stress	56
3.6.2	Sticking	57
4.	Mechanics of Membranes and Beams	59
4.1	Dynamics of the Mass Spring System	59
4.2	Strings	63
4.3	Beams	65
4.3.1	Stress and Strain	65
4.3.2	Bending Energy	66
4.3.3	Radius of Curvature	67
4.3.4	Lagrange Function of a Flexible Beam	70
4.3.5	Differential Equation for Beams	70
4.3.6	Boundary Conditions for Beams	72
4.3.7	Examples	73
4.3.8	Mechanical Stability	75
4.3.9	Transversal Vibration of Beams	77
4.4	Diaphragms and Membranes	80
4.4.1	Circular Diaphragms	80
4.4.2	Square Membranes	82
	Appendix 4.1: Buckling of Bridges	84
5.	Principles of Measuring Mechanical Quantities:	
	Transduction of Deformation	85
5.1	Metal Strain Gauges	85
5.2	Semiconductor Strain Gauges	86
5.2.1	Piezoresistive Effect in Single Crystalline Silicon	87
5.2.2	Piezoresistive Effect in Polysilicon Thin Films	88
5.2.3	Transduction from Deformation to Resistance	89
5.3	Capacitive Transducers	90
5.3.1	Electromechanics	90
5.3.2	Diaphragm Pressure Sensors	94
6.	Force and Pressure Sensors	97
6.1	Force Sensors	98
6.1.1	Load Cells	101
6.2	Pressure Sensors	106
6.2.1	Piezoresistive Pressure Sensors	107
6.2.2	Capacitive Pressure Sensors	112
6.2.3	Force Compensation Pressure Sensors	119

6.2.4	Resonant Pressure Sensors.....	121
6.2.5	Miniature Microphones.....	126
6.2.6	Tactile Imaging Arrays.....	130
7.	Acceleration and Angular Rate Sensors.....	132
7.1	Acceleration Sensors.....	133
7.1.1	Introduction.....	133
7.1.2	Bulk Micromachined Accelerometers.....	134
7.1.3	Surface Micromachined Accelerometers.....	138
7.1.4	Force Feedback.....	143
7.2	Angular Rate Sensors.....	145
8.	Flow sensors.....	153
8.1	The Laminar Boundary Layer.....	153
8.1.1	The Navier-Stokes Equations.....	153
8.1.2	Heat Transport.....	157
8.1.3	Hydrodynamic Boundary Layer.....	158
8.1.4	Thermal Boundary Layer.....	163
8.1.5	Skin Friction and Heat Transfer.....	166
8.2	Heat Transport in the Limit of Very Small Reynolds Numbers.....	168
8.3	Thermal Flow Sensors.....	173
8.3.1	Anemometer Type Flow Sensors.....	174
8.3.2	Two-Wire Anemometers.....	181
8.3.3	Calorimetric Type Flow Sensors.....	183
8.3.4	Sound Intensity Sensors - The Microflow.....	188
8.3.5	Time of Flight Sensors.....	194
8.4	Skin Friction Sensors.....	195
8.5	“Dry Fluid Flow” Sensors.....	200
8.6	“Wet Fluid Flow” Sensors.....	205
9.	Resonant Sensors.....	209
9.1	Basic Principles and Physics.....	209
9.1.1	Introduction.....	209
9.1.2	The Differential Equation of a Prismatic Microbridge.....	211
9.1.3	Solving the Homogeneous, Undamped Problem using Laplace Transforms.....	212
9.1.4	Solving the Inhomogeneous Problem by Modal Analysis.....	215
9.1.5	Response to Axial Loads.....	217
9.1.6	Quality Factor.....	219
9.1.7	Nonlinear Large-Amplitude Effects.....	220
9.2	Excitation and Detection Mechanisms.....	222
9.2.1	Electrostatic Excitation and Capacitive Detection.....	223
9.2.2	Magnetic Excitation and Detection.....	223
9.2.3	Piezoelectric Excitation and Detection.....	223
9.2.4	Electrothermal Excitation and Piezoresistive Detection.....	224
9.2.5	Optothermal Excitation and Optical Detection.....	224

9.2.6	Dielectric Excitation and Detection.....	225
9.3	Examples and Applications.....	225
10.	Electronic Interfacing	229
10.1	Piezoresistive Sensors.....	230
10.1.1	Wheatstone Bridge Configurations.....	230
10.1.2	Amplification of the Bridge Output Voltage.....	233
10.1.3	Noise and Offset.....	235
10.1.4	Feedback Control Loops.....	236
10.1.5	Interfacing with Digital Systems.....	237
10.1.5.1	Analog-to-Digital Conversion.....	237
10.1.5.2	Voltage to Frequency Converters.....	240
10.2	Capacitive Sensors.....	240
10.2.1	Impedance Bridges.....	241
10.2.2	Capacitance Controlled Oscillators.....	245
10.3	Resonant Sensors.....	248
10.3.1	Frequency Dependent Behavior of Resonant Sensors.....	248
10.3.2	Realizing an Oscillator.....	249
10.3.3	One-Port Versus Two-Port Resonators.....	251
10.3.4	Oscillator Based on One-Port Electrostatically Driven Beam Resonator.....	251
10.3.5	Oscillator Based on Two-Port Electrostatically Driven H-shaped Resonator.....	257
11.	Packaging	259
11.1	Packaging Techniques.....	260
11.1.1	Standard Packages.....	260
11.1.2	Chip Mounting Methods.....	262
11.1.2	Wafer Level Packaging.....	263
11.1.3	Interconnection Techniques.....	265
11.1.4	Multichip Modules.....	267
11.1.5	Encapsulation Processes.....	269
11.2	Stress Reduction.....	269
11.3	Pressure Sensors.....	270
11.4	Inertial Sensors.....	272
11.5	Thermal Flow Sensors.....	272
	References	274
	Index	291