

Table of Contents

Symbols.....	XI
1 Introduction.....	1
2 Technological Basis of Bulk-Silicon-Microtechnique	5
2.1 The silicon wafer as a basis material of microtechnique	5
2.2 Technological processes.....	6
2.2.1 The basic conception of the bulk-silicon-microtechnique	6
2.2.2 Deposition and structuring of passivation layers	7
2.2.3 Wet and dry etching of silicon.....	8
2.2.4 Metallization	10
2.2.5 Wafer bonding	11
2.2.6 Plastic reshaping of silicon microstructures	13
3 Orientation Dependent Etching of Silicon	17
3.1 Fundamental principles of the generation of shapes	17
3.1.1 Atomic scale features of silicon etching	17
3.1.2 The formation of shapes by etching masked wafers	20
3.1.3 The importance of different oriented Si-wafers in the microtechnique: {100}, {110}, {112} and {111}	30
3.1.4 Detection of the correct orientation between wafer and mask	33
3.2 Chemistry and techniques of wet silicon etching	37
3.2.1 Chemical reactions and dependence on temperature	37
3.2.2 Influence of composition	39
3.2.3 Influence of doping.....	41
3.2.4 Equipment and etching technology.....	43
3.2.5 Isotropic etching	44
3.3 Etch mask design and simulation of silicon etching.....	46
3.3.1 Calculation of the etch mask.....	46
3.3.2 Addition of compensation masks	49
3.3.3 Simulation and design tools.....	50
3.4 Basic processes of the bulk-silicon-microtechnique	52
3.4.1 Shape definition by variation of etch steps	52
3.4.2 Changing of the mask between two etch steps	55
3.4.3 Examples of the most important basic processes and process interfaces.....	57

4 General Overview of the Shape- and Functional Elements and the Procedure of their Design.....	71
4.1 Survey and methodical procedure	71
4.2 Guide for the design procedure	73
4.3 Legend of the sketches	73
5 Simple Shape Elements	75
5.1 Definitions of shapes by the combination of sidewalls	75
5.1.1 Types of sidewalls arising from one-step etch processes.....	75
5.1.2 Types of sidewalls arising from two-step etch processes	78
5.1.3 Combinations of sidewalls.....	85
5.2 Qualities of etch ground and sidewall-faces and of the edges between them	86
5.2.1 Quality of the etch ground	87
5.2.2 Quality of sidewalls	91
5.2.3 Quality of edges.....	93
5.3 Shape elements made by one-step etch processes	94
5.3.1 Hollows (Deepenings)	94
5.3.2 Mesas (Elevations)	101
5.3.3 Grooves (Trenches)	106
5.3.4 Walls.....	109
5.3.5 Front-back combinations	113
5.4 Shape elements made by two-step etch processes.....	114
5.4.1 General remarks.....	114
5.4.2 Alteration of the etch mask.....	115
5.4.2 Change of the type of orientation dependent etchant.....	119
5.4.3 Change between orientation dependent and isotropic etchants.....	122
6 Elements for Mechanical Applications	127
6.1 Spring elements.....	127
6.1.1 Overview and used crystal faces.....	127
6.1.2 Bending springs	128
6.1.3 Torsion-bar springs.....	130
6.2 Levers / Spring hinges.....	143
6.2.1 Overview	143
6.2.2 Levers / Hinges for out-of-plane movements	144
6.2.3 Levers / Hinges for in-plane movements	144
6.3 Sliding guides.....	146
6.3.1 Overview	146
6.3.2 Four-wafer-guide	147
6.3.3 Two-wafer-guide	147
6.3.4 Three-wafer-guide	147
6.3.5 Sliding guide with plastically deformed elements	147
6.4 Bearings	149
6.4.1 Overview	149
6.4.2 Edge bearings	150
6.4.3 Tip bearings	150

7 Elements for Fluidic Applications	159
7.1 Channels.....	159
7.2 Alterations of cross section of channels	162
7.2.1 General remarks.....	162
7.2.2 Abrupt alterations of the cross section	163
7.2.3 Gradual alterations of the cross section	163
7.3 Elbows.....	163
7.3.1 General remarks.....	163
7.3.2 Elbows out-of-plane.....	164
7.3.3 Elbows in-plane	164
7.4 Branchings (Mixers).....	166
7.4.1 General remarks.....	166
7.4.2 Branching out-of-plane	166
7.4.3 Branching in-plane.....	167
7.5 Caverns (Cavities).....	169
7.6 Nozzles.....	171
 8 Elements for Optical Applications.....	 177
8.1 Grooves for fibre positioning	177
8.1.1 General remarks.....	177
8.1.2 Grooves in an angle of 0 or 90° to the flat.....	179
8.1.3 Grooves with an angle of 45° to the flat	179
8.1.4 Grooves in a direction range of $\Delta\alpha$ around the 0° or 90° directions to the flat.....	179
8.1.5 Grooves in any direction to the flat.....	180
8.1.6 Grooves with inclined direction to the wafer plane	180
8.2 Micro mirrors	180
8.2.1 Useable mirror faces on the {100}-wafer	180
8.2.2 Reflection at the {100}-wafer surface or {100}-etch ground	181
8.2.3 Reflection at sidewall faces out of the {100}-wafer plane	181
8.2.4 Reflection at sidewall faces inside the {100}-wafer plane	182
8.2.5 Useable mirrors on the {110}-wafer.....	184
8.3 Beam Splitters	185
8.3.1 Principles of beam splitting and suitable crystal faces.....	186
8.3.2 Beam splitting at a membrane built by the etch ground and the wafer back side	186
8.3.3 Beam splitting out of the wafer plane	186
8.3.4 Beam splitting inside the wafer plane	187
8.4 Concave Micro Mirrors.....	188
8.4.1 Introduction	188
8.4.2 Parabolic concave mirrors	188
8.4.3 Spherical concave mirrors	188
8.5 Gratings.....	189

8.6 Infrared Prisms	193
8.6.1 General remarks.....	193
8.6.2 The prism edge lies inside the wafer plane.....	193
8.6.3 The prism edge lies perpendicular to the wafer plane	193
Appendix.....	199
Physical Properties of Silicon	201
Survey and comparison with properties of other materials.....	201
Mechanical properties.....	206
Thermal and caloric properties	211
Optical properties	213
Index	217