

Ceramics Processing in Microtechnology

Edited by

Dr. H.-J. Ritzhaupt-Kleissl

Forschungszentrum Karlsruhe GmbH (FZK)

Institute for Materials Research (IMF III), Karlsruhe, Germany

Assoc. Professor Per Johander

Senior Researcher, Swerea IVF, Mölndal, Sweden



Whittles Publishing

Contents

Foreword

Preface

The Ceramic Division within the 4M Network

Abbreviations

List of contributing authors' affiliations

1	Ceramics in microtechnology: status, requirements and challenges	1
1.1	Introduction	1
1.2	Material development	2
1.2.1	Moulds and powders	2
1.2.2	Advanced synthesis methods	3
1.2.3	Sinter shrinkage and distortion	4
1.3	Processing routes for the fabrication of ceramic microcomponents	5
1.3.1	Processing techniques	5
1.3.2	Microinjection moulding	7
1.3.3	Micromachining of ceramics	9
1.3.4	Electrodischarge machining (EDM)	10
1.4	Component development and fabrication	11
1.4.1	General considerations	11
1.4.2	Materials development for special applications	11
1.5	Integration of piezoelectric ceramics	15
1.5.1	Challenges to integration	16
1.5.2	Approaches to integration	17
	Conclusions	18
	References	18
2	Design rules for microcomponents	23
2.1	Introduction	23
2.2	Derivation of design rules	24
2.3	Design rules for knowledge representation	24
2.4	Design rules in knowledge-based engineering	26
2.4.1	Integration in the CAD system	27
2.4.2	Scheme of rule check	27
2.4.3	Adapting rules	28
2.4.4	Analysing CAD part geometry	29
2.4.5	Evaluation of the rules	30
2.4.6	Realized prototype	30
	Conclusions	31
	Acknowledgements	32
	References	32
3	Process simulation with particle methods: micropowder injection moulding and hot embossing	34
3.1	Introduction	34
3.2	Particle methods	35
3.2.1	Smoothed particle hydrodynamics	35
3.2.2	Dissipative particle dynamics	36
3.2.3	Local thermostat for dissipative particle dynamics	36

3.3	A yield-stress model for polymethylmethacrylate	37
3.4	A model for powder migration	38
3.4.1	Continuum model	38
3.4.2	Smoothed particle hydrodynamics discretization	38
3.5	Results	39
3.5.1	Segregation through migration	39
3.5.2	Embossing simulation of polymethylmethacrylate	41
	Conclusions	42
	Acknowledgments	42
	References	42
4	Finite element modeling of the pressing of ceramic powders to predict the shape of a pellet after die compaction and sintering	44
4.1	Introduction	44
4.2	Mechanical modeling of die-pressing	44
4.2.1	Main steps of ceramics forming pressing: case of the UO_2	44
4.2.2	Influence of frictional forces	45
4.2.3	Powder compaction model	46
4.2.4	Calculation of pellet shrinkage after sintering	47
4.3	Identification of model parameters	47
4.3.1	Methodology	47
4.3.2	Model parameters for a UO_2 powder	49
4.4	Code performances	49
4.4.1	Green compact characteristics	49
4.4.2	Sintered pellets characteristics	51
4.5	Analysis of the effect of tools displacements	52
	Conclusion	53
	References	54
5	Wet chemical synthesis for multinary oxide ceramics	55
5.1	Introduction	55
5.2	Thermal two-step process	56
5.3	Spray drying	56
5.4	Calcination	57
5.5	Examples of powders produced	58
5.5.1	Lead zirconate titanate	59
5.5.2	Indium tin oxide	60
5.5.3	Bismuth strontium calcium cuprate	60
5.6	Sol-gel film formation	61
	Conclusions	64
	References	64
6	Synthesis of nanoscaled powders for applications in microsystems technology	67
6.1	Introduction	67
6.2	Gas phase methods for the synthesis of nanoparticles	68
6.3	The Karlsruhe microwave plasma process	69
6.4	Examples of nanoparticles and their application possibilities in microsystems technology	73
6.4.1	Application potential of nanoparticles in microoptics	74

6.4.2	Application of nanoparticles in sensor technology	78
	Conclusions	81
	References	81
7	Near net shaping of ceramics in microsystems technology	85
7.1	Introduction	85
7.2	2D net shaping	86
7.3	3D net shaping	89
7.3.1	Nonoxide ceramics	89
7.3.2	Oxide ceramics	91
7.3.3	Shaping of 3D microparts	95
	Conclusions	97
	References	98
8	(Ba/Sr)TiO₃: A perovskite-type ferroelectric for tunable dielectric applications at radio frequencies	101
8.1	Tunable dielectrics for radio frequency components and systems	101
8.2	Materials, dielectric and tunable properties of BT and BST	104
8.3	Tunable RF components based on BST	111
	References	115
9	Properties and application of polymer–ceramic–composites in microsystem technologies	120
9.1	Introduction	120
9.2	Composites with high solid load for feedstock development	121
9.3	Functional composite development	125
9.3.1	Adjustment of the thermal expansion coefficient	125
9.3.2	Adjustment of Vickers hardness	125
9.3.3	Refractive index modification	126
9.3.4	Increase in relative permittivity	128
	Conclusions	130
	Acknowledgements	130
	References	130
10	Micromoulds for injection moulding with ceramic feedstocks	134
10.1	Introduction	134
10.2	Tooling concepts	135
10.3	Mould insert concepts	136
10.4	Cutting processes	138
10.4.1	Cutting with geometrically defined cutting edges	138
10.4.2	Diamond cutting tools	138
10.4.3	Micromilling of steel	139
10.5	Ablation processes	140
10.5.1	Electro-discharge machining processes	140
10.5.2	Micro-electrodischarge machining processes	141
10.5.3	Laser beam machining	141
	Conclusions	142
	References	143

11 High-pressure microceramic injection moulding	146
11.1 Introduction	146
11.2 Micropowder injection moulding	147
11.2.1 Objectives and features	147
11.2.2 Evaluations on the accuracy of the MicroCIM process	149
11.2.3 Actual applications and further projects on MicroCIM	150
11.3 Micro-two-component injection moulding	151
11.3.1 General remarks	151
11.3.2 Fixed connections with metals or ceramics	153
11.3.3 Mobile connections	155
Conclusions	155
Acknowledgements	156
References	156
12 Low-pressure injection moulding	158
12.1 Introduction	158
12.2 Feedstocks for low-pressure injection moulding	159
12.3 Rheology of LPIM feedstocks	161
12.4 Machines and tooling for low-pressure injection moulding	162
12.5 Thermal treatment	164
12.6 Examples	166
Conclusions	168
References	169
13 Fabrication of ceramic microcomponents by electrophoretic deposition	171
13.1 Introduction	171
13.2 Properties of suspensions for electrophoretic deposition	172
13.2.1 Suspension stability	172
13.2.2 Derjaguin, Landau, Verwey and Overbeck theory	173
13.2.3 Electrokinetic effects	174
13.3 Electrophoretic deposition	176
13.3.1 Principles and models	176
13.3.2 Applications	179
13.4 Microstructures fabricated by electrophoretic deposition	182
Conclusions	184
References	184
14 Tape casting in micro- and nanofabrication	193
14.1 Introduction	193
14.2 Microsystem applications of tape casting	196
14.2.1 Micro-actuators	196
14.2.2 Fuel cell membranes	196
14.2.3 Microcombustion chamber	197
14.2.4 Photonic bandgap structures	197
14.3 Aqueous tape casting	198
14.4 Dispersion of fine powders for tape casting	200
14.5 Optimization of dispersants and binders for tape casting systems	202
14.6 Precision and shrinkage in tape casting	203
14.7 Templated grain growth	204

14.8 New materials and composite structures	204
Conclusions	205
References	206
15 Low temperature cofired ceramic-processing for microsystem applications	209
15.1 Introduction	209
15.2 Materials	210
15.3 General processing	212
15.4 Machining	213
15.4.1 Computer numerically controlled micromachining of low temperature cofired ceramic tapes	213
15.4.2 Jet vapour etching	213
15.4.3 Punching	214
15.4.4 Laser machining	215
15.4.5 Embossing	216
15.4.6 Photolithographic patterning	217
15.4.7 Photoformable low temperature cofired ceramic tapes	217
15.5 Lamination	218
15.5.1 Deposition of thick films	218
15.5.2 Use of sacrificial materials	218
15.6 Bonding and assembling	220
15.6.1 Tape joining	221
15.6.2 Bonding of fired low temperature cofired ceramic-stacks	221
15.6.3 Component integration in low temperature cofired ceramic module	221
15.6.4 Anodic bonding	223
Conclusions	224
References	224
16 Different ceramic materials for micromilling of high aspect ratio microstructures	227
16.1 Introduction	227
16.2 Ceramic materials for micromilling	228
16.2.1 <i>Ceramics for machining in the final state</i>	228
16.2.2 <i>Ceramics for machining in the pressed state</i>	229
16.2.3 <i>Ceramics for machining in the presintered state</i>	229
16.2.4 <i>Machining of ceramics before ceramization</i>	230
16.3 Micromilling of ceramic microstructures	232
Conclusions	233
Acknowledgments	233
References	234
17 High precision microgrooving on ceramic substrates	235
17.1 Introduction	235
17.1.1 Shaped grooves and process chain	236
17.2 Verification of grooves	239
Conclusions	240
Acknowledgments	240
References	240

18 Patterning of ceramics and glass surfaces	241
18.1 Patterning of quartz by CO ₂ -laser radiation	241
18.2 Patterning of ceramics	243
18.3 Laser-induced surface modification of ceramics	245
Conclusions	251
Acknowledgements	251
References	251
19 Free form microprocessing of ceramic materials by electrodischarge machining	254
19.1 Introduction	254
19.2 Micro electrodischarge machining	255
19.3 Micromachining performance of erodable ceramic materials	257
19.3.1 Silicon nitride based ceramics	258
19.3.2 Silicon and boron carbide-based ceramics	263
19.3.3 Alumina- and zirconia-based ceramics	265
19.4 Applications	268
Conclusions	270
References	271
20 Layer manufacturing of ceramic microcomponents	274
20.1 Introduction	274
20.2 Basic principles	275
20.3 Direct manufacturing	277
20.4 Manufacturing of microparts	277
20.5 Layer deposition	278
20.6 Solidification process	278
20.7 Rinsing process	279
20.8 Layer manufacturing by ink-jet printing	279
20.9 Resolution limiting factors	281
20.10 Stereolithography	282
20.11 Process parameters and binders	284
20.12 Layer manufacturing by microstereolithography	285
20.13 Mechanical properties	287
20.14 Selective laser sintering	288
Conclusions	289
References	289
21 Micro direct writing of ceramics	293
21.1 Introduction	293
21.2 Technologies	294
21.2.1 Ink-jet printing	294
21.2.2 Electrohydrodynamic atomization printing	299
21.2.3 Contact direct wiring	300
Conclusions	300
References	301

22 Quality assurance and metrology	305
22.1 Introduction	305
22.2 Metrology	306
22.3 Metrology terminology	307
22.4 Shape and dimensional measurements	308
22.5 Surface roughness	311
22.6 Microstructural analysis	312
22.7 Mechanical testing	315
22.8 Microtribological testing	317
Conclusions	320
References	320
Index	326