

Contents

List of Contributors XIII

1	Overview of Inkjet-Based Micromanufacturing	1
	<i>David Wallace</i>	
1.1	Introduction	1
1.2	Inkjet Technology	1
1.2.1	Continuous Mode Inkjet (CIJ) Technology	2
1.2.2	Demand Mode Inkjet Technology	2
1.3	Fluid Requirements	3
1.4	Pattern Formation: Fluid/Substrate Interaction	5
1.5	Micromanufacturing	6
1.5.1	Introduction	6
1.5.2	Limitations and Opportunities in Micromanufacturing	7
1.5.3	Benefits of Inkjet in Microfabrication	8
1.6	Examples of Inkjet in Micromanufacturing	9
1.6.1	Chemical Sensors	9
1.6.2	Optical MEMS Devices	10
1.6.3	Bio-MEMS Devices	12
1.6.4	Assembly and Packaging	13
1.7	Conclusions	14
	Acknowledgments	14
	References	14
2	Combinatorial Screening of Materials Using Inkjet Printing as a Patterning Technique	19
	<i>Anke Teichler, Jolke Perelaer, and Ulrich S. Schubert</i>	
2.1	Introduction	19
2.2	Inkjet Printing – from Well-Defined Dots to Homogeneous Films	20
2.3	Thin-Film Libraries Prepared by Inkjet Printing	25
2.4	Combinatorial Screening of Materials for Organic Solar Cells	28

2.5	Conclusion and Outlook	34
	References	35
3	Thermal Inkjet	41
	<i>Naoki Morita</i>	
3.1	History of Thermal Inkjet Technology	41
3.2	Market Trends for Inkjet Products and Electrophotography	42
3.3	Structures of Various TIJ Heads	43
3.4	Research on Rapid Boiling and Principle of TIJ	44
3.5	Inkjetting Mechanism of TIJ	47
3.6	Basic Jetting Behavior of TIJ	48
3.6.1	Input Power Characteristics	48
3.6.2	Frequency Characteristics	49
3.6.3	Dependency on Temperature	49
3.7	TIJ Behavior Analysis Using Simulation	51
3.7.1	Cylindrical Thermal Propagating Calculation Based on the Finite Element Method (Software Name: Ansys)	51
3.7.2	Fluidic Free Boundary Calculation Based on the Finite Differentiation Method (Software name: Flow3D)	51
3.8	Issues with Reliability in TIJ	53
3.9	Present and Future Evolution in TIJ Technology	54
	References	55
4	High-Resolution Electrohydrodynamic Inkjet	57
	<i>Park Jang-Ung and John A. Rogers</i>	
4.1	Introduction	57
4.2	Printing System	57
4.3	Control of Jet Motions	59
4.4	Drop-on-Demand Mode Printing	60
4.5	Versatility of Printable Materials and Resolutions	62
4.6	Applications in Electronics and Biotechnology	64
4.7	High-Resolution Printing of Charge	69
	References	70
5	Cross Talk in Piezo Inkjet	73
	<i>Herman Wijshoff</i>	
5.1	Introduction	73
5.2	Electrical Cross Talk	73
5.3	Direct Cross Talk	74
5.4	Pressure-Induced Cross Talk	76
5.5	Acoustic Cross Talk	78
5.6	Printhead Resonance	81
5.7	Residual Vibrations	83
	References	84

6	Patterning	87
	<i>Patrick J. Smith and Jonathan Stringer</i>	
6.1	Introduction	87
6.1.1	Droplet Impact and Final Droplet Radius	88
6.1.2	Evaporation of Inkjet-Printed Droplets at Room Temperature	90
6.1.3	Morphological Control for Ink Droplets, Lines, and Films	91
6.2	Conclusion	94
	References	95
7	Drying of Inkjet-Printed Droplets	97
	<i>Hans Kuerten and Daniel Siregar</i>	
7.1	Introduction	97
7.2	Modeling of Drying of a Droplet	98
7.2.1	Fluid Model	98
7.2.2	Lubrication Approximation	99
7.2.3	Solute Concentration	101
7.2.4	Evaporation Velocity	102
7.2.5	Numerical Method	103
7.3	Results	103
7.3.1	Droplet Shape Evolution	104
7.3.2	Layer Thickness	106
7.3.3	Effect of Diffusion	108
	Acknowledgments	109
	References	109
8	Postprinting Processes for Inorganic Inks for Plastic Electronics Applications	111
	<i>Jolke Perelaer</i>	
8.1	Introduction	111
8.1.1	Inkjet Printing	111
8.1.2	Printed Electronics	111
8.2	Inkjet Printing and Postprinting Processes of Metallic Inks	112
8.2.1	Choice of Metal	112
8.2.2	Postprinting Processes to Convert Inorganic Precursor Ink	115
8.2.3	Conventional Sintering Techniques	116
8.2.4	Alternative and Selective Sintering Methods	116
8.2.5	Room-Temperature Sintering	119
8.3	Conclusions and Outlook	121
	Acknowledgments	122
	References	122
9	Vision Monitoring	127
	<i>Kye-Si Kwon</i>	
9.1	Introduction	127
9.2	Measurement Setup	127

- 9.3 Image Processing 130
- 9.4 Jetting Speed Measurement 134
- 9.5 Head Normalization and Condition Monitoring 139
- 9.6 Meniscus Motion Measurement and Its Application 141
- References 144

- 10 Acoustic Monitoring 145**
Herman Wijshoff
- 10.1 Introduction 145
- 10.2 Self Sensing 145
- 10.3 Measuring Principle 146
- 10.4 Drop Formation, Refill, and Wetting 150
- 10.5 Dirt 152
- 10.6 Air Bubbles 153
- 10.7 Printhead Control 156
- References 157

- 11 Equalization of Jetting Performance 159**
Man-In Baek and Michael Hong
- 11.1 Equalization of the Droplet Volume on the Fly 160
- 11.1.1 Components of a Drop Watcher 160
- 11.1.2 Equalization through Volume Control 160
- 11.1.3 Results of the Droplet Volume Measurement and Equalization Process 161
- 11.1.4 Speed Equalization 164
- 11.1.5 Problems with the Droplet Equalization Methods on the Fly 164
- 11.1.5.1 Distortion of the Captured Droplet Images 166
- 11.1.5.2 Relation between Droplet Volume and Speed 166
- 11.2 Droplet Volume Equalization with Sessile Droplets 166
- 11.2.1 Equalizing the Droplet Volume with the Measurement of Sessile Droplets 167
- 11.2.2 Results of the Sessile Droplet Measurement and Equalization Process 168
- 11.2.3 Usefulness of the Sessile Droplet Measurement and Equalization Process 169
- 11.2.4 The Droplet Volume Equalization Process Using Light Transmittance 170
- 11.2.5 Result of the Droplet Volume Equalization Process Using Light Transmittance 171
- Further Reading 171

- 12 Inkjet Ink Formulations 173**
Alexander Kamyshny and Shlomo Magdassi
- 12.1 Introduction 173
- 12.2 Ink Formulation 174

12.2.1	Functional Materials	176
12.2.2	Solvents	177
12.2.2.1	Solvent-Based Inks	177
12.2.2.2	Water-Based Inks	178
12.2.3	Hot-Melt (Phase-Change) Inks	178
12.2.4	UV-Curable Inks	178
12.3	Ink Parameters and Additives	179
12.3.1	Rheology Control	179
12.3.2	Surface Tension Modifiers	180
12.3.3	Electrolytes and pH	180
12.3.4	Foaming and Defoamers	181
12.3.5	Humectants	181
12.3.6	Binders	181
12.3.7	Biocides	182
12.3.8	Examples of Inkjet Ink Formulations	182
12.4	Jetting Performance	182
12.4.1	Drop Formation	183
12.4.2	Ink Latency	183
12.4.3	Recoverability	184
12.4.4	Ink Supply	184
12.5	Ink Interaction with Substrates	185
12.6	Nongraphic Applications	186
12.7	Conclusions	187
	References	187
13	Issues in Color Filter Fabrication with Inkjet Printing	191
	<i>Dong-Youn Shin and Kenneth A. Brakke</i>	
13.1	Introduction	191
13.2	Background	191
13.3	Comparison of Printing Technologies	195
13.4	Printing Swathe due to Droplet Volume Variation	199
13.5	Subpixel Filling with a Designed Surface Energy Condition	204
13.6	Other Technical Issues	212
13.7	Conclusion	213
	References	213
14	Application of Inkjet Printing in High-Density Pixelated RGB Quantum Dot-Hybrid LEDs	217
	<i>Hanna Haverinen and Ghassan E. Jabbour</i>	
14.1	Introduction	217
14.2	Background	218
14.3	Experimental Procedure and Results	220
14.3.1	Role of Droplet Formation	221
14.3.2	Atomic Force Microscopy	222
14.3.3	Electroluminescence	225

14.4	Inkjet-Printed, High-Density RGB Pixel Matrix	229
14.5	Conclusion	234
	Acknowledgment	234
	References	234
	Further Reading	236
15	Inkjet Printing of Metal Oxide Thin-Film Transistors	237
	<i>JooHo Moon and KeunKyu Song</i>	
15.1	Introduction	237
15.2	Materials for Metal Oxide Semiconductors	237
15.3	Inkjet Printing Issues	239
15.3.1	Ink Printability	239
15.3.2	Influence of Substrate Preheat Temperature	242
15.4	Solution-to-Solid Conversion by Annealing	247
15.5	All-Oxide Invisible Transistors	251
15.6	Summary	254
	References	254
16	Inkjet Fabrication of Printed Circuit Boards	257
	<i>Thomas Sutter</i>	
16.1	Introduction	257
16.2	Traditional Printed Circuit Board Processes	257
16.3	Challenges for Inkjet in Printed Circuit Boards	258
16.4	Legend-Marking Processes	261
16.4.1	Cost Comparison	262
16.4.2	Materials for Legend Printing	262
16.5	Innerlayer Copper Circuit Patterning	263
16.5.1	Materials for Copper Etch Resists	264
16.5.2	Substrate Modification	265
16.6	Copper Plating Resist	266
16.7	Waste Reduction Using Inkjet Printing	268
16.8	Solder Mask Printing	269
16.9	Metallic Inks	273
16.10	Theoretical Printing Example for PCB Manufacturing	275
16.11	Digital Printing Alternatives to Inkjet Fabrication	276
16.12	Future Applications for Inkjet in Printed Circuit Boards	276
	References	277
17	Photovoltaics	279
	<i>Heather A.S. Platt and Maikel F.A.M. van Hest</i>	
17.1	Introduction	279
17.2	Device Structures	280
17.3	Small- and Large-Area Printing for Photovoltaics	283
17.4	Commercial Inkjet for Photovoltaics	289

- 17.5 Summary and Perspective 291
References 292
- 18 Inkjet Printed Electrochemical Sensors 295**
Aoife Morrin
- 18.1 Introduction 295
- 18.2 Printed Sensor Manufacturing 297
- 18.3 Inkjet Printing of Sensor Components 298
- 18.3.1 Substrates 299
- 18.3.2 Conducting Tracks 300
- 18.3.3 Transducer Materials 300
- 18.3.4 Biomolecules 305
- 18.4 Inkjet-Printed Sensor Applications 306
- 18.5 Future Commercial Projection 306
- Abbreviations 309
References 309
- 19 Antennas for Radio Frequency Identification Tags 313**
Vivek Subramanian
- 19.1 Introduction 313
- 19.1.1 Introduction to RFID 313
- 19.1.1.1 RFID Tag Classification 314
- 19.1.2 Applications of Printing to RFID Antenna Production 317
- 19.1.2.1 An Overview of RFID–HF versus UHF 318
- 19.1.2.2 Silicon-Based RFID Tag Construction – from Chip to Tag 319
- 19.2 Printed Antennas 319
- 19.2.1 HF Tag Antenna Considerations 320
- 19.2.2 UHF Tag Antenna Considerations 321
- 19.2.3 Application of Printing to Antenna Fabrication 322
- 19.2.4 Materials for Printed Antennas 323
- 19.2.4.1 Metallic Pastes 324
- 19.2.4.2 Particle-Based Inks 325
- 19.2.4.3 Organometallic Precursors 326
- 19.3 Summary of Status and Outlook for Printed Antennas 327
References 328
- 20 Inkjet Printing for MEMS 331**
K. Pataky, V. Auzelyte, and J. Brugger
- 20.1 Introduction 331
- 20.2 Photolithography and Etching 331
- 20.2.1 Photolithography 332
- 20.2.2 Etching 332
- 20.3 Direct Materials Deposition 333
- 20.4 Optical MEMS 336
- 20.5 MEMS Packaging 339

20.6	Functionalization and Novel Applications	340
20.7	Conclusion	342
	References	342
21	Inkjet Printing of Interconnects and Contacts Based on Inorganic Nanoparticles for Printed Electronic Applications	347
	<i>Jolke Perelaer and Ulrich S. Schubert</i>	
21.1	Introduction	347
21.2	Inkjet Printing of Metallic Inks for Contacts and Interconnects	348
21.2.1	Inkjet Printed Contacts and Interconnects for Microelectronic Applications	348
21.3	Inkjet Printing in High Resolution	351
21.3.1	Surface Wetting and Ink Modifications	351
21.3.2	Reduced Printed Droplet Diameter	353
21.3.3	Physical Surface Treatment	357
21.3.4	Inkjet-Printed Ionogels	359
21.4	Conclusions and Outlook	361
	Acknowledgments	362
	References	362
	Index	365