

Table of Contents

Introduction *xxix*

Volume 1

Part One Pros and Cons of Inkjet Technology 1

- 1 **Pros and Cons of Inkjet Technology in Industrial Inkjet Printing** 3
Werner Zapka
- 2 **Comparing Inkjet with Other Printing Processes and Mainly Screen Printing** 7
Gunter Huebner
 - 2.1 Comparing Inkjet with Screen Printing 11
 - 2.2 Screen Printing Principles and Capabilities 13
 - 2.3 Variants of Screen Printing Techniques 14
 - 2.4 Controlling Layer Thickness 16
 - 2.5 Achievable Resolution 17
 - 2.6 Application Examples 18
 - 2.6.1 Printed Antennae 18
 - 2.6.2 Printed Batteries 18
 - 2.6.3 Fine Line Printing 19
 - 2.7 Conclusion and Further Sources of Information 20
 - References 21

Part Two Inks 23

- 3 **A System Approach to Develop New Platforms of Industrial Inkjet Inks** 25
Mark Bale
 - 3.1 Introduction 25
 - 3.2 Ink Technologies for Industrial Inkjet 26
 - 3.2.1 Aqueous 27

3.2.2	Solvent	28
3.2.3	Oil	29
3.2.4	Hot Melt	30
3.2.5	Energy-Curable	30
3.2.6	Hybrids	31
3.2.7	Choosing an Ink Type	31
3.3	Ink Characterization Methods	31
3.3.1	Overview of Fluid Measurements	33
3.3.1.1	Viscosity	33
3.3.1.2	Surface Tension	33
3.3.1.3	Particle Size	33
3.3.1.4	Sedimentation	34
3.3.1.5	Other Properties	35
3.3.2	Examples of Dried Ink Evaluation	36
3.3.2.1	Color	36
3.3.2.2	Adhesion	36
3.3.2.3	Mechanical Resistance	37
3.3.2.4	Fluid Resistance/Compatibility	37
3.3.2.5	Weathering and Other Stress Tests	37
3.4	Printhead Evaluation	38
3.4.1	Equipment	38
3.4.1.1	Ink Supply	38
3.4.1.2	Drop Viewing	39
3.4.2	Drop Visualization in Practice	39
3.4.2.1	Drop Velocity Determination	40
3.4.2.2	Waveform Basics	40
3.4.2.3	Frequency Dependence	41
3.4.3	Jetting Sustainability	42
3.4.3.1	Manual Methods	42
3.4.3.2	Automated Methods	43
3.4.4	Nozzle Latency/Open Time	43
3.5	Print Process Factors	44
3.5.1	Surface Wetting	44
3.5.1.1	Contact Angle Testing	45
3.5.1.2	Pretreatment	45
3.5.1.3	Print Evaluation Methods	46
3.5.2	Ink–Ink Interactions	47
3.5.3	Drying Considerations	47
3.6	Case Study: Hybrid Aqueous–UV	48
3.6.1	Ink Concept Introductions	48
3.6.2	Head Interactions: Latency	49
3.6.2.1	Head Design Comparisons	49
3.6.2.2	Influence of Waveform	51
3.6.2.3	Ink Recirculation	51
3.6.2.4	Managing Nozzle Health	53
3.6.3	Head Interactions: Sustainability	54
3.6.4	Substrate Interactions	55

3.6.4.1	Substrate and Ink Comparisons	55
3.6.4.2	Print Process Factors	56
3.6.5	Outlook	56
	References	57
4	Photoinitiators	59
	<i>Kurt Dietliker and Jürgen Baro</i>	
4.1	Historical Background	59
4.2	Photoinitiators	60
4.2.1	Photoinitiators for UV Radical Curing	62
4.2.1.1	Type I Photoinitiators	64
4.2.1.2	Type II Photoinitiators	78
4.2.1.3	Type II Photoinitiators: Photoinitiators with Type I and Type II Functionality	84
4.2.1.4	Type II Photoinitiators: Coinitiators	85
4.2.2	Photoinitiators for Special Applications	86
4.2.2.1	Low-Migration Food Packaging	86
4.2.2.2	UV LED Curing	104
4.2.2.3	Water-Based UV Inkjet	108
	References	111
5	UV Radiation Sources and UV Radiation Measurement	117
	<i>Kurt Dietliker and Jürgen Baro</i>	
5.1	UV Radiation and Energy	117
5.2	UV Radiation Sources	118
5.2.1	Medium-Pressure Mercury Lamp	119
5.2.2	Doped Medium-Pressure Mercury Lamp	120
5.2.3	UV LED	122
5.3	UV Radiation Measurement	123
	References	128
6	UV-Curable Inkjet Inks and Their Applications in Industrial Inkjet Printing, Including Low-Migration Inks for Food Packaging	129
	<i>Marc Graindourze</i>	
6.1	UV Inks for Industrial Applications	129
6.2	UV Curing Process and UV Inkjet Ink Types	130
6.3	UV Inkjet Ink Requirements	132
6.4	UV Inkjet Ink Compounds and Ink Formulations	134
6.5	UV Inkjet Ink Production	138
6.6	Application of UV Inks in Industrial Print Systems	139
6.6.1	Marking and Coding	141
6.6.2	Product Printing	141
6.6.3	Label Printing	142
6.6.4	Packaging	142
6.6.5	Interior Decoration	142
6.7	Low-Migration Inkjet Inks for Migration-Sensitive Applications	142
	References	148

7	Ceramic Inkjet Inks	151
	<i>R&D Colorobbia Department</i>	
7.1	Introduction	151
7.1.1	Industrial Ceramic Process	151
7.1.2	Digital Ceramic Decoration	151
7.2	Ceramic Ink Characteristics	152
7.2.1	Liquid Fraction	152
7.2.2	Solid Fraction	153
7.2.2.1	Pigments	153
7.2.2.2	Others	154
7.3	Ink Properties	154
7.3.1	Viscosity	155
7.3.2	Surface Tension	156
7.3.3	Density	156
7.3.4	Other Properties	156
7.3.4.1	Filtration Time	156
7.3.4.2	Color/Effect	156
7.4	Shelf Life and Storage	156
7.5	Printing	157
7.5.1	Glaze/Ink Interaction	157
7.5.1.1	Interaction before Firing	157
7.5.1.2	Interaction during Firing	158
7.6	Safety Considerations	160
8	Aqueous Inks and Their Application Areas in Industrial Inkjet Printing and Desktop Printing	163
	<i>Philip Double and John Stoffel</i>	
8.1	Introduction	163
8.2	Dye-Based Inks	167
8.2.1	Inks with Dyes as Colorants	167
8.2.1.1	Background	167
8.2.1.2	Process	168
8.2.1.3	Dyes and Inks	168
8.2.2	Reactive Dye Inks	169
8.2.2.1	Background	169
8.2.2.2	Process	170
8.2.2.3	Inks and Dyes	170
8.2.3	Disperse Dye Inks	170
8.2.3.1	Dye Sublimation Inks	172
8.3	Inks with Pigments as Colorants	172
8.3.1	Nonfunctional Pigment Inks	173
8.3.1.1	Background	173
8.3.1.2	Processing	173
8.3.2	Pigment Inks with Emulsion Polymers: Latex Inks	173
8.3.2.1	Background	173
8.3.2.2	Processing	174

8.3.2.3	Inks and Pigments	175
8.4	Other Aqueous Inks	176
8.5	Summary and Outlook	176
	References	176
9	Dye Sublimation Inkjet Inks and Applications	179
	<i>Ming Xu</i>	
9.1	Overview	179
9.2	Introduction	179
9.3	Major Advantages of Sublimation Imaging	181
9.4	Sublimation Colorants in Digital Imaging	182
9.5	Ink, Transfer Media, and Substrate	184
9.6	Color Considerations	187
9.7	Major Engineering Aspects	188
9.8	Major Development Opportunities	191
9.9	Summary	193
	References	193
10	A Full-System Approach to Formulation of Metal Nanoparticle Inks for Industrial Inkjet Printing	195
	<i>Carsten Schauer and Alexander Rösch</i>	
10.1	Introduction Inks	195
10.2	Development and Manufacturing of Functional Particles and Inks	195
10.2.1	Synthesis of Metal Nanoparticles for Functional Inks: Comparison of Available Methods	196
10.2.2	Formulation and Application of Functional Inks	199
10.2.2.1	Formulation Additives	199
10.3	Characterization of Fluid Systems and Printed Patterns	200
10.3.1	Physical and Chemical Characterization of Inks	200
10.3.2	Physical and Electrical Characterization of Printed Patterns	203
10.3.2.1	Topography Measurement	205
10.3.2.2	Resistance and Resistivity	205
10.4	Reliability Characterization	212
10.5	Summary	213
	References	213
11	Metal Nanoparticle Conductive Inks for Industrial Inkjet Printing Applications	215
	<i>Hiroshi Saito and Haruyuki Nakajo</i>	
11.1	Introduction	215
11.2	Results and Discussion	216
11.2.1	Conductive Ink	216
11.2.2	Inkjet Printing	218
11.3	Conclusions	222
	References	222

12	Organic Light-Emitting Diode (OLED) and Quantum Dot (QD) Inks and Application	225
	<i>Alexander Lange and Armin Wedel</i>	
12.1	OLED Basics	225
12.2	Inkjet Printing of OLED Devices	225
12.2.1	Substrate and Pretreatment for Inkjet Printed OLEDs	225
12.2.1.1	Bottom Emitting OLEDs with Thin, Transparent Electrodes Such as Indium Tin Oxide (ITO)	225
12.2.1.2	An Alternative to ITO: A Grid Structure and a Conductive Polymer	227
12.2.2	Inkjet Printed PEDOT:PSS Layers	228
12.2.3	Inkjet Printed Layers Based on Emissive Polymers	230
12.2.4	Example of a Printed OLED Security Feature	232
12.3	QD Basics	233
12.3.1	Inkjet Printing of QLED Devices	235
12.3.2	Inkjet Printing of QDs on Paper	235
	References	236
	 Part Three Inkjet Printhead Technology	 239
13	Concepts and Strategies to Adapt Inkjet Printing to Industrial Application Requirements	241
	<i>Timothy N. Rosario</i>	
13.1	Introduction	241
13.2	Legacy Products	241
13.3	Establishing New Technologies	241
13.3.1	MEMS Technology	242
13.3.2	VersaDrop	242
13.4	Q-Class Delivers New Technologies to Market	243
13.5	RediJet: An Innovative New Technology	244
13.6	StarFire™ SG1024/C: A Direct Response	245
13.7	StarFire™ SG1024/A: Built on Success	246
13.8	Samba: Embracing Printhead Technologies	246
13.9	Key Samba Technologies	247
13.9.1	Sputtered Nb-PZT Film	247
13.9.2	Nonwetting Coatings	247
13.10	Looking Forward	248
13.11	Printhead Offerings	249
14	Konica Minolta's Inkjet Printhead Technology	253
	<i>John Corral</i>	
14.1	Early History	253
14.1.1	Type 204 Printhead	254
14.1.2	512 Series	255
14.1.3	KM1024	262
14.1.4	KM1024i	263

14.1.5	KM1800i	266
14.2	Strengths	267
14.2.1	KM Printhead Strengths	267
14.2.2	Reliability	267
14.2.3	Quality	271
14.2.4	Consistency	272
14.2.5	Life	273
14.2.6	Alignment	277
14.3	Markets and Geography	278
14.4	Future Direction	280
15	Xaar's Inkjet Printing Technology and Applications	285
	<i>Jürgen Brünahl, Angus Condie, Mark Crankshaw, Tony Cruz-Uribe, and Werner Zapka</i>	
15.1	Xaar Company Introduction	285
15.2	Bulk Technology	285
15.2.1	Piezoelectric Shear Mode and Shared Wall Technology	285
15.2.2	Monolithic Cantilever Architecture	287
15.2.3	Chevron Architecture	289
15.3	Three-Cycle Acoustic Firing	289
15.3.1	Cycles, Phases, and Grayscale	289
15.3.2	Waveforms	291
15.3.3	Additional Waveform Features	293
15.4	Hybrid Side Shooter Architecture: Xaar 1001 Family	295
15.5	Edge-Mounted Side Shooter Architecture: Xaar 501 Family	296
15.6	Ink Recirculation (TF) Technology	297
15.6.1	Hydra Ink Supply	299
15.7	Print Bar System	300
15.8	MEMS Drop Ejectors with Thin Film Piezoelectric Actuators	301
15.8.1	Xaar's 5601 MEMS Drop Ejector	301
15.8.2	Xaar's 5601 Printhead	304
15.9	New Inkjet Applications and Development	306
15.10	Summary	309
	References	310
16	Hewlett Packard's Inkjet Printhead Technology	313
	<i>Steven J. Simske</i>	
16.1	Fundamentals of Inkjet Printing	313
16.1.1	Overview of Inkjetting and Continuous Inkjet (CIJ)	313
16.1.2	Piezoelectric Inkjetting	315
16.1.3	Thermal Inkjetting	316
16.1.4	Other Forms of Inkjetting	319
16.2	Evolution of the Number of Nozzles	319
16.3	Current/Future Improvements: Page-Wide Printing	320
16.4	Inkjetting for Other Processes	321
16.5	A Possible Future of Inkjet in Custom and Surface Manufacturing	322

- 16.6 Case Study: HP PageWide Array 326
- 16.6.1 Specifics of the TII Technology 326
- 16.6.2 Printhead Design 327
- 16.6.3 Drop Formation Process 329
- 16.6.4 Application Areas 331
- References 331

17 Memjet's Inkjet Printhead Technology and Associated Printer Components 335

Mike Puyot

- 17.1 A History of Innovation 335
- 17.2 The Memjet Printing System 335
- 17.3 The Technical History of Memjet 336
- 17.4 The Memjet Printhead 336
- 17.5 Manufacturing the Memjet Printhead 338
- 17.6 Designed for Success 339
- 17.7 Balancing Cost vs. Performance 341
- 17.8 Memjet Inks 342
- 17.9 A Holistic Approach to Printing Systems 342
- 17.10 Memjet in the Marketplace 343
- 17.11 Future Innovations for Ink and Printheads 346
- 17.12 Continuing to Set the Standard 347
- References 348

18 KODAK's Stream Inkjet Technology 351

Michael Piatt, Douglas Bugner, James Chwalek, and James Katerberg

- 18.1 Introduction 351
- 18.2 Principle of Operation 351
- 18.3 MEMS Technology-Based Printheads 354
- 18.4 Scalable Technology 354
- 18.5 Image Quality 355
- 18.5.1 Dot Size and Resolution 355
- 18.5.2 Color Gamut 356
- 18.5.3 Image Registration and Artifact Detection 356
- 18.6 Ink Technology 357
- 18.7 Substrates 358
- 18.8 The Future of Stream Technology 359
- References 359

Part Four Substrates 361

19 Paper and Paper-Based Substrates for Industrial Inkjet Printing 363

Wolfgang A. Schmidt

- 19.1 Definition of Paper 363
- 19.2 Properties of Paper 364
- 19.2.1 Bulk Properties 364

19.2.2	Wetting and Surface Properties	366
19.2.3	Porosity and Ink Penetration	366
19.2.4	Physical–Chemical Interaction of Inks with the Paper	367
19.3	Coated Paper, Coating Types, and Surface Properties	368
19.3.1	Porous Coatings	368
19.3.2	Film Coatings	369
19.3.3	Laminates and Composites	369
	References	370
20	Polymeric Nonabsorbing Substrates for Industrial Inkjet Printing Applications	373
	<i>Rita Hofmann</i>	
20.1	Materials: Chemical Composition, Manufacturing Process	373
20.1.1	Polymer Types	373
20.2	Film Manufacturing	377
20.2.1	Film Casting and Extrusion Processes	377
20.2.2	Film Surface Tension and Surface Tension Modification	378
20.3	Material Properties: Chemical, Thermal, Mechanical, Optical, Eco-Environmental	380
20.3.1	Chemical Properties	381
20.3.2	Thermal Properties	381
20.3.3	Mechanical Properties	383
20.3.4	Electrical and Optical Properties	384
20.3.5	Environmental Effects and Durability	386
20.3.6	Barrier Properties	387
20.4	Long-Term Durability and Recycling	388
	References	389
21	Glass Substrates for Industrial Inkjet Printing Applications	391
	<i>Lutz Parthier, Thomas Wiegel, Clemens Ottermann, and Fredrik Prince</i>	
21.1	Introduction: Glass a Universal Material	391
21.2	Glass Types and Main Characteristics	391
21.3	Manufacturing Process	392
21.3.1	Conventional Technology	393
21.3.2	Thin Glass Technology	393
21.4	Physical and Chemical Properties	393
21.4.1	Geometrical Properties	395
21.4.2	Enhanced Glass Strength	395
21.4.3	Glass Surface Properties	396
21.5	Surface Treatments	396
21.5.1	Determination of Surface Quality	396
21.5.2	Surface Treatment Methods to Clean a Surface	398
21.5.3	Surface Cleaning and Coating for Touchscreen Application	400
21.6	Glass Material	401
21.6.1	Optical Glass	401
21.6.2	MEMpax®	402
21.6.3	AF 32® Eco Thin Glass	402

21.6.4	D 263® T Eco Thin Glass	402
21.6.5	B 270® i Ultrawhite Glass	404
21.6.6	Glass Ceramic	404
21.6.7	Photosensitive Glass	405
21.7	Structuring	405
	References	407

Part Five Metrology 409

22	Measurement of Complex Rheology and Jettability of Inkjet Inks	411
	<i>Tri Tuladhar</i>	
22.1	Introduction	411
22.2	Ink Flow Behavior	413
22.3	Bulk and Dynamic Ink Properties	414
22.3.1	Surface Tension	414
22.3.2	Viscoelasticity	415
22.3.3	Other Properties	416
22.4	Complex Rheology Characterization Tools at Jetting Conditions	416
22.4.1	Steady Shear Rheometers	417
22.4.2	High-Frequency Rheometers	417
22.4.3	Extensional Rheometers	418
22.5	Selective Selection of Additives to Optimize Complex Rheology during Ink Formulations	423
22.6	Correlation of Complex Rheology with Jetting Behavior	425
22.6.1	Continuous Inkjet (CIJ)	425
22.6.2	Drop-on-Demand Inks	428
22.7	Conclusions	428
	References	429
23	Printhead Health in Industrial Inkjet Printing: In-Line and Off-Line Detection of Poor Drop Formation	431
	<i>Herman Wijshoff</i>	
23.1	Introduction	431
23.2	Failure Origins	432
23.2.1	Introduction	432
23.2.2	Meniscus Consistency	432
23.2.3	Nozzleplate Wetting	433
23.2.4	Satellite Drops	434
23.2.5	Air Bubbles	435
23.3	Sensing	435
23.3.1	Acoustic Sensing, Paint	435
23.3.2	Capacitive Sensing	436
23.3.3	Impedance Spectroscopy	437
23.3.4	Monitoring Droplet Formation	438
23.4	Feedforward Control	441
	References	442

- 24 Quantitative Assessment of Inkjet Reliability under Industrial Conditions: Measuring All Drops during Extended High-Duty Printing 445**
Ingo Reinhold and Tomáš Černý
- 24.1 Summary 445
- 24.2 Idea and Experimental Setup 446
- 24.3 Theoretical Considerations 447
- 24.4 Analysis Algorithm 449
- 24.4.1.1 Robustness to Nozzle Position Variation 450
- 24.4.1.2 Low Contrast Optimization 451
- 24.4.1.3 Histogram Matching 451
- 24.4.1.4 Summary of the Preflight Techniques 453
- 24.4.1.5 Analysis of the Droplet Presence 454
- 24.4.2 Computing Time 456
- 24.4.3 Conclusion 457
- References 457
- 25 In-Line Resistance and Temperature Measurement of Conductive Inks 459**
Pit Teunissen, Robert Abbel, Rob Hendriks, and Pim Groen
 Reference 461

Part Six Data Flow 463

- 26 Data Handling in Industrial Inkjet Printing 465**
Steven J. Simske
- 26.1 The Extent of Data 465
- 26.2 Preparing for the Data 466
- 26.2.1 Using the Data 466
- Reference 467

Volume 2

Part Seven Machine Integration 469

- 27 System Approach: An Integrator's Advice on a System Approach for Industrial Inkjet Implementations 471**
Werner Van de Wyncel
- 27.1 System Approach 471
- 27.2 The Demonstrator Fail 472
- 27.3 Automate the Right Process 472
- 27.4 Early Total Cost of Ownership 473
- 27.5 Chemical Compatibility 474
- 27.6 Pressures: Wanted and Unwanted 475

27.7	Temperature Affects Not Just the Fluid	477
27.8	Ink Systems	478
27.9	Maintenance Systems	480
27.10	Motion Systems	481
27.10.1	Speed	481
27.10.2	Wobble	482
27.10.3	Encoder	483
27.10.4	Printhead	483
27.11	Preprocesses	484
27.12	Postprocesses	485
27.13	Electronics and Software	485
27.14	Humans Are Part of the Total System	487
27.15	A Small System Approach Example: To Pin or Not to Pin	487
27.16	Be Not Afraid of the System But Use It	488
	Reference	488
28	Inkjet Platforms for Functional Material Applications: Modular Integration of Industrial Production Processes	489
	<i>Kai Keller and David Stüwe</i>	
28.1	Introduction	489
28.1.1	Simultaneous Application to Different Industries	489
28.2	Role of the Integrator	490
28.3	Inkjet is Complex: There Is No “Best for Anything”	490
28.4	Important Aspects of Realizing an Inkjet Process	492
28.4.1	Choice of the Printhead	493
28.4.1.1	Material Compatibility	493
28.4.1.2	Recirculating Printhead?	494
28.4.1.3	Rheology	494
28.4.1.4	Availability	494
28.4.1.5	Resolution and Minimal Feature Size	494
28.4.1.6	Productivity	496
28.4.1.7	Specific Pattern Requirements	496
28.4.2	Print Strategy	497
28.4.2.1	Pattern Generation and Adaptation of Print Direction	497
28.4.2.2	Printing onto a Substrate Grid	498
28.4.2.3	Dosing Applications	499
28.4.2.4	Process Evaluation	499
28.4.2.5	Preprocessing	499
28.4.2.6	Postprocessing	500
28.4.2.7	Jetting Evaluation	501
28.5	Platform Design	501
28.5.1	Precision and Repeatability	502
28.5.2	Nozzle Calibration	502
28.5.3	Modular Engineering	502
28.5.4	Platform Layout	502
28.5.5	Print Stage	502
28.5.5.1	Substrate Fixation	502

28.5.5.2	Substrate Temperature	502
28.5.5.3	Adaptation of Print Direction	503
28.5.6	Process Unit	503
28.5.7	Ink Supply System	503
28.5.7.1	Static Ink Supply	504
28.5.7.2	Recirculating Ink Supply	504
28.5.7.3	Size and Refill Concept	504
28.5.8	Drop Formation Analysis	504
28.5.9	Maintenance	504
28.5.10	Environment	505
28.5.11	Automation	505
28.6	Complexity and Performance	506
	Reference	506

Part Eight Pre- and Postprocesses 507

29	Surface Pretreatment for Wettability Adjustment	509
	<i>Gerhard Liebel and Matthias Beß</i>	
29.1	Substrate Surface Condition Matters!	509
29.1.1	Ever Tried to Paint a Wax Candle?	509
29.1.2	Describing Surface Properties	510
29.1.3	Some Facts About Cleanliness of Supplied Substrates	510
29.1.4	Test Methods for Surface Activity	511
29.1.4.1	Test Inks	511
29.1.4.2	Contact Angle Test	511
29.2	Surface Pretreatment Methods	512
29.2.1	The Gentle Power of the Fourth Aggregate State and How Does Plasma Work?	512
29.2.2	A Brief Excursion into Chemistry and Physics of the Plasma Reaction	513
29.2.3	Methods for Surface Pretreatment: Cleaning and Activation	515
29.2.3.1	Vacuum or Low-Pressure Plasma: Chemical Energy without Heat Load	515
29.2.3.2	Corona and Atmospheric Plasma	515
29.2.3.3	Flame Treatment	516
29.2.3.4	UV Ozone Treatment	517
29.3	Industrial Use of Surface Pretreatment	518
29.3.1	Corona	518
29.3.2	Atmospheric Plasma	519
29.3.3	Vacuum Plasma (or Low-Pressure Plasma)	521
29.3.3.1	Plasma Cleaning	522
29.3.3.2	Plasma Activation (or Plasma Modification, Plasma Conditioning)	523
29.3.3.3	Other Terms for Plasma Processing	524
29.4	Choosing the Right Pretreatment Method	525
29.4.1.1	Geometry of Parts and Substrates	525

29.4.2	Process Gas Limitations	525
29.4.3	Process Temperature Limitations	526
29.5	Shelf Life	527
29.6	Summary	528
30	UV LED Ink Curing: UV LED Technology and Solutions for Integration into Industrial Inkjet Printing	529
	<i>Dirk Exner</i>	
30.1	What Is UV LED Curing?	529
30.2	UV LED Technology Components	529
30.2.1	LEDs: The Base Building Block	530
30.2.2	Array: Grouping of LEDs	531
30.2.3	Cooling: Thermal Management	532
30.2.4	Optics: Guiding the Light	533
30.3	Emission Spectrum	533
30.3.1	UV-A	533
30.3.2	UV-B and UV-C	534
30.4	Power Specifications	535
30.4.1	Peak Irradiance	535
30.4.2	Power	535
30.4.3	Dose	536
30.4.4	Emitting Window Width	536
30.5	Material Formulation	537
30.6	UV LED Benefits	537
30.7	Markets and Applications	538
30.7.1	Digital Inkjet, Screen, and Flexographic Printing	538
30.7.2	Labels and Packaging	539
30.7.3	Posters and Signage	539
30.7.4	Coding and Marking	539
30.7.5	Container Printing	539
30.7.6	Braille Printing	539
30.7.7	Decoration	539
30.7.8	3D Textured Printing	540
30.8	Integration Considerations	540
30.8.1	Pinning	540
30.8.2	Thermal Management and Aerodynamics	540
30.8.3	Stray Light	541
30.9	Summary and Outlook	541
31	Electron-Beam Processing for Industrial Inkjet Printing: Cross-Linking and Curing	543
	<i>Urs V. L��uppi</i>	
31.1	EB Processes	543
31.1.1	Cross-Linking	543
31.1.2	Curing or Drying	544

31.1.3	EB Curing Enhances Product Qualities	544
31.2	Advantages of EB-Processing	544
31.3	Differences between EB and UV Curing	545
31.4	Curing or Drying	545
31.5	Operating Parameters	547
31.5.1	Penetration of Energetic Electrons	547
31.5.2	Dose	547
31.5.3	Dose Rate: Throughput	548
31.5.4	Operation and Maintenance	548
31.5.5	Inerting	549
31.5.6	Energy Consumption	549
31.5.7	Safety/Shielding	549
31.6	The Classic EB Processor	550
31.7	The ebeam Lamp	550
31.8	EB for Inkjet Applications	553
31.8.1	Inkjet EB Inks	555
31.9	Summary	555
	Further Reading	556
32	Photonic Curing Enabling High-Speed Sintering of Metal Inkjet Inks on Temperature-Sensitive Substrates	557
	<i>Vahid Akhavan, Kurt Schroder, and Stan Farnsworth</i>	
32.1	Photonic Curing of Inkjet-Printed Films	557
32.2	Technology Behind Photonic Curing	558
32.3	Inkjet Printing Combined with Photonic Curing	561
32.4	Summary and Conclusions	564
	References	565
33	Oven Drying of Inkjet-Printed Functional Fluids on Industrial Scale	567
	<i>Gerard Kaper and Ronald de Graaf</i>	
33.1	Drying Process: How to Open the Black Box	567
33.2	Convective Drying Oven	567
33.3	Convective Drying Process	569
33.3.1	Evaporation	570
33.3.2	Curing and Sintering	570
33.4	Oven Temperatures	571
33.5	Air Flow Speed	572
33.6	Web Temperature	573
33.6.1	Infrared Drying in Support of Convective Heating	574
33.7	Lower Explosion Level (LEL)	574
33.8	Condensation	575
33.9	Contamination Control	575
33.9.1	Ambient Control	577
33.9.2	Web Transport through the Oven	577
33.10	Conclusion	578

Part Nine Printing Strategies 579**34 Turning Industrial Application Requirements into Real Solutions 581**
Timothy N. Rosario

- 34.1 Application Development 581
- 34.2 Productivity 582
- 34.3 Single-Pass Printing 583
 - 34.3.1 Introduction 583
 - 34.3.2 Drop Size Requirement 583
 - 34.3.3 Drop Placement 585
 - 34.3.4 Placement Error in X 585
 - 34.3.5 Placement Error in Y 587
- 34.4 Imaging Models 589
- 34.5 High Standoff Printing 591
- 34.6 Summary 596
- References 597

Part Ten Application Development 599**35 Inkjet Printing for Printed Electronics 601***Pit Teunissen, Robert Abbel, Tamara Eggenhuizen, Michiel Coenen, and Pim Groen*

- 35.1 Technology 601
 - 35.1.1 Introduction 601
 - 35.1.2 Production Upscaling 602
- 35.2 Application Examples 605
 - 35.2.1 Printed Smart Card 605
 - 35.2.2 Inkjet Printing of the Bezel in Touch Panels 606
 - 35.2.3 Multilayer IJP for Smart Labels 609
 - 35.2.4 Inkjet Printed Organic Photovoltaics 610
 - 35.2.5 Inkjet Printing of Two-Colored Organic Light-Emitting Diodes 613
- 35.3 Conclusions 614
- References 615

36 Inkjet-Printed Metal Lines and Sensors on 2D and 3D Plastic Substrates 617*Polzinger Bernhard, Keck Jürgen, Eberhardt Wolfgang, and Zimmermann André*

- 36.1 Introduction 617
- 36.2 Inkjet Printing of Metal Lines on Injection-Molded Substrates 618
 - 36.2.1 Printing Results 618
 - 36.2.2 Resistance 619
 - 36.2.3 Adhesion 619
- 36.3 Electrical Connection of Printed Metal Lines 620
 - 36.3.1 Overprinting of Contact Pads 620
 - 36.3.2 Spring Contacts 621

36.3.3	Soldering	621
36.3.4	Isotropic Conductive Adhesive	622
36.4	Inkjet Printing of Metal Lines on 3D Surfaces	622
36.5	Sensors on Injection-Molded Thermoplastic Substrates	624
36.5.1	Temperature Sensor	624
36.5.2	Stress Sensor	625
36.5.3	Touch Sensor	626
36.5.4	Humidity Sensor	627
36.5.5	Fluid-Level Sensor	628
36.5.6	Intrusion Sensor	629
36.5.7	Antennas	630
36.6	Challenges for Commercialization	631
36.7	Summary	632
36.8	About Hahn-Schickard	632
	References	632
37	Inkjet and Laser Hybrid Processing: An Enabling Technology for Reliable Production of Fine Interconnects in Large-Area Electronics	635
	<i>Adam Brunton and Mickey Crozier</i>	
37.1	M-Solv	635
37.2	Introduction	635
37.3	Hybrid Process Examples	636
37.3.1	Manufacture of Capacitive Touch Screens	636
37.3.2	One-Step Interconnect for Thin Film PV	639
37.3.3	Other Benefits of Hybrid Processes	642
37.3.4	Hybrid Processing Machines and Outlook for the Future	644
37.4	Conclusion	645
	References	646
38	Industrial 3D Inkjet Printing/Additive Manufacturing	649
	<i>Neil Hopkinson and Patrick J. Smith</i>	
38.1	Overview of Additive Manufacturing	649
38.2	Inkjet as a Commercially Attractive Enabler in Industrial 3D Printing/Additive Manufacturing	649
38.3	Inkjet Printing and Reaction	651
38.3.1	Direct 3D Inkjet Printing	651
38.4	Inkjet Printing to Enable Selective Sintering	654
38.5	Future Outlook for Inkjet in Industrial 3D Printing/Additive Manufacturing	659
	References	659
39	Industrial Applications of 3D Inkjet Printing in the Life Sciences	661
	<i>James W. Stasiak</i>	
39.1	Introduction	661
39.2	Inkjet Printhead Technology	662
39.3	Printing Functional Materials	664

39.4	Inkjet-Based Bioprinting	666
39.5	Commercial Inkjet-Based Bioprinting Technologies	669
39.5.1	Commercial Bioprinting Technologies	669
39.5.2	From Lab to Fab – Scaling Inkjet-Based Bioprinting	671
39.6	Inkjet-Based Drug Discovery	674
39.7	Summary and Outlook	677
	References	678

Part Eleven Successful Implementations and Case Studies 681

40	Inkjet Technology within the Label Converting Market	683
	<i>Carl Smith</i>	
40.1	Inkjet Printing of Labels	683
40.2	Label Functionality	684
40.3	Not Just a Print Process, but a Manufacturing Process	685
40.3.1	Substrates	686
40.4	Converting Processes	689
40.4.1	Unwinding/Rewinding	689
40.4.2	Web Cleaning and Corona Treatment	689
40.4.3	Primer	690
40.4.4	Printing with High Opacity White Ink	691
40.4.5	CMYK Process Printing	692
40.4.6	Spot Color Printing and Emulation	694
40.4.7	Pantone System	695
40.4.8	Gamut	696
40.5	The Advantage of Digital Hybrid	697
40.5.1	Inline Flood Coat and Spot Varnish	698
40.5.1.1	Lamination	700
40.5.2	Peel and Reveal	700
40.5.3	Cold Stamp Foil	700
40.5.4	Metallic Process	701
40.5.5	Spot Colors and Specialist Inks	701
40.6	Models of Converting Using Inkjet	702
40.6.1	Desktop Converting	702
40.6.2	Low Investment	703
40.6.3	Reel to Reel with Offline Finishing	703
40.6.4	Reel to Reel with Inline Finishing	704
40.6.5	Fully Integrated Semirotary or Full Rotary Magnetic Die-Cutting, Slitting, and Sheeting	704
40.6.6	Fully Integrated Laser-Based Finishing	705
40.6.7	Third-Party Finishing Solution	705
40.6.8	Full Hybrid Solution	705
40.6.9	Retrofit Hybrid Solution	706
40.7	The Inkjet Advantage	707
40.8	Market Sectors	708
40.9	Trends in the Industry	708

40.9.1	Reduced Lead Time	708
40.9.2	Reduction in Quantities and Increase in Frequency of Orders	711
40.9.3	Clearer More Transparent Labeling	711
40.9.4	Variable Data	711
40.9.5	More Stringent Guidelines: New Labeling Technologies	712
40.9.6	Anticounterfeiting and Brand Protection	712
40.9.7	Supply Chain Tracking	713
40.9.8	Sustainability and Eco-friendly Materials	713
40.9.9	Shrink/Stretch Sleeve	713
40.10	Creating a Successful Integration	714
40.10.1	Selecting the Right Printhead Technology for the Label Market	714
40.10.2	Qualifying a Head to a Specific Application	714
40.10.3	Factors to Consider When Selecting a Printhead	714
40.10.4	Reliability	715
40.10.5	Viscosity Range	716
40.10.6	Gray Levels and Resolutions	716
40.10.7	Ability to Print Flat Vibrant Colors	718
40.10.8	Uniformity	718
40.10.9	Highlight Detail	719
40.10.10	Smooth Blends	719
40.10.11	Performance	720
40.11	Example of Commercially Available Inkjet Label Press – Graphium	720
	Further Reading	722
41	Case Study: Digital Label Converting FFEI Ltd – Graphium	723
	<i>Carl Smith</i>	
41.1	Graphium Digital Hybrid Label Press	723
41.2	Productivity	723
41.2.1	Modular	724
41.2.2	Wide Web Width	724
41.2.3	Automated Cleaning	724
41.2.4	Manipulation of the Crossover	724
41.2.5	Finishing	725
41.2.6	Workflow	725
41.2.7	Print Bar	725
41.3	Reliability	725
41.3.1	Printheads	725
41.3.2	Industrial-Grade Transport System	726
41.4	Easing the Production of Complex Label Designs	726
41.4.1	Combining the Power of Digital with the Versatility of Flexo	726
41.4.2	Substrate Choice	726
41.4.3	Fit-for-Purpose	726
41.4.4	Variable Data	727
41.4.5	Banner Printing	727
41.5	Print Quality	727
41.6	Managing a Hybrid Production System	727

41.7	Intelligent Layout	728
41.7.1	MIS Integration	728
41.7.2	CAD Import	728
41.7.3	Automated Image Matching	728
41.7.4	Rules-Based Step and Repeat	728
41.7.5	Versioned and Ganged Labels	728
41.7.6	Object Specific Optimization	729
41.7.7	Job Container with Multiworkflow Automation	729
41.7.8	Variable Data	729
41.7.9	Wide Range of Supported Devices	729
42	Case Study Gallus Labelfire 340: Guiding Question to Choose a Hybrid Inline Label Converting System	731
	<i>Martin Leonhard</i>	
42.1	Summary	736
43	Cylindrical Packaging Decoration: A Breakthrough in Inkjet Technology	737
	<i>John Corral and Saverio Ardizzone</i>	
43.1	Introduction	737
43.2	Background to the Client	737
43.3	Background to IJ and Konica Minolta Ink Jet Division	738
43.4	The Link with Martinenghi	738
43.5	Ink and UV	741
43.6	Projects and Delivering	742
43.7	Realization of a Dream	745
44	Industrial Inkjet Printing in Decorative Web Print Applications	747
	<i>Patrik Lutz</i>	
44.1	Introduction	747
44.1.1	History of Décor Paper Printing	747
44.1.2	Markets and Market Sizes	748
44.1.3	Situation and Preview	748
44.2	Technical Description of Décor Printing with Inkjet Printing	748
44.2.1	Décor Paper	748
44.2.2	Applications	751
44.2.2.1	Main Processes	751
44.2.2.2	Products	752
44.2.3	Metamerism	752
44.2.4	Light Shades	752
44.2.5	Selection Criteria for Inkjet Printheads and Inks for Décor Printing	753
44.2.6	What Would Be the Perfect Printhead for a Décor Printing Application?	754
44.2.7	Paper Growth and Ink Type Selection	754
44.2.8	Drying	755

44.2.9	Impregnation	755
44.2.10	Pressing	756
44.3	Applications	756
44.3.1	Printing Applications in Digital Production	756
44.3.1.1	Project Printing Application	756
44.3.1.2	Design Development	756
44.3.1.3	Lab Printing	757
44.3.1.4	Production Printing	757
44.4	Example of an Inkjet-Based Machine for Décor Printing	757
	References	759
45	Case Study at TecnoFerrari: Design of a Single-Pass Inkjet Printer for Ceramic Tile Decoration – From Machine Concept to a Complete Solution	761
	<i>Alberto Annovi</i>	
45.1	Ceramic Tiles Decoration Requirements	761
45.1.1	Background: Ceramic Tiles Manufacturing Process	761
45.1.2	Ceramic Tiles Typology, Sizes, and Glazing Line Speed	763
45.1.3	Ceramic Tiles Printing Quality and Color Intensity	765
45.1.4	Ceramic Inks and Consumption	767
45.1.5	Productivity and Maintenance	769
45.1.6	Stability and Reliability	770
45.1.7	Integration between Analog and Digital Equipment	771
45.2	Design of a Single-Pass Inkjet Printer for Ceramic Tile Decoration	772
45.2.1	Frame and Color Bars	772
45.2.2	Printheads	773
45.2.3	IDS: Ink Distribution System	775
45.2.4	Electronics and Print Engine	777
45.2.5	RIP and Color Management Software	778
45.2.6	Maintenance Procedure Devices	780
45.3	Roadmap for Next Future Tile Inkjet Printing	781
45.3.1	Aqueous-Based Inks versus Solvent-Based Inks	781
45.3.2	Fully Digital Multiprinter Production Lines	784
	Bibliography	785
46	Concepts for “Direct-to-Shape” Inkjet Printing onto Curved Surfaces	787
	<i>Debbie Thorp and Nick Geddes</i>	
46.1	Introduction	787
46.1.1	Core Concepts	787
46.1.1.1	Printing onto Cylinders or Tubes	795
46.1.1.2	Printing onto Cones	795
46.1.1.3	Printing onto Spheres	796
46.1.1.4	Printing onto Tubs	797
46.1.2	Looking to the Future	797

47	Case Study at KHS: Digital Decoration of Plastic Bottles – From Machine Concept to a Complete Solution	799
	<i>Martin Schach and Katrin Preckel</i>	
47.1	Introduction	799
47.1.1	Motivation for Digital Direct-to-Shape	800
47.2	Machine Concept	802
47.2.1	Influencing Factors	803
47.3	Ink	811
47.3.1	Robustness and Appearance	811
47.3.2	Food Safety and Sustainability	812
47.3.2.1	Ink Migration	812
47.3.2.2	Recyclability	813
47.4	Customers Requirements, Software, and User Concept	814
47.4.1	Customers and Environment	814
47.4.2	Software and Workflow Concepts	814
47.5	Industry 4.0 and Direct Print	815
48	Hymmen Digital Décor Printing: Empowering the Laminate Industry	817
	<i>Aliasgar Eranpurwala</i>	
48.1	Introduction	817
48.2	The Laminate Flooring Industry	817
48.3	Why the Shift to Digital Printing?	820
48.4	Hymmen's Approach: The JUPITER Digital Printing Line	821
48.5	Technical Challenges	825
48.6	Case Study 1: Roll to Roll JUPITER JPT-W-840	827
48.7	Case Study 2: Board Printing JUPITER JPT-C-2100	828
48.8	Key Features	831
48.9	Outlook: Improvements Ahead	831
49	High-Speed Inkjet Application in Newspaper Printing	833
	<i>Peter Schulmeister</i>	
49.1	Introduction	833
49.2	Applications and Business Models	833
49.2.1	Gaming and Lotteries	833
49.2.2	Cross Media	835
49.2.3	Microzoning	835
49.2.4	Logistics	835
49.2.5	Combination of Various Applications in One Print Product	835
49.3	Newspaper Printing	836
49.3.1	Newspaper Printing Presses	839
49.3.2	Newspaper Print Production	839
49.3.3	Arrangement of the Digital Print Unit in the Press	839
49.4	Requirements for Inline Digital Printing in Newspapers	840
49.5	Inkjet Print Technologies	841
49.5.1	Selection of Inkjet Technology	841
49.6	The manroland web systems Product Inkjet Integration	842

49.6.1	Web Lead Module Details	843
49.6.2	Automation Module Details	845
49.6.3	Integrated Inkjet Workflow/Usability	847
49.6.4	Integrated Inkjet Operation	848
49.7	Print Quality Optimization	848
50	Inkjet for Nanoimprint Lithography	851
	<i>Whitney Longsine, Matt C. Traub, and Van N. Truskett</i>	
50.1	Introduction	851
50.2	Nanoimprint Lithography Process	853
50.3	Inkjet System Design Considerations	854
50.4	J-FIL Applications in Semiconductors	862
50.5	Looking Forward	864
	References	866
	Glossary	869
	Index	877

