

# Contents

<i>Preface</i>	vii
<i>Acknowledgments</i>	xi
<i>Contributors</i>	xiii
1. Liquid Crystals: A Unique Phase of Matter	1
<i>Gregory P. Crawford and Scott J. Woltman</i>	
1.1 Introduction . . . . .	1
1.1.1 Calamitic thermotropic liquid crystals . . . . .	2
1.1.2 Discotic liquid crystals . . . . .	6
1.1.3 Polymer liquid crystals . . . . .	9
1.1.4 Lyotropic liquid crystals . . . . .	12
1.2 Basic Properties of Liquid Crystals . . . . .	15
1.2.1 Surface anchoring conditions . . . . .	16
1.2.2 Dielectric anisotropy . . . . .	17
1.2.3 Optical anisotropy . . . . .	19
1.2.4 Elasticity . . . . .	20
1.2.5 Basic liquid crystal configurations . . . . .	21
1.2.6 Optical modeling . . . . .	22
1.2.7 Viscosity . . . . .	23
1.2.8 Eutectic mixtures . . . . .	23
1.2.9 Non-planar confinement . . . . .	24
1.3 Applications . . . . .	26
1.3.1 Liquid crystal display configurations . . . . .	26
1.3.2 Ferroelectric liquid crystals . . . . .	43
1.3.3 Reflective mode cholesteric LCDs . . . . .	47

1.3.4	Liquid crystal polymer dispersions . . . . .	49
1.3.5	Rotating configurations . . . . .	58
1.4	Grating Applications . . . . .	59
1.5	Discotic Applications . . . . .	61
1.5.1	Thin film polarizers . . . . .	61
1.5.2	Compensation films . . . . .	63
1.5.3	Photovoltaic discotic liquid crystals . . . . .	65
1.5.4	Electron transport in discotic liquid crystals . . . . .	65
1.5.5	Liquid crystal nanotubes . . . . .	67
1.6	Conclusion . . . . .	68
<i>Bibliography</i>		71
2.	Medical Displays	81
<i>Frederick Y. Biga, Francois I. Luks, John W. McMurdy and Gregory P. Crawford</i>		
2.1	Introduction . . . . .	81
2.2	Display Technology for Medical Imaging Systems . . . . .	85
2.2.1	Cathode ray tubes . . . . .	86
2.2.2	Liquid crystal displays . . . . .	87
2.3	Display Device Metrics . . . . .	89
2.3.1	Luminance . . . . .	90
2.3.2	Contrast ratio . . . . .	93
2.3.3	Grayscale . . . . .	94
2.3.4	Resolution . . . . .	95
2.3.5	Color . . . . .	97
2.3.6	Viewing angle . . . . .	99
2.3.7	Veiling glare . . . . .	106
2.3.8	Uniformity . . . . .	108
2.4	Integrated Medical Imaging Systems . . . . .	109
2.5	Optimization of Displays for Medical Applications . . . . .	109
2.6	Image Processing . . . . .	111
2.7	3-D displays . . . . .	112
2.7.1	Passive barrier 3-D displays . . . . .	113
2.7.2	3-D displays based on lenticular lenses . . . . .	115
2.7.3	Luminance modulated 3-D displays . . . . .	118
2.7.4	Active barrier 3-D displays . . . . .	119
2.7.5	Field-sequential LCD 3-D displays . . . . .	120
2.7.6	Volumetric 3-D displays . . . . .	122

2.8	Liquid Crystal Thermography . . . . .	123
2.9	Future Outlook . . . . .	128
2.9.1	Head mounted displays . . . . .	129
2.9.2	Projection displays . . . . .	131
2.9.3	Acousto-optic liquid crystal sensors . . . . .	132
2.9.4	Flexible displays . . . . .	133
2.10	Conclusion . . . . .	134
<i>Bibliography</i>		137
3.	Liquid Crystals in Spectroscopy, Microscopy and Hyperspectral Imaging	149
<i>John W. McMurdy, Gregory P. Crawford and Selim Suner</i>		
3.1	Introduction . . . . .	149
3.2	Diffraction Gratings and Tunable Filter Spectrometers . .	153
3.2.1	Dispersive devices . . . . .	153
3.2.2	Nondispersive devices . . . . .	157
3.2.3	Acousto-optic tunable filters . . . . .	160
3.2.4	Liquid crystal tunable filters . . . . .	162
3.2.5	Hyperspectral imaging in medicine . . . . .	175
3.2.6	Raman imaging with liquid crystals . . . . .	182
3.3	Fourier Transform Spectrometers . . . . .	184
3.3.1	Operation and advantages . . . . .	184
3.3.2	Michelson-based FT spectrometers . . . . .	186
3.3.3	Liquid crystal Fourier transform spectrometers . .	187
3.3.4	Applications in medicine . . . . .	197
3.4	Polarimeters and Polarization Microscopy . . . . .	197
3.4.1	Polarimetry and polarization microscopy . . . . .	197
3.4.2	Stokes parameters and the Mueller matrix . . . . .	199
3.4.3	Liquid crystals in polarimeters . . . . .	201
3.4.4	Polarimetric imaging and spectro-polarimeters . .	203
3.4.5	Liquid crystals in polarization microscopy . . . . .	205
3.4.6	Polarimetry and polarization imaging in biology .	208
3.5	Liquid Crystals Spatial Light Modulation in Microscopy . . . . .	210
3.5.1	Phase contrast and interference microscopy . . . . .	210
3.5.2	Scanning microscopy . . . . .	213
3.5.3	Liquid crystal shutters in microscopy . . . . .	217
3.5.4	Liquid crystal SLM in optical trapping . . . . .	217

3.5.5	Liquid crystal SLM in adaptive optics . . . . .	219
3.6	Conclusion . . . . .	223
	<i>Bibliography</i>	225
4.	Liquid Crystal Biosensors	241
	<i>Maureen K. McCamley, Andrew W. Arstenstein and Gregory P. Crawford</i>	
4.1	Background and Introduction . . . . .	241
4.1.1	Scope of the problem . . . . .	244
4.1.2	Engineering a solution . . . . .	245
4.2	Current Diagnostic Techniques . . . . .	247
4.2.1	Molecular diagnostics and microfluidics . . . . .	249
4.2.2	Quartz crystal microbalance assays . . . . .	251
4.2.3	Non-liquid crystal optical techniques . . . . .	253
4.3	Basic Biological Concepts . . . . .	256
4.3.1	Phospholipids . . . . .	256
4.3.2	Free surface interactions and surface anchoring . . . . .	257
4.3.3	Liquid crystal confinement . . . . .	258
4.4	Biosensors using Liquid Crystal Technology . . . . .	259
4.4.1	Background — interfaces . . . . .	260
4.4.2	Liquid crystal biocompatibility . . . . .	263
4.4.3	Other techniques for liquid crystal biosensors . . . . .	267
4.4.4	Imaging of protein immobilization . . . . .	269
4.4.5	Virus detection using liquid crystals . . . . .	282
4.4.6	Bacterial detection using liquid crystals . . . . .	285
4.5	Conclusion . . . . .	286
	<i>Bibliography</i>	289
5.	Liquid Crystal Lasers	297
	<i>Scott J. Woltman</i>	
5.1	Introduction . . . . .	297
5.2	Dye Laser Systems and Photonic Crystals . . . . .	301
5.2.1	The distributed feedback laser . . . . .	301
5.2.2	Organic laser dyes and dye laser systems . . . . .	303
5.2.3	Photonic crystals . . . . .	307
5.3	Liquid Crystal Lasers . . . . .	310

5.3.1	Experimental setup for lasing . . . . .	311
5.3.2	Cholesteric liquid crystals . . . . .	312
5.3.3	Other liquid crystal configurations . . . . .	335
5.3.4	Liquid crystals in distributed feedback lasers . . .	348
5.4	Liquid Crystal Lasers in Biology and Medicine . . . . .	351
5.4.1	Lasing in biology . . . . .	352
5.4.2	Lasing in medicine . . . . .	357
5.4.3	Conclusion . . . . .	360

*Bibliography* 361

6. Biomimicking with Liquid Crystals 375

*Scott J. Woltman, John W. McMurdy, Gregory P. Crawford and Suraj P. Gorkhali*

6.1	Introduction . . . . .	375
6.2	Color . . . . .	377
6.2.1	Structural color in nature . . . . .	378
6.2.2	Liquid crystal structural color biomimicking . . .	387
6.3	Anti-reflection . . . . .	396
6.3.1	Anti-reflection layers in nature . . . . .	396
6.3.2	Anti-reflection using liquid crystals . . . . .	398
6.4	Lenses . . . . .	400
6.4.1	Biological lenses . . . . .	401
6.4.2	Liquid crystal lenses . . . . .	403
6.5	Biotemplating . . . . .	409
6.6	Biomimetic Patterning . . . . .	412
6.6.1	Optical patterning techniques . . . . .	412
6.6.2	Mechanical patterning techniques . . . . .	421
6.7	Natural Occuring Liquid Crystalline Phases . . . . .	426
6.8	Conclusion . . . . .	427

*Bibliography* 429

7. Actuators and Delivery Systems 441

*Leslie J. Shelton, Scott J. Woltman and Gregory P. Crawford*

7.1	Introduction . . . . .	442
7.2	Liquid Crystal Polymer Materials . . . . .	444
7.2.1	Main-chain and side-chain liquid crystal polymers	444

7.2.2	Reactive mesogens . . . . .	444
7.2.3	Elastomers . . . . .	453
7.2.4	Gels and hydrogels . . . . .	459
7.2.5	Carbon nanotube doped materials . . . . .	465
7.3	Actuators . . . . .	467
7.3.1	Muscles . . . . .	468
7.3.2	Heart valves . . . . .	469
7.3.3	Other actuator applications . . . . .	471
7.4	Drug Delivery Systems . . . . .	473
7.4.1	Drug delivery systems with elastomers . . . . .	473
7.4.2	Drug delivery systems with hydrogels . . . . .	474
7.5	Liquid Crystalline Contact Lenses . . . . .	476
7.6	Conclusion . . . . .	477
	<i>Bibliography</i>	479
	<i>Index</i>	489