

Contents

Preface *xiii*

Session I Soft Sensors for Diagnosis 1

- 1 Mechanics Design of Flexible Sensors** 3
Li Yuhang, Zhao Zhao, and Wu Wenbin
- 1.1 Design of Stretchable Flexible Device Structure 3
 - 1.1.1 Ripple Method 3
 - 1.1.2 Island Bridge Structure-Curved Line 12
 - 1.1.3 Island Bridge Structure-Serpentine Line 15
 - 1.1.4 2D Spiral Interconnects 26
 - 1.1.5 3D Spiral Interconnects 32
 - 1.1.6 2D Fractal Structure 35
- 1.2 Structural Design of Substrate 38
 - 1.2.1 Surface Structure Designs 39
 - 1.2.2 Cellular Substrate Designs 40
 - 1.2.3 Curvilinear Substrate Designs 43
- 1.3 Structural Designs for Spatial Integration of Device Systems 45
 - 1.3.1 Strategy of Folding-Based Origami 45
 - 1.3.2 Strategy of Buckling-Guided 3D Assembly 51
 - 1.3.3 Stacked Multilayer Designs 57
- References 59

- 2 Epidermal Wearable Biosensors** 67
Xingcan Huang, Yanli Jiao, Yawen Yang, and Jiyu Li
- 2.1 Wearable Biosensing Technology 67
 - 2.1.1 History of Wearable Biosensors 67
 - 2.1.2 Wearable Enzymatic Biosensors 68
 - 2.1.3 Wearable Immunosensors 69
 - 2.1.4 Wearable Ion Biosensors 70

2.2	Epidermal Wearable Biosensors	73
2.2.1	Introduction	73
2.2.2	Flexible and Stretchable Epidermal Sensors	74
2.2.3	Self-powered Sweat Sensors	76
2.3	Ocular Wearable Sensors	79
2.3.1	Ocular Biomarkers	79
2.3.2	Wearable Ocular Sensors	80
2.3.2.1	Contact Lens Sensor	81
2.3.2.2	Capsule-based Tear Sensors	87
2.3.2.3	Wearable Eye Patch	87
2.3.2.4	Eyeglass Sensor	88
2.3.3	Conclusion	88
2.4	Wound Sensor	88
	List of Abbreviations	91
	References	92
3	Soft Sensors for Disease Diagnosis	101
	<i>Huihui Hu, Yuyan Su, and Kewang Nan</i>	
3.1	Introduction	101
3.2	Materials and Structures of Flexible Sensors	103
3.2.1	Materials	103
3.2.1.1	Nanomaterials	103
3.2.1.2	Liquid Conductors	105
3.2.1.3	Elastomer	106
3.2.1.4	Conductive Polymer	106
3.2.1.5	Hydrogel	107
3.2.1.6	Textile	108
3.2.2	Structures	109
3.2.2.1	Serpentine Structure	109
3.2.2.2	Mesh Structure	110
3.2.2.3	Kirigami Structure	111
3.2.2.4	Fractal Structure	112
3.2.2.5	Coiled Structure	112
3.2.2.6	Wave Structure	113
3.2.2.7	Three-Dimensional Porous Structure	114
3.3	Application of Flexible Sensors in Disease Diagnosis	114
3.3.1	Diagnosis of Cardiovascular Diseases	115
3.3.1.1	Heart Rate	115
3.3.1.2	Blood Pressure	117
3.3.1.3	Blood Oxygen Saturation	117
3.3.2	Diagnosis of Brain Disease	118
3.3.2.1	Soft Sensor Materials for Brain Interfaces	119
3.3.2.2	Applications	121
3.3.3	Diagnosis and Self-management of Chronic Disease	123

3.3.3.1	Flexible Sensors for Diabetes	123
3.3.3.2	Flexible Sensors for Chronic Inflammatory Diseases	125
3.3.3.3	Flexible Sensors for Chronic Respiratory Diseases	126
3.3.3.4	Flexible Sensors for Cancers	127
	List of Abbreviations	128
	References	129
4	Wearable Chemical Sensors for Noninvasive Monitoring	147
	<i>Hnin Yin Yin Nyein, Asmita Veronica, Yanan Li, and Yue Guo</i>	
4.1	Introduction	147
4.2	Biofluids of Interest for Wearable Chemical Sensors	150
4.2.1	Dermal Biofluids	153
4.2.1.1	Sweat	153
4.2.1.2	Interstitial Fluid	155
4.2.2	Oral Biofluids	157
4.2.2.1	Saliva	157
4.2.2.2	GCF	160
4.3	Biofluid Enabled Platforms: Traditional to Wearable	161
4.3.1	Need for Noninvasive Wearable Chemical Sensing	161
4.3.2	Potential Challenges in Wearable Chemical Sensors	162
4.4	Sampling and Detection Strategies for Biofluid-Based Wearable Sensors	163
4.4.1	Sweat Sampling and Induction Methods	163
4.4.2	ISF Sampling Methods	165
4.4.3	Saliva Sampling Methods	168
4.4.4	Detection Mechanisms for Noninvasive Wearable Sensors	169
4.5	Outlook	172
	References	174
5	Flexible Electrode for Noninvasive Brain–Computer Interfaces	181
	<i>Sen Lin</i>	
5.1	Introduction	181
5.2	Development of Noninvasive BCIs	182
5.3	Electrode Technologies for Noninvasive BCIs	183
5.3.1	Rigid Electrodes	183
5.3.1.1	Wet Electrodes	184
5.3.1.2	Dry Electrode	184
5.3.2	Flexible Electrodes	186
5.3.2.1	Flexible Dry Electrodes	186
5.3.2.2	Semi-dry Electrode	189
5.4	Challenges	191
5.5	Conclusion	193
	References	194

- 6 Chronic Neural Interfaces 203**
Enming Song, Yifei Lu, and Hehua Zhang
- 6.1 Introduction 203
 - 6.2 Architectures for Mechanical Compliance and Biocompatibility 204
 - 6.3 Advanced Chronically Stable Materials for Neural Interfaces 209
 - 6.4 Encapsulation for Stable Operation 211
 - 6.5 Engineering Strategies for Chronic Active Sensing 220
 - 6.6 Multimodal Functions of Long-Term Stable Implants 225
 - 6.7 Challenges and Future Directions 228
 - References 229
- 7 Mechanical Sensors (Transducers) for Motion Detection of Humans and Organs 235**
Chengfeng Pan
- 7.1 Introduction 235
 - 7.2 Classification of Stretchable Mechanical Sensors 236
 - 7.2.1 Resistive Sensors 236
 - 7.2.2 Capacitive Sensors 236
 - 7.2.3 Piezoelectric Sensors 237
 - 7.2.4 Triboelectric Sensors 237
 - 7.2.5 Electromagnetic Sensors 238
 - 7.3 Material Architectures 238
 - 7.3.1 Flexible/Stretchable Matrix Materials 239
 - 7.3.2 Electrically Conductive Materials 241
 - 7.4 Sensing Mechanisms 244
 - 7.4.1 Geometrical Effect 244
 - 7.4.2 Piezoresistive Effect 245
 - 7.4.3 Disconnection Mechanism 246
 - 7.4.4 Crack Propagation 247
 - 7.4.5 Tunneling Effect 247
 - 7.5 Representative Applications 248
 - 7.5.1 Small Strain Detection 248
 - 7.5.2 Large Motion Monitoring 250
 - References 252
- 8 Smart Optoelectronics in Health Monitoring and Human-Machine Interactions 257**
Leilei Gu, Yuanjing Lin, and Qianpeng Zhang
- 8.1 Fundamentals on Photodetectors 257
 - 8.1.1 Figures-of-Merit of Photodetectors 257
 - 8.1.2 Classification of Photodetectors 259
 - 8.1.3 Material Advances in Photodetectors 261
 - 8.1.3.1 2D Materials 262
 - 8.1.3.2 Quantum Dots 262
 - 8.1.3.3 Perovskites and Other Organic Materials 263

8.1.3.4	Nanostructure-based Photodetectors	264
8.2	Integrated Optoelectronic Systems	264
8.2.1	Integration of Photodetectors with LEDs	266
8.2.2	Photodetectors Integrated with Energy Storage Devices	267
8.2.3	Self-powered Optoelectronic Systems	268
8.2.4	Integration Strategies	270
8.3	Flexible Integrated Systems Based on Photodetectors for Advanced Applications	273
8.3.1	Clinical Diagnostic	273
8.3.1.1	Lab-on-a-Chip Systems for Diagnostics	273
8.3.1.2	Wearable Biosensing for Daily Health Monitoring	275
8.3.1.3	Optoelectronics for Advanced Human-Machine Interaction	277
8.3.1.4	Autopilot Systems	280
8.4	Future Trend of Photodetectors for Soft Electronics	282
	References	283
9	Wearable Sensor for Bioimaging	287
	<i>Cunman Liang, Zhou Jiang, Ni Zhao, Puxiang Lai, and Yingying Zhou</i>	
9.1	Introduction	287
9.2	Wearable Ultrasound Bioimaging Sensor	288
9.2.1	Overall Description	288
9.2.2	Imaging Principles	289
9.2.3	Structures and Materials	290
9.2.4	Typical Devices and Applications	292
9.2.4.1	1D Transducer Array	292
9.2.4.2	2D Transducer Array	294
9.2.4.3	Orthogonal Transducer Array	296
9.2.5	Summary	298
9.3	Wearable Photoacoustic Imaging Sensor	299
9.3.1	Overall Description	299
9.3.2	Imaging Principles	299
9.3.3	Structures and Materials	301
9.3.4	Typical Devices and Applications	302
9.3.5	Summary	304
9.4	Wearable Electrical Impedance Tomography	305
9.4.1	Overall Description	305
9.4.2	Imaging Principles	305
9.4.3	Structures and Materials	306
9.4.4	Typical Devices and Applications	307
9.4.4.1	Pulmonary Imaging	307
9.4.4.2	Cancer Detection	309
9.4.4.3	Gesture Recognition	310
9.4.5	Summary	312
9.5	Wearable Terahertz Imaging Sensor	312
9.5.1	Overall Description	312

- 9.5.2 Imaging Principles 313
- 9.5.3 Structures and Materials 313
- 9.5.4 Typical Devices and Applications 314
- 9.5.5 Summary 316
- 9.6 Wearable Bioimaging Device for Biomedical Applications 316
- 9.6.1 Ultrasound Imaging 316
- 9.6.2 Photoacoustic Imaging 327
- 9.7 Conclusion 329
- References 330

Session II Soft Sensors for Therapy 333

10 Thermotherapy (Resistive Heaters, Photothermal Nanomaterials, Textile Devices, Cryotherapy, etc.) 335

Xiao Yang and Zuankai Wang

- 10.1 Introduction 335
- 10.2 Resistive Heaters 336
- 10.2.1 Metal Wire 336
- 10.2.2 Two-Dimensional (2D) Materials 339
- 10.2.3 Conductive Polymers 341
- 10.2.4 Conclusion 343
- 10.3 Photothermal Nanomaterials 343
- 10.4 Textile Devices 348
- 10.5 Cryotherapy 354
- List of Abbreviations 355
- References 356

11 Soft Electronics for Drug Delivery 361

Lelun Jiang and Jingbo Yang

- 11.1 Introduction 361
- 11.2 Skin Structure 362
- 11.3 Soft Electronics-Assisted TTDS for Drug Delivery 364
- 11.3.1 MNs for Passive Drug Delivery 364
- 11.3.2 Soft Electronics-MNs Systems for Active Drug Delivery 367
- 11.3.3 Soft Electronics-MN Systems for Closed-Loop Drug Delivery 372
- 11.3.4 Soft Electronic Systems for Closed-Loop Drug Delivery 375
- 11.4 Conclusions and Perspectives 379
- List of Abbreviations 380
- References 380

12 Wearable and Implantable Drug Delivery System 387

Xinran Jiang, Han Wu, Ao Xiao, Ya Huang, Xinge Yu, and Lingqian Chang

- 12.1 Introduction 387
- 12.2 Categories of Soft Electronics for Drug Delivery 389

12.2.1	Wearable Systems	390
12.2.2	Implantable Systems	394
12.3	Challenges and Prospects	399
	References	400
13	Soft Robotic Sensing and Medicine	403
	<i>Dengfeng Li</i>	
13.1	Introduction	403
13.2	Soft Robotic Tactile Sensing	403
13.3	Soft Robotic Environmental Sensing	406
13.4	Miniature Robotic <i>In Vivo</i> Medicine	409
	References	410
	Session III Soft Sensors for Interaction	415
14	Integration System	417
	<i>Chun Ki Yiu, Pengcheng Wu, Jingkun Zhou, and Park Wooyoung</i>	
14.1	Power Supply Strategy of Soft Electronics	417
14.1.1	Introduction	417
14.1.2	Power Source	418
14.1.3	Regulation	419
14.2	Encapsulation	422
14.3	Communication	424
14.4	Closed-Loop Control (AI, Deep Learning, Microcontroller Unit, etc.)	427
	List of Abbreviations	432
	References	432
15	Self-powered Sensors	437
	<i>Binbin Zhang and Zhiming Lin</i>	
15.1	Introduction	437
15.2	Piezoelectric Sensor	439
15.3	Triboelectric Sensor	441
15.4	Piezoionic Sensor	445
15.5	Electromagnetic Sensor	446
15.6	Thermoelectric Sensors	448
15.7	Potentiometric Ion Sensors	453
15.8	Conclusion	455
	References	457
	Index	461

