

Optical Fiber Sensors Volume Three
Components and Subsystems

Brian Culshaw
John Dakin

Artech House
Boston • London

Contents

Preface	ix
Chapter 1 Revisiting Optical-Fiber Sensors	1
1.1 Introduction	1
1.2 Fiber Sensors—Why They Are Still Interesting	2
1.3 What Has Happened in the Interim—The Major Technical Innovations	3
1.4 Consolidating the Applications	6
1.5 The Basics Are Still the Basics	7
1.6 And for the Future	8
Chapter 2 Fiber Gratings	9
2.1 Introduction	9
2.2 Optical Properties	12
2.2.1 Coupled-Wave Theory	13
2.2.2 Bragg Gratings	15
2.2.3 Bragg Grating Output Couplers	19
2.2.4 Long-Period Codirectional Grating Couplers	20
2.3 Grating Fabrication: Writing Techniques	21
2.3.1 Internal	22
2.3.2 External	23
2.3.3 Nonuniform Gratings	26
2.4 Grating Fabrication: Writing Regimes	27
2.4.1 Continuous Wave	27
2.4.2 Multiple Pulse and Single Pulse	27
2.4.3 Type I, II, and III Gratings	28
2.5 Characterization and Design of Gratings	32
2.5.1 Optical Characterization Techniques	32
2.5.2 Design Limits	34
2.6 Origins and Control of Photosensitivity	35

2.6.1	Characteristics of Photoinduced Index Change	36
2.6.2	Models for Photoinduced Index Change	37
2.6.3	Techniques for Enhancing Photosensitivity	40
2.7	Physical Properties	45
2.7.1	Temperature, Strain, and Pressure Dependence	45
2.7.2	Thermal Stability and Aging	46
2.8	Applications	49
2.8.1	Laser Diode Stabilization	49
2.8.2	Fiber Amplifiers	51
2.8.3	Fiber Lasers	52
2.8.4	Bandpass and Add-Drop Filters	55
2.8.5	Dispersion Compensation	58
2.9	Conclusions	59
	References	60
	Selected Bibliography	67
Chapter 3	Evanescently Coupled Components	69
3.1	Introduction	69
3.2	Evanescence Waves for Chemical Sensor Applications	70
3.2.1	Introduction to Fiber-Optic Chemical Sensors	70
3.2.2	Fundamental Principles of Optical Chemical Sensors	70
3.2.3	Evanescence Field Sensor Types	73
3.2.4	Operation and Sensitivity of Evanescent Field Chemical Sensors	75
3.2.5	Sol-Gel Coatings for Evanescent Field Sensors	83
3.2.6	Surface Contamination in Evanescent Wave Sensors	84
3.2.7	Examples of Evanescent Field Sensors	85
3.2.8	Evanescence Coupled Chemically Active Components—Conclusion	86
3.3	Fiber-to-Planar Waveguide Couplers	87
3.3.1	Introduction	87
3.3.2	Evanescence Field Exposure—Side-Polished Fiber Blocks	88
3.3.3	Thin Metal Film Surface Plasmon Polarizers	88
3.3.4	Bandstop Filters	89
3.3.5	Bandpass Filters	96
3.3.6	Fiber-to-Planar Waveguide Couplers—Conclusion	98
	References	99
Chapter 4	Optical-Fiber Lasers and Amplifiers	103
4.1	Introduction	103
4.2	Optical-Fiber Lasers	104
4.2.1	Fiber Laser Resonators	106

4.2.2	Rare-Earth-Doped Fiber Laser Transitions	107
4.2.3	Single-Frequency and Pulsed Fiber Laser	117
4.3	Optical-Fiber Amplifiers	118
4.3.1	Erbium-Doped Fiber Amplifiers	121
4.3.2	Neodymium- and Praseodymium-Doped Fiber Amplifiers	126
4.3.3	Nonlinear Fiber Amplifiers	128
4.4	Fiber Lasers and Amplifiers in Sensing Applications	134
4.4.1	Fiber Lasers	134
4.4.2	Fiber Amplifiers	137
4.5	Conclusions	141
	References	142
Chapter 5 Advances in High-Speed OTDR Detection Techniques		145
5.1	Introduction	145
5.2	Basic Considerations for High-Speed, High-Sensitivity Detection	150
5.3	Basic Concepts of Photon Counting	154
5.3.1	The Photon-Counting Process: Sensitivity, Nonlinearity, and Dynamic Range	156
5.3.2	Minimum Detectable Signal Levels	160
5.4	Photon Counting Using Semiconductor APD Devices	163
5.4.1	Geiger-Mode Operation of Avalanche Photodiodes	163
5.4.2	Photon Counting: Time-Dependence of the Avalanche Current	165
5.4.3	Quantum Efficiency and Traps	169
5.4.4	Influence of Traps on the Photon-Counting Process	170
5.5	Sensitivity and Measurement Time Issues for Low-Level Signal Detection	171
5.5.1	Photon-Counting System-Level Tradeoff Evaluation in Practical Cases	176
5.6	Potential Advances in Detection and Signal-Generation Techniques	183
5.6.1	Signal-Generation Enhancement	186
	References	188
Chapter 6 Spectral Measurement Techniques for Optical-Fiber Sensors		191
6.1	Introduction	191
6.1.1	Spectral Measurements in Optical-Fiber Sensor Systems	191
6.1.2	Spectral Measurements—An Overview	192
6.2	Review of Spectral Measurement Techniques	193
6.2.1	Spectrometers and Monochromators	193
6.2.2	Tunable Lasers	198
6.2.3	Electronic Color Measurement Systems	201
6.2.4	Interferometric Filters for Spectral Analysis	204

6.3	Case Studies	212
6.3.1	A Compact Rugged Spectrometer for Fiber-Optic Applications	212
6.3.2	Decoding Bragg Grating Sensors	214
6.4	Selecting Spectral Measurement Techniques for Fiber-Optic Systems	220
6.4.1	Defining the Spectral Measurement Process	220
6.4.2	Optical Sources for Spectral Measurement	221
6.4.3	Spectrometers—Global Properties	221
6.5	Concluding Observations	221
	References	224
	About the Authors	225
	Index	229