

Contents

1 Characteristics of Optical Communication Networks	
Sonny Johansson, Erland Almström	1
1.1 Optical Network Issues	1
1.2 Long-Haul Networks	3
1.3 WDM Networking	4
1.4 Connection Patterns	6
1.5 Optical Network Protection	8
1.5.1 Protection Schemes	8
1.5.2 Ring Protection	10
1.6 Optical Network Elements	12
1.6.1 Optical WDM Terminal Multiplexer	12
1.6.2 Optical WDM Add/Drop Multiplexers	14
1.6.3 Optical WDM Cross-Connects	16
References	18
2 The Optical Fibre	
Réal Vallée	21
2.1 Introduction	21
2.2 Waveguiding Properties	22
2.2.1 Basic Concepts and Parameters	22
2.2.2 Basic Equations for the Step-Index Fibre	27
2.2.3 Graded-Index Fibres	37
2.3 Fibre Materials	39
2.3.1 Silicate Glasses	39
2.3.2 Plastics	40
2.4 Basic Optical Properties	41
2.4.1 Losses	41
2.4.2 Dispersion	44
2.4.3 Polarisation	48
2.5 Nonlinear Optical Properties	50
2.5.1 Stimulated Scattering Processes	51
2.5.2 Third-Order Nonlinear Parametric Processes	57
2.5.3 Photosensitivity	60
2.6 Pulse Propagation in Optical Fibres	63

2.6.1	Derivation of the Wave Equation for the Pulse Envelope . . .	63
2.6.2	Solution of the Envelope Wave Equation: The Soliton	65
References	67
3	Transmitters	
Herbert Burkhard, Stefan Hansmann	71
3.1	Introduction	71
3.2	Theory	72
3.2.1	Rate Equations for Single-Mode Operation	72
3.2.2	Material Properties	76
3.2.3	Steady-State Characteristics	83
3.2.4	Small-Signal Modulation Characteristics	85
3.2.5	Noise Properties	89
3.3	Basic Design of Semiconductor Laser Structures	91
3.3.1	Concepts of Lateral Confinement	91
3.4	Single-Mode Laser Structures	94
3.4.1	Coupled-Mode Theory	96
3.4.2	Basic Properties of Index-Coupled DFB Lasers	98
3.4.3	Advanced DFB Laser Structures	102
3.4.4	Gain-Coupled Lasers	103
3.4.5	Modelling of DFB Lasers	103
3.5	Tunable Lasers	110
3.5.1	External Cavity Laser (ECL)	110
3.5.2	Thermal Tuning	110
3.5.3	Multisection DFB Laser	111
3.5.4	DBR Laser	111
3.5.5	Tunable Twin-Guide Laser (TTG)	111
3.5.6	Codirectionally Coupled Lasers (CCL)	112
3.5.7	Y-Laser	113
3.5.8	Superstructure Grating DBR Laser or Sampled Grating Laser (SSG-Laser)	113
3.5.9	Bent-Waveguide DFB Laser (BWL)	114
References	114
4	Optical Photodetectors	
André Scavennec, Louis Giraudet	117
4.1	Introduction	117
4.2	The PIN Photodiode	117
4.2.1	PIN Photodiode Operation	117
4.2.2	PIN Photodiode Characteristics	120
4.2.3	Edge-Illuminated PIN Photodiodes	127
4.2.4	Metal-Semiconductor-Metal Photodiodes	129
4.3	The Avalanche Photodiode (APD)	131
4.3.1	Characteristics of APDs	132

4.3.2	APD Noise	133
4.3.3	Structures for Improved Noise Characteristics	134
4.4	Photodiodes	136
4.4.1	Silicon Photodiodes	136
4.4.2	InGaAs Photodiodes	137
4.5	Photoreceivers	141
4.5.1	Conventional Photoreceivers	141
4.5.2	Specific Photoreceivers	144
4.5.3	OEIC Photoreceivers	144
4.6	Conclusion	147
	References	148
5 Optical Amplifiers		
	Mikhail N. Zervas, Gerlas van den Hoven	151
5.1	Optical Fibre Amplifiers	152
5.1.1	Erbium-Doped Fibre Amplifiers	152
5.1.2	Other Fibre Amplifiers	172
5.2	Semiconductor Optical Amplifiers	173
5.2.1	Optical Gain in Compound Semiconductor Materials	173
5.2.2	Basic Heterojunction Device Structure	175
5.2.3	Rate Equations, Saturation Behaviour, Noise Figure	177
5.2.4	Effect of Optical Reflections (Gain Ripple)	181
5.2.5	Gain-Clamping	183
5.2.6	General Applications of Semiconductor Optical Amplifiers in Communication Systems	184
5.2.7	Digital Transmission Systems	185
5.2.8	WDM Systems	188
5.2.9	Analogue Transmission Systems	189
5.2.10	Other Applications	189
	References	191
6 Passive and Active Glass Integrated Optics Devices		
	Antoine Kévorkian	197
6.1	General Introduction	197
6.2	Passive Power Splitters	199
6.2.1	Splitters and Their Basic Functions	199
6.2.2	Computing Waveguide Modes	201
6.2.3	Tapers and Branches	208
6.2.4	Bends	209
6.2.5	2×2 Splitters	211
6.2.6	$P \times N$ Star Couplers	213
6.2.7	Ion Exchange in Glass	213
6.2.8	Characterization Methods	217
6.2.9	Performance and Reliability of Commercial Devices	222

6.3	Integrated Optic Yb/Er Glass Amplifiers	224
6.3.1	Introduction	224
6.3.2	Rate Equations for Yb/Er Co-doping	226
6.3.3	Propagation Equations	228
6.3.4	The Power-Transfer Equation	229
6.3.5	Yb/Er Co-doping Enhances the Inversion	232
6.3.6	Effective Inversion Coefficients	234
6.3.7	Gain of a Co-doped Waveguide Section	236
6.3.8	Adverse Effects of High Rare-Earth Concentration	239
6.3.9	Technologies and Devices	244
6.4	Integrated Optic Er/Yb Laser Oscillators	251
6.4.1	Continuous Wave (CW) Operation	251
6.4.2	Experimental Soliton and Q-Switch Operation	256
	References	258

7 Wavelength-Selective Devices

	Meint K. Smit, Ton Koonen, Harald Herrmann, Wolfgang Sohler	262
7.1	Introduction	262
7.2	Device Specifications	265
7.3	Fabry-Perot Interferometer Filters	266
7.4	Dielectric Interference Filters	271
7.5	Fibre Gratings	273
7.6	Grating-based Demultiplexers	275
7.7	PHASAR-based Devices	281
7.7.1	Introduction	281
7.7.2	Principle of Operation	282
7.7.3	Technologies	283
7.7.4	Device Characteristics	284
7.7.5	Wavelength Routeing Properties	290
7.7.6	Multiwavelength Transmitters and Receivers	291
7.7.7	Multiwavelength Add-Drop Multiplexers and Crossconnects	292
7.8	Integrated Acousto-Optical Devices in LiNbO_3	296
7.8.1	Introduction	296
7.8.2	Basic Building Blocks	297
7.8.3	Tunable Wavelength Filters	301
7.8.4	Wavelength-selective Switches and Add-Drop Multiplexers ..	303
7.8.5	Applications in WDM Systems	306
7.8.6	Outlook	307
	References	308

8 Optical Switching

R. Ian MacDonald, Ken Garrett, Philip Garel-Jones, Winfried H.G. Horsthuis, Edmond J. Murphy.....	313
8.1 Introduction	313
8.2 Applications	313
8.2.1 Optical Component Characterization and Testing	313
8.2.2 Test Access.....	316
8.2.3 Telecommunications	317
8.3 Technologies	322
8.3.1 Non-interferometric Switches	323
8.3.2 Interferometric Switches	332
8.4 Summary	336
References	336

9 All-Optical Time-Division Multiplexing Technology

Masatoshi Saruwatari.....	338
9.1 Role of All-Optical TDM Technology	338
9.2 Key Technologies for All-Optical TDM Systems.....	339
9.2.1 Ultrashort Optical Pulse Generation Technology	339
9.2.2 All-Optical MUX/DEMUX Technology	346
9.2.3 Optical Timing Extraction Technology	357
9.2.4 High-Speed Optical Waveform Measurement	360
9.3 Demonstration of OTDM and OTDM/WDM Transmission.....	363
9.3.1 100–400 Gbit/s OTDM Transmission Experiment.....	363
9.3.2 400 Gbit/s to 3 Tbit/s OTDM/WDM Transmission Experiments.....	367
References	369

10 Optical Hybrid Integrated Circuits

Yasufumi Yamada, Yuji Akahori, Hiroshi Terui	376
10.1 Introduction	376
10.2 Key Technologies for Hybrid Integration	378
10.2.1 Platform for Hybrid Integration	378
10.2.2 Passive Alignment Technique	381
10.2.3 OE-device for Hybrid Integration.....	386
10.3 Contributions of Hybrid Integration to Optical Communication Technology	389
10.3.1 Application of Hybrid-Integration Technology.....	389
10.3.2 Optical Module for Fibre-optic Subscriber System	390
10.3.3 Optical Modules for WDM Applications	396
10.3.4 Optoelectronic Hybrid Modules for High-speed Applications	401
10.4 Future Prospects	408

10.5 Summary	410
References	411
11 Monolithic Integration	
Herbert Venghaus, Heinz-Gunter Bach, Frank Fidorra, Helmut Heidrich, Ronald Kaiser, Carl Michael Weinert	414
11.1 Introductory Remarks	414
11.2 Waveguides	416
11.3 Integrated Spot-Size Converters	418
11.4 Monolithic Laser Integration	420
11.4.1 Vertical Laser–Waveguide Coupling	421
11.4.2 Laser–Waveguide Butt Coupling	422
11.4.3 Laser-HBT Integration	426
11.5 Integrated Receiver	427
11.6 Crosstalk	432
11.6.1 Electrical Crosstalk	432
11.6.2 Optical Crosstalk	434
11.6.3 Thermal Crosstalk	435
11.7 Current Status of Optoelectronic Integration	435
11.8 Outlook	441
References	442
Biographical Notes	449
Index	457