

Contents

1. Introduction	
By J.-P. Huignard and P. Günter	1
2. Amplification, Oscillation, and Light-Induced Scattering in Photorefractive Crystals	
By S.G. Odoulov and M.S. Soskin (With 25 Figures)	5
2.1 Fundamentals of Light Amplification Due to Quasi-Degenerate Four-Wave Mixing	5
2.1.1 Beam Coupling on Dynamic Gratings: A New Type of Coherent Light Amplification	5
2.1.2 Spatial Shift of Recording Patterns and Holographic Gratings as Prerequisite for Energy Transfer	6
2.1.3 Holographic Amplification of Quasi-Degenerate Frequency Beams	8
2.2 Steady-State Frequency Degenerate Amplification in Two-Beam Coupling	10
2.2.1 Amplification Due to Diffusion Nonlinearity	10
2.2.2 Amplification at Large Transport Lengths	14
2.2.3 Amplification Due to Circular Photovoltaic Currents ..	15
2.3 Steady-State Amplification Due to Degenerate Parametric Interactions	17
2.3.1 Degenerate Backward Four-Wave Mixing	17
2.3.2 Degenerate Noncoplanar Forward Four-Wave Mixing	20
2.3.3 Degenerate Coplanar Forward Four-Wave Mixing for Orthogonally Polarized Beams	21
2.4 Quasi-Degenerate Two-Beam Interaction	23
2.4.1 Amplification of Difference-Frequency Waves	23
2.4.2 Transient Energy Transfer	24
2.5 Light-Induced Scattering	27
2.5.1 Asymmetric Scattering in Crystals with Considerable Diffusion-Type Amplification	27
2.5.2 Polarization-Anisotropic Scattering by Photovoltaic Amplification	29
2.5.3 Forward Polarization-Anisotropic Parametric Scattering	30

2.5.4 Polychromatic Scattering in Nonlocal-Response Photorefractive Crystals	31
2.5.5 Transient Scattering in Local-Response Photorefractive Crystals	32
2.6 Oscillation in Photorefractive Crystals	33
2.6.1 Diffusion-Type Amplification Oscillators	35
2.6.2 Oscillators Based on Circular Photovoltaic Currents	37
2.6.3 Other Oscillator Types	39
2.7 Conclusion	40
References	41
3. Photorefractive Effects in Waveguides By V.E. Wood, P.J. Cressman, R.L. Holman, and C.M. Verber (With 15 Figures)	45
3.1 Overview	45
3.1.1 Integrated Optics	46
3.1.2 Optical Waveguide Formation	49
3.2 Historical Sketch	52
3.3 Experimental Techniques	55
3.3.1 Hologram Formation	55
3.3.2 Single Beam Methods	57
3.3.3 Channel Waveguide Devices	59
3.4 Experiments on Planar Guides	60
3.4.1 Holographic Experiments	62
3.4.2 Single-Beam Experiments	67
a) Waveguide Formation	67
b) Optical Characteristics	68
c) Steady-State Laser Power-Handling Performance of Lithium Niobate Waveguides	68
d) Effects of Preparation Conditions; "Optical Cleanup"	74
e) Discussion	75
3.5 Two-Step Photorefractive Processes	76
3.5.1 Two-Photon Absorption	76
3.5.2 Observations in Bulk Crystals	77
3.5.3 Waveguide Experiments	79
3.6 Photorefractivity in Channel Waveguides	81
3.6.1 Experiments and Interpretations	84
3.6.2 Polarization Conversion	88
3.7 Other Materials	92
3.8 Summary and Conclusions	93
References	95
Addendum	100

4. Wave Propagation in Photorefractive Media	
By J.O. White, Sze-Keung Kwong, M. Cronin-Golomb, B. Fischer, and A. Yariv (With 34 Figures)	101
4.1 Two-Wave Interactions Via a Third Order Nonlinearity	102
4.1.1 Diffraction from Fixed Gratings, Coupled Wave Theory	102
4.1.2 The Coupled Wave Theory of Dynamic Gratings	104
4.1.3 Dynamic Gratings in the Transmission Geometry	106
4.1.4 Dynamic Gratings in the Reflection Geometry	108
4.1.5 Coupling Between Counterpropagating Waves in a Ring Resonator	111
4.2 Oscillation in a Resonator with Photorefractive Gain	112
4.2.1 Nondegenerate Two-Wave Mixing in a Ring Resonator	113
4.2.2 Experimental Results	114
4.2.3 Relaxing the Plane Wave Constant	117
4.2.4 One-Way, Real-Time Wavefront Conversion	119
4.3 Four-Wave Interactions Via a Third Order Nonlinearity	121
4.3.1 Holographic Formulation of Four-Wave Mixing	122
4.3.2 Single Grating, Undepleted Pumps Approximation	124
4.3.3 Transmission Grating, Undepleted Pumps	125
4.3.4 Reflection Grating, Undepleted Pumps	128
4.3.5 Pump Depletion in the Single Grating Approximation	128
4.3.6 Transmission Grating with Pump Depletion	129
4.3.7 Reflection Grating with Pump Depletion	131
4.3.8 Oscillation in Four-Wave Mixing	134
4.4 Self-Pumped Phase Conjugate Mirrors and Lasers	135
4.4.1 Self-Pumped Mirror Based on a Fabry-Perot Resonator with Photorefractive Gain	135
4.4.2 Self-Pumped Mirrors Based on the Fanning Effect	137
4.4.3 Laser with Dynamic Holographic Intracavity Distortion Correction Capability	138
4.4.4 Self-Pumped Mirrors as Tuning Elements	140
4.4.5 Self-Pumped Mirror Based on a Ring Cavity	142
4.A Appendix	145
References	149
5. Phase-Conjugate Mirrors and Resonators with Photorefractive Materials	
By J. Feinberg and K.R. MacDonald (With 35 Figures)	151
5.1 A Brief History of Phase Conjugation in Photorefractive Materials	152
5.1.1 Holography	152
5.1.2 Real-Time Holography	153

5.1.3 Photorefractive Phase Conjugators	154
5.1.4 Self-Pumped Phase Conjugators	155
5.2 The Photorefractive Effect	156
5.3 Two-Wave and Four-Wave Mixing in Photorefractive Materials	160
5.3.1 Two-Wave Mixing	161
5.3.2 Example: Obtaining a Large Coupling Strength in BSO	163
5.3.3 Four-Wave Mixing	164
5.4 Ring Resonators	165
5.4.1 Unidirectional Ring Resonator	165
5.4.2 Bidirectional Ring Resonator	168
5.4.3 Four-Wave-Mixing Ring Resonator	169
5.5 Self-Pumped Phase Conjugation	170
5.6 Frequency Shifts in Self-Pumped Phase Conjugation	176
5.7 Stimulated Scattering That Does Not Produce a Phase-Conjugate Wave	179
5.7.1 Dancing Modes	179
5.7.2 Stimulated Scattering	180
5.8 Applications of Phase Conjugation	184
5.8.1 Phase-Conjugating Laser Cavity	184
5.8.2 Phase-Locking Lasers	186
5.8.3 Interferometry with a Self-Pumped Phase-Conjugating Mirror	187
5.8.4 Photolithography	190
5.8.5 Parallel Optical Processing: Image Correlation, Convolution, and Subtraction	191
5.8.6 Edge and Defect Enhancement; Vibrational Modes	192
5.8.7 Associative Memory	193
5.8.8 Optical Novelty Filter	195
5.9 Conclusion	195
References	198

6. Optical Processing Using Wave Mixing in Photorefractive Crystals

By J.-P. Huignard and P. Günter (With 56 Figures)	205
6.1 Photoinduced Space-Charge Field in Photorefractive Crystals	205
6.1.1 Photorefractive Sensitivity	205
6.1.2 Steady-State Diffraction Efficiency	207
6.1.3 Spatial Frequency Response	209
6.1.4 Response Time of the Photorefractive Effect	211
6.1.5 Isotropic Bragg Diffraction	213
6.1.6 Anisotropic Bragg Diffraction	213

6.1.7	Space-Charge Field Nonlinearities	215
6.1.8	Collinear Bragg Diffraction	216
6.2	Selection of Materials	218
6.2.1	Review of Photorefractive Crystal Performance	218
6.2.2	Crystal Quality and Availability	221
6.2.3	Dark Storage Time	221
6.3	Holography with Photorefractive Crystals	222
6.3.1	General Introduction	222
6.3.2	Review of the Properties of Two- and Four-Wave Mixing Configurations	223
6.3.3	Imaging Through a Phase Disturbing Medium	226
6.3.4	Real-Time Interferometry	228
6.3.5	Speckle-Free Imaging	229
6.3.6	Photolithography	232
6.3.7	Multiple Image Storage	232
6.3.8	Beam Deflection and Interconnection	233
6.4	Image and Signal Processing	237
6.4.1	Image Convolution and Correlation	237
6.4.2	Image Edge Enhancement and Inversion	239
6.4.3	Image Subtraction and Parallel Optical Logic	241
6.4.4	Acousto-Photorefractive Effect	242
6.5	Summary of Crystal Properties	243
6.6	Energy Transfer in Wave Mixing with Photorefractive Crystals	244
6.6.1	Degenerate and Nearly Degenerate Two-Wave Mixing .	244
6.6.2	Degenerate and Nearly Degenerate Four-Wave Mixing	247
6.6.3	Transient Energy Transfer	248
6.6.4	Spatial Frequency Dependence of the Gain	248
6.6.5	Beam Ratio Dependence of the Gain	250
6.6.6	Further Comments on the Beam Coupling	251
6.6.7	Frequency Shifters for Photorefractive Crystals	252
6.6.8	Summary of Crystal Performance	253
6.7	Applications of the Energy Transfer	253
6.7.1	Image Amplification	253
6.7.2	Interferometry of Large Objects	254
6.7.3	Laser Beam Steering	256
6.7.4	Amplified Phase Conjugation in Photorefractive BSO Crystals	258
6.7.5	Self-Induced Optical Cavities	259
6.7.6	Image Threshold Detector Using a Phase Conjugate Resonator	262
6.7.7	Optical Logic Using Two-Beam Coupling	263
6.7.8	Image Subtraction Using a Self-Pumped Phase Conjugate Mirror Interferometer	264

6.7.9 Associative Memories	265
6.7.10 Laser Beam Cleanup	267
6.7.11 Phase Locking of Lasers	268
6.8 Conclusion	270
References	271
7. The Photorefractive Incoherent-To-Coherent Optical Converter	
By J.W. Yu, D. Psaltis, A. Marrakchi, A.R. Tanguay, Jr., and R.V. Johnson (With 32 Figures)	275
7.1 Overview	275
7.2 Physical Principles and Modes of Operation	277
7.3 Delineation of the Analytical Model	284
7.3.1 Constant Recombination Time Approximation	284
7.3.2 Perturbation Series Approximation	285
7.4 The Recording Process	288
7.4.1 Physical Model and Sample Solutions	288
7.4.2 Nonlinear Transfer Response	295
7.4.3 Spatial Resolution Issues for the Recording Process ...	300
7.4.4 Temporal Response	304
7.5 The Readout Process	310
7.5.1 Isotropic Phase Grating Model	311
7.5.2 Polarization Issues	318
7.6 Conclusion	320
7.A Appendix. Steady State and Temporal Behavior of the Space-Charge Field Components in PICOC (Simultaneous Erasure/Writing Mode)	321
7.A.1 Steady State Behavior	321
7.A.2 Temporal Response	322
References	324
8. Photorefractive Crystals in PRIZ Spatial Light Modulators	
By M.P. Petrov and A.V. Khomenko (With 12 Figures)	325
8.1 Background	325
8.2 Basic Parameters of Spatial Light Modulators	327
8.3 Anisotropy of the Transfer Function and Diffraction Efficiency	330
8.4 Image Recording	335
8.5 The Transfer Function	337
8.6 Image Transformation by the PRIZ	338
8.7 Linearity of Image Recording	341
8.8 Noise, Phase Distortions, Dynamic Range	343
8.9 Speed of Operation	345
8.10 Dynamic Image Selection	345

8.11 Recording of "Latent" Images	348
8.12 Photoinduced Piezoelectric Phase Modulation	349
8.13 Conclusions	350
References	351
Additional References with Titles	353
Subject Index	363