

CONTENTS

I. NONLINEAR OPTICS OF STRATIFIED MEDIA *by S. DUTTA GUPTA (HYDERABAD, INDIA)*

§ 1. INTRODUCTION	3
§ 2. NONLINEAR TRANSMISSION AND OPTICAL BISTABILITY IN LAYERED MEDIA	6
2.1. Normal incidence	7
2.1.1. Chen-Mills exact solution	7
2.1.2. Other numerical and approximate methods	11
2.2. Oblique incidence	19
2.2.1. TE- or s-polarized waves	19
2.2.2. TM- or p-polarized waves	24
2.3. Periodic and quasiperiodic layered media	32
2.3.1. Periodic layered media: optical bistability and gap solitons	32
2.3.2. Quasiperiodic layered media: weak photon localization	39
2.4. Experiments on nonlinear transmission in layered media	41
§ 3. HARMONIC GENERATION AND OTHER NONLINEAR PHENOMENA IN LAYERED GEOMETRY	50
3.1. Harmonic generation	50
3.1.1. Harmonic generation in reflection and transmission	50
3.1.2. Harmonic generation in guided wave configuration	56
3.2. Other miscellaneous effects	63
3.2.1. Cascaded second-order nonlinear effects	63
3.2.2. Four-wave mixing	64
§ 4. NONLINEAR OPTICAL PROPERTIES OF LAYERED COMPOSITES	66
§ 5. CONCLUSIONS	75
ACKNOWLEDGEMENT	76
REFERENCES	76

II. OPTICAL ASPECTS OF INTERFEROMETRIC GRAVITATIONAL-WAVE DETECTORS *by P. HELLO (ORSAY, FRANCE)*

§ 1. INTRODUCTION	87
§ 2. PRINCIPLE AND PRACTICE OF THE INTERFEROMETRIC DETECTION	89
2.1. Physical effect induced by a gravitational wave	89
2.2. The DC Michelson: minimal phase shift detectable	90
2.3. Realistic detection scheme	93

2.4. Optical layout of a gravitational-wave interferometric detector	94
2.5. Main noise sources	95
2.5.1. Seismic noise	95
2.5.2. Thermal noise	96
2.5.3. Quantum limit	97
§ 3. COUPLING WITH GRAVITATIONAL WAVES	99
3.1. Optical properties of reflective Fabry–Perot resonators	99
3.2. Power recycling in interferometric detectors	105
3.2.1. Improvement of the basic Michelson interferometer	105
3.2.2. Sensitivity of the power-recycled Fabry–Perot arms interferometer	107
3.3. Dual recycling in interferometers	112
3.4. Other configurations	115
3.4.1. Synchronous recycling	115
3.4.2. Detuned recycling	116
3.4.3. Resonant sideband extraction	118
3.5. Conclusion	120
§ 4. OPTICAL COUPLINGS	121
4.1. Matching the laser input beam to a real interferometer	121
4.1.1. Optical specifications for the VIRGO interferometer	122
4.1.2. Optical specifications for dual recycling interferometers	126
4.2. Coupling the real laser input beam to a perfect interferometer	127
4.2.1. Power losses due to the laser beam distortions	127
4.2.2. Low-loss beam expander design	128
4.3. Effect of laser geometry fluctuations	132
4.3.1. Modelling of laser jitters and cavities misalignments	133
4.3.2. Coupling of laser angular jitter and misaligned cavities	134
4.3.3. Phase noise induced by the laser geometrical fluctuations	137
4.4. Conclusion	140
§ 5. THERMO-OPTICAL COUPLING	141
5.1. Introduction	141
5.2. Thermal aberrations of a mirror heated by a high power laser source	141
5.2.1. The heating problem and the temperature distribution	141
5.2.2. Thermal lensing in the mirror	146
5.2.3. Thermoelastic deformation	146
5.2.4. Thermal birefringence	149
5.3. Heating effects in the VIRGO interferometer	149
5.3.1. Heating effects in a VIRGO-like cavity	149
5.3.2. Heating effects in the VIRGO interferometer	152
5.4. Conclusion	159
ACKNOWLEDGEMENTS	160
REFERENCES	160

III. THERMAL PROPERTIES OF VERTICAL-CAVITY
SURFACE-EMITTING SEMICONDUCTOR LASERS

by WŁODZIMIERZ NAKWASKI (ŁÓDŹ, POLAND) AND MAREK OSIŃSKI (ALBUQUERQUE, NM, USA)

§ 1.	INTRODUCTION	167
§ 2.	COMPARISON OF VERTICAL-CAVITY SURFACE-EMITTING AND EDGE-EMITTING DIODE LASERS	168
§ 3.	EFFECTS OF TEMPERATURE ON VCSEL OPERATION	182
3.1.	Temperature dependence of the longitudinal mode spectra	182
3.2.	Temperature dependence of the threshold current	189
3.3.	Temperature dependence of transverse-mode properties	196
3.4.	Temperature dependence of the output power	201
§ 4.	FUNDAMENTALS OF THERMAL MODELING OF VCSELS	205
4.1.	Heat conduction equation	206
4.2.	Heat-sink and contact/solder-layer temperature increase	208
4.3.	Heat sources	209
4.3.1.	Active-region heating	211
4.3.2.	Absorption of laser radiation	214
4.3.3.	Absorption of spontaneous radiation	214
4.3.4.	Joule heating	215
4.4.	Self-consistent approaches	215
§ 5.	COMPREHENSIVE THERMAL MODELS OF VCSELS	218
5.1.	Comprehensive analytical models	219
5.1.1.	Multilayer radially uniform structures	219
5.1.2.	Multilayer radially nonuniform structures	229
5.1.2.1.	GaAs/AlGaAs lasers	229
5.1.2.2.	InGaAsP/InP lasers	237
5.2.	Comprehensive numerical models	243
§ 6.	CONCLUSIONS	254
ACKNOWLEDGMENTS		255
REFERENCES		256

IV. FRACTIONAL TRANSFORMATIONS IN OPTICS

*by ADOLF W. LOHMANN (ERLANGEN, GERMANY),
DAVID MENDLOVIC AND ZEEV ZALEVSKY (TEL-AVIV, ISRAEL)*

§ 1.	INTRODUCTION	265
1.1.	What is meant by “fractional”?	265
1.2.	Simple examples, based on a finite set of integers	265
1.3.	An example based on an infinite set of integers	267
1.4.	Motivation	267
1.5.	Outline	268
§ 2.	THE FRACTIONAL FOURIER TRANSFORMATION (FRT)	268
2.1.	Fundamentals	268
2.1.1.	Definition based on light propagation in graded index media	268

2.1.2. Definition based on the Wigner distribution function	270
2.1.3. Properties of the FRT	272
2.2. Anamorphic FRT	273
2.3. Some applications	275
§ 3. THE FRACTIONAL HILBERT TRANSFORMATION (FHiT)	276
3.1. Fundamentals	276
3.2. One-dimensional implementation	281
3.3. Two-dimensional implementation	283
§ 4. THE FRACTIONAL ZERNIKE TRANSFORMATION (FZT)	284
§ 5. THE HARMONIC REAL TRANSFORMATIONS	286
5.1. The fractional sine and cosine transformations	286
5.2. The fractional Hartley transformation	287
5.3. Implementations	288
§ 6. OTHER FRACTIONAL TRANSFORMATIONS	289
6.1. The <i>ABCD</i> -Bessel transformation	289
6.1.1. The ABCD transformation family	290
6.1.2. From Cartesian to polar coordinates	291
6.1.3. The Bessel series	291
6.1.4. Rotationally symmetric input	292
6.2. The fractional Bessel transformation	293
6.3. The Fresnel transformation and the fractional Talbot effect	293
6.4. The fractional Legendre transformation	298
6.5. Alternate fractional Fourier transformation	299
6.5.1. The alternate concept	299
6.5.2. Comparison of the two FRTs	300
6.5.3. From two to four contacts of the two FRTs	301
§ 7. FRACTIONAL FILTERING	302
7.1. Fractional correlation, convolution	302
7.2. The fractional Radon transformation	304
7.3. The fractional Wiener filter (FWF)	309
7.3.1. Fractional spectral density	311
7.3.2. Mean square error minimization	311
7.3.3. Computer simulation	313
7.3.4. An alternative way to derive the FWF	315
7.4. The fractional wavelet transformation	317
7.4.1. FWT – Mathematical definition	320
7.4.2. Computer simulations	320
7.4.3. Optical implementation	322
§ 8. OTHER ASPECTS OF FRACTIONALIZATION	324
8.1. Fractionalization as interpolation	324
8.2. The fractional Fourier–Kravchuk transformation	325
8.3. Complex fractional index	325
8.4. The significance of phase and amplitude in the context of the FRT	326
8.5. Estimation of the FRT degree p	326
8.6. Fractional and fractal	326

§ 9. FRACTIONALIZATION AND GROUP THEORY	326
9.1. Motivation	326
9.2. Elementary group theory	327
9.3. The canonical ABCD transformation as a group	328
9.4. Isomorphism of the ABCD transformation and the "Wigner algebra"	329
9.5. Subgroups in both isomorphic domains	330
9.6. The inhomogeneous canonical transformation	332
9.7. Some other integral transformations and their groups	332
§ 10. CONCLUSIONS	333
ACKNOWLEDGMENTS	334
APPENDIX A. ABOUT THE WIGNER DISTRIBUTION	334
A.1. Definition	334
A.2. Properties	336
A.2.1. Fourier representation	336
A.2.2. Projection properties	336
A.2.3. Shifting the object	336
A.2.4. Tilting the wavefront	337
A.2.5. Lens operation	337
A.2.6. Free-space propagation	338
A.2.7. Fractional Fourier transformation	338
A.3. A look back	338
REFERENCES	339

V. PATTERN RECOGNITION WITH NONLINEAR TECHNIQUES IN THE FOURIER DOMAIN
by BAHRAM JAVIDI (STORRS, CT) AND JOSEPH L. HORNER (BEDFORD, MA)

§ 1. INTRODUCTION	345
§ 2. NONLINEAR JOINT TRANSFORM CORRELATORS	347
2.1. Linear joint transform correlators	347
2.2. Analysis of nonlinear joint transform correlators	348
2.3. Binary nonlinear joint transform correlators	351
§ 3. MULTIOBJECT DETECTION USING BINARY JOINT TRANSFORM CORRELATORS	353
3.1. Separation requirements of the joint transform correlator for multiobjects detection	354
3.2. Multiple input objects detection with a binary JTC using threshold functions	356
§ 4. COMPOSITE FOURIER-PLANE NONLINEAR FILTERS	359
§ 5. ILLUMINATION DEPENDENCE OF BINARY NONLINEAR JOINT TRANSFORM CORRELATOR	370
§ 6. CHIRP-ENCODED JOINT TRANSFORM CORRELATORS	375
6.1. Analysis of the chirp-encoded joint transform correlator	376
6.2. Chirp-encoded nonlinear joint transform correlator	381
6.3. On-axis chirp-encoded joint transform correlator	383
6.4. Computer simulation of the chirp-encoded joint transform correlator	385
§ 7. RANDOM PHASE ENCODED JOINT TRANSFORM CORRELATOR	390
7.1. Implementation of random phase encoded joint transform correlator	390
7.2. Analysis of random phase encoded linear joint transform correlators	393

7.3. Computer simulations	394
§ 8. SECURITY VALIDATION AND SECURITY VERIFICATION	398
§ 9. SUMMARY	404
ACKNOWLEDGEMENT	405
LIST OF SYMBOLS AND ABBREVIATIONS	405
APPENDIX A. PERFORMANCE METRICS	409
APPENDIX B. FREQUENCY-DEPENDENT THRESHOLD FUNCTION METHODS	411
B.1. Spatial-frequency dependent threshold functions	413
B.2. Sliding-window local-median thresholding	413
B.3. Global median thresholding	414
REFERENCES	416

VI. FREE-SPACE OPTICAL DIGITAL COMPUTING AND INTERCONNECTION

by JÜRGEN JAHNS (HAGEN, GERMANY)

§ 1. FACETS	421
1.1. A look back	421
1.2. What's in a name?	423
1.3. Limitations of electronic systems	425
1.3.1. Physical limitations	426
1.3.2. Topological limitations of 2-D interconnections	428
1.3.3. Von Neumann bottleneck	429
1.4. Optics as an interconnection technology	429
1.5. Outline	432
§ 2. SYSTEM MODEL AND COMPUTATIONAL ASPECTS	433
2.1. Computational properties of nonlinear optical devices	435
2.2. Computational aspects of the optical interconnects	439
§ 3. NONLINEAR OPTICAL DEVICES	447
3.1. Nonlinear optical devices	448
3.1.1. Classification	448
3.1.2. Physical background	448
3.2. Optical switching devices – overview	451
3.3. Examples of nonlinear optical devices	457
3.3.1. Nonlinear Fabry–Perot switching devices	457
3.3.2. Self-electro-optic effect devices	460
3.3.3. Vertical-cavity surface-emitting laser diodes	463
3.3.4. Smart pixels	465
§ 4. OPTICAL INTERCONNECTIONS	466
4.1. Macro-optics and micro-optics	467
4.2. Array illumination	468
4.2.1. Fourier-type array illuminators	470
4.2.2. Fresnel-type array generation using Talbot self-imaging	475
4.2.3. Array generation using imaging	476
4.2.4. Comparison	478

4.3. Imaging	479
4.4. Optical multistage interconnection networks	482
§ 5. ARCHITECTURES AND SYSTEMS	486
5.1. Implementation of logic operations on 2-D arrays	489
5.1.1. Symbolic substitution	489
5.1.2. Optical programmable logic arrays	491
5.1.3. Computational origami	492
5.2. Networks	493
5.2.1. Network properties	494
5.2.2. Switching nodes	495
5.2.3. Sorting networks	497
5.3. System demonstrators	499
5.3.1. Hybrid processors with electronic control	499
5.3.2. Digital optical processors using PLA logic and split-and-shift interconnect	501
5.3.3. Photonic switching systems using multistage interconnection network	502
§ 6. CONCLUSION AND OUTLOOK	503
ACKNOWLEDGEMENT	504
REFERENCES	504
AUTHOR INDEX	515
SUBJECT INDEX	533
CONTENTS OF PREVIOUS VOLUMES	537
CUMULATIVE INDEX	547