

Contents

Series Editor's Foreword	xiii
Preface	xv
Acknowledgments	xix
List of Abbreviations	xxi
About the Companion Website	xxiii
1 Polarization of Monochromatic Waves. Background of the Jones Matrix Methods. The Jones Calculus	1
1.1 Homogeneous Waves in Isotropic Media	1
1.1.1 Plane Waves	1
1.1.2 Polarization. Jones Vectors	3
1.1.3 Coordinate Transformation Rules for Jones Vectors. Orthogonal Polarizations. Decomposition of a Wave into Two Orthogonally Polarized Waves	9
1.2 Interface Optics for Isotropic Media	14
1.2.1 Fresnel's Formulas. Snell's Law	14
1.2.2 Reflection and Transmission Jones Matrices for a Plane Interface between Isotropic Media	20
1.3 Wave Propagation in Anisotropic Media	23
1.3.1 Wave Equations	23
1.3.2 Waves in a Uniaxial Layer	25
1.3.3 A Simple Birefringent Layer and Its Principal Axes	30
1.3.4 Transmission Jones Matrices of a Simple Birefringent Layer at Normal Incidence	32
1.3.5 Linear Retarders	36
1.3.6 Jones Matrices of Absorptive Polarizers. Ideal Polarizer	38
1.4 Jones Calculus	41
1.4.1 Basic Principles of the Jones Calculus	42
1.4.2 Three Useful Theorems for Transmissive Systems	46
1.4.3 Reciprocity Relations. Jones's Reversibility Theorem	50
1.4.4 Theorem of Polarization Reversibility for Systems Without Diattenuation	53
1.4.5 Particular Variants of Application of the Jones Calculus. Cartesian Jones Vectors for Wave Fields in Anisotropic Media	55
References	57

2	The Jones Calculus: Solutions for Ideal Twisted Structures and Their Applications in LCD Optics	59
2.1	Jones Matrix and Eigenmodes of a Liquid Crystal Layer with an Ideal Twisted Structure	59
2.2	LCD Optics and the Gooch–Tarry Formulas	64
2.3	Interactive Simulation	67
2.4	Parameter Space	69
	References	73
3	Optical Equivalence Theorem	75
3.1	General Optical Equivalence Theorem	75
3.2	Optical Equivalence for the Twisted Nematic Liquid Crystal Cell	77
3.3	Polarization Conserving Modes	77
	3.3.1 <i>LP1 Modes</i>	78
	3.3.2 <i>LP2 Modes</i>	79
	3.3.3 <i>LP3 Modes</i>	80
	3.3.4 <i>CP Modes</i>	81
3.4	Application to Nematic Bistable LCDs	82
	3.4.1 <i>2π Bistable TN Displays</i>	82
	3.4.2 <i>π Bistable TN Displays</i>	83
3.5	Application to Reflective Displays	84
3.6	Measurement of Characteristic Parameters of an LC Cell	86
	3.6.1 <i>Characteristic Angle Ω</i>	86
	3.6.2 <i>Characteristic Phase Γ</i>	87
	References	87
4	Electro-optical Modes: Practical Examples of LCD Modeling and Optimization	91
4.1	Optimization of LCD Performance in Various Electro-optical Modes	91
	4.1.1 <i>Electrically Controlled Birefringence</i>	91
	4.1.2 <i>Twist Effect</i>	101
	4.1.3 <i>Supertwist Effect</i>	109
	4.1.4 <i>Optimization of Optical Performance of Reflective LCDs</i>	116
4.2	Transflective LCDs	119
	4.2.1 <i>Dual-Mode Single-Cell-Gap Approach</i>	119
	4.2.2 <i>Single-Mode Single-Cell-Gap Approach</i>	122
4.3	Total Internal Reflection Mode	124
4.4	Ferroelectric LCDs	131
	4.4.1 <i>Basic Physical Properties</i>	131
	4.4.2 <i>Electro-optical Effects in FLC Cells</i>	135
4.5	Birefringent Color Generation in Dichromatic Reflective FLCs	145
	References	149
5	Necessary Mathematics. Radiometric Terms. Conventions. Various Stokes and Jones Vectors	153
5.1	Some Definitions and Relations from Matrix Algebra	153
	5.1.1 <i>General Definitions</i>	153
	5.1.2 <i>Some Important Properties of Matrix Products</i>	160
	5.1.3 <i>Unitary Matrices. Unimodular Unitary 2×2 Matrices. STU Matrices</i>	160
	5.1.4 <i>Norms of Vectors and Matrices</i>	163
	5.1.5 <i>Kronecker Product of Matrices</i>	166
	5.1.6 <i>Approximations</i>	167

5.2	Some Radiometric Quantities. Conventions	167
5.3	Stokes Vectors of Plane Waves and Collimated Beams Propagating in Isotropic Nonabsorbing Media	169
5.4	Jones Vectors	171
5.4.1	<i>Fitted-to-Electric-Field Jones Vectors and Fitted-to-Transverse-Component-of-Electric-Field Jones Vectors</i>	171
5.4.2	<i>Fitted-to-Irradiance Jones Vectors</i>	172
5.4.3	<i>Conventional Jones Vectors</i>	175
	References	176
6	Simple Models and Representations for Solving Optimization and Inverse Optical Problems. Real Optics of LC Cells and Useful Approximations	177
6.1	Polarization Transfer Factor of an Optical System	178
6.2	Optics of LC Cells in Terms of Polarization Transport Coefficients	182
6.2.1	<i>Polarization-Dependent Losses and Depolarization. Unpolarized Transmittance</i>	185
6.2.2	<i>Rotations</i>	187
6.2.3	<i>Symmetry of the Sample</i>	190
6.3	Retroreflection Geometry	192
6.4	Applications of Polarization Transport Coefficients in Optimization of LC Devices	195
6.5	Evaluation of Ultimate Characteristics of an LCD that can be Attained by Fitting the Compensation System. Modulation Efficiency of LC Layers	207
	References	216
7	Some Physical Models and Mathematical Algorithms Used in Modeling the Optical Performance of LCDs	217
7.1	Physical Models of the Light-Layered System Interaction Used in Modeling the Optical Behavior of LC Devices. Plane-Wave Approximations. Transfer Channel Approach	217
7.2	Transfer Matrix Technique and Adding Technique	237
7.2.1	<i>Transfer Matrix Technique</i>	238
7.2.2	<i>Adding Technique</i>	242
7.3	Optical Models of Some Elements of LCDs	246
	References	248
8	Modeling Methods Based on the Rigorous Theory of the Interaction of a Plane Monochromatic Wave with an Ideal Stratified Medium. Eigenwave (EW) Methods. EW Jones Matrix Method	251
8.1	General Properties of the Electromagnetic Field Induced by a Plane Monochromatic Wave in a Linear Stratified Medium	252
8.1.1	<i>Maxwell's Equations and Constitutive Relations</i>	252
8.1.2	<i>Plane Waves</i>	256
8.1.3	<i>Field Geometry</i>	259
8.2	Transmission and Reflection Operators of Fragments (TR Units) of a Stratified Medium and Their Calculation	275
8.2.1	<i>EW Jones Vector. EW Jones Matrices. Transmission and Reflection Operators</i>	275
8.2.2	<i>Calculation of Overall Transmission and Overall Reflection Operators for Layered Systems by Using Transfer Matrices</i>	281

8.3	Berreman's Method	283
	8.3.1 <i>Transfer Matrices</i>	283
	8.3.2 <i>Transfer Matrix of a Homogeneous Layer</i>	285
	8.3.3 <i>Transfer Matrix of a Smoothly Inhomogeneous Layer. Staircase Approximation</i>	287
	8.3.4 <i>Coordinate Systems</i>	289
8.4	Simplifications, Useful Relations, and Advanced Techniques	291
	8.4.1 <i>Orthogonality Relations and Other Useful Relations for Eigenwave Bases</i>	291
	8.4.2 <i>Simple General Formulas for Transmission Operators of Interfaces</i>	297
	8.4.3 <i>Calculation of Transmission and Reflection Operators of Layered Systems by Using the Adding Technique</i>	303
8.5	Transmissivities and Reflectivities	304
8.6	Mathematical Properties of Transfer Matrices and Transmission and Reflection EW Jones Matrices of Lossless Media and Reciprocal Media	311
	8.6.1 <i>Properties of Matrix Operators for Nonabsorbing Regions</i>	311
	8.6.2 <i>Properties of Matrix Operators for Reciprocal Regions</i>	313
8.7	Calculation of EW 4×4 Transfer Matrices for LC Layers	319
8.8	Transformation of the Elements of EW Jones Vectors and EW Jones Matrices Under Changes of Eigenwave Bases	322
	8.8.1 <i>Coordinates of the EW Jones Vector of a Wave Field in Different Eigenwave Bases</i>	322
	8.8.2 <i>EW Jones Operators in Different Eigenwave Bases</i>	326
	References	328
9	Choice of Eigenwave Bases for Isotropic, Uniaxial, and Biaxial Media	331
9.1	General Aspects of EWB Specification. EWB-generating routines	331
9.2	Isotropic Media	338
9.3	Uniaxial Media	342
9.4	Biaxial Media	352
	References	365
10	Efficient Methods for Calculating Optical Characteristics of Layered Systems for Quasimonochromatic Incident Light. Main Routines of LMOPTICS Library	367
10.1	EW Stokes Vectors and EW Mueller Matrices	368
10.2	Calculation of the EW Mueller Matrices of the Overall Transmission and Reflection of a System Consisting of "Thin" and "Thick" Layers	375
10.3	Main Routines of LMOPTICS	384
	10.3.1 <i>Routines for Computing 4×4 Transfer Matrices and EW Jones Matrices</i>	384
	10.3.2 <i>Routines for Computing EW Mueller Matrices</i>	388
	10.3.3 <i>Other Useful Routines</i>	391
	References	392
11	Calculation of Transmission Characteristics of Inhomogeneous Liquid Crystal Layers with Negligible Bulk Reflection	393
11.1	Application of Jones Matrix Methods to Inhomogeneous LC Layers	394
	11.1.1 <i>Calculation of Transmission Jones Matrices of LC Layers Using the Classical Jones Calculus</i>	394
	11.1.2 <i>Extended Jones Matrix Methods</i>	404
11.2	NBRA. Basic Differential Equations	409
11.3	NBRA. Numerical Methods	420
	11.3.1 <i>Approximating Multilayer Method</i>	421

11.3.2	<i>Discretization Method</i>	427
11.3.3	<i>Power Series Method</i>	428
11.4	NBRA. Analytical Solutions	430
11.4.1	<i>Twisted Structures</i>	430
11.4.2	<i>Nontwisted Structures</i>	432
11.4.3	<i>NBRA and GOA. Adiabatic and Quasiadiabatic Approximations</i>	434
11.5	Effect of Errors in Values of the Transmission Matrix of the LC Layer on the Accuracy of Modeling the Transmittance of the LCD Panel	437
	References	438
12	Some Approximate Representations in EW Jones Matrix Method and Their Application in Solving Optimization and Inverse Problems for LCDs	441
12.1	Theory of STUM Approximation	442
12.2	Exact and Approximate Expressions for Transmission Operators of Interfaces at Normal Incidence	447
12.3	Polarization Jones Matrix of an Inhomogeneous Nonabsorbing Anisotropic Layer with Negligible Bulk Reflection at Normal Incidence. Simple Representations of Polarization Matrices of LC Layers at Normal Incidence	463
12.4	Immersion Model of the Polarization-Converting System of an LCD	466
12.5	Determining Configurational and Optical Parameters of LC Layers With a Twisted Structure: Spectral Fitting Method	474
12.5.1	<i>How to Bring Together the Experiment and Unitary Approximation</i>	476
12.5.2	<i>Parameterization and Solving the Inverse Problem</i>	480
12.5.3	<i>Appendix to Section 12.5</i>	489
12.6	Optimization of Compensation Systems for Enhancement of Viewing Angle Performance of LCDs	490
	References	504
13	A Few Words About Modeling of Fine-Structure LCDs and the Direct Ray Approximation	507
13.1	Virtual Microscope	508
13.2	Directional Illumination and Diffuse Illumination	513
	References	516
A	LCD Modeling Software MOUSE-LCD Used for the HKUST Students Final Year Projects (FYP) from 2003 to 2011	517
A.1	Introductory Remarks	517
A.2	Fast LCD	517
A.2.1	<i>TN Cell</i>	517
A.2.2	<i>Effect of d/p Ratio</i>	519
A.2.3	<i>Effect of K_{22}/K_{11}</i>	520
A.2.4	<i>Effect of K_{33}/K_{11}</i>	520
A.2.5	<i>Effect of $\Delta\epsilon$</i>	521
A.2.6	<i>Effect of γ_1</i>	521
A.2.7	<i>Effect of Anchoring Strength W</i>	523
A.2.8	<i>Optimized TN Cell With Fast Response Time</i>	523
A.2.9	<i>Other LC Modes</i>	524
A.3	Color LCD	524
A.3.1	<i>The Super-Twisted Nematic Cell</i>	524
A.3.2	<i>STN Birefringent Colors in Transmissive and Reflective Modes</i>	525

A.4	Transflective LCD	525
	A.4.1 <i>Vertical Aligned Nematic Cell</i>	525
A.5	Switchable Viewing Angle LCD	535
A.6	Optimal e-paper Configurations	535
A.7	Color Filter Optimization	536
	References	536
B	Some Derivations and Examples	537
B.1	Conservation Law for Energy Flux	537
B.2	Lorentz's Lemma	538
B.3	Nonexponential Waves	538
B.4	To the Power Series Method (Section 11.3.3)	540
B.5	One of the Ways to Obtain the Explicit Expressions for Transmission Jones Matrices of an Ideal Twisted LC Layer	541
	Reference	543
Index		545