

Contents

Preface *xi*

Overview *xiii*

1	Crystal Optics	1
1.1	Introduction	1
1.2	Index Ellipsoid or Optical Indicatrix	1
1.3	Effect of Crystal Symmetry	3
1.4	Wave Surface	4
1.4.1	Uniaxial Crystal	4
1.4.2	Biaxial Crystal	5
1.5	Birefringence	6
1.6	Polarization of Light	8
1.6.1	Linear Polarization – Equal Amplitudes	10
1.6.2	Linear Polarization – Unequal Amplitudes	10
1.6.3	Circular Polarization	11
1.6.4	Elliptical Polarization	12
1.7	Changing the Polarization of Light	13
1.7.1	Polarizer and Polarizing Beam Splitters	13
1.7.2	Birefringent Wave Plate	14
1.8	Effects of Reflection and Transmission on Polarization	16
1.8.1	Interface Between Two Media	16
1.8.2	Multilayer Thin-Film Filters	17
1.9	Light Polarizing Devices	20
1.9.1	Polarizing Plate	20
1.9.2	Polarizing Prism	20
1.9.3	Phase Plate	21
1.9.4	Optical Isolator	22
1.9.5	Optical Attenuators	22
1.9.6	Polarization Rotator	23
	References	25

2	Photoelasticity	27
2.1	Introduction	27
2.2	Principle of Photoelasticity	27
2.3	History of Photoelasticity	28
2.4	Phenomenological Theory of Photoelasticity	30
2.5	Atomic Theory of Photoelasticity	33
2.6	Photoelastic Devices	35
2.6.1	Photoelastic Modulator	36
2.6.2	Photoelastic Q-Switch	38
2.6.3	Photoelastic Accelerometer	41
2.6.4	Photoelastic Force Sensor	45
2.7	Photoelastic Materials and Applications	50
2.7.1	LiNbO ₃ and LiTaO ₃ Crystals	51
2.7.2	Li ₂ Ge ₇ O ₁₅ Crystals	53
	References	55
3	Acousto-Optics	59
3.1	Introduction	59
3.2	Short History of Acousto-optics	59
3.3	Principle of Acousto-optic Effect	61
3.4	Acousto-optic Devices	63
3.4.1	Acousto-optic Modulator	63
3.4.1.1	Acousto-optic Modulator Construction	64
3.4.1.2	Digital Modulation	65
3.4.1.3	Analog Modulation	66
3.4.1.4	Dynamic Contrast Ratio	67
3.4.1.5	Applications of Acousto-optic Modulators	68
3.4.2	Acousto-Optic Beam Deflector	69
3.4.2.1	Definition of Optical Deflector Resolution	70
3.4.2.2	Modulation Transfer Function	71
3.4.2.3	Scan Flyback Time	72
3.4.2.4	Cylinder Lensing Effect	72
3.4.2.5	Applications of AOBD	72
3.4.3	Acousto-optic Frequency Shifter	73
3.4.3.1	Principles of Operation	73
3.4.3.2	Laser Doppler Vibrometer (LDV)	75
3.4.4	Acousto-optical Q-Switch	76
3.4.4.1	Applications of Acousto-optical Q-Switches	77
3.4.5	Acousto-optic Tunable Filter	83
3.4.5.1	Principles of AOTF Operation	83
3.4.5.2	Infrared Multispectral Imaging	86
3.4.5.3	Analytical Applications of AOTF	88
3.4.5.4	Satellite- and Space-Based Applications of AOTF	112
3.5	Acousto-optic Materials and Their Applications	124
3.5.1	Lead Molybdate (PbMoO ₄)	125
3.5.2	Tellurium Dioxide (TeO ₂)	125
3.5.3	Lithium Niobate (LiNbO ₃)	131
	References	134

4	Magneto-optics	143
4.1	Introduction	143
4.1.1	Gyrotropic Permittivity	143
4.1.2	Kerr Rotation and Kerr Ellipticity	144
4.2	Mode of Interaction	145
4.2.1	Transmission Mode	145
4.2.2	Reflection Mode	148
4.2.3	The Absorption Mode	149
4.3	Magneto-optic Materials Classification	149
4.3.1	Ferromagnetic Metals and Alloys	151
4.3.1.1	Ferromagnetic Semiconductor	152
4.3.1.2	Magnetic Fluid	153
4.3.2	Ferrimagnetic Compounds	156
4.3.3	Antiferromagnetic Compounds	159
4.4	Magneto-optic Devices	161
4.4.1	Magneto-optic Modulator	161
4.4.1.1	Magneto-optic Spatial Light Modulator	161
4.4.1.2	Mach–Zehnder Magneto-optic Modulator	166
4.4.1.3	Magnetic Fluid-Based Magneto-optic Modulator	170
4.4.1.4	Terahertz Magneto-optic Modulator	174
4.4.2	Magneto-optical Circulator	177
4.4.2.1	T-shaped Magneto-optical Circulator	177
4.4.2.2	Multiple-Port Integrated Optical Circulators	186
4.4.2.3	Terahertz Magneto-optical Circulator	189
4.4.3	Magneto-optical Isolator	190
4.4.3.1	Quasi-Phase-Matching Faraday Rotation Isolator	192
4.4.3.2	Nonreciprocal Phase-Shift Isolator	193
4.4.3.3	TM-Mode Waveguide Isolator	193
4.4.3.4	Silicon-Based MO Isolator and Circulator	197
4.4.3.5	THz Isolators Based on Plasmonics	201
4.4.3.6	THz Isolators Based on Metasurfaces	204
4.4.4	Magneto-optical Sensor	205
4.4.4.1	All-Fiber Sensors	207
4.4.4.2	Bulk-optic Sensors	209
4.4.4.3	Magnetic Force Sensors	211
4.4.5	Magneto-optical Recording	219
4.4.5.1	Principles of MO Recording	220
4.4.5.2	MO Recording Process	222
4.4.5.3	Magneto-optical Readout	225
4.4.5.4	MO Recording Materials	226
4.4.5.5	High-Density MO Recording	239
4.4.5.6	Ultrahigh-Density MO Recording	245
	References	247
5	Electro-optics	265
5.1	Introduction	265
5.2	History of Electro-optic Effects	265
5.3	Principles of Electro-optic Effects	270

5.4	Phenomenological Theory of Electro-optic Effect	271
5.4.1	Linear Electro-optic Effect	272
5.4.2	Quadratic Electro-optic Effect	274
5.5	Electro-optic Devices	275
5.5.1	Phase Modulator	275
5.5.2	Dynamic Wave Retarder	277
5.5.3	Intensity Modulators (Type 1)	278
5.5.4	Intensity Modulator (Type 2)	279
5.5.5	Scanners	280
5.5.6	Directional Couplers	282
5.5.7	Spatial Light Modulators (Electrically Addressed)	285
5.5.8	Spatial Light Modulators (Optically Addressed)	285
5.5.9	Pockels Readout Optical Modulator	287
5.6	Electro-optic Materials and Applications	288
5.6.1	Barium Titanate (BaTiO_3)	288
5.6.1.1	Waveguide Electro-optic Modulator	289
5.6.1.2	Plasmonic Interferometer	292
5.6.2	Lead Lanthanum Zirconate Titanate (PLZT)	293
5.6.2.1	Electro-optic Tunable Etalon	294
5.6.2.2	Nanosecond Speed PLZT Optical Switch	294
5.6.3	Lithium Tantalate (LiTaO_3)	295
5.6.3.1	Second Harmonic Generator, EO Lens, and EO Scanner	295
5.6.4	Lithium Niobate (LiNbO_3)	298
5.6.4.1	Application of LiNbO_3	299
5.6.5	Barium Strontium Titanate (BST)	327
5.6.6	Lead Magnesium Niobate–Lead Titanate (PMN–PT)	328
5.6.6.1	Electro-optic Tunable Filter	329
5.6.6.2	Electro-optic Q-Switches	330
5.6.6.3	Variable Optical Attenuator	332
5.6.6.4	Polarization Controller (PC)	334
5.6.6.5	Variable Gain Tilt Filters (VGTF) and Dynamic Gain Flattening Filters (DGFF)	335
5.6.7	Potassium Niobate (KNbO_3)	338
5.6.8	Potassium Tantalate Niobate (KTN)	339
5.6.8.1	Electro-optic Phase Modulator	340
5.6.8.2	KTN Fast Varifocal Lenses	346
5.6.8.3	Electro-optic Deflectors	347
5.6.8.4	KTN Optical Beam Scanner	350
5.7	Electro-optic Plasmonic Materials and Applications	354
5.7.1	Transparent Conducting Oxides	360
5.7.2	Ultracompact Plasmonic Modulators	362
5.7.3	Silicon Waveguide-Based Modulators	364
5.7.4	CMOS Compatibility	367
5.7.5	Perspectives of EO-Plasmonic Materials	368
	References	372

6	Photorefractive Effect	409
6.1	Introduction	409
6.2	Photorefractive Effect	409
6.2.1	Conventional Model of Photorefractive Effect	412
6.2.1.1	Photorefractive Index Gratings	413
6.2.1.2	Space Charge Field for Sinusoidal Illumination	415
6.2.2	Inter-band Photorefractive Effect	417
6.3	Applications of Photorefractive Effect	418
6.3.1	Holographic Storage	419
6.3.2	Two Waves Mixing	420
6.3.3	Light-Induced Waveguides	421
6.4	Photorefractive Materials and Devices	422
6.4.1	Electro-optic Photorefractive Crystals	424
6.4.1.1	Photorefractive Waveguides	425
6.4.1.2	Photorefractive Tunable Filters	432
6.4.1.3	Photorefractive Switches	439
6.4.1.4	Holographic Interferometers	444
6.4.2	Photorefractive Polymers	451
6.4.2.1	Holographic Display	452
6.4.2.2	Holographic Autocorrelator	453
6.4.2.3	Laser Ultrasonic Receiver	454
6.4.2.4	Ultrasound-Modulated Optical Tomography	454
6.4.2.5	Holographic Optical Coherence Imaging	455
6.4.2.6	Surface Waveguide	457
6.4.3	Holographic Polymer Dispersed Liquid Crystal (H-PDLC)	457
6.4.3.1	Wavelength Switch	458
6.4.3.2	Electrically Switchable Cylindrical Fresnel Lens	460
6.4.4	Photosensitive Glass	467
6.4.4.1	VBG Discrete Filter Elements	472
6.4.4.2	Universal WDM Combiners/Splitters	473
6.4.4.3	Integrated Combiner Modules	473
6.4.4.4	Other VBG-Based Devices and Subsystems	473
	References	475
	Index	487

