

# Optical Waves in Layered Media

**POCHI YEH**

**Rockwell International Science Center, Thousand Oaks, California**



*A Wiley-Interscience Publication*

*John Wiley & Sons*

*New York | Chichester | Brisbane | Toronto | Singapore*

# Contents

<b>Chapter 1. The Electromagnetic Field</b>	<b>1</b>
1.1 Maxwell's Equations and Boundary Conditions	1
1.2 Energy Density and Energy Flux	5
1.3 Complex Numbers and Monochromatic Fields	6
1.4 Wave Equations and Monochromatic Plane Waves	8
1.5 Polarization States of Light	14
1.6 Partially Polarized and Unpolarized Light	22
1.7 Elementary Theory of Coherence	25
References and Suggested Readings	29
Problems	30
<b>Chapter 2. Interaction of Electromagnetic Radiation with Matter</b>	<b>36</b>
2.1 Dielectric Constant and Atomic Polarizability	36
2.2 Classical Electron Model	37
2.3 Dispersion and Complex Refractive Index	38
2.4 Kramers–Kronig Relations	44
2.5 Optical Pulses and Group Velocity	50
Problems	54
<b>Chapter 3. Reflection and Refraction of Plane Waves</b>	<b>58</b>
3.1 Snell's Law and Fresnel's Formulas	58
3.2 Total Internal Reflection	68
3.3 Polarization by Reflection; Brewster Angle	76
3.4 Reflection at Surface of Absorbing Medium	77
References and Suggested Readings	79
Problems	79
<b>Chapter 4. Optics of A Single Homogeneous and Isotropic Layer</b>	<b>83</b>
4.1 Electromagnetic Treatment	83
4.2 Airy's Formulas	86
4.3 Transmittance, Reflectance, and Absorptance	90
4.4 Examples	91
4.5 Thick Layers and Spectral Averaging	98
Problems	99

<b>Chapter 5.</b>	<b>Matrix Formulation for Isotropic Layered Media</b>	<b>102</b>
5.1	$2 \times 2$ Matrix Formulation	102
5.2	Transmittance and Reflectance	109
5.3	General Theorems on Layered Media Problems	112 114
<b>Chapter 6.</b>	<b>Optics of Periodic Layered Media</b>	<b>118</b>
6.1	Periodic Layered Media	118
6.2	Bloch Waves and Band Structures	123
6.3	Bragg Reflectors	128
6.4	Form Birefringence	135
6.5	Resonant Tunneling	138
	References	142
	Problems	142
<b>Chapter 7.</b>	<b>Some Applications of Isotropic Layered Media</b>	<b>144</b>
7.1	Fabry–Perot Interferometers	144
7.2	Gires–Tournois Interferometers	150
7.3	Antireflection Coating	151
7.4	Ellipsometry	155
7.5	High-Reflectance Coating	157
7.6	Field of View of Spectral Filters	161
	References	163
	Problems	163
<b>Chapter 8.</b>	<b>Inhomogeneous Layers</b>	<b>166</b>
8.1	The WKB Approximation	166
8.2	Some Exact Solutions	168
8.3	Reflectance and Transmittance of Inhomogeneous Layers	173
8.4	Exponentially Graded Multilayers	176
8.5	Sinusoidal Layers	186
8.6	Rays in Inhomogeneous Media	192
	References	195
	Problems	195
<b>Chapter 9.</b>	<b>Optics of Anisotropic Layered Media</b>	<b>201</b>
9.1	Plane Waves in Homogeneous and Anisotropic Media	201
9.2	Plane Waves in Uniaxially Anisotropic Media	211

9.3	Jones Matrix Formulation	216
9.4	Intensity Transmission and Some Examples	224
9.5	Double Refraction at a Boundary	227
9.6	Reflection and Refraction of Electromagnetic Radiation at a Crystal Surface	232
9.7	$4 \times 4$ Matrix Formulation	239
	References	247
	Problems	248
<b>Chapter 10.</b>	<b>Some Applications of Anisotropic Layered Media</b>	<b>254</b>
10.1	Lytot–Ohman Filters	254
10.2	Solc Filters	260
10.3	Angular Properties of Birefringent Filters	270
10.4	Dispersive Birefringent Filters	277
10.5	Iso-Index Filters	284
10.6	Light Propagation in Twisted Anisotropic Media	289
	References	293
	Problems	294
<b>Chapter 11.</b>	<b>Guided Waves in Layered Media</b>	<b>298</b>
11.1	Symmetric Slab Waveguides	298
11.2	Asymmetric Slab Waveguides	308
11.3	Multilayer Waveguides	319
11.4	Surface Plasmons	332
11.5	Electromagnetic Bloch Surface Waves	337
11.6	General Properties of Dielectric Waveguides	345
11.7	Perturbation Theory and Mode Coupling	351
11.8	Coupling of Two Waveguides	357
11.9	Effective Index Theory	363
11.10	Coupling of $N$ Identical Waveguides	365
	References and Suggested Readings	369
	Problems	369
<b>Chapter 12.</b>	<b>Optics of Semiconductor Quantum Wells and Superlattice Structures</b>	<b>375</b>
12.1	Quantum Wells	375
12.2	Multiple Quantum Wells	379
12.3	Optical Properties of Superlattices and Quantum Wells	383

12.4	Superlattices as Soft x-Ray Media	385
	References	391
	Problems	392
<b>Appendix A.</b>	<b>Zeros of Mode Dispersion Relation</b>	<b>395</b>
<b>Author Index</b>		<b>397</b>
<b>Subject Index</b>		<b>399</b>