THEORY OF DIELECTRIC OPTICAL WAVEGUIDES

Second Edition

Dietrich Marcuse

AT&T Bell Laboratories Crawford Hill Laboratory Holmdel, New Jersey





ACADEMIC PRESS, INC. Harcourt Brace Jovanovich, Publishers Boston San Diego New York London Sydney Tokyo Toronto

CONTENTS

PREFACE TO THE SECOND EDITION	XI

xiii

PREFACE TO THE FIRST EDITION

Chapter 1. The Asymmetric Slab Waveguide

1.1	Introduction	1
1.2	Geometrical Optics Treatment of Slab Waveguides	3
1.3	Guided Modes of the Asymmetric Slab Waveguide	7
1.4	Radiation Modes of the Asymmetric Slab Waveguide	19
1.5	Leaky Waves	31
1.6	Hollow Dielectric Waveguides	43
1.7	Rectangular Dielectric Waveguides	49

Chapter 2. Weakly Guiding Optical Fibers

2.1	Introduction	60
2.2	Guided Modes of the Optical Fiber	62
2.3	Waveguide Dispersion and Group Velocity	78
2.4	Radiation Modes of the Optical Fiber	83
2.5	Cutoff and Total Internal Reflection	91

Chapter 3. Coupled Mode Theory

3.1	Introduction	97
3.2	Expansion in Terms of Ideal Modes	100
3.3	Expansion in Terms of Local Normal Modes	108
3.4	Perturbation Solution of the Coupled Amplitude Equations	113
3.5	Coupling Coefficients for the Asymmetric Slab Waveguide	118
3.6	Coupling Coefficients for the Optical Fiber	128

Chapter 4. Applications of the Coupled Mode Theory

Introduction	134
Slab Waveguide with Sinusoidal Deformation	135
Hollow Dielectric Waveguide with Sinusoidal Deformation	147
Fiber with Sinusoidal Diameter Changes	155
Change of Polarization	161
Fiber with More General Interface Deformations	165
Rayleigh Scattering	171
	Slab Waveguide with Sinusoidal Deformation Hollow Dielectric Waveguide with Sinusoidal Deformation Fiber with Sinusoidal Diameter Changes Change of Polarization Fiber with More General Interface Deformations

Chapter 5. Coupled Power Theory

5.1	Introduction	177
5.2	Derivation of Coupled Power Equations	179
5.3	cw Operation of Multimode Waveguides	185
5.4	Power Fluctuations	197
5.5	Pulse Propagation in Multimode Waveguides	205
5.6	Diffusion Theory of Coupled Modes	231
5.7	Power Coupling between Waves Traveling in Opposite Directions	241

Chapter 6. Theory of the Directional Coupler

6.1	Introduction	251
6.2	Coupled Equations for Sum and Difference Fields	255
6.3	General Discussion of the Directional Coupler Theory	261
6.4	Vector Wave Equation and Definition of Inner Product	264
6.5	Approximation of $\beta_{e} - \beta_{o}$	267
6.6	Discussion of Approximation of $\beta_e - \beta_o$	271
6.7	TM Modes of a Slab Waveguide Coupler	272
6.8	Numerical Examples	276

Chapter 7. Grating-Assisted Direction Couplers

7.1	Introduction	280
7.2	Theory of the Grating-Assisted Directional Coupler	285

7.3	Approximations for the Forward Grating Coupler	289
7.4	Grating-Assisted Backward Couplers	293
7.5	Coupling Coefficients for Grating-Assisted Couplers	299

Chapter 8. Approximate and Numerical Methods

8.1	Introduction	305
8.2	The Beam Propagation Method	306
8.3	The Role of the FFT in the Beam Propagation Method	310
8.4	Application of the Beam Propagation Method	314
8.5	A Numerical Method for Modal Solutions of the Wave Equation	319
8.6	The Effective Index Method	330

Chapter 9. Nonlinear Effects

9.1	Introduction	335
9.2	Incorporating Dispersion into the Wave Equation	336
9.3	Derivation of the Nonlinear Wave-Envelope Equation	340
9.4	Redefining the Nonlinear Coefficient	343
9.5	Energy Conservation	346
9.6	Self-Pace Modulation	
9.7	Nonlinear Wave Equation in Frequency-Domain Representation	348
9.8	Frequency Mixing of Pure Sine Waves	350
9.9	Derivation of the First-Order Soliton	354
9.10	Soliton Properties	360

References

INDEX

367 373