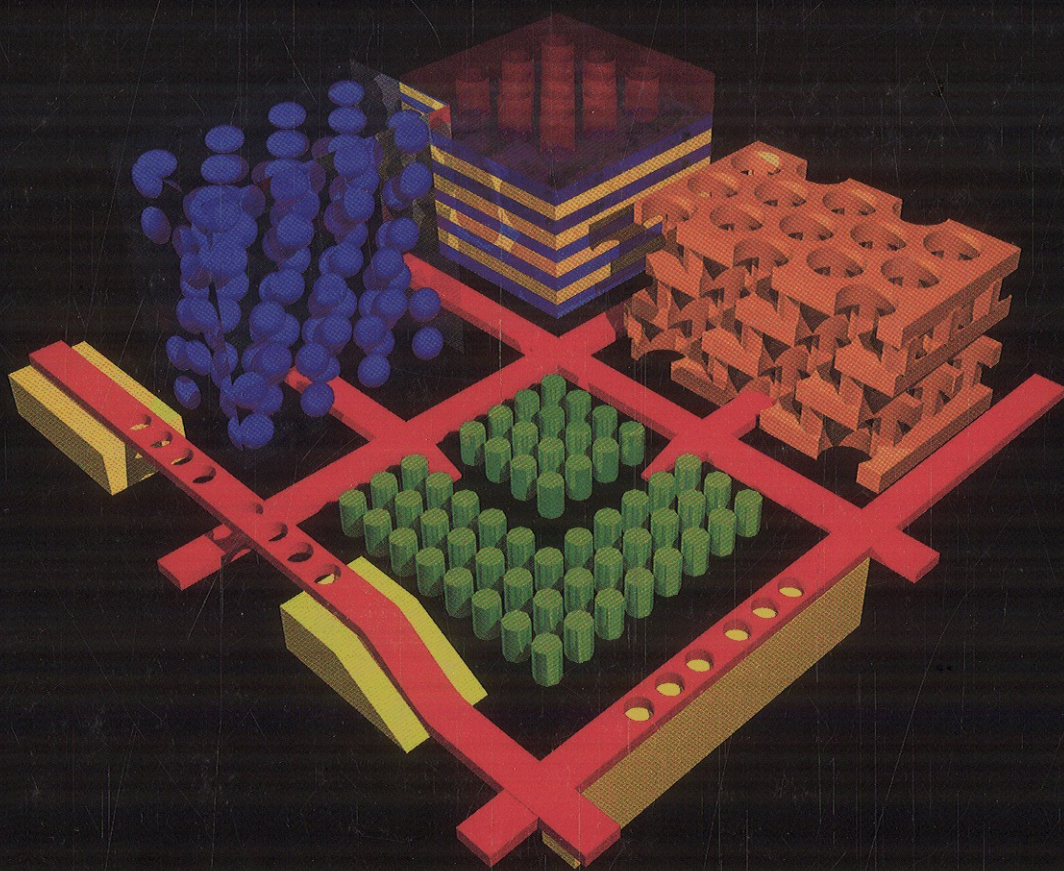


Photonic Crystals

Molding the Flow of Light

SECOND EDITION



John D. Joannopoulos
Steven G. Johnson
Joshua N. Winn
Robert D. Meade

CONTENTS

<i>Preface to the Second Edition</i>	xiii
<i>Preface to the First Edition</i>	xv
1 Introduction	1
Controlling the Properties of Materials	1
Photonic Crystals	2
An Overview of the Text	3
2 Electromagnetism in Mixed Dielectric Media	6
The Macroscopic Maxwell Equations	6
Electromagnetism as an Eigenvalue Problem	10
General Properties of the Harmonic Modes	12
Electromagnetic Energy and the Variational Principle	14
Magnetic vs. Electric Fields	16
The Effect of Small Perturbations	17
Scaling Properties of the Maxwell Equations	20
Discrete vs. Continuous Frequency Ranges	21
Electrodynamics and Quantum Mechanics Compared	22
Further Reading	24
3 Symmetries and Solid-State Electromagnetism	25
Using Symmetries to Classify Electromagnetic Modes	25
Continuous Translational Symmetry	27
Index guiding	30
Discrete Translational Symmetry	32
Photonic Band Structures	35
Rotational Symmetry and the Irreducible Brillouin Zone	36
Mirror Symmetry and the Separation of Modes	37
Time-Reversal Invariance	39
Bloch-Wave Propagation Velocity	40

Electrodynamics vs. Quantum Mechanics Again	42
Further Reading	43
4 The Multilayer Film: A One-Dimensional Photonic Crystal	44
The Multilayer Film	44
The Physical Origin of Photonic Band Gaps	46
The Size of the Band Gap	49
Evanescent Modes in Photonic Band Gaps	52
Off-Axis Propagation	54
Localized Modes at Defects	58
Surface States	60
Omnidirectional Multilayer Mirrors	61
Further Reading	65
5 Two-Dimensional Photonic Crystals	66
Two-Dimensional Bloch States	66
A Square Lattice of Dielectric Columns	68
A Square Lattice of Dielectric Veins	72
A Complete Band Gap for All Polarizations	74
Out-of-Plane Propagation	75
Localization of Light by Point Defects	78
<i>Point defects in a larger gap</i>	83
Linear Defects and Waveguides	86
Surface States	89
Further Reading	92
6 Three-Dimensional Photonic Crystals	94
Three-Dimensional Lattices	94
Crystals with Complete Band Gaps	96
<i>Spheres in a diamond lattice</i>	97
<i>Yablonovite</i>	99
<i>The woodpile crystal</i>	100
<i>Inverse opals</i>	103
<i>A stack of two-dimensional crystals</i>	105

Localization at a Point Defect	109
<i>Experimental defect modes in Yablonovite</i>	113
Localization at a Linear Defect	114
Localization at the Surface	116
Further Reading	121
7 Periodic Dielectric Waveguides	122
Overview	122
A Two-Dimensional Model	123
Periodic Dielectric Waveguides in Three Dimensions	127
Symmetry and Polarization	127
Point Defects in Periodic Dielectric Waveguides	130
Quality Factors of Lossy Cavities	131
Further Reading	134
8 Photonic-Crystal Slabs	135
Rod and Hole Slabs	135
Polarization and Slab Thickness	137
Linear Defects in Slabs	139
<i>Reduced-radius rods</i>	139
<i>Removed holes</i>	142
<i>Substrates, dispersion, and loss</i>	144
Point Defects in Slabs	147
Mechanisms for High Q with Incomplete Gaps	149
<i>Delocalization</i>	149
<i>Cancellation</i>	151
Further Reading	155
9 Photonic-Crystal Fibers	156
Mechanisms of Confinement	156
Index-Guiding Photonic-Crystal Fibers	158
<i>Endlessly single-mode fibers</i>	161
<i>The scalar limit and LP modes</i>	163
<i>Enhancement of nonlinear effects</i>	166

Band-Gap Guidance in Holey Fibers	169
<i>Origin of the band gap in holey fibres</i>	169
<i>Guided modes in a hollow core</i>	172
Bragg Fibers	175
<i>Analysis of cylindrical fibers</i>	176
<i>Band gaps of Bragg fibers</i>	178
<i>Guided modes of Bragg fibers</i>	180
Losses in Hollow-Core Fibers	182
<i>Cladding losses</i>	183
<i>Inter-modal coupling</i>	187
Further Reading	189
 10 Designing Photonic Crystals for Applications	 190
Overview	190
A Mirror, a Waveguide, and a Cavity	191
<i>Designing a mirror</i>	191
<i>Designing a waveguide</i>	193
<i>Designing a cavity</i>	195
A Narrow-Band Filter	196
Temporal Coupled-Mode Theory	198
<i>The temporal coupled-mode equations</i>	199
<i>The filter transmission</i>	202
A Waveguide Bend	203
A Waveguide Splitter	206
A Three-Dimensional Filter with Losses	208
Resonant Absorption and Radiation	212
Nonlinear Filters and Bistability	214
Some Other Possibilities	218
Reflection, Refraction, and Diffraction	221
<i>Reflection</i>	222
<i>Refraction and isofrequency diagrams</i>	223
<i>Unusual refraction and diffraction effects</i>	225
Further Reading	228
Epilogue	228
 A Comparisons with Quantum Mechanics	 229

CONTENTS	xii
B The Reciprocal Lattice and the Brillouin Zone	233
The Reciprocal Lattice	233
Constructing the Reciprocal Lattice Vectors	234
The Brillouin Zone	235
Two-Dimensional Lattices	236
Three-Dimensional Lattices	238
Miller Indices	239
 C Atlas of Band Gaps	 242
A Guided Tour of Two-Dimensional Gaps	243
Three-Dimensional Gaps	251
 D Computational Photonics	 252
Generalities	253
Frequency-Domain Eigenproblems	255
Frequency-Domain Responses	258
Time-Domain Simulations	259
A Planewave Eigensolver	261
Further Reading and Free Software	263
 <i>Bibliography</i>	 265
<i>Index</i>	283