Index

Absorbing boundary conditions (ABC),
finite-difference time-domain methods, 118–122
Absorption intensity dependence,
multiphoton absorption,
three-dimensional photonic crystal fabrication, 353–358
Air-bridge microcavity, strong confinement in photonic crystals, 157–158
AlAs compounds, Yablonovite photonic crystal fabrication, 326–327
AlGaAs compounds:
two-dimensional photonic crystal fabrication, 268–269
woodpile photonic crystal fabrication,
wafer bonding techniques, 290–297
Algebraic vector equation, optical electromagnetic waves equifrequency surfaces, anisotropic materials, 26–28
Alignment accuracy:
woodpile crystal fabrication, wafer bonding techniques, 294–297
woodpile photonic crystals, fabrication techniques, 285–297
Ampere’s law, electromagnetic waves, linear, homogeneous media, 18–21
Amplitude distribution, three-dimensional subwavelength imaging, photonic crystal flat lens, 250–253
Analog-to-digital converter (ADC), self-collimating photonic crystal dispersion, 224–231
Anisotropic materials:
equifrequency surfaces, optical electromagnetic waves, 25–28
three-dimensional photonic crystal fabrication, bulk silicon sculpting, inductively coupled plasma, 329–333
two-dimensional photonic crystal fabrication, 270–274
Yablonovite photonic crystal fabrication, 325–327
Anisotropic permittivity tensor, plane-wave expansion method, perfectly matched layers, photonic crystal slabs, 96–102
Antenna performance, photonic bandgap enhancement of, 188
Array waveguide gratings (AWGs), optical spectrometer, strong confinement in photonic crystals, 161–163
Asymmetry, three-dimensional subwavelength imaging, photonic crystal flat lens, 250–253
“Atoms” in lattices, primitive vectors and cells, 42–44
Autocloning technique, three-dimensional photonic crystal fabrication, 297–307
Axis-free lenses, left-handed behavior and negative refraction, 246–253
Back-side illumination, three-dimensional photonic crystal fabrication, electrophotochemical etching, 315–318
Band-energy discontinuity, heterostructure photonic crystals, 165–167

Copyright © 2009 John Wiley & Sons, Inc.

383
Bandgap:
dispersion surfaces and band diagrams, 60
three-dimensional photonic crystals, layer-by-layer fabrication, 280–281

Band structure:
dielectric waveguides, 35–37
homogeneous media, group velocity, 37–38
periodic media, 57–60
plane-wave expansion method:
one-dimensional method, 68–72
perfectly matched layers, photonic crystal slabs, 96–102
photonic-crystal slabs, dispersive material calculations, 102–108
three-dimensional method, 84–87	
two-dimensional method, 76–83
three-dimensional subwavelength imaging, photonic crystal flat lens, 247–253

Basis functions:
plane-wave expansion method, 66
two-dimensional method,
transverse-electric polarization, 78–79
primitive unit cells, 40–44

Beam splitting:
coupled photonic-crystal waveguides:
applications, 186–188
frequency-selective filters, 179–182
heterostructure photonic crystals, 165–168
self-collimating photonic crystals, 217–224
analog-to-digital converter, 226–231
strong confinement in photonic crystals, narrow-band beam splitter, 156–157

Beam steering:
holographic photonic crystal fabrication, interference lithography, 337–341
photonic crystal dispersion, superprism effect, 205
Bessel function, plane-wave expansion method, two-dimensional method, 76–83
\( \beta \) factor, photonic crystal cavity design, 139

Bias illumination, three-dimensional photonic crystal fabrication, electrophochemical etching, 315–318
Bias-sputter process, three-dimensional photonic crystal fabrication, autocloning technique, 298–307
Bloch boundary conditions, finite-difference time-domain methods, photonic crystals, 122–124

Bloch’s theorem:
periodic dielectric structures, 51–55
photonic crystal line defect analysis, finite-difference time-domain method, 143–144
plane-wave expansion method, one-dimensional method, 68–72

Bloch waves:
periodic media group velocity, 55–57
photonic-crystal slabs, line defect analysis, 147
photonic vs. semiconductor crystals, 7–8
plane-wave expansion method, 66
photonic crystal slabs, 93–95
dispersive materials, 105–108
perfectly matched layers, 98–102
three-dimensional method, 85–87

Body-centered cubic (BCC) lattices:
first Brillouin zone, 48–49
photonic crystals, 44–46
three-dimensional subwavelength imaging, photonic crystal flat lens, 247–253

Body-centered tetragonal lattices,
three-dimensional photonic crystals, layer-by-layer fabrication, 280–281

Boltzmann constant, three-dimensional photonic crystal fabrication, electrophochemical etching, 316–318
Bosch processes, two-dimensional photonic crystal fabrication, 267–269

Boundary conditions:
dielectric waveguides, 30–37
electromagnetic waves, linear, homogeneous media, 18–21
finite-difference time-domain methods: absorbing boundary conditions, 118–122
Constitutive relations:
dielectric waveguides, 30–37
optical electromagnetic waves
equifrequency surfaces, anisotropic materials, 25–28
Continuum flux model, three-dimensional photonic crystal fabrication, glancing angle deposition, 307–313
Convective assembly, self-assembled three-dimensional photonic crystal fabrication, 365–366
Coupled-cavity waveguides, photonic bandgap applications, 189
Coupled photonic-crystal waveguides, 171–188
applications, 178–188
frequency-selective filter, 179–182
optical switch, 183–186
splitters, 186–188
theoretical background, 172–178
Crossbar switches, coupled photonic-crystal waveguides, 183–186
Cross-talk (CT), waveguide crossing, 154–156
Cylindrical voids, three-dimensional photonic crystals, layer-by-layer fabrication, 275–281

Dense wavelength-division multiplexing (DWDM):
coupled photonic-crystal waveguides, frequency-selective filters, 182
optical spectrometer, strong confinement in photonic crystals, 160–163
Diamond lattice, photonic crystals, 44–46
Dielectric constant:
one-dimensional plane-wave expansion methods, 66–72
two-dimensional photonic crystal fabrication, 264–269
Dielectric permittivity, plane-wave expansion method, photonic crystal slabs, three-dimensional method, 92–95
Dielectric reflectors, photonic crystal optical network, 170–171
Dielectric rods:
heterostructure photonic crystals, 164–167
optical spectrometer, 161–163
supercell construction, point defect analysis, plane-wave expansion method, 135–137
two-dimensional photonic crystal fabrication, 269–274
two-dimensional plane-wave expansion method, 72–83
transverse-magnetic polarization, 81–83
woodpile photonic crystals, fabrication, 282–297

Dielectric tensor:
optical electromagnetic waves, 25–28
photonic crystal dispersion, 198–201
Dielectric waveguides, total internal reflection, 29–37
Diffraction, optical electromagnetic waves, 23–25
Diffraction grating:
holographic photonic crystal fabrication: diffractive element methods, 343–346
interference lithography, 336–341
optical electromagnetic waves, 25
Diffractive element methods, holographic photonic crystal fabrication, 342–346
Digitization, self-collimating photonic crystal dispersion, analog-to-digital converter, 224–231
Dirac delta function, woodpile crystal fabrication, wafer bonding techniques, 296–297
Directional bandgap, heterostructure photonic crystals, 165–167
Directional deposition, three-dimensional photonic crystals, layer-by-layer fabrication, 277–281
Directional gap, dispersion surfaces and band diagrams, 60
Direct-write electron-beam lithography:
three-dimensional photonic crystal fabrication, multiphoton absorption, 358
two-dimensional photonic crystal fabrication, 266–269
Discretized Fourier transform (DFT):
finite-difference time-domain methods, transient and steady-state response, 118
plane-wave expansion method, perfectly matched layers, photonic crystal slabs, 98–102
three-dimensional plane-wave expansion method, 84–87, 89
Dispersion relation:
dielectric waveguides, 35–37
finite-difference time-domain methods, 114–116
homogeneous media, group velocity, 37–38
photonic crystals:
left-handed behavior and negative refraction, 245–253
flat lens three-dimensional subwavelength imaging, 247–253
research background, 197–201
self-collimation, 205–244
beam splitting, 217–224
experimental demonstration, 208–211
light redirection, 214–217
optical analog-to-digital converter, 224–231
self-guiding heterolattice, 211–214
three-dimensional photonic crystals, 231–244
superprism effect, 201–205
negative refraction, 254–259
plane-wave expansion method:
one-dimensional method, 68–72
photonic crystal slabs, three-dimensional method, 91–95
two-dimensional method, 76–83
Dispersive material:
periodic media, 57–60
photonic-crystal line defects, single-frequency source, 147–150
plane-wave expansion method, 102–108
Dissolution valence, three-dimensional photonic crystal fabrication,
macroporous silicon, 313–318
Double inversion, three-dimensional photonic crystal fabrication, glancing angle deposition, 312–313
Dry etching, three-dimensional photonic crystal fabrication, macroporous silicon, 319–320
Effective-index value, waveguide bends, 153–154
Eigenfrequencies:
photonic bandgap structural analysis, 9–11
three-dimensional self-collimated photonic crystals, 234–239
Eigenmodes, coupled photonic-crystal waveguides, 172–178
Eigenvalues:
anisotropic materials, dielectric tensors, 27–28
periodic dielectric structures, variational principle, 53–55
photonic vs. semiconductor crystals, 8
plane-wave expansion method, 65–66
one-dimensional method, 68–72
perfectly matched layers, photonic crystal slabs, 99–102
photonic crystal slab:
dispersive materials, band structure calculations, 104–108
three-dimensional method, 92–95
three-dimensional methods, 88–89
two-dimensional method:
transverse-electric polarization, 78–79
transverse-magnetic polarization, 79–83
Electrically tunable photonic crystals, strong confinement, 167–169
Electromagnetic waves:
basic principles, 17–38
group velocity, homogeneous media, 37–38
guided waves, 28–37
left-handed behavior and negative refraction, 245–253
Maxwell’s equations:
isotropic homogeneous media, 21–23
linear, homogeneous media, 18–21
optical waves, 23–28
dielectric tensor and equifrequency surfaces, anisotropic materials, 25–28
reflection, refraction, and diffraction, 23–25
Electromagnetic waves (Continued)
periodic dielectric structures:
  Bloch’s theorem proof, 52–53
eigenvalue variational principle,
  53–55
  wave equations, 49–55
  photonic crystal dispersion, 198
self-collimation, 210–211
Electron-beam lithography:
  three-dimensional photonic crystals:
    glancing angle deposition, 310–313
    layer-by-layer fabrication, 277–281
    Yablonovite photonic crystal
    fabrication, 324–327
two-dimensional photonic crystal
    fabrication, 266–269
Electron-hole pairing, three-dimensional
photonic crystal fabrication,
electrophotochemical etching,
  315–318
Electrophoretic assembly, self-assembled
three-dimensional photonic crystal
fabrication, 364–365
Electrophotochemical etching:
  three-dimensional photonic crystal
    fabrication, macroporous silicon,
    313–318, 320–323
two-dimensional photonic crystal
    fabrication, 270–274
Electrostatic interaction, self-assembled
three-dimensional photonic crystal
fabrication, colloidal crystallization,
  364
Envelope function:
  homogeneous media, group velocity, 38
  periodic media group velocity, 55–57
Equifrequency contour (EFC):
  left-handed behavior and negative
    refraction, 246–253
  photonic crystal dispersion, 200–201
    self-collimation, 206–208
    beam splitting, 218–224
    light redirection, 214–217
    self-guiding heterolattice, 213–214
    three-dimensional crystals, 231–244
  superprism, negative refraction, and
    self-collimation, 254–259
  superprism effect, 201–205
Equifrequency surface (EFS):
  anisotropic materials, optical
    electromagnetic waves, 25–28
  periodic media, 57–60
  photonic crystal dispersion:
    superprism effect, 204–205
    three-dimensional self-collimated
      crystals, 234–239
    three-dimensional photonic crystals, self-
      collimation verification, 232–244
    three-dimensional subwavelength
      imaging, photonic crystal flat lens,
      247–253
Erbium-doped fiber amplifier (EDFA),
  optical spectrometer, strong
  confinement in photonic crystals,
  160–163
Etching properties and byproducts:
  three-dimensional photonic crystals:
    autocloning techniques, 305–307
    bulk silicon sculpting, inductively
      coupled plasma, 328–333
    layer-by-layer fabrication, 276–281
    macroporous silicon fabrication,
      320–323
two-dimensional photonic crystal
    fabrication, 273–274
Even mode, coupled photonic-crystal
waveguides, 173–178
Expansion function, plane-wave expansion
method, 66
  one-dimensional method, 69–72
Exponential function, periodic media group
velocity, 55–57
Fabrication of photonic crystals:
  three-dimensional crystal techniques:
    holographic lithography, 333–349
      coherent wave interference,
      334–336
diffractive element methods,
  342–346
interference lithography patterning,
  336–341
multiple exposure methods,
  346–349
micromachining, 274–274
    autocloning technique, 297–307
    glancing angle deposition, 307–313
interference lithographic patterning, 336–341, 349
layer-by-layer fabrication, 274–281
macroporous silicon, 313–323
electrophotochemical etching, 313–318
patterned porous growth, 318–320
photocurrent modulation, 320–323
reactive plasma sculpting, bulk silicon, 327–333
woodpile photonic crystals, 281–297
alignment, 294–297
substrate removal, 293–294
wafer bonding, 292–293
Yablonovite for near infrared ion beam etching, 323–327
multiphoton polymerization, 350–358
multiphoton absorption, 350–358
stereolithography/laser rapid prototyping, 350
self-assembly, 358–369
colloidal crystallization, 362–364
electrophoretic assembly, 364–365
monodisperse colloidal suspension, 359
monodisperse particle suspension, 359–362
packing cells, 366–368
spin-annealing, 369
template-directed colloidal epitaxy, 366
vertical meniscus deposition/convective assembly, 365–366
two-dimensional crystals, 263–274
basic techniques, 269–274
planar photonic crystals, 266–269
Face-centered-cubic (FCC) lattice:
first Brillouin zone, 48–49
photonic crystal dispersion:
self-collimation, three-dimensional crystals, 232–239
superprism effect, 204–205
photonic crystals, 44–46
photonic crystals origins and, 3–6
three-dimensional photonic crystals:
layer-by-layer fabrication, 275–281
self-assembled fabrication, 367
Yablonovite photonic crystal fabrication, 324–327
woodpile photonic crystals, fabrication techniques, 283–297
Face-centered-tetragonal (FCT) lattice, woodpile photonic crystals, fabrication techniques, 283–297
Faraday’s law, electromagnetic waves, linear, homogeneous media, 18–21
Fast Fourier transform (FFT), plane-wave expansion method:
one-dimensional method, 71–72
photonic crystal slabs, dispersive materials, 105–108
three-dimensional methods, 89
two-dimensional method, transverse-magnetic polarization, 80–83
Filleting method, woodpile photonic crystal fabrication, 287–297
Finite-difference time-domain (FDTD), 108–125
absorbing boundary conditions, 118–122
coupled photonic-crystal waveguides, 177–178
optical switches, 185–186
splitting, 187–188
heterostructure photonic crystals, 166–167
Maxwell’s equations central-difference equations, 109–110
numerical stability and dispersion, 114–116
overview, 63–65
photonic bandgap structural analysis, 10–11
photonic crystal optical networks, 170–171
Finite-difference time-domain (FDTD) [Continued]
photonic crystals, 122–125
Bloch boundary conditions, 122–124
cavity design criteria, 138–139
finite section analysis, 124–125
line defect analysis, 141–144
plane-wave expansion method vs., 144
single-frequency signal, 147–150
strong confinement in:
channel-drop filters, 159–160
waveguide bends, 150–154
zero cross-talk waveguide crossing, 155–156
photonic crystal slabs, line defect analysis, 144–147
point defects, photonic crystals, 134–137
self-collimated photonic crystal dispersion, 208–211
light redirection, 214–217
self-guiding heterolattice, 212–214
three-dimensional photonic crystals, 235–244
three-dimensional photonic crystals, 112–114
transient and steady-state system response, 116–118
two-dimensional photonic crystals, 110–112
zero cross-talk waveguide crossing, 156
Finite element method, overview, 63–65
Finite height, photonic crystal development, 5–6
Finite section analysis, finite-difference time-domain methods, photonic crystals, 124–125
First Brillouin zone (FBZ):
photonic crystal dispersion, 198–201
reciprocal lattice structures and Brillouin zone, 48–49
Flash analog-to-digital converter, self-collimating photonic crystal dispersion, 225–231
Flat lens photonic crystals, three-dimensional subwavelength imaging, 247–253
Focused-ion-beam (FIB) milling, three-dimensional photonic crystal fabrication, electrophotochemical etching, 322–323
Focusing evolution, three-dimensional subwavelength imaging, photonic crystal flat lens, 249–253
Fourier transform:
finite-difference time-domain methods:
photonic crystal line defect analysis, 142–144
transient and steady-state response, 117–118
periodic dielectric structures, Bloch’s theorem, 52–55
photonic crystal line defect analysis, single-frequency signal, 148–150
photonic-crystal slabs, line defect analysis, 147
plane-wave expansion method:
one-dimensional method, 69–72
overview, 63–65
photonic crystal slabs:
dispersive materials, 105–108
perfectly matched layers, 98–102
three-dimensional method, 84–87
two-dimensional method, 75–83
transverse-electric polarization, 77–79
reciprocal lattice structures and Brillouin zone, 47–49
strong confinement in photonic crystals:
optical spectrometer, 162–163
waveguide bends, 153–154
Fraction of energy calculations, plane-wave expansion method, perfectly matched layers, photonic crystal slabs, 102
Free-carrier injection, electrically and thermally tunable photonic crystals, 168–169
Free-space optics, photonic crystal dispersion:
self-collimation:
beam splitting, 221–224
light redirection, 214–217
superprism, negative refraction, and self-collimation, 254–259
INDEX

Frequency dependence, photonic crystal dispersion, self-collimation, beam splitting, 220–224
Frequency-selective filters, coupled photonic-crystal waveguides, 179–182
Frequency-space analysis, photonic crystal dispersion, self-collimation, 206–208
Full width at half maximum (FWHM): photonic crystal cavity design criteria, 139
three-dimensional photonic crystals: self-collimation verification, 234–239, 242–244
subwavelength imaging, photonic crystal flat lens, 250–253
GaAs membranes:
holographic photonic crystal fabrication, interference lithography, 337–341
two-dimensional photonic crystal fabrication, 268–269, 271–274
woodpile photonic crystal fabrication, 289–297
Yablonovite photonic crystal fabrication, 323–327
GaAsP slabs, photonic crystal development, 5–6
Galerkin method, plane-wave expansion method, 66
one-dimensional method, 70–72
Gaussian beam profile:
multiphoton absorption, three-dimensional photonic crystal fabrication, 353–358
self-collimating photonic crystal, light redirection, 214–217
Gaussian temporal pulse, finite-difference time-domain methods, line defect analysis, 143
Gauss’s law, electromagnetic waves:
isotropic, homogeneous media, 22–23
linear, homogeneous media, 18–21
Glancing angle deposition (GLAD), three-dimensional photonic crystal fabrication, 307–313
Group III-V transition metals:
photonic crystal development, 5–6
two-dimensional photonic crystal fabrication, 271–274
woodpile photonic crystal fabrication, 289–297
Group velocity:
homogeneous media, 37–38
periodic media, 55–57
photonic crystal dispersion, self-collimation and, 206
Guided wave electromagnetic waves, basic principles, 28–37
Heterostructure photonic crystals:
photonic crystal dispersion, self-guiding heterolattice, 211–214
strong confinement, 163–167
Hexagonal lattice, waveguide bends, 152–154
High-aspect-ratio openings, two-dimensional photonic crystal fabrication, 270–274
High-index medium:
dielectric waveguides, 32–37
photonic crystal optical networks, 170–171
photonic crystal waveguide bends, 151–154
three-dimensional photonic crystal fabrication, autocloning technique, 299–307
two-dimensional photonic crystal fabrication, 269–274
zero cross-talk waveguide crossing, 154–156
Holographic fabrication methods, three-dimensional photonic crystals, 333–349
coherent wave interference, 334–336
diffractive element methods, 342–346
interference lithography, 336–341
multiple exposure methods, 346–349
Homogeneous media:
electromagnetic waves:
group velocity, 37–38
isotropic media, 18–21
linear media, 18–21
photonic crystal dispersion, 198–201
self-collimation, 206–208
Huygens’ principle, optical electromagnetic waves, 24–25
Hybrid photonic-crystal structures, strong confinement, 163–167

Image shifting, three-dimensional photonic crystals, layer-by-layer fabrication, 280–281

InAs quantum dots, photonic crystal development, 5–6

Incident angle:
  photonic crystal dispersion:
    superprism and self-collimation, 258–259
    superprism effect, 204–205
  three-dimensional photonic crystal fabrication, autocloning technique, 298–307

Inductively coupled plasma (ICP):
  self-collimating photonic crystals, analog-to-digital converter, 228–231
  three-dimensional photonic crystal fabrication, bulk silicon sculpting, 327–333
  two-dimensional photonic crystal fabrication, 272–274
  woodpile photonic crystals, fabrication techniques, 284–297

InP substrates:
  two-dimensional photonic crystal fabrication, 271–274
  woodpile photonic crystal fabrication, 289–297

Intensity distribution:
  multiphoton absorption, three-dimensional photonic crystal fabrication, 353–358
  three-dimensional subwavelength imaging, photonic crystal flat lens, 252–253

Intentional defects, three-dimensional fabrication techniques, multiphoton absorption, 356–358

Interference lithography, holographic photonic crystal fabrication, 336–341
diffractive element methods, 342–346
Interferometric fabrication, photonic crystals, 346–349

Inverse fast Fourier transform (IFFT), three-dimensional plane-wave expansion method, 89

Irreducible Brillouin zone (IBZ):
  dispersion surfaces and band diagrams, 58–60
  photonic crystal dispersion, 200–201
  self-collimation, three-dimensional crystals, 232–239

plane-wave expansion method:
  one-dimensional method, 68–72
  photonic crystal slabs, 94–95
  three-dimensional method, 84–87, 89
  two-dimensional method, transverse-magnetic polarization, 80–83
  reciprocal lattice vectors, 48–49

Isotropic, homogeneous media:
  electromagnetic waves, 21–23
  self-collimating, three-dimensional photonic crystals, 235–239
  three-dimensional photonic crystal fabrication, bulk silicon sculpting, inductively coupled plasma, 329–333

J-couplers, photonic crystal dispersion:
  self-collimation, 208–211
  beam splitting, 219–224
  light redirection, 216–217
  superprism and self-collimation, 258–259

k-differences, holographic photonic crystal fabrication, interference lithography, 337–341

Kronecker delta function:
  plane-wave expansion method, two-dimensional method, 74–83
  reciprocal lattice structures and Brillouin zone, 48–49

Large-scale integrated photonic circuits (LSIPCs), photonic bandgap applications, 133

Laser rapid prototyping, multiphoton polymerization of three-dimensional photonic crystals, 350
INDEX

Lattice vectors, 39–47
primitive vectors, 39–44
reciprocal lattice vectors, 47–49
Launched-signal frequency, coupled photonic-crystal waveguides,
frequency-selective filters, 179–182
Layer-by-layer fabrication, three-dimensional photonic crystals, 247–281
Left-handed behavior, dispersion relation, photonic crystals, 245–253
flat lens three-dimensional subwavelength imaging, 247–253
Length scales, photonic vs. semiconductor crystals, 8
Light redirection, photonic crystal dispersion, self-collimation, 214–217
Linear, homogeneous media, electromagnetic waves, Maxwell’s equations, 18–21
Linear superposition, holographic photonic crystal fabrication, coherent wave interference, 334–336
Line defects, photonic bandgap devices and applications, 139–150
photonic-crystal slabs, 144–147
single-frequency dispersion property extraction, 147–150
waveguide branching, 140–144
finite-difference time-domain analysis, 141–144
finite-difference time-domain analysis vs. plane-wave expansion method analysis, 144
plane-wave expansion method analysis, 140–141
waveguiding photonic-crystal line defects, 140–144
Liquid crystals, electrically and thermally tunable photonic crystals, 169
Lithography techniques:
three-dimensional photonic crystals:
layer-by-layer fabrication, 276–281
macroporous silicon fabrication, 319–320
two-dimensional photonic crystal fabrication, 270–274
woodpile photonic crystals, fabrication techniques, 284–297
Low-index medium:
dielectric waveguides, 32–37
three-dimensional photonic crystal fabrication, autocloning technique, 299–307
Macroporous silicon, three-dimensional photonic micromachining, 313–323
electrophotochemical etching, 313–318
patterned porous growth, 318–320
photocurrent modulation, 320–323
Macroporous structures, three-dimensional photonic crystal fabrication, electrophotochemical etching, 315–318
Magnetic field:
photonic vs. semiconductor crystals, 8
self-collimating, three-dimensional photonic crystals, 236–239
Manhattan geometry, three-dimensional photonic crystals, layer-by-layer fabrication, 280–281
Matrix eigenvalues, photonic bandgap structural analysis, 9–11
Maxwell’s equations:
dielectric waveguides, 30–37
electromagnetic waves:
equifrequency surfaces, anisotropic materials, 25–28
isotropic, homogeneous media, 21–23
linear, homogeneous media, 18–21
finite-difference time-domain:
central-difference expressions, 109–110
three-dimensional method, 112–114
two-dimensional method, 110–112
finite-difference time-domain method, overview, 63–65
left-handed behavior and negative refraction, 245–253
periodic dielectric structures, 50–55
eigenvalue variational principle, 53–55
periodic media:
dispersion surfaces and band diagrams, 58–60
group velocity, 55–57
photonic bandgap structural analysis, 10–11
Maxwell’s equations (Continued)
photonic crystals origins, 3–6
photonic vs. semiconductor crystals, 6–8
plane-wave expansion method:
one-dimensional method, 67–72
overview, 63–65
photonic-crystal line defects analysis, 140–141
photonic crystal slab:
dispersive materials, 104–108
perfectly matched layers, 97–102
source-free equations, 65–66
three-dimensional method, 84–87
two-dimensional method, 77–83
transfer-matrix method, 64
Metallo-organic vapor-phase epitaxy
(MOVPE), two-dimensional photonic
crystal fabrication, 272–274
Microcavities:
design criteria, point defect analysis,
137–139
strong confinement in photonic crystals:
air-bridge microcavity, 157–158
channel-drop filters, 159–160
Microelectronic circuits, woodpile photonic
crystals, fabrication techniques,
285–297
Micromachining fabrication, three-
dimensional photonic crystals,
274–349
autocloning technique, 297–307
glancing angle deposition, 307–313
interference lithographic patterning,
336–341, 349
layer-by-layer fabrication, 274–281
macroporous silicon, 313–323
electro-photo-chemical etching,
313–318
patterned porous growth, 318–320
photocurrent modulation, 320–323
reactive plasma sculpting, bulk silicon,
327–333
woodpile photonic crystals, 281–297
alignment, 294–297
substrate removal, 293–294
wafer bonding, 292–293
Yablonovite for near infrared ion beam
etching, 323–327
Micron-scale photonic bandgap, origins,
3–6
Microporous structures, three-dimensional
photonic crystal fabrication,
electrophotochemical etching,
315–318
Miller’s index, photonic crystals, 45–47
Mirror offset, self-collimating photonic
crystals, reflection vs., 214–217
Misalignment detection, three-dimensional
photonic crystals, layer-by-layer
fabrication, 279–281
Modal field distribution, coupled
photonic-crystal waveguides, 177–179
Molecular-beam epitaxy (MBE):
three-dimensional photonic crystals:
layer-by-layer fabrication, 278–281
woodpile crystal fabrication, 292–297
two-dimensional photonic crystal
fabrication, 272–274
Monodisperse colloidal suspensions, self-
assembled three-dimensional photonic
crystal fabrication, 359
Monodisperse particle suspension, self-
assembled three-dimensional photonic
crystal fabrication, 359–362
polystyrene, 359–362
silica, 359
Monodisperse spheres, micron-scale
photonic bandgap, 3–6
Monopole sources, three-dimensional
subwavelength imaging, photonic
crystal flat lens, 248–253
Moore’s law, photonic crystal optical
networks, 169–171
Multichannel optical spectrometer, strong
confinement in photonic crystals, 163
Multiphoton absorption (MPA), three-
dimensional photonic crystal
fabrication, 350–358
Multiphoton polymerization, three-
dimensional photonic crystal
fabrication, 350–358
multiphoton absorption, 350–358
stereolithography/laser rapid
prototyping, 350
Multiple exposure methods, holographic
photonic crystal fabrication,
346–349
Multiple quantum well (MQW) heterostructures, woodpile crystal fabrication, wafer bonding techniques, 293–297

Mur absorbing boundary condition, finite-difference time-domain methods, 118–122

Nanophotonic circuits (NPC), photonic bandgap applications, 133

Narrow-band beam splitter, strong confinement in photonic crystals, 156–157

Near-infrared techniques:
photonic crystal dispersion, self-collimation, 210–211
three-dimensional photonic crystal fabrication, Yablonovite photonic crystals, 323–327

Negative refraction:
dispersion relation, photonic crystals, 245–253
flat lens three-dimensional subwavelength imaging, 247–253
self-collimated photonic crystals, superprism effects, 254–259

Nonlinear optical effects, multiphoton absorption, three-dimensional photonic crystal fabrication, 350–358

Nth photonic band:
dispersion surfaces and band diagrams, 58–60
waveguide bends, 153–154
n-type materials, coupled photonic-crystal waveguides, optical switches, 185–186

Numerical methods:
finite-difference time-domain method, 108–125
absorbing boundary conditions, 118–122
Maxwell’s equations central-difference equations, 109–110
numerical stability and dispersion, 114–116
photonic crystals, 122–125
Bloch boundary conditions, 122–124

finite section analysis, 124–125
three-dimensional method, 112–114
transient and steady-state system response, 116–118
two-dimensional method, 110–112

overview, 63–65
plane-wave expansion method, 65–108
basic equations, 65–66
implementation issues, 87–89
one-dimensional method, 66–72
photonic-crystal slabs, 90–108
dispersive material and band-structure calculations, 102–108
perfectly matched layers, 95–102
three-dimensional methods, 90–95
three-dimensional method, 84–87
photonic-crystal slabs, 90–95
two-dimensional method, 72–83
transverse-electric polarization, 77–79
transverse-magnetic polarization, 79–83
point defects, photonic crystals, 134–137
three-dimensional photonic crystals, self-collimation verification, 239–242

Odd modes, coupled photonic-crystal waveguides, 173–178

One-dimensional plane-wave expansion method, 66–72

One-dimensional thin films, photonic crystals origins, 1–3
One-to-three beam splitter, self-collimating photonic crystal dispersion, 222–224

Optical electromagnetic waves, 23–28
dielectric tensor and equifrequency surfaces, anisotropic materials, 25–28
reflection, refraction, and diffraction, 23–25
strong confinement in photonic crystals:
channel-drop filters, 159–160
waveguide bends, 150–154
Optical isolator, photonic bandgap applications, 189
Optical limiter, photonic bandgap applications, 189
Optical networks, photonic crystals, basic properties, 169–171
Optical path-length difference, woodpile crystal fabrication, wafer bonding techniques, 295–297
Optical signal processing:
  electrically and thermally tunable photonic crystals, 168–169
  self-collimating photonic crystal dispersion, analog-to-digital converter, 224–231
Optical spectrometer, strong confinement in photonic crystals, 160–163
Optical switching, coupled photonic-crystal waveguides, 183–186
Organometallic vapor-phase epitaxy (OMVPE), three-dimensional photonic crystals, woodpile crystal fabrication, 292–297

Packing cells, self-assembled
  three-dimensional photonic crystal fabrication, 367–368
Particle deposition, three-dimensional photonic crystal fabrication, autocloning technique, 301–307
Passive devices, woodpile photonic crystal fabrication, 289–297
Passive wavelength demultiplexing, photonic crystal dispersion, superprism effect, 205
Patterned pore growth, three-dimensional photonic crystal fabrication, macroporous silicon, 318–320
Perfect electric conductor (PEC) boundary conditions, self-collimation, three-dimensional photonic crystals, 235–239
Perfectly matched layers (PML), photonic crystal slabs:
  coupled photonic-crystal waveguides, 181–182
  frequency-selective filters, 181–182
  finite-difference time-domain methods: absorbing boundary condition, 118–122
  line defect analysis, 143–144
  plane-wave expansion method, 95–102
  point defect analysis, 136–137
  self-collimation:
    light redirection, 214–217
    three-dimensional structures, 235–239
Periodicity:
  dielectric wave equations, 49–55
  Bloch’s theorem, 51–53
eigenvalue variational principle, 53–55
finite-difference time-domain, photonic crystals, 122–124
plane-wave expansion method:
  one-dimensional method, 66–72, 68–72
  photonic crystal slabs, 93–95
  photonic crystal slabs, three-dimensional method, 91–95
three-dimensional photonic crystal fabrication, glancing angle deposition, 310–313
woodpile photonic crystals, micromachine fabrication, 282–297
Periodic media:
  basic principles, 38–39
dispersion surfaces and band diagrams, 57–60
group velocity, 55–57
photonic bandgap, 1–3
plane-wave expansion method, photonic crystal slab, dispersive materials, 104–108
real-space lattices, lattice vectors, 39–47
  Miller’s index system for crystals, 45–47
  primitive lattice vectors and cells, 39–44
two- and three-dimensional structures, 44–45
reciprocal lattice and Brillouin zone, 47–49
wave properties, 49–55
  Bloch’s theorem, 52–53
eigenvalue variational principle, 53–55
periodic dielectric structures, 49–52
Permittivity tensor, anisotropic materials, optical electromagnetic waves, 27–28
Phase distribution, three-dimensional subwavelength imaging, photonic crystal flat lens, 252–253
Phase factor, dielectric waveguides, 32–37
Photocurrent modification, three-dimensional photonic crystal fabrication, macroporous silicon, 320–323
Photonic bandgaps (PBGs):
  coupled photonic-crystal waveguides, basic principles, 171–172
devices and applications:
  antenna performance enhancement, 188
coupled-cavity waveguides, 189
line defects, 139–150
photonic-crystal slabs, 144–147
single-frequency dispersion property extraction, 147–150
waveguiding photonic-crystal line defects, 140–144
optical isolator, 189
optical limiter, 189
overview, 133–134
point defects, 134–139
  numerical analysis, 134–137
photonic-crystal cavity design criteria, 137–139
spontaneous emission applications, 188
strong confinement in PHC, 150–188
air-bridge microcavity, 157–158
channel-drop filters, photonic crystals, 159–160
coupled waveguides, 171–188
electrically and thermally tunable photonic crystals, 168–169
hybrid photonic-crystal structures, 163–168
narrow-band beam splitter, 156–157
optical networks, 169–171
optical spectrometer, 160–163
waveguide bends, 150–154
zero cross-talk waveguide crossing, 154–156
finite-difference time-domain methods, 124–125
historical overview, 3–6
photonic crystals origins, 1–3
plane-wave expansion method:
  one-dimensional method, 72
two-dimensional method, transverse-magnetic polarization, 81–83
self-collimating photonic crystals, beam splitting, 218–224
structural analysis, 8–11
three-dimensional photonic crystal fabrication, autocloning techniques and absence of, 304–307
Photonic-crystal cavities, design criteria, point defect analysis, 137–139
Photonic-crystal slabs (PCS):
development of, 5–6
dielectric waveguides, 31–37
line defect analysis, 144–147
optical networks, 169–171
plane-wave expansion methods, 90–108
dispersive material and band-structure calculations, 102–108
perfectly matched layers, 95–102
three-dimensional methods, 90–95
two-dimensional photonic crystal fabrication, 264–269
waveguide bends, 152–154
Photonic crystals (PhCs):
dispersion surfaces and band diagrams, 58–60
finite-difference time-domain, 122–125
  Bloch boundary conditions, 122–124
  finite section analysis, 124–125
historical overview, 3–6
Miller’s index, 45–47
origins, 1–3
periodicity, 25
photonic-bandgap structures, 8–11
plane-wave expansion methods:
  one-dimensional method, 66–72
two-dimensional plane-wave expansion method, 72–83
reciprocal lattice structures and Brillouin zone, 47–49
semiconductor crystal analogy, 6–8
two- and three-dimensional lattice types and structures, 44–45
Photoresist masking, holographic photonic crystal fabrication:
diffractive element methods, 342–346
interference lithography, 336–341
Physical vapor deposition (PVD),
three-dimensional photonic crystals,
glancing angle deposition, 311–313
Planar photonic crystal:
fabrication techniques, 264–269
waveguide origins, 4–6
Planck’s constant, photonic vs.
semiconductor crystals, 7–8
Plane-wave expansion method (PWEM),
65–108
basic equations, 65–66
coupled photonic-crystal waveguides,
177–178
implementation issues, 87–89
one-dimensional method, 66–72
overview, 63–65
periodic media group velocity, 55–57
photonic bandgap structural analysis,
9–11
photonic-crystal line defects, 140–141
finite-difference time-domain methods
vs., 144
photonic-crystal slabs, 90–108
dispersive material and band-structure
calculations, 102–108
line defect analysis, 144–147
perfectly matched layers, 95–102
three-dimensional methods, 90–95
point defects, photonic crystals, 134–137
three-dimensional photonic crystals,
84–87
computational costs, 87–90
photonic-crystal slabs, 90–95
self-collimation verification, 239–244
two-dimensional photonic crystals,
72–83
transverse-electric polarization, 77–79
transverse-magnetic polarization,
79–83
Point defects:
coupled-cavity waveguides, 189
optical spectrometer, 161–163
photonic crystals, 134–139
numerical analysis, 134–137
optical networks, 169–171
photonic-crystal cavity design criteria,
137–139
Point source, three-dimensional
subwavelength imaging, photonic
crystal flat lens, 252–253
Polarization:
multiphoton absorption,
three-dimensional photonic crystal
fabrication, 350–358
two-dimensional plane-wave expansion
method:
transverse-electric polarization, 77–79
transverse-magnetic polarization,
79–83
Polymers:
photonic crystal dispersion, superprism
effect, 203–205
three-dimensional photonic crystal
fabrication:
holographic techniques, 347–349
multiphoton polymerization, 350–358
multiphoton absorption, 350–358
stereolithography/laser rapid
prototyping, 350
self-assembled fabrication techniques,
359–362
Poly-methyl-methacrylate (PMMA):
self-assembled three-dimensional
photonic crystal fabrication, 367
two-dimensional photonic crystal
fabrication, 266–269, 272–274
Yablonovite photonic crystal fabrication,
325–327
Polystyrene, self-assembled
three-dimensional photonic crystal
fabrication, monodisperse particle
suspension, 359–362
Positive refraction, photonic crystal
dispersion, superprism and
self-collimation, 257–259
Potassium hydroxide (KOH):
three-dimensional photonic crystal
fabrication, electrophotochemical
etching, 321–323
woodpile photonic crystals, fabrication
techniques, 284–297
Power transfer:
coupled photonic-crystal waveguides,
171–172
INDEX

photonic crystal dispersion,
self-collimation, 210–211
three-dimensional crystals,
232–239
Poynting vector, left-handed behavior and
negative refraction, 245–253
Primitive cells:
plane-wave expansion method, photonic
crystal slabs, three-dimensional
method, 91–95
real-space lattices, 39–44
Primitive lattice vectors:
real-space lattices, 39–44
two-dimensional plane-wave expansion
method, 73–83
Printed circuit boards (PCBs), photonic
crystal optical networks,
169–171
Probability amplitude function, photonic vs.
semiconductor crystals, 7–8
Propagation constants, coupled
photonic-crystal waveguides,
177–178
Propagation loss, photonic crystal
dispersion, self-collimation, 209–211
p-type materials, coupled photonic-crystal
waveguides, optical switches,
185–186
Pulsed source, finite-difference
time-domain methods, transient and
steady-state response, 117–118
Pythagorean theorem, dielectric
waveguides, 31–37
Q factors:
photonic crystal cavity design criteria,
138–139
plane-wave expansion method, perfectly
matched layers, photonic crystal
slabs, 100–102
strong confinement in photonic crystals:
air-bridge microcavity, 157–158
narrow-band beam splitter, 156–157
Quantization, self-collimating photonic
crystal dispersion, analog-to-digital
converter, 225–231
Quantum well/quantum dot layers,
two-dimensional photonic crystal
fabrication, 272–274
Rapid active beam steering, photonic
crystal dispersion, superprism effect,
205
Reactive ion etching:
three-dimensional photonic crystals,
woodpile crystal fabrication,
wafer bonding technique,
291–297
two-dimensional photonic crystal
fabrication, 273–274
Real-space lattices, 39–47
photonic crystal dispersion,
self-collimation, 206–208
plane-wave expansion method,
two-dimensional method, 74–83
primitive cells, 39–44
Reciprocal lattice vectors (RLVs):
Fourier analysis, 47–49
plane-wave expansion method:
three-dimensional method, 84–87
two-dimensional method, 73–83
transverse-magnetic polarization,
79–83
Redeposition modeling, three-dimensional
photonic crystal fabrication,
autocloning technique, 302–307
Reflected amplitude, dielectric waveguides,
31–37
Reflection:
optical electromagnetic waves, 23–25
self-collimating photonic crystals, mirror
offset vs., 214–217
Reflection coefficient, photonic crystal
waveguide bends, 151–154
Refraction:
optical electromagnetic waves, 23–25
strong confinement in photonic crystals,
waveguide bends, 152–154
Refractive index:
strong confinement in photonic crystals,
waveguide bends, 152–154
two-dimensional photonic crystal
fabrication, 271–274
Relative permittivities, electromagnetic
waves, linear, homogeneous media,
18–21
Resonator defects, three-dimensional
photonic crystals, layer-by-layer
fabrication, 279–281
Sampling process, self-collimating photonic crystal dispersion, analog-to-digital converter, 224–231

Scalar wave equation:
- optical electromagnetic waves, equifrequency surfaces, anisotropic materials, 25–28
- periodic dielectric structures, 51–55

Scattering theory, photonic crystal waveguide bends, 151–154

Schrödinger equation:
- dispersion surfaces and band diagrams, 58–60
- photonic vs. semiconductor crystals, 6–8

Sedimentation dynamics, self-assembled three-dimensional photonic crystal fabrication, colloidal crystallization, 363–364

Seed layer substrate pattern, three-dimensional photonic crystal fabrication, glancing angle deposition, 310–313

Self-assembly techniques,
- three-dimensional photonic crystal fabrication, 358–369
- colloidal crystallization, 362–364
- electrophoretic assembly, 364–365
- monodisperse colloidal suspension, 359
- monodisperse particle suspension, 359–362
- packing cells, 366–368
- spin-annealing, 369
- template-directed colloidal epitaxy, 366
- vertical meniscus deposition/convective assembly, 365–366

Self-collimation, photonic crystal dispersion, 205–244
- beam splitting, 217–224
- experimental demonstration, 208–211
- light redirection, 214–217
- negative refraction, superprism effects, 254–259
- optical analog-to-digital converter, 224–231
- self-guiding heterolattice, 211–214
- three-dimensional photonic crystals, 231–244

Self-guiding heterolattice, photonic crystal dispersion, self-collimation, 211–214

Self-organizing photonic bandgap structures, origins of, 3–4

Semiconductor crystals:
- photonic bandgap applications, 133
- photonic crystal analogy to, 6–8
- two-dimensional photonic crystal fabrication, 270–274
- woodpile photonic crystal fabrication, 289–297
- Yablonovite photonic crystal fabrication, 324–327

Sequential oxidation, three-dimensional photonic crystal fabrication, electrophotochemical etching, 321–323

Sidewall movement, three-dimensional photonic crystal fabrication, autocloning technique, 299–307

Signal attenuation, self-collimated three-dimensional photonic crystals, 242–244

Silica, self-assembled three-dimensional photonic crystal fabrication, monodisperse particle suspension, 359

Silicon. See Macroporous silicon

Silicon nitride:
- two-dimensional photonic crystal fabrication, 272–274
- woodpile photonic crystals, fabrication techniques, 287–297

Silicon-on-insulator (SOI) planar dielectric slabs:
- photonic bandgap applications, 133
- photonic crystal dispersion, self-collimation, 208–211
- analog-to-digital converter, 228–231
- beam splitting, 221–224
- light redirection, 216–217
- self-guiding heterolattice, 212–214
- two-dimensional photonic crystal fabrication, 266–269

Simple cubic (SC) lattices:
- first Brillouin zone, 48–49
- photonic crystals, 44–46
INDEX 401

three-dimensional plane-wave expansion
method, 87–89
three-dimensional self-collimated
photonic crystals, 232–239
Single-channel optical spectrometer, strong
confinement in photonic crystals,
161–163
Single-frequency signal, photonic-crystal
line defects, 147–150
65-nm technology, two-dimensional
photonic crystal fabrication,
265–269
Slab effective index, photonic-crystal slabs,
dispersive material calculations,
102–108
Smoothed dielectric constant, plane-wave
expansion method, perfectly
matched layers, photonic crystal slabs,
97–102
Snell's law of reflection and refraction:
left-handed behavior and negative
refraction, 246–253
optical electromagnetic waves, 23–25
superprism effect, photonic crystal
dispersion, 201–205
Space-charge region (SCR),
three-dimensional photonic crystal
fabrication, electrophotocatalytic
etching, 315–318, 320–323
Spatial field distribution, three-dimensional
subwavelength imaging, photonic
crystal flat lens, 248–253
Spatial-frequency distribution:
homogeneous media, group velocity,
37–38
photonic-crystal line defects,
single-frequency signal,
147–150
Spin-annealing, self-assembled
three-dimensional photonic crystal
fabrication, 369
Spiral rod structures, three-dimensional
photonic crystal fabrication, glancing
angle deposition, 309–313
Splitting techniques:
coupled photonic-crystal waveguides,
186–188
photonic crystal dispersion, superprism
effect, 202–205
Spontaneous emission, photonic bandgap
control of, 188
Sputtering techniques:
three-dimensional photonic crystal
fabrication, autocloning technique,
297–307
three-dimensional photonic crystals,
layer-by-layer fabrication,
277–281
Squared intensity, multiphoton absorption,
three-dimensional photonic crystal
fabrication, 354–358
Square lattices:
heterostructure photonic crystals,
164–167
holographic photonic crystal fabrication,
interference lithography,
337–341
photonic crystal dispersion, 198–201
superprism, negative refraction, and
self-collimation, 254–259
photonic crystal waveguide bends,
151–154
primitive vectors and cells, 39–44
self-collimating photonic crystals,
analog-to-digital converter,
227–231
two-dimensional plane-wave expansion
method, 72–83
transverse-magnetic polarization,
80–83
Stability condition, finite-difference
time-domain methods,
114–116
Standing wave phenomenon, holographic
photonic crystal fabrication, coherent
wave interference, 334–336
Steady-state response:
finite-difference time-domain methods,
116–118
narrow-band beam splitter, 156–157
photonic crystal dispersion,
self-collimation, 208–211
light redirection, 215–217
Stereolithography, multiphoton
polymerization of three-dimensional
photonic crystals, 350
Stop band, dispersion surfaces and band
diagrams, 60
Strong confinement in PHC:
- devices and applications, 150–188
- air-bridge microcavity, 157–158
- channel-drop filters, photonic crystals, 159–160
- coupled waveguides, 171–188
- electrically and thermally tunable photonic crystals, 168–169
- hybride photonic-crystal structures, 163–168
- narrow-band beam splitter, 156–157
- optical networks, 169–171
- optical spectrometer, 160–163
- waveguide bends, 150–154
- zero cross-talk waveguide crossing, 154–156
- two-dimensional photonic crystal fabrication, 266–269, 271–274

Substrate index, waveguide bends, 153–154

Substrate properties:
- three-dimensional photonic crystal fabrication, glancing angle deposition, 307–313
- two-dimensional photonic crystal fabrication, 266–269
- woodpile crystal fabrication, wafer bonding techniques, 293–297
- Yablonovite photonic crystal fabrication, 325–327

Summation index, plane-wave expansion method, one-dimensional method, 70–72

Supercell construction:
- coupled photonic-crystal waveguides, 175–178
- line defect analysis, plane-wave expansion method, 140–141
- point defect analysis, plane-wave expansion method, 135–137

Superprism effect, photonic crystal:
- development process, 5–6
- dispersion, 201–205
- negative refraction, 254–259

Tangent function, dielectric waveguides, 34–37

Taylor expansion:
- finite-difference time-domain,
  central-difference expressions, Maxwell’s equations, 109–110
- homogeneous media, group velocity, 37–38

Template-directed assembly, self-assembled three-dimensional photonic crystal fabrication, 367

Testing functions, plane-wave expansion method, 66
- two-dimensional method, transverse-electric polarization, 78–79

Thermal expansion coefficients, woodpile crystal fabrication, wafer bonding techniques, 293–297

Thermally tunable photonic crystals, strong confinement, 167–169

Three-dimensional finite-difference time-domain, 112–114

Three-dimensional photonic crystals:
- development, 4–6
- fabrication techniques:
  - holographic fabrication methods, 333–349
  - coherent wave interference, 334–336
  - diffractive element methods, 342–346
  - interference lithography, 336–341
  - multiple exposure methods, 346–349
  - micromachining, 274–291
  - autocloning technique, 274–291
  - glancing angle deposition, 307–313
  - interference lithographic patterning, 336–341, 349
  - layer-by-layer fabrication, 274–281
  - macroporous silicon, 313–323
  - electro-photo-chemical etching, 313–318
  - patterned porous growth, 318–320
  - photocurrent modulation, 320–323
  - reactive plasma sculpting, bulk silicon, 327–333
woodpile photonic crystals, 281–297
alignment, 294–297
substrate removal, 293–294
wafer bonding, 292–293
Yablonovite for near infrared ion beam etching, 323–327
multiphoton polymerization, 350–358
multiphoton absorption, 350–358
stereolithography/laser rapid prototyping, 350
self-assembly, 358–369
colloidal crystallization, 362–364
electrophoretic assembly, 364–365
monodisperse colloidal suspension, 359
monodisperse particle suspension, 359–362
packing cells, 366–368
spin-annealing, 369
template-directed colloidal epitaxy, 366
vertical meniscus deposition/convective assembly, 365–366
lattice types and, 44–45
self-collimation in, 231–239
Three-dimensional plane-wave expansion method, 84–87
dispersive material calculations, 102–108
photonic-crystal slabs, 90–95
Three-dimensional subwavelength imaging, photonic crystal flat lens, 247–253
Time-multiplexed reactive ion etch (TM-RIE), three-dimensional photonic crystal fabrication, bulk silicon sculpting, inductively coupled plasma, 329–333
Time-variable optical signal, self-collimating photonic crystals, analog-to-digital converter, 227–231
Total field distribution, self-collimating, three-dimensional photonic crystals, 236–239
Total internal reflection (TIR): dielectric waveguides, 29
optical electromagnetic waves, 24–25
photonic crystal slabs: line defect analysis, 145–147
plane-wave expansion methods, 90–108
two-dimensional photonic crystal fabrication, 266–269
Transfer-matrix method, overview, 63–65
Transient response, finite-difference time-domain methods, 116–118
Transmission spectrum: coupled photonic-crystal waveguides, frequency-selective filters, 180–182
heterostructure photonic crystals, 164–167
optical electromagnetic waves, 23–25
strong confinement in photonic crystals: air-bridge microcavity, 158
waveguide bends, 153–154
Transverse-electric (TE) mode: dielectric waveguides, 31–37
electrically and thermally tunable photonic crystal, 169
finite-difference time-domain: line defect analysis, 143–144
two-dimensional method, 111–112
photonic crystal dispersion, self-collimation, 211–214
plane-wave expansion method: perfectly matched layers, photonic crystal slabs, 99–102
photonic crystal slabs, 92–95, 104–108
point defect analysis, 137
two-dimensional method, 77–83
strong confinement in photonic crystals, waveguide bends, 153–154
Transverse-magnetic (TM) mode: electrically and thermally tunable photonic crystal, 169
finite-difference time-domain: line defect analysis, 143–144
two-dimensional method, 111–112
plane-wave expansion method: perfectly matched layers, photonic crystal slabs, 99–102
photonic crystal slabs, 92–95, 104–108
point defect analysis, supercell construction, 135–137
two-dimensional method, 77–83
Triangular lattice:
electrically and thermally tunable
photonic crystals, 169
heterostructure photonic crystals,
164–167
photonic crystal dispersion, 198–201
self-collimation, beam splitting,
221–224
two-dimensional plane-wave expansion
method, 72–83
Trigonal (rhombohedral) lattice,
holographic photonic crystal
fabrication, 342–346
Two-dimensional fast Fourier transform,
plane-wave expansion method,
photonic crystal slabs, dispersive
materials, 105–108
Two-dimensional finite-difference
time-domain method, 110–112
photonic crystal waveguide bends,
152–154
Two-dimensional lattice structure:
photonic crystals, 44–45
square lattices, 39–44
Two-dimensional periodicity:
dispersion surfaces and band diagrams,
58–60
planar-based photonic crystal waveguide,
4–6
Two-dimensional photonic crystals:
cavity design criteria, 139
fabrication techniques, 263–274
basic techniques, 269–274
planar photonic crystals, 266–269
line defect analysis, 144–147
Two-dimensional plane-wave expansion
method (PWEM), 72–83
transverse-electric polarization, 77–79
transverse-magnetic polarization, 79–83
Uniaxial perfectly matched layer (UPML),
finite-difference time-domain
methods, absorbing boundary
condition, 119–122
Unit cell:
plane-wave expansion method:
perfectly matched layers, photonic
crystal slabs, 96–102
two-dimensional method, 75–83
real-space lattices, 39
woodpile photonic crystals, fabrication
techniques, 283–297
Valence band, photonic crystal dispersion,
self-collimation, 211–214
Variational principle, periodic dielectric
structures, eigenvalue problem,
53–55
Vector-wave calculations:
holographic photonic crystal fabrication,
coherent wave interference,
334–336
photonic vs. semiconductor crystals, 8
Vertical meniscus deposition,
self-assembled three-dimensional
photonic crystal fabrication, 365–366
Wafer bonding, woodpile photonic crystal
fabrication, 290–297
Wave equation:
left-handed behavior and negative
refraction, 245–253
periodic dielectric structures, 49–55
Bloch’s theorem proof, 52–53
Waveguide crossing, zero cross-talk,
154–156
Waveguides:
coupled photonic-crystal waveguides,
171–188
applications, 178–188
frequency-selective filter, 179–182
optical switch, 183–186
splitters, 186–188
theoretical background, 172–178
photonic crystal line defects, 140–144
finite-difference time-domain analysis,
141–144
finite-difference time-domain analysis
vs. plane-wave expansion method
analysis, 144
plane-wave expansion method
analysis, 140–141
photonic crystals, branching
development, 4–6
strong confinement in photonic crystals:
channel-drop filters, 159–160
optical spectrometer, 161–163
waveguide bends, 150–154
three-dimensional photonic crystals, layer-by-layer fabrication, 279–281
Wavelength-division multiplexing (WDM)/demultiplexing (WDD) systems, optical spectrometer, strong confinement in photonic crystals, 160–163
Wavelength sensitivity: coupled photonic-crystal waveguides, frequency-selective filters, 180–182
photonic crystal dispersion, superprism effect, 202–205
Weight functions, plane-wave expansion method, 66
Wide wavelength division multiplexing (WWDM), coupled photonic-crystal waveguides, frequency-selective filters, 182
Wigner–Seitz cell: conventional primitive cell vs., 43–44
photonic crystal lattices, 44–45
reciprocal lattice structures and Brillouin zone, 48–49
Woodpile photonic crystal structure: dispersion materials, superprism effect, 204–205
photonic bandgap, 3–6
two-dimensional methods, 111–112
Yee’s leapfrog scheme, finite-difference time-domain methods:
Bloch boundary conditions, 122–124
line defect analysis, 143–144
three-dimensional methods, 114
two-dimensional methods, 111–112
Zero cross-talk waveguide crossing, strong confinement in photonic crystals, 154–156
Zincblende lattice, photonic crystals, 46
three-dimensional fabrication techniques, 281–297
alignment, 294–297
multiphoton absorption, 356–358
substrate removal, 293–294
wafer bonding, 292–293
Yablonovite structures: holographic photonic crystal fabrication, 347–349
three-dimensional photonic crystal fabrication:
electrophotochemical etching, 322–323
near infrared chemically assisted ion beam etching, 323–327