

## Index

### a

- acoustic waves, definition 184
  - in homogeneous fluid materials 187–188
- acoustic–optical devices 264–268
- air cylinders, photonic band gap 160–161
- air spheres, structures made of 240–242
- all-angle negative refraction, definition 270
- arbitrary unit cells 25

### b

- backfilling 133–134
- band diagrams
  - in three dimensions 168–170
  - in two dimensions 157–160
  - of photonic crystals 147
  - structures for localization of light 260–261
- band gap
  - phononic *see* complete phononic band gap
  - photonic *see* complete photonic band gap
- beam configuration, periodic structure
  - fabrication 119–121
- beam direction, preserving 128–130
- beam parameters, periodic structure
  - fabrication
    - three-dimensional 107–109
    - two-dimensional 102–103
- beam splitter, polarizing 119
- bicontinuous structures 93
- binary composite structures 272
- Bloch wave
  - definition 147–148
  - elastic 194
- body-centered-cubic lattice 51–59
  - Bravais 242
  - primitive vectors 165

- body-centered-cubic photonic crystals 173–176
- body-centered unit cells, definition 14
- Bravais lattices
  - body-centered-cubic 242
  - cubic 165
  - definition 12–14
- Brillouin zones
  - definition 155
  - in three dimensions 164–167
  - in two dimensions 152–157
  - irreducible 156, 167
- bulk modulus, cubic crystals 237–238

### c

- CAR *see* chemically amplified resists
- cellular solids
  - closed-cell 216
  - definition 215–216
  - fabrication 249–250
  - open-cell 216
  - periodic *see* periodic cellular solids
- channel, defect 262–263
- characteristic distance, between atoms 184
- chemical modification, photoresist materials 89–91, 122
- chemically amplified resists (CAR) 124
- circularly polarized waves
  - definition 72
  - plane waves 74–75
- closed-cell cellular solids 216
- CO<sub>2</sub>, supercritical drying 133
- collinearity, and interference 83
- complete band gaps
  - in photonic–phononic crystals 264–267
  - phononic 201, 204–206
  - three-dimensional 209–210

- photonic
    - alternative definitions 159
    - localization of light 260
    - three-dimensional 163, 169
    - two-dimensional 158
    - wave guiding 264
  - compliance
    - definition 219
    - *see also* elastic constants
  - composite structures, binary 272
  - constitutive parameters, Maxwell's equations 66
  - contrast, definition 131–132
  - conventional unit cells 12
    - definition 15
  - crystal systems, definition 13–14
  - crystals
    - cubic *see* cubic crystals
    - phononic *see* phononic crystals
    - photonic *see* photonic crystals
  - cubic Bravais lattices, primitive vectors 165
  - cubic crystals
    - elastic constants 232–238
    - photonic
      - body-centered 173–176
      - face-centered 172–173
      - simple 172
  - cubic lattices
    - body-centered 51–59
    - Bravais 165
    - face-centered 47–51
    - simple 44–46
  - cubic periodic structures, mechanical properties 244
  - cylinders, photonic, elastic 189
- d**
- Darcy's law 274
  - defect channel, in photonic crystals 262–263
  - defects, structural 267
  - deformation
    - as strain plus rotation 227–228
    - definition 221–222
    - general 226–228
  - deformation tensor, definition 224
  - density, as a material parameter 187
  - developing of photoresist materials
    - definition 89
    - structure obtaining 93
  - diamond structure, definition 168–169
  - diazonaphthoquinone (DNQ) 126–127
  - dielectric constant, Maxwell's equations 66
  - dielectric-constants ratio, photonic band gaps 169–170
  - direct structure
    - definition 34–35
    - three-dimensional 45
  - dispersion relation
    - definition 147
    - in two dimensions 157–159, 199
    - solid–fluid phononic crystals 203
    - solid–solid phononic crystals 195–197
  - displacement vectors
    - definition 222–223
    - transverse elastic plane waves 186
  - distance, characteristic 184
  - DNQ *see* diazonaphthoquinone
  - drying, photoresists 132–133
- e**
- elastic constants, cubic crystals 232–238
  - elastic cylinders 189
  - elastic layers 189, 191
  - elastic mechanical properties, linear 243–247
  - elastic spheres 189
  - elastic wave equations 186
  - elastic wave velocity, as a material parameter 187
  - elastic waves
    - Bloch 194
    - definition 184
    - forbidden propagation 198
    - in homogeneous solid materials 184–187
  - electric field vector, definition 64
  - electric permittivity *see* dielectric constant
  - electricity transport, maximum 272–273
  - electromagnetic (plane) waves 68–69
    - basic description 64–65
    - electromagnetic energy 76–81
    - energy density 77
    - energy flux 77
    - forbidden propagation 162
    - in-plane 157
    - intensity 80–81
    - interference 81–89
    - out-of-plane 200
    - phase properties 72
    - polarization 69–75
    - propagation in photonic crystals
      - three-dimensional 168–170
      - two-dimensional 157–160
    - superposition 83
    - time-averaged values 77–80
    - transverse character 69–72
    - wave equation 65–68

- electromagnetic spectrum, classification 65  
 elliptical polarization, electromagnetic plane waves 75  
 emission of light, spontaneous 256–259  
 energy  
 – electromagnetic 76–81  
 – per unit area per unit time 78–80  
 energy conservation law 76  
 energy density  
 – electromagnetic (plane) waves 77  
 – instantaneous 76  
 – time-averaged 78  
 energy flux, electromagnetic plane waves 77  
 expansion, periodic cellular solids 225
- f**
- F-RD structure 242–243  
 – inverse 247–248  
 face-centered-cubic lattice 47–51  
 – Bravais 242  
 – primitive vectors 165  
 face-centered unit cells, definition 14  
 figure of merit, efficiency of thermoelectric materials 277  
 finite element program, to calculate linear elastic mechanical properties 243  
 finite periodic structures 143–146  
 – phononic crystals 190–194  
 – versus infinite 150–151  
 fluid materials, acoustic waves 187–188  
 fluid permeability, definition 274  
 fluid–fluid phononic crystals 207  
 foaming, nonperiodic cellular solids 217  
 forbidden propagation  
 – elastic waves 198, 201  
 – electromagnetic waves 162  
 four-beam interference 116–117  
 four-beam technique  
 – periodic structure fabrication 119–120  
 – prism configuration 130–131  
 Fourier coefficients  
 – calculation of 21–23  
 – definition 21  
 – relative weight 33  
 Fourier series 20–26  
 – and interference 98–99  
 – for three-dimensional periodic functions 23–25  
 – for two-dimensional periodic functions 20–23  
 Fourier series expansion 98  
 – definition 21  
 – three-dimensional 42–43  
 – to create periodic structures 29–61  
 frequency, definition 64  
 frequency ranges, in photonic crystals 146, 148  
 fringe-to-fringe spacing, definition 86
- g**
- gamma point, Brillouin zone 156  
 generalized Hooke's law  
 – definition 219  
 – matrix notation 230–232  
 – stress–strain relationship 229  
 geometry of the periodic structure 169–170  
 gold spheres, phononic crystal 208–209  
 guiding mechanisms, in photonic crystals 262–264
- h**
- half-wave plate, polarization 120  
 heat transport, maximum 272–273  
 holographic interference lithography *see* interference lithography  
 homogeneity, material parameter 66  
 homogeneous materials  
 – fluid 187–188  
 – solid 184–187  
 – wave vector 147  
 Hooke's law  
 – generalized *see* generalized Hooke's law  
 – one-dimensional 218–219
- i**
- I-WP structure 242  
 – negative refraction 271  
 in-plane waves  
 – definition 200  
 – electromagnetic 157  
 incident light beam, TE and TM components 129–130  
 infinite periodic structures 147–149, 194–198  
 – three-dimensional 5  
 – versus finite 150–151  
 inks, polyelectrolyte 239  
 intensity, definition 80–81  
 intensity distribution  
 – and interference parameters 94  
 – spatial 88–89  
 interference  
 – and Fourier series 98–99  
 – definition 83  
 – electromagnetic plane waves 81–89

- interference lithography 89–94
  - and periodic structures 97–110
  - backfilling 133–134
  - contrast 131–132
  - fabrication technique 239
  - obtaining structure by 92–94
  - practical considerations 128–135
  - simple cubic cellular solid fabrication 249–250
  - technique 92–93
  - three-dimensional periodic structures 104–110
  - two-dimensional periodic structures 100–104
  - volume fraction control 134–135
- interference parameters, and intensity distribution 94
- interference patterns
  - definition 86
  - three-dimensional 86–89
- interference terms 98
- inverse structures
  - creation of 133–134
  - definition 34–35
  - three-dimensional 45
- irradiance *see* intensity
- irreducible Brillouin zone
  - definition 156
  - three-dimensional 167
- isotropic solid material, mechanical properties 244
- isotropy, material parameter 66
  
- k**
- Kelvin (Thomson) relations 277
  
- l**
- Lame coefficients
  - fluid material 188
  - homogeneous solid material 187
- laser beams 115, 123, 135
  - four-beam technique 131
  - interference lithography 97
  - negative refraction 270
  - *see also* light beams
- lattice constants
  - three-dimensional 12
  - two-dimensional 8
- layers, elastic 189, 191
- lenses, photonic crystals 269
- level-set structures 240–242
  - negative refraction 271
- light
  - localization of 259
  - simultaneous localization with sound 264–268
  - spontaneous emission of 256
- light beams
  - periodic structure fabrication 116–118
  - *see also* laser beams
  - TE and TM components 129–130
- linear elastic mechanical properties 243–247
  - calculated with finite element program 243
  - periodic cellular solids 243–247
- linear polarization, basics 73–75
- linearity, material parameter 66
- linearly polarized waves
  - definition 72
  - plane waves 73–74
- liquid CO<sub>2</sub>, supercritical drying 133
- lithography
  - interference *see* interference lithography
  - phase mask 120–121
  - road map 123
  - two-photon 239
- localization of light
  - and sound 264–268
  - definition 259
  - microcavities and waveguides 259–264
  - spatial 261
- longitudinal plane wave 184–185
  
- m**
- magnetic field vector, definition 64
- magnetic permeability, Maxwell's equations 66
- maximum transport of heat and electricity 272–273
- Maxwell's equations 65–66
  - curl 76
- mechanical waves, propagation 184–187
- methacrylate polymers (PMMA) 127
- microcavities 259–264
- microchips, optical 264
- microfluidics 273–275
- microframes, plastic deformation 250–252
- monochromatic waves, definition 69
- monomeric systems, negative photoresists 123
- multifunctional periodic structures 272–273
- multiple gratings, and the registration challenge 118

- n**
- negative photoresists 124–125
    - definition 92
    - monomeric systems 123
    - oligomeric systems 124
  - negative refraction
    - and superlenses 268–272
    - definition 268–269
  - noncollinearity, as prerequisite for interference 83, 86
  - nonconductivity, material parameter 66
  - noncoplanarity, and interference 86
  - nondimensional frequency
    - phononic crystals 192–193
    - photonic crystals 145
  - nondispersivity, material parameter 66
  - nonhomogenous material, wave vector 147
  - nonperiodic cellular solids, definition 216
  - nonperiodic structures, versus periodic structures 4–6
  - nonperpendicularity, as prerequisite for interference 83
  - nonprimitive unit cells 14–16
    - definition 15
  - normal stress, definition 220
  - Novolac resin 126–127
  - numerical techniques, plane-wave method 148
- o**
- oligomeric systems, negative photoresists 124
  - omnidirectional reflection, definition 150
  - one-dimensional Hooke’s law 218–219
  - one-dimensional phononic crystals 190–198
    - solid–solid 195–197
  - one-dimensional photonic crystals 143–151
  - open-cell cellular solids, definition 216
  - optical microcavity 262
  - optical microchips 264
  - optical resonators 262
  - organic–inorganic hybrids photoresists 128
  - out-of-plane waves, definition 200
- p**
- P structures 249
  - PAG *see* photoacid generator
  - parameter *d*
    - periodic functions in three dimensions 43
    - square lattice 31–33
    - triangular lattice 39
  - pattern transfer, periodic structure fabrication 122–128
  - Peltier effect 275–276
  - periodic cellular solids 215–252
    - body-centered-cubic Bravais lattice 242
    - definition 216
    - expansion 225
    - face-centered-cubic Bravais lattice 242
    - general deformation 226–228
    - linear elastic mechanical properties 243–247
    - simple cubic 249–250
    - strain tensor 221–228
    - stress tensor 219–221
    - topological design 238–243
    - twelve-connected stretch-dominated 247–249
  - periodic functions
    - and structures 29–61
    - combination 59–61
    - simple 33–38, 40–41
    - three-dimensional 23–25, 41–59
    - two-dimensional 20–23, 31–41
  - periodic structure fabrication 115–135
    - beam configuration 119–121
    - beam parameters 102–103, 107–109
    - four-beam technique 119–120
    - interference lithography 97–110
    - light beams 116–118
    - material platforms 122–128
    - multiple gratings 118
    - pattern transfer 122–128
    - photoresists 122–128
    - prism configuration 130–131
  - periodic structures
    - creation of 133–134
    - design of 93–94
    - finite *see* finite periodic structures
    - further applications 255–278
    - infinite *see* infinite periodic structures
    - level-set 240–242
    - light-emission control 256–259
    - mathematical description 16–20
    - microfluidics 273–275
    - multifunctional 272–273
    - phononic band gaps 205–207
    - photonic band gaps 160–162, 170–176
    - thermoelectric energy 275–278
    - three-dimensional 5, 104–110
    - two-dimensional 100–104, 205–207
    - versus nonperiodic structures 4–6
    - wave vector prerequisites 99–103
    - waveguides 259–264

- periodicity, spatial 7
- permeability, fluid 274
- perpendicularity, and interference 83
- phase control 118
- phase mask lithography 120–121
- phononic band gaps
  - complete 201
  - definition 193
  - origin 189
  - solid–solid 196–197
  - two-dimensional 205–207
- phononic crystals 183–210
  - definition 188–190
  - examples 189
  - finite periodic structures 190–194
  - infinite periodic structures 194–198
  - one-dimensional 190–198
  - solid cylinders 202–205
  - solid spheres 208–210
  - solid–fluid 198–207
  - solid–solid 194–198
  - solid–vacuum 199–200
  - three-dimensional 207–210
  - two-dimensional 198–207
  - vacuum cylinders 198–202
- PHOST *see* polyhydroxystyrene
- photoacid generator (PAG) 124
- photonic band gap maps
  - as a function of the volume fraction 170
  - definition 160
  - for simple periodic structures 172–175
- photonic band gaps 142
  - calculation of 148–149
  - complete 158–159
  - definition 146
  - three-dimensional 168–176
  - two-dimensional 157–162
- photonic crystals 141–175
  - as lenses 269
  - band diagram 147
  - body-centered 173–176
  - cubic 172
  - definition 142
  - face-centered cubic 172–173
  - frequency ranges 146
  - guiding mechanisms 262–264
  - one-dimensional 143–151
  - three-dimensional 162–176
  - two-dimensional 151–162
- photonic–phononic crystals
  - complete band gaps 264–267
  - simultaneous localization of light and sound 264–268
  - structural defects 267
- photoresists 89–92
  - chemical modification 89–91
  - definition 122
  - developing 89
  - drying 132–133
  - negative 124–125
  - negative and positive, definition 92
  - organic–inorganic hybrids 128
  - periodic structure fabrication 122–128
  - shrinkage 133
  - wave vectors in 128–129
  - work done on 90
- photosensitizers 124
- plane-wave method, numerical technique 148
- plane waves, electromagnetic 68–69
- plastic deformation, of microframes 250–252
- point lattices
  - primitive and nonprimitive unit cells 14–16
  - three-dimensional 10–16
  - two-dimensional 6–10
  - types 9
- Poisson's ratio
  - cubic crystals 233–235
  - definition 234
- polarization
  - electromagnetic plane waves 69–75
  - elliptical 75
  - linear 73–75
  - preserving of 128–131
- polarizing beam splitter 119
- polyelectrolyte inks 239
- polyhydroxystyrene (PHOST) polymers 127
- positive photoresists 126–127
  - definition 92
- positive refraction, definition 268
- Poynting vector, instantaneous 76
- primitive unit cells 14–16
- primitive vectors
  - cubic Bravais lattices 165
  - three-dimensional 12
  - two-dimensional 8
- prism configuration, periodic structure fabrication 130–131
- r**
- reciprocal lattice vectors 153
  - definition 25

- reciprocal lattices
  - in three dimensions 164–167
  - in two dimensions 152–157
- reflectance 144–145
  - as a function of the nondimensional frequency 145, 192–193
- reflection, omnidirectional 150
- refraction
  - in photoresist 129
  - negative 268–272
    - all-angle 270
    - definition 268–269
- registration challenge 118
- rod-connected model 240–242
- rotation tensor, definition 224
  
- S**
- scaling, in periodic structures 145
- Seebeck effect 277–278
- shear modulus, cubic crystals 235–237
- shrinkage, photoresists 133
- side-centered unit cells, definition 14
- silicon, as background material 208–210
- simple cubic lattice, primitive vectors 165
- simple periodic functions
  - combinations 59–61
  - square lattice 33–38
  - three-dimensional 41–59
    - body-centered-cubic lattice 51–55
    - face-centered-cubic lattice 47–49
    - simple cubic lattice 44
    - triangular lattice 40–41
- simple periodic structures, photonic band gap maps 172–175
- simultaneous localization of light and sound 264–268
- single beam technique, periodic structure fabrication 120–121
- solid cylinders, in air 202–205
- solid materials, elastic waves 184–187
- solid spheres
  - in solid background material 208–210
  - structures made of 240–242
- solid–fluid phononic crystals 198–207
  - dispersion relation 203
- solid–solid phononic crystals 194–198, 207
  - dispersion relation 195–197
- solid–vacuum phononic crystals 199–200, 205–207
- solids, periodic cellular *see* periodic cellular solids
- sound, simultaneous localization with light 264–268
- spacing, fringe-to-fringe 86, 88
- spatial period
  - in three dimensions 42
  - square lattice 31
  - triangular lattice 39
- spatial periodicity, definition 7
- spheres
  - elastic 189
  - solid *see* solid spheres
- spontaneous emission of light
  - controlling 256–259
  - definition 256
- square lattice 31–38
  - primitive vectors 154
- stiffness constant, definition 219, 234
- strain, definition 218
- strain tensor
  - definition 224
  - periodic cellular solids 221–228
- stress, definition 218
- stress tensor
  - periodic cellular solids 219–221
  - symmetry 221
- stress–strain relationship
  - definition 222
  - generalized Hooke’s law 229
  - *see also* Young’s modulus
- stretch-dominated periodic cellular solids 247–249
- structural defects
  - and localization of light 261
  - photonic–phononic crystals 267
- structural periodicity 3–25
  - nonperiodic versus periodic structures 4–6
- structures
  - bicontinuous 93
  - binary composite 272
  - cubic periodic 244
  - diamond 168–169
  - direct *see* direct structure
  - F-RD 242–243, 247–248
  - finite periodic *see* finite periodic structures
  - geometry of periodic 169–170
  - I-WP 242, 271
  - infinite periodic *see* infinite periodic structures
  - inverse 34–35, 45
  - level-set 240–242, 271

- multifunctional periodic 272–273
  - nonperiodic versus periodic structures 4–6
  - obtained by interference lithography 92–94
  - P 241, 249
  - periodic *see* periodic structures
  - simple periodic 172–175
  - three-dimensional 5, 104–110
  - two-dimensional 100–104
  - SU-8 microframes 250–252
  - SU-8 photoresist 124–125
  - supercritical drying 133
  - superlenses, and negative refraction 268–272
  - superposition
    - definition 83
    - of two or more waves 86
- t**
- TE and TM waves
    - in two-dimensional photonic crystals 151–152
    - photonic band gap 158–159
    - *see also* transverse electric/magnetic
  - tensile stress, definition 218
  - thermoelectric energy, periodic structures 275–278
  - Thomson effect 276
  - three-dimensional band diagrams 168–170
  - three-dimensional Brillouin zones 164
  - three-dimensional fluid–fluid phononic crystals 207
  - three-dimensional interference patterns 86–89
  - three-dimensional periodic functions
    - creation 41–59
    - Fourier series 23–25
  - three-dimensional phononic crystals 207–210
    - gold spheres 208–209
  - three-dimensional photonic crystals 162–176
  - three-dimensional point lattices 10–16
  - three-dimensional solid–fluid phononic crystals 207
  - three-dimensional solid–solid phononic crystals 207
  - three-dimensional structures
    - infinite periodic 5
    - nonperiodic 5
    - periodic, via interference lithography 104–110
  - time-averaged values, electromagnetic waves 77–80
  - TM *see* transverse electric/magnetic
  - topological design, periodic cellular solids 238–243
  - topology optimization, definition 272
  - traction vectors, definition 219–220
  - translation in space, definition 221
  - transport of heat and electricity, maximum 272–273
  - transverse character, electromagnetic plane waves 69–72
  - transverse electric/magnetic (TE/TM) components
    - incident light beam 129–130
    - *see also* TE and TM waves
  - transverse plane wave, mechanical 184–185
  - transverse waves, definition 69
  - triangular lattice, primitive vectors 154
  - triaryl sulfonium salt 125
  - tubular P structures 241, 249
  - twelve-connected stretch-dominated periodic cellular solids 247–249
  - two-dimensional periodic functions
    - creation 31–41
    - Fourier series 20–23
  - two-dimensional periodic structures, via interference lithography 100–104
  - two-dimensional phononic crystals 198–207
  - two-dimensional photonic crystals 151–162
    - Brillouin Zones 152–157
    - dispersion relation 157–158
    - reciprocal lattices 152–157
    - TE and TM waves 151–152
  - two-dimensional point lattices 6–10
    - types 9
  - two-photon lithography 239
- u**
- umbrella configuration 120
  - unit cells
    - arbitrary 25
    - conventional 12
    - primitive and nonprimitive 14–16
    - three-dimensional 11, 46
    - two-dimensional 8
- v**
- vacuum cylinders, in a solid background 198–202
  - velocity, of longitudinal and transverse elastic plane wave 187

- volume fraction
  - and linear elastic mechanical properties 243–247
  - control of 134–135
  - definition 35
  - photonic band gaps 169–170
- w**
- wave equation 65–68
  - definition 67
- wave vectors
  - for three-dimensional periodic structures 105–109
  - for two-dimensional periodic structures 99–103
  - in photoresist 128–129
- interference in three dimensions 88
- of homogeneous/ nonhomogenous material 147
- waveguides 259–264
  - in photonic crystals 262–263
- wavelength
  - definition 64
  - mechanical waves 184
- work, done on photoresist material 90
- y**
- Young's modulus
  - cubic crystals 233–235
  - definition 234
  - *see also* stress–strain relationship