

Index

- Abbe criterion, 357
- absorption, 7, 14, 16, 27, 35, 41–43, 67, 75–77, 81, 82, 84, 85, 106, 125, 126, 156, 175, 176, 178, 181, 183–185, 187, 190, 191, 194, 210, 223, 225, 236, 239, 240, 254, 273, 274, 277, 284, 286, 303, 323–331, 334, 335, 337, 338, 353, 370, 381, 382
 - absorbed power, 42, 43
 - absorption coefficient, 53, 322, 335
 - absorption cross-section, 42, 43, 75, 118, 191, 194, 274, 330
 - absorption depth, 321–323, 333, 334, 338
 - absorption enhancement, 323–325, 328–332, 382
 - absorption spectrum, 76, 178, 179, 185, 193, 203, 204, 207, 209, 242, 307, 337, 341
 - extraordinary optical absorption (EOA), 322, 325
 - multiphoton absorption, 225
 - surface-enhanced infrared absorption (SEIRA), 75, 76, 148, 187, 340
 - two-photon absorption, 126, 195, 242
- accepted power, 17, 46
- active element, 117, 262
- active nanoantenna (ANA), 49, 50, 57, 58, 60–63
- adaptive optimization, 148, 152
- angular directivity, 87, 88, 96
- angular emission, 86, 88, 93, 97, 98, 114
- anharmonic oscillator, 124, 126
- antenna
 - antenna directivity, 18, 87, 266
 - antenna efficiency, 262
 - antenna element, xvi, 16, 97, 132, 257, 259, 261, 262, 265, 267, 271, 272, 353
 - antenna gain, 13, 18, 87, 256, 262
 - antenna gap, 10, 15, 19, 21, 24, 226
 - antenna impedance, xvi, 21, 22, 26, 31, 32, 37, 40
 - antenna load, 14, 25
 - antenna resonance, 17, 48, 70, 76, 84, 88, 172, 215, 223–225, 227, 231, 247, 261, 273, 337, 340
- aperture antenna, xvii, 369, 370, 372–374, 377, 383–385
- array factor, 257–260, 269
- aspect ratio, 69, 70, 127, 213, 344, 348, 349, 353, 375
- atom, 3, 4, 33, 35, 39–43, 49, 81, 100–103, 106, 107, 109, 110, 113, 116, 117, 126, 186, 189, 193, 220
- atomic polarizability, 40, 186
- autocorrelation trace, 249–252
- automated optimization, 145
- back focal plane, 96–98, 237, 264
- bandwidth, 18, 21–25, 32, 48, 49, 83, 98, 135, 144, 243, 253, 277
- beam narrowing, 261, 271
- beam steering, 256, 259, 269–271, 274, 275, 294. *See also* beam shaping
- binding event, 344, 352, 380
- biological sensor, 63, 175, 293. *See also* biosensor
- Bloch equations, 35
- bonding dimer plasmon (BDP), 73, 74
- boundary elements, 166, 167, 171. *See also* boundary-element method
- bowtie antenna, 9, 10, 16, 24, 46, 60, 72, 102, 111, 130, 131, 152, 174, 231, 245–247, 250, 278, 279, 282, 289–293, 385
- bright mode, 303–309, 314, 315, 352
- capacitance, 15, 21, 37, 48, 186, 296, 333, 383
- carrier transit time, 333
- Casimir force, 100, 116, 117
- Casimir–Polder force, 116
- cathodoluminescence (CL), 233, 235
- cavity mode, 30, 83, 84, 108, 113, 288, 289
- cavity quantum electrodynamics (CQED), 101, 106, 107, 109
- centrosymmetric, 126, 131
- chemical enhancement, 73
- chemical etching, 282, 347, 359

- chemical sensor, 175, 293
- Chu limits, 49
- circularly polarized pulse
- Clausius–Mossotti polarizability, 340
- cloaking, 50, 59
- cluster, xvii, 177–179, 188, 190, 199, 295–302, 305–316
- coated nanoparticle (CNP), 49–59, 61–63.
See also nano-shell
- coherent control, xvi, 135–140, 144, 148, 150, 154–156, 275
- collection efficiency, 86, 113, 115, 120, 351
- color center, 111, 112, 115, 116, 264
- computational electrodynamics, xvi, 159
- conduction current, 12, 13, 15
- conduction electrons, 52, 79, 175, 177
- confocal imaging, 9, 130, 225, 228, 373, 376.
See also confocal microscopy
- conjugate impedance matching, 41, 42
- constitutive relations, 161
- constructive interference, 113, 128, 140, 141, 259, 267, 274, 307, 309, 354
- contact angle, 300
- coupling factor, 113, 348
- coupling rate, 39, 103, 104, 106, 107
- critical angle, 96, 97, 265, 271, 347, 361
- cross-section
 - absorption cross-section, 42, 43, 75, 118, 191, 194, 274, 330
 - extinction cross-section, 42, 43, 66, 100
 - Raman cross-section, 73, 75
 - scattering cross-section, 42, 43, 61, 168, 171, 312
- current, 13–15, 26, 28, 36, 37, 43, 46, 48, 50, 61, 62, 89, 124, 167, 195, 215, 223, 247, 256–259, 262, 263, 265–267, 271, 272, 274, 296, 298, 315, 338, 344, 353
- conduction current, 12, 13, 15
- current density, 14, 62, 125, 332
- displacement current, 12–17, 22, 23, 48, 315, 335
- photocurrent, 165, 195, 335, 337, 338
- short circuit current, 331, 332
- dark mode, 230, 284, 303–310, 314, 315, 352, 353
- dark-field scattering, 224, 300, 305, 350, 351
- de Feijter formula, 348
- degree of (linear) polarization (DOP), 94–96, 98
- density matrix, 34, 189, 248
- depolarization, 67, 197, 202–205, 207, 209, 210
- destructive interference, 76, 113, 142, 143, 185, 245, 247, 281, 309, 331
- dielectric antenna, 112, 115
- dielectric waveguide, 132, 275
- diffraction limit, 6, 71, 136, 142, 148–150, 175, 227, 228, 234, 240, 253–255, 289, 323, 333, 356, 357, 361, 362, 367, 368, 376, 377
- dimer, 8, 16, 18, 24, 26, 46, 60, 74, 79, 131, 177–180, 198, 200, 202–211, 213, 214, 277, 278, 289–293, 305. *See also* nanodimer
- DIM/QM hybrid method, 186, 189
- dipole, *see also* nanodipole
 - dipole antenna, 9, 15–17, 19, 20, 25, 47, 83, 88, 89, 93, 95–97, 133, 160, 169, 172–174, 256, 258, 262, 269, 275, 276, 333, 334
 - dipole approximation, 32, 136, 140, 155, 239
 - dipole array, 257, 263, 266, 267
 - dipole emitter, 96, 114, 115, 265, 266, 271, 272, 277, 286
 - dipole mode, 56, 61–63, 219, 243, 264, 268, 297, 298, 301, 302, 307, 315
 - dipole moment, 18, 27, 28, 30, 33–36, 41, 42, 50, 51, 54, 84–86, 88, 89, 93, 94, 100, 101, 112, 115–117, 171–173, 185, 186, 190, 192, 271, 283, 289, 301, 303, 307, 309, 314, 315, 348
 - dipole radiation, 101, 301, 302, 315
 - dipole resonance, 57, 88, 261, 295–297, 301, 305, 315
 - electric dipole, 18, 28, 33, 36, 81, 100, 128, 140, 297, 298, 300–303, 305–307, 314, 315
 - image dipole, 108, 173, 286, 289
 - magnetic dipole, 4, 5, 42, 101, 295–298, 301–303, 315
- dipole–dipole interaction, 101, 116, 117
- directivity, 18, 87, 96–98, 216, 231, 232, 256, 261, 262, 266, 267, 269–276, 353, 373.
See also antenna directivity
- director, 97, 98, 131, 216, 232, 262–268, 270–272, 274
- discrete reaction field (DRF), 189
- discrete-dipole approximation (DDA), 189
- displacement current, 12–17, 22, 23, 48, 315, 335
- dissipated power, 17, 27, 28, 34, 41, 43, 44, 86
- DNA assembly, 295, 316
- double negative (DNG), 47, 48
- Drude model, 31, 52, 65, 106, 185, 202, 203, 340, 343
- effective wavelength, 17, 69, 114
- electric dipole, 18, 28, 33, 36, 81, 100, 128, 140, 297, 298, 300–303, 305–307, 314, 315
- electric displacement, 14, 161

- electric field, 3, 4, 14, 15, 22, 24, 27, 29, 31, 33, 34, 44, 47, 51, 54–59, 61, 62, 68, 83–85, 89, 90, 101, 120, 123, 130, 135, 136, 139, 142, 149, 150, 152–154, 156, 161, 162, 166, 167, 169, 171, 178–180, 187, 194, 197, 198, 200, 202, 203, 205–214, 228, 238, 241, 246, 255, 258, 260, 265, 267, 284–286, 288–290, 292, 297, 298, 302, 305–307, 309, 314, 315, 323, 336
- electric potential, 198, 297, 298
- electrically small antenna, 47, 48, 105, 106, 118, 369
- electrically small resonator, 47, 49, 63, 103
- electromagnetic enhancement, 74, 189
- electromagnetic wave, 11–13, 26, 46, 102, 234, 236, 238, 245, 255, 296, 340, 374
- electromagnetically induced transparency (EIT), 353
- electron energy loss spectroscopy (EELS), 233
- electron spill-out, 79
- electron tunneling, 73, 80, 172, 178, 199, 213, 219
- electron-beam lithography (EBL), 9, 95, 98, 130, 220, 223, 232, 278, 279, 281, 283, 294, 385
- electronic transition, 81, 104, 127, 175, 177, 334, 382
- electronic wave function, 34, 35, 79, 104, 136, 140, 145, 146, 154, 190, 199. *See also* wave function
- electrostatic field, 116, 236, 237, 251
- ellipsoid, 42, 67–69, 83, 106, 110, 112, 182, 184, 198, 207, 209. *See also* spheroid
- emission enhancement, 215, 216, 231, 253, 372
- emission spectrum, 127, 227
- energy harvesting, xvii, 175, 193, 321, 328. *See also* light harvesting
- energy transfer, 4, 27, 40, 64, 122, 176, 194, 303
- epsilon-negative (ENG), 47–49
- equivalent circuit, 13, 28, 31, 32, 34, 35, 37, 38, 41, 42, 44
- evanescent field, 4, 32, 66, 67, 234, 347, 357, 360, 367, 368. *See also* evanescent light and evanescent wave
- excitation energy, 69, 140, 182, 191, 242
- excitation enhancement, 371, 372
- excited state, 10, 34, 35, 43, 44, 75, 77–79, 85, 86, 100, 113, 125, 176, 194, 216, 231
- exponential decay, 38, 39
- extinction, 132, 133, 168, 223, 230, 268, 284, 286, 307, 310, 341, 342, 350, 351, 354
 - extinction cross-section, 42, 43, 66, 100
 - extinction spectroscopy, 242, 342
 - extinction spectrum, 132, 176, 223, 303, 306–309, 311, 314, 352, 381
- extraordinary optical absorption (EOA), 322, 325
- extraordinary optical transmission (EOT), 147, 323–325, 354, 369, 370, 374
- Fabry–Perot resonator, 101, 103, 132, 228, 324
- Fano effect, 76
- Fano interference, 303–307, 310, 352
- Fano resonance, 295, 305–310, 312, 314, 316, 351
- far-field localization microscopy, 91
- feed, 18, 19, 97, 98, 232, 262–268, 270–276. *See also* feeding element
- femtosecond pulse, 135, 141, 145
- Fermi golden rule, 28, 38, 191, 238
- field confinement, 32, 71, 84, 138, 217, 274, 347, 348, 353. *See also* near-field confinement
- field enhancement, xvi, 8, 24, 64, 65, 67, 75, 77, 79, 83, 101, 106, 110, 118, 120, 130, 131, 135, 138, 140, 151, 159, 160, 171–174, 178, 194, 197, 198, 203, 205, 206, 208, 211–214, 216–218, 225, 227, 228, 231, 234, 240, 242, 251, 263, 264, 266, 274, 277, 279, 285, 286, 289, 293, 328, 344, 360, 372, 385. *See also* near-field enhancement
- field-enhanced spectroscopy, xv, xvi, 68, 69
- figure of merit (FOM), 310, 342–345, 350, 352, 353
- finesse, 103, 108
- finite differences, 162–165, 171
- finite elements, 162, 164, 165, 169, 297
- finite integration technique (FIT), 264, 271
- finite-difference frequency-domain (FDFD), 323–325, 328
- finite-difference time-domain (FDTD), 161–163, 165, 171, 189, 194, 195, 226, 284, 286, 288, 289, 291, 292, 367, 368
- fitness function, 145, 146, 151
- fluorescence, xvi, 4, 5, 10, 35, 50, 76–78, 85, 90, 93, 94, 102, 107–109, 111, 114, 118–120, 154, 176, 182, 191, 192, 194, 370–378, 382
 - fluorescence correlation spectroscopy (FCS), 372, 377, 378
 - fluorescence enhancement, 27, 78, 118, 370, 371, 373–377
 - fluorescence quenching, 78, 372
 - fluorescence resonance energy transfer (FRET), 101, 194
 - fluorescence spectroscopy, 376
 - resonance fluorescence, 101

- single-molecule fluorescence, 102, 372, 376
- surface-enhanced fluorescence (SEF), 72, 176, 182, 186, 187, 191, 192, 194, 340, 348
- focused ion beam (FIB), 9, 89, 220–223, 232, 278, 279, 281, 294
- force field, 189
- forward–backward ratio, 98, 264, 273
- Fourier image, 96–98, 230, 232. *See also* back focal plane
- Fourier transform infrared spectroscopy (FTIR), 256, 268, 272
- Fourier transformation, 79, 140, 143, 144, 161, 239, 325. *See also* Fourier transform
- four-wave mixing (4WM), 124, 125, 130, 131, 225, 374
- free spectral range (FSR), 103
- frequency mixing, 123, 228
- Friis equation, 20
- full-wave simulation, 16, 21, 265. *See also* computational electrodynamics
- full-width at half maximum (FWHM), 90, 118, 249–252, 284, 285, 343, 345, 350, 366
- functionalization, 95, 344, 348, 350
- fundamental frequency, 124
- gain medium, xvi, 49, 50, 53, 54, 56, 57, 59–61, 63. *See also* gain material
- grain, 217–223, 242, 279, 294, 360
- grating, 131, 269, 284, 288, 300, 327, 329, 330, 333, 354, 373, 374, 383, 384
- grating period, 269, 328, 384
- Green function, 166, 169, 173, 174
 - Green function singularity, 28–30, 166, 169
- Green tensor, 27, 28, 30–32, 36, 41, 165.
 - See also* dyadic Green function
 - vacuum Green tensor, 28–30, 166
- ground state, 34, 77–79, 85, 100, 238
- group theory, 296, 306, 315
- harmonic oscillator, 67, 124, 341
- Hartree–Fock theory, 189
- Heisenberg uncertainty principle, 357
- Helmholtz equation, 162–164
- heptamer, 295, 305, 308–310, 316, 352
- Hertz contact theory, 366
- hot spot, 72, 74, 118, 133, 151, 178, 193, 195, 211, 248, 274, 285, 286, 292, 294, 316, 348
- image dipole, 108, 173, 286, 289
- imaging
 - confocal imaging, 9, 130, 225, 228, 373, 376
 - high-resolution imaging, 74, 228, 235, 362
 - near-field imaging, 215, 229. *See also* SNOM
 - two-photon photoluminescence (TPL) imaging, 130, 133, 225–227
- impedance, 10, 13–17, 19, 26–33, 35–42, 44, 47, 86, 277
 - antenna impedance, xvi, 21, 22, 26, 31, 32, 37, 40
 - conjugate impedance matching, 41, 42
 - impedance matching, 13, 25, 26, 42, 46, 47, 264, 353
 - impedance transformer, 47, 48
 - input impedance, 13, 15–19, 21, 22, 28
 - internal impedance, 13, 19, 33
 - intrinsic impedance, 16, 19, 21, 22, 24
 - line impedance, 16, 19
 - load impedance, 22, 24, 41
 - sensitivity, 18, 21–25
 - specific impedance, 14, 28, 30, 33, 34, 37, 41, 42
 - vacuum impedance, 28, 29, 42
- inductance, 37, 48, 296
- inelastic scattering, 250
- inhomogeneous broadening, 137, 223, 343
- interference
 - constructive interference, 113, 128, 140, 141, 259, 267, 274, 307, 309, 354
 - destructive interference, 76, 113, 142, 143, 185, 245, 247, 281, 309, 331
 - Fano interference, 182, 303–307, 310, 352
- input impedance, 13, 15–19, 21, 22, 28
- internal impedance, 13, 19, 33
- inverse solvent-assisted nanoscale embossing (inSANE), 281, 282
- inversion symmetry, 123, 131, 200, 302, 315
- irreducible representation, 306, 315
- J-aggregate, 182–184
- Jablonski diagram, 191
- Jellium model, 79, 177, 178, 180
- Kerr nonlinearity, 124
- Kirchoff circuit law, 14
- Kretschmann configuration, 380, 381
- $\lambda/2$ antenna, 69. *See also* dipole antenna
- $\lambda/4$ antenna, 64, 90. *See also* monopole antenna
- Lambert–Beer law, 322
- Laplace equation, 65, 198, 297
- lifetime, 10, 26, 81, 86, 107–111, 113, 120, 137, 153, 231, 248–252, 255, 264, 272, 275, 283, 303, 372, 373, 382
- light emission, 26, 97, 199
- light extraction, 322, 338

- light-matter interaction, xv, xvi, 81, 82, 100, 104, 106, 124, 134, 149, 156, 215, 322, 338, 357, 369, 370, 372, 375
- local density of states (LDOS), 28, 30, 32, 39, 41, 112, 133, 231, 237
- strong coupling, 27, 36–38, 40, 41, 99, 100, 103, 120, 132, 133, 176, 181–185, 210, 211, 213, 232, 283, 329, 330
- weak coupling, 27, 36, 37, 39, 40, 85, 181–183, 186
- lightning rod effect, 67, 71, 72, 251
- line impedance, 16, 19
- linear antenna, 64, 68–72, 244, 266
- linear array, 259, 260, 262
- linewidth, 76, 103, 104, 108, 119, 268, 281, 285, 288, 301, 303–305, 307, 310, 312, 315, 343, 384, 385. *See also* FWHM
- Liouville–von Neumann equation, 248, 249
- load, 14–16, 19–24, 26–28, 35, 41. *See also* nanoload
- load impedance, 22, 24, 41
- local density of states (LDOS), 28, 30, 32, 39, 41, 112, 133, 231, 237
- local field, 13, 46, 62, 64, 65, 70, 72, 74, 75, 81, 82, 89, 125, 130, 132, 135, 136, 139, 140, 142–146, 150, 152, 154, 175, 176, 178, 187–189, 191, 193–195, 211, 216, 219, 225, 227–229, 239, 245, 247, 279, 288. *See also* near-field
- local field correction, 29
- localized surface plasmon-polariton
 - resonance (LSPR), 6, 32, 33, 42, 57, 64, 65, 67, 71, 76, 78, 81, 101, 107–112, 117, 119, 120, 126–132, 134, 140, 141, 168, 172, 175–178, 181, 182, 184–190, 192–195, 197–199, 202, 203, 205–211, 213–215, 223, 235, 239, 240, 242, 250, 255, 264, 265, 268–271, 277, 279, 283, 288–292, 297, 298, 302, 310, 312, 316, 340–343, 345, 348–352, 354
- longitudinal mode, 68
- loop antenna, 48, 226
- Lorentz model, 16, 60, 124, 183, 185
- LSPR sensor, 310, 342, 349–351, 354. *See also* LSPR sensing
- luminescence, 7, 95–98, 125, 127, 132, 225, 227, 372, 376. *See also* fluorescence
- lumped element, 13, 14, 18, 24, 27, 32, 35
- magnetic dipole, 4, 5, 42, 101, 295–298, 301–303, 315
- magnetic field, 3, 4, 22, 51, 162, 166, 167, 253, 254, 323, 336
- magneto-optical Kerr effect, 253
- Maxwell equations, 10, 66, 68, 124, 139, 145, 148, 159–161, 164–167, 174, 177, 189, 198, 215, 218, 219, 336
- mean free path, 52, 160, 177, 199, 218, 236
- metal–dielectric–metal (MDM) waveguide, 324
- metallo-dielectric antenna, 112
- metamaterial (MTM), 47, 49, 50, 60, 63, 295–297, 337, 342, 353, 355
- metasurface, 24
- microcavity, 26, 28, 30–34, 37, 39, 40, 101, 104, 113, 181–183. *See also* resonator
- Mie theory, 5, 66, 83, 168, 183, 193, 199
- mixing amplitude, 147
- mixing angle, 147
- mode volume, 30, 33, 101, 106, 108, 253, 269, 270, 286, 372
- molecular orbital, 183
- molecular polarizability, 185, 189, 347
- molecule, 3, 4, 8, 33, 36, 43, 44, 49, 71, 73–78, 81, 84, 89, 90, 93–95, 102, 107–111, 114, 116, 118, 120, 127, 137, 146, 153, 171, 175–177, 180–194, 196, 215, 231, 232, 264, 269, 270, 312, 313, 323, 340, 341, 345, 347–352, 354, 365, 370–372, 374–378, 380, 382
- momentum mismatch, 127, 359
- monopole antenna, 89, 90, 92, 93, 172
- mu-negative (MNG), 48
- multiphoton absorption, 225
- multiple scattering, 36
- multipolar mode, 128, 204, 214
- nano-cone, 110, 112, 114, 119, 120, 192, 355, 359. *See also* cone
- nano-imprint lithography, 232, 281. *See also* nanoimprinting
- nano-optics, xv–xvii, 82, 99, 120, 148, 150, 369, 370
- nano-ring, 72
- nano-rod, 68, 70, 73, 83, 89, 106, 129, 130, 149, 203, 207–213, 242, 244, 272, 277, 316, 353, 359, 366–368
- nano-shell, 50–52, 56, 59, 72, 298–302, 305–310, 312–316
- nanohole, 282, 345, 346, 354, 381. *See also* subwavelength aperture
- nanolens, xvii, 367, 368, 383
- nanoload, 14–16, 19–24, 26–28, 35, 41. *See also* load
- nanosphere, 26, 28, 31, 33, 43, 66, 67, 79, 102, 110, 111, 113, 114, 117, 150, 156, 204, 297, 298, 305, 312–315, 354
- nanostrip, 9, 15, 19, 20, 326–332, 379, 380. *See also* strip
 - nanostrip waveguide, 19, 21
- nanostructure, xvi, 32, 64, 72, 109, 110, 118, 123, 127, 128, 135, 136, 138, 140–142, 149–153, 160, 169, 213, 216, 217, 219, 221, 228, 234–237, 240–252, 255, 265,

- 268, 270, 279–281, 294, 295, 297,
299–301, 303, 310–312, 316, 322, 323,
326, 332, 334, 335, 337, 338, 340, 342,
352, 359, 364, 370, 382
- nano-wire, 44, 123, 127, 132, 133, 154, 219,
242, 244, 262, 266, 272, 273, 278,
335–338, 344, 345
- near-field control, 138, 148–150, 152, 154, 240
- near-field imaging, 215, 229. *See also* SNOM
- near-field optics, xv, 4–6, 10, 114, 358
- non-centrosymmetric, 131
- non-radiative decay rate, 33, 35, 78, 84–86,
110, 192, 303
- nonlinear optics, xvi, 10, 123, 134
- nonlinear photochemistry, 195
- nonlinear polarization, 124, 126
- nonlinear susceptibility, 4, 124, 126, 128
- normal mode, 188, 191
- normalized radiation resistance (NRR), 51,
52, 54–59, 62
- Ohmic losses, 23, 31, 33, 41, 42, 217, 218,
262, 272, 344, 371
- open-circuit resonance, 16, 17, 19, 22
- optical gain constant, 53, 59
- optical theorem, 29, 168
- optical trapping, 379, 380
- optimal control, 144–147, 153
- passive element, 216, 262
- pentamer, 295, 312–315
- perfect conductor, 69, 71
- permeability, 50, 52, 53, 161, 165
- permittivity, 13, 16, 19, 22, 23, 47, 50, 52,
53, 61, 160, 161, 165, 370
- phase
 - phase matching, xvi, 126–128
 - phase propagation, 252
 - phase shift, 83, 93, 135, 246, 252, 257–261,
263, 266, 267, 275, 276, 303, 331, 383
 - relative phase, 142, 143, 150, 245, 246,
258, 266, 267
 - spatial phase, 149, 154
 - spectral phase, 138, 140, 141, 143, 144,
146–150, 152–154, 245
- phase-shifting photolithography (PSP), 281,
283, 289
- phased array, 261
- photochemistry, 136, 153, 176, 192–194, 196,
235–238
 - nonlinear photochemistry, 195
 - plasmon-enhanced photochemistry, 193,
196
 - surface-enhanced photochemistry, 193–196
- photoelectric effect, 176, 192, 236, 238
- photoelectron, 136, 153, 193, 194, 196,
235–238, 240, 247, 249, 251, 253–255
- photoemission, 141, 151–153, 235–248, 250,
251, 254, 255
- photoemission electron microscopy (PEEM),
xvii, 146, 151, 153, 155, 235–238,
240–247, 249–255
 - two-photon photoemission (2PPE) PEEM,
9, 150–153, 241, 252
- photoluminescence, 225, 373, 376. *See also*
fluorescence
- photophysics, 120, 193
- picosecond pulse, 10
- planar antenna, 105, 107, 108, 112, 116
- planar array, 24, 25, 259–261
- plane wave, 36, 42, 52, 54, 60, 61, 63, 65, 66,
68–70, 84, 85, 87, 90, 126, 128, 137,
264–266, 274, 322–324, 328
- plasmon damping, 269, 351
- plasmon-enhanced photochemistry, 193, 196
- plasmon–exciton hybridization, 176, 181,
183–187
- plasmon-induced transparency, 353
- plasmonic resonance energy transfer
(PRET), 176
- plasmonic waveguide, 15, 16, 20, 153, 275,
334. *See also* SPP waveguide
- point group, 297, 309
- Poisson equation, 197
- polarizability, 22, 23, 29–31, 34, 35, 41,
65–67, 79, 105, 112, 118, 125, 185, 188,
202, 229, 301, 341, 347
 - atomic polarizability, 40, 186
 - Clausius–Mossotti polarizability, 340
 - molecular polarizability, 185, 189, 347
 - static polarizability, 29, 30, 340
- polarizable continuum model (PCM)
- polarization, xvi, 7, 21, 66, 68, 69, 81, 82, 84,
86, 87, 89, 90, 93–96, 99, 105, 109, 117,
122, 124, 128, 129, 132, 133, 135, 136,
138, 139, 141–144, 147, 150, 152, 153,
172, 195, 197, 199, 200, 224, 228, 230,
232, 240, 241, 243–245, 247, 250, 254,
264, 272, 273, 277, 288, 290–292,
300–303, 305, 306, 308, 309, 314, 315,
328, 330, 334, 372, 375, 383, 384
- degree of (linear) polarization (DOP),
94–96, 98
- linear polarization, 97, 151, 239, 245
- nonlinear polarization, 124, 126
- polarization mismatch, 20
- polarization shaped laser pulse, 123
- polarization shaping, 142, 151, 152
- polarization state, 129, 141, 142, 150, 153
- polarization vector, 123, 124, 200
- TE polarization, 168, 241
- TM polarization, 241, 242, 329
- polarization pulse shaping, 138, 150–153

- polarization-shaped laser pulse, 137, 150–153
- power
 - absorbed power, 42, 43
 - dissipated power, 17, 27, 28, 34, 41, 43, 44, 86
 - scattered power, 43, 61
- power ratio, 51, 62, 63
- power transfer, 18, 42
- Poynting vector, 4
- Poynting theorem, 125
- propagating wave, 32, 294
- propagation length, 153, 219, 221, 242, 244
- pulse
 - femtosecond pulse, 135, 141, 145
 - picosecond pulse, 10
 - pulse shape, 139, 145, 146, 150, 155, 156, 239
 - polarization shaped laser pulse, 123
 - pulse shaping, 137, 138, 140, 244
- pump-probe, 155, 250, 252
- Purcell factor, 26, 30, 32, 33, 36, 39, 44, 108, 113, 269, 372
- QM/MM method, 187, 189, 190
- quadrumer, 295, 305–308, 310, 315
- quadrupole, 128, 131, 243, 244
- quality (Q) factor, 30, 32, 39, 101, 103, 105, 106, 108, 217, 223, 279, 283, 286
- quantum efficiency, 33, 43, 44, 86, 110–113, 191, 194, 195, 231, 338, 371, 383. *See also* quantum yield
- quantum electrodynamics (QED), 100, 107, 116
- quantum emitter, xvi, 26, 30, 35, 37, 41, 44, 81, 84, 86, 97, 99, 104, 113, 215, 216, 223, 230, 264, 269, 272, 274, 275, 322, 338, 371, 374
- atom, 3, 4, 33, 35, 39–43, 49, 81, 100–103, 106, 107, 109, 110, 113, 116, 117, 126, 186, 189, 193, 220
- color center, 111, 112, 115, 116, 264
- molecule, 3, 4, 8, 33, 36, 43, 44, 49, 71, 73–78, 81, 84, 89, 90, 93–95, 102, 107–111, 114, 116, 118, 120, 127, 137, 146, 153, 171, 175–177, 180–194, 196, 215, 231, 232, 264, 269, 270, 312, 313, 323, 340, 341, 345, 347–352, 354, 365, 370–372, 374–378, 380, 382
- quantum dot (QD), 81, 84, 95–98, 112, 113, 116, 127, 137, 138, 154, 155, 181, 182, 232, 264, 269, 372–375
- single-photon source, 113, 120
- two-level system (TLS), 26, 27, 29, 30, 33–40, 42, 43, 84, 100, 108
- quantum optics, 28, 100–104, 116, 231
- quasistatic approximation, 65, 66, 183, 198–200, 213. *See also* long wavelength approximation
- quasistatic limit, 283, 295, 297, 309
- Rabi frequency, 40, 103
- Rabi oscillation, 40
- Rabi splitting, 176, 182, 330
- radiation
 - radiation damping, 42, 242, 262
 - radiation loss, 16, 29, 31, 35, 105, 221, 283, 285, 314, 344. *See also* radiative loss
 - radiation reaction, 29, 30
- radiation efficiency, 12, 131, 17, 18, 23, 48, 105, 277, 279. *See also* antenna efficiency
- radiation pattern, xvii, 18, 96, 98, 216, 230, 232, 256, 258, 259, 261, 263–266, 271–273, 275, 283, 373, 374
- radiative decay rate, xvi, 33, 43, 44, 67, 78, 88, 110, 181, 215, 343
- radiative resistance, 35. *See also* radiation resistance
- radio-frequency (RF) antenna, 9, 11, 12, 19, 24, 25, 42, 46, 79, 89, 96, 102, 107, 232, 256, 261, 262, 268, 276, 340
- radio-frequency (RF) waveguide, 46, 62. *See also* transmission line
- Raman cross-section, 73, 75
- Raman scattering, 73, 74, 187, 189, 215, 360–362, 364, 366, 374, 382
- Raman spectroscopy, 74, 120, 360, 362
- Raman spectrum, 363, 365, 381
- surface-enhanced Raman scattering (SERS), 22, 190
- surface-enhanced resonance Raman scattering (SERRS), 190
- tip-enhanced Raman scattering (TERS), 71, 74, 360–366, 368
- Rayleigh scattering, 73, 101, 108
- reactance, 47, 48
 - input reactance, 17, 21
- reactive energy, 19, 106
- reactive ion etching (RIE), 282, 283
- receiver, 10, 12, 18, 122, 131, 148, 256, 277, 340
- receiving antenna, 13, 18, 21, 46, 264
- reciprocity, 19, 21, 23, 64, 72, 73, 77, 87, 99, 120, 148, 159, 171, 265, 266, 269, 272, 322
- reception, 96, 102, 105, 256, 263, 265–267, 369, 373
- rectification, 123, 124
- reflection, 6, 7, 18, 70, 83, 89, 93, 107, 119, 224, 261, 262, 272, 302, 324, 325, 329, 342, 350, 376
 - reflection coefficient, 19, 20, 22, 23, 324
 - total internal reflection, 335, 359
- reflector, 97, 232, 262–268, 270–272, 274, 369

- refraction, 6, 7, 10, 12, 13, 18, 19, 21, 23, 46, 64, 70, 72, 73, 77, 83, 87, 89, 93, 97, 99, 107, 114, 116, 119, 120, 122–124, 131, 148, 159, 171, 224, 232, 256, 261–272, 274, 277, 302, 322, 324, 325, 329, 340, 342, 347, 350, 369, 376
- refractive-index unit (RIU), 310, 353
- relative phase, 142, 143, 150, 245, 246, 258, 266, 267
- resistance, 28, 32–35, 37, 39, 42–44, 272
 - input resistance, 17, 19–21
 - radiation resistance, 17, 26, 30, 43, 51, 52
 - specific resistance, 27, 33–35
 - vacuum resistance, 29, 30, 35, 37, 39, 44, 51
- resonance
 - antenna resonance, 17, 48, 70, 76, 84, 88, 172, 215, 223–225, 227, 231, 247, 261, 273, 337, 340
 - dipole resonance, 57, 88, 261, 295–297, 301, 305, 315
 - Fano resonance, 295, 305–310, 312, 314, 316, 351
 - resonance frequency, 16, 22, 61–63, 65, 103, 119, 160, 181, 263, 290, 326, 359
 - resonance wavelength, 168, 169, 172, 173, 206, 217–220, 243, 273, 275, 288, 289, 291, 292, 342, 343, 350
 - super-resonance, 54, 56, 58
 - vibrational resonance, 76
- resonance fluorescence, 101
- resonator, 38, 47, 49, 82, 83, 103, 105–108, 148, 286, 295, 324, 336, 352
 - electrically small resonator, 47, 49, 63, 103
 - Fabry–Perot resonator, 101, 103, 132, 228, 324
 - magnetic dipole resonator, 295, 296
 - ring-disk resonator, 30, 352
 - RLC resonator, 47
 - split-ring resonator, 295, 296
- response function, 139, 143, 146, 147, 149, 152, 239, 245, 252
- retardation, 14, 29, 66, 68, 117, 198, 213, 297, 309, 312
 - phase retardation, 245, 251, 252, 353, 372
- ring-disk resonator, 352
- RLC circuit, 31–33, 35, 37, 38, 44
- RLC resonator, 47
- scanning near-field optical microscope (SNOM), 5–7, 78, 82, 89, 102, 118–120, 137, 138, 230, 234, 235, 266, 277, 370, 378
 - aperture SNOM, 7, 119
 - apertureless SNOM, 102, 118, 228, 265, 272
- scanning transmission microscopy (STM), 195, 356, 359
- scattering, xvii, 5–7, 11, 14, 22, 23, 29, 35, 42, 49, 50, 57, 63, 66, 85, 101, 102, 107, 118, 119, 127, 129, 148, 149, 160, 167, 168, 171, 177, 215–219, 223, 224, 229, 233, 242, 264, 269, 273, 279, 284–286, 300–303, 305, 307, 309, 324–326, 328, 331, 337, 338, 341, 342, 347, 352, 355, 358, 360, 380, 382
 - dark-field scattering, 224, 300, 305, 350, 351
 - inelastic scattering, 250
 - multiple scattering, 36
 - Raman scattering, 73, 74, 187, 189, 215, 360–362, 364, 366, 374, 382
 - scattered power, 43, 61
 - scattering cross-section, 42, 43, 61, 168, 171, 312
 - scattering spectrum, 132, 219, 223, 224, 230, 300–302, 305, 306, 309–311, 314, 315, 342, 351
 - surface-enhanced Raman scattering (SERS), 22, 190
 - surface-enhanced resonance Raman scattering (SERRS), 190
- Schrödinger equation, 72–75, 145, 146
- second-harmonic generation (SHG), 124, 127–131, 239, 372, 374
- self-assembly, 29, 221, 295, 297, 305, 312, 316
- self-interaction, 30
- self-phase modulation, 123
- sensitivity, 18, 21–25
- sensor, xvii, 5–7, 49, 50, 57, 63, 355, 380, 382
 - biological sensor, 63, 175, 293
 - figure of merit (FOM), 310, 342–345, 350, 352, 353
 - LSPR sensor, 310, 342, 349–351, 354
 - refractive-index unit (RIU), 310, 353
 - SPR sensor, 350
- shear force, 6
- short circuit current, 331, 332
- short circuit resonance, 16
- Silberstein equations, 77, 78, 82, 185–188
- single-molecule detection, 102, 192, 355
- single-molecule fluorescence, 102, 372, 376
- single-photon source, 113, 120
- skin depth, 12, 160, 277
- soft nanolithography, 279–281, 283, 289, 293
- solvent-assisted nanoscale embossing (SANE), 281, 282
- spatial phase, 149, 154
- spatial resolution, xvii, 118, 152, 155, 156, 194, 197, 225, 228, 235, 255, 265, 316, 356–358, 360–368, 378

- specific impedance, 14, 28, 30, 33, 34, 37, 41, 42
- spectral amplitude, 138, 140, 141, 144, 147, 245
- spectral phase, 138, 140, 141, 143, 144, 146–150, 152–154, 245
- spectral representation theory, 199
- spectroscopy
 - absorption spectroscopy, 382
 - extinction spectroscopy, 242, 342
 - field-enhanced spectroscopy, xv, xvi, 68, 69
 - fluorescence correlation spectroscopy (FCS), 372, 377, 378
 - fluorescence spectroscopy, 376
 - Raman spectroscopy, 74, 120, 360, 362
 - single molecule spectroscopy, 74, 137
 - surface-enhanced spectroscopy, 196, 348
 - two-dimensional (2D) spectroscopy, 155
- split-ring resonator, 295, 296
- spontaneous emission, xv, 28, 33, 77, 100–104, 107–113, 120, 286
- SPR sensor, 350, 380
- standing wave, 228, 229, 244, 262, 345
- static polarizability, 29, 30, 340
- strong coupling, 27, 36–38, 40, 41, 99, 100, 103, 120, 132, 133, 176, 181–185, 210, 211, 213, 232, 283, 329, 330
 - plasmon–exciton hybridization, 176, 181, 183–187
 - Rabi frequency, 40, 103
 - Rabi oscillation, 40
 - Rabi splitting, 176, 182, 330
- subradiant lattice surface plasmon-polariton (SPP), 284, 285
- subwavelength aperture, 131, 228, 369–373, 375–378, 380, 382, 383. *See also* submicrometric aperture
- super-resonance, 54, 56, 58
- surface charge, 130, 167, 197, 201, 214, 215, 297, 306–308, 314, 315, 341
 - surface charge density, 59, 64, 66, 68, 71, 88, 200, 202, 204, 209, 307
 - surface charge distribution, 202, 204, 205, 207, 213
- surface integral equation, 166, 167, 174, 199
- surface plasmon-polariton (SPP)
 - localized surface plasmon-polariton resonance (LSPR), 6, 32, 33, 42, 57, 64, 65, 67, 71, 76, 78, 81, 101, 107–112, 117, 119, 120, 126–132, 134, 140, 141, 168, 172, 175–178, 181, 182, 184–190, 192–195, 197–199, 202, 203, 205–211, 213–215, 223, 235, 239, 240, 242, 250, 255, 264, 265, 268–271, 277, 279, 283, 288–292, 297, 298, 302, 310, 312, 316, 340–343, 345, 348–352, 354
 - subradiant lattice surface plasmon-polariton (SPP), 284, 285
 - surface plasmon-polariton (SPP) mode, 115, 127, 129, 132, 154, 219, 288, 323–325, 373–375, 380, 382
 - surface plasmon-polariton (SPP) wave, 235, 244, 252, 325
 - surface-plasmon-polariton (SPP) wavelength, 83, 84, 261, 262
 - surface-plasmon-polariton (SPP) wave vector, 84
 - surface plasmon-polariton resonance (SPR), 326, 327, 330, 349, 350, 354, 355, 380, 381
- surface roughness, 218–222, 279, 286
- surface wave, 57, 69, 219, 374, 383
- surface-enhanced Raman scattering (SERS), 22, 190
 - chemical enhancement, 73
 - charge-transfer (CT), 188, 190
 - electromagnetic enhancement (EM), 74, 189
 - molecular resonance (RRS), 188, 190
 - non-resonant chemical (CHEM), 188, 190, 191
- surface-enhanced fluorescence (SEF), 72, 176, 182, 186, 187, 191, 192, 194, 340, 348
- surface-enhanced infrared absorption (SEIRA), 75, 76, 148, 187, 340
- surface-enhanced photochemistry, 193–196
- surface-enhanced resonance Raman scattering (SERRS), 190
- susceptibility, 200, 201, 239, 251
 - nonlinear susceptibility, 4, 124, 126, 128
 - susceptibility tensor, 126, 128
- template stripping, 220, 282, 284, 286, 289
- test function, 162–164
- Thal limits, 49, 109
- Thevenin theorem, 13, 14, 109, 110, 120
- Thevenin circuit model, 15–17, 19, 120, 176, 178, 187
- third-harmonic generation (THG), 124, 130, 132, 133
- time reversal, 24, 148, 149, 153
- time-correlated single-photon counting, 231
- time-dependent density functional theory (TDDFT), 79, 178–180, 186
- time-reversal mirror (TRM), 148
- tip-enhanced Raman scattering (TERS), 71, 74, 360–366, 368
- total decay rate, 77, 86, 191, 192
- total internal reflection, 335, 359
- transducer, 11, 46, 343, 345, 354

- transmission, 5, 7, 26, 36, 75, 76, 102, 105, 119, 148, 224, 229, 230, 256, 263, 265, 268, 270, 272, 275, 290, 325, 354, 374–376, 379–382
 - extraordinary optical transmission (EOT), 147, 323–325, 354, 369, 370, 374
 - transmission coefficient, 19, 147, 324
- transmission line, 153, 294
- transmitter, 21, 122, 277
- transverse mode, 68, 69, 149
- trimer, 295, 296, 298–303, 305, 306, 310, 311, 315, 316
- tuning fork, 359
- tweezer, 152, 379. *See also* optical trapping
- two-dimensional (2D) spectroscopy, 155
- two-level system (TLS), 26, 27, 29, 30, 33–40, 42, 43, 84, 100, 108
- two-photon absorption, 126, 195, 242
- two-photon photoemission (2PPE), 238, 241, 248–250, 252, 254, 255
- two-photon photoluminescence (TPL), 9, 125–127, 129, 130, 132, 133, 225, 227, 233, 252
- up-conversion, 77, 375, 376
- vacuum Green tensor, 28–30, 166
- vacuum fluctuations, 101, 117
- vacuum impedance, 28, 29, 42
- vacuum resistance, 29, 30, 35, 37, 39, 44, 51
- van der Waals force, 100, 116, 300
- vibrational energy, 360
- vibrational excitation, 75, 76
- vibrational resonance, 76
- voltage, 5, 8, 12–16, 26, 28, 33, 36, 37, 41, 44, 46, 236, 300
- volume integral equation, 165, 166, 168, 338
- waveguide, 7, 10, 11, 56, 132, 133, 153, 154, 324, 329–331, 336
 - dielectric waveguide, 132, 275
 - metal dielectric metal (MDM) waveguide, 324
 - nanostrip waveguide, 19, 21
 - plasmonic waveguide, 15, 16, 20, 153, 275, 334. *See also* SPP waveguide
 - radio-frequency (RF) waveguide, 46, 62. *See also* transmission line
 - transmission line, 153, 294
 - waveguide mode, 326–330
- weak coupling, 27, 36, 37, 39, 40, 85, 181–183, 186
 - Fermi golden rule, 28, 38, 191, 238
 - Purcell factor, 26, 30, 32, 33, 36, 39, 44, 108, 113, 269, 372
- wire antenna, 12, 28, 216–219, 224, 226, 227, 229, 230, 262
- wireless link, 18–20, 25. *See also* wireless connection
- wireless connection, 20
- Yagi–Uda antenna, 46, 64, 93, 96–98, 102, 113, 187–192, 194, 232, 239, 253, 256, 259, 262–279, 340, 348, 353, 369, 372, 382, 383