

Index

Abbe numbers, 56, 129, 225, 226
aberration theory, 13, 51, 61, 62
aberrations, 3, 103, 105, 113, 114, 115, 119, 121, 122, 128–133, 138, 141, 145, 147, 148, 150, 154, 161, 163, 207, 219, 225, 226, 227, 349, 375, 385, 387, 390, 391, 396, 401–410, 412, 414, 416, 417, 427, 433, 435, 436, 437
absorption coefficient, 2
absorption filters, 182
absorption, 1–10, 233, 243, 247, 249, 250, 252, 257, 258, 273
absorptive polarizers, 255, 258
acceptance angle, 68–72, 75, 82, 86, 98, 108, 109, 111, 152, 160, 255, 256, 257, 272, 307
achromat, 110, 113, 120, 129, 130, 131, 135
achromatization, 389
acousto-optical deflectors, 324
acousto-optical tunable filters, 182
air-guiding fibers, 68
Airy disk, 322, 323, 330, 373, 398
analyzer, 246, 247, 248, 250, 251, 252, 253, 280
angular magnification, 13
anisotropy, 4, 7, 9
antireflective (AR), 219, 220, 258, 268, 273, 281, 283, 284, 285, 293, 294, 297, 299, 300, 388, 439
aperture stop, 16, 17, 32, 36, 58, 59, 65
aplanatic conditions, 123, 125

aplanatic lens, 57
aplanatic surface, 56, 57
apodization, 274, 286
aspherical surfaces, 57, 58
astigmatism, 29, 34, 35, 36, 37, 44, 46, 48, 51, 56, 58, 113, 119, 121, 122, 126, 129, 130, 133, 134, 140, 141, 142, 144, 145, 148, 150, 151, 328, 344, 345, 346, 349
atom, 3, 7
autofluorescence, 8, 165, 169, 170, 171, 177, 183, 185, 186, 190–193, 201, 202, 203, 204, 212, 218, 221, 222, 224, 225, 226, 228, 229, 232
avalanche photodiodes (APDs), 174, 178
average passband transmission, 180, 188
axial chromatic aberration, 129, 138
axial resolution, 111
Babinet compensator, 270
back focal length (BFL), 14, 138, 399
back focal plane, 104, 120
bandpass filter, 171, 180, 181, 182, 185, 187, 191, 192, 199, 200, 216
bandwidth, 176, 178, 180, 184, 187, 188, 190, 192, 193, 194, 199
barrel distortion, 38
base curvature, 57
beam deviation, 255, 268, 270
beam scan, 324, 326, 328, 330, 331
beamsplitter, 105

- beamsplitting polarizers, 255, 258
Beer's law, 3, 4
bi-crystalline achromatic retarder, 269
biocompatibility, 170
bioluminescence, 171, 197
biomarkers, 1
birefringence, 7, 268, 273, 288, 289, 306
blur, 3
Brewster's angle, 258, 275, 276, 294
bright field, 117, 152, 153, 160
brightness, 80, 86, 89, 98, 116, 117, 154–158
buffer, 68, 69
- camera equation, 25
capsule endoscopy, 430, 442
cardinal points, 13, 14, 15
catadioptric lenses, 145
center wavelength, 180, 188
central obscuration, 362, 363, 364
charge-coupled device (CCD), 47, 48, 174, 178, 179, 180, 204, 384, 402, 432
chief ray, 16, 26, 32, 34, 36, 40, 41, 47, 48, 58, 119, 150, 153, 154, 156, 385, 386, 387, 399, 402, 408, 411
chromatic aberration, 26, 39, 40, 43, 44, 51, 56, 58, 59, 60, 113, 114, 119, 120, 122, 127, 129, 131, 133–138, 140, 145, 146, 147, 148, 150, 154, 156, 157, 220, 225, 228
circular polarization, 245
circular polarizer, 263
cladding modes, 370
cladding, 68–73, 76, 78, 81, 82, 84, 86, 92, 93, 210, 211, 212
clear aperture, 188, 189
close coupled, 339
close-up mode, 412, 413, 414, 415
coherence gating, 10
cold mirror, 87
- collector, 105, 117, 153, 156, 157, 158
color centers, 220, 221
color fidelity, 118
color temperature, 86
colored filter glass, 183
coma, 29, 32, 33, 34, 43, 44, 45, 48, 51, 56, 58, 59, 60, 121, 328, 335, 336, 343, 349, 350, 387, 391, 394, 396, 400, 403, 404, 405, 408, 409, 410, 412, 435
complementary metal-oxide semiconductor (CMOS), 47, 48, 174, 178, 180, 197, 204, 230, 231, 384, 432
compound parabolic concentrator (CPC), 90, 91
compound zero-order retarder, 267
condenser, 105, 110, 111, 112, 117, 119, 153–158, 160, 161, 162
confocal aperture, 11
confocal fluorescence imaging, 211
confocality, 322
conic constant, 57
conjugate distance, 105
contrast agents, 1, 2
contrast ratio, 255, 256, 258, 261, 263, 270, 271, 272
contrast, 1–11, 165, 172, 174, 191–196, 199, 200, 201, 202, 204, 211, 212, 218, 224, 229
Cooke triplet, 62
copolarization, 244, 246, 301
core–cladding boundary, 68
correction collar, 114
cosine-fourth falloff law, 23, 24
coupling lens, 358, 368, 369
cover glass, 108, 109, 114, 118, 121, 125, 132, 134, 139, 140, 141, 142
critical angle, 276, 277
cross-polarization, 244
cut-off wavelength, 180–183, 185, 199
cypate-mono-2-deoxy-glucose, 170
cystoscope, 379

- cytoplasm, 2
- dark field, 117, 152, 153, 160, 162
- defocus, 28–32, 43
- degree of circular polarization (DOP_C), 241
- degree of linear polarization (DOP_L), 239, 241
- degree of polarization (DOP), 239
- deoxyribonucleic acid (DNA), 3, 168, 171, 197, 231
- depolarization length, 244
- depolarization, 7
- depolarizers, 253
- depth of field, 19, 20
- diagnostic window, 3
- diattenuation, 7, 243, 271, 273–277, 281, 282, 283, 286, 287, 288, 293, 295, 297, 298, 299, 300
- dichroic beamsplitter, 172, 174, 186, 180, 181, 182, 190, 191, 193, 195, 198–200, 202, 208, 227
- dichroic mirrors, 108, 181, 214, 215
- dichroic polarizers, 256
- diffraction, 110, 112, 119, 120, 128, 129, 131, 132, 134, 136, 138, 140, 141, 145, 146, 156, 160
- diffractive optical element (DOE), 205
- diffuser, 154, 155, 156
- diffusion theory, 5
- digital micromirror devices (DMDs), 175
- distortion 29, 38, 51, 58, 59, 60, 118, 122, 148, 327, 328, 335, 336, 343, 348, 349, 351, 354, 356, 357, 360, 368, 371, 387, 390–410, 412, 416, 417, 433, 435, 436, 437, 443
- dome, 431–442
- double Gauss, 62
- double telecentric, 17, 18
- duty cycle, 337, 339, 342
- dynamic range, 118
- edge filters, 181
- effective focal length (EFL), 138, 399
- effective refractive index, 186
- eigenpolarizations, 266
- electromagnetic actuator, 209
- electron-multiplying charge-coupled device (EMCCD), 179
- ellipticity angles, 239
- ellipticity, 234, 235, 236, 239, 261, 267
- emission filters, 177, 195, 200, 207
- emission spectrum, 8, 167, 169, 178, 192, 193
- emission, 8, 117, 156, 165, 166, 167, 168, 169, 170, 172, 173, 174, 175, 176, 177, 178, 180, 181, 183, 190–202, 204–209, 211, 212, 213, 215–219, 222, 223, 225
- enamel, 2, 4
- encircled energy, 43, 47, 64
- endogenous, 169
- endoscopy, 67
- ensquared energy, 47
- entrance pupil, 16, 17, 44
- entrance window, 17
- epifluorescence, 313
- epi-illumination, 105, 117, 119, 152, 153, 158, 162
- étendue, 21, 23
- excitation filters, 213
- excitation, 3, 8, 11, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 180, 181, 190–214, 216–219, 222, 223, 224, 225, 226, 227, 311, 312, 315, 319, 321, 329, 351, 352, 355, 364, 373
- excitation-emission matrices (EEM), 84, 212, 213
- exit pupil, 16, 17, 19, 28, 32, 48, 103, 104, 115, 116, 120, 145, 146, 148, 149, 150, 151
- exit window, 17
- exitance, 22
- exogenous fluorophores, 165, 169, 170, 199

- eye relief, 115, 149, 151
eyepiece matching distance, 108
eyepiece, 103, 105, 108, 109, 110, 113, 115, 116, 122, 131, 147–151, 163, 379, 380, 381, 383, 384, 385, 387, 388, 398, 419
- F*-number (*f*#\$), 51, 55, 61
faceplates, 81
fiber bundles, 67, 68, 79, 81–87, 91–93, 95, 98, 101, 379, 381, 382, 385, 386, 400, 401, 403, 410, 420, 421, 422, 424–430
fiber light guide, 79, 82, 83, 175, 219
fiber tips, 77, 80
field curvature, 29, 36, 37, 43, 48, 49, 51, 58, 61, 65, 113, 119–121, 125–131, 133–137, 145, 147, 148, 151, 154, 207, 208, 228, 327, 328, 332, 335, 336, 343, 344, 346, 348, 349, 351, 353, 356–371, 390–397, 399, 402, 403, 404, 409, 410, 414–416, 433, 436
field lens, 61
field of view (FOV), 14, 17, 24, 32, 37, 40, 49–52, 61, 62, 63, 113, 118–122, 128, 129, 130, 133, 134, 138, 141, 145, 146, 149, 151, 153, 160, 175, 196, 203, 204, 207, 217, 218, 219, 225, 228, 246, 300, 312, 329, 335, 337, 340, 345, 346, 353, 355, 356, 357, 360, 363, 364, 365, 368, 370–373, 382, 383, 391, 395, 396, 398, 402–421, 427, 431, 432, 433, 435, 437–441
field stop, 17, 153, 154
finite-corrected, 103, 104
flavin adenine dinucleotide (FAD), 167, 169
fluence rate, 78
fluorescein isothiocyanate (FITC), 169, 176
fluorescence decay time, 173
fluorescence filters, 174, 177, 180
fluorescence imaging, 165, 167, 169–180, 182, 183, 186, 190–193, 196–221, 229, 231
fluorescence lifetime imaging, 173
fluorescence lifetime, 8
fluorescence process, 165, 166
fluorescence, 1, 7, 8, 10, 11, 165–182, 183, 186, 189–226, 229–232
fluorescent dyes, 166
fluorescent light, 171
fluorescent probes, 166
fluorochromes, 166, 172, 179
fluorophores, 8, 167–170, 174, 175, 176, 177, 191, 192, 194, 200, 201, 213, 217
focal planes, 14
focal points, 13, 14, 15
focusing lens, 381, 398
Fourier transform spectroscopic imaging, 173
frequency domain, 173, 230
frequency-domain imaging, 10, 11
Fresnel loss, 82
Fresnel number, 323
Fresnel reflection, 82, 410, 430, 437, 442
Fresnel rhomb, 269, 272
front focal length (FFL), 14
full width at half maximum (FWHM), 9, 180, 192, 245
full-wave retarder, 266
- galvanometer scanners, 324
galvanometer, 324–326, 339, 356
gastroscope, 379
Gaussian equations, 15
Gaussian optics, 13
geometrical extent. *See* throughput
geometrical optics, 13
graded-index fiber, 71
graticule, 115
green fluorescent protein (GFP), 167, 169–171
GRIN lens, 385, 389, 397, 410, 411

- hard coating, 186
hard tissues, 2
hard-coated filters, 186
helicity, 245
hemoglobin, 3, 247, 252
heterogeneity, 9
hexagonal packing, 81
higher-order aberrations, 43
hollow waveguides, 67, 101
holographic filters, 182
Hopkins rod-lens relay, 391, 393
hot mirror, 86, 87
hybrid imaging, 216
- illumination, 67, 68, 77, 79, 80, 82, 84, 86, 87, 89, 91, 92
image formation, 13
image quality, 13, 17, 29, 31, 43, 47, 48, 49, 61, 65
imaging fiber bundles, 79, 82
immersion liquid, 109, 125, 132, 139, 140
incoherent fiber bundle, 79
index-guiding fibers, 68
indocyanine dye Cy5.5, 170
indocyanine green dye (ICG), 170
infinity-corrected, 104, 105, 106, 108, 110, 114, 115, 122, 145
infrared (IR), 3, 170, 175, 178, 182, 420
intensified CCD (ICCD), 179
intermediate image plane, 103, 104, 105, 108, 114, 145, 146, 149, 151
intermediate images, 381
intrinsic absorption, 72
intrinsic birefringence, 288, 291
inverse-square law, 23, 24
irradiance, 9, 10, 22–25
- Jablonski energy diagram, 165, 166
Jones calculus, 236, 237
Jones matrix, 236, 237, 303
Jones vector, 236, 243
- kidney bean effect, 149
- Köhler illumination, 105, 153, 156–159, 191, 204, 218
- Lagrange invariant, 20, 21, 23
Lambert's cosine law, 23
Lambertian source, 23
laser damage threshold, 255, 270
lateral chromatic aberration, 122, 131, 134, 140, 146, 147, 327, 328, 343, 349–352, 356, 357, 370, 373, 390, 391, 394, 396, 398–406, 408, 409, 417, 435, 436
lateral magnification, 15
lateral resolution, 110, 111
lens bending, 51, 54, 122
lens combination, 55
lens compounding, 55
lens design, 13, 51, 61, 65
lenslet array, 204, 205, 219
light absorber, 200
light collection efficiency, 108, 118
light gathering power, 108
linear birefringence, 243
liquid crystal devices (LCDs), 175
liquid crystal tunable filters, 182
liquid light guides, 67, 87
Lister objective lens, 129, 130
longitudinal aberration, 26, 27, 35, 37
longitudinal magnification, 15, 16
longpass filter, 171, 180, 181, 183, 192, 199
- macrofluorescence, 203
macroimaging, 196, 203, 205, 219
magnetic resonance imaging (MRI), 1
magnification, 104, 109–113, 115, 119, 120, 121, 128, 129, 131, 133, 135, 136, 140, 149, 162, 320, 323, 330, 343, 351, 353, 367, 370
Maréchal criterion, 51
marginal focus, 31
marginal ray bundle, 136
marginal ray, 16, 20, 31, 40, 41, 61

- mechanical tube length, 107
melanin, 2, 3
meridional rays, 70
merit functions, 62, 64
metal halide, 175
micro-elecromechanical system (MEMS), 209, 210, 324, 326, 339, 359, 360, 362, 363, 365, 376
microimaging, 196, 199
Mie scattering, 3
mitochondria, 2
modal dispersion, 71
mode mixing, 72
mode stripping, 72
modulation transfer function (MTF), 43, 48, 49, 62, 64, 323, 324, 343, 345, 346, 347, 364, 370, 413, 416
molecular imaging, 1
molecule, 3, 6, 7, 167, 170
monochromatic aberration, 26, 31
Mueller matrix, 241, 253, 303, 305, 306
multicolor, 172, 213
multimode fibers, 70, 71, 78, 92, 209
multiphoton imaging, 11
multiple-order retarder, 267, 268
- natural birefringence, 288
Newtonian equations, 15
nicotinamide adenine dinucleotide (NADH), 8, 167
Nipkow disk, 330, 332–337, 375
noncoherent light sources, 174
noninvasive, 2
normalized frequency, 70, 71
nuclei, 2
Nyquist frequency, 48
- object distance, 123, 124
objective lens, 17, 47–52, 62, 105–110, 114, 119–123, 126–130, 132, 134, 135, 136, 139, 140, 145, 153, 192, 199, 201, 202, 206, 218–220, 225–228, 232
- oblique aberrations, 58
odd aberrations, 32, 59, 387
off-axis aberration, 31
oil immersion, 124, 125, 132, 134
optical activity, 243
optical activity, 7
optical coherence tomography (OCT), 17, 216, 217, 231
optical contrasts, 1
optical fibers, 67, 70
optical path difference (OPD), 19, 289
optical properties, 1, 2, 12
optical sectioning, 313, 321, 322
optical sections, 311, 313
optical spectroscopy, 67
optical tube length, 103, 107, 108
organelles, 2
orientation, 233–236, 239, 247, 264, 291, 295
orientational birefringence, 289
orientational coefficient, 289
- packing fraction, 81, 93
paddle scanner, 340, 341
Pancharatnam achromatic retarder, 269
parameters, 70, 86, 105, 108, 115, 116, 118, 123, 139, 141, 144, 147, 149, 160
paraxial approximation, 25
paraxial focus, 31
paraxial image plane, 26–31, 38, 40, 45
parfocal distance, 105, 106
patterned polarizers, 264
penetration depth, 5, 249
Petzval curvature, 36, 37, 61, 113, 126, 129, 135
Petzval curvature
Petzval sum, 61, 394, 415
Petzval surface, 36, 37
phase contrast, 103, 114
photobleaching, 166, 168, 192, 207
photoelastic coefficient, 291

- photomultiplier tube (PMT), 174, 178, 191, 196, 205, 209, 211
photonic crystal fibers (PCFs), 67
photonic crystals, 67
photons, 3, 6, 7, 8, 11, 173, 178, 179, 183, 250
phototoxicity, 207
phycoerythrin (PE), 169
piezoelastic modulators (PEMs), 270
piezoelectric driven actuator, 209
pincushion distortion, 38
pinhole lens, 322, 323, 324, 330
pinhole, 188, 189, 191, 311, 313–318, 321–324, 330, 333, 335, 337, 339, 349, 351, 358, 359, 361, 366, 367
pivot point, 316, 337, 339, 340, 342, 360, 361, 365
plan apochromat, 49–52, 110, 120, 135, 137, 148
plan apochromatic
plan fluorite, 110, 120, 133
plate polarizer, 258
Pockels cells, 270
Poincaré sphere, 236
point spread function (PSF), 47, 49, 51
polarization aberrations, 273, 288, 293, 295, 299, 300
polarization beamsplitter, 246, 258, 259, 261, 263, 288
polarization converter, 265
polarization ellipse, 236, 239, 295
polarization gating, 7
polarization ratio image, 248
polarization splitting, 187
polarization state, 5
polarization, 1, 5–11, 186, 187, 216, 233–261, 263, 264, 265, 266, 267, 270, 271, 272, 273, 274, 276, 279, 280, 281, 283, 286, 287, 288, 291, 292, 293, 294, 295, 296, 297, 299–308
polarizers, 236, 239, 241, 253–259, 261–265, 271, 272, 280, 281, 288, 295, 430, 432
polygonal scanners, 324, 325
porphyrins, 167, 169, 228
power density, 78
principal planes, 14, 15
principal points, 13, 14, 51
principal rays, 14
prismatic scanner, 325
projected area, 21–23
projected, 22
protected-graft copolymer (PGC), 170
protein, 3
pupil spherical aberration, 148
pushbroom scanning, 173
pyramidal error, 325
pyramidal scanner, 325
quantum efficiency (QE), 118, 168
quarter-wave retarder, 263
radiance, 23, 25
radianc intensity, 23
Raman scattering, 1, 3, 6
ray aberration, 26–30, 32, 35, 37, 38, 43
Rayleigh criterion, 110
Rayleigh scattering, 3
red fluorescence protein (RFP), 170
reflectance, 10, 11, 12, 22, 171, 172, 184, 201, 216, 217, 229, 230
reflection, 1, 2, 5, 11
refraction, 125, 160
refractive index, 2, 3, 5, 8, 9, 108, 109, 113, 123–127, 132, 133, 139, 140, 383, 387, 388, 391, 394, 403
relay lens, 316, 317, 325, 335, 336, 340, 342–346, 357, 368
resolving power, 108, 110, 111, 160
resonant scanner, 325
retardance, 266–277, 281–287, 293, 295, 297–300

- retarders, 236, 241, 253–270, 272, 273, 295
rms spot radius, 44, 49, 62, 390, 391
rms wavefront error, 48, 62
rod lenses, 379, 380, 392, 394, 396, 398
rotation matrix, 243
rotators, 253
- sagittal coma, 34
scatterers, 233
scattering coefficient, 2, 5, 9
scattering function, 4
scattering, 1–11, 160, 170, 173, 185, 186, 196, 201, 216, 233, 243–245, 247–253, 258, 270, 304–306
Schwarzschild objective lens, 141, 144, 145, 146, 300–303
scratches and digs, 188
second harmonic generation (SHG) imaging, 11
secondary chromatic aberration, 40
Seidel aberrations, 40
sheet polarizer, 255–257
shortpass filter, 180–182, 192
side view, 360
signal-to-noise ratio (SNR), 93, 312, 322
single-mode fiber
single-mode fibers, 70, 71, 92, 209
skew rays, 70
slope, 181, 185, 192
Snell’s law, 25, 53
soft coatings, 184
solarization, 220
solid angle, 4, 21, 22
solid-core fibers, 67, 68
solid-state detector, 118
spatial filtering, 10
spatial light modulators, 175
spectra, 1, 8, 11, 167, 168, 170, 173, 176, 193, 194, 199, 222, 223
spectral imaging, 11
spectral polarization difference imaging (SPDI), 249–251
- specular reflection, 246–250, 253
spherical aberration, 3, 9, 29–32, 43, 44, 46, 51, 53, 55–59, 113, 119–122, 125, 129–136, 138, 140–145, 148, 149, 151, 154, 157, 313, 320, 328, 335, 349, 350, 360, 363, 365, 371
spot diagram, 43, 44, 45, 46
square packing, 81
stage scan, 324, 328, 329, 330, 352
step-index fiber, 68, 71, 73
Stokes shift, 167, 193, 199
Stokes vector, 238, 239, 241, 243
stop shift, 58, 59
straight view, 360
Strehl ratio, 43, 49, 51, 52, 64, 119, 128, 130, 131, 140, 145
stress-induced birefringence, 270, 273, 289, 291–294
stress-optical coefficient, 289, 293
surface flatness, 188, 189
- tandem-scanning reflected-light microscope (TSRLM), 332, 333
tangential coma, 34
Telan system, 104, 108
telecentric, 17, 18, 60, 103, 119, 129, 153, 384, 385, 389, 401–404, 413, 415
telecentricity, 17, 119, 131, 153, 384, 385, 386, 398, 400
therapeutic window, 3, 5, 6
thin-film filters, 182, 184, 186, 188, 203
third-order aberrations, 29, 51, 64
through-focus, 44, 46
throughput, 19, 21, 23
time domain, 173
time gating, 10
total internal reflection (TIR), 67, 68, 73, 78, 82, 276, 283
transillumination, 10, 117, 119, 152, 153, 158, 162, 247
transmission, light, 1

- transmitted wavefront distortion, 188
transverse ray aberrations, 27
true zero-order retarder, 267
tube lens, 104, 105, 108, 110, 114, 115, 118, 119, 121, 122, 131, 145, 146, 147

ultrasound imaging, 1, 11
ultraviolet (UV), 3, 165, 168, 175, 176, 182, 183, 188, 192, 201, 216, 220, 221, 222, 225, 226, 228, 420, 421
unit magnification, 14, 60, 381
unpolarized light, 236

variable retarders, 270
video endoscope, 379, 386, 387, 419
viewing window, 432, 433, 436
vignetting, 17, 119, 149, 389, 390, 391, 394, 395, 415

wave plate, 265, 266, 268
wavefront aberration, 26–29, 31, 40, 42
wavefront deformation, 9
wavefront quality, 255, 257, 268, 270, 271
wedge error, 186
wedge, 185, 186, 188, 189, 191
wide-angle mode, 411–414
wire-grid polarizer, 261–263, 272, 307
wireless endoscope, 379, 430, 437, 438
working distance, 14, 25, 62, 106, 108, 113, 114, 121, 128–130, 135, 136, 138, 139, 141

x-ray imaging, 1

zero-order retarder, 267, 268



Rongguang (Ron) Liang is currently a Senior Principal Research Scientist at Carestream Health, Inc. (formerly Health Group of Eastman Kodak Company), where he develops and designs biomedical optical imaging systems. Previously, he was a Principle Research Scientist at Eastman Kodak Company, where he developed imaging technologies for medical/biomedical systems, display, digital imaging, and printing. Dr. Liang currently serves as a topical editor for *Applied Optics*. He received his Ph.D. in Optical Sciences from the College of Optical Sciences, University of Arizona.