

# Glossary of Symbols and Acronyms

$A$	area ( $\text{m}^2$ ); optical absorption
$A_b$	beam area ( $\text{mm}^2$ )
$A_d$	detector area ( $\text{mm}^2$ )
$A_{EP}$	entrance pupil area ( $\text{mm}^2$ )
$A_o$	illuminated object area ( $\text{mm}^2$ )
$A_p$	pixel area ( $\mu\text{m}^2$ )
AO	acousto-optic
AOI	angle of incidence (rads)
APD	avalanche photodiode
APS	active-pixel sensor
AR	antireflection
ASE	amplified spontaneous emission
$A\Omega$	étendue ( $\text{m}^2\text{-sr}$ )
$B$	focused blur diameter ( $\mu\text{m}$ ); PSD frequency exponent
$B_{SA}$	focused blur diameter due to spherical aberration ( $\mu\text{m}$ )
BFD	back focal distance
BPF	bandpass filter
BPP	beam-parameter product (mm-mrad)
BPDF	bidirectional scatter distribution function
$c$	speed of light, $\approx 3 \times 10^8$ m/sec
$C$	wavefront or surface curvature (1/mm)
$C_o$	wavefront curvature incident on lens (1/mm)
$C_i$	wavefront curvature exiting lens (1/mm); image contrast
$C_{sp}$	speckle contrast
$C_{well}$	charge-well capacitance (pF)
CA	clear aperture
CCD	charge-coupled device
CDS	correlated double sampling
CMOS	complementary metal-oxide semiconductor

CoO	cost of ownership
COTS	commercial off-the-shelf
cps	counts per second
CRT	cathode-ray tube
CTE	charge-transfer efficiency; coefficient of thermal expansion
CTIA	capacitive transimpedance amplifier
CW	continuous wave
<i>d</i>	distance (m)
$d_c$	coherence length (m)
$d_{c,n}$	coherence length in a medium of index $n$ (m)
$d_{FP}$	Fabry–Pérot cavity thickness (mm)
$dn/dT$	change in index with temperature (1/K)
$d_p$	pixel size ( $\mu\text{m}$ )
$D$	lens diameter or aperture size (mm); fiber diameter ( $\mu\text{m}$ )
$D_{1/e^2}$	beam diameter ( $1/e^2$ ) incident on or exiting from a lens (mm)
$D_b(z)$	beam diameter (mm)
$D_{EP}$	entrance-pupil diameter (mm)
$D_o$	waist diameter (mm)
DBR	distributed Bragg reflector
DCR	dark-count rate [ $e^-/\text{sec}$ or counts per sec (cps)]
DE	directed energy
DFG	difference-frequency generation
DI	direct injection
DLC	diamond-like carbon
DoF	degrees of freedom
DOF	depth of focus ( $\mu\text{m}$ )
dpi	dots per inch
DPSS	diode-pumped solid-state
DWDM	dense wavelength-division multiplexing
$E$	irradiance ( $\text{W}/\text{m}^2$ ); Young's modulus (GPa)
$E_g$	bandgap energy (J or eV)
$E_i$	electron energy for energy level $i$ (J or eV)
$E_o$	Gaussian peak irradiance ( $\text{W}/\text{m}^2$ )
$E_p$	photon energy (J or eV)
EB-CCD	electron-bombarded CCD
EB-CMOS	electron-bombarded CMOS
EFL	effective focal length (mm)
EM	electromagnetic
EM-CCD	electron-multiplying CCD
EOL	end of life

EOM	electro-optic modulator
ESD	energy spectral density
$f$	focal length (mm); electrical frequency (Hz)
$f_d$	FPA cutoff frequency (lp/mm)
$f_{RO}$	relaxation-oscillation frequency (Hz)
$f_s$	spatial frequency (lp/mm); mirror scan frequency (Hz)
$f/\#$	relative aperture, $\equiv f/D$
$F$	fluence ( $J/m^2$ )
$F(G)$	excess noise factor
$F_R$	cavity finesse based on power reflectivity $R_p$
FBG	fiber Bragg grating
FET	field effect transistor
FF	FPA fill factor
FHG	fourth-harmonic generation
FOI	field of illumination (rad)
FOR	field of regard (rad)
FOV	field of view (rad)
FP	Fabry–Pérot
FPA	focal plane array
FPN	fixed-pattern noise
FR	frame rate [Hz or frames per sec (fps)]
FSM	fast-steering mirror
FSR	free spectral range (Hz)
FWHM	full-width at half-maximum
$g$	laser gain (1/cm)
$g_i$	laser-cavity stability parameter
$G$	detector gain; thermo-optic constant (1/K)
GM-APD	Geiger-mode APD
GVD	group-velocity dispersion
$h$	Planck's constant, $= 6.626 \times 10^{-34}$ J-sec; mirror thickness (mm)
HFOV	half-FOV (rad)
HAZ	heat-affected zone
HPD	hybrid photodetector
HR	high reflectivity
HSF	high spatial frequency
HT	high transmission
HWP	half-wave plate
$i$	current (A)
$i_b$	detector background current (A)

$i_d$	detector current (A)
$i_{dc}$	detector dark current (A)
$i_s$	detector signal current (A)
$i_{th}$	laser threshold current (A)
$I$	intensity (W/sr)
IAD	ion-assisted deposition
IBS	ion-beam sputtering
ICCD	intensified CCD
IFOV	instantaneous FOV ( $\mu\text{rad}$ )
IR	infrared
IRCM	IR countermeasure
ISO	International Standards Organization
$J$	rotational moment of inertia ( $\text{kg}\cdot\text{m}^2$ )
$k$	APD ionization coefficient; thermal conductivity (W/m-K)
$K_{SA}$	blur size factor due to spherical aberration
$K_T$	truncation factor
KTP	potassium titanium-oxide phosphate
$L$	length (m); radiance or brightness ( $\text{W}/\text{m}^2\text{-sr}$ )
$L_i$	image radiance ( $\text{W}/\text{m}^2\text{-sr}$ )
$L_s$	source radiance ( $\text{W}/\text{m}^2\text{-sr}$ )
$L_\lambda$	spectral radiance or brightness ( $\text{W}/\text{m}^2\text{-sr}\cdot\text{nm}$ )
LAM	laser additive manufacturing
LCOS	liquid crystal on silicon
LCPG	liquid crystal polarization grating
LDT	laser damage threshold ( $\text{J}/\text{cm}^2$ or $\text{W}/\text{cm}^2$ )
LED	light-emitting diode
LIDT	laser-induced damage threshold
LLL	low light level
LMA	large mode area
LM-APD	linear-mode APD
lp	line pair
LWIR	longwave IR
$m$	integer, 1, 2, 3...; waist magnification $w_{02}/w_{01}$ ; mass (kg)
$m_i$	image modulation; image magnification
$m_{\text{lens}}$	lens object-image magnification
$m_p$	peak waist magnification $w_{02}/w_{01}$ at $1f:1f$ conjugates
$M$	square-root of $M^2$
$M^2$	beam quality compared with a diffraction-limited $\text{TEM}_{00}$ beam

$M_a$	afocal telescope magnification
MCP	micro-channel plate
MCT	mercury cadmium telluride
MEMS	micro-electromechanical system
MLM	multiple longitudinal mode
MMF	multimode fiber
MOPA	master-oscillator power amplifier
MPE	maximum permissible exposure; multiphoton excitation
MPN	mode-partition noise
MPPC	multipixel photon counter
MRF	magneto-rheological finishing
MSF	mid-spatial-frequency
MTF	modulation transfer function
$MTF_{det}$	detector MTF
$MTF_{opt}$	optical MTF
$MTF_{sys}$	system MTF
MTTF	mean time-to-failure
MWIR	midwave IR
$n$	refractive index
$n_e$	number of electrons
$n_f$	number of polygon facets
$n_p$	number of photons
$n_s$	number of signal electrons
$n_w$	well depth ( $e^-$ )
$n_{\sigma amp}$	number of amplifier noise electrons ( $e^-$ )
$n_{\sigma b}$	number of background noise electrons ( $e^-$ )
$n_{\sigma dc}$	number of dark-current noise electrons ( $e^-$ )
$n_{\sigma FPN}$	number of spatial noise electrons ( $e^-$ )
$n_{\sigma read}$	number of read noise electrons ( $e^-$ )
$n_{\sigma RIN}$	number of RIN noise electrons ( $e^-$ )
$n_{\sigma s}$	number of signal noise electrons ( $e^-$ )
$n_{\sigma sp}$	number of speckle noise electrons ( $e^-$ )
$N$	number of longitudinal modes; resolvable spots; detector noise ( $A$ or $e^-$ )
$N_e$	number of electrons per second ( $e^-/sec$ )
$N_i$	number of electrons per unit volume in energy level $i$ ( $1/m^3$ )
$N_p$	number of photons per second ( $\#/sec$ ); number of pixels
NBF	narrow-band filter
NEP	noise-equivalent power ( $W$ or $W/Hz^{1/2}$ )
$NEP_{amp}$	amplifier-limited NEP ( $W$ or $W/Hz^{1/2}$ )
$NEP_s$	signal-limited NEP ( $W$ or $W/Hz^{1/2}$ )

NEPh	noise-equivalent photons (# of photons)
NIR	near-IR
NPRO	nonplanar ring oscillator
NRE	nonrecurring engineering
NSD	noise spectral density (A/Hz <sup>1/2</sup> )
NUC	non-uniformity correction
NUV	near UV
OCS	optical cross-section (m <sup>2</sup> /sr)
OCT	optical coherence tomography
OPA	optical phased array
OPL	optical path length (= $nd$ , $\mu\text{m}$ or waves)
OPO	optical parametric oscillator
OPSL	optically pumped semiconductor laser
OXT	optical crosstalk
$P$	CW output power (W)
$P_{\text{avg}}$	average output power (W)
$P_{\text{elec}}$	electrical power (W)
$P_{\text{d}}$	probability of detection
$P_{\text{fa}}$	probability of false alarm
$P_{\text{h}}$	horizontally polarized power
$P_{\text{inc}}$	optical power incident on a lens or surface (W)
$P_{\text{peak}}$	peak output power (W)
$P_{\text{r}}$	optical power reflected by a lens or surface (W)
$P_{\text{t}}$	optical power transmitted by a lens or surface (W)
$P_{\text{th}}$	thermal heat load due to lens absorption (W)
$P_{\text{v}}$	vertically polarized power
PBS	polarizing beamsplitter
PCF	photonic crystal fiber
PDE	photon detection efficiency
PDH	Pound, Drever, and Hall
PER	polarization extinction ratio
PIB	power-in-bucket
PIN	<i>p-i-n</i> photodetector
PM	polarization-maintaining
PMT	photomultiplier tube
PRF	pulse repetition frequency (Hz)
PRNU	photo-response non-uniformity
PRR	pixel readout rate (Hz)
PSD	power spectral density (nm <sup>2</sup> -m), aka energy spectral density
PV	peak to valley; photovoltaic
PZT	piezoelectric transducer

$q$	electron charge, = $1.602 \times 10^{-19}$ C/e <sup>-</sup> ; lens shape factor
$Q$	heat load (W)
$Q_c$	cavity quality
$Q_p$	pulse energy (J)
$Q_{\text{store}}$	cavity photon-energy storage (J)
QCL	quantum-cascade laser
QCW	quasi-continuous wave
QE	quantum efficiency
QWP	quarter-wave plate
$r$	radial coordinate (m)
$R$	average power reflectivity; diffraction ripple; range (m)
$R(z)$	Gaussian wavefront radius of curvature (mm)
$R_f$	Fresnel surface reflectivity
$R_g$	responsivity after including detector gain $G$ (A/W)
$R_i$	wavefront radius of curvature exiting lens (mm)
$R_o$	wavefront radius of curvature incident on lens (mm); detector responsivity (A/W)
$R_p$	reflectance of $p$ -polarized light
$R_{pi}$	power reflectivity of surface $i$
$R_s$	reflectance of $s$ -polarized light
$R_t$	thermal resistance (K/W)
RHS	right-hand side
RIN	relative intensity noise (1/Hz or dB/Hz)
RMS	root mean square
ROI	region-of-interest
ROIC	readout integrated circuit
RPM	revolutions per minute
RSS	root sum square
$s$	incoherent source size (mm)
$s_o$	object distance (mm)
$s_i$	image distance (mm)
sCMOS	scientific-grade CMOS
$S$	Strehl ratio; mirror width (mm); detector signal (A or e <sup>-</sup> )
SA	spherical aberration
SAM	saturable-absorber mirror
SESAM	semiconductor saturable-absorber mirror
SFE	surface figure error ( $\mu\text{m}$ or waves)
SFG	sum-frequency generation
SHG	second-harmonic generation
SiPM	silicon photomultiplier
SLM	single longitudinal mode

SMF	single-mode fiber
SNR	signal-to-noise ratio
SPAD	single-photon avalanche detector
SPCM	single-photon counting module
SPDT	single-point diamond turning
SRS	stimulated Raman scattering
STED	stimulated emission depletion
SWaP	size, weight, and power
SWIR	shortwave IR
$t$	time (sec)
$t_f$	time of flight (sec)
$t_{\text{int}}$	detector integration time (sec)
$t_s$	scan time (sec)
$T$	truncation ratio; optical transmittance; temperature (K); torque (N-m)
$T_{\text{atm}}$	atmospheric transmission
$T_{\text{ext}}$	external transmission
$T_{\text{int}}$	internal transmission
$T_{\text{opt}}$	optical transmission
$T_p$	pulse period (sec)
$T_{\text{PIB}}$	transmitted power-in-bucket
$T_{\text{trunc}}$	optical transmission after truncation losses
TCK	transfer clock
TDL	times diffraction limited
TEA	transversely excited atmospheric
TEC	thermoelectric cooler
$\text{TEM}_{pq}$	transverse electro-magnetic mode with integer number of nodes $p$ and $q$
THG	third-harmonic generation
TIA	transimpedance amplifier
TIR	total internal reflection
TIS	total integrated scatter
ToF	time of flight (sec)
ULE	ultralow expansion
USP	ultrashort pulse
UV	ultraviolet
$v$	scan velocity (m/sec)
$v_g$	group velocity (m/sec)
$V$	volume (cm <sup>3</sup> )
$V_b$	bias voltage (V)



$V_{br}$	breakdown voltage (V)
VAC	volts of alternating current
VCSEL	vertical-cavity surface-emitting laser
VECSEL	vertical-external-cavity surface-emitting laser
VIS	visible
VPR	pixel reset voltage
VUV	vacuum UV
$w(z)$	Gaussian $1/e^2$ beam radius (mm)
$w_o$	Gaussian $1/e^2$ waist radius (mm)
$w_{01}$	Gaussian $1/e^2$ object-waist radius (mm)
$w_{02}$	Gaussian $1/e^2$ image-waist radius (mm)
$w_{oM}$	laser waist radius for an embedded beam with quality $M^2$ (mm)
WD	working distance
WFE	wavefront error ( $\mu\text{m}$ or waves)
WP	wall plug
$x$	transverse coordinate (m)
$x_p$	pixel pitch ( $\mu\text{m}$ )
$y$	transverse coordinate (m)
$y_{MSF}$	surface error (nm)
$z$	axial (or longitudinal) propagation axis (m)
$z_1$	object waist-to-lens distance (mm)
$z_2$	lens-to-image waist distance (mm)
$z_{FF}$	far-field distance (m)
$z_R$	Rayleigh range (m)
$z_{R1}$	Rayleigh range of the object waist (m)
$z_{R2}$	Rayleigh range of the image waist (m)
$\alpha$	angular acceleration ( $\text{rad}/\text{sec}^2$ )
$\alpha_{int}$	internal loss (1/cm)
$\alpha_m$	mirror loss (1/cm)
$\alpha_m(\lambda)$	material attenuation coefficient (1/cm)
$\alpha_t$	coefficient of thermal expansion (1/K)
$\beta_{SA}$	angular blur size due to spherical aberration ( $\mu\text{rad}$ )
$\delta$	mirror dynamic deflection ( $\mu\text{m}$ )
$\delta_{RMS}$	RMS surface finish ( $\text{\AA}$ or nm)
$\delta_T$	mirror thermal distortion ( $\mu\text{m}$ )

$\Delta d$	surface figure error (SFE) or irregularity ( $\mu\text{m}$ or waves)
$\Delta f$	electrical bandwidth (Hz)
$\Delta L$	change in cavity length ( $\mu\text{m}$ )
$\Delta L_t$	change in cavity length due to thermal expansion ( $\mu\text{m}$ )
$\Delta Q$	gain bandwidth (J)
$\Delta R$	range resolution (m)
$\Delta t_p$	pulse width (sec)
$\Delta T$	temperature change (C or K)
$\Delta v$	velocity variation (m/sec)
$\Delta x$	distance between spatial features (mm)
$\Delta y$	change in beam-pointing location ( $\mu\text{m}$ )
$\Delta z_{\text{ast}}$	axial astigmatism ( $\mu\text{m}$ )
$\Delta \phi$	phase difference (rad)
$\Delta \lambda$	emission linewidth ( $\mu\text{m}$ or nm)
$\Delta \lambda_g$	gain bandwidth ( $\mu\text{m}$ or nm)
$\Delta \nu$	emission linewidth (Hz)
$\Delta \nu_a$	axial mode spacing (Hz)
$\Delta \nu_g$	gain bandwidth (Hz)
$\Delta \nu_L$	frequency shift or broadening due to change in cavity length (Hz)
$\Delta \nu_{\text{MLM}}$	multi-longitudinal-mode emission linewidth (Hz)
$\Delta \nu_R$	laser or etalon cold-cavity transmission bandwidth (Hz)
$\Delta \nu_{\text{SLM}}$	single-longitudinal-mode cold-cavity linewidth (Hz)
$\Delta \nu_{\text{ST}}$	Schawlow–Townes single-longitudinal-mode emission linewidth (Hz)
$\Delta \theta$	mirror misalignment angle or change in beam pointing angle ( $\mu\text{rad}$ )
$\Delta \theta_d$	diffraction angle
$\Delta \theta_m$	change in mirror mechanical pointing angle
$\Delta \omega$	linewidth (rad/sec)
$\Delta \omega_a$	axial mode spacing (rad/sec)
$\varepsilon$	obscuration ratio
$\Phi$	optical power collected by an optical system (W)
$\Phi_L$	refractive or reflective power of a lens or mirror (1/m)
$\gamma_{\text{obs}}$	obscuration loss
$\eta$	polygon geometric efficiency factor
$\eta_{\text{GM}}$	Geiger-mode avalanche efficiency
$\eta_s$	slope efficiency (W/A)
$\eta_{\text{QE}}$	quantum efficiency – also see QE
$\eta_{\text{WP}}$	wall-plug efficiency (%)

$\lambda$	wavelength ( $\mu\text{m}$ or $\text{nm}$ )
$\lambda_o$	center wavelength ( $\mu\text{m}$ or $\text{nm}$ )
$\nu$	optical frequency ( $= c/\lambda$ , Hz)
$\nu_m$	axial mode frequency (Hz)
$\nu_p$	pump optical frequency (Hz)
$\nu_{pqm}$	transverse mode frequency (Hz)
$\theta$	angular coordinate or angular scan range (rad)
$\theta_{01}$	far-field half-divergence angle incident on lens (rad)
$\theta_{02}$	far-field half-divergence angle exiting lens (rad)
$\theta_d$	diffraction angle (rad)
$\theta_{DL}$	diffraction-limited full-divergence angle (rad)
$\theta_o$	far-field half-divergence angle (rad)
$\theta_s$	scatter angle (rad)
$\theta_{\text{slow}}$	slow-axis full-divergence angle (rad)
$\dot{\theta}$	angular velocity (rad/sec)
$\ddot{\theta}$	angular acceleration (rad/sec <sup>2</sup> )
$\rho$	power reflectivity; mass density ( $\text{kg}/\text{m}^3$ )
$\sigma_{\text{amp}}$	amplifier noise (A)
$\sigma_{\text{APD}}$	APD-detector signal noise (A)
$\sigma_b$	detector background noise (A)
$\sigma_{\text{dc}}$	detector dark-current noise (A)
$\sigma_{\text{FPN}}$	detector spatial noise (A)
$\sigma_n$	detector noise current (A)
$\sigma_o$	second-moment beam radius (mm)
$\sigma_p$	standard deviation of output power (W)
$\sigma_{\text{read}}$	detector read noise (A)
$\sigma_{\text{RIN}}$	detected RIN noise (A)
$\sigma_s$	detector signal noise (A)
$\sigma_{\text{sp}}$	detected speckle noise (A)
$\tau_c$	coherence time (sec)
$\tau_p$	photon lifetime or energy storage time (sec)
$\omega$	optical frequency ( $= 2\pi\nu$ , rad/sec)
$\Omega$	modulation frequency (rad/sec); solid angle (sr)
$\Omega_{f/\#}$	solid angle of lens focusing cone (sr)
$\Omega_{\text{IFOV}}$	solid angle of pixel IFOV (sr)



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