OPTICAL AND ELECTRO-OPTICAL ENGINEERING SERIES

ELECTRO-OPTICS HANDBOOK

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MARWOOD EDIGER

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ELECTRO-OPTICS HANDBOOK

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ACRONYMS

2DEG	two dimensional electron gas
2PA	two photon absorption
III-V	Group III, group V of periodic table
3HG	third harmonic generation
AEL	accessible emission limit
AM	amplitude modulation
ANSI	American National Standards Institute
AO	acousto-optic
APD	avalanche photodiode
APDs	avalanche photodiodes
APM	additive pulse mode locking
AR	anti reflection
ASE	amplified spontaneous emission
BEFWM	Brillouin enhanced four wave mixing
BH	buried heterostructure
BLIP	background-limited infrared performance
C/S	coupler/splitter
CAD	computer-aided design
CAIBE	chemically assisted ion-beam etching
CARS	coherent anti-stokes Raman spectroscopy
CBE	chemical beam epitaxy
CCD	charge coupled device
CDRH	Center for Devices and Radiological Health (of FDA)
Ch	choroid
CID	charge-injection device
CIE	Commission International de l'Eclairage
COD	catastrophic optical damage
CPM	colliding-pulse mode-locked
cw	continuous wave
D*	detectivity
DBR	distributed Bragg reflector
DCG	dichromated gelatin
DFB	distributed feedback
DFDL	distributed feedback dye lasers
DIN	Deutsche Institüt für Normung
DM	depth of modulation
DODCI	diethyloxadicarbon-cyanine iodide
DOES	double heterostructure optoelectronic switches
DoF	depth of focus
DUT	device under test
EA	electron affinity
EB	electron beam

EBCCD	electron bombarded charge coupled device
EBS	electron bombardment silicon
ECL	emitter-coupled logic
EKE	electronic Kerr effect
EL	exposure limits
EMI/ESD	electromagnetic impulse/electrostatic discharge
EO	electro-optic
ESA	excited state absorption
FAFAD	fast axial flow with axial discharge
FDA	Food and Drug Administration
FEL	free electron laser
FELs	free electron lasers
FET	field-effect transistors
FFT	fast Fourier transform
FGC	focusing grating coupler
FHD	flame hydrosis deposition
FID	free-induction decay
FM	frequency modulation
FOV	field of view
FTFTD	fast transverse flow with transverse discharge
FTP	Fourier transform plane
FWHM	full width half-maximum
G-R	generation-recombination
GRIN-SCH	graded index waveguide separate confinement heterostructure
GRO	Gamma Ray Observatory
GSMBE	gas source molecular beam epitaxy
GVD	group velocity dispersion
GVDC	group velocity dispersion compensation
HAZ	heat-affected zone
HbO	oxyhemoglobin (blood)
HBT	heterojunction bipolar transistors
HEAO	High Energy Astronomy Observatory
HEMTs	high-electron-mobility transistors
HID	high intensity discharge
HOE	holographic optical element
HpD	hematoporphyrin derivative
HR	high reflection
HR	high resistivity
HUD	head-up display
IC	integrated circuit
ICI	International Commission on Illumination
IDT	interdigital transducer
IEC	International Electrotechnical Commission
ILD	injection laser diodes
IO	image orthicon
IODPU	integrated optic disk pickup
IOSA	integrated optic spectrum analyzer
IPC	imaging proportional counter

ir	infrared
JFETs	junction FETs
KTP	$KTiOPO_4$, potassium tellurium phosphate
LANs	local area networks
LAVA	laser assisted vascular anastomosis
LDV	laser Doppler velocimeter
LED	light emitting diode
lidar	light detection and ranging
LIF	laser induced fluorescence
LIS	laser isotope separation
$LiTaO_3$	lithium tantalate
LLLTV	low light level television
LLNL	Lawrence Livermore National Laboratory
LM	light microscopy
LPE	liquid phase epitaxy
LSI	large scale integration
LSO	laser safety officer
LTE	local thermal equilibrium
LURE	Laboratoire pour l'Utilisation du Rayonment Electromagnetic
μm	micrometers (microns) = 10^{-6} meters
MAMA	multianode microchannel array
MBE	molecular beam epitaxy
MCP	microchannel plate
MES	metal semiconductor
ml	mode-locked
MMIC	monolithic microwave integrated circuit
MO	magneto-optic
MOCVD	metal organic chemical vapor deposition
MOPA	master oscillator power amplifier
MOS	metal-oxide-semiconductor
MOVPE	metal organic vapor phase epitaxy
MPE	maximum permissible exposure
MPI	multiphoton ionization
MQW	multiple quantum well
MSM	metal semiconductor metal
MTBF	mean time between failure
MTF	modulation transfer function
NA	numerical aperture
NALM	nonlinear amplifying loop mirror
NEP	noise-equivalent power
NHZ	nominal hazard zone
NIST	National Institute of Standards and Technology
nm	nanometers = 10^{-9} meters
NO	nitric oxide
NO	non-linear optic
NOHA	nominal ocular hazard area
NRL	Naval Research Laboratory
OD	optical density
OEIC	optoelectronic integrated circuits
OIC	optical integrated circuit
OKE	orientational Kerr effect

OODR	optical-optical double resonance
OPD	optical path difference
OPO	optical parametric oscillator
OSSE	Oriented Scintillation Spectrometer Experiment
PAC	photoactive compounds
PC	photoconductive
PDT	photodynamic therapy
PE	pigment epithelium
PES	photoelectron spectroscopy
PFL	pulse forming line
PGC	phase-generated carrier
PLL	phase-locked-loop
PM	polarization maintaining
PMMA	polymethyl methacrylade
PMT	photomultiplier tube
PPCM	passive phase conjugate mirror
PVF	polyvinyl fluoride
PWS	port wine stains
PZT	lead zirconate
PZT	piezoelectric transducer
QE	quantum-effect
QW	quantum-well
RC	resistance-capacitance
RE	rare earth
REC	rare earth cobalt
REMPT	resonantly enhanced multiphoton ionization
RGH	rare gas halide
RIBE	reactive-ion-beam etching
RIE	reactive ion etching
RIKES CARS	Raman-Induced Kerr-effect spectroscopy
RIMS	resonance ionization mass spectroscopy
RPM	resonant passive mode-locking
SAFAD	slow axial flow with axial discharge
SAW	surface acoustic waves
SBN	strontium barium nitrate
SBS	stimulated Brillouin scattering
SEBIR	secondary electron bombardment-induced response
SEC	secondary electron conduction
SEED	self-electro-optic effect devices
SELFOC	self-focusing
SEVA	slowly varying envelope approximation
SHG	second harmonic generation
SI	semi-insulating
SIT	silicon intensified tube
SLB	super lattice buffer
SLD	superluminescent diodes
SLM	single longitudinal mode
SMF	spectral matching factor
SNR_D	signal to noise ratio of a display
SNR_{DT}	signal to noise ratio of a display at threshold

SNR_{VO}	signal to noise ratio of video (for white noise)
SPM	self-phase modulation
SQW	single-quantum-well
SRS	stimulated Raman scattering
TCDD	tetra chlorodibenzo-*p* dioxin
TCE	trichloroethane
TEA	transversely excited atmospheric
TEA	trienthylamine
TEM	transmission electron microscopy
TGFBS	twin-grating focusing beam splitter
TGS	triglycerine sulfide
TGSe	triglycerine selanate
THG	third harmonic generation
TIR	total internal reflection
TMAE	tetraKis-(dimethylamino) ethylene
TMAH	trimethylaluminum hydride
TO	thermo-optic
TPF	two-photon fluorescence
TVL	threshold limit values
TVL/PH	television lines/picture height
uv	ultraviolet
VCO	voltage-controlled oscillator
VCSEL	vertical cavity surface emitting lasers
VLSI	very large scale integration
VLSIs	very large scale integrated circuits
VSTEP	vertical to surface transmission electro-photonic
vuv	vacuum ultraviolet
WDM	wavelength division multiplexing
XPM	cross phase modulation
YAG	yttrium aluminum garnet
YLF	$LiYF_4$, lithium yttrium fluoride

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CHAPTER 1
INTRODUCTION TO ELECTRO-OPTICS

Ronald W. Waynant and Marwood N. Ediger

1.1 INTRODUCTION

The field of electro-optics has become increasingly more important in the last 20 years as its prodigies and applications have found their way into most facets of science, industry, and domestic use. This near-revolution, which essentially started with the advent of the laser, has been the result of extensive parallel and often symbiotic development of sources, materials, and microelectronics. The combination of these technologies has enabled a great variety of compact devices with ever greater intelligence and performance. If source development was instrumental in initiating the field, materials and detectors were the binding elements. Vast improvements in optical materials have made fiber optics feasible and the availability of high-quality, affordable fibers has, in turn, made optical circuits and a variety of optical sensors possible. Refinement and development of new materials have resulted in an astonishing variety of devices to modulate, polarize, frequency-shift, and otherwise control coherent radiation. In turn, detectors have achieved greater performance and smaller size and cost.

This handbook attempts to cover a broad spectral bandwidth—from x-rays to far infrared. A primary motivation in extending the short-wavelength limit of the source spectrum, and the handbook's coverage of it, is the demand for higher resolving powers in materials and device fabrication applications as well as medical and biological imaging. Figure 1.1 depicts the size of objects of interest in the biological, materials science, and electronics worlds, and the wavelength necessary to resolve them as prescribed by the Rayleigh criterion. The infrared boundaries of the spectrum are also continually being strained by sources, materials, and detectors in the development of a variety of applications such as imaging, optical diagnostics, and spectroscopy.

Each chapter of this handbook falls into one of four categories: sources, materials, and their properties (e.g., nonlinear optics), detectors, and applications. In the remainder of this chapter we present some simple overlying principles of each category and a topical map to aid the reader in finding the desired information.

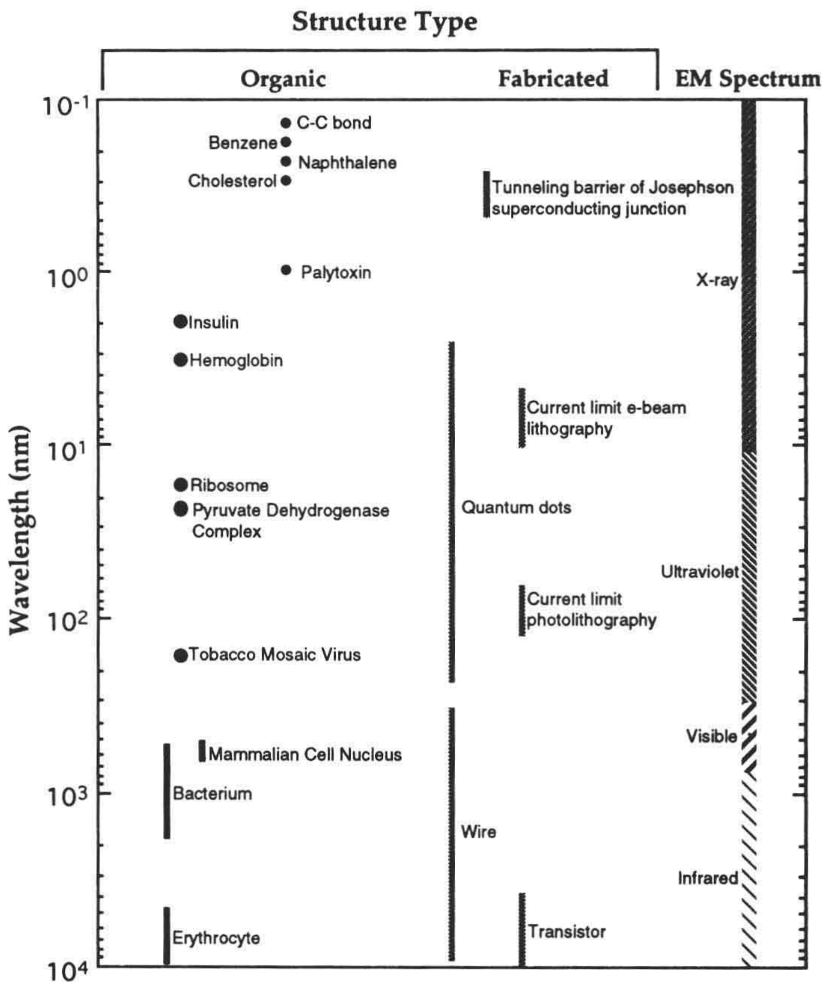

FIGURE 1.1 Relation of object size and resolving wavelength.

1.2 TYPES OF LIGHT SOURCES

Chapter 2 takes a detailed look at incoherent sources, and Chaps. 3 through 8 are devoted to the numerous laser sources grouped in part by media and in part by wavelength. Ultrashort pulse lasers and techniques are covered in Chap. 9.

Although the activity in the field of electro-optics has often been mirrored by events in laser development, incoherent sources still have an important role. Lasers are much newer and more space is devoted to them in the chapters to follow; however, the inescapable fact is that lamps currently have a much greater effect on our everyday lives than do lasers. With hundreds of millions of plasma discharge lamps and billions of incandescent light bulbs in constant use on a worldwide basis, power expenditure on lighting alone approaches the Terawatt level. Even the 22 percent or lower efficiency of most lamps still exceeds that of most lasers.

Arc lamps are characterized by high currents (several amperes) and high pressures (atmospheres) with ballast resistors used to prevent complete runaway. The lamps can be exceedingly bright. Examples include high-pressure (3 to 10 atmo-