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Biophotonics

Concepts to Applications

Springer

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To
Ching-yun, Nishla, Kai, and Neyla
for their loving patience and encouragement

Preface

The discipline of biophotonics or biomedical optics has undergone a fascinating journey in the past several decades and it is still growing rapidly. As the name *biophotonics* implies, the application of this field to biological disciplines is based on the wide range of photonics technologies, which involve the generation, detection, and control of photons for enabling functions such as transferring or processing information, analyzing material characteristics, sensing or measuring changes in physical parameters, and modifying material characteristics. Basically biophotonics deals with the interaction between light and biological material. The resulting interactions can be used in almost all biomedical areas for basic life science research and for biomedical diagnosis, therapy, monitoring, imaging, and surgery.

Owing to the importance of biophotonics to all aspects of human health, it is essential that a wide range of biomedical researchers, healthcare professionals, clinical technicians, and biomedical engineers have a good understanding of biophotonics and its applications. To address the attainment and implementation of these skills, this book provides the basic material for a one-semester entry-level course in the fundamentals and applications of biophotonics technology for senior or postgraduate students. It also will serve well as a working reference or as a short-course textbook for biomedical researchers, practicing physicians, healthcare professionals, clinical technicians, and biomedical engineers and technicians dealing with the design, development, and application of photonics components and instrumentation to biophotonics issues.

In Chap. 1–5 the sequence of topics takes the reader systematically from the underlying principles of light and biology, through the fundamentals of optical fiber light guiding, and then through optical sources and photodetection methods. Next, the topics in Chap. 6–10 address the concepts of light–tissue interactions, various optical probes and photonics sensing techniques, the principles of microscopy and spectroscopy, and biophotonics imaging modalities. The final chapter discusses advanced techniques and developments such as optical trapping, miniaturized instruments, single nanoparticles detection, and optogenetics procedures. By mastering these fundamental topics the reader will be prepared not only to contribute to

current biomedical photonics disciplines, but also to understand quickly any further technology developments for future enhanced biophotonics developments.

The background required to study the book is that of typical senior-level science and engineering students. This background includes introductory biology and chemistry, calculus, and basic concepts of electromagnetism and optics as presented in a freshman physics course. To assist readers in learning the material and applying it to practical situations, 104 worked examples are given throughout the text. A collection of 129 homework problems is included to test the readers' comprehension of the material covered, and to extend and elucidate the text.

The articles and books cited as references in the text were selected from among numerous texts and thousands of papers in the literature relating to the material covered in each chapter. Because biophotonics brings together research, development, and application efforts from many different scientific, medical, and engineering disciplines, these references are a small sample of the major contributions to biophotonics. A number of these references are review papers and provide a starting point for delving deeper into any given topic.

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Gerd Keiser is Research Professor at Boston University and Professor and consultant at PhotonicsComm Solutions, a firm specializing in education and consulting for the optical communications and biophotonics industries. Previously he was involved with telecom technologies at Honeywell, GTE, and General Dynamics. His technical achievements at GTE earned him the prestigious Leslie Warner Award. In addition, he has served as Adjunct Professor of Electrical Engineering at Northeastern University, Boston University, and Tufts University, and was an industrial advisor to the Wentworth Institute of Technology. Formerly he was a chair professor in the Electronics Engineering Department at the National Taiwan University of Science and Technology. He also was a visiting researcher at the Agency for Science, Technology, and Research (A*STAR) in Singapore and at the University of Melbourne, Australia. He is a life fellow of the IEEE, a fellow of OSA and SPIE, an associate editor and reviewer of several technical journals, and the author of five books. He received his B.A. and M.S. degrees in Mathematics and Physics from the University of Wisconsin and a Ph.D. in Physics from Northeastern University. His professional experience and research interests are in the general areas of optical networking and biophotonics.

Abbreviations

ADP	Adenosine diphosphate
AMP	Adenosine monophosphate
APD	Avalanche photodiode
ATP	Adenosine triphosphate
BFP	Blue fluorescent protein
CARS	Coherent anti-Stokes Raman spectroscopy
CCD	Charge-coupled device
CFP	Cyan fluorescent protein
CMOS	Complementary metal-oxide-semiconductor
CW	Continuous wave
DCF	Double-clad fiber
DCS	Diffuse correlation spectroscopy
DFB	Distributed feedback (laser)
DIC	Differential interference contrast
DNA	Deoxyribonucleic acid
DOF	Depth of field
DPSS	Diode-pumped solid-state
DRS	Diffuse reflectance spectroscopy
ELISA	Enzyme-linked immunosorbent assay
ESS	Elastic scattering spectroscopy
eV	Electron volt
FBG	Fiber Bragg grating
FCS	Fluorescence correlation spectroscopy
FD-OCT	Fourier domain OCT
FEL	Free-electron laser
FIDA	Fluorescence intensity distribution analysis
FLIM	Fluorescence lifetime imaging microscopy
FN	Field number
FOV	Field of view
FRET	Fluorescence resonance energy transfer
FRET	Förster resonance energy transfer

FTIR	Fourier transform infrared
FWHM	Full-width half-maximum
FWM	Four-wave mixing
GFP	Green fluorescent protein
GRIN	Graded-index
HCPCF	Hollow-core photonic crystal fiber
HCS	Hard-clad silica
HMFG	Heavy metal fluoride glasses
HRCT	High-resolution computed tomography
HSI	Hyperspectral imaging
IR	Infrared
IRIS	Interferometric reflectance imaging sensor
LED	Light-emitting diode
LITT	Laser-induced interstitial thermotherapy
LLLT	Low-level light therapy (photobiomodulation)
LOC	Lab-on-a-chip
LP	Linearly polarized
LPG	Long-period grating
LSFM	Light sheet fluorescence microscopy
LSPR	Localized surface plasmon resonance
LSS	Light scattering spectroscopy
MFD	Mode-field diameter
MI	Michelson interferometer
MMF	Multimode fiber
MOSFET	Metal-oxide-semiconductor field-effect transistor
MRI	Magnetic resonance imaging
MZI	Mach–Zehnder interferometer
NA	Numerical aperture
Nd:YAG	Neodymium:yttrium aluminum garnet
NEP	Noise equivalent power
NIR	Near-infrared
NO	Nitric oxide
OCE	Optical coherence elastography
OCT	Optical coherence tomography
OSA	Optical spectrum analyzer
PALM	Photo activated localization microscopy
PAT	Photoacoustic tomography
PCF	Photonic crystal fiber
PCH	Photon counting histograms
PCS	Photon correlation spectroscopy
PDL	Polarization dependent loss
PDT	Photodynamic therapy
PLA	Percutaneous laser ablation
PMMA	Polymethylmethacrylate
PMT	Photomultiplier tube

POC	Point of care
POF	Plastic optical fiber
POF	Polymer optical fiber
PSF	Point-spread function
QCL	Quantum cascade laser
RET	Resonance energy transfer
RI	Refractive index
RNA	Ribonucleic acid
ROS	Reactive oxygen species
SD-OCT	Spectral domain OCT
SERS	Surface-enhanced Raman scattering
SFG	Sum-frequency generation
SHG	Second-harmonic generation
SM	Single-mode
SMF	Single-mode fiber
SNR	Signal-to-noise ratio
SPR	Surface plasmon resonance
SRG	Stimulated Raman gain
SRI	Surrounding refractive index
SRL	Stimulated Raman loss
SRS	Stimulated Raman scattering
SSIM	Saturated structured illumination microscopy
SS-OCT	Swept source OCT
STED	Stimulated emission depletion microscopy
STORM	Stochastic optical reconstruction microscopy
TD-OCT	Time domain OCT
TE	Transverse electric
TFF	Thin film filter
THG	Third-harmonic generation
TPEF	Two-photon excitation fluorescence
TRT	Thermal relaxation time
UV	Ultraviolet
VCSEL	Vertical cavity surface-emitting laser
WDL	Wavelength dependent loss
YAG	Yttrium aluminum garnet
YFP	Yellow fluorescent protein