This impressive volume represents a landmark publication on the use of optical methods for deep biomedical imaging—a field that has been transformed by a variety of technical innovations in recent years. Editors Shi and Alfano have secured contributions from top names in the field, for an extensive compilation that comprehensively details the new state of the art, including forefront advances and developments. Fully covering theory, methods and applications, this lavishly illustrated book is destined to become a reference classic.

Prof. David L. Andrews
University of East Anglia, UK

I highly recommend this book as an introductory guide on optical imaging for students, scientists, engineers, and biomedical researchers who seek a better understanding of deep optical imaging in biological tissues or biomaterials in life science research.

Prof. Paras N. Prasad
State University of New York at Buffalo, USA

This is an excellent and up-to-date account of biomedical imaging research. Each topic is well written by subject matter experts, and the book is comprehensive and self-contained.

Dr. Daniel A. Nolan
Corning Inc., USA

Drs. Shi and Alfano have expertly put together an extremely strong collection of chapters written by leaders in the field. This book is a must-read for both active researchers and students.

Prof. Alan E. Willner
University of Southern California, USA

The use of light for probing and imaging biomedical media is promising for the development of safe, noninvasive, and inexpensive clinical imaging modalities with diagnostic ability. The advent of ultrafast lasers has enabled applications of nonlinear optical processes, which allow deeper imaging in biological tissues with higher spatial resolution. This book provides an overview of emerging novel optical imaging techniques, Gaussian beam optics, light scattering, nonlinear optics, and nonlinear optical tomography of tissues and cells. It consists of pioneering works that employ different linear and nonlinear optical imaging techniques for deep tissue imaging, including the new applications of single- and multiphoton excitation fluorescence, Raman scattering, resonance Raman spectroscopy, second harmonic generation, stimulated Raman scattering gain and loss, coherent anti-Stokes Raman spectroscopy, and near-infrared and mid-infrared supercontinuum spectroscopy. The book is a comprehensive reference of emerging deep tissue imaging techniques for researchers and students working in various disciplines.

Lingyan Shi is a research scientist at Columbia University, USA. Her current research focuses on metabolic imaging with stimulated Raman scattering microscopy. She was a research associate studying deep imaging and drug delivery in the brain at the Institute for Ultrafast Spectroscopy and Lasers, the City College of New York, USA, where she received her PhD in biomedical engineering.

Robert R. Alfano is a distinguished professor of science and engineering at the City College of New York. He has pioneered many applications of light and photonics technology to study biological, biomedical, and condensed matter systems using optical spectroscopy and imaging. He discovered and has used supercontinuum. Prof. Alfano is a fellow of the American Physical Society, the Optical Society, and the Institute of Electrical and Electronics Engineers.
Deep Imaging in Tissue and Biomedical Materials
Deep Imaging in Tissue and Biomedical Materials
Using Linear and Nonlinear Optical Methods

edited by
Lingyan Shi
Robert R. Alfano
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Preface

The use of light for probing and imaging biomedical media is promising for developing safe, noninvasive, and inexpensive clinical imaging modalities with diagnostic ability. The advent of ultrafast lasers enables the applications of nonlinear optical processes for deeper imaging into biological tissues with higher spatial resolution. The primary goals of this book are to review the fundamentals in biophotonics and to introduce emerging novel optical imaging techniques for deep tissue imaging. This book is intended to serve as an introductory guide of optical imaging for students and a reference for engineers and researchers who seek a better understanding of deep imaging in tissues.

The book consists of 16 chapters and is divided into three parts. Part I consists of eight chapters. The first chapter, by Murugkar and Boyd, reviews the basic concepts of nonlinear optical imaging, including second harmonic generation, coherent Raman scattering, and self-phase modulation. The next chapter, by Galvez, reviews the fundamentals and physical phenomena of complex light beams, including Gaussian beam, Bessel beam, Airy beam, and Poincare beam. The third chapter, by Shi and coworkers, inspects the properties of Gaussian beam optics in multiphoton fluorescence imaging. The deep imaging in the optical windows in near-infrared (NIR) and short-wave infrared (SWIR) from 700 nm to 2500 nm is reviewed by Jacques. Next, Alfano and coworkers review the salient properties of light propagation in highly scattering media and tissue. The application of non-linear microscopy to life science is reviewed by Svindrych and Periasamy, which is followed by the chapter on smart biomarker of quantum dots for NIR fluorescence imaging by Jin, Sasaki, and Imamura. The last chapter of Part I, by Seddon, describes biomedical applications for deep probing in materials by using mid-infrared supercontinuum laser and new optical fibers.

Part II reviews the theories and properties of light propagating in tissue. The first chapter, by Bykov, Doronin, and Meglinski,
overviews the theories and derived model for understanding light propagation in tissue-like media using Monte Carlo. The cumulant solution for light propagation in a turbid medium and its applications in deep imaging are reviewed in the following chapter by Xu, Cai, and Alfano. The final chapter of Part II, by Pu and coworkers, reviews the latest advancement of NIR scanning polarization imaging unit for prostate and presents an algorithm for diffusive image reconstruction using NIR banana pathways.

Part III presents recent technology developments in optical imaging and introduces the applications of different techniques for detecting disordered media and tissue. Karagoz and Altan introduce terahertz propagation in tissues and its limitation for thick tissue and present ways for use in smears and thin tissues for histology applications. The use of stimulated Raman scattering gain and loss microscopy in detecting brain tumor is then reviewed by Lewis and Orringer. The next chapter, by Cao and Cheng, introduces the technology of using new photoacoustics approach for deep imaging by detecting molecules’ vibrational overtone of chemical bonds. Gannot and coworkers presents multiple acoustic and thermal methods for light–tissue interaction for detecting deeper structures. The final chapter, by Davy, Gigan, and Genack, describes the properties of transmission matrix that determine the net transmission pathways in biomedical and condensed media, and its use for deep imaging.

As will be seen, much has been accomplished and reviewed in the book, but much remains for the future. Therefore, not only is this book an introduction to students in the field, but it proposes directions for researchers to adapt their own or to explore new optical technologies for deeper and better imaging in life science. We wish to thank all the invited authors, who presented very interesting and knowledgeable chapters.

**Lingyan Shi**  
**Robert R. Alfano**  
New York  
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