

# Introduction to the Issue on Biophotonics

**W**ELCOME to the IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS (JSTQE) Issue on Biophotonics! The Biophotonics field is an emerging biomedical technology that has opened up new horizons for transfer of state-of-the-art techniques from the areas of quantum electronics, lasers, fiber optics, and electro-optics to the life sciences and medicine. This field continues to vastly expand with advanced developments across the entire spectrum of biomedical applications ranging from fundamental “bench” laboratory studies to clinical patient “bedside” diagnostics and therapeutics. Recently developed innovative biophotonics technologies have made a significant impact on biomedical research and public health, since they provide advanced minimally invasive, cost-effective, and rapid techniques for diagnostics, monitoring, and treatment of a variety of diseases. Devices utilizing minimally invasive biophotonics technology are rapidly finding their way into the mainstream for early disease diagnosis and improved patient acceptance and comfort. In the papers included in this JSTQE Issue on Biophotonics, you will be introduced to some of the latest state-of-the-art developments in biophotonics. Some of these developments include advanced optical imaging, microscopy, and sensing techniques, which remain one of the most widely employed biomedical technologies because of their advanced features. Nonionizing radiation provides minimally invasive tissue sensing and imaging *in vivo* with a high spatial resolution in the micron, submicron, and nanometric range beyond the diffraction limit. Recently, minimally invasive biophotonics techniques have been developed as potential alternatives to conventional medical methods for diagnostics, monitoring and therapeutics of diseases, drug discovery, proteomics, and environmental detection of biological agents. These techniques offer a noncontact, effective, fast, and painless way for sensing and monitoring various biomedical quantities. Clinical prospects in biophotonics are vast including applications in both disease diagnostics and therapeutics areas. Moreover, the biophotonics field has introduced opportunities for interdisciplinary research between physicists and life scientists leading to the development of novel laser, biomedical and fiber optics tools, and devices employed in the biophotonics areas.

The objective of this JSTQE Issue on Biophotonics is to highlight recent progress and trends in innovative biophotonics technology development. The papers published in this issue cover a broad range of advanced biophotonics areas summarized in the following sections:

- 1) **bioimaging:** optical coherence tomography and microscopy, nonlinear optical imaging, and novel multimodality imaging approaches;
- 2) **biosensing:** multifunctional biosensing, and novel biosensing approaches;

- 3) **biophotonic science:** mechanisms of light-cell and light-tissue interactions, advanced modeling methods in biophotonics, and light induced biophotonics effects;
- 4) **biophotonic technology:** advanced technologies in biophotonic diagnostics and therapeutics, infrared technology in biophotonics, and novel laser, biomedical and fiber optics tools and devices in biophotonics.

These key research topics are highlighted as comprehensive overviews of the current status and future trends, as well as original results and recent developments in the field of biophotonics.

This issue contains 33 papers, including 18 invited and 15 contributed papers authored by well-established research groups and promising scientists from all over the world. The invited papers include extended reviews on recent biophotonic developments and clinical applications in the areas of high-resolution multispectral bioimaging, combined multifunctional microscopy, nonlinear deep tissue imaging, single molecule imaging, optical coherence elastography, cellular and molecular mechanisms of photobiomodulation, tissue optical clearing, clinical ultrafast laser surgery, infrared laser nerve stimulation, and novel tapered diode lasers for biophotonics. The contributed papers cover a broad variety of key biophotonic research areas including recently obtained original results on multimodal bioimaging and sensing, high resolution phase-sensitive magnetomotive optical coherence microscopy and elastography, and laser-assisted typing of polymorphic human genes.

We hope you will find this JSTQE Issue on Biophotonics to be an interesting and useful reference that will impact, stimulate, and promote further advances in biophotonics.

## ACKNOWLEDGMENT

This issue was made possible by dedicated efforts of a number of people. First, we would like to thank the authors of all the papers in this issue as well as many reviewers around the world who, despite their many other commitments, provided high-quality reviews of the manuscripts. We would like to thank the IEEE publications staff for their general support, and C. T. Lutz, in particular, for her prompt help, boundless energy, and excellent organization skills in helping us meet the deadlines. We would like to thank Dr. J. Cartledge, Editor-in-Chief of the JOURNAL OF SPECIAL TOPICS IN QUANTUM ELECTRONICS, for his stimulating encouragements for this Special Issue.

ILKO K. ILEV, *Primary Guest Editor*  
Center for Devices and Radiological Health  
U.S. Food and Drug Administration  
Silver Spring, MD 20993 USA  
(e-mail: ilko.ilev@fda.hhs.gov)

STEPHEN A. BOPPART, *Guest Editor*  
 Beckman Institute for Advanced Science and Technology  
 Departments of Bioengineering, Electrical and Computer  
 Engineering, and Medicine  
 University of Illinois at Urbana-Champaign  
 Urbana, IL 61801 USA

STEFAN ANDERSSON-ENGELS, *Guest Editor*  
 Division of Atomic Physics  
 Lund University  
 Lund, SE-22100, Sweden

BEOP-MIN KIM, *Guest Editor*  
 Department of Biomedical Engineering  
 Korea University  
 Seoul 136-703, Korea

LEV PERELMAN, *Guest Editor*  
 Center for Advanced Biomedical Imaging and Photonics  
 Beth Israel Deaconess Medical Center  
 Biological and Biomedical Sciences Program  
 Departments of Medicine, Ob/Gyn and Reproductive Biology  
 Harvard University  
 Boston, MA 02215 USA

VALERY TUCHIN, *Guest Editor*  
 Division of Optics and Biophotonics  
 Saratov State University  
 Saratov 410012, Russia  
 Institute of Precision Mechanics and Control  
 Russian Academy of Sciences  
 Saratov 410028, Russia  
 Optoelectronics and Measurement Techniques Laboratory  
 University of Oulu  
 Oulu FI-90014, Finland



**Ilko K. Ilev** (M'93–SM'99–F'14) received the M.S. degree in quantum physics from Sofia University, Bulgaria, and the Ph.D. degree in laser physics from the Technical University of Sofia in 1983 and 1992, respectively. He has more than 25 years of experience in the United States, Europe, and Japan in the field of laser physics and technologies, biophotonics, nanobiophotonics, laser medicine, biomedical and fiber optics, biosensing, and ultrahigh-resolution optical imaging. During 1995, he was with the Optoelectronics Division, Strathclyde University, Glasgow, U.K. From 1995 to 1997, he was with the Laser Technology Laboratory, Institute of Physical and Chemical Research (RIKEN), Tokyo, Japan. From 1998 to 2001, he was an American Academy of Science/National Research Council (NRC) Research Associate in U.S. Food and Drug Administration (U.S. FDA). Since May 2001, he has been with the Center for Devices and Radiological Health at U.S. FDA, where he is the Leader of the Optical Therapeutics and Medical Nanophotonics Laboratory. In 2012, he was appointed to the DHHS/FDA Senior Biomedical Research Service. He is also an Adjunct Professor in the Department of Bioengineering, University of

Maryland. He has produced more than 350 papers in peer-reviewed journals and presentations at major conferences and meetings. Along with multiple original publications, he holds ten granted and pending patents. His current research interests include development of novel minimally invasive biophotonics and nanobiophotonics techniques including multifunctional bioimaging and biosensing modalities for studying fundamental mechanisms of light-tissue interactions at cellular and subcellular level, ultrashort femtosecond laser-based diagnostics and therapeutics, super-resolution nanoscopy beyond the diffraction limit in the sub-wavelength nanoscale range, and laser safety. Dr. Ilev served as Biophotonics Committee Chair of the IEEE Photonics Society and IEEE LEOS-Lasers and Electro-Optics Society. He has organized and chaired numerous conferences on biophotonics and nanobiophotonics topics within the IEEE Photonics Society, the IEEE Engineering in Medicine and Biology Society, The International Society for Optical Engineers, and the Optical Society of America. He serves as a Primary Guest Editor of the IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS (JSTQE) on Biophotonics and Nanobiophotonics, and as an Associate Editor of the IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING.



**Stephen A. Boppert** (S'90–M'90–SM'06–F'11) was born in Harvard, IL, USA, in 1968. He received the B.S. and M.S. degrees in electrical engineering from the University of Illinois at Urbana-Champaign, Urbana-Champaign, IL, in 1990 and 1991, respectively, the Ph.D. degree in electrical and medical engineering from the Massachusetts Institute of Technology, Cambridge, MA, USA, in 1998, and the M.D. degree from Harvard Medical School, Boston, MA, in 2000. He completed residency training in internal medicine from the University of Illinois at Urbana-Champaign in 2005. Prior to beginning his doctoral work, he was a Research Scientist at the Air Force Laser Laboratory, Brooks Air Force Base, San Antonio, TX, USA, where he was involved in developing national (ANSI) and Air Force laser safety standards. Following the doctoral studies, he returned to the University of Illinois at Urbana-Champaign in 2000, where he is currently holds a Bliss Professorship of Engineering, with appointments in the departments of electrical and computer engineering, bioengineering, and medicine, and is Head of the Biophotonics Imaging Laboratory, Beckman Institute for Advanced Science and Technology. He also holds an

appointment as the Director of a campus-wide *Imaging at Illinois* initiative. He is the author or coauthor of more than 200 invited and contributed publications and has made more than 450 invited and contributed presentations. He is the holder of more than 30 patents filed or pending. His current research interests include the development of novel optical imaging technologies for biological and medical applications, with particular emphasis on translating these to clinical applications in cancer detection and primary care. Dr. Boppert is a Fellow of the Optical Society of America, The International Society for Optical Engineers, the American Association for the Advancement of Science, and the American Institute for Medical and Biological Engineering. In 2002, he was named one of the Top 100 Innovators in the World by Technology Review Magazine for his research in medical technology. He received the IEEE Engineering in Medicine and Biology Society Early Career Achievement Award, and in 2009, was recognized with the Paul F. Forman Engineering Excellence Award from the OSA for dedication and advancement in undergraduate research education. In 2012, he received the international Hans Sigrist Prize for his research in diagnostic laser medicine.



**Stefan Andersson-Engels** received the M.Sc. degree in engineering physics and the Ph.D. degree in physics from Lund University, Lund, Sweden, in 1985 and 1990, respectively. He was involved in developing methods for tissue diagnostics based on optical spectroscopic techniques. He was at McMaster University, Hamilton, ON, Canada, for one year, and was involved in tissue optics as well as confocal and two-photon microscopy. In 1993, he joined Lund University as an Assistant Professor, and became an Associate Professor in 1994 and a Full Professor in 1999. He is the author or coauthor of more than 160 articles published in peer reviewed journals. His current research interests include optical spectroscopy for biomedical and pharmaceutical applications as well as interstitial photodynamic therapy of malignant tumors. Dr. Andersson-Engels has been a co-organizer of several international conferences including the Gordon Conference on Lasers in Biology and Medicine in 2000, the European Conference on Biomedical Optics in 2003, and a series of biannual international summer schools in biophotonics at the Island Ven in Sweden.



**Beop-Min Kim** received the B.S. degree in mechanical engineering from Korea University, Seoul, Korea, in 1989, and the M.S. and Ph.D. degrees in bioengineering from Texas A&M University, College Station, TX, USA, in 1991 and 1996, respectively. He was a Predoctoral fellow with the University of Texas, M.D. Anderson Cancer Center, Houston, and University of Texas Medical Branch, Galveston from 1993 to 1996. From 1996 to 2001, he was with the Medical Technology Program, Lawrence Livermore National Laboratory, Livermore, CA, USA, where he was the Staff Scientist. From 2001 to 2009, he was an Assistant/Associate Professor with the Department of Biomedical Engineering, Yonsei University, Korea, where he was also the Department Head and the Director of the Institute of Advanced Biomedical Engineering. He is currently a Professor in the Department of Biomedical Engineering, Korea University. He is the author or coauthor of more than 50 papers in peer-reviewed journals and has made numerous presentations at major national and international conferences and chaired many conferences on biophotonics in the Asian and Pacific-rim region. His research interests include optical applications in neuroscience,

optical coherence tomography, and optical tweezers. Dr. Kim is currently a board member of the Optical Society of Korea (OSK) and the Korea Society of Medical and Biological Engineering (KOSOMBE).



**Lev T. Perelman** received the M.S. degree in physics from Belarus University, Minsk, Belarus, in 1982, and the Ph.D. degree in physics from the Institute of Physics, Minsk, in 1989. In 1992, he joined the Massachusetts Institute of Technology, Cambridge, MA, USA, as a Postdoctoral Fellow in medical physics and in 1995 was appointed a Principal Scientist and Group Leader at MIT George R. Harrison Spectroscopy Laboratory. In 2000, he joined the faculty of Harvard University, where he is currently a Full Professor with appointments in the Departments of Medicine, Ob/Gyn and Reproductive Biology and Biological and Biomedical Sciences program. He is also the Director of the Center for Advanced Biomedical Imaging and Photonics, Beth Israel Deaconess Medical Center. He is the author or coauthor of more than 150 invited and contributed publications and the holder of more than 20 patents, filed or pending. His current research interests include application of optics to medicine and biology and include light-scattering spectroscopy, surface-enhanced Raman spectroscopy, nanophotonics, laser ablation, optical imaging, and cancer detection with light. Dr. Perelman served on the U.S. Department of Health and Human Services

Joint Working Group charged with setting up funding priorities in oncologic imaging in the U.S. for the past decade. He received the Honorary Master of Medicine degree from Harvard University. He was a General Chair of the 2012 and is a Plenary Speaker at 2014 Optical Society of America (OSA) Biomedical Optics and 3-D Imaging Congress. He was also a Keynote Speaker at 1997 Gordon Research Conference. He is an Associate Editor of the *Biomedical Optics Express* and the *Nanophotonics* journals.



**Valery V. Tuchin** received the M.S. degree in radio-physics and electronics, the Ph.D. degree in optics, and Dr.Sc. from the Saratov State University, Saratov, Russia, in 1966, 1974, and 1982, respectively. He is currently a Professor and holds the Optics and Biophotonics Chair. He is also the Director of Research-Educational Institute of Optics and Biophotonics, Saratov State University, Russia, and the Head of the Laboratory on Laser Diagnostics of Technical and Living Systems, Institute of Precision Mechanics and Control, Russian Academy of Sciences, Saratov, Russia. He is a FiDiPro Professor of University of Oulu (Finland). He has authored more than 400 peer-reviewed papers and books. His research interests include biophotonics, tissue optics and laser medicine, tissue optical clearing, physics of optical and laser measurements, biosensing, photonic crystal fibers, nanobiophotonics, and theranostics. Dr. Tuchin is a member SPIE, OSA, and IEEE. He has been awarded Honored Science Worker of the Russian Federation and SPIE Fellow; he is a Vice-President of Russian Photobiology Society. In 2007, he received the SPIE Educator Award. He has been an organizer and coorganizer of several annual and biannual

international conferences and summer schools, including subconferences of SPIE BiOS (USA), SPIE Photonics Europe (Belgium), PIBM (China), and Saratov Fall Meeting (SFM) (Saratov, Russia).