Polarized Light for Biomedical Applications

Tatiana Novikova
Igor Meglinski
Jessica C. Ramella-Roman
Valery V. Tuchin
Polarized Light for Biomedical Applications

Tatiana Novikova  
Laboratoire de Physique des Interfaces et des Couches Minces  
CNRS, Ecole Polytechnique  
Université Paris-Saclay  
91128 Palaiseau, France  
E-mail: tatiana.novikova@polytechnique.edu

Igor Meglinski  
University of Oulu  
Laboratory of Opto-Electronics and Measurement Techniques  
P.O. Box 4500  
Oulu, FI-90014, Finland  
E-mail: igor.meglinski@oulu.fi

Jessica C. Ramella-Roman  
Florida International University  
Department of Biomedical Engineering and Herbert Wertheim College of Medicine  
E8 2610, 10555 West Flagler Street  
Miami, Florida 33174, United States  
E-mail: jramella@fiu.edu

Valery V. Tuchin  
Saratov National Research State University  
Research-Education Institute of Optics and Biophotonics  
Department of Physics  
83 Astrakhanskaya str., Saratov 410012, Russia  
and  
Institute of Precision Mechanics and Control of the RAS  
Saratov 410028, Russia  
and  
National Research Tomsk State University  
Laboratory of Biophotonics  
Tomsk 634050, Russia  
E-mail: tuchinvv@mail.ru

Polarization is one of the most salient features of light, even more so than its spectral or coherence properties. Imaging and diagnostics modalities that utilize light polarization could translate into fast, accurate, and highly sensitive techniques for probing structures of living cells, for the purpose of cancer detection and stage identification. It has been roughly ten years since a publication of papers on tissue polarimetry has been edited and a number of new research groups from around the world have entered this research field. The aim of this special section is to present the current state-of-the-art in this fast-growing research field. Focus area are advances in polarized light diagnostics and imaging, physical, mathematical and computational foundations, innovative optical instrument designs, as well as clinical, preclinical, and laboratory applications.

This special section was prepared in memoriam of Dr. Antonello De Martino – one of the pioneers of the tissue polarimetry in France and in the world.

The special section includes a tutorial on polarimetry (by V. Tuchin) covering the fundamentals of polarized light and tissue interaction, recent advances in the theoretical aspects of polarization transfer in scattering media, the development of polarimetric optical diagnostic techniques, and examples of numerous biomedical applications of these techniques. Many modeling results of tissue polarization properties discussed in this tutorial were authored by Prof. Irina L. Maksimova, who passed away in 2013. Irina was one of the pioneers of modeling polarization properties of eye tissues and designing precise algorithms for their measurements. She was a talented person and a great worker, a brilliant representative of women in optics.

The obvious complexity of polarized light interaction with biological samples is reflected in a significant number of papers dealing with the measurements of the test samples’ complete Mueller matrix. Despite more complex polarimetric instrument design and calibration, the use of Mueller matrix algebra for data analysis allows straightforward phenomenological interpretation of basic optical properties of the tissue, such as depolarization, dichroism, and birefringence. For many decades the depolarization of light due to scattering was used for tissue diagnosis. The above-mentioned studies clearly demonstrate that tissue scalar retardance developing due to the presence of aligned collagen fibers is extremely sensitive to the small pathological alterations of tissue. Consequently, the tissue scalar retardance, as well as the azimuth of optical axis could also be used as the optical markers of different diseases which break or modify the fine-ordered...
A new instrument combining two different optical techniques: (i) surface imaging with Mueller matrix polarimetry (MMP) and (ii) cross-sectional imaging with polarization-sensitive optical coherence tomography (PS-OCT) is discussed by J. Chue-Sang et al. The co-registration of two systems provides both bulk and local polarization properties of thick tissue, which could be used for both lesion boundary detection and optical biopsy of tissue. An interesting extension of conventional MMP is proposed by A. G. Ushenko et al. The authors study the application of laser-induced autofluorescence of dried peritoneal liquid for endometriosis diagnostics using Mueller matrix formalism which relates the distinct excitation and detection wavelengths of light. The use of angle-resolved Mueller polarimetry as a dosimetric technique for emergency reconstruction of the exposure dose of ionizing radiation in large population is discussed in the paper of Savenkov et al. The use of multi-spectral Mueller polarimetric imaging technique for cervical cancer detection is discussed by J. Rehbinder et al.

Many papers of this special section are dedicated to the design and fabrication of new polarimetric instruments. The development of a miniaturized, noise-immune optical rotation polarimeter (C. Weissman and D. Goldberg), Mueller matrix microscope (C. Wang et al.), and polarimetric endoscopic imaging systems (J. Vizet et al. and K. Kanamori), all reflect a growing trend towards clinical applications.

In-depth experimental and numerical studies of anisotropy of light scattering in tissue (S. L. Jacques et al.), scattering of polarized light on rough surfaces (A. Doronin et al.), polarization gating technique, combining co-elliptical and counter-elliptical measurements for image contrast enhancement (S. Sridhar and A. Da Silva), statistical analysis of polarization-inhomogeneous images of skin taken in Fourier plane (A. G. Ushenko et al.), comparative studies of confocal imaging technique and polarization diffraction imaging flow cytometry for the classification of cancerous and healthy prostate epithelial cells (W. Jiang et al.), and polarized laser speckle imaging for the medical diagnosis of dental erosion (C. Abou Nader et al.) explore new ideas in the domain of polarized light scattering and pave the way for the development of new unconventional polarimetric techniques for various biomedical applications.

References


Tatiana Novikova, PhD, is a permanent research staff member of the Laboratory of Physics of Interfaces and Thin Films (LPICM), CNRS, Ecole polytechnique, France. She received a master’s degree in applied mathematics from the Moscow State University, Russia, PhD degree in physics and mathematics from the Institute of Mathematical Modeling, Moscow, Russia and habilitation degree in optics from University Paris-Sud, Orsay, France. Her scientific interests include optics of polarized light, interaction of electromagnetic waves with matter, Mueller polarimetry and its application in biomedical engineering and microelectronics, as well as computational physics of weakly ionized plasma.

Igor Meglinski is a head of the Opto-Electronics and Measurement Techniques Unit in the University of Oulu (Finland). His research interests include propagation of coherent polarized light in turbid tissue-like scattering media, coherent effects of multiple scattering of light, tissue polarimetry, angular momentum of light, optical phase singularities, dynamic light scattering, Monte Carlo modeling, and multimodal imaging. He is Fellow of the Institute of Physics (London, United Kingdom), and a senior member of IEEE and Fellow of SPIE.

Jessica C. Ramella-Roman is an associate professor in the Department of Biomedical Engineering and an associate research professor in the Herbert Wertheim College of Medicine at Florida International University. She received an electrical engineering degree from the University of Pavia, Italy, and a master and PhD degree in electrical engineering from OHSU in Portland, Oregon. Her research interests include polarized light transport, imaging spectroscopy applied to eye disease, and the study of anisotropic tissue.

Valery V. Tuchin is a professor and head of optics and biophotonics at Saratov National Research State University and several other universities and institutions. His research interests include tissue optics, laser medicine, tissue optical clearing, and nanobiophotonics. He is a fellow of SPIE and OSA, has been awarded Honored Science Worker of Russia, SPIE Educator Award, FiDiPro (Finland), Chime Bell Prize of Hubei Province (China), and Joseph W. Goodman Book Writing Award (OSA/SPIE).