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APPLICATION OF LASERS AND LASER-OPTICAL METHODS IN LIFE SCIENCES

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Lasers in life sciences

A.V. Priezzhev, A.V. Bykov, R.A. Myllylä

The current issue of 'Quantum Electronics' presents a series of articles reflecting the modern state of applications of lasers and laser-optic techniques in life sciences. This is a wide area of interdisciplinary research aimed at the assessment of the principles and mechanisms of operation of live systems and their separate components, as well as of the origin of different deviations and pathologies forming the basis of diseases, and diagnostic and treatment modalities. The rapid progress in development of laser-optic techniques that started practically right after the invention of lasers half a century ago has become especially apparent in their applications in biology and medicine and, also, in the growth of research volumes in very different biomedical directions.

One of the most important results of this research where Russian scientists play an important and internationally acknowledged role is the development of tissue optics, which has become the basis for a wide range of other works. Multiple light scattering typical of the majority of biological tissues heavily determines the possibilities and application limits of different laser-optic techniques including the imaging techniques. The analysis of scattering effect on the characteristics of images of optically thick samples of biotissues formed, in particular, by means of two-photon fluorescence microscopy is presented in the article of E. Sergeeva et al. of this special issue. Such analysis can be based only upon careful choice of a theoretical model. Comparison of the obtained results with those of Monte Carlo simulations has exhibited the efficiency of the used small-angle diffuse approximation. The results obtained by the authors allow predicting the extent of attenuation of the fluorescence signal under conditions of strong scattering in the devices of two-photon fluorescence microscopy equipped with different types of detectors.

Strong light scattering from biological tissues makes the basis of optical diffuse tomography, which allows for the two or three dimensional reconstruction of the inner structure of biological tissues using the distribution of absorption and scattering coefficients measured with the help of several source – detector pairs. The measured intensity of light transmitted through the tissue can be used to calculate the concentrations of oxy- and deoxyhaemoglobin determining the selective absorption of the main chromophores of blood by means of IR spectroscopy. Spectral selectivity of the system and, also, the estimated volume of circulating blood and its oxygenation together with the reconstruction of the tissue internal structure can improve the precision of early diagnostics of cancer based on the characterization of the tissue blood vessels. The article of M. Patachia et al. is devoted to the study of these issues with the help of the physical models (phantoms) of the blood containing tissues.

A number of methods of medical functional diagnostics are based on the noninvasive optical measurement of alterations of blood oxygenation in human brain. As a rule, the complex diagnostics of brain is conducted by using the magnetic resonance imaging (MRI). In this respect the optical devices and measurement techniques should be MRI-compatible. This problem is discussed in the article of H. Sorvoja et al. While developing the device, the numerical Monte Carlo simulations of the propagation of the probing radiation in a multilayered model of human brain were performed to evaluate the signal level at various source – detector separations for several wavelengths.

The optical properties of thick samples of biotissue are determined by the optical properties of the comprising cells. In particular, the optical properties of blood and blood-containing tissues, as well as the blood flow parameters in these tissues heavily depend on the optical properties of the erythrocytes and on their ability to change their shape in the flow. Diffractometry is one of the efficient techniques for studying these properties. Theoretical bases and practical aspects of implementing this technique are discussed in the article by S. Nikitin et al.

Currently, the intensive studies of the mechanisms of the modifying effect of laser radiation on biological objects are continuously going on. It appears that under low-intensity (less than 100 mW cm^{-2}) cw laser irradiation of human skin this tissue exhibits the effect of 'photomemory', which is manifested by the reduction of the intensity of autofluorescence from preliminarily irradiated areas of healthy skin.

A.V. Priezzhev Department of Physics, International Laser Center, M.V. Lomonosov Moscow State University, Vorob'evy gory, 119992 Moscow, Russia; e-mail: avp2@mail.ru;
A.V. Bykov Department of Physics, International Laser Center, M.V. Lomonosov Moscow State University, Vorob'evy gory, 119992 Moscow, Russia; present address: University of Oulu, Technology Department, Optoelectronics and Measurement Techniques Laboratory, P.O. Box 4500, 90014, Oulu, Finland;
R.A. Myllylä University of Oulu, Technology Department, Optoelectronics and Measurement Techniques Laboratory, P.O. Box 4500, 90014, Oulu, Finland

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The mechanism of this phenomenon is presumably related to the reduction of the concentration of the endogenous fluorophores in the superficial layers of the skin. However, the reduction of the absorbing properties of the skin chromophores induced by laser irradiation cannot be excluded.

Laser-induced hyperthermia is another type of modifying action of laser radiation. The methods of local hyperthermia of separate regions of the organism, e.g. of tumour localisation sites, are being actively developed along with the use of nanosized inclusions carrying out the resonance absorption of laser radiation. To introduce these techniques into clinical practice it is necessary to be able to adequately estimate the level of doze-effect hyperthermia and adaptively control the processes induced both in comparatively large areas of biotissue and in a cell. These issues are explored in the article by Yu. Avetisyan et al., in which a two-scale scheme for simulating the characteristic peculiarities of nonstationary temperature fields induced in the media with absorbing particles is considered and the calculation of the parameters of spatiotemporal thermal action on biotissue are performed.

Contemporary laser-optic techniques allow observing the interaction of biologically important molecules with nanoparticles, whose perspective applications for biomedical diagnostics and targeted delivery of medicines in the organism are widely discussed. In the article by E. Perevedentseva et al., the problem of interaction of diamond nanoparticles with blood plasma proteins is analysed. These nanoparticles are considered to be among the most perspective fluorescent markers of tumours and other neoplasms. However, as shown by the authors (so far in the in vitro experiments with protein solutions) at the interaction with nanoparticles the major blood plasma proteins, albumin and γ-globulin, are adsorbed on their surface. This can lead to an alteration on the structure and functional state of these proteins and, as a result, to the impairment of such important properties of blood as its fluidity. These studies show the importance of testing all materials offered for biomedical applications from the viewpoint of nanosafety.

In particular, this concerns the nanoparticles of gadolinium borate and borate glasses activated with Nd^{3+} ions, the spectroscopic investigations of which in the near-IR range were conducted and described in the article by A. Popov et al. from the viewpoint of their applications as luminescent biosensors and radiopharmpreparations for cancer diagnostics by radiosensitive techniques. The study of the distribution of the nanoparticles within the organs and tissues of laboratory animals conducted by the authors with the use of a 810-nm laser as the excitation source and a multichannel fibreoptic spectrometer for fluorescence detection in the range $0.8-1.2$ μm has shown the sensitivity of the technique to be sufficient for reliable determination of the concentration of the nanoparticles in biotissues and the dynamics of its alteration.

Contemporary laser technologies, in particular, the methods of nonlinear laser spectroscopy allow for assessing the basic phenomena that determine the functioning of biologically important molecules. In particular, this concerns the interaction of DNA molecules with water. In the work of A. Bunkin and S. Pershin, the four-photon scattering spectroscopy was implemented for detecting the rotational resonances of the H_2O and H_2O_2 molecules in aqueous solutions of DNA and denaturated DNA. A significant rise of the resonant input of rotational transitions of these molecules in the solution as compared to the distilled water was found. This fact was interpreted as a manifistation of the specific properties of the hydrated layer at the water boundary with these molecules that determine the difference in the properties of DNA and denaturated DNA.

All featured articles are based on the materials of the papers presented at XII International Conference on Laser Applications in Life Sciences (LALS) held from 9 to 11 June 2010 in Oulu, Finland. The first conference in this series was held in Prague in 1986 under the initiative of S.A. Akhmanov. The last conference was organised by Lomonosov Moscow State University, University of Oulu and National Research Center (VTT) of Finland. Over 200 participants from many countries of the world attended the conference. The editors of the special issue hope that the published articles will be interesting for a wide readership of the journal.