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Lasers and biomedical diagnostics

A.V. Priezzhev

Laser biomedical diagnostics is being rapidly developed in the last years. First of all this is explained by the development of laser, optoelectronic, and computer technologies, the methods for generation of laser radiation, the means for its delivering to an object, and photodetectors. Another reason is a rapid accumulation of the data on the optical properties of biological objects at the level of molecules, cells, tissues, and an organism as a whole. Note that the term diagnostics in biomedical studies (detection of deviations in the properties of an object from the norm, which indicate the illness) has also the physical meaning (obtaining new data on the physical properties of an object under study).

A growing interest of physicists and engineers in biomedical diagnostics is explained by a variety of challenging physical and technical problems. At the same time, the possibility to obtain new, inaccessible so far information on living objects and their structure by using new physical methods and instruments attracts the attention of biologists and physicians. The problems encountered by physicists and engineers due to the complexity and variability of biological objects and by physicians due to the complexity of new methods and instruments, as well as the interpretation of new information are justified by the social importance of the tasks being solved. Among these tasks are:

(i) The improvement of safety, accuracy, and reliability of diagnostic studies; (ii) the earlier detection of the deviation of the properties of a human organism from the norm (i.e., illness); (iii) the development of compact and fast diagnostic devices; (iv) the elucidation of physical and, in particular, molecular mechanisms of functioning of living systems and the origin and development of pathologic disorders; (v) the development of the methods for monitoring of the structure and functions of biological objects during their normal activity, during pathologic processes, and upon the therapeutic treatment; and (vi) the development of new methods for studying living matter and manipulating biological structures.

Based on laser and optoelectronic technologies using rapidly developing computer technologies for signal and image processing, the highly efficient methods and equipment have been developed for solving these tasks. We can say without any exaggeration that virtually all the advances of these technologies have found applications in medicine. However, sophisticated laser and optoelectronic technologies used for medical diagnostics require the participation of physicists and engineers. This is explained by a complicated interaction of laser radiation with biological objects and by a great information content of detected physical signals used for biomedical diagnostics.

The interaction of laser radiation with biological objects strongly depends on the type of propagation of photons inside the object and at the object environment interface. Because most biological objects (tissues) are optically inhomogeneous, scattering process play the predominant role during the propagation of laser radiation in tissues. The role of scattering is especially important in the spectral range from 0.6 to 1.5 μm, which is called 'the diagnostic window'. The scattering coefficient of most tissues in this range is tens and hundreds times greater than their absorption coefficient. The depth of penetration of red and near-IR radiation to biological tissues substantially exceeds that of radiation of shorter or longer wavelengths. The shorter-wavelength radiation is absorbed by pigments, proteins, and other biological molecules, while the longer-wavelength radiation is absorbed by water. Due to the presence of the diagnostic window, it is possible to study noninvasively the structure and composition of biological objects at large penetration depths. The methods of optical medical tomography being developed at present are based on this principle.

The time-of-flight and frequency-domain methods of optical tomography are based on the generation of ultrashort laser pulses and laser radiation modulated at frequencies of hundreds and thousands of megahertz. These methods are used for solving most important medical problems such as an early, noninvasive detection of cancer tissues (in particular, milk gland tissues), hemorrhages and aneurysms of the brain vessels. One of the most important problems is the monitoring of the sugar level in the human blood without taking blood samples. Recent studies showed that the methods of laser optoacoustic tomography are promising for solving this task.

The methods of correlation and Doppler spectroscopy, laser interferometry and optical coherent tomography use narrow-band highly coherent radiation and broadband radiation with a small coherence length.

These methods are efficiently used for studying the dynamic and structural properties of normal and pathologic biological objects both *in vivo* and *in vitro*, in particular, of solutions of biological molecules and cell suspensions (for

A.V. Priezzhev Department of Physics, M.V. Lomonosov Moscow State University, Vorob'evy gory, 119992 Moscow, Russia

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example, blood). Upon the interference of laser radiation scattered by optically inhomogeneous tissues, the regions of the maximal and minimal intensity (speckles) are formed, which retain coherent properties. The detection and correlation processing of speckles provide the diagnostic information on the space–time stricture of biological objects, in particular, on the dynamics of the blood and lymph streams in tissues, as well as on the parameters of propagation of pulse waves during heart contractions.

As mentioned above, the mechanisms of most of the processes of vital activity and of their disorders (illnesses) have a molecular origin. An important information on the structure, functions, and the interaction between biological molecules in various tissues of a human organism can be obtained by the methods of laser-induced fluorescence, Raman spectroscopy, and vibrational spectroscopy in the mid-IR range. These methods are being extensively developed and applied in biomedical studies, for example, for the visualisation of pathologic (in particular, oncological), atherosclerotic, and other disorders in tissues. Note that the methods for measuring the kinetics and the relaxation time of signals are highly informative.

Polarisation methods provide the efficient visualisation of various structures and pathology loci in tissues. This is explained by the fact that laser radiation of different polarisations propagates in tissues differently. The methods of polarisation visualisation using computer-aided image processing have found wide applications in the diagnostics of the skin structure and hypodermic microcirculation.

Note that, along with the development and applications of the methods for noninvasive diagnostics of tissues and organs, the measurements of tissue samples and products of the living activity of a human organism are also very important. This concerns, in particular, biological liquids such as blood, saliva, mucus, tear, neuraxis and articulation liquids, as well as expired gases. The composition, the structural, rheologic, and other parameters of these liquids and gases provide valuable information and reflect the state of the organism. The development of new efficient methods for measuring these parameters is one of the problems of biomedical optics.

Not all the parameters determining the properties of biological objects and the propagation of probe laser radiation in them can be measured experimentally. In particular, this concerns the absorption and scattering coefficients, the mean free path and the form of the propagation trajectory of photons in strongly scattering tissues. This stimulates the development of the methods for numerical simulation of the propagation of laser radiation in tissues for laser biomedical diagnostics. Among them are the method of finite elements and the Monte Carlo method of statistical tests.

Many of the above-mentioned methods and problems are discussed in papers published in this and the next issues of Quantum Electronics, which are devoted to laser biomedical diagnostics. We hope that these papers will be of interest to many readers of the journal.