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Laser Interaction with Biological Material

Mathematical Modeling

Springer

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Preface

One of the most important areas of application of laser radiation is biomedical optics. Here, laser sources are used for diagnosis, therapy, or surgery.

Note that for the development of new methods of laser biomedical diagnostics, a detailed study of the propagation of light in biological tissues is required, as theoretical studies improve understanding of the optical measurements, increase capacity, reliability, and usefulness of optical technologies.

To solve these problems in the first place the most informative indicators of the functioning of the organism must be chosen. These indicators are the results of the analysis of peripheral blood. Peripheral blood provides the complete information on the status of the human organism. A comprehensive study of the characteristics of light scattering and absorption can quickly detect intact physiological and morphological changes in the cells due to thermal, chemical, antibiotic treatments, etc.

The choice of the laser beam to study the structure of biological particles is conditioned by the fact that it does not induce gross pathological changes and diagnostics will ensure effective use of all the coherence properties of laser radiation, monochromatic directional.

Note that for laser processing of the biological environment it is also necessary to perform a selective thermal influence facility located in the environment. For these purposes it is necessary for a selection of optimal spectral, temporal, and energy characteristics of the laser source.

The main parameter to reach selectivity (choice) is the wavelength of the radiation. If we choose a wavelength of light which is absorbed by the object, but not absorbed by the surrounding tissues, the selectivity is achieved.

However, such a situation is ideal and cannot always be achievable in practice. Considerable value is also placed on the duration of treatment, the size of the object, and the depth of its location.

After laser irradiation on biological tissues factors need to be considered such as the movement of blood through the vessels and thermoregulation.

Blood flow can have significant impact on the result of exposure if it is dependent on the degree of thermal damage to the tissue because blood flow may be an additional and sufficiently effective mechanism heat removal from the site of exposure. Note that this effect may influence both the efficiency and the safety of the procedure, because it violates the local heating.

Thus, the optimization of the laser emitter for selective heating of multicomponent media is an ambiguous problem.

For these purposes various mathematical models have been developed, usually designed to solve a specific task. In most cases, the problem of choice of the laser source and its performance is decided on the basis of the absorption and relaxation times of the objects (media). Modeling of this kind is usually designed to solve the problem of optimizing the parameters of the laser transmitter and evaluate the results obtained under the influence of the pre-selected laser on the biological environment. In order to correctly construct a mathematical model that describes the interaction of laser radiation with tissue, it is first and foremost an established good understanding of the structure of biological tissues, their optical and thermal properties, as well as the main effects in the propagation of radiation in biological tissues.

The monograph discusses problems related to the study of mechanisms of interaction of laser radiation with biological tissues, the study of effects of laser interaction with biological tissues methods of the asymptotic theory of diffraction and computer modeling. By virtue models, described in the monograph, on the basis of result of influence of laser biological tissue under certain conditions, can be consistently changed to input characteristics to produce an optimization of the spectral and energy parameters of laser emitters to achieve the desired effect in each case.

The book presents the original results of theoretical studies of electromagnetic waves in media simulating biological layered structure. Concepts and methods for studying the laser radiation interaction with multicomponent heterogeneous tissue with a complex structure of the asymptotic theory of diffraction methods are presented. These methods can serve as the basis for creating software for the biomedical diagnostics.

The monograph is addressed to researchers and specialists in biomedical physics interested in the development and application of laser and optical diagnostic methods in medical research.

The monograph consists of ten chapters.

In Chap. 1 we consider the structure and optical properties of biological tissues, blood, and human skin.

In Chap. 2 we expand methods of light scattering for the quantitative study of the optical characteristics of the tissue, and the results of theoretical and experimental studies of photon transport in biological tissues.

In Chap. 3 we describe the optical characteristics, namely, dispersion and absorption spectra of an ensemble of spherical particles randomly oriented inside an optical cavity. The study is based on the self-consistent matching of new data from the inhomogeneous optical cavity with data from the scattering of an ensemble of spherical particles of different size, randomly oriented in free space.

In Chap. 4 we discuss a mathematical model for calculating the interaction of laser radiation with a turbid medium and a model for the prediction of the optical characteristics of blood (refractive index and absorption coefficient) and for the determination of the rate of blood flow in the capillary bed under irradiation of a laser beam is proposed.

In Chap. 5 we construct electrodynamic model which makes it possible to vary the electrophysical parameters of a biological structure in calculations with allowance for roughness.

In Chap. 6 the mathematical model is proposed for predicting optical characteristics (refractive index and absorption coefficient) of a biotissue being simulated, which is probed in vivo by a laser beam. Blood corpuscles in this case are simulated by particles of irregular shape and various sizes, which are oriented arbitrarily in free space.

In Chap. 7 we construct a mathematical model, which allows us to vary the electrical parameters and structure of the simulated biological tissue with fibrillar structure for case in vivo.

In Chap. 8 we expand a mathematic model for predicting the absorption spectrum and dispersion of a section of a biological structure consisting of epidermis, upper layer of the derma, blood, and lower layer of the derma and placed in the cavity of an optical resonator.

In Chap. 9 we discuss a mathematical model, which makes it possible to vary the characteristic sizes of roughness, the electrophysical parameters of the biological sample under investigation, and its geometrical characteristics and to establish the relations between these parameters and biological properties of the biological tissue being modeled, as well as to calculate theoretically the absorption spectra of optically thin biological samples placed into the cavity of an optical resonator.

In Chap. 10 we propose mathematical model for calculation of the hyperthymia of a multilayer biological structure under the action of laser radiation.

Before closing, I want to acknowledge my sincere thanks to my colleagues Prof. Boris G. Vager, Prof. Anatoly M. Radin, and also Prof. Michael A. Narbut for a critical reading of the manuscript, and my wife Tetiana Koshlan. My thanks are to Springer-Verlag, in particular Dr. habil. Claus E. Ascheron and Elke Sauer, for constant encouragement.

Saint Petersburg Kirill Kulikov

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