



On Acoustic-optical effect originated as a result of laser radiation on bio tissue through nano-measure spreader

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Abstract: - A single physical model is proposed that takes into account some real-world factors to obtain a possible solution to the respective task of temperature deviation at a small distance from surface of the biofiber, which satisfactorily describes the biophysical and medical picture of the tumor formation. The above model discusses the differential equation for temperature deviation at a small distance from surface of the biofiber, which takes into account the thermal conductivity of the biofiber, dimensions of the structural elements, the density of the environment and the specific thermal conductivity.

Keywords: Laser radiation, optical-acoustic model, nanomedicine, oncological diseases.

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Introduction

During the last decades the desire to study the effects of the impulsive laser radiation on biotissues with nano-measure spreader. Optical-acoustic effect is the most important effect during this process. Studying the distribution of sound and light in the surroundings is the most important scientific problem because we can use it for medical diagnostic. Nanotubes have strong adhesion toward bacteria cells and they absorb laser radiation. For the carbon nanotubes we should use irritation near the infrared environment – 850 nanometers (nm.)

The stronger is laser impulse, the more powerful will be the acoustic signal. Additionally, the effects of the nanotube during light transformation into sound, given the opportunity to use less powerful laser impulse (for example of 20 mj/cm² capacity). the impulse if it has more power than it should have, may cause the damage of bio-tissue. Withal, sound, spread through nano particles could be observed by the ultrasound converters [1].

The form of acoustic impulse depends on patterns of the environment – on the coefficient of light absorption, the rate of sound and laser radiation parameters which includes impulse expectancy and spot diameter. Optical-acoustic signals are determined by absorbed environment with the characteristics of radiation, and also with optic, thermo physical and acoustic properties. This helps us to determine above-mentioned patterns of environment by using optical-acoustic signal's time profile.

In the given work is discussed the aspects of opto-acoustic radiation which forms in result of impulsive laser radiation of biotissue. There is given one physical model, which describes the real image. Results of the research can be verified experimentally.

Theoretical Model

From the standpoint of modern medical science, the occurrence of pathology of an organ and pathology of the nervous system is based on a viewpoint, according to which, pathological formations are cell structures with changed parameters, that is a united, integrated system [1]. Systemic mechanisms of pathological disorders are manifested in various forms of pathology, at different levels of structural-functional organization of the nervous system, causing various pathological processes appear in various forms of disease. Methods of regulating the whole system of the organism – in various embodiments – are interdisciplinary scientific problem [2]. Proceeding from the fact that this issue – from the practical point of view – is very complex, a mathematical model is presented to solve it, that will relatively facilitate the control of treatment process, and, accordingly, it will be focused on results.

In work [3] there was suggested one model of laser radiation on the nanoparticle or cell, because formation of acoustic wave is observed during this process, which affects not only nanoparticle, but only the surrounding area. In result, bifurcation area formed near tumor cells. In above mentioned work was found so called reversed distributive function for which was Newton's approximate solution;

$$\varphi(x) = F(x) - \alpha; \quad 0 \leq \alpha \leq 1. \quad (1)$$

Here $F(x)$ is the distribution function. The solution of this task is written as recurrent formula, which helps to find index function.

On the other side solution of sound irritation during impulse laser radiation is divided into 3 stages:

- 1) Calculating heat dissipation density in the scattering environment
- 2) Calculating heat field, which is formed by the heat source in the environment, during the first stage
- 3) Finding acoustic field in the environment, which is calculated with the help of abovementioned heat field [2].

Each of this task generally have no decision analysis. That is why the analysis of sound thermo-optical excitement is possible by additional simplified access in the scattering environment.

If we say that environment is a strong scattering:

$$\mu_a \ll \mu'_s$$

The width and the size of laser beam, which is used to describe the sound, is noticeably more than the size of pierce in the light environment:

$$Z_L = \mu_{eff}^{-1}, \quad (2)$$

Where μ_{eff} is light extinction coefficient, L - the width of environment, Z_L characteristic size of light.

To make it easy, let us discuss one-dimensional acoustic and thermal task. In addition, we have to consider that trial environment is homogeneous in terms of acoustic and heat. In this case, it can be described with "effective" parameters – such as are specific heat capacity, heat speed, heat conductivity, the coefficient of heat extension. If relaxation time in heat environment is more than laser impulse durability:

$$t_{th} = \frac{1}{\mu_{eff}^2 \chi}; \quad (3)$$

Here t_{th} is heat environment relaxation time, χ - heat conductivity, then heating the environment with laser beams can be omitted. The intensity of radiation during absorption in the short laser impulse will be the following:

$$I_0 f(t) H(z) = I_0 \tau_L \delta(t) H(z) = E_0 \delta(t) H(z); \quad (4)$$

Where V_L is phase velocity of longitudinal sound wave in the absorbable environment, τ_L laser beam duration, E_0 - compactness of laser radiation energy on the surface of environment $z = 0$; I_0 - laser intensity envelope; $f(t)$ form of impulse in time, $H(z)$ distribution of light in the distribution.

In this case, on the aforesaid period of time within the absorbable area in the radiated movable acoustic wave dependence on the pressure time equals to:

$$p\left(\tau = t - \frac{z}{V_L}\right) = \frac{\beta V_L^2}{2C_p} \mu_0 E_0 \begin{cases} H(-V_L \tau), & \tau < 0 \\ \left[\left(\frac{1-N}{1+N}\right)\right] H((-V_L \tau)), & \tau > 0 \end{cases} \quad (5)$$

Here $\tau = t - \frac{z}{V_L}$ is time in corresponding coordinative system, β - coefficient of thermal expansion, C_p specific heat capacity, N is absorbable and transparent area acoustic impedances difference (for acoustically hard border $N \gg 1$); $R_{ac} = \frac{1-N}{1+N}$ is reflectance of ultrasound wave from interface.

Therefore, optical acoustic signal (5) represents compression wave, which is followed by rarefaction wave (when $N > 1$) or compression wave (when $N < 1$). $\mu_{eff} V_L \tau_L (\leq 0,1)$

least, though during completed meaning transferrin zone between zones, may have τ_L line duration. Total duration of optical acoustic signal is determined pursuant to calorification area and equals:

$$(4 \div 6)(\mu_{eff} V_L)^{-1}.$$

It is essential to be denoted that (5) figure is accepted in discussable area taking into consideration diffraction of optical-acoustic signal.

It is known that, during continuous laser irradiation, the one time shift of the bilipid membrane sections occurs. The change in the initial volume is as follows:

$$\Delta V = \beta_T V_0 \Delta(T(t, z), \quad (6)$$

where:

β_T - is the volumetric thermal expansion coefficient of substance;

V_0 - is the initial volume of some limited volume;

$T(t, z)$ - is the change in temperature.

During the irradiation time t of the volume under consideration, the wavelength λ and the intensity $I(t, z)$ in the absence of heat outflow from the heating environment (i.e. from the zone of structural element), the deviation of the temperature value from the original value at the moment of t time is determined by the distance z from the biofiber surface, it is defined by the following differential equation:

$$\Delta T(t, z)'_t = bI(t, z) - \frac{\Delta T(t, z)}{\tau}, \quad (7)$$

where:

$b = \frac{\Delta u(\lambda)}{\rho c}$; $\Delta u(\lambda) = \alpha_1(\lambda) - \alpha_2(\lambda)$ $\alpha_1(\lambda)$ and $\alpha_2(\lambda)$ - is the absorption coefficients of the wavelength λ (structural element) for environment-1 and environment-2 (fluid, surrounding structural environment) respectively;

ρ, c - is the density of the environment and the specific heat capacity in the structural element;

$\tau = \frac{L^2}{\chi}$ - is the time of thermal relaxation of the structural element;

L - is the linear size of the structural element;

$\chi = \frac{k}{\rho c}$ - is the coefficient of thermal conductivity of biofiber;

k - is the thermal conductivity of the biofiber.

In case when $I(t, z) = I(z)$ and in the initial moment of time ($t = 0$) $\Delta T(0, z) = 0$, (7) the solution of the equation is expressed as follows:

$$\Delta T(t, z) = bI(z)\tau \left(1 - \exp\left(-\frac{t}{\tau}\right)\right). \quad (8)$$

From equation (8), in the case of fairly long irradiation of the biofiber with constant intensity ($t = \infty$), we obtain the marginally possible change in temperature $\Delta T_{lim}(z) = bI(z)\tau$. After cessation of irradiation, the structural element cools down gradually.

During laser irradiation with amplitude-modulated rectangular impulses, periodic shift of lipid clusters in the membranes occurs and it returns close to the original state.

$$\Delta T(t, z) = bI(z)\tau \left(1 - \exp\left(-\frac{t}{\tau}\right)\right), \quad 0 \leq t \leq t_{puls} \quad (\text{during irradiation}),$$

$$\Delta T(t_{puls}, z) = bI(z) \left(1 - \exp\left(-\frac{t_{puls}}{\tau}\right)\right), \quad t = t_{puls}. \quad (\text{immediately after termination of irradiation}),$$

$$\Delta T(t_{puls}, z) = bI(z) \left(\exp\left(\frac{t_{puls}}{\tau} - 1\right)\right) \exp\left(-\frac{t}{\tau}\right), \quad t_{puls} \leq t \leq t_{per}. \quad (\text{during pause}) \quad (9)$$

where:

t_{puls} - is the duration of the impulse;

t_{paus} - is the duration of the pause;

$t_{per} = t_{puls} + t_{paus}$ - is the pulsation period.

As can be seen from equation (4), the dynamic of temperature changes and, consequently, the volume of the structural element depends on the difference between the coefficients of its thermal relaxation τ , and the absorption coefficients of the structural element and the fluid, its surrounding environment

$$\left(\frac{d\Delta T(t, z)}{dt}\right) = bI(z) \exp\left(-\frac{t}{\tau}\right). \quad (10)$$

There is an optimal pulsation frequency, which is determined by the temperature relaxation of the structural element τ and it depends, first of all, on their dimensions. However, both the duration of pulses and pauses between them should be in the range of $(4 \div 20) \cdot \tau$ [7].

Discussion and Analysis

As seen from expression (10) ahead front $p(\tau(0))$ of opticalacoustic signal repeats distribution through space of beam intensity in the area. Moreover time scale of p amendment time scale τ and space scale H are inter-connected in the surrounding through sound speed $z = -V_L \tau$. In case of free border of absorbable $p(\tau = 0) = 0$ (at the expense of the reflected signals), and in case of inflexible border $p(\tau = 0)$ it has local minimum, which supports in distribution of beam intensity to local minimum of $H(z)$ when $z = 0$ (see above). Determination of experimentally excepted and corrected pressure profile ($\tau = 0$) of optical-acoustic impulse, by the moment of time, gives possibility to transfer time dependence of optical-acoustic impulse into the space one $\left(\frac{\beta V_L^3}{2C_p}\right) \cdot \mu_0 E_0$, which is distribution of beam intensity in the space $H(z)$.

In this work discussed differential equation (7) is presented, which determines the deviation of the temperature value from the surface of the biofiber at a distance of z , which takes into account the thermal conductivity of the biofiber, dimensions of the structural elements, environmental density and specific heat capacity.

Above-discussed model might be used not only nearby the origination location of optical-acoustic effect, but also for direct study of biophysical and biochemical processes. In addition to this, through above-indicated figures, it is possible to calculate physical processes quite precisely.

Conclusion

To summarize, if the beam absorption coefficient, speed of sound, thermophysical parameters, also laser radiation density on the environmental surface is known, we can directly measure light beam's spatial distribution of intensity using optical-acoustic method. The usage of this method helps us to directly measure acoustic pressure. If its size is known, we can calculate bacteria in the process of blood circulatory process.

It is discussed in this work the differential equation (7) for the deviation of the temperature value over the distance z from the surface of biotissue during volume radiation in which there are considered heat capacity of biotissue, size of structural elements, density and specific heat capacity

It's known that structural elements (biotissues) gradually cool down after stopping radiation. In addition, as we can see from the equation discussed in the article (9), dynamics of temperature change and the volume of structural elements depends on its temperature relaxation time τ , structural element of the environment and fluid and the difference (10) in the absorption coefficients of the surrounding environment.

There is indicated that optimal pulse frequency and is given possible duration range of laser impulses which is determined $(4 \div 20) \tau$ range.

In addition, the issue under discussion needs further study and requires clarification of certain details at the level of clinical experiments, which will help us to improve the quality of treatment of various nosological diseases. Therefore, it has its advantages in terms of method accuracy and achieving the desired result. The issue discussed in the paper is important in terms of the application of nanotechnologies in medicine, which will be essential for the treatment of cancer.

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