GENERATION OF INFRARED RADIATION WITH MODULATED AMPLITUDE AT TERAHERTZ FREQUENCIES

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Abstract

The role of infrared radiation in stimulating cellular metabolism can be dual. Firstly, the energy of light quanta is used by the cell instead of the energy of adenosine triphosphate hydrolysis. Secondly, light absorption cannot replace this hydrolysis. However, it can accelerate its rate and thus the productivity of metabolic reactions associated with it. This process is significantly enhanced by the use of terahertz modulation of infrared radiation, which is manifested, for example, in optically stimulated transport of ions through biological membranes. For therapeutic effects on the above-described processes in biological tissues, a device has been developed that generates infrared radiation with wavelengths in the range of maximum transparency of biological tissues modulated in amplitude in a frequency range of 10^{11}–10^{12} Hz. The modulation of radiation has been produced by the method of interference.

Keywords: cell metabolism, IR radiation, modulation

Rezumat

Rolul radiațiilor infraroșii în stimularea metabolismului celular poate fi dublu. În primul rând, energia cuantelor luminoase este folosită de celulă în locul energiei asociate hidrolizei adenozin trifosfatului. În al doilea rând, absorbția luminii nu poate înlocui această hidroliză; cu toate acestea, poate accelera viteza și astfel și productivitatea reacțiilor metabolice asociate. Acest proces este îmbunătățit semnificativ prin utilizarea modulării la frecvențe terahertz a radiației infraroșii, care se manifestă, de exemplu, în transportul stimulat optic al ionilor prin membranele biologice. Pentru efectele terapeutice asupra proceselor descrise mai sus în țesuturile biologice, a fost dezvoltat un dispozitiv care generează radiații infraroșii cu lungimi de undă în domeniul de transparență maximă a țesuturilor biologice modulate în amplitudine într-un interval de frecvență de 10^{11}–10^{12} Hz. Modularea radiațiilor a fost produsă prin metoda interferenței.

Cuvinte cheie: metabolism cellular, radiație IR, modulație

1. Introduction

The role of infrared radiation in stimulating cellular metabolism can be dual. First, the energy of light quanta is used by the cell instead of the energy of adenosine triphosphate (ATP) hydrolysis. Second, light absorption cannot replace this hydrolysis; however, it can accelerate its flow and thus the flow of metabolic reactions associated with it. It should be noted that this reaction is crucial for the transport of proteins between the membranes inside and outside the cell. Due to the fact that the points at which hydrolysis occurs and at which its energy is consumed are frequently separated by distances significantly exceeding the interatomic distances [1], mediation by linear protein molecules is necessary for an efficient energy transfer along the chains from peptide groups. The energy of these oscillations is 0.21 eV; for their excitation, the energy of ATP hydrolysis is sufficient (0.54 eV). The long lifespan of excitations in this system compared with the duration of their life on an isolated peptide group (10–12 s) is attributed to the formation of solitons—related states of intra peptide oscillations and chain vibrations as a whole. A soliton is a solitary form of a solitary wave propagating along a protein molecule, which is not subject to dispersion and does not lose energy [1]. Solitons can be excited not only chemically, but also optically. These solitons can come to the areas where the energy required for metabolism is consumed and thus increase their intensity. In the spectral range of the excitation of the hydrogen bond (0.165–0.3 eV), which corresponds to the wavelength range of the infrared (IR) range of 4–7.5 μm, there is the oscillation energy of linear molecules. The action of optically induced solitons, which are ideal carriers of the energy of the hydrolysis of ATP molecules along α-helical protein molecules with almost no loss, can be multiplied if the light generating them is modulated in the terahertz range of "shaking" bonds inside the radicals that constitute the protein molecules [2]. In this case, the optical excitation and transport of solitons can stimulate the removal of oxygen-containing radicals trapped in the damaged areas of protein molecules, which is of great importance for practical medicine. It should be noted that optically induced solitons can have a direct effect on the occurrence of ATP hydrolysis. In this case, optical IR radiation leads to the formation of a soliton with a subsequent increase in the probability of the "shooting" of the phosphate group:

ATP + "IR radiation" => ADP + F.

Accordingly, this process is significantly enhanced by the use of terahertz modulation of infrared radiation, which is manifested, for example, in optically stimulated transport of ions through biological membranes in the “potassium–sodium pump” mode [3]. Within the framework of the mechanisms described above, IR radiation can be used to increase the efficiency of oxygen binding in hemoglobin and myoglobin. During the optical IR irradiation of a heme, which is a porphyrin complex of a bivalent iron ion, a soliton is formed, followed by a change in the heme. As a result of this process, an intense capture of the oxygen molecule on the Fe_2 ion is stimulated, which is followed by the destruction of the soliton. Hemoglobin containing oxygen is referred to as oxyhemoglobin. The process of reversible addition of an oxygen molecule to an iron ion in a heme is referred to as oxygenation. This process, as described above, is abruptly enhanced with terahertz modulation of IR radiation, the frequency of which corresponds to the “shaking” of bonds within the porphyrin ring. It should be noted that continuous irradiation using infrared radiation leads to an abrupt increase in the concentration of oxyhemoglobin, the saturation time of which corresponds to the soliton lifetime and can reach 22.5 min. In turn, the releasing of an oxygen molecule is referred to as deoxygenation. It is of interest that the spectral ranges for optimum stimulation of the above-discussed important biochemical reactions by IR radiation correlate well with the positions of IR atmospheric windows in the transmission spectrum of the

Earth's atmosphere (Fig. 1).

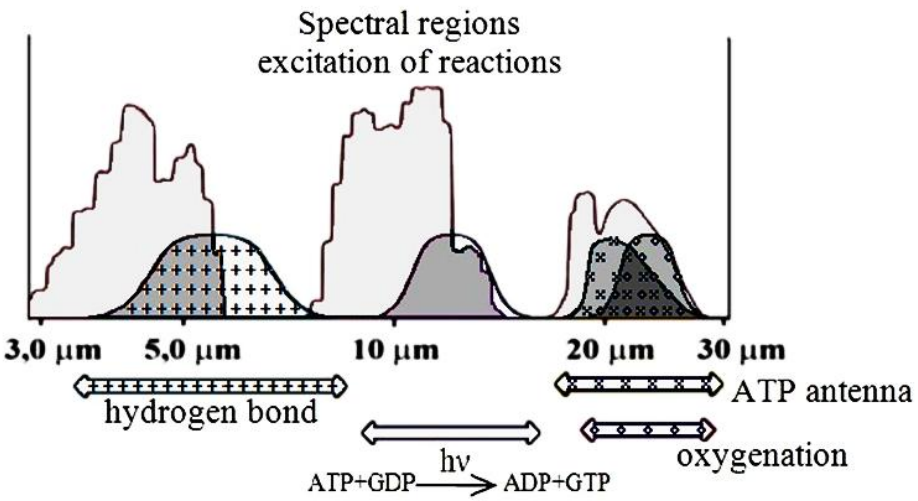


Fig. 1. Optimum excitation spectra of the most important biochemical reactions by IR radiation with terahertz modulation compared with the transmission spectra of atmospheric IR windows in the Earth's atmosphere [4].

For therapeutic initiation of the above-described processes in biological tissues, we have developed a device that generates IR radiation at wavelengths of 0.7–0.9 μm, i.e., in the range of maximum transparency of biological tissues, modulated by amplitude in a frequency range of 10^{13}–10^{14} Hz. The radiation power density of 6 mW/cm^2 is selected on the basis of safety requirements. The total radiation power with a collimator diameter of 50 mm is 100 mW.

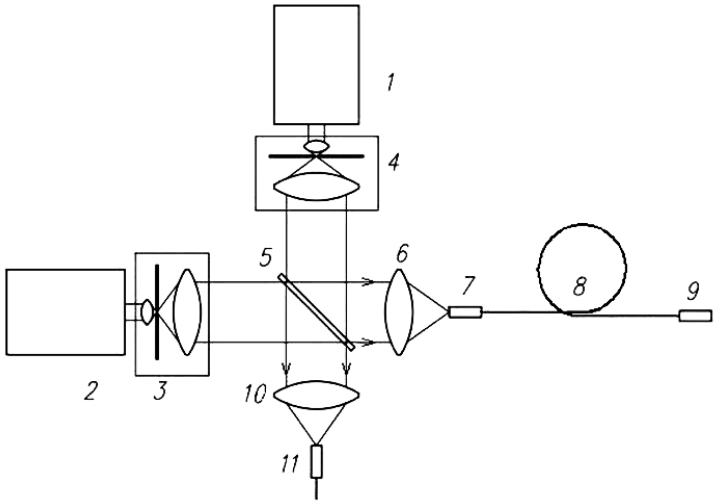
Radiation is modulated by the interference method. Unlike the classical interference between two coherent radiation beams, in this device, it was decided to use the interaction of the radiation of two lasers. Therefore, the concept of coherence is not applicable here; the case in hand is a sliding interference pattern. The interference of two beams from ideal lasers should lead to a classical interaction with the release of harmonics referred to as heterodyning. Real lasers, even single-mode ones, emit in a certain frequency range. Therefore, the interference pattern, when they interact, will be a set that includes, in addition to frequencies f_1 and f_2 of both lasers, their half sum f_Σ and half difference f_Δ and frequencies determined by the width of the central modes Δf of each laser.

The amplitude of these frequencies will be significantly less than the amplitude of the half-sum and half-difference; this fact is associated with the shape of the amplitude-frequency characteristic of the radiation in the central mode region.

2. Optical Scheme of the Device

The optical scheme of the device consists of two lasers emitting at a wavelength of λ_1 and λ_2, respectively, and connected to an optical mixer. The result is a combination of the original signals: $f_1 = c / \lambda_1$ and $f_2 = c / \lambda_2$, their half sum is $f_\Sigma = (f_1 + f_2)/2$ and the half difference is $f_\Delta = (f_1 - f_2)/2$. The operating frequencies of the lasers are chosen so that they are suitable; their

half-difference is determined by the frequency of interference (Fig. 2).



1,2 Laser diodes. 3,4 Beam cleaning systems. 5 Beam splitting plate. 6,10 Lens. 7 Fiber end. 8 Light guide. 9 Collimator. 11 Photosensor.

Fig. 2. Optical scheme of the device

A necessary condition for obtaining high-quality interferences is the equality of the amplitude vectors E_1 and E_2 of both radiations and the coincidence of their polarization planes. To provide this situation, it is necessary to control and stabilize the power of each of the lasers. Thermal stabilization of laser diodes is also required.

However, the cost of single-mode lasers makes the medical device inaccessible to a wide range of users. It is possible to use multimode lasers; however, in this case, the selection of the central mode is necessary. The easiest way to suppress transverse modes is filtering on a small hole. The beam cleaning system (3.4) consists of a micro lens, a pinhole, and a collimating lens.

The point aperture is located at the junction of the foci of both lenses. With the correct adjustment of the diaphragm, the cross section of the beam after the collimating lens is uniformly filled with radiation and has a maximum intensity. The process of adjustment is extremely difficult, especially when working in the IR region, where visual perception does not work. In addition, with uneven heating of the installation, misalignment of the beam cleaning system is possible. To stabilize the operation of the beam cleaning system, a method of auto-adjusting the diaphragm on the feedback signal is applied.

3. Beam Cleaning System

The position of the diaphragm (12) in the plane perpendicular to the beam axis is given by the piezoelectric elements *X* and *Y*, which are supplied with voltage from the controller, which receives the feedback signal from the photodiode (16), which measures the radiation intensity (Fig. 3).

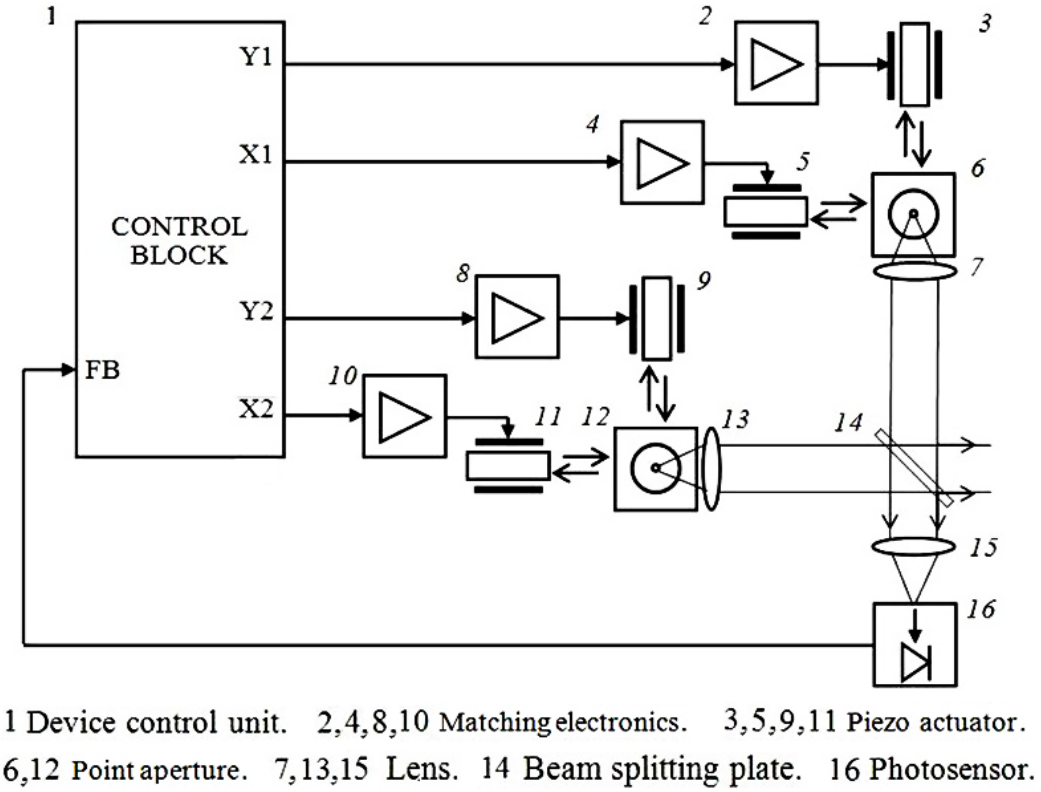


Fig. 3. Beam cleaning system

According to the alignment algorithm, the controller measures the current value of the radiation intensity, then changes the voltage across piezoelectric element *X* and repeats the measurement to find the extremum. After this, the procedure of searching for the maximum is performed with a change in voltage across piezoelectric element *Y*, and finally again across piezoelectric element *X*. This procedure completes the adjustment of the diaphragm (12). Next, the controller repeats the entire alignment cycle for the diaphragm (6). The adjustment of the device is over. To eliminate mutual influence, when adjusting one of the lasers, the other one is turned off for this time. Control adjustment can be carried out periodically without participation of an operator.

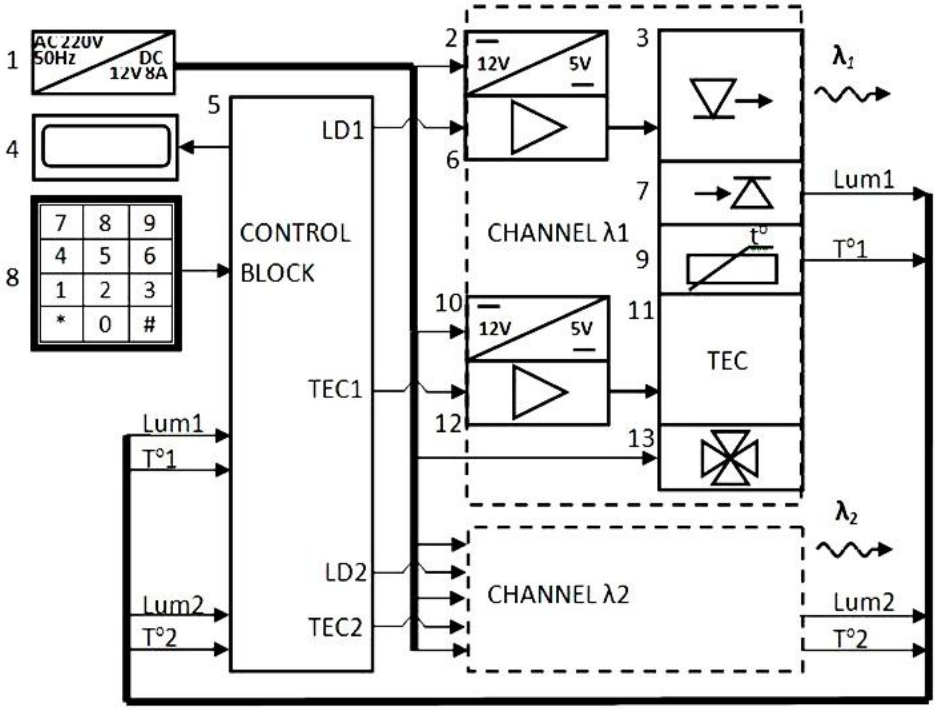
4. Design of the Device

The device is made in a 200 × 150 × 80 mm case. The device includes the following units: a 12V-4 A power supply, a control board, a radiator with forced air cooling, a Peltier element, two laser diodes of the brand with λ_1 = 785 nm and λ_2 = 830 nm, a BSW26 mixer (350–1100 nm), a connector for connecting the radiating head, a radiating head with an optical cable, and a collimator (Fig. 4).

The control board contains the following units: two Peltier elements, a temperature controller to stabilize the temperature of the lasers, two laser power stabilizers with the possibility of balancing them, and a timer for a fixed interval of 10 min.

The front panel contains the following units: a power-on indicator, a START/STOP

button, and a "RADIATION" indicator. The front panel contains an optical connector for connecting the radiating head. The rear panel contains a connector for connecting to the network cord. Laser diodes are placed on a Peltier element, which gives heat to a cooled radiator. Laser power is controlled according to classical schemes using photodiodes.



1. AC / DC converter ~220V / 12V. 2, 10. DC / DC converter 12V / 5V. 3. Laser Diode 4. Display. 5. Device control unit. 6. Laser Diode power control circuit output stage. 7. Sensor monitoring the power of the laser diode radiation. 8. Data entry panel. 9. Sensor temperature control laser diode. 11. Peltier element. 12. Peltier element power control circuit output stage. 13. Cooler

Fig. 4. Block diagram of the device

5. Conclusions

A generator of IR radiation packages in the wavelength range of maximum transparency of biological tissues is proposed. The packets follow each other in the range of natural frequencies of oscillations of the cell membranes, cytoskeleton, and cells as a whole. The radiation generated by the generator can affect not only the skin, but also deep structures of the body. However, it, having a powerful regulatory effect on the processes occurring in the body at the molecular, cellular, tissue, organ, and system levels, is not ionizing; that is, it does not cause mutations. The generator is designed for use in medical practice to improve the nervous and humoral regulation of body functions and metabolic processes.

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