# Diode Laser as an Electronic System of Surgical Influence on Soft Biological Tissues

I.M. Lukavenko*

*Sumy State University, 2, Rymsky-Korsakov St., 40007 Sumy, Ukraine*

(Received 20 December 2019; revised manuscript received 15 February 2020; published online 25 February 2020)

The analysis of the physical bases, features of the design and clinical application of diode lasers (laser scalpels) in surgical practice, mechanism of action of a laser scalpel, which is based on the fact that the energy of a monochromatic coherent light beam sharply increases the temperature at the corresponding limited area of biological tissue, is carried out in the work. It is shown that under the effect of laser radiation the tissue is destroyed by the influence of a kind of shock wave, which is formed during the instantaneous transition of tissue fluid to a gaseous state. The surgical action of laser radiation depends on the wavelength, pulse duration, structure, and physical properties of the tissue. When calculating the results of laser heating of tissue it is necessary to take into account that optical, mechanical and thermal properties of tissue change in the course of its laser heating and are observed not separately, but in a complex. This is due to the heterogeneity of the tissue heating and the temperature gradients. The depth of incision of breast tissue was estimated by a laser scalpel "Lika-surgeon" (Ukraine), which is used for treatment of nodal formations of breast or residual cystic cavities with a fixed instrument. The depth of the hole changes inversely proportional to the size of the irradiated area, which is in good agreement with the experimental data.

**Keywords**: Diode laser, Laser scalpel, Coherent radiation, Biological tissue, Coagulation, Ablation.

DOI: 10.21272/jnep.12(1).01014 PACS numbers: 42.55.Wd, 42.62.Be

## 1. INTRODUCTION

Finding and developing methods for reducing trauma, blood loss and pain during surgery to accelerate the healing of postoperative wounds and resection of scars are important tasks of modern surgery, which is facilitated by the use of laser [1-3], ultrasonic [4-6] and radio waves [7] technologies in medicine. The nature of tissue destruction under the action of a surgical instrument depends on the structure of its working part, the amplitude and direction of a particular type of waves, as well as on the properties and homogeneity of biological tissue.

Semiconductor diode laser is an electronic system based on laser diode matrix, which emits light of a well-defined wavelength. This is a relatively new technology with many advantages. Two plates of semiconductor materials with different types of conductivity (electronic and hole) are in contact with each other. Transmission of electric current in the forward direction stimulates the movement of electrons from the *n*-plate to the *p*-*n* junction. By getting into the *p*-plate, electrons collide with atoms and release light photons. This process avalanches until a laser beam directed perpendicular to the plates is formed.

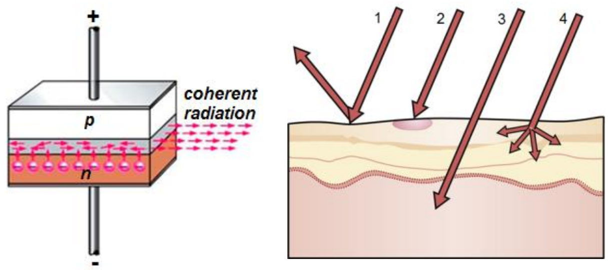
A feature of diode lasers (laser scalpels) is the location of the emitting element in the control handle, and not in the device itself. This provides several important advantages at once such as minimal energy loss, because the laser diode blocks (diode matrix) are usually located in the handle of the device, there is no need to use a complex system of mirrors or optical fibers to deliver radiation.

This results in significantly lower energy losses compared to crystalline or gas lasers in which radiation is generated in the device itself, high efficiency (amounts to 30 % ) [8]. For comparison, Nd:YAG laser – about 3 %, $CO_2$ laser – 5-15 %, fiber lasers – up to 20 %.

The purpose of this paper was to analyze the physical basis, to describe the clinical application of diode laser for surgical influence on soft biological tissues and to evaluate the dependence of the depth of cut on the laser beam diameter.

## 2. PHYSICAL ASPECTS OF THE LASER SURGERY METHOD

In the treatment of benign breast dysplasia we used a laser scalpel "Lika-surgeon" (Ukraine) for the surgical treatment of nodular breast or residual cystic cavities.




a b

**Fig. 1** – Structure of a diode laser (a); processes in biological tissue under the influence of laser radiation (b): 1 – reflection; 2 – absorbtion; 3 – transmission, 4 – scatter

When calculating the results of laser tissue heating, it must be taken into account that the optical, mechanical and thermal properties of the tissue change during its laser heating. In particular, the rate of tissue absorption increases sharply with carbonization. As a result, the temperature reached in the area of influence near the surface increases sharply, and the heating process becomes purely nonlinear. Acceleration of heating (on the surface) usually occurs also during tissue dehydration. This is due to a decrease in thermal conductivity during

* doctorlv@ukr.net

dehydration, which reduces heat removal from the irradiated region. All considered types of changes in biological tissue are usually observed not separately, but in a complex. This is due to the heterogeneity of tissue heating and the presence of temperature gradients.

At temperatures above 43 °C, protein molecules are irreversibly damaged (denature), the tissue dies, undergoing thermal coagulation; at temperatures above 100 °C, evaporation of water begins; at temperatures above 300 °C, combustion occurs with the release of combustion products and their deposition on the surface of the crater.

The destruction of tissue by forming a crater, hole, or incision during laser operation is called ablation, and the conditions under which it occurs are called the ablation mode of the laser. At low radiation power and short-term exposure, tissue heating is insignificant and only coagulation or melting occurs (subablative mode).

The mechanism of action of the laser scalpel is based on the fact that the energy of a monochromatic coherent light beam sharply increases the temperature in the corresponding limited area of the body and leads to its instantaneous combustion and evaporation. In this case, the thermal effect on the surrounding tissues spreads over a very small distance, since the width of the focused beam is 0.1-0.9 mm. Under the influence of laser radiation, "explosive" destruction of tissue under the action of a peculiar shock wave, which occurs when the tissue fluid instantly transitions to a gaseous state, takes place. Features of the biological effect of laser radiation depend on a number of its characteristics such as wavelength, pulse duration, tissue structure, physical properties of the tissue (Fig. 2).

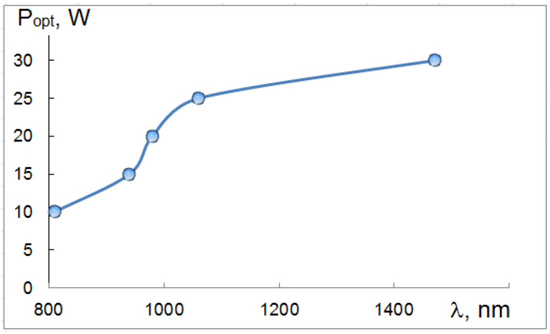



**Fig. 2** – Experimental dependences of the output optical power of a diode laser versus the working wavelength of laser radiation with stepwise adjustment of power

Radiation from a surgical laser causes damage or death of living tissues, and with a sufficiently high density of absorbed energy – tissue ablation. The term «ablation» means the removal of a substance from the body surface.

The ablation mechanism and its parameters are determined by: radiation characteristics (wavelength $\lambda$, time duration $\tau$, power $W$, etc.); physical and structural properties of the tissue (ratio of liquid and dense components, physicochemical composition, thermal sensitivity of cells and macromolecules, tissue blood supply, etc.); optical and thermophysical properties of the tissue (reflection coefficient, absorption and scattering in the tissue, its heat capacity and thermal conductivity).

The interaction of laser radiation with biological tissue, including its ablation, is one of the fundamental and intensively studied problems [8-12], although not yet completely resolved. It is despite the fact that at the present stage of medicine development, diode lasers are widely used in surgery, including for the treatment of benign breast diseases (see, for example [13, 14]).

Based on numerous studies of the interaction of laser radiation with biological tissue, four interaction mechanisms can be distinguished, which differ from each other by the characteristics of the processes. These mechanisms can be considered (depending on the power of exposure), both above and below the threshold for tissue ablation. We will call these modes, respectively, the ablative mode of radiation exposure and the subablative mode. Both these modes are effectively used in modern laser surgery.

*Non-contact application.* In this case, the laser radiation reaches biological tissue using the radiation delivery system without touching biological tissue. How delivery systems are used: mirror-lens manipulators or fiber optics. The radiation passing through the delivery system focuses on a spot whose diameter is less than the diameter of the fiber. The fiber does not ensure the preservation of coherence and collimation of the beam, and the radiation leaves it at a rather large angle of divergence.

*Contact application.* In the contact method, the optical fiber used to deliver the radiation is in contact with the tissue. How optical devices are used: research probes, manual applicators can be gas and liquid flushed, focusing manipulators, endoscopes, operating microscopes.

A typical combination: a mirror-lens manipulator and an operating microscope. The manipulator provides the ability to move the beam along the surgical field within a few centimeters. Radiation is focused in all radiation delivery systems. With surface coagulation or coagulation of small vessels, the use of a defocused beam is more preferable.

The size of the laser spot can be changed by changing the focal length of the focusing lens or by varying the distance from the lens to the tissue surface.

You can work in a converging or diverging beam. When working in a converging beam with weak absorption, greater uniformity of the radiation power density over the tissue depth can be ensured (a decrease in the radiation power density due to attenuation during absorption is compensated by its increase due to focusing). However, if the change in radiation power density is difficult to control, it is best to work in a diverging beam to avoid undesirably high energy densities. When working in a converging beam, it is necessary to take into account that the optical refractive index of biological tissue is greater than that of air; therefore, the focus in the tissue is deeper than in air.

Optical fiber can be used for endoscopic purposes. Liquid or gas cooling of the fiber tip is often used. When using fiber, its tip is of fundamental importance. Various options are possible: flat end (bare fiber); in the form of a focon (provides a large divergence); with a «hot» tip – a metal cap, in the center of which a hole is sometimes made through which part of the radiation reaches the tissue. The tip converts light energy into heat (there is no optical energy transfer, heat is transferred by heat conduction), sapphire tips (spherical, cylindrical for coagulation, conical for dissection). Sapphire is transparent for a wide range of wavelengths, physiologically neutral, resistant to acids and alkalis, has a high melting point (~ 2000 °C) and very high thermal conductivity among non-metals. Sapphire tips are attached to the end of the fiber.

They change the characteristics of the laser radiation emerging from the fiber and add the evaporation effect to the coagulation effect. The pointed sapphire tips highly concentrate the radiation and are therefore used to dissect tissue. When using rounded tips, a uniform distribution of radiation is achieved, and subsequent coagulation is ensured. The use of cylindrical sapphire tips with a flat base is effective for achieving hemostasis.

## 3. RESULTS AND DISCUSSION

We estimated the depth of incision of the breast tissue with a fixed tool that works for a certain time laser scalpel "Lika-surgeon".

The energy spent on heating the tissue and its evaporation is equal to

$$E = m\left(c\Delta T + L\right) = \pi d^2 h\left(\rho c\Delta T + L\right) = P_{abs}\cdot\tau,$$

where $d$ is the beam diameter; $h$ is the cut depth; $\Delta T$ is the the difference between the evaporation temperature and the initial tissue temperature; $\rho$ is the density; $c$ is the specific heat; $L$ is the specific energy of tissue evaporation; $(\rho c\Delta T + L) = 2256$ kJ/kg; $P_{abs} = \eta P_{el} = 0.3P_{el}$ is the power absorbed by tissue; $P_{el}$ is the electrical laser power; $\tau$ is the laser beam time.

Then the fabric is cut in depth

$$h = \frac{\eta\cdot P_{el}\cdot\tau}{\pi d^2\left(\rho c\Delta T + L\right)}.$$

The results are shown in Fig. 3.

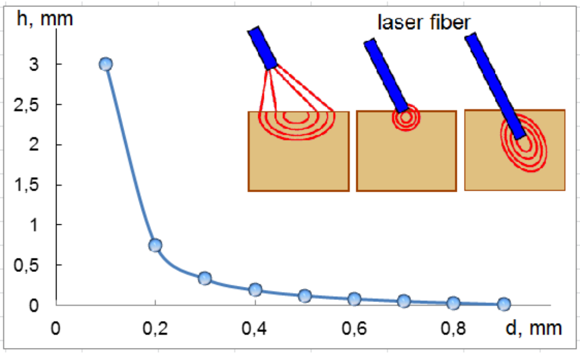
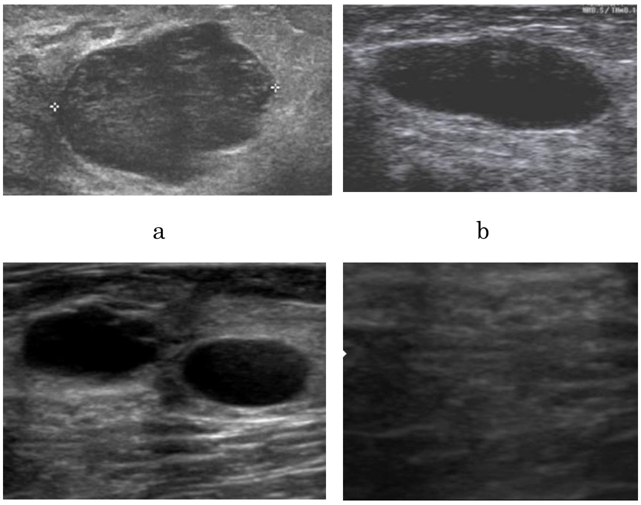



**Fig. 3** – Experimental dependence of the cutting depths versus the diameter of the laser beam at a wavelength $\lambda = 980$ nm and time of laser exposure $\tau = 5$ s

Thus, when using the same laser unit, when irradiating the same tissue ($\eta$, $P$, $\tau$, $\rho$, $c$, $\Delta T$, $L$ = idem), the hole depth will change inversely proportional to the size of the irradiated region. In surgery, the incision depth is inversely proportional to the beam diameter. This is a good agreement with the experimental data.

Fig. 4 shows sonograms of benign breast diseases that are treated with the help of laser radiation.



a b

c d

**Fig. 4** – Sonograms: a – breast fibroadenoma; b – large cyst of the breast; c – multiple breast cysts and d – the breast tissue example after 3 months after surgical laser removal of benign fibroadenoma and cysts

## 4. CONCLUSIONS

1. Laser excision is the best way to treat those patients who have neoplasms. This is mainly due to the features of the laser diode scalpel: bleeding decreases, blood vessels coagulate, ablation properties increase. Thanks to the laser beam, there is no physical effect on the tissue, because of this, the feeling of pressure decreases, negative emotions decrease, and so on. The laser scalpel guarantees the highest invasiveness and the highest degree of sterility.

2. The scalpel inflicts minimal trauma on the tissues, which means that a smooth postoperative course is guaranteed. The period after the operation takes place without the occurrence of severe inflammation.

3. We estimated the depth of incision of the breast tissue with a fixed instrument at a wavelength $\lambda = 980$ nm under the action of laser radiation for 5 s. The calculated dependence of the depth of cut on the diameter of the laser beam is obtained, which agrees well with the experimental results. It is shown that the depth of incision is inversely proportional to the diameter of the laser beam during surgery.

## REFERENCES

1. V. Gafiychuk, I. Lubashevsky, B. Datsko, *Phys. Rev. E* **72**, 051920 (2005).
2. I.M. Lukavenko, V.V. Andryushchenko, A.V. Yazykov, *J. Nano-Electron. Phys.* **10**, 6, 06031 (2018).
3. N. Salas Jr., Fabrice Manns, Peter J. Milne, David B. Denham, Ahmed M. Minhaj, Jean-Marie Parel, David S. Robinson, *Phys. Med. Biol.* **49**, 9 (2004).
4. I.M. Lukavenko, V.V. Andryushchenko, A.V. Yazykov, *J. Nano-Electron. Phys.* **11**, 3, 03008 (2019).
5. A. Golberg, M.L. Yarmush, *IEEE T. Biomed. Eng.* **60**, 707 (2013).
6. M.L. Yarmuch, A. Golberg, G. Sersa, T. Kotnik, D. Miklavčič, *Ann. Rev. Biomed. Eng.* **16**, 295 (2014).
7. I.M. Lukavenko, *J. Nano- Electron. Phys.* **11**, 6, 06015 (2019).
8. J.L. Johnson, Kasper van Wijk, J.N. Caron, Miriam Timmerman, *J. Opt.* **18**, 2, 024005 (2016).
9. Steven L. Jacques, *Physics in Medicine & Biology* **58**, 11, 5007 (2013).
10. L.Cummins, M. Nauenberg, *Biophys J.* **42**, 1, 99 (1983).
11. A. Roggan, U. Bindig, W. Wäsche, F. Zgoda, R. Steiner, R. Senz, J. Helfmann, K. Dörschel, *Applied Laser Medicine,* pp 73-127.
12. Mohammed M. Jawad, Sarah T. Abdul Qader, A.A. Zaidan, B.B. Zaidan, A.W. Naji, Ibraheem T. Abdul Qader, *International Journal of Pharmacology* **7**, 2, 149 (2011).
13. I.M. Lukavenko, V.V. Andryushchenko, V.Iu. Garbuzova, A.V. Yazykov, *Georgian Medical News* No 1 (238), 12 (2015).
14. A.V. Yazikov, V.V. Leonov, V.V. Andryushchenko, I.M. Lukavenko, *Georgian Medical News* No 2 (239), 11 (2015).

## Діодний лазер як електронна система хірургічного впливу на м’які біологічні тканини

І.М. Лукавенко

*Сумський державний університет, вул. Римського-Корсакова, 2, Суми 40007, Україна*

У роботі проведено аналіз фізичних основ, особливостей конструкції та клінічного застосування діодних лазерів (лазерних скальпелів) у хірургічній практиці; механізму дії лазерного скальпеля, який заснований на тому, що енергія монохроматичного когерентного світлового пучка різко підвищує температуру на відповідній обмеженій ділянці біологічної тканини. Показано, що під впливом лазерного випромінювання відбувається руйнування тканини від впливу своєрідної ударної хвилі, що утворюється при миттєвому переході тканинної рідини в газоподібний стан. Хірургічна дія лазерного випромінювання залежить від довжини хвилі, тривалості імпульсів, структури та фізичних властивостей тканини. Оптичні, механічні та термічні властивості тканини змінюються в процесі її лазерного нагрівання і спостерігаються не окремо, а в комплексі, що пов’язано з неоднорідністю нагріву тканини та наявністю градієнтів температури. Проведена оцінка глибини розрізу тканини молочної залози при нерухомому інструменті лазерним скальпелем «Ліка-хірург» (Україна), який призначений для лікування доброякісних вузлових утворень або залишкових кістозних порожнин. Глибина отвору змінюється обернено пропорційно розміру опроміненої області, що добре узгоджується з експериментальними даними.

**Ключові слова**: Діодний лазер, Лазерний скальпель, Когерентне випромінювання, Біологічна тканина, Коагуляція, Абляція.