

Gas-discharge laser with controlled output power for medical applications

V V Chernigovskiy, S A Martsinukov, D K Kostrin and A S Kiselev

Department of electronic instruments and devices, Saint Petersburg Electrotechnical University "LETI", 197376, Saint Petersburg, Russia

E-mail: sergm2006@mail.ru

Abstract. In this work the possibility of control of power of radiation of the carbon dioxide laser intended for surgeries is considered. It is shown that the electromagnetic control system allows regulating laser radiation power in the wide range of values that gives the chance of use of the only laser machine in various medical applications. Experimental results of impact of the modulated laser radiation on biological tissues are given.

The use of lasers in surgical practice has a number of advantages due to the specific impact of laser radiation on biological tissues. The possibility of a high concentration of light energy in small volumes makes it possible to selectively affect the biotissue and dose the degree of this effect from coagulation to their evaporation and cut.

Laser radiation allows removing pathological tissue without damaging the surrounding healthy tissue, laser operations are almost bloodless; healing of laser wounds occurs faster and better than using other methods of surgical treatment. Non-contact removal of biological tissues is carried out with minimal trauma and with high accuracy. Good hemostasis in the zone of laser action leads to the fact that there is practically no edema in the wound area, and, consequently, the postoperative period proceeds without pain. Laser radiation has a bactericidal effect, so laser wounds are sterile. Penetrating deep into the tissue, the laser activates the cells, resulting in faster healing of laser wounds. Considering all the advantages of high-energy lasers, it is clear that they are widely used in virtually all areas of surgery.

Very popular are the CO₂-lasers, known as "laser scalpels". For the best use of a CO₂-laser, it is necessary to control the output power of the radiation [1, 2].

Of the main methods used, it should be noted: mechanical, acousto-optical, electro-optical, current. Each of these methods has its own specific drawbacks: the mechanical method does not allow changing the amplitude of the radiation, the acousto-optical modulator has a small radiation stability of the crystal and a large inertia; in the electro-optical one the strong sensitivity of the crystal to damage and the small radiation resistance; with the current control method, oscillatory processes arise establishment of the coherent power of the CO₂-laser, caused by a change in the temperature of the resonator and a change in the composition of the gas mixture [3].

To eliminate these drawbacks, it is advisable to use electromagnetic modulation. In this case, a transverse magnetic field is used to modulate the power of the CO₂-laser. The electromagnetic method of modulation is based on the plasma-optical effect, which is caused by the interaction of the magnetic field with the active medium of the laser. This method allows controlling the output



power of a continuous laser, changing its value from maximum to zero according to a linear law with sufficient speed [4].

The principle of operation of the CO₂-laser is as follows (figure 1). When it is turned on in the discharge tube, a glow discharge is formed [5]. The electrons interact with molecules of the gas mixture and excite the upper metastable levels of the CO₂ molecule, thereby providing a population inversion of the active medium. The resulting coherent quanta due to induced transitions lead to additional induced transitions. The energy density of these coherent quanta begins to increase. In accordance with the Einstein relation, the probability of induced transitions increases. The process itself is avalanche-like. As a result, the laser goes into a quasi-stationary mode. The amplification of coherent radiation balances the output of the coherent laser power and the loss of radiation in the active medium. Between the mirrors of the optical resonator of the laser, a standing electromagnetic wave is established. The energy density of this wave in the cross section of the discharge has a Gaussian character, i.e., it is maximal on the discharge axis and drops practically to zero to the walls of the discharge tube. The same distribution has the density of discharge electrons and excited molecules of carbon dioxide.

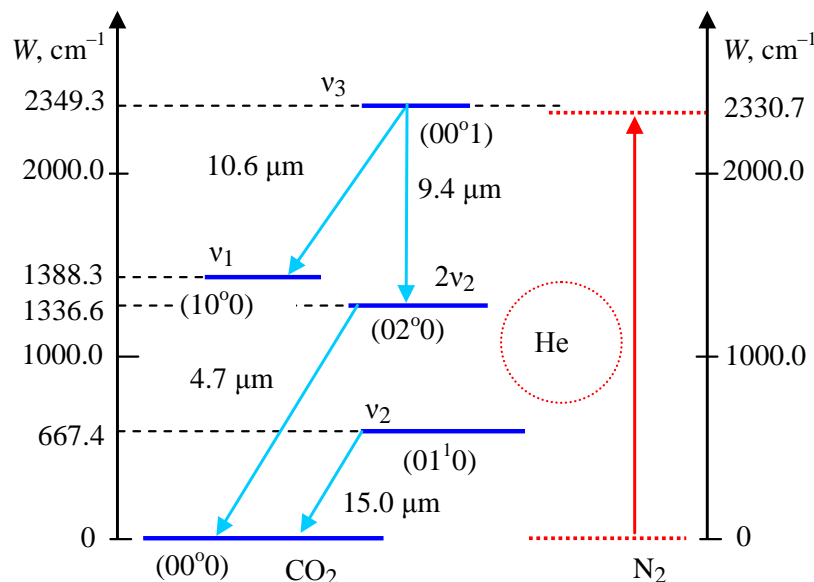


Figure 1. Generation scheme for the CO₂-laser.

Consequently, the distribution of the density of coherent quanta and the distribution of the density of excited molecules of carbon dioxide are approximately of the same nature, this provides the necessary probability of induced transitions and the normal operation of the laser (figure 2 for $B_1 = 0$ and curve 1).

When a current flows through the coils of an electromagnet, a magnetic field arises in the air gap of the magnetic cores, the induction vector of which is perpendicular to the axis of the discharge tube [2]. Due to the Lorentz force, discharge electrons rush to the glass wall of the discharge tube and create a significant negative potential. Under the action of this potential, the discharge ions also rush to the wall and the entire gas discharge densely presses against one of the walls of the discharge tube. The distribution of electrons and, respectively, excited molecules of carbon dioxide in a plane perpendicular to the axis of the discharge begins to be of an inhomogeneous nature: the concentration of excited molecules of carbon dioxide on the axis decreases practically to zero, and at one of the walls of the discharge tube increases (figure 2 for B_2, B_3 and curves 2, 3).

In modern lasers, the mirrors of an optical resonator of spherical type are used and the coherent quantum arising near the wall (outside the resonator axis) will be largely lost and do not establish a stationary standing wave in the resonator. In this case, the laser ceases to generate coherent radiation.

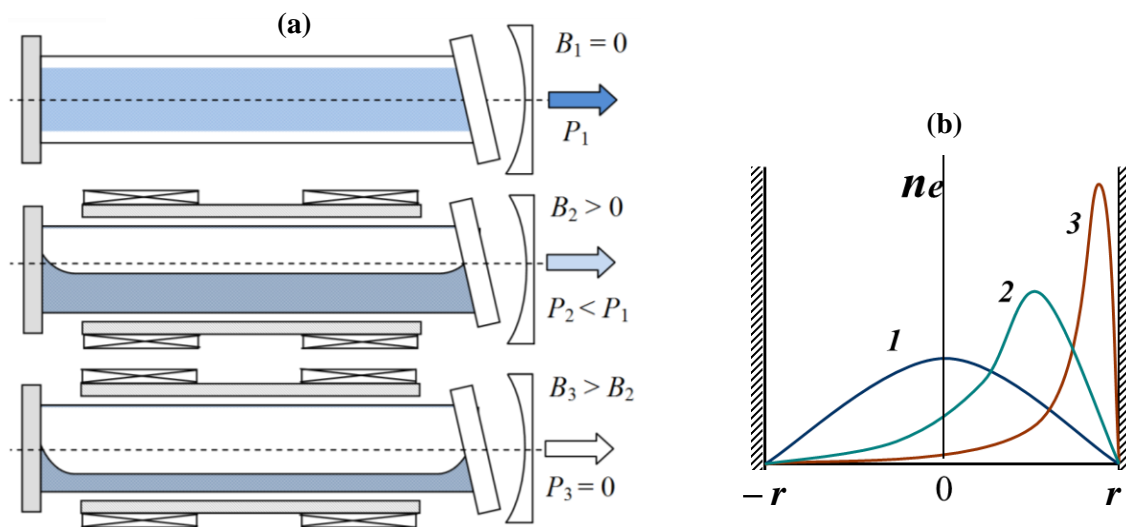


Figure 2. Distribution of charged particles: (a) – in the discharge tube of laser, (b) – in the discharge gap; 1 – $B_1 = 0$; 2 – $B_2 > 0$; 3 – $B_3 > B_2$.

The electromagnetic modulation system allows adjusting the duration and frequency of the pulses, and also allows adjusting the output power of the laser radiation. This fact makes it possible to use such a laser in many areas of surgery, rather than having many different lasers with different output powers.

Using a CO₂-laser with electromagnetic control of the output power of the radiation, a number of experimental studies were carried out. Investigations were carried out on dead tissues of a pig (skin, kidney and others).

The results of the investigation of the depth of dissection from the duration of pulses show that the dependence has an optimum value in the pulse duration range of 5...10 ms (figure 3). Also, studies have shown that with increasing pulse duration, the efficiency of laser destruction and the level of traumatism increase (figure 4). Therefore, it is necessary to use pulses of short duration.

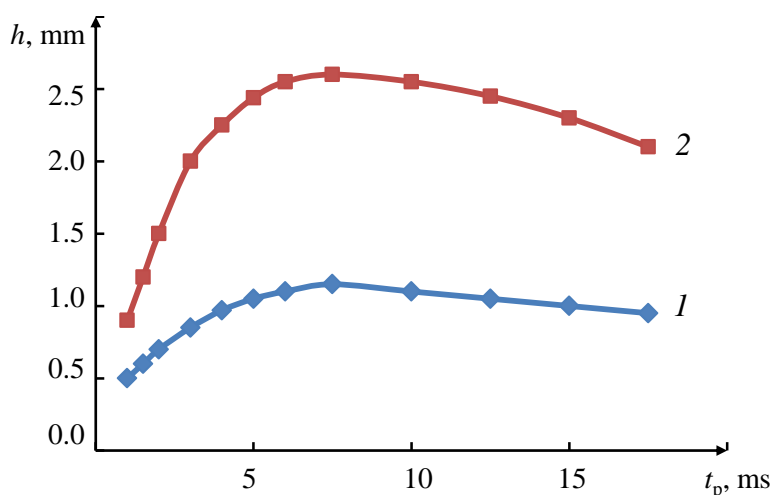


Figure 3. Dependence of depth of opening on pulse duration: 1 – bone, 2 – kidney.

The mode of operation of the laser has a strong effect on the width of the cut, with increasing frequency and duration of laser pulses, the width of the cut and the zone of traumatism increase [6]. The smallest zone of traumatism is observed at a repetition rate of pulses per unit Hz.

Studies were carried out on the quality of the biotissue cut by the laser beam at a relative speed of 3 cm/s in the continuous mode of operation of the laser and pulsed with duration of 5 ms and a

repetition rate of 30 and 55 Hz (figure 4). From figure 4 follows that the continuous mode of operation of the laser gives a large depth and width of the cut and a high level of traumatism. With pulsed operation at a repetition rate of 55 Hz, a smaller depth of cut was observed, but the level of traumatism was still high. A clean and good quality cut was obtained at a pulse repetition rate of 30 Hz.

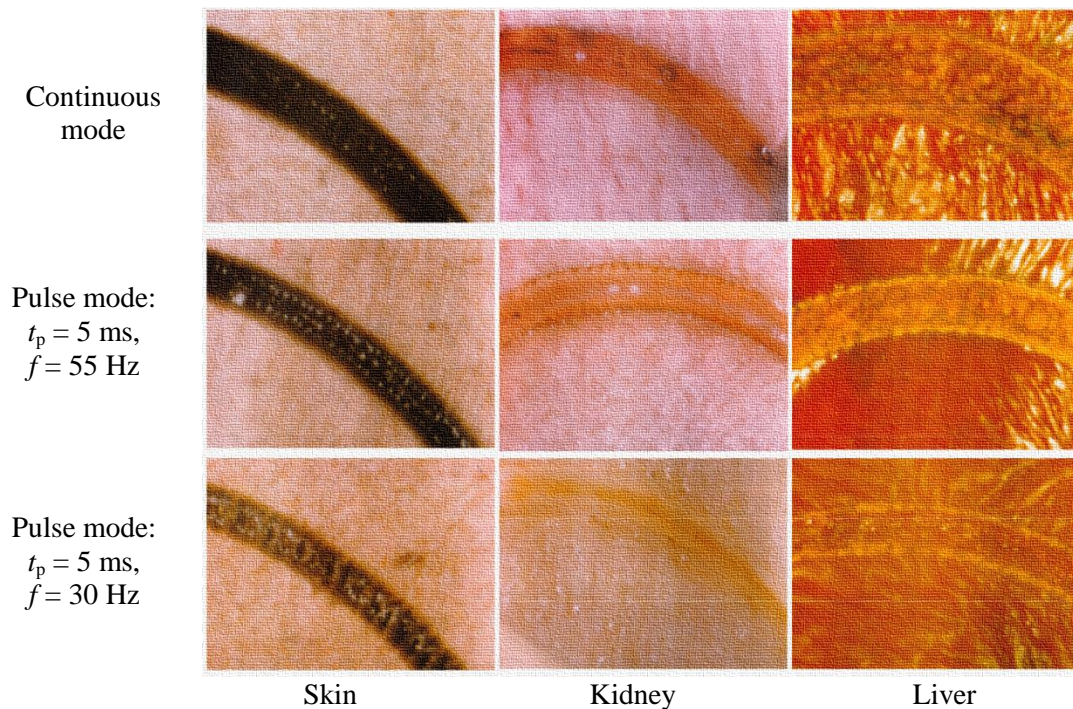


Figure 4. The top view of the cut made by a laser beam with a speed of 3 cm/s and its different modes of operation.

Thus, in order to ensure a low level of traumatism in healthy tissues, it is preferable to use CO₂-laser installations operating in the pulsed mode at pulse duration of several milliseconds and a repetition rate of up to 10 Hz in the case of laser surgery. When the laser moves, the repetition rate can be increased to several tens of Hz.

References

- [1] Kiselev A S and Smirnov E A 2017 *Journal of Physics: Conference Series* **929** 012050
- [2] Chernigovskiy V V, Kostrin D K, Martsinukov S A and Lisenkov A A 2016 *Vakuum in Forschung und Praxis* **6** 34–7
- [3] Kiselev A S, Kostrin D K, Lisenkov A A and Smirnov E A 2017 *Journal of Physics: Conference Series* **789** 012027
- [4] Martsinukov S A, Kostrin D K, Chernigovskiy V V and Lisenkov A A 2016 *Journal of Physics: Conference Series* **729** 012023
- [5] Ramazanov A N, Kostrin D K, Goncharov V D and Lisenkov A A 2016 *Journal of Physics: Conference Series* **729** 012004
- [6] Martsinukov S A, Kostrin D K, Chernigovskiy V V and Lisenkov A A 2016 *Journal of Physics: Conference Series* **735** 012049