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PROGRAMMABLE CONTROL OF THE PULSE REPETITION RATE IN THE MULTIWAVE STRONTIUM VAPOR LASER SYSTEM

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Abstract. The aim of the present work was the development of laser systems for ablation of biological tissues with a programmable control over the lasing pulse repetition rate in a wide range. A two-stage laser system consisting of a master oscillator and a power amplifier based on strontium vapor laser has been developed. The operation of the laser system in a single-pulse mode operation, multipulse mode operation, and with a pulse repetition rate up to 20 kHz has been technically implemented. The possibility of a bone tissue ablation with no visible thermal damage is shown.

1 Introduction

Currently, the use of lasers lies at the heart of many technologies. The unique properties of laser radiation allow achieving high precision of material processing and small sizes of the treated area. This is relevant for the use of lasers in medicine as well. The use of lasers for ablation allows performing tissue removal without damaging surrounding areas. That is, when a laser radiation is absorbed by a biological tissue there is a conversion of the photon energy into the vibrational energy of molecules leading to their destruction, which are the basis for the subsequent photothermal ablation. The process begins immediately after reaching the required radiation power density.

At any interaction of laser radiation with a matter, an important role is played by properties of the substance itself, as well as by properties of laser radiation and the environment. Plenty of works are devoted to the study of parameters of laser radiation on the material [1–4]. However there are no separate studies on the effect of the pulse repetition rate on the ablation process and, in some cases, this parameter is a result of preselected durations and energies of the laser pulse.

It shall be noted that pulse repetition rate determines, to a large extent, the collateral thermal effect, or in other words the thermal damage zone (TDZ) of the target. When only biological tissues are considered as a target, the value of the interpulse interval is of greater

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importance than for any other material, because during the action of a laser pulse the accumulated heat in tissues must dissipate during the inerpulse interval. Otherwise, the accumulation of heat in the areas adjacent to the radiation zone will lead to tissue coagulation followed by carbonization, i.e. the tissue loses its vitality. Therefore, for a more effective impact on the biological target to produce the ablation it is necessary to vary the characteristics both of the oscillator pulse and the repetition rate of these pulses in a fairly wide range, selecting optimal conditions for each specific material. As studies show [5], strontium vapor laser (SVL) is a promising laser source for medicine or, for example, for processing of polymers, because SVL radiation enters the absorption bands of polymers and biological tissues. The advantages of using strontium vapor laser for ablation of biological tissues: resonance wavelength, nanosecond pulse duration, minimum TDZ.

2 Experimental setup

A laser system consisting of an oscillator and an amplifier based on active elements of a strontium vapor laser (Figure 1), providing the ablation mode of hard biological tissues, has been developed. Specifications are given in Table 1.

Table 1. Specifications of experimental setup.

Parameter	Value
Wavelength, μm	1.03; 1.09; 2.60; 2.69; 2.73; 2.92, 3.01 and 6.45
Spreading	0.5
Pulse duration: 6.45 um ~ 3 um ~ 1 um	 20 150 80
Maximum pulse energy, mJ,	1.7
Beam diameter, mm	35
Average power, W	1…28
Pulse repetition rate, kHz	15…20
Cooling	water

Laser active elements on strontium vapors were used as the master oscillator (1) and the power amplifier (7). The master oscillator was a cylindrical gas discharge tube (GDT) with a diameter and a length of the operating channel 26 and 800 mm, respectively. The telescopic unstable resonator (with M = 35) consisted of two spherical mirrors, a concave (2) and a convex (3) with curvature radii of 3500 mm and 100 mm, respectively. The spatial filter collimator (with M = 1.5) included two concave spherical mirrors (4,5) with an aluminum coating with radii of 3000 mm and 2000 mm, and a spatial filter (6) with a hole diameter of 0.3 mm, which has allowed to allocate from the oscillator radiation a spatial component with a spreading close to the diffraction limit (~ 0.5 mrad).

GDT with a diameter of 35 mm and a length of 1000 mm was used as the amplifier. Windows of both GDTs were made of CaF_2, an optical material with low absorption in the mid IR-range and good performance characteristics. Heating and excitation of active elements was carried out using pulse power supplies (8,9), in which thyratrons TGI1-1000/25 were used as a switchboard. The control and synchronization unit (10) consisted of the master oscillator (10a), the delay module (10b), and allowed to adjust the relative delay time of oscillator and amplifier pumping pulses.

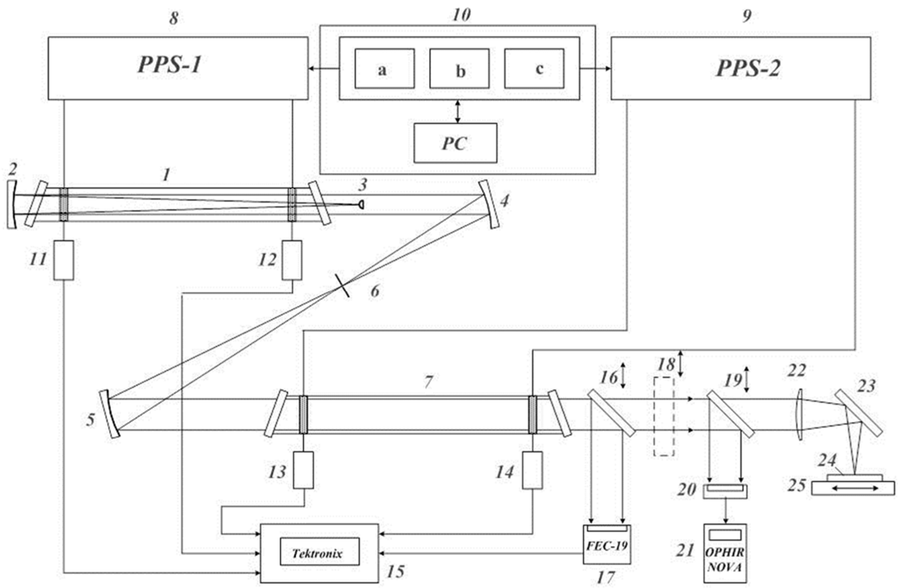

Figure 1. The schematic of the experimental setup:
1 – GDT-1; *2* – rear mirror; *3* – output mirror; *4* – input mirror; *5* – output mirror; *6* – spatial filter; *7* – GDT-2; *8, 9* – high-voltage power supplies; *10* – control and synchronization unit (CSU); *11, 13* – voltage dividers; *12, 14* – low-resistance shunts; *15* – multi-channel oscilloscope; *16, 19, 23* – rotary mirrors; *17* – FEC-19; *18* – unit of spectral filters; *20, 21* – power meter; *22* – spherical lens; *24* – target; *25* –coordinate table.

3 Discussion and results

A feature of the operation of active elements of metal vapor lasers is their operation in the self-heating mode [6, 7]. Heating of the active medium and its excitation takes place during the excitation pulse. Thus, pulse repetition rate cannot be reduced unlimitedly, because it is necessary to maintain a certain concentration of metal vapors. On the other hand, PRR cannot be increased indefinitely, since it leads to overheating of the active medium. Therefore, pulse-periodic discharges with the excitation pulse repetition rate in the range of 15…20 kHz were formed in active elements of the oscillator-amplifier, maintaining the necessary concentration of strontium vapors. Setting on a PC the time shift of oscillator and amplifier launch pulses included the cutoff of the laser radiation for a predetermined period of time, the multipulse (tandem) oscillation mode and the single-pulse mode were set as well. Thus, the possibility to set the lasing pulse repetition rate under the action of radiation on the target while keeping the pulse energy unchanged has been implemented.

Figure 2 shows examples of ablated areas of hard biotissues made with the use of the developed setup.

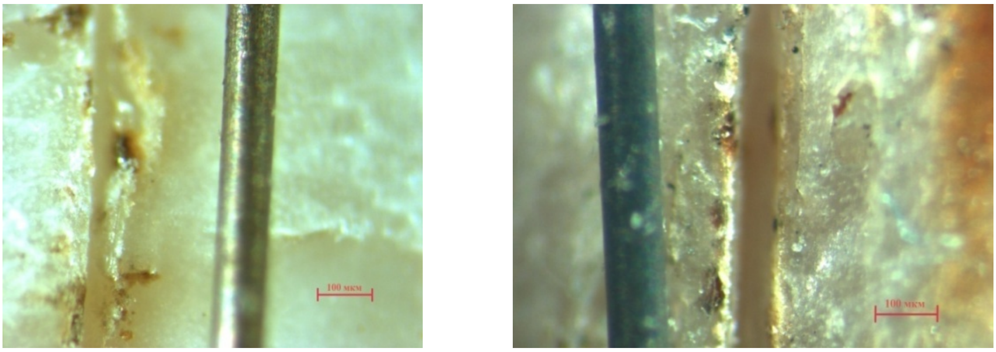

Figure 2. Photo of the ablated area of a pig cortical bone, 16 mm/sec., 1.5 mJ, 1 pass.

4 Conclusion

Currently, the search for small-sized laser sources operating in the mid-IR range for medicine is carried out. From this viewpoint, strontium vapor lasers with nanosecond duration of pulses and oscillating in the range of 1 – 6.45 μm are promising laser sources for laser ablation.

A two-stage laser system consisting of a master oscillator and a power amplifier based on strontium vapor laser has been developed. The control range of the lasing pulse repetition rate of the setup, determined by a PC user, is from units of hertz up to tens of kilohertz. The possibility of a bone tissue ablation without visible thermal damage has been demonstrated using the given system.

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