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The Interaction of Series-Connected Discharge Modules

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Abstract: In the manufacture of lasers with a long discharge tube, which is composed of separate series-connected modules, the question arises of how the instability that accidentally arises in one of the modules will affect the other ones. This is especially important with the acoustoplasma power supply of at least one of the modules, when we create these instabilities ourselves. In the experiment, the discharge tube is composed of two series-connected modules having a common gas volume and an optical resonator. One of the modules was powered by direct current, and the other was fed by modulated alternating current, which contained constant and variable components and worked in acoustoplasma mode. The depth of current modulation, which occurs in a module with DC power due to the influence of the module with a modulated current, is measured. It has been experimentally shown that by choosing the magnitude of the constant component of the discharge current in each module and the modulation frequency of the variable component of the discharge current in the acoustoplasma module, it is possible to control the degree of influence of the acoustoplasma module on the DC-powered module.

Keyword: acoustoplasma, gas discharge, CO_2 laser.

1. Introduction

The laser radiation power can be increased in three ways:

1. By increasing the discharge cross section;
2. Parallel connection of discharge tubes;
3. By increasing the length of the discharge tube or by connecting the discharge tubes in series.

With an increase in the discharge cross section, the conventional electric discharge is not possible because of contraction of the discharge. Therefore, large-diameter electron beam pumping or ultraviolet preionization is used. We will not consider this option.

The construction of serial connection of discharge tubes is described in the literature [1]. To reduce the length of the discharge tube, it is folded, as shown in Fig. 1a. The length of the single tubes is about $1m$ and each tube is powered by a separate power supply. Another way to increase the total laser power is to parallelly incorporate the discharge tubes into a common cavity as shown in Fig.1b [2]. Parallel beams from different laser tubes are focused by a large-diameter lens. For example, the $TL-6$ multibeam CO_2 laser had 124 tubes and the radiation power $6kW$ [1,2].

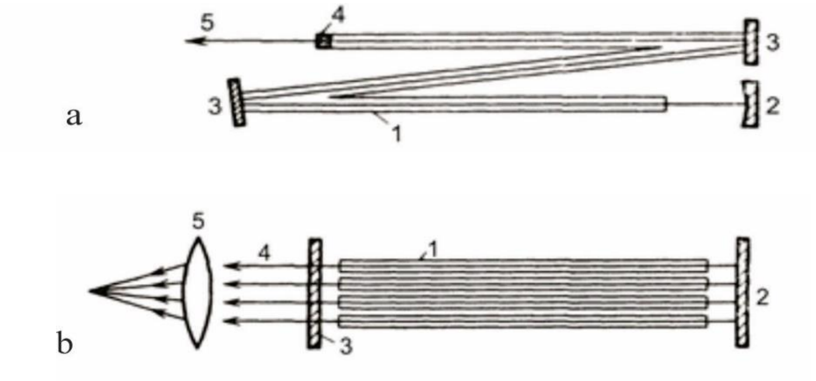

Fig.1. Diagrams of multisectional (modular) tube lasers with diffusion cooling [1]; a - serial connection of modules, 1 – discharge tubes, 2 – deaf mirror, 3 - rotary mirrors, 4 – translucent output mirror, 5 – output beam; b – parallel connection of the discharge tubes in the optical resonator, 1 – discharge tubes, 2 – deaf mirror, 3 – translucent output mirror, 4 – output rays, 5 – focusing lens.

2. Experimental setup

When compiling a long discharge tube from separate series-connected or parallel-connected modules, the issue of the stability of such a multi-module tube becomes relevant. The question arises how the instability that accidentally occurred in one of the modules will affect the other modules. This is especially important with the acoustoplasma power mode of at least one of the modules. In this case, we ourselves create instabilities that are periodic in time and space, which lead to the acoustosplasma mode of operation [3-5].

The experiment was carried out with a discharge tube composed of two series-connected modules (Fig. 2), which were located in a common optical cavity formed by translucent mirror 1 and blind mirror 9. The modules were connected to each other by bellows 5. Each of the modules had its own separate water-cooling jacket (not shown in Fig. 2), separate electrodes, and separate power supplies. One of the modules was powered by direct current and the other was fed by modulated alternating current, which contained constant and variable components and worked in the acoustoplasma mode [6].

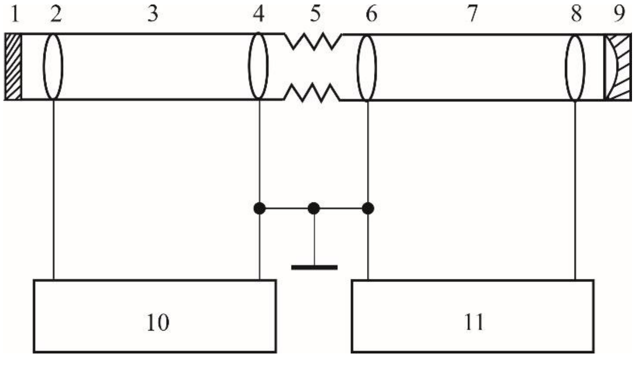

Fig.2. Scheme with serial connection of two modules. 1-flat translucent mirror, 2-anode tube module with DC power, 3-module with DC power, 4-cathode, 5-bellows, 6-cathode, 7-module with acoustoplasma power mode, 8-anode, 9- blind mirror, 10-DC power supply, 11-module power supply with acoustoplasma mode.

The influence of the module with acoustoplasma mode on the module powered by a direct current source was measured. This influence led to the fact that in the module powered by a direct current source there was a modulation of the supply voltage.

The appearance of the manufactured modular laser is shown in Fig. 3a. The appearance of the bellows assembly of the modules is shown in Fig. 3b.

Fig. 3.a. The appearance of the manufactured modular laser.

Fig. 3.b. The appearance of the bellows assembly of the modules.

3. Results and discussion

Fig. 4 shows the dynamic characteristic of the influence of a module with acoustoplasma power on a module with DC power. The abscissa axis represents the current voltage value between the anode and cathode in the tube with an acoustoplasma power mode, with the voltage sinusoidal modulation. The ordinate represents, at the same time, the current voltage value between the anode and cathode in the module powered by a direct current source. If there was no interaction, then one would have a straight line parallel to the abscissa axis.

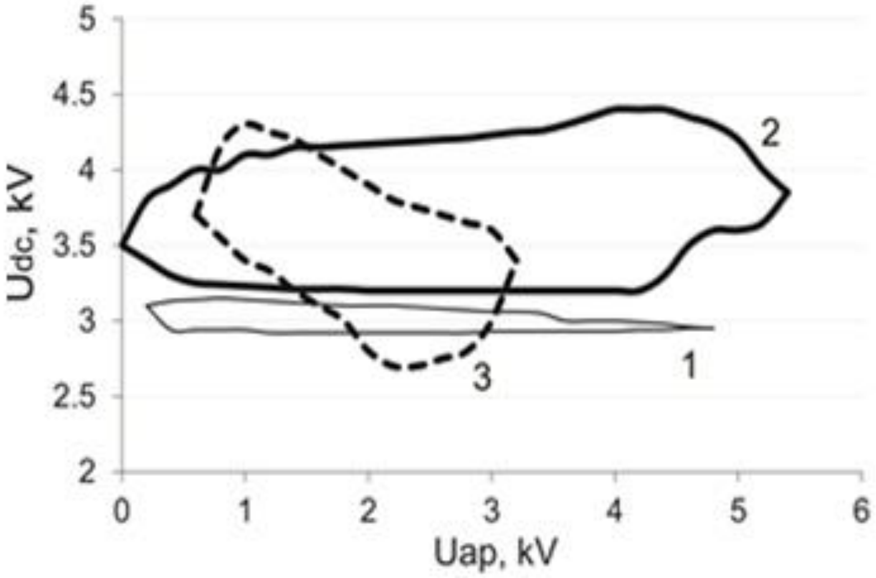

Fig.4. Dynamic characteristics of the interaction of modules. 1 - f = 1kHz, I_{dc} = 10mA; 2 - f = 1kHz, I_{dc} = 6mA; 3 - f = 5kHz, I_{dc} = 6mA

Since both the modules have both constant and variable components of the supply voltage, the curves are above the zero point. When assessing the voltage modulation it is convenient to introduce the concept of modulation depth M, i.e. the ratio of the amplitude of the variable component to the value of the constant component.

It can be seen from Fig. 4 that in the first case, for modulation frequency $f = 1\,kHz$ and for the depth of voltage modulation in the acoustoplasma module $M_{ap1} \approx 1$, for the module powered by direct current source, because of the appearance of induced modulation one has $M_{dc1} \approx 0.03$. The modulation depth $M = A\sim / < A >$ is the ratio of the amplitude or of the average value of the variable component $A\sim$ for the parameter under consideration to the corresponding value of the constant component $< A >$. In the second case, one has $f = 1\,kHz, M_{ap1} \approx 1$ and for smaller constant current we obtain $M_{dc1} \approx 0.15$. For the third case, for $M_{ap1} \approx 0.75$ one gets $M_{dc1} \approx 0.3$. Thus, by choosing the magnitude of the constant component of the discharge current or voltage in each of the modules and the modulation frequency of the variable component of the discharge current in the module with acoustoplasma power, one can control the degree of influence of the acoustoplasma module on the module with direct current power.

It is especially important to note the first mode of Fig. 4. In this mode, the acoustoplasma module has almost no influence on the DC-powered module, despite the fact that the discharge tubes are connected by a common volume.

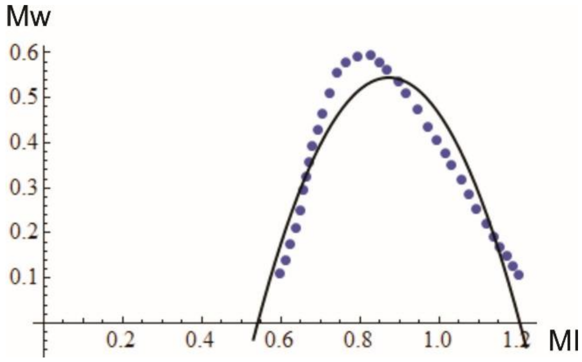

Fig.5. Dependence of the modulation depth of the laser radiation power M_W on the modulation depth of the shot current M_I.

Figure 5 shows the dependence of the modulation depth of the power M_W of the acoustoplasma CO_2 laser radiation on the modulation depth of the discharge current M_I for modulation frequency $0.1\,kHz$. It can be seen from Fig. 5 that the depth of modulation of the laser radiation power nonlinearly depends on the modulation depth of the discharge current and has a threshold character. With current modulation depth $M_I < 0.5$, the power modulation M_W is close to zero, i.e. there is almost no modulation of radiation power. For the depth of modulation of the discharge current $M_I = 0.8$, the depth of modulation of the power reaches the maximum value $M_W = 0.6$. At the maximum depth of current modulation $M_I = 1.2$, there is almost no modulation of radiation power again. This, at first glance, paradoxical result is explained by the fact that with such a large modulation depth, the acoustoplasma mode is destroyed and at the same time a large number of harmonics are present in the discharge tube in the variable component of the discharge current. As a result, the radiation power is averaged.

Fig.6 shows the manufactured discharge modules. Four tandem modules have rigid connection (glass junction or long tube). The water shirts are visible outside, separate for each module. The electrode leads from each module come out in the gaps between the water jackets.

From such modules, it is possible to assemble both tandem tubes (connecting the modules using bellows) and parallel circuits, where each such tube is a separate laser.

Fig.6. Manufactured discharge modules.

4. Conclusion

1. The effect of modules on each other in a two-module serial design with a common vacuum volume was studied. One of the modules was supplied with direct current and the other worked in the acoustoplasma mode (it had direct and alternating components of the discharge current).
2. It is shown that the interaction of the modules depends on the frequency of the current modulation in the module with acoustoplasma power. One can select a frequency that the module with modulation of the discharge current has almost no influence on the module with DC power.
3. By choosing the optimal depth of modulation of the discharge current, especially when overmodulating $(M_I > 1)$, the output optical power of the laser is practically not modulated. In this mode, the mutual influence of the modules in optical power will be minimal.

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Conflict of Interest
The authors declare no conflict of interest.

Author Contributions
The authors equally contributed to all steps of the paper preparation.

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