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An experiment with continuous-pulsed excitation of a conventional low-power CO_2 gas laser

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Operation of a conventional CO_2 gas laser in discharge conditions when current pulses are superimposed on arbitrary value of DC discharge current has been described. This type of supply has been named continuous-pulsed (CP) excitation. The properties of the same CO_2 gas laser at the CP excitation and at the "pure" CW one have been also compared. At the continuous-pulsed excitation the mean value of the output increased more than two times compared to the CW output power.

1. Introduction

A conventional CO_2 gas laser can operate both in the regime of the direct current excitation and in conditions of excitation by pulses of arbitrary length and repetition rate. In the latter case considerable increase of the output power can be obtained in comparison to the CW operation [1, 2]. Certain modification of both the types of supply is the excitation called here the continuous-pulsed (CP) one. The essence of the CP excitation lies in formation of current pulses in supply circuit of a conventional CO_2 gas laser. These pulses are superimposed on an arbitrary value of DC current. This optionally fixed value of DC current determines initial discharge conditions at the given total gas pressure. At the CP excitation the output power, instead of being continuous, is in the form of pulses imposed on a CW output power level. This level is defined by fixed initial discharge conditions, it is by the DC current and total gas pressure in discharge tube. The continuous-pulsed excitation differs from that described in papers [3–10], where current pulses started from zero-amper level, i.e., from the level at which discharge was switched off.

An experiment with the CP excitation of a CO_2 laser will be described below. The purpose of the experiment was to study the properties of a CO_2 gas laser in a wide range of the plasma discharge parameters, for various pulsing parameters. A comparison of properties of the same CO_2 laser at the CP excitation and the CW one is also given. A wide discussion of the obtained results connected with the analysis of the phenomena occurring in a CO_2-mix discharge plasma during the CP excitation will be given in the subsequent paper.

2. Description of experiment

2.1. Construction of the CO_2 laser

A two-sectional CO_2-mixture gas laser was used in the experiment. Brewster-angle water-cooled discharge tube had 14 mm in diameter and 1.2 m in length. The windows were made of polished sodium chloride crystal. The laser interferometer consisted of a pair of gold coated mirrors. One of them, a 10 m curved mirror, had a 3 mm hole output power coupling and was mounted on a piezoceramic driver for a precise adjustment of the laser cavity. Diameter of the hole was optimum for the CW work of the CO_2 gas laser. The other one was flat and had zero transmission. The total length of the interferometer was 1.8 m. Power supply system of the CO_2 laser is presented in Fig. 1. A high voltage power supply was used for the excitation of the gases in the tube equipped with three electrodes, the central one being the anode (A) and the other two – the cathodes (C). The electric current capacity of this power supply was 100 mA and the voltage was varied from zero to 10 kV. The electrical supply circuits of both the sections contained independent discharge current stabilizers. Dynamic impedance of each of the current stabilizers approached 10 MΩ.

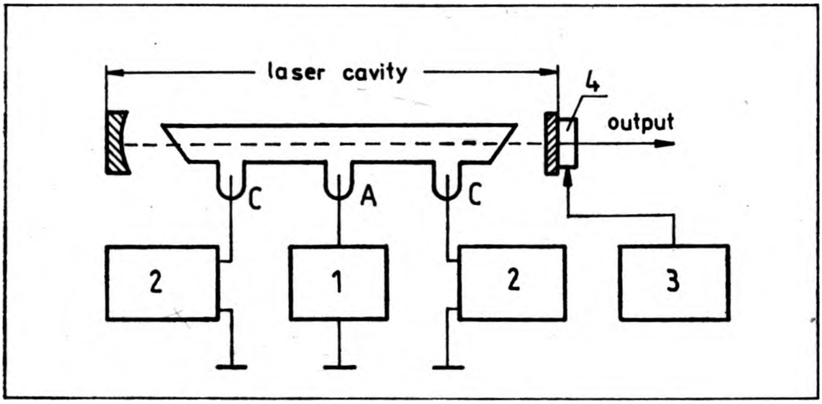

Fig. 1. Supply circuit of the CO_2 laser. 1 – high voltage power supply, 2 – discharge current stabilizer, 3 – DC supply of piezoceramic driver, 4 – PZT driver

2.2. Experimental procedure

In order to obtain the CP operation of the CO_2 gas laser the current pulses of rectangular shape were formed in the supply circuit of each of the tube section. These pulses were shaped by means of the stabilizers to which a square wave generator was connected. The possibility of such an additional use of the current stabilizers was checked in auxiliary circuit in which, instead of each of the tube sections, a passive impedance was included. Oscilloscopic observations of the current pulses were made at various DC currents at the amplitude of the pulses ranging within 0–40 mA. When repetition frequency of the pulses ranged from 30 Hz to 20 kHz that the observed current pulses had a rectangular waveform.

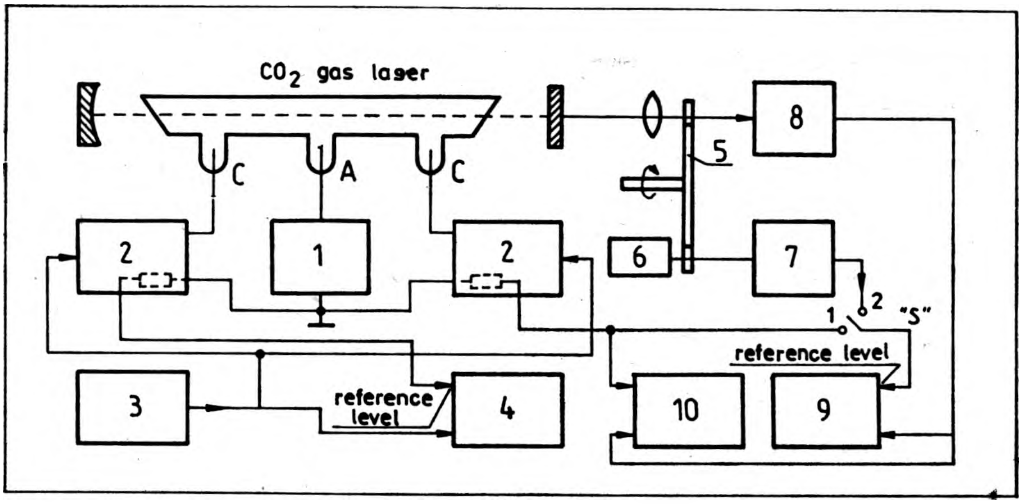

Fig. 2. Block-diagram of the measuring system. 1 – high voltage power supply, 2 – current stabilizer identical for both sections, 3 – square-wave generator, 4 – lock-in nanovoltmeter for measurements of current pulse amplitude, 5 – mechanical chopper, 6 – lamp for reference beam, 7 – visible light detector, 8 – (Hg, Cd)Te detector, 9 – lock-in nanovoltmeter for measurements of the output power level P_0 (switch S in position 2) as well as output peak power P_p (swith S in position 1), 10 – dual-beam oscilloscope

The CP operation of the CO_2 laser has been studied in a measuring system of the block-diagram which is presented in Fig. 2. For each fixed value of total gas pressure and each value of DC current, three quantities were measured, namely:

— output light DC component, P_0,

— amplitude of the current pulses, I_p,

— amplitude of the output pulses, P_p, corresponding to the given amplitude of the current pulses I_p.

These measurements were made according to the following procedure. Firstly, the glow discharge was switched-on at optional fixed mix pressure in the laser tube and desirable, the same in both the tube sections, value of DC current was fixed. Next, a mechanical chopper of the laser beam was switched-on and the output power level P_0 was measured in arbitrary units. Subsequently, the mechanical choppering was turned-off and the current pulses with different amplitudes were overlapped on the fixed value of DC current. In both the tube sections the amplitudes of the pulses were the same. Last of all, the dependence of the P_p on the I_p was measured. The above procedure was repeated for various initial discharge parameters, it is, for different mix pressures and DC currents. Repetition rate of the current pulses in these measurements was the same and equalled 200 Hz (see explanation in Sec. 2.3). The amplitude of the pulses was changed from zero to 30 mA.

The measurements of the P_0, I_p, and P_p quantities have been based on phase sensitive detection technique which made it precise and independent of the changes of infrared detector parameters with temperature. The possibility of the use of such a technique results from the fact that all three types of pulses, the amplitudes of which have been subjected to measurements, were of rectangular waveform. Therefore, their amplitudes could be calculated by measuring rms of the first harmonic component.

All the measurements have been made for gas mixture composition $CO_2 : N_2 : He = 1:1:4$ in no-flow conditions. This species composition was optimum for the CW work of the CO_2 gas laser. Total mix pressure was changed within 8–16 hPa, whereas the values of DC current were changed from 2 to 25 mA.

2.3. Auxiliary measurements

As a result of auxiliary measurements two different problems have been solved: pressure-current conditions for the CW operation of the CO_2 laser and optimum repetition frequencies of the current pulses. The CW-conditions have been defined by measuring of the output power P_0, for different total gas pressures and various DC currents. During the measurements the laser cavity was precisely adjusted by means of the piezoceramic driver. The obtained results are presented in Fig. 3 as dependence of P_0 on DC current at various mix pressures as a parameter. Best conditions for the CW operation have been found for total pressure of about 13.3 hPa and for DC current in each of the tube sections equal to 10 mA.

A range of repetition frequencies of the current pulses in which the output pulses were of rectangular waveform and had extreme peak power has been determined by the auxiliary measurements. These measurements have confirmed that both the requirements are fulfilled within the frequency range of 150–250 Hz. Below the frequency of 150 Hz and also above the frequency of 250 Hz the rectangular shape of the output pulses was strongly distorted.

Additionally, above 250 Hz the output peak power decreased fast. For the above reasons further studies have been performed at the frequency of 200 Hz. Duration of the current pulses was one half of the period, it is 2.5 ms.

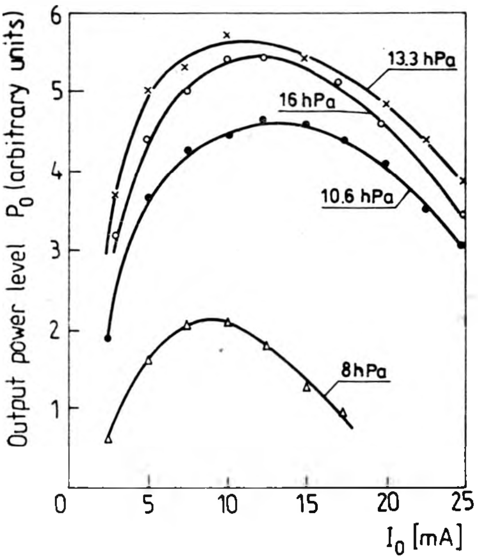

Fig. 3. Output power level P_0 against the DC current I_0 for different total gas mixture pressures

3. Experimental results

Initial observations and measurements of the CP operation of the CO_2 laser have yielded two interesting results. Firstly, above the optimum 10–15 mA range of DC currents the output power P_0 decreases and so does the output peak power P_p. Furthermore, amplitude of these pulses is strongly unstable. Secondly, at mix pressure greater than 16 hPa, a stable CP operation of the CO_2 laser was possible only at continuous and precise manual adjustment of the laser cavity by means of the piezoceramic driver. That is why the detailed studies performed in mix pressure ranging within 8–16 hPa, were confined to DC currents lower than or at most equal to the optimum values of DC current. The amplitude of the current pulses was changed from zero to the maximum value of 30 mA.

In accordance with the experimental procedure described in Sec. 2.2, the amplitude variations of the output pulses vs. the amplitude of the current pulses have been measured for different mix pressures as well as initial DC currents. The obtained results are shown in Figs. 4–7 for the pressures of 8, 10.7, 13.3, and 16 hPa, respectively, where different values of DC current are the parameter and the output peak power P_p is given in arbitrary units.

A few interesting properties of the CO_2 laser with the CP excitation result from the experimental data. Irrespective of the total pressures fixed in the discharge tube, the output peak power P_p increases initially with the current amplitude I_p. The output peak power ceases to increase when a certain value of the I_p is exceeded, and in some cases it even drops when the I_p further increases. As a rule, at the same amplitude of the current pulses, the reference DC current is the greater the smaller is the amplitude of the output pulses. Moreover, monotonic increase of the output peak power can be observed when gas pressure grows.

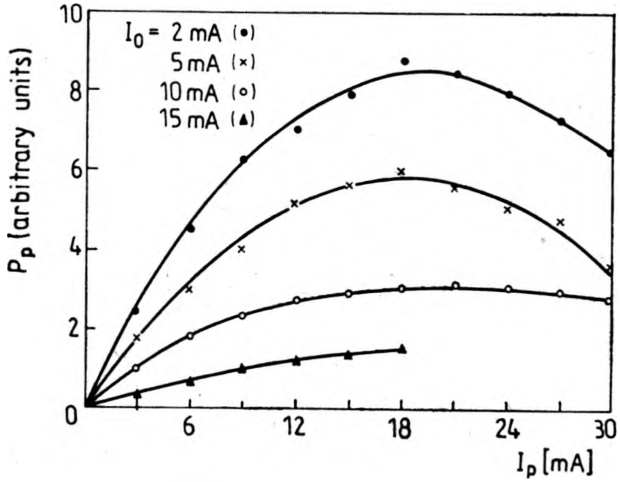

Fig. 4. Output peak power P_p vs. the current pulse amplitude I_p for a few values of the DC current I_0 at total gas pressure of 8 hPa

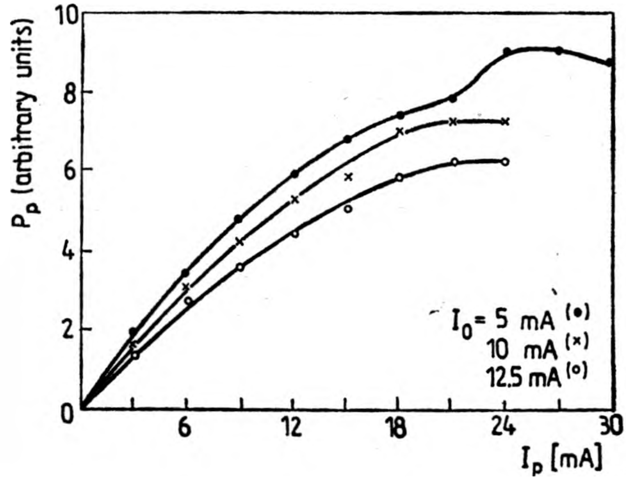

Fig. 5. Same as Fig. 4 at total gas pressure of 10.6 hPa

4. Continuous-pulsed and CW excitation

Certain comparison of the output parameters of the CO_2 gas laser at the CP and CW excitations can be based on the results presented above. It is of particular interest for farther interpretation of the experimental results. As to the CP excitation this comparison can concern both the output peak power P_p and the mean value of the output power, called P_m. Taking into account that the output pulses were of rectangular waveform, the values of the P_m can be easily calculated from formula $P_m = P_0 + 0.5\ P_p$. It is evident that the optimal values of the P_0, P_p and P_m occur at various discharge parameters. The Table includes optimal values of these three parameters of the output calculated for the four total pressures.

The maximum values of the output peak power exceed the maximum level of the P_0 from about two times at the pressure of 16 hPa to four times at the pressure of 8 hPa. The maximum of the mean output power P_m, however,

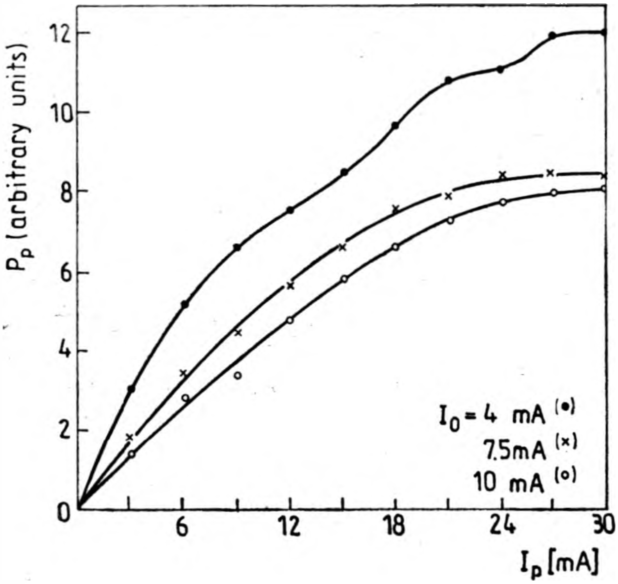

Fig. 6. Same as Fig. 4 at total gas pressure of 13.3 hPa

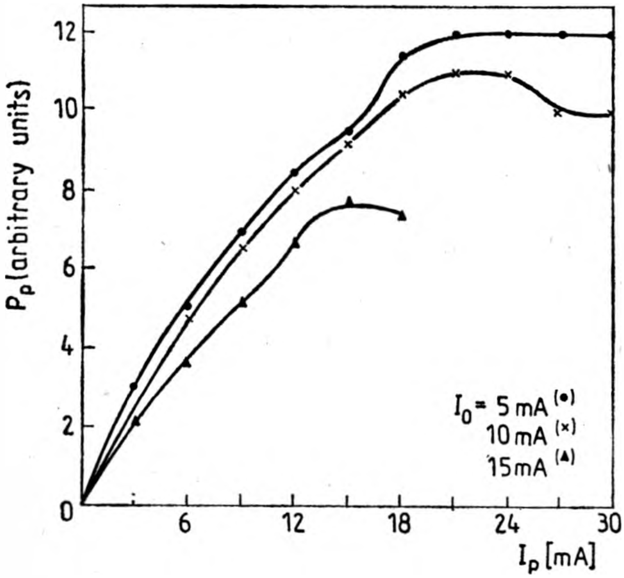

Fig. 7. Same as Fig. 5 at total gas pressure og 16 hPa

Comparison of optimal values of the output power P_0 at the CW excitation with the output peak power P_p and the mean values of output P_m at the CP excitation for various total gas pressures

Total gas pressure [hPa]			8.0	10.6	13.3	16.0
CW excitation		Optimum discharge current [mA]	8.0	12.5	10.0	12.0
		Maximum output power P_0 (arb. unit)	2.1	4.63	5.7	5.4
Continuous pulsed excitation	Optimum values of the P_p	Parameters of excitation	$I_0 = 2$ mA $I_p = 18$ mA	= 5 mA = = 24 mA =	4 mA = 27 mA =	5 mA 25 mA
		Maximum output peak power (arb. unit)	8.65	8.8	12.0	12.0
	Optimum mean power	Parameters of excitation	$I_0 = 5$ mA $I_p = 18$ mA	= 10 mA = = 21 mA =	4 mA = 28 mA =	10 mA 22 mA
		Maximum values of the P_m (arb. unit)	4.5	7.7	10.0	10.8

exceeds the maximum output power P_0 from about 1.7 times at the pressure of 10.6 hPa to about 2.2 times at the pressure of 8 hPa.

It is interesting to compare optional mean value of the output power P_m (measured at given DC current I_0 and at arbitrary value of the current pulse amplitude I_p) with the output power P_0, for DC current (I_0+I_p). The corresponding dependences calculated from the experimental data have been illustrated in Fig. 8.

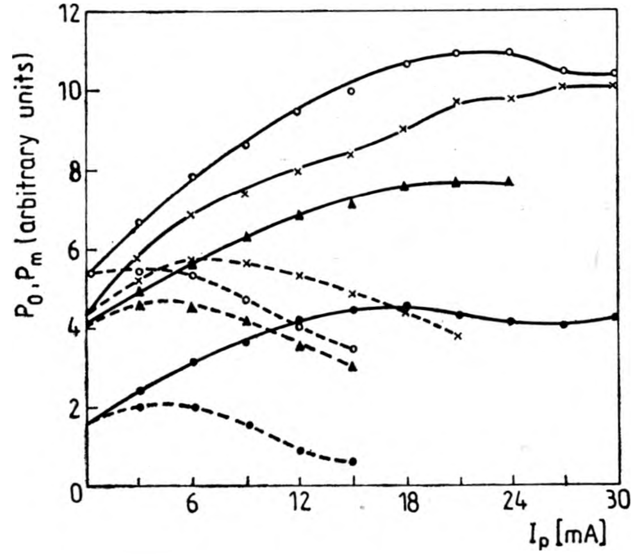

Fig. 8. Comparison of the mean output power P_m at the CP excitation (continuous line) with the output power P_0 at the CW one (dotted line) at various total pressures: ● – 8 hPa, ▲ – 10.6 hPa, × – 13.3 hPa, ○ – 16 hPa, and initial DC currents (at the CP excitation): 5 mA, 10, mA, 4 mA, 10 mA, respectively

It is very characteristic that the mean values of the output at the CP excitation always exceed the output power P_0 at the CW excitation, provided that the comparison concerns the same total pressure.

5. Conclusions

The presented experiment is interesting for two reasons. Firstly, it shows that the output power of a conventional CO_2 gas laser can be increased in a simple and cheap manner. Using the CP excitation and appropriately choosing the initial discharge condition (i.e., total pressure and DC current) as well as pulsing parameters (i.e., repetition rate of the current pulses and their amplitude) the mean output power can be considerably increased, in particular, above twofold increase of the output has been measured in the presented experiment. Secondly, this experiment is of importance for studies of some processes in the CO_2-mix discharge plasma (see next paper).

Certain part of the experimental results can be elucidated with a relative ease. Thus (see Figs. 4–7), the observed variations of the P_p vs. the I_p can be simply explained. When there occurs any current pulse, then the electron concentration grows in volume of the discharge and, consequently, electron impact excitation of the CO_2 molecules on the upper laser level increases considerably. It explains initial, often linear, increase of the P_p vs. the I_p. Farther growth of the I_p causes more slower and slower increase of the P_p. The maxima or "saturation effects" observed in these dependences can be explained by the growing influence of the electrons on the life time of the $CO_2(00^01)$ level. CHINH DANG et al. [11] have ascertained recently that electron deexcitation makes a substantial contribution to the relaxation rate of the $CO_2(00^01)$ and dominates other relaxation processes at high current. The fall of the P_p with increase of the initial DC current, observed at the given total pressure, can be explained by the growth of the gas temperature and as a consequence by the decrease of the lifetime of the $(00^01)CO_2$.

The answers to the questions why the output pulses were of rectangular shape only within the frequency range of 150–250 Hz, as well as why the mean output power P_m at the CP excitation always exceeded the level of the output power at the CW excitation (see Fig. 8) are much more complicated. Wide explanation of these two facts, based on analysis of time-dependence of the gas temperature and on CO_2 dissociation kinetics, has been given in subsequent paper.

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Эксперимент со стационарно-импульсным возбуждением разрядного CO_2 лазера

Описана работа CO_2 лазера в условиях возбуждения, когда на стационарный ток разряда наложены токовые импульсы. Этот род возбуждения назван стационарно-импульсным (С-И). Сравнены свойства CO_2 лазера при С-И возбуждении и стационарном возбуждении. Средняя мощность излучения при С-И возбуждении всегда превышает выходную мощность при чисто стационарном возбуждении, максимально в два раза.