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Atmospheric-pressure CO_2 laser with an electron-beam-initiated discharge produced in a working mixture

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***Abstract*. An atmospheric-pressure CO_2 laser with an electron-beam-initiated discharge produced in a working mixture is developed. The laser output energy of 18 mJ from a $\sim$6-cm^3 active volume is achieved. The laser operation with a pulse repetition rate of up to 5 Hz is demonstrated. The specific energy deposit of $\sim$ 0.1 J cm^{-3} is obtained in the $CO_2 : N_2 : He = 1 : 1 : 4$ gas mixture at the atmospheric pressure during a pulsed nonself-sustained discharge with ionisation amplification.**

Keywords: *CO_2 laser, preionisation by an electron beam formed in a working mixture.*

1. Introduction

The use of an electron beam as an external source for ionising compressed gases allows an active medium in pulsed and repetitively pulsed CO_2 lasers to be produced with a lower energy consumption [1, 2]. In the case of short electron pulses ($\sim$ 1 ns), the main part of the energy is introduced during a plasma decay, while the electron beam produces preionisation in the active volume. The shortening of an electron-beam pulse used to initiate a discharge in CO_2 lasers allows one to reduce substantially the energy spent to create conductivity in a gas discharge. Under optimal conditions, this energy does not exceed 1 % of the energy deposited into the active medium during the main discharge [2]. It was shown in papers [3, 4] that the use of sealed off vacuum diodes and diode linear arrays with distributed parameters to obtain a beam of accelerated electrons resulted in a substantial decrease in the dimension of CO_2 lasers pumped by an electron-beam-initiated discharge.

The formation of nanosecond electron beams is a quite challenging problem, which involves the generation of electron beams and their extraction through a window separating gas and vacuum cells. In Ref. [5], the active volume of a CO_2 laser was preliminary ionised by an electron beam produced in the same working mixture. However, the working pressure of this laser was low ($\sim$ 20 Torr), the output pulse energy did not exceed 0.3 mJ for the active length of $\sim$ 12 cm, and the electron beam was formed in a gas diode at large parameters E/p (E is the electric field strength and p is the gas pressure), which were greater than critical parameters for the formation of an electron beam in gases [6]. It was shown in papers [7, 8] that, by applying nanosecond pulses to a gas diode, an electron beam can be obtained with parameters E/p that are substantially lower than the critical parameters. In Ref. [7, 8], the electron beam was obtained at the atmospheric pressure in helium (the current amplitude was $J_{max} = 200$ A, the current density $j > 10$ A cm^{-2}, the average electron energy $\varepsilon \sim 150$ keV), in air ($J_{max} = 20$ A, $j > 2$ A cm^{-2}, $\varepsilon \sim 90$ keV), in nitrogen ($J_{max} = 3.5$ A, $j > 0.35$ A cm^{-2}), and in the $CO_2 - N_2 - He$ mixture ($J_{max} = 12$ A).

The aim of this paper is to develop a repetitively pulsed CO_2 laser with a discharge initiated by an electron beam formed in the same gas mixture at the atmospheric pressure. We used our previous studies [7 – 9] on the formation of electron beams in gas diodes.

2. Experimental

The scheme of the experimental setup is shown in Fig. 1. An electron beam was formed by pulse generator (*1*), which was described in detail in Ref. [10]. The generator produced on a matched load of 30 Ω a 200-kV pulse with a FWHM duration of $\sim$ 3 ns, whose leading edge duration was $\sim$ 1 ns. The setup had two connected gas gaps filled with the $CO_2 - N_2 - He$ mixture. The first gap of length 20 mm was formed by cathode (*2*) and grid (*3*). The

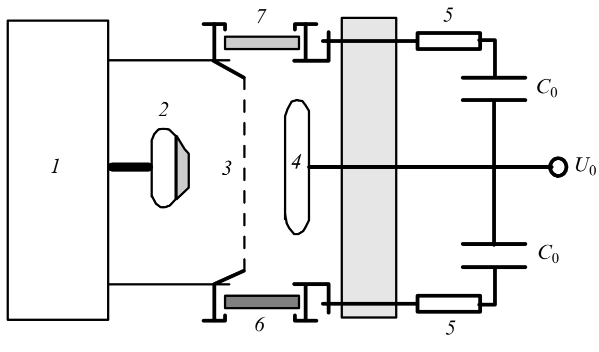

Figure 1. Scheme of the experimental setup: (*1*) generator; (*2*) cathode; (*3*) foil or grid; (*4*) electrode; (*5*) shunt for measuring the beam current; (*6, 7*) mirrors.

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cathode was made of graphite in the form of a pellet of diameter 29 mm, which was convex to the side of a foil with the radius of curvature equal to 10 cm. The grid was made of steel and had the ~ 50-% transparency. In some experiments, we used an aluminium – beryllium foil of thickness 40 μm instead of the grid.

The output voltage pulse from pulse generator (*1*) was fed to cathode (*2*). The electron beam formed during a pulsed discharge in the first gap was extracted through the grid or the aluminium – beryllium foil to the second gap of length 10 mm. The second gap was formed by grid or aluminium – beryllium foil (*3*) and profiled stainless steel electrode (*4*) of size 70 mm×10 mm. The diameter of the electron beam at a distance of 1 cm from the grid was 80 mm, providing the ignition of a discharge over the entire length of electrode (*4*). The voltage applied across the interelectrode gap was varied from 5 to 15 kV. The total capacity of capacitors C_0 was 9.9 nF. The resonator consisted of copper mirror (*6*) (with the radius of curvature of 2.5 m) and ZnSe mirror (*7*) with a multilayer coating (with the reflection coefficient 90 %). A signal from low-resistance shunt (*5*) was detected with a TDS-220 oscilloscope. The pulse energy and the average laser output energy was measured with an IMO-2H calorimeter. The laser pulse duration was measured with an FP-1 or an FSG-22-3A2 photodetectors. The discharge emission was photographed with a digital camera.

3. Experimental results and discussion

An electron-beam pulse of duration no more than 1 ns was formed in the first gas gap by applying to it a nanosecond voltage pulse [7 – 9]. The maximum of the energy distribution of electrons in the extracted beam depended on the type of the gas and corresponded to the electron energies between 70 and 100 keV, the beam density also depended on the type of the gas and was 0.3 – 15 A cm^{-2}. The electron beam was used to initiate a discharge in the second gas gap. Both gas gaps were filled with the same gas mixture ($CO_2 : N_2 : He = 1 : 1 : 4$) at the same pressure and connected with each other via the grid or holes in the foil. The latter were made on the side, beyond the discharge region.

Figure 2 shows the oscillograms of the discharge current in the second gap and of the laser output pulse for a working mixture pressure of 1 atm as well as the photograph of the discharge emission. The rise time of the discharge current up to its maximum was ~ 80 ns. After the propagation of the beam current and the discharge of capacitors C_0, a voltage remained at the capacitors, indicating to the formation of a volume discharge. Comparison of the measurements of the decrease in the voltage across the capacitor with the oscillograms of the current pulse through the gas gap shows that almost all the energy is deposited to the gas for ~ 170 ns. The amplitude of the discharge current for the conditions of Fig. 2 was 800 A. As mentioned above, the discharge was homogeneous and filled uniformly the entire interelectrode region (see inset in Fig. 2). The emission pulse appeared 550 – 650 ns after the onset of the current pulse and had a FWHM duration of ~ 80 ns at a pressure of 1 atm.

Figure 3 shows the dependences of the specific energy deposited into gas upon ionisation of the active medium by an electron beam injected through the grid and of the laser

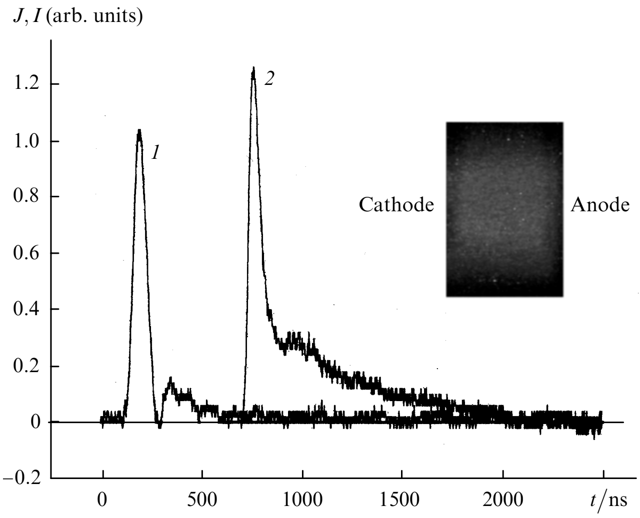

Figure 2. Oscillograms of the discharge current J (*1*) and of lasing intensity I (*2*), as well as the photograph of the discharge emission (inset) for the pressure of the $CO_2 : N_2 : He = 1 : 1 : 4$ mixture equal to 1 atm.

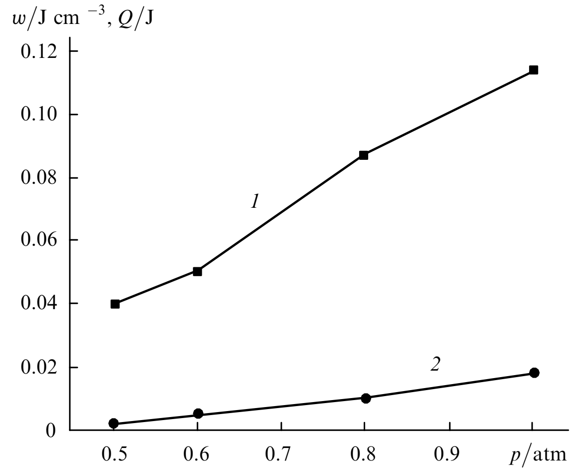

Figure 3. Specific energy w (*1*) deposited into gas and the laser output energy Q (*2*) upon ionisation of the active medium by an electron beam injected through the grid as functions of pressure p for the $CO_2 : N_2 : He = 1 : 1 : 4$ mixture.

output energy on pressure. The maximum output energy of 18 mJ was obtained for the lasing efficiency approximately equal to 2.3 % of the energy stored in capacitors C_0. The laser could operate with a pulse repetition rate up to 5 Hz, no experiments were performed at higher pulse repetitions rates.

Note that, unlike papers [11, 12], where the main capacitor was also charged up to the voltage that was lower than the static breakdown voltage, and an additional high-voltage pulse or a series of pulses were used for preionisation, we managed to increase substantially the working pressure in the laser chamber. Thus, the working pressure of the mixture containing 50 % of helium did not exceed 30 Torr in paper [11], while in Ref. [12] the working pressure did not exceed 150 Torr although additional UV preionisation was used and the amount of helium in the mixture was increased up to ~ 70 %.

4. Conclusions

We have demonstrated for the first time the operation of a CO_2 laser pumped by a discharge initiated by an electron beam formed in the working mixture at the atmospheric pressure. This method for initiating a discharge is quite promising for the development of short-pulse, high-pressure lasers.

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