Quasistationary atmospheric-pressure CO_2 laser with non-self-maintaining discharge controlled by an electron beam

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Quasistationary generation was achieved in an atmospheric-pressure CO_2 laser with a non-self-maintaining discharge controlled by an electron beam of current density $\sim 50 \mu A/cm^2$. Calculated and experimental values of the weak-signal gain are given. The generation is seen to consist of spikes.

Stationary non-self-maintaining discharges in molecular mixtures at a gas pressure on the order of atmospheric were first investigated in[1]. It was shown that it is possible to deliver electric power amounting to several kW/cm^3 to a stationary discharge in a CO_2-N_2-He mixture. The ratio of the average electric field intensity penetrating into the gas-discharge plasma to the gas pressure can in this case amount to $E/P \gtrsim 5$ V/cm-Torr, thus ensuring an effective conversion of the electric energy into vibrational energy of the CO_2 molecules. It was therefore suggested in[1] that stationary lasing may be feasible in CO_2-N_2-He gas mixture at atmospheric pressures.

In[1], the discharge was maintained stationary by rapidly pumping the gas through, thus carrying the heat away from the discharge zone. It was shown in[2] that an analogous quasistationary non-self-maintaining discharge can be produced also without pumping the gas through. The time of stable existence of the discharge is then governed by the superheating of the gas and is of the order of several hundred microseconds.

We report here realization of quasistationary lasing in a CO_2-N_2-He gas mixture at atmospheric pressure, with the quasistationary non-self-maintaining discharge maintained by a weak-current electron beam.

The experimental setup is shown in Fig. 1.

An electron beam of cross section 1×30 cm is shaped by a two-electrode gun, the cathode of which is an incandescent tungsten filament. A voltage pulse of duration 1—3 msec and amplitude 120—160 kV is applied to the gun electrodes. The electron beam is extracted from the vacuum volume of the beam into the discharge chamber through a window covered with aluminum foil 15 μ thick. The distance between the anode and the cathode in the discharge chamber anode is connected to a 27-μF capacitor C charged to a voltage 5—15 kV. The lasing was excited with a resonator consisting of a flat mirror (1) and a spherical mirror (2) with curvature radius 5 m. A central hole of 2 mm diameter in the spherical mirror served as an exit opening for the radiation, which was registered with a Ge-Au receiver.

The experiments were performed at different values of the electron-beam intensity, of the electric field applied to the discharge gap, and of the composition of the CO_2-N_2-He gas mixture. This made it possible to investigate the gain and duration of the lasing in a sufficiently wide range of values of the electric power input to the discharge.

Typical oscillograms of the current pulse in the discharge chamber and of the coherent-radiation pulse are shown in Fig. 2. The dashed curve in Fig. 3 represents the experimental values of the gain, obtained using a master generator whose emission was amplified by single passage through the excited medium.

The experimental results have shown, first, that electron beams with low current densities (~50 A/cm^2) bring about a plasma conductivity such that the electric power input to the non-self-maintaining discharge is of the order of 1 kW/cm^3, enough to produce an optically active medium at atmospheric pressure. We note that the energy gain obtained in this case, i.e., the ratio of the per-unit electric energy input to the per-unit electron-beam power, is ~10^3, which is at least one order

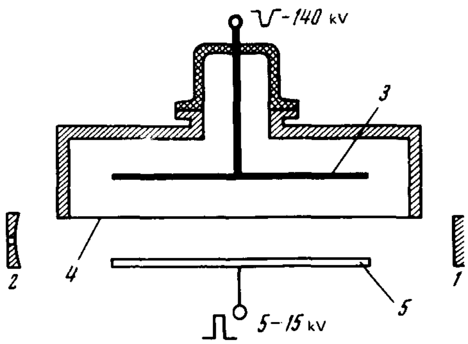


FIG. 1. Experimental setup: 1- flat mirror, 2- spherical mirror, 3- cathode assembly of electron gun, 4- aluminum-foil window for beam extraction, 5- discharge-chamber anode.

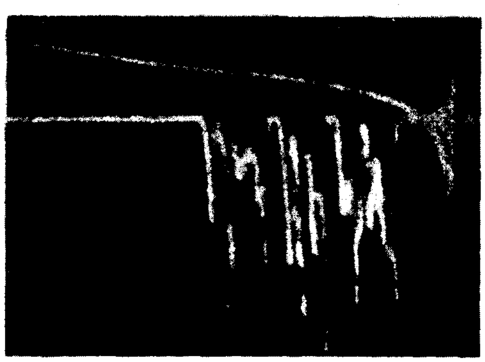
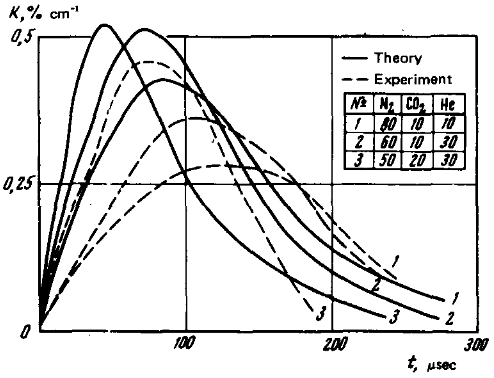


FIG. 2. Oscillograms of the current in the discharge chamber (upper trace) and of the lasing pulse (lower trace). Mixture composition $N_2 : CO_2 : He = 8:1:1$.



№	N_2	CO_2	He
1	80	10	10
2	60	10	30
3	50	20	30

FIG. 3. Gain at a pump power 1 kW/cm^3. The table indicates the percentage compositions of the mixtures.

of magnitude more than the value obtained to date with electron beams of larger power.

In addition, our experiments have shown that the duration of the stable homogeneous discharge at a ratio $E/P \sim 5$ V/cm-Torr is usually somewhat longer than the lasing duration, which is determined primarily by the electric pump power. Thus, when the specific electric pump power is varied from 1 to 4 kW/cm^3, the generation duration changes in a range of about 100 microseconds.

On the other hand, at a constant electric input power, the lasing duration depends rather weakly on the composition of the gas mixture, although it does have a tendency to increase with increase of the CO_2 fraction. It should be noted, however, that, depending on the composition of the gas mixture, the same electric energy input at a fixed E/P can be obtained by different electron-gun currents. This circumstance, which had been noted in[1], is connected with the different recombination mechanisms of the charged particles.

The general character of the obtained experimental results, and primarily the decrease of the lasing duration with increase electric input power, is obviously connected with the heating of the gas during the course of the quasistationary pulse, the duration of which greatly exceeds the durations of all the elementary processes in the investigated gas-discharge plasma. At the same time, simple estimates of the dependence of the lasing duration on different plasma parameters are quite difficult, in view of the strong temperature dependence of the relaxation times of the laser levels of the CO_2 molecules[4]. To obtain the theoretical characteristics of the optical properties of the investigated quasistationary pulses we have calculated numerically the time variation of the gain in CO_2-N_2-He mixtures at atmospheric pressure with allowance for the increase of the gas temperature during the course of the pulse.

The calculations were performed using the usual equations for the energy balance between the different vibrational modes and the gas temperature, [5] assuming an initial conversion of the electric energy only into vibrational energy of the N_2 molecules.

Some of the calculation results, corresponding to different gas-mixture compositions and to an electric pump power 1 kW/cm^3, are shown by the solid curve of Fig. 3. It is seen that the calculated values of the gain are quite close to the experimental ones.

It should be noted that, as seen from Fig. 2, the radiation has a spiked character of the emission from solid-state lasers. The reason may be that with respect to the characteristic parameters of the laser-level population relaxation parameters, the electromagnetic field, and the polarization, a CO_2 laser at atmospheric pressure is similar to a solid-state laser.

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