CO_2 laser operating at 10.6 μ with optical pumping at 9.6 μ

V. I. Balykin, A. L. Golger, Yu. R. Kolomiiskii, V. S. Letokhov, and O. A. Tumanov

Spectroscopy Institute, USSR Academy of Sciences

(Submitted March 6, 1974)
ZhETF Pis. Red. **19**, 482–485 (April 5, 1974)

We observed for the first time lasing of the CO_2 molecule in the region of the 10.6 μ with optical pumping of the composite 02°0–00°1 vibrational band by a pulsed CO_2 laser in the 9.6-μ band.

We report here the first successful experimental realization of lasing of the CO_2 molecule in the region of 10.6 μ with pumping by a pulse from a CO_2:N_2He laser at $\lambda = 9.6$ μ with a quantum efficiency 90%. We obtained amplification and lasing in pure CO_2 gas up to atmospheric pressure. Observation of lasing of the CO_2 mol-

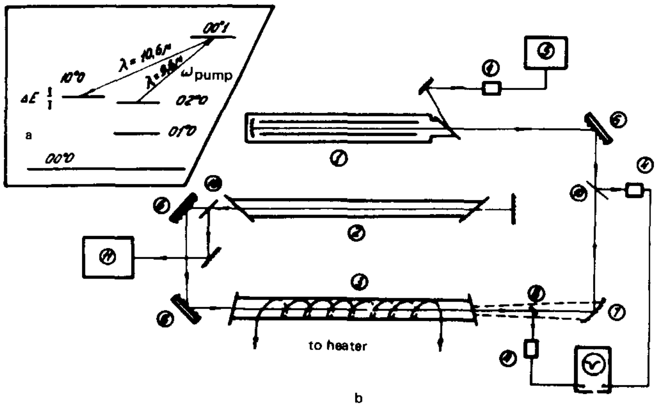

FIG. 1. a) Lower energy levels of the CO_2 molecule. b) Block diagram of setup: 1 – pulsed CO_2 laser, 2 – cw CO_2 laser, 3 – cell, 4 – radiation receiver, 5 – F118 naonovoltmeter, 6 – diffraction gratings, 7 – focusing mirror, 8 – small-aperture mirror, 9 – oscilloscope, 10 – NaCl plates, 11 – IKM-1 monochromator.

ecule with optical pumping is of great interest for the development of simple and effective tunable sealed CO_2 lasers.

The idea of a CO_2 laser optically pumped at 9.6 μ is based on the singularities of the structure of two composite vibrational bands of the CO_2 molecule (Fig. 1), which have a common upper level.

Owing to the closeness of the vibrational levels 10 °0 and 02 °0 (Fermi resonance) and the small energy defect in the vibrational exchange between the levels 00 °0, 01 °0, and 10 °0, the time needed to establish an equilibrium population ratio of these levels in pure CO_2 is of the order of $\tau_{rel} = 10^{-9}$ sec-atm^{-1}.[1,2] Thus, under the influence of resonant optical pumping in the 02 °0–00 °1 band, with a pulse duration $\tau_{pul} \gg \tau_{rel}$, and equalization of the populations of the levels 02 °0 and 00 °1 will take place in the absorbing CO_2 gas, whereas the rapid relaxation processes will maintain an equilibrium population of the levels 02 °0 and 10 °0. Then, at a sufficient degree of saturation of the transition 02 °1–00 °1 there will occur on the transition 00 °1–10 °0 a population inversion with a maximum gain $\kappa_g = \kappa_{abs}[\exp(\Delta E/kT) - 1]$, where κ_{abs} is the absorption coefficient of the weak signal in the 10 °0 → 00 °0 transition and ΔE is the energy difference between the levels 10 °0 and 02 °0. With increasing temperature of the absorbing CO_2 gas, κ_{abs} and κ_g increase. However, with increasing temperature the populations of the levels 10 °0 and 02 °0 become equalized $[\exp(\Delta E/kT) - 1 \to 0]$, and in addition, the decrease in the pump radiation over the length of the cell with the absorbing CO_2 gas becomes appreciable, as does also the decrease of the time of vibrational relaxation of the 00 °1 level, which amounts to ~3.8×10^{-6} sec-atm^{-1} at $T = 296$ °K.[3] These processes limit the growth of the gain with increasing temperature.

A block diagram of the experimental setup for the measurement of the gain produced by pulsed pumping on the 10 °0–00 °1 transition is shown in Fig. 1. Previously purified CO_2 at various pressures, 50–760 Torr, is admitted into a cell (3) whose temperature could be varied in the range 23–240 °C and kept constant within

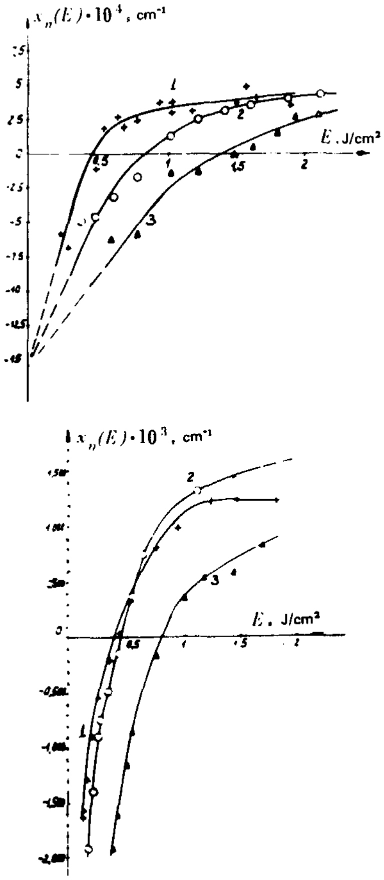

FIG. 2. Gain vs the pump energy density: a – $t = 23$ °C, 1 – $P_1 = 330$ Torr, 2 – $P_2 = 500$ Torr, 3 – $P_3 = 1$ atm. b – $P = 330$ Torr, 1 – $t_1 = 320$ °C, 2 – $t_2 = 343$ °C, 3 – $t_3 = 400$ °C.

±1 °C. The radiation from the two CO_2 lasers, with selection of the vibrational-rotational transitions, was directed to the same cell. Pump radiation with a pulse energy 10 J and durations 3 μsec, and a pump radiation wavelength 9.6 μ (P branch of the 00 °1–02 °0 transition) was applied from one side. From the other side, direction of a probing cw laser at 10.6 μ [the $P(20)$ line of the 00 °1–10 °0 transition] was directed to the same cell. To prevent the pulsed CO_2 laser from affected the operation of the cw probing laser, the two lasers were optically decoupled by diffraction gratings (6) and a system of diaphragms.

The lasing pulse of the CO_2 pump laser, the radiation of which saturated the 02 °1–10 °0 transition of the molecule CO_2 was fed to the screen of a two-beam oscillo-

FIG. 3. Oscillogram of pump pulse and generation pulse.

scope together with the signal representing the change of absorption on the $P(20)$ line of the $10\,°0-00\,°1$ transition.

Figure 2 shows plots of the gains on the $P(20)$ line of the $10\,°0-00\,°1$ transition against the pump energy density (J/cm^2) for different pressures and temperatures. The gain at room temperature reached 4×10^{-4} cm^{-1}. The maximum value was $\kappa_g = 2.1\times10^{-3}$ cm^{-1} at a pressure 100 Torr and a temperature 130 °C, corresponding to a 23% gain per pass in a cell 10 cm long.

To observe the generation, the following modifications were made to the experimental setup. The mirror (8) together with a total-reflection mirror with $R = 2$ m formed a semiconfocal resonator. Part of the radiation was extracted from this resonator by reflection from the Brewster window of the cell, was incident on a system of dispersion filters cutting off the 9.6 μ radiation. Thus, we were able to eliminate almost completely the radiation of the pulsed pump laser. The generation signal was observed simultaneously with the pump pulse. An oscillogram of the pump pulse at a wavelength 9.6 μ and of the generation pulse at the wavelength 10.6 μ is shown in Fig. 3. The generation was effected in a wide range of pressures and temperatures of the molecular CO_2 gas (80–600 Torr, 40–240 °C). We measured the value of $E_{\text{threshold}}$ for the pump energy density.

The developed CO_2 laser with optical pumping can be used to produce a sealed CO_2 laser using a mixture of the isotopic molecules $^{12}C^{16}O_2$, $^{13}C^{16}O_2$, $^{12}C^{18}O_2$, etc. This will permit overlap of the lines a smooth tuning of the frequency at atmospheric pressure.

In conclusion, the authors thank M. A. Moskaleva and E. B. Perminov for supplying the system for thermal stabilization of the cell.

[1]R. I. Abrams and P. K. Cheo, Appl. Phys. Lett. 14, 47 (1969).
[2]C. K. Rhodes, M. I. Kelley, and A. Javan, J. Chem. Phys. 48, 5730 (1968).
[3]R. I. Abrams and R. K. Cheo, Appl. Phys. Lett. 15, 177 (1969).
[4]A. B. Provorov and V. P. Chebotaev, Dokl. Akad. Nauk SSSR 208, 318 (1973) [Sov. Phys.-Dokl. 18, 56 (1973)].