Effect of deuterium on the operation of a CO_2 TEA laser

H. Albrecht, V. A. Bespalov, and V. T. Platonenko

Moscow State University

(Submitted December 10, 1974)

ZhETF Pis. Red. **21**, No. 1, 74–77 (January 5, 1975)

We describe experiments that show that addition of deuterium greatly improves the characteristics of the working mixtures in a CO_2 laser. In the case of mixtures containing nitrogen, addition of deuterium has made is possible to increase the output laser energy by 22%. In the case of mixtures that contain no nitrogen, replacement of the helium by deuterium leads to an increase of the output energy by 3–4 times with a negligible change in the pulse duration.

As is well known,[1] to excite effectively molecule vibrations in the discharge of a TEA CO_2 laser it is necessary to realize the optimal electron energy distribution. Since the maximum of the cross section for the excitation of the nitrogen vibrations by electron impact lies in the low energy region, the optimal field intensities in the discharge are relatively low, making it necessary to use a nonautonomous discharge for this optimization, and imposes a practical limit on the power input to the discharge. We think it advisable to use systems with autonomous discharge to obtain short high-power radiation pulses. In this case there are certain possibilities of improving the discharge parameters by introducing impurities that lower the discharge temperature, or that utilize the energy of the relatively "hot" electrons.

We report here an experimental investigation of the influence of deuterium on the operation of a TEA CO_2 laser with autonomous discharge. This influence can be due to a number of causes. First, deuterium contributes to the production of a "softer" discharge. Second, the deuterium should "cool" the electron gas by exciting vibrational and rotational levels, and lead by the same token to a better matching of the electron energy distribution function to the cross section for the excitation of the nitrogen and CO_2 vibrations. Finally, vibrationally excited deuterium can transfer energy to the CO_2 molecules in reactions of the type

$$D_2(v) + CO_2(000) \rightleftarrows D_2(v-1) + CO_2(011)\ . \qquad (1)$$

It appears (from the analogy with hydrogen[2]) that the cross section for the excitation of deuterium vibrations by electron impact is not small at energies above 3 eV, so that there should be no competition between the deuterium and the nitrogen. A harmful role may be played by deuterium in the laser mixture as a result, for example, of deactivation of the antisymmetrical CO_2 vibrations.

The experimental study was made with a TEA laser with preionization by a weak-current electron beam with an approximate energy 100 keV. To supply the main discharge we used either a capacitor bank of $C = 120$ nF with a shaping capacitor $C = 10$ nF charged to 25 kV, or else a Blumlein doubling circuit, both stages of which ($C = 80$ nF) were charged to 25 kV.

All the experiments were performed at a working pressure of 1 atm, a discharge gap height 2.2 cm, and a volume 80 cm^3.

The radiation was extracted from the cell through BaF_2 windows mounted at the Brewster angle. The resonator was 1.5 m long and consisted of a total-reflection mirror with curvature radius 6 m and a flat semitransparent mirror with reflectance 70%.

To measure the laser output energy we used a TPI-2 calorimeter; to investigate the time characteristics was used a Gu : Au photoresistor cooled with liquid nitrogen, and a S1-17 oscilloscope. Figure 1 illustrates the variation of the output energy of a $CO_2:N_2:He = 10:10:80$ laser when part of the helium is replaced by hydrogen, deuterium, and nitrogen. The supply circuit had a shaping capacitor that produced a current pulse of duration ~1 μsec. The addition of hydrogen at a fixed voltage does not lead to an increase of the output energy (curve a). Addition of deuterium (curve b), on the other hand, increases the output energy by approximately 25%. We note that the observed bend of curve b can be due to the presence of the hydrogen in the initial deuterium (about 10% of hydrogen).

Just like hydrogen[3,4] deuterium improves the structure of the discharge and makes it possible to obtain an arcless discharge in mixtures richer in nitrogen, and thus obtain higher output energies. Curves c and d of Fig. 1 illustrate the possibility of increasing the nitrogen concentration and the output energy in the presence and absence of deuterium in the mixture. The use of a $CO_2:N_2:D_2:He = 10:25:10:35$ mixture has made it possible to increase the output energy, in comparison with the optimal ternary mixture $CO_2:N_2:He = 10:25:70$, from 3.7 to 4.5 J (from 46 to 56 J/liter-atm).

A much stronger influence is exerted on the laser

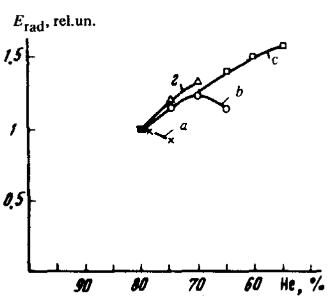

FIG. 1. Dependence of the laser output energy on the mixture composition: a) $P_{CO_2} = 0.1$ atm, $P_{N_2} = 0.1$ atm, $P_{H_2} + P_{He} = 0.8$ atm; b) $P_{CO_2} = 0.1$ atm, $P_{N_2} = 0.1$ atm, $P_{D_2} + P_{He} = 0.8$ atm; c) $P_{CO_2} = 0.1$ atm, $P_{D_2} = 0.1$ atm, $P_{N_2} + P_{He} = 0.8$ atm; d) $P_{CO_2} = 0.1$ atm, $P_{N_2} + P_{He} = 0.9$ atm.

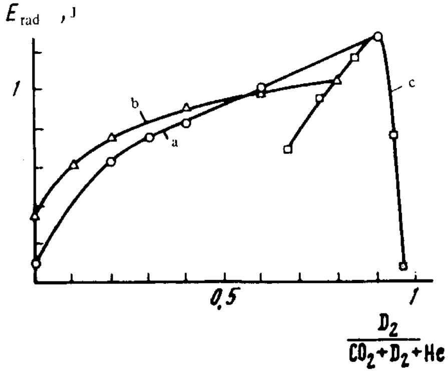

FIG. 2. Dependence of the output energy of the laser on the mixture composition: a) $P_{CO_2} = 0.1$ atm, $P_{He} + P_{D_2} = 0.9$ atm; b) $P_{CO_2} = 0.2$ atm, $P_{He} + P_{D_2} = 0.8$ atm; c) $P_{CO_2} + P_{D_2} = 1$ atm, $P_{He} = 0$.

output energy by deuterium if mixtures that contain no nitrogen are used. Figure 2 shows the dependence of the output energy of the laser on the deuterium concentration in the working mixture. (A Blumlein circuit was used for the supply, and the current pulse duration was ~0.3 μsec). It is interesting that the maximum energies were obtained with mixtures that contained no helium (at a CO_2 concentration larger than 25%, small helium impurities exert a favorable influence). The maximum energy obtained with the binary mixture $CO_2 : D_2 = 1 : 9$ was approximately 1.3 J (16 J/liter-atm), and exceeds by four times the energy obtained with the optimal binary mixture of CO_2 with helium ($CO_2 : He = 1 : 4$).

The radiation was generated in the form of an approximately triangular pulse. The duration of the leading front was less than 100 nsec. With changing of the relative $CO_2 : D_2$ concentrations, from 5 : 95 to 25 : 75, the pulse duration varies approximately in inverse proportion to the CO_2 concentration, from 0.5 to 0.1 μsec. Assuming that the duration of the trailing edge of the generated pulse is determined by the rate of the reaction (1), we can estimate this rate at $\sim 4 \times 10^7$ sec^{-1} atm^{-1}.

The use of deuterium-enriched mixtures may turn out to be particularly useful for the generation or amplification of nanosecond pulses. The advantages of deuterium over nitrogen are due in this case to the fact that, owing to the large difference in the energies of the vibration quanta of D_2 and CO_2, practically the entire vibrational energy of the deuterium can be transferred to the CO_2 prior to the start of lasing, or prior to the arrival of the amplified pulse. Nitrogen, on the other hand, effectively supplies the antisymmetrical CO_2 vibrations only before the populations of the vibrational level of CO_2 and N_2 become equalized.

[1]N. G. Basov *et al.* Zh. Eksp. Teor. Fiz. **64**, 108 (1973) [Sov. Phys.-JETP **37**, 58 (1973)].
[2]G. J. Schulz, Phys. Rev. 135, No. 4a, A988 (1964).
[3]A. M. Orishich, A. G. Ponomarenko, and R. N. Soloukhin, Dokl. Akad. Nauk. SSSR, 212, 1099 (1973) [Sov. Phys.-Dokl. 18, 671 (1974)].
[4]T. F. Deutsch, Appl. Phys. Lett. **20**, 315 (1972).