INFLUENCE OF RATE OF DISINTEGRATION OF THE LOWER LASER LEVEL ON THE POWER OF A CO_2 LASER

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In an earlier note [1] we advanced the assumption that the dominating process among those leading to population inversion of CO_2 laser levels is direct electronic excitation of the vibrational levels of the CO or N_2 molecules which are present in the gas-discharge tube together with the CO_2, followed by resonant transfer of their vibrational quanta to the CO_2 molecules. Simple calculations show that this mechanism ensures an upper-level population rate of 10^{18} cm^{-3} sec^{-1}, which agrees with the experimentally observed generating-power density [2]. It is clear that 10^{18} quanta/sec should pass also through the lower laser level in the stationary mode, meaning that at CO_2 pressure of 1 Torr the relaxation time of this level should not exceed 10^{-4} - 10^{-3} sec. According to recent measurements by Bridges [3], for example, it amounts to 10^{-5} sec. We note, however, that he used in his experiments a CO_2-N_2 mixture. The partial pressures of the components were identical and equal to 4 Torr. When the data are converted to a pressure of 1 Torr, the relaxation time becomes $\approx 10^{-4}$ sec. 1)

We shall consider below the influence of the relaxation rate of the lower laser level on the magnitude of the inverse population, and by the same token, on the generation power.

It is known that selective disintegration of the lower level can in itself not lead to population inversion [4]. In the case of a CO_2 laser, when the upper laser level is pumped by the aforementioned resonant transfer of vibrational energy, it is necessary also to effect rapid disintegration of the lower laser level in order to maintain the inversion. Indeed, according to Herzfeld's calculations [5], at room temperature only $\approx 5 \times 10^2$ collisions will suffice for the CO_2 molecule to go from the state 10^00 to the state 01^10. At a CO_2 pressure of 1 Torr, this corresponds to a relaxation time 4.3×10^{-5} sec, which agrees with the large values of the observed per unit generation powers.

It is clear, however, that if the lower deformational level (01^10) is not depleted sufficiently effectively, then this leads not only to an increase in its population, but also to an increase in the number of the inverse processes whereby the lower laser level becomes populated, i.e., to a decrease of the inversion. Therefore, in order to maintain the inverse population it is necessary that the relaxation time of the 01^10 level be at least not larger than the relaxation time of the lower laser level.

The relaxation times of the first level of the deformational vibration of the CO_2 molecule were thoroughly investigated both in pure CO_2 and in its mixtures with different gases (see [6-9]). These times are listed in the table for 300°K and 1 Torr. We see from the table that at a CO_2 pressure of 1 Torr, the disintegration of the 01^10 level will be much slower than the disintegration of the 10^00 level, and consequently the CO_2 molecules will accumulate at the level 01^00. The situation is essentially different in the presence of impurities. If we disregard the exchange of deformation quanta between the components, then the relaxation time τ of the 01^10 level in the mixture, at a total pressure p, can be determined from the relation (see, for example, [9]) $1/\tau = \Sigma_i(p_i/\tau_{CO_2,i})$, where p_i are the partial pressures of the components and $\tau_{CO_2,i}$ are the relaxation times of the CO_2 molecules in the gas i at a pressure of 1 Torr.

Relaxation times of the 01^10 level of CO_2 in varius gases [7,8]
(pressure 1 Torr, temperature 300°K)

Gas	Average number of gas-kinetic collisions leading to loss of a vibrational quantum	τ* (sec)
CO_2	51300	$4.4 \cdot 10^{-3}$
N_2	1200	$1.04 \cdot 10^{-4}$
CO	230	$2.0 \cdot 10^{-5}$
NO	260	$2.26 \cdot 10^{-5}$
H_2	300	$2.6 \cdot 10^{-5}$
H_2O	60	$5.2 \cdot 10^{-6}$
He	2600	$2.26 \cdot 10^{-4}$
Ar	47000	$4.1 \cdot 10^{-3}$

* The number of gas-kinetic collisions is taken to be the same for all gases, 1.15×10^7 sec^{-1}.

Using this relation, we can easily verify that addition to CO_2 of nitrogen at 1 Torr pressure leads to a relaxation time of $\approx 10^{-4}$ sec for the 01^10 level. Nitrogen is usually used in lasers at higher pressures, which should decrease τ much more. It should be borne in mind that, owing to the dissociation of the main molecules, CO_2 lasers always contain CO molecules, while $CO_2 + N_2$ lasers contain CO and NO molecules, the presence of which, even in small amounts, also greatly reduces τ (see the table). We note, for example, that the presence of even 0.1 Torr of CO in the laser tube leads to a relaxation time of 2×10^{-4} sec for the 01^10 level of CO_2. The table also shows that the greatest decrease in $\tau(01^10)$ is produced by water vapor. Witteman [10] advanced the hypothesis that the H_2O molecules, owing to the almost resonant coincidence of the levels, can also directly disintegrate the lower laser level of CO_2. Both mechanisms greatly increase the relaxation rate of the lower laser level, a fact manifest in the increase of the generation power.

In the explanation of the influence of helium on the power of CO_2 lasers [1] it was noted that He not only increases the population of the upper laser level, but also reduces the population of the lower one [11]. The latter circumstance is connected, of course, with the fact that the helium decreases the relaxation time of the lower level of CO_2 (see the table). We note in this connection that the relaxation mechanism explains to some degree the absence of a positive effect when helium is replaced by other noble gases [12]. It is seen from the table that, for example, argon causes practically no change in the relaxation time of the 01^10 level of CO_2.

We can thus conclude that absolutely pure undissociated CO_2 cannot provide appreciable generation power, for in this case the power is limited by the slow rate of disintegration of the lower laser level. Usually insufficiently pure commercial grades of CO_2 are used in lasers. On the other hand, the presence of certain impurities is not only harmless, but to the contrary is useful. To obtain very high powers, the presence of impurities in the CO_2 is obligatory, i.e., they must either be introduced into the laser tube or must result from the dissociation of the CO_2.

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1) The interpretation of Bridges' results is not unambiguous. A discussion of this question is contained in a paper by the author [2].

POSSIBILITY OF INVESTIGATING THE pp INTERACTION IN THE ENERGY INTERVAL 30 - 700 GeV

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At present decisive answers to a large number of fundamental problems [1] can be obtained only by investigating elementary processes at energies reaching hundreds and thou-