INFLUENCE OF HYDROGEN ON THE PERFORMANCE PROPERTIES OF A CO_2-LASER ACTIVE MEDIUM

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We present here our investigation of the effects, that may produce an admixture of hydrogen into a CO_2-laser active medium, on the energy that may be deposited into the gas at a pulsed volume electric discharge and on the laser lifetime. We also discuss the mechanisms resulting in an improvement of the discharge stability and CO_2 regeneration that we revealed in this study.

It is a well known fact that a tiny addition of some gas component into the gas mixture of a gas-discharge device may essentially change its energy and other performance characteristics. The gas admixtures that have low ionization potentials are most practical since they provide for better ignition of a volume discharge and enable one to increase the output energy[1] and lifetime[2] of sealed-off devices.

The molecular hydrogen admixtures into the active medium of CO_2-lasers are used most widely. Initially, it was assessed as most attractive that the rate of depopulation of the low lasing levels, 10^00 and 02^00, of the CO_2 molecules through the 01^10 energy level drastically increased due to collisions with the H_2 molecules.[3]

Later on, one more remarkable property of the hydrogen has been revealed that favors an improvement in the CO_2-laser lifetime.[4] This effect has been related to the mechanism of CO oxidizing completion that is as follows. In the gas mixture there occur chemical reactions among the atomic and molecular hydrogen and the oxygen that yield the OH radical. Then there takes place the reaction between the OH and vibrationally excited CO molecules that yields CO_2 and H,

$$OH + CO \rightarrow CO_2 + H.$$

The constant K of this reaction equals $1.3 \cdot 10^{14}$ (mm Hg)$^{-1}$ s^{-1} at 600 K temperature.

The data of other experiments in this field[5] have also confirmed the favorable effect of adding hydrogen on the laser lifetime.

In this paper we present some results of an investigation of effects that an admixture of hydrogen may produce on the energy that can be deposited into the active gas medium from a volume gas discharge as well as of its influence on the CO_2 dissociation rate.

In this study we used an experimental model of a technological CO_2-laser in which we used an original method[6] of combined excitation of the volume electric discharge. According to this approach, the plasma is first initiated in the discharge gap by a short-pulse self-maintained electric discharge, while the main portion (95 to 97%) of energy is deposited into the gap from a semi-self-maintained discharge at the stage of plasma decay. The voltage to be applied to the discharge gap, at the stage of a semi-self-maintained discharge, is chosen so that it provides for the most efficient transfer of energy to the upper lasing level. The power supply circuitry used provided for an effective decoupling of power supplies for the semi-self-maintained and self-maintained discharges without the use of components that could limit the discharge current.

The discharge zone we used in our experiments was 1000 cm^3 in volume and the gas flow rate through the discharge gap was 50 m/s. The pulses of a self-maintained discharge were applied to the gap at a repetition rate of 100 Hz. The maximum energy, W_m, deposited into the gas, at the volume discharge stage (without the discharge contraction), was determined from the oscillograms of the discharge voltage and current.

The maximum amount of energy dissipated in the gas mixture, at the semi-self-maintained discharge stage, is shown in Fig. 1 as a function of the H_2 partial pressure. It is seen from this figure that the maximum energy dissipated in the gas medium during a single pulse (W_m) rapidly increases with the pressure increasing up to 20 mm Hg regardless of the mixture composition. It is also clear that the further increase of the H_2 partial pressure does not yield any significant increase in W_m. In our opinion this may occur because of a fall off of the direct and step-wise ionization rates at increasing hydrogen concentration that, as known, causes the discharge contraction.

To check up this assumption we have been calculating the excitation and ionization constants of nitrogen molecules in the excited states. The calculations used the Boltzmann equation.[7] By equating the two constants we determined the maximum E/P ratio for the positive column of the semi-self-maintained discharge as a function of the hydrogen partial pressure (see Fig. 2) in the gas mixture CO_2:N_2:He = 1:4:7 at a

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pressure of 50 mm Hg. One can see from this figure that the experimental data well agree with the calculated ones. As a result, one may state that the hydrogen inhibits the development of the discharge instabilities by lowering the rate of the step-wise ionization.

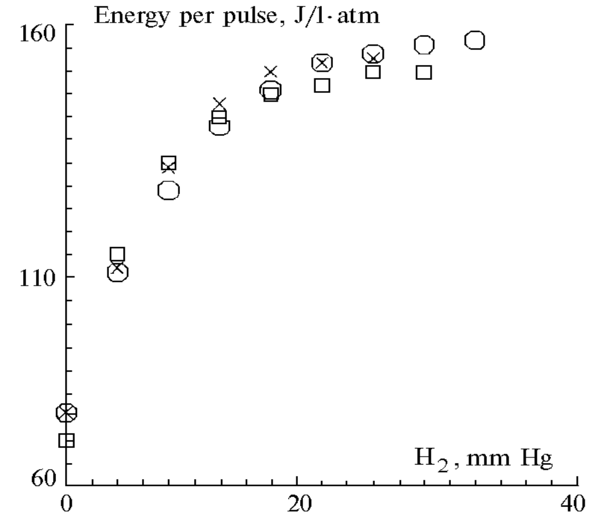

FIG. 1. The pulse energy deposited into the active medium at the stage of a semi-self-maintained discharge as a function of H_2 *partial pressure and the composition of the gas mixture:* $CO_2:N_2:He = 1:4:5$, *partial pressure is* 80 mm Hg (×); $CO_2:N_2:He = 1:3:6$, *partial pressure is* 60 mm Hg ( ); $CO_2:N_2:He = 1:4:7$, *partial pressure being* 50 mm Hg (O).

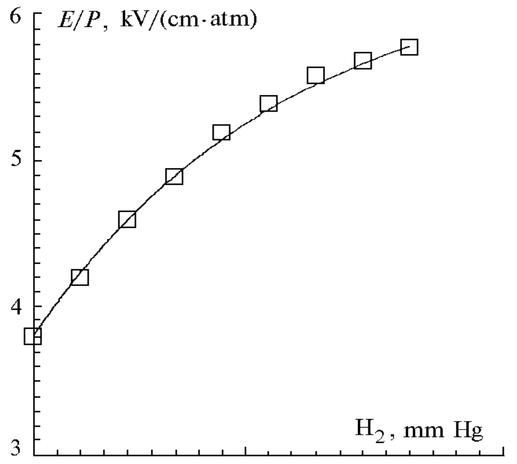

FIG. 2. Maximum achievable values of the E/P ratio as a function of the hydrogen partial pressure in the mixture $CO_2:N_2:He=1:4:7$ *at a pressure of* 50 mm Hg*; solid curves presents calculated data; is for experimental points.*

It is worth noting here that this effect will not manifest itself so strongly in a self-maintained discharge under high overvoltage that may occur at gas pressure of 1 atm. This is explained by the fact that in this case the direct ionization prevails, as a rule, over the step-wise one.

However, in these conditions the hydrogen has one more useful property of lowering the rate of the working gas mixture degradation. This phenomenon has been studied using a MI-1201 mass spectrometer,[8] in a TEA CO_2-laser ($CO_2:N_2:He = 1:1:3$) operated at the atmospheric pressure of the active medium and pumped with the electric discharge. In the course of these experiments it was found that small (about 5%) addition of the hydrogen significantly lowers the CO_2 dissociation degree while the further increase in the hydrogen content does not produce that strong effect (see curve *1* in Fig. 3).

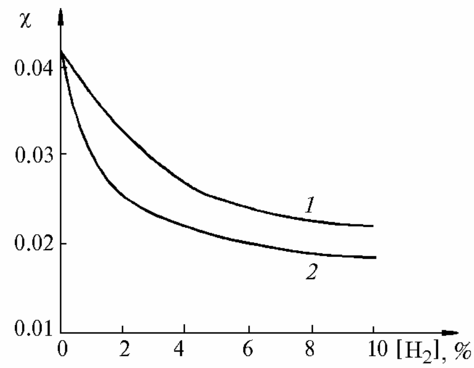

FIG. 3. Dependence of the CO_2 *dissociation degree (after* 10^4 *cycles) on the hydrogen partial pressure in a gas mixture; the curve 1 is obtained experimentally and the curve 2 presents the calculated results; the dissociation degree* $\chi = \ln([CO_2(n)]/[CO_2(0)])$, *where* $[CO_2(0)]$ *is the initial concentration and* $[CO_2(n)]$ *is the concentration in* 10^4 *switchings.*

In our opinion the reason for the decrease in the CO_2 dissociation degree, when adding an amount of hydrogen into the gas mixture, is as follows.

We think that when the discharge current terminates and plasma recombines ($\tau < 10^{-3}$ s) there may take place chemical reactions among various radicals and unstable molecules in the discharge gap between the electrodes that may result in a partial regeneration of the CO_2. It is just this recombination that may be taken for the dissociation degree fall in the experiments since the processes lasting in shorter than 10^{-3} s can not be recorded with the mass spectrometer used.

To check up this assumption we have stated and solved the following problem. Let the decomposition of CO_2 be taking place in the discharge gap during 50 seconds under conditions of the above experiment (the mixture of $CO_2:N_2:He = 1:1:3$, at 1 atm pressure). Then we followed up the chain of reactions among various radicals and molecules that result in a partial regeneration of the CO_2. We solved the balance equations for the gas mixture components (CO, O, H, OH, O_2, H_2O, HO_2 and H_2O_2) numerically using the

Rosenbrok method of the 3rd-order accuracy. The plasmochemical reactions and their constants have been taken from Refs. 9 and 10.

The results calculated showed that during a 10^{-3} s time interval after adding of H_2 into the mixture there occurs a partial regeneration of the CO_2 following the scheme presented in Fig. 4.

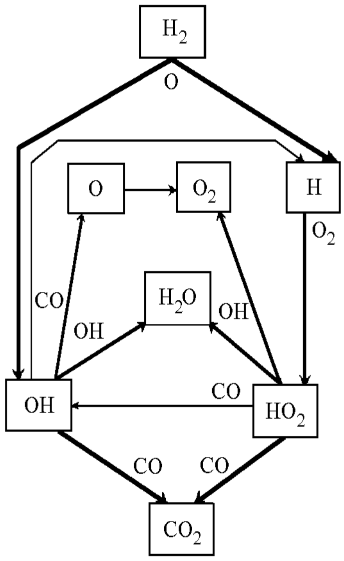

FIG. 4. The scheme of basic plasmochemical processes yielding the CO_2 *regeneration.*

As seen, the CO_2 regeneration happens in two ways. One way involves the radical OH while the other one the H_2O molecules (shown in Fig. 4 by bold arrows). The rates of these processes drastically increase with the H_2 content increase up to 3 to 5% of the entire mixture and practically do not change at its further growth. Good agreement observed between the experimental and calculated curves in Fig. 3 evidence the validity of the assumption that the lowering of the CO_2 dissociation degree observed when adding H_2 into the mixture is due to a partial regeneration of the CO_2 in the discharge gap between the electrodes yielding from plasmochemical reactions according to the scheme in Fig. 4.

Thus, in conclusion we may state that we have proposed an explanation of the mechanism that results in an improvement of the energy characteristics of a semi-self-maintained electric discharge when adding the hydrogen into the laser working gas mixture. We have also suggested a new extended scheme of the CO_2 regeneration that enabled us to explain the decrease observed in the CO_2 dissociation degree in the self-maintained discharge.

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