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INCREASE OF CO_2 LASER POWER UNDER THE INFLUENCE OF A BEAM OF FAST PROTONS

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Gas lasers are usually excited by an electric discharge. It is also of interest to attempt to produce electrons exciting the working levels of the molecules not in an electric discharge but by ionization with fast charged particles. Such particles may be the products of nuclear reactions, nuclear fission fragments, etc.

Let us estimate, for example, the rate of excitation ($\Gamma(N_2)$) of the lower vibrational levels of nitrogen in a CO_2-N_2-He^3 mixture of the same component concentrations as in electrically excited lasers. when the mixture is irradiated with a flux of thermal neutrons ($\Pi = 10^{18}$ $cm^{-2}sec^{-1}$). We assume here that the entire $He^3(n, p)H^3$ energy is consumed in ionization and that all the electrons, which are produced with an average energy equal to the ionization potential, are decelerated and pass through the energy region 1.5 - 3.5 eV, where the main energy-loss process is excitation of the lower vibrational levels of the N_2 and CO molecules [1]:

$$\Gamma(N_2) \approx N(He^3)\sigma_p \Pi Q/I \approx 10^{20}\ cm^{-3}\ sec^{-1},$$

where $N(He^3)$ is the He^3 concnetration, σ_p the nuclear-reaction cross section (500 b), and Q and I are the energies of the reaction and of the electron-ion pair production. This value of Γ greatly exceeds the rates of population in lasers with electric pumping. Variants with other active impurities, such as BF_3 (the reaction $B^{10}(n, \alpha)Li^7$) and UF_6 (fission reaction) do not differ in principle from the foregoing one.

For an exact calculation it is necessary to know in detail the mechanism whereby the energy of the fast particles is used. We set up a model experiment on the influence of a beam of fast protons on the power of a CO_2 laser. The experimental setup is illustrated in Fig. 1.

The quanrtz tube had an inside diameter 22 mm and a length 1600 mm, the distance between electrodes being 1000 mm. The tube was coupled to an EG-8 electric proton accelerator and

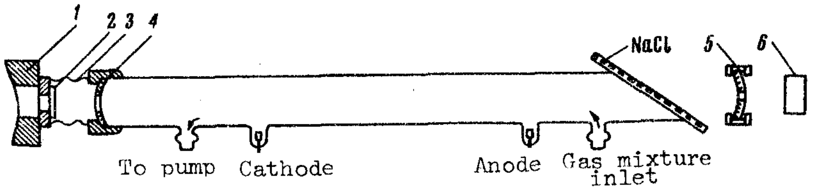

Fig. 1. Setup for the study of the influence of a fast-proton beam on the power generated by a CO_2 laser: 1 - accelerator output flange, 2 - aluminum membrane, 3 - bellows, 4 - internal mirror, 5 - external mirror, 6 - radiation receiver.

was partitioned from the accelerator tube, in which high vacuum had to be maintained, by an aluminum membrane of 7 mm diameter and 15 μ thick, cooled with liquid nitrogen.

A 1:2:5 mixture of CO_2-N_2-He with total pressure 10 Torr, which was found to be optimal, was continuously pumped through the tube. The discharge was fed with direct current, which could be varied in the range from 5 to 30 mA.

The resonator consisted of two spherical mirrors (gold sputtered on glass) with radius of curvature 3 m, spaced 1650 mm apart. The radiation emerged from the tube through an NaCl window mounted at the Brewster angle. The internal mirror had a central opening of 10 mm diameter to admit the proton beam. The power decoupling was through a 5 mm dia central opening in the external mirror. The receiver was a thermocouple. The electric pump threshold was about 35 W.

The employed accelerator generated a proton beam of energy up to 2.8 MeV. The measurements of the intensity of the beam passing through the internal mirror have shown that the intensity does not exceed 7 μA in the immediate vicinity of the mirror and amounts to 5 μA in the middle of the tube.

Estimates show that at a pressure of 10 Torr the beam gives up to the working gas about half its power, i.e., about 10 W. Owing to the incomplete absorption of the protons in the working gas, the NaCl window is subjected to appreciable bombardment, which causes it to cloud up rapidly.

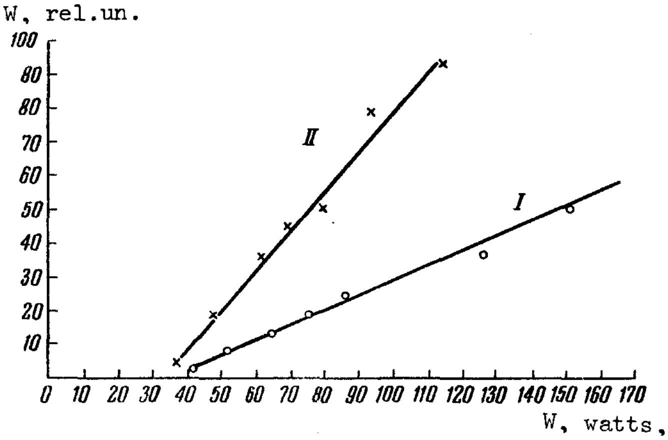

Fig. 2. Generation power vs. electric pump power without the proton beam (I) and upon passage of the proton beam (II).

Note. The electric power input to the beam, W, is proportional to the discharge current, since the voltage in the discharge gap remains constant when the current is varied.

The passage of the proton beam produces intense glow of the gas, but no generation is observed. However, the beam exerts a strong influence on the output power of a laser excited by direct current (Fig. 2). It should be pointed out that upon passage of the beam the discharge-gap voltage decreases to 4.8 kV from the value 5.3 kV characteristic of the electric discharge in the absence of the beam. The power consumed by the discharge from the power source decreases, whereas the generation power greatly increases. It is seen from the curves of Fig. 2 that the slope of the plot of the generation power against the current increases very strongly.

This phenomenon can be explained by using the following simple consideration. Assuming the customary hypothesis that the main population mechanism in a CO_2 laser is resonant energy transfer from the N_2 and CO molecules [1, 2], whose first few vibrational levels are directly excited by the electrons, we can write the following expression for the rate of population of the upper laser level of the CO_2 molecules:

$$\Gamma(CO_2) \sim \Gamma(N_2) = N_0 N_e f\left(\frac{E_b}{<E>}\right)\sigma v,$$

where N_0 is the concentration of the unexcited N_2 molecules, σ the resonant value of the cross section for electronic excitation of the working vibrational levels, N_e the total concentration of electrons with average energy $<E>$, $N_e f(E_b/<E>)$ the concentration of the electrons whose energy E_b lies in the region of the resonant value of σ, and v is the electron velocity corresponding to the energy E_b.

In the absence of the proton beam, the electric field heats the electrons, under optimal conditions, to an energy somewhat higher than E_b. This is caused by the fact that under optimal conditions the product $N_e f(E_b/<E>)$ should be maximal. The electron density N_e is determined by the number of fast ionizing electrons. The product is therefore maximal if the distribution function is shifted away somewhat from E_b towards higher energies. Since the value of $f(E_b/<E>)$ lies near the maximum of $f(E/<E>)$, it changes little when the current changes, and the radiation power increases in proportion to the electron density, i.e., to the current.

In the presence of a beam, there appears an additional ionization source. Therefore the distribution function, at a given current, shifts towards lower energies, i.e., closer to resonance. This corresponds to the experimentally observed decrease of the electric field. With further increase of the current, the considerations advanced above concerning the proportionality of the generation power to the current remain in force, but the proportionality coefficient $f(E_b/<E>)$ increases. A detailed explanation calls for knowledge of the form of the electron distribution function.

Thus, under the conditions of the performed model experiment, the effectiveness of the utilization of the fast-proton energy greatly exceeds the effectiveness of utilization of the electric energy. Final conclusions call for experiments with more powerful beams.

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