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ELECTRON ENERGY DISTRIBUTION IN DISCHARGES USED FOR CO_2 LASERS

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The pumping rate at the upper lasing level of a CO_2 laser depends not only on the electron concentration, but also on their energy distribution f(E). It is therefore possible to construct a theory [1] of the operation of a laser of this type, and all the more to calculate [2] the inverted population, only if the distribution function is known. There are practically no such data in the literature. The two- and single-probe methods with the usual procedure for processing the probe characteristics, used by the authors of [3, 4] to obtain the electron temperature, can hardly be applied to discharges in mixtures with CO_2. Our measurements have shown that in the absence of a Maxwellian energy distribution we can not speak of an electron temperature in the usual sense.

We measured with the aid of probes the electron energy distribution in discharges used for CO_2 lasers. We used for this purpose a well known method, employing an expression first derived by Langmuir and Mott-Smith [5]:

$$f(E) = A\sqrt{V}\frac{d^2I_e}{dV^2},$$

where f(E) is the electron energy distribution function, A is a constant, V is the potential of the probe relative to the space potential, and I_e is the electron current in the probe. The problem thus reduces to a determination of the second derivative of the electron current in the probe with respect to the voltage. There are several methods of differentiating the probe characteristic [6]. It is shown in [7], which is devoted to a comparison of three methods of determining the second derivative, that the second-harmonic method and the intermodulation method have noticeable advantages and are more accurate than the method of modulation with a high frequency. We used the second-harmonic method. A sinusoidal signal of 367 Hz frequency and low amplitude (0.8 V) was fed to the probe circuit. A narrow-band amplifier and a synchronous detector were used to separate the second harmonic of this signal, the amplitude of which was proportional to the second derivative of the probe current with respect to the voltage. The space potential was chosen to be the zero of the second derivative.

The measurements were made in a discharge tube of 20 mm inside diameter and 55 cm length, with cold molybdenum electrodes. In all the experiments, the gas flow rate was about 1 m/sec. A cylindrical gold probe of 0.04 mm diameter and 2 mm length was located on the tube axis 15 cm away from the anode. We investigated the positive column of a glow discharge in commercial nitrogen at pressures 1.8, 3.6, and 5.2 Torr and at a current of 60 mA, in carbon dioxide at pressure 2.4 Torr, and in a mixture of CO_2 with helium, in a 1:2 ratio, at the same total pressure and discharge current. The pressure, current, and composition of the mixture were chosen such that there were no oscillations or noises in the discharge, and the conditions under which the probe procedures are valid were satisfied. Unfortunately, owing to the strong oscillations, it was impossible to obtain f(E) in the mixture of CO_2 with N_2.

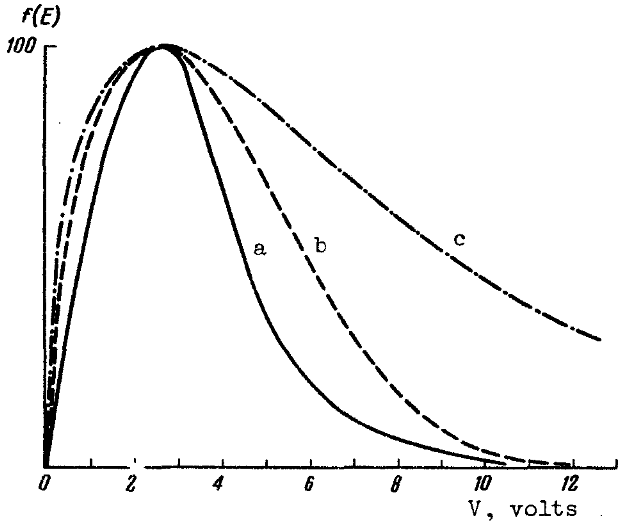

Fig. 1. Electron energy distribution: a - in nitrogen, p = 1.8 Torr, $\bar{\varepsilon}$ = 3.3 eV; b - Druyvesteyn distribution, $\bar{\varepsilon}$ = 3.7 eV; c - Maxwellian distribution, $\bar{\varepsilon}$ = 5 eV.

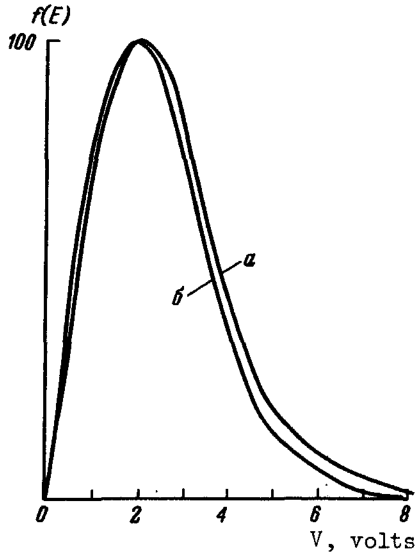

Fig. 2. Electron energy distribution in nitrogen: a - 3.6 Torr, b - 5.2 Torr.

The results of the measurements of the electron distribution function in nitrogen are shown in Figs. 1 and 2. A characteristic feature is the strong deviation of the obtained distribution from the Maxwell and Druyvesteyn distributions, manifest in a paucity of electrons with energy larger than 3 - 4 eV. The average energy, defined as

$$\bar{\varepsilon} = \int_0^\infty \varepsilon f(\varepsilon) d\varepsilon / \int_0^\infty f(\varepsilon) d\varepsilon ,$$

is 3.3 eV at a pressure 1.8 Torr. It should be noted that analogous results were obtained by Swift [8], who investigated the electron distribution in nitrogen under conditions different from ours (p = 0.2 Torr, d = 9 cm, i_p = 300 mA) and using a different method of determining the second derivative.

The energy distribution of the electrons in CO_2, shown in Fig. 2, is similar to that in nitrogen. The only difference is that in pure CO_2 the tail of the distribution falls off more rapidly. Consequently the average energy in CO_2 is somewhat lower and equals 2.6 eV. This result can apparently be understood by taking into account the fact that the cross sections for the inelastic collisions of the electrons with N_2, CO, and CO_2 molecules has a clearly pronounced resonant character [9, 10]. In addition, our own measurements [11] have shown that the concentration of the electrons in such discharges is too low to make electron-electron interactions capable of establishing a Maxwellian distribution significant.

Addition of helium to CO_2 with the total pressure and discharge current the same increases the average energy to 2.5 eV, the maximum shifts to 2.5 V, and the number of fast

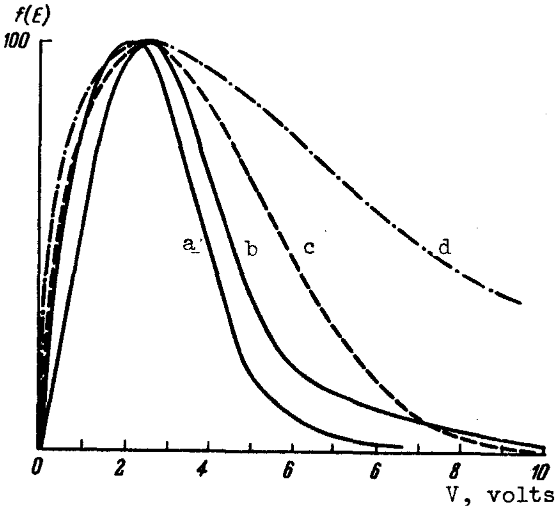

Fig. 3. Electron energy distribution: a - CO_2, p = 2.4 Torr, $\bar{\varepsilon}$ = 2.6 eV; b - CO_2 + He (1:2), p_Σ = 2.4 Torr, $\bar{\varepsilon}$ = 3.4 eV; c - Druyvesteyn distribution, $\bar{\varepsilon}$ = 3.7 eV, d - Maxwellian distribution, $\bar{\varepsilon}$ = 5 eV.

electrons on the distribution tail, at 4 - 11 eV, increases. The electron concentration on the discharge axis, determined from measurements of the area under the curves, is increased by the addition of the He by a factor larger than 2. The intensity of the longitudinal field in the tube decreases accordingly.

A very important factor in the explanation of the CO_2-laser operating mechanism is that the electron concentration in the discharge increases when He is added. If we bear in mind the hypothesis [1] that the vibrational levels of the CO molecule are directly excited by the electrons, with subsequent transfer of energy to the CO_2 molecules, this can apparently serve as one of the explanations of the increase in the laser power when He is added.

We note also that when He is added to CO_2 the maximum of the electron distribution shifts only slightly towards higher energies, and remains in the region where the maximum is observed in the cross sections for elastic collisions between the electrons and the CO and N_2 molecules.

As already mentioned, a Maxwellian electron energy distribution was assumed in the calculations [2] of the inverted population. The true distribution, however, differs from Maxwellian, so that, given the same electron concentration and the same maximum energies in the distributions, the averaged cross sections of the vibrational levels of N_2 and CO will be larger for the true distributions than for the Maxwellian ones.

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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]:

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

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

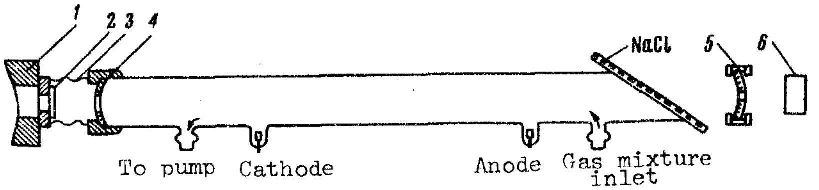

Fig. 1. Setup for the study of the influence of a fast-proton beam on the power generated by a CO_2 laser: 1 - accelerator output flange, 2 - aluminum membrane, 3 - bellows, 4 - internal mirror, 5 - external mirror, 6 - radiation receiver.