GAS LASERS AT HIGH PRESSURES

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Submitted 26 August 1971
ZhETF Pis. Red. 14, No. 7, 421 - 426 (5 October 1971)

We consider in this paper a method of combined excitation of a gas laser at pressures on the order of several dozen atmospheres, making it possible to obtain powerful short pulses of coherent light [1]. The active medium of the laser is excited by electrons produced by a source of ionizing radiation and heated in an electric field. In estimating the effectiveness of such an excitation method it is necessary to ascertain the mechanism whereby energy is introduced into the medium, to find the conditions for the stability of the space charge, and to show that quenching processes do not cause interruption of the laser generation.

1. The power p = IU released in the laser active medium is determined by the total current I and by the voltage U applied to the discharge gap. If there is no space charge, then the current is produced mainly by the electronic component I_e. Conversely, if there is spatial separation of the charges, then the motion of the carriers assumes an ambipolar character and the current is determined by the ionic component I_i. Since $I_e >> I_i$, the power released in the case of free motion of the electrons exceeds by several orders of magnitude the power of the ambipolar carrier motion. The energy input to the discharge therefore depends strongly on the character of the carrier transport. In the general case the processes occurring in a non-spontaneous discharge can be described by the following system of equations:

$$\frac{\partial n_e}{\partial t} = -\frac{\partial}{\partial x} n_e v_e + \alpha n_e v_e + \left(\frac{\partial n}{\partial t}\right)_i - b n_e n_i ,$$

$$\frac{\partial n_i}{\partial t} = -\frac{\partial}{\partial x} n_i v_i + \alpha n_e v_e + \left(\frac{\partial n}{\partial t}\right)_i - b n_e n_i , \qquad (1)$$

$$\frac{\partial E}{\partial x} = 4\pi e(n_i - n_e),$$

$$\int_0^L E dx = U, \quad \int_0^L (n_i - n_e) dx = 0, \quad [j_i + \beta j_i + j_a]_{x=0} = [j_e]_{x=L},$$

where n_e, n_i, v_e, and v_i are the densities and drift velocities of the electrons and ions, respectively, $\alpha(E)$ is the first Townsend coefficient describing the cascade multiplication of the electrons in regions with large field intensity E, $(\partial n/\partial t)_i$ is the rate of production of electron-ion pairs by the ionizing radiation, b is the coefficient of electron-ion recombination, j_e, j_i, and j_a are the electron, ion, and field-emission currents, β is the coefficient of electron emission in the case of ion bombardment of the cathode, and $x \in [0, L]$ is the distance from the cathode gap.

The system (1) can be integrated approximately. It turns out that if U/pL is lower than the breakdown value, then a field sufficient for cascade ionization of the gas is produced only in a narrow region Δx near the cathode. At $x > \Delta x$, the stationary density of the electrons does not depend on x and is determined by the relation $n_{e0} = [(1/b)(\partial n/\partial t)_i]^{1/2}$. If

$$p \approx 10^4\,\text{Torr};\quad \frac{U}{pL} \approx 10\,\text{V/cm-Torr};\; b \approx 10^{-7}\,\text{cm}^{-3}/\text{sec} \tag{2}$$

and $(\partial n/\partial t)_i \simeq 10^{23}\ \text{cm}^{-3}\text{sec}^{-1}$, then the potential drop $E(0)\Delta x$ amounts to $\sim(1 - 3) \times 10^2$ V.

The cathode-drop region is $\Delta x \simeq (0.5 - 1) \times 10^{-4}$ cm, and consequently the voltage is distributed practically uniformly over the entire length L of the discharge gap. The motion of the charges obviously does not have an ambipolar character and the current I is determined by the mobility of the electronic component in a field of intensity U/L. Under conditions (2) and at an ionization pulse duration $\sim 2 \times 10^{-8}$ sec, the electron concentration is $\sim 10^{15}$ cm^{-3}, and the per-unit energy input to the discharge is $\sim 3 - 4$ J/cm^3.[1]

At high electron concentrations the maximum length of infrared lasers can be limited by the bremmstrahlung absorption of the light by the electrons. In the case of lasers with resonant excitation transfer, for example using a CO_2:N_2 mixture, this limitation does not exist even at short powerful ionization pulses, owing to the low values of the electron concentration at the instant of the generation pulse.

2. At a voltage U larger than the breakdown value, the space charge is stable during the course of the characteristic time of development of the spark breakdown. Let us examine the stability of the space charge at voltages below breakdown. Assume that some random increase of the current density in some current filament originating at the point (y, z) of the cathode has led to an increase of the temperature, and consequently to a lowering of the gas-particle concentration. With decreasing concentration, the current in the filament increases, causing a further rise of the temperature and a corresponding decrease of the gas density. When the gas density drops to the critical value, the usual breakdown of the discharge gap takes place.

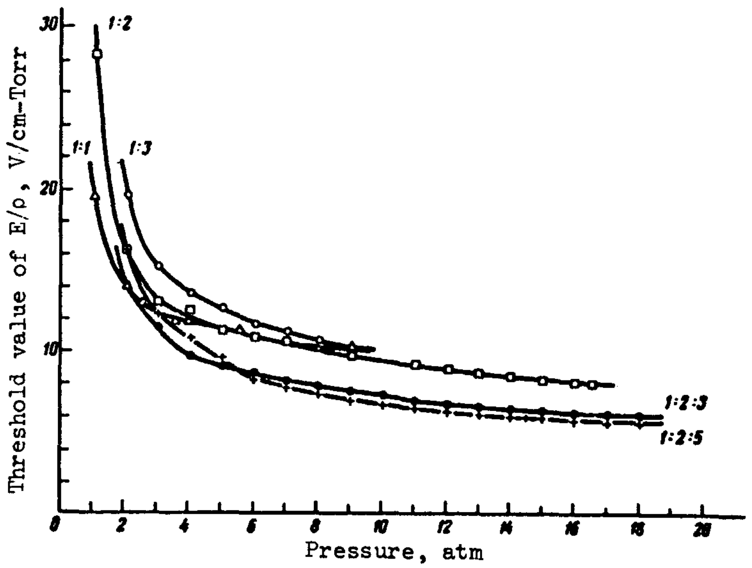

Fig. 1. Dependence of $(E/p)_{thr}$ on the mixture pressure. The curves are labeled with the mixture proportions CO_2:N_2 and CO_2:N_2:Hi. In all the mixtures water vapor was present at a pressure $\sim$10 Torr.

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[1] Estimates made without taking into account the near-cathode effects considered above lead to a decrease of the energy input to the discharge by a factor of at least 10^3, and excitation of generation by direct current becomes practically impossible. The difficulty of excitation in the presence of screening internal fields is pointed out in [2]; for example, the use of microwaves calls for powerful sources with wavelength $\sim$1 - 3 mm.

The dynamics of the perturbations occurring in the gas will be described by the following hydrodynamic equations

$$\frac{\partial \rho}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r} r v \rho ,$$
$$\rho \frac{\partial v}{\partial t} = -v\frac{\partial v}{\partial r} - \frac{\partial p}{\partial r} , \tag{3}$$
$$\frac{\partial}{\partial t}\left(\rho\epsilon + \rho\frac{v^2}{2}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left[r v \rho\left(\epsilon + \frac{v^2}{2} + \frac{p}{\rho}\right)\right] = Q ,$$

where ρ and p are the density and pressure of the gas, v the velocity $r = [y^2 + z^2]^{1/2}$, $\varepsilon = p/[\rho(\kappa - 1)]$ is the per unit energy, κ is the adiabatic exponent, and Q is the Joule heat released per unit volume per second. We shall assume the recombination coefficient to be a power-law function of E/ρ, namely $b \sim (E/\rho)^{-k}$. In this case $Q = Q_0(\rho/\rho_0)^{-(1+k)/2}$, where Q_0 is the power released in the unperturbed ($\rho = \rho_0$, $V = 0$) medium. From the linearized system (2) we can find the law governing the growth of the fluctuations. In particular, for the density fluctuations $\delta\rho = \rho - \rho_0$ we have

$$\delta\rho = \Delta\rho \exp \gamma t , \quad \gamma = \frac{(\kappa - 1)(k + 1)}{2\kappa}\frac{Q_o}{p} .$$

If the applied voltage amounts to half the breakdown voltage, and the initial density fluctuation is $\Delta\rho \approx 10^{-3}\rho_0$, then the breakdown of the gap ($\Delta\rho \approx \rho_0$) occurs after the following energy is released per unit volume of the gas

$$Q_o r \approx 15\frac{\kappa}{(\kappa - 1)(k + 1)} . \tag{4}$$

At $p \approx 10^4$ Torr, $k \approx 3$ and $\kappa = 7/5$, we have $Q_0 r \approx 20$ J/cm^3.

The density criterion (4), obtained from (3) under the condition that during the discharge time the pressure in the system has time to become equalized, is not valid for short times ($\tau < 5 \times 10^{-7}$ sec). In the latter case, the breakdown does not have time to develop at all, and the energy input reaches $\sim 10^2$ J/cm^3.

It can be assumed that the electric processes occurring in the laser plasma can qualitatively duplicate the processes in electric discharge gaps. Mesyat et al. [3], in an investigation of high-speed discharge gaps with external initiation of the discharge, obtained experimentally energy input values up to several dozen J/cm^3.

3. Experiments were performed on the excitation of a molecular CO_2 laser at 25 atm, with the discharge initiated by an electron beam. The experimental setup and the parameters of the apparatus are given in [1]. Figure 1 shows the experimentally obtained dependence of the threshold electric field on the gas pressure. A decrease of the generation pressure at high pressures is observed, pointing to a relatively weak influence of the quenching collisions on the population inversion of the CO_2 molecules at high pressures. With increasing pressure of the working mixture, the limiting value of the electric voltage across the discharge gap increases, the energy input per cm^3 of gas

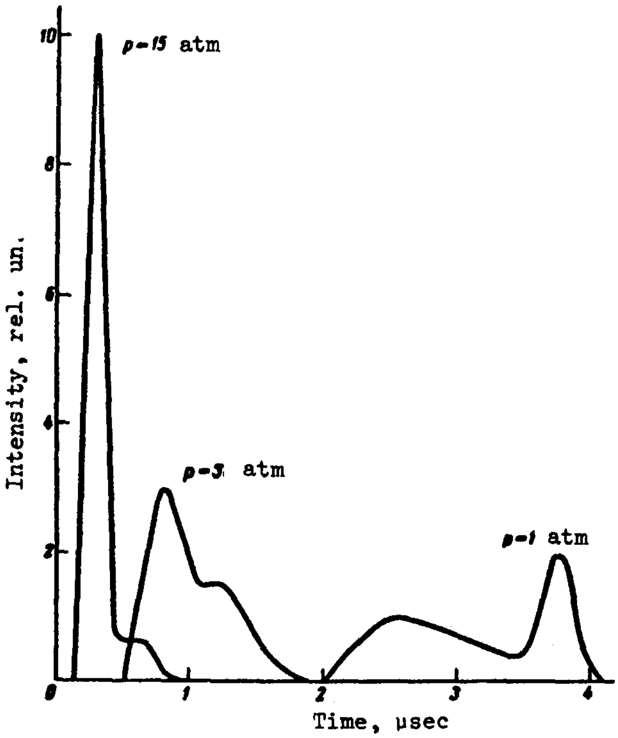

Fig. 2. Shape of generation pulse at different pressures. The pulses were obtained at the following ratios of the energy input to the discharge W to the threshold energy W_{thr}: $W/W_{thr} \simeq 1.5$ for p = 1 atm, ≈ 1.1 for 3 atm, and ≈ 1.02 for 15 atm. Mixture composition $CO_2:N_2$ = 1.2.

increases, and, as a result of the increase of the frequency of the collisions between the excited N_2 molecules and the CO_2 molecules, a decrease takes place in the duration of the generation pulse and in the delay of the generation pulse relative to the ionization pulse (see Fig. 2).

[1] N.G. Basov, E.N. Belenov, V.A. Danilychev, and A.F. Suchkov, Kvantovaya elektronika (Quantum Electronics), No. 3, 121 (1971).

[2] A.B. Eletskii and B.M. Smirnov, Dokl. Akad. Nauk SSSR 190, 809 (1970) [Sov. Phys.-Dokl. 15, 109 (1970)].

[3] B.M. Koval'chuk, G.A. Mesyats, and Yu.F. Potalitsyn, Zhurnal prikladnoi mekhaniki i tekhnichesko fiziki (Journal of Applied Mechanics and Technical Physics), No. 6, 120 (1971).

DETERMINATION OF THE AXIAL FORM FACTOR OF THE NUCLEON FROM THE CROSS SECTION FOR ELECTROPRODUCTION OF PIONS AT THRESHOLD

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Submitted 23 June 1971; resubmitted 30 August 1971
ZhETF Pis. Red. 14, No. 7, 426 - 428 (5 October 1971)

The methods of current algebra in conjunction with the hypothesis of partial conservation of the axial current (PCAC) show that the cross section for the electroproduction of pions at the threshold is sensitive to the axial-vector form factor F_A of the nucleon [1]. An analysis of the first experimental data [2] has shown that the cross section at the threshold can be satisfactorily described at the values of F_A obtained in neutrino experiments. In the present paper we use the previously obtained data [2, 3] and some new ones to determine F_A in the interval of the 4-momentum transfer squared k^2 from 2.5 to 10.4 F^{-2}. In the determination of F_A, we use the same theory as in [2]. New data at $k^2 = 5.2\ F^{-2}$ and $k^2 = 10.4\ F^{-2}$ were obtained with the aid of a procedure described in [3], however, to identify the electrons we used a telescope made up of threshold gas Cerenkov and scintillation counters. Figure 1