TWO OPERATING MODES OF A PLASMA SOURCE

S. N. Popov
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 5 January 1966
ZhETF Pis'ma 3, No. 7, 275-279, 1 April 1966

During the course of an investigation of a titanium source [1] it was noted that two qualitatively different plasma generation modes exist, with different particle acceleration mechanisms.

In one of the modes, which we call "slow," the average ion energy is 150 - 200 eV, and the number of particles with energy 1 keV is smaller by one order of magnitude than the number with the average energy.

The second mode, called "fast," sets in when the main capacitance C_0 of the discharge circuit is reduced. In this case the energy spectrum of the ions in the plasma changes, the relative weight of the tails increases, and the average ion energy increases by one order of magnitude. Simultaneously with generating the plasma, the source injects an electron beam of intensity of the order of one ampere and energy higher than 1 keV. Experiments have shown that the fast mode sets in with the energy input to the discharge much lower and with the working voltage applied to the source U_0 remaining the same.

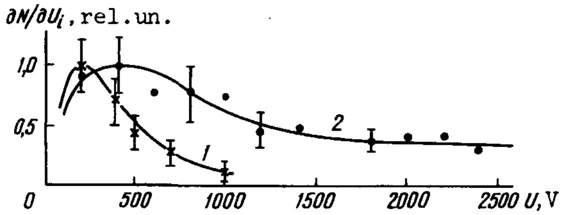

Fig. 1. Ion energy distribution: 1 - slow mode, 2 - fast mode.

Fig. 2. Oscillograms of ion current in the probe (a) and of the source current (b). Time markers every 1 μsec.

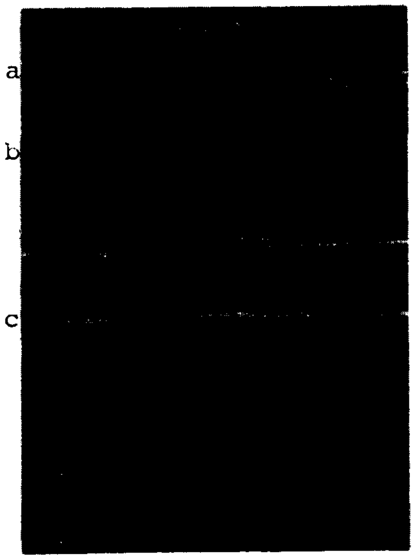

Fig. 3. Oscillograms of the ion current in the probe (a and b) and of the source current (c). Time markers every 1 μsec.

Figure 1 shows by way of an example the ion energy distribution in the slow mode (1) (C_0 = 5.3 μF, U_0 = 8 kV) and in the fast mode (2) (C_0 = 0.3 μF, U_0 = 8 kV).

The measurement procedure and the source model employed are described in [2].

The slow mode was realized in our experiments with C_0 = 7.5, 5.3, and 1.7 [1)] μF and a working voltage U_0 = 4 - 10 kV. The number of generated particles was proportional to the stored energy, and the energy spectrum was practically constant.

The tail of the energy distribution extended to 10 keV, but the number of particles with energy more than 1 keV did not exceed 5% of all the particles.

Typical oscillograms of the ion current in the measuring probe and of the source current are shown in Figs. 2a and 2b respectively.

Fast mode. When C_0 is reduced from 5.3 to 0.3 μF the duration of the current pulse (Fig. 3c) was 2 μsec instead of the expected 1 μsec, and the discharge had an aperiodic character. This shows that the resistance of the plasma in the source has changed radically.

The pulse waveforms are different in the two modes (compare Figs. 2b and 3c). The speed of the leading front v_f exceeds 1.5×10^8 cm/sec. An exact determination of v_f is made difficult by the presence of a negative (electronic) pulse preceding the plasma pulse (Figs. 3a and 3b).

The ion-current oscillograms obtained at U_0 = 8 kV and at probe repelling potentials U_{rep} = +100 V and +2500 V are shown in Figs. 3a and 3b respectively. We see that approximately 30% of all the particles have an energy exceeding 2.5 keV. The tail of the distribution, measured with an electrostatic analyzer, extends beyond 17 keV.

Comparison of the source operation in the two modes shows the following:

1. The total number of particles in the fast mode is 1 - 2 orders of magnitude smaller than in the slow mode.

2. The average energy of the fast-mode ions is one order of magnitude larger than in the slow mode. In all probability the far tails of the energy distributions have the same order of magnitude in both modes, thus pointing to a single acceleration mechanism in this energy region. Indeed, during the initial instant of the source operation the current mode does not depend on C_0 so that for a short time (compared with the source operating time) the physical processes in the discharge should be the same for all C_0.

3. The resistance R_p of the plasma pinch at the instant of the current maximum is very small in the slow mode. Taken together with the electrode-plasma and plasma-electrode contact resistance it amounts to about 0.05 ohm. In the fast mode the same resistance exceeds 1 ohm. Assuming the contact resistances to be the same in both modes, the increase of R_p in the fast mode must be attributed wholly to the change in the plasma resistance.

4. The current I in the source is 10 - 12 kA and 4 - 5 kA in the slow and fast modes, respectively. The character of the current is different in the two cases. From a comparison of Figs. 2 and 3 we can conclude that in the fast mode the source current grows "unsteadily"; breaks and 5 - 10 Mc current oscillations are observed.

5. In the fast mode the average electric field intensity (at the current maximum) in the source plasma is $\bar{E}_{pf} = IR_p/\ell_0 \approx 1$ kV/cm (ℓ_0 = length of source). It is impossible to determine the field $\bar{E}_{ps}$ in the slow mode because of the uncertainty in the value of R_p. We can merely assert that $\bar{E}_{pf} \gg \bar{E}_{ps}$.

6. Electrons that move with velocities exceeding v_f and have an energy > 1 keV are generated in the fast mode simultaneously with the plasma.

The processes observed when the source operates in the fast mode are characteristic, judging from a number of the aforementioned features, of excitation of two-stream instability in a plasma. In particular, the strong electric fields observed in the experiments (item 5) can exist in the plasma as a result of this instability. Indeed, with decreasing C_0 the density of the generated plasma decreases and the collision frequency ν is accordingly reduced. For a given U_0 the ratio E_p/ν can be sufficient to excite and maintain two-stream instability during the entire plasma generation time. The value of E_p maintained in the plasma is relatively large, and this leads in the final analysis to acceleration of the plasma.

In the case of large C_0, with increasing current in the source the ratio E_p/ν decreases rapidly (compared with the plasma generation time) to a value below critical, and therefore the instabilities that set in during the start of the discharge are rapidly suppressed. The source will then operate in the slow mode.

In conclusion we note that the observed effect is in all probability not a property peculiar to the source employed. To obtain the fast mode it is important apparently to ensure, by some means, a sufficiently large value of E_p/ν in the plasma. In other sources this condition can be satisfied by reducing the quantity of gas admitted in to the source, by reducing the delay between the admission of the gas and the application of the voltage, etc.

The author is grateful to I. S. Danilkin, E. K. Zavoiskii, A. A. Plyutto, and A. A. Rukhadze for useful advice and discussion.

[1] F. H. Coensgen, W. F. Cummins, and A. E. Sherman, Phys. Fluids 2, 350 (1959).
[2] S. N. Popov, Coll. Fizika plazmy (Plasma Physics), Nauka, 1966.
[3] E. D. Andryukhina and I. S. Shpigel', ibid.

1) The measurements at C_0 = 1.7 μF were made by Andryukhina and Shpigel' [3].

FEATURES OF THE TIME BEHAVIOR OF THE GENERATION IN A LASER WITH MOVING RUBY CRYSTAL

B. L. Livshitz, V. P. Nazarov, L. K. Sidorenko, A. T. Tursunov, and V. N. Tsikunov
Institute of General and Inorganic Chemistry, USSR Academy of Sciences
Submitted 7 January 1966
ZhETF Pis'ma 3, No. 7, 279-281, 1 April 1966

We have shown recently [1] that a laser with a ruby crystal moving along the axis of a planar resonator with speed v ~ 30 cm/sec radiates energy in a narrower spectral interval than a laser with stationary crystal, and that this increases the spectral density of the stimulated emission. This narrowing of the stimulated-emission spectrum is due to the decrease in the number of generating axial modes and is an experimental confirmation of the correctness of the theoretical premises of the model of Tang, Statz, and de Mars [2], which explains the nature of the mode makeup of solid-state lasers with homogeneously broadened luminescence