EXCITATION OF ELECTROMAGNETIC OSCILLATION IN
THE PLASMA ZONE OF AN ELECTRON–ION OSCILLATING DISCHARGE

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Experimental data are presented on the excitation of electromagnetic oscillations in the plasma of an electron–ion oscillating discharge. The mechanism by which the neutral medium is excited by means of a beam of oscillating electrons and the resulting excitation of electromagnetic radiation are considered. The experimental results reasonably agree with theoretical conclusions for the idealized case of the passage of an electron beam through a neutral medium. A possible mechanism for the acceleration of high-energy electrons by an electromagnetic wave is hypothesized.

It has been demonstrated in a number of works [1-3] that studied an electron–ion oscillating discharge in a magnetic field, that the discharge cavity divides into two mutually connected regions in which the electrons and ions oscillate at low pressures in a system of electrodes whose potential alternates in sign. The electron component of the plasma is continuously populated basically by ionization processes within the discharge. The ion component is continuously populated due to ionization of the atoms of the neutral gas by the oscillating electrons.

The ionization mechanism for a neutral medium by an electron beam was theoretically solved in [4]. It was demonstrated that bremsstrahlung and scattering is accompanied by a disturbance of the medium in some spatial zone, formed due to cascade ionization processes by the electrons of the neutral atoms. Oscillations with a frequency [4]

$$\omega = \left( \frac{4e^2}{M} \left( \frac{3\pi \alpha^4 N_0}{48 \pi \alpha^3} \right)^{1/2} \right)^{-1} \frac{1}{2}$$

having the sense of the plasma frequency $\omega$ of the zone of maximal concentration, such that the basic contribution to the density of successively emitted electrons is made by electrons with energy $E$ less than the ionization energy $\Delta$, can be excited in the resulting plasma surrounding the beam.

Beam energy oscillates along the electromagnetic field, measured in one direction by multigrid probes, significantly exceeds the transverse kinetic energy of the successively emitted electrons, and is determined by values near the maximum ionization cross section of the neutral gas. It amounts to 80–100 eV for nitrogen.

The recombination coefficient $\alpha$ takes low values, $\alpha \approx 10^{-13} \text{ cm}^3/\text{sec}$, for these experimental conditions. The neutral gas density $N = 5 \times 10^{15} \text{ cm}^{-3}$ and the value of $n_0\nu_0$ corresponding to a 6 mA current of oscillating electrons is equal to $3.6 \times 10^{16} \text{ sec}^{-1}$ (here $n_0$ is the linear density of the oscillating electrons).

An estimate of $\omega$ for the discharge conditions presented above and the values $E_0 = 80 \text{ eV}$, $\Delta = 15 \text{ eV}$, $\sigma = 3 \times 10^{-46} \text{ cm}^2$ (nitrogen), and $Z = 1$ (since we are considering electron–electron collisions) yields a value $\approx 2.02 \times 10^{10} \text{ sec}^{-1}$ ($f = 3220 \text{ MHz}$).

Electromagnetic radiation from the discharge plasma was received by a telescope antenna mounted outside the discharge. The spectral composition of the electromagnetic radiation was determined by the S4–5 spectrum analyzer. The antenna was oriented and adjusted to the maximal signal and its position was a function of the discharge conditions. Moreover, electrostatic plasma oscillations were registered by a high-frequency probe. The high-frequency probe and its calibration were as in [5]. The probe was mounted in the plasma of the electron oscillating region (in its center) or near the plasma boundary and could shift in the axial and radial directions of the discharge (Fig. 1, where 1–4 and 6 are the electrodes, 5 is a cylindrical anode, 7 is the telescopic antenna, 8 is the high-frequency probe, and IOR and EOR are the ion and electron oscillating regions).

Values of frequencies fixed in the experiment by the high-frequency probe and antenna at $U_2 = 10 \text{ kV}$ and $D = 600 \text{ G}$ basically coincide and amount to 3280–3400 MHz as a function of pressure and voltage $U_1$ on the electrodes of the electron oscillating region.

The experimental dependence of the plasma frequencies on pressure (Fig. 2a, $U_1 = 5 \text{ kV}$) is close to that previously presented [4] (broken curve), but is somewhat steeper. The growth in the frequency of radiation of maximal amplitude with increasing pressure is explained by the increase in the number of electron–electron collision events.

The amplitude maximum of electromagnetic radiation increases with increasing electric field strength within the volume of electron oscillations (Fig. 2b, $p = 1.4 \times 10^{-4} \text{ torr}$). An amplitude oscillation peak ($A$ increases to 9 dB) is observed with a voltage $U_1$ across the electrodes of between 5.5 kV and 6 kV, this peak exceeding the mean value by a factor between 4 and 6. This is explained in the readjustment of the topography of the electric field of the ion and electron oscillating regions, when excitation is complemented by the secondary electrons of the ion region. These electrons as they approach the anode, additionally disturb the neutral medium as well as its ionization.

A stable value for the frequency of electromagnetic radiation is most likely at primary beam energies close to the values of $m\Delta$ in the ionization cross-section maximum (for a given gas). Maximal values of the oscillation amplitudes also correspond to these conditions.

The influence of a magnetic field (in the range of $B$ between 230 G and 600 G) is insignificant, and it can be seen that the amplitude of electromagnetic oscillations linearly increases with increasing inductance of the applied magnetic field.

Such electromagnetic radiation accompanies ionization processes of the neutral atoms and ion recombination in an oscillating electron discharge and is apparently the source of energy for fast electrons in the