# MEASUREMENT OF THE ELECTRON CONCENTRATION IN A PLASMA GENERATED BY A HIGH-VELOCITY ELECTRON BEAM

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The probing of gas and plasma flows by beams of accelerated electrons is now coming into wide use [1,2]. In colliding with particles of the gas being investigated the beam electrons ionize these particles and either generate an independent plasma or increase the ion concentration in the plasma under investigation. This can introduce considerable error into the measurements of plasma parameters. Consequently, the problem can arise of the need to evaluate such error. This can be done by our investigating parameters of the plasma generated by ionization of the gas by a beam of accelerated electrons.

The ionization of a gas by an electron beam produces a plasma whose parameters, such as electron concentration N, the effective frequency of electron collisions, etc., can be easily varied by a suitable selection of gas, or by our varying the gas pressure, the electron-beam current and energy, etc.

Modification or displacement of the zone occupied by the plasma can be important in certain applications. Such modification can evidently be most readily achieved with a plasma generated by an electron beam.

Available experimental data [3,4] pertain to ionization of a rarefied gas by means of pulsed beams (pulses on the order of a few μsec at pressures ranging from $10^{-5}$ to $10^{-2}$ mm Hg. At low pressures and short pulses the ionization processes play a fundamental role in plasma generation, since in this case there is little electron recombination and diffusion. Consequently, data obtained under these conditions are not applicable to the case of gas ionization by a steady electron beam.

Preliminary results from measurement of electron concentration in plasma generated in air, helium, and argon by a high-velocity electron beam at current intensities varying between 0.1 and 0.6 mA are presented in this paper.

The mean concentration of electrons in the plasma was measured along the beam cross section, with the plasma-column diameter assumed equal to the bright region of the gas ionized by the beam (Fig. 1). This model is somewhat crude approximation of phenomena actually taking place in the beam, since it does not take account of irregularity in electron distribution across the beam, and of electron diffusion outside the bright zone. However, consideration of these phenomena is extremely complex.

The electron concentration in the plasma was measured by means of a superhigh frequency resonator in the three-centimeter range of wave-lengths [5]. A cylindrical resonator with $TM_{010}$ oscillations and an electron beam along its axis was selected for these experiments. The resonator was 26.4 mm in diameter and 10 mm in height.

The electron concentration in the plasma was determined in the usual manner from change in the transmission ratio and from the shift in the resonance frequency of the resonator during passage of an electron beam through it. The experimental setup is shown diagrammatically on Fig. 2.

The energy from superhigh frequency oscillations at 8530 mHz was fed from a klystron generator to the resonator located in a vacuum chamber together with the waveguides. The controlled admission of gas to the chamber made possible variation of the ionized gas pressure within the required limits.

Fig. 1

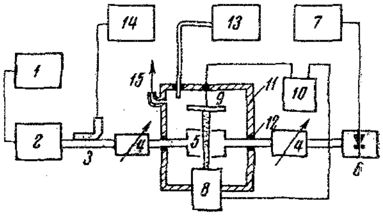

Fig. 2

The resonator is connected to the waveguides by means of circular diaphragms. To eliminate possible parasitic resonances in the circuit between the detector head and the resonator, a resolving attenuator is provided in this part of the circuit.

Holes 4 mm in diameter are provided in the top and bottom covers of the resonator and along the axis of the latter to allow passage of an electron beam 1.5 mm in diameter. This beam of accelerated electrons is generated by an electron gun with a tungsten cathode, and is focused by a magnetic coil. The beam is led out through a gasdynamic aperture with a pressure differential. The accelerating voltage was varied from 15 to 30 kV, the beam current from 0 to 0.6–2.5 mA, and the gas pressure from 0.2 to 2.5 mm Hg. The range of gas pressure and beam current intensity was limited by the equipment available and by the method used.

It will be seen from the photograph (Fig. 1) that within the pressure range considered here, the electron beam emerging from the gun aperture is of a slightly divergent form, and can, therefore, be considered to be of a constant diameter during its passage through the resonator, after which the beam electrons strike the collector.

Experimental data defining the dependence of electron concentration in the plasma on the beam current at the constant accelerating voltage U = 22 kV and various air pressures are shown on Fig. 3. It will be seen that in the pressure and current ranges investigated the electron concentration in the plasma increases linearly with increasing beam current.

At pressure p = 0.2 mm Hg this dependence was determined for a somewhat wider variation in the beam current (from 0.1 to 2.5 mA).

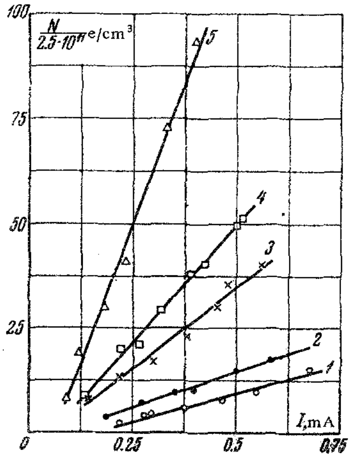

Fig. 3

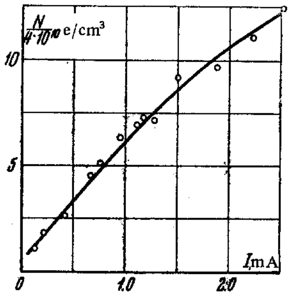

Fig. 4

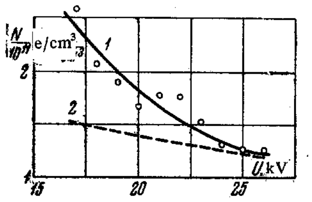

Fig. 6

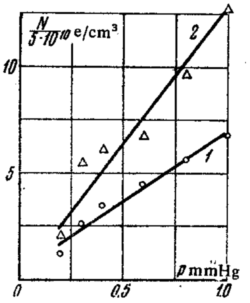

Fig. 5

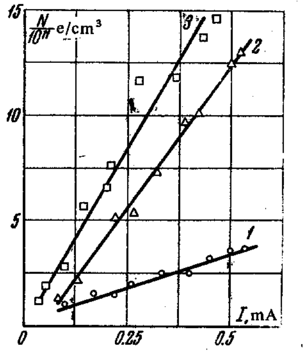

Fig. 7

Figure 4 shows that when the beam current exceeds 1.2–1.5 mA this dependence deviates slightly from the linear: the concentration increases at a lower rate than the current.

The observed concentration of electrons in the plasma at various gas pressures and beam currents ranged from $2 \cdot 10^{10}$ to $2 \cdot 10^{12}$ electrons/cm$^3$. (For comparison note that the theoretical electron concentration in a monoenergetic primary beam, i.e., with the effect of gas ionization omitted, is on the order of $2 \cdot 10^7$ electrons/cm$^3$ for a beam current of 0.5 mA).

The curves of Fig. 5 show the electron concentration in the plasma as a function of pressure for two constant beam currents: 0.2 and 0.35 mA. They indicate this dependence to be approximately linear. A definitive conclusion cannot, however, be drawn from this in view of the insufficient number of experimental points and their considerable scatter.

The dependence of electron concentration on the accelerating voltage U at constant beam current I = 0.3 mA and air pressure p = 0.4 mm Hg is presented in Fig. 6, which shows that the electron concentration decreases with increasing accelerating voltage. Theoretical curve 2 of this diagram shows the dependence of the primary-electron concentration in the beam (with the ionization effect omitted) on the accelerating voltage for the same beam current. Comparison of this curve with experimentally obtained values shows that with decreasing accelerating voltage the electron concentration in the plasma increases considerably more rapidly than does the concentration of primary electrons in the beam. This is due to the increase in the ionization cross section.

A comparison of the beam-current effect on electron concentration in helium and argon appears on Fig. 7. It shows the concentration to be considerably lower in helium, and higher in argon than in air for the same beam current and gas pressure.

We note that for helium and argon the dependence of electron concentration on current within the range investigated is linear, as in the case of air.

This experimental investigation of gas ionization by a monoenergetic electron beam has shown that with such a beam it is possible to generate a plasma in which the electron concentration can be varied within a wide range by a suitable selection of gas, and by our varying the gas pressure, the beam current, and the acceleration voltage.

The observed concentration of electrons in the plasma is on the order of $2 \cdot 10^{10}$ to $2 \cdot 10^{12}$ electrons/cm$^3$, i.e., it is higher by three to five orders of magnitude than that of the primary electrons in a beam. This range can certainly be extended by our varying the beam current and the gas pressure beyond the limits imposed in this experiment.

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