Development of Diagnostic Stands on the Basis of Pulse Plasma Accelerators

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Abstract – the results of researches of work of pulse plasma KPU and UPT accelerators, developed as diagnostic and material science stands in SRIETP, are submitted.

1. Introduction

Plasma accelerators are now widely used as laboratory plasma sources and for surface processing. Therefore for many applications it is necessary to determine parameters of plasma flow – temperature and concentration of particles as well as their velocity.

Operation of a pulsed plasma accelerator strongly depends on geometry of its electrode system and on the mode of its operation. Accelerators with conical electrode geometry are considered to have the most advanced construction, however, the most widely used are accelerators with cylindrical electrode geometry, which is explained by the simplicity of the system. There are two modes of accelerator operation - pulse and continuous ones. In the latter mode the working gas fills all the space of the working chamber of the accelerator. Each mode has its advantages, which can be used for different applications.

Paper [1] described investigations of power characteristics of KPU pulsed plasma accelerator in impulse mode. The present paper presents the results of investigation of KPU and UPT accelerators, operation in continuous mode, carried out with the help of probe techniques.

2. Experimental devices

Both accelerators are designed with coaxial cylindrical system of electrodes, but the parameters of stores and operation principles essentially differ. The accelerator KPU has condensers 75 μF on 30 kV, and accelerator UPT – 4800 μF on 5 kV. Operation of the facility is based on the acceleration of plasma formed in the inter-electrode space by its own magnetic field under electric discharge. In order to create the above conditions a high voltage is applied to the electrodes and vacuum sufficient for discharge development is created in the working chamber. The main elements of the accelerator are the working chamber with two coaxial electrodes and accumulating capacitors. The task to control the facility means to fulfill Pashen condition for gas under which practically all working substance is ionized. In case of impulse injection of a working gas it is necessary to coordinate the time of gas injection into the inter-electrode space with the voltage pulse. For this purpose a special pulse generator is used. In case of continuous filling, the chamber is first filled with a gas to the pressure at which discharge may occur and the dependence of discharge current on pressure is studied.

At first we studied modes of accelerator operation at different input pressures. The tests showed that accelerator may work in the continuous mode in a rather wide range of working pressures (~10^{-3}–10^{-2} Torr). Maximal power density and, hence, efficient acceleration of the plasma flow was obtained at a pressure of about 0.1 Torr and it was equal to 45 Joule/cm^2 at a discharge voltage of 25 kV.

For UPT accelerator obtained followed results: discharge current up to 56 kA at 5 kV, duration of pulse 120 μsec, energy dense 1–12 Joule/cm^2.

3. Magnetic probe techniques

At the beginning of this section we present the results of investigations of the structure of current layers formed in a coaxial plasma accelerator. The purpose of the investigations was to develop a one-dimensional model of a thin current layer, separating the "pushing" magnetic field and the plasma influenced by the field. Such investigations are important for determining dynamics of creation of a plasma cluster in the coaxial accelerator.

The magnetic probe was made of 15 coils of 0.13 mm-wire wound on the frame of 1.5 mm in diameter. The coil was attached at the end of tightly interweaved conductor which was placed in a quartz tube of 4 mm in diameter and 60 cm long. The probe was placed on a special support. The signal was sent to the measuring oscillograph through a 50 Ohm coaxial cable. The equivalent coil cross-section nS was 0.26 cm^2 and inductivity Fn^{2}r was 1.0 μHenry. The constant of time L/R$_0$ was about 2 ns, i.e. very short for the considered experiment. As the time during which changes in the magnetic field were considered was about 10μs, a passive integrating circuit with RC=50 Ohm 1.5 μF=75 μs was used. Therefore we could obtain the probe sensitivity:

$$\frac{V}{B}=\frac{nS}{RC}=34\mu V/G.$$

Such sensitivity enabled to make a direct connection to the oscillograph without additional amplifiers at not very high but acceptable signal-to-noise ratio. Using the probe we obtained oscillograms $B_\varphi(t)$ for various positions of the probe. The results showed high signal reproducibility for different discharges. Typical oscillograms are shown in Figure 1.

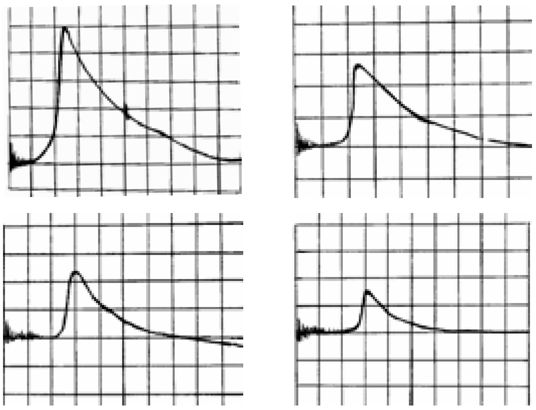

Fig. 1. Oscillograms of magnetic field variations

Analysis of the oscillograms shows that the magnetic field moves along the axial direction and that the layer of current directed radially has an alternating thickness of about 20 centimeters.

Fig. 2 shows curves $B_\varphi(z)$ for two different moments of time of the discharge. It follows from the analysis of the curves that the amplitude of the field behind the current layer decreases monotonically, which is characteristic of the uniform distribution of pressure along the way of cluster movement. It may witness effective plasma sweeping by the current layer i.e. in this case the model of snow-plough works.

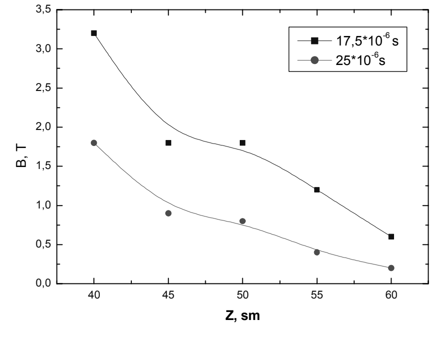

Fig. 2. Curves $B(z)$ for two different moments of discharge

It was also established that at a certain distance from the edge of the gun the probe signal changed its polarity whereas the amplitude of the signal increased by a factor of 2. This effect may be caused by the formation of a second current layer as in this case the direction of the current will be reverse. The increase in the signal amplitude is most likely caused by low pressure after passing of the first cluster. Indeed, signal polarity changes at a distance of 30 cm from the insulator whereas the cluster needs only a few microseconds to arrive to the position, which is approximately equal to the half-period of discharge current.

To analyze plasma deviation from the axial direction behind the electrode edge probes of large cross-section (diameter of 0.5 cm) were made. A ring with four similar calibrated probes placed along its diameter was manufactured and to register deviation of the plasma flow from the system axis two two-channel oscillographs were used. Analysis of several oscillograms showed that inside the outer electrode the shapes of signals practically did not differ from each other, which showed that there were no noticeable plasma deviations from equilibrium. The signal amplitude after passing the electrode edge sharply decreased and at a distance of 10 cm it was impossible to distinguish it from the noise. This phenomenon was caused by low plasma density.

In order to study currents inside the working chamber of the accelerator we used magnetic sensors such as Rogovsky's belts embracing the plasma flow passing through its cross-section. The belts were placed at a fixed distance of 30 cm from each other and this system could be moved along the accelerator liner. The above method gave current oscillograms, which enabled to derive concentration of plasma components if their speed was known. The speed of plasma flow was determined in [2], and on its base it was found that concentrations of plasma flow were approximately equal to ~10^{13} sm^{-3}.

4. Usage of electric probe

Using a probe method for carrying out measurements in plasma accelerators it is necessary to measure parameters of particles (temperature, concentration) in a pulsed plasma flow. Realization of this method may face some difficulties which are caused by considerable dispersion of values as it is known that the plasma flow generated by the accelerator may be not uniform. The other difficulty may be probe melting after several measurements as the energy density above 40 Joule/cm^2 is critical for the surface of some metals [2]. In case of plasma flows moving at high speed tasks of their diagnostics become even more complicated as the number of parameters to be determined increases by including velocity of plasma particles.

Nevertheless, in spite of the above-mentioned difficulties parameters of such plasma can be measured using the existing theory of probe diagnostics. Further we will consider application of this theory to the experimental determination of electron temperature and concentration in more detail.

It is known [3,4] that to determine plasma parameters it is possible to use single and double cylindrical probes. These probes are placed directly in the area of plasma where it is necessary to measure the temperature and concentration. It is supposed that electrons and ions in plasma have Maxwell distribution. In our investigations VAC of the probe was determined as follows. Currents for the same phase of discharge were measured at different probe potentials. Currents passing through the probe at a certain moment of time were measured with the help of oscillograph. Then a series of volt-ampere characteristics for a certain moment of time was plotted and temperature and concentration of charged particles were determined.

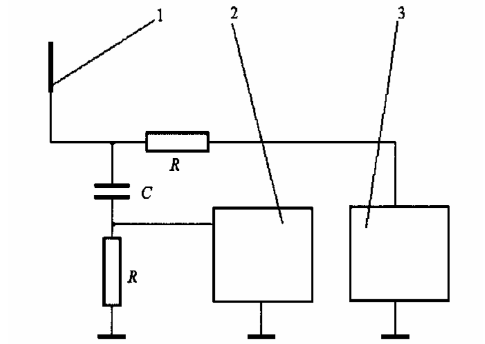

Fig. 3. The principal scheme for measuring plasma parameters using a single Lengmuire probe: 1 – a single Lengmuire probe; 2 – oscillograph; 3 – power supply for a circuit of probe measurements

A probe is a cylindrical steel electrode 19 cm long and 1.8 mm in diameter. Changing the potential difference between the probe and the grounded outer KPU casing (Fig. 3) and measuring current in the probe we obtained the following oscillograms (Fig. 4).

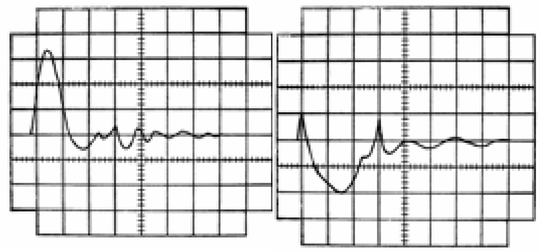

Fig. 4. Oscillograms of probe signals, measured at ±50 V probe potential

As on the oscillograms the signal initiating ocsillograph scanning is synchronized with the KPU discharge, the values of current passing through the probe are different in the same moments of time.

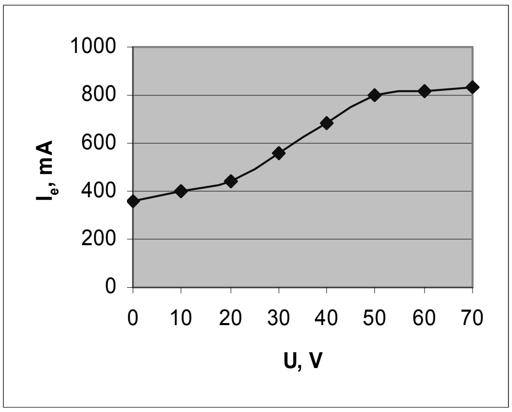

Fig. 5. VAC of Lengmuir probe

Using oscillograms one can obtain a volt-ampere curve (Fig. 5), and calculate the temperature of electrons. The electron temperature have found equal to 57±5 eV. Using the value of saturation current it is not difficult to calculate concentration of charged particles. Calculations show that concentration of charged particles is $2 \cdot 10^{11}$ cm^{-3}.

5. Conclusion

It should be noted that operation of a pulsed plasma accelerator in the continuous mode of filling does not differ considerably from the pulsed mode. However, in the latter case it is possible to carry out smooth regulation of plasma parameters in a wider range as the energy of the flow is affected both by the working gas pressure and the applied voltage.

The probe techniques developed in this work may be successfully used for different types of pulsed plasma accelerators as it does not depend on system geometry.

References

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