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Development of a device for automating the diagnostics of plasma parameters by probe method

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Abstract. This work is devoted to the improvement of the probe method of plasma diagnostics in order to obtain more accurate results, as well as to simplify this process by developing new schemes for obtaining and processing data acquired in the study.

One of the main methods of plasma diagnosis is the probe method. The advantage of this method over others [1–9] is its direct contact with the plasma, which allows to accurately determine its parameters. For example, in the analysis of plasma using the optical method, it is necessary to observe the same solid angle of the plasma tube with the reference sample, also this method has a large error in the identification of data using spectrometers. In the probe method, this error is much smaller, since modern ammeters allow quite accurate measurements.

Also, the probe method has its drawback. This method applies to active methods of investigation of plasma. In such measurements, sensors are used that come into contact with the plasma, violating its initial state. However, taking into account the perturbation introduced by the electrode into the plasma, it is possible to achieve high accuracy results.

Summing up, we can formulate some basic requirements for modern methods of diagnostics of plasma parameters: accuracy of parameters measurement; ability to work at different pressures; simple design, easy operation and low cost; ability to work at different temperatures; speed of the study.

In this method, a laboratory model is used as a source of gas-discharge plasma. Into the gas-discharge plasma is introduced a perturbing metal body, which can be of different shapes and from different materials. A metal body is supplied with some potential relative to the anode. Schematic implementation of this model equipment is shown in figure 1(a).

In this model, the main element is a vacuum lamp with a pressure of $10^1$–$10^2$ Pa, in which 2 electrodes are placed. Using the power supply 1 between the electrodes the voltage for the ignition of the gas discharge is set. The discharge current is determined by the resistor connected in series to the circuit. The bias potential on the probe is set by the power supply 2 relative to the anode and is controlled by a voltmeter connected in parallel to the power supply.

With the help of an ammeter the current flowing on it is also controlled. According to the data obtained, a probe current-voltage characteristic is plotted, from which such important plasma parameters as the electron and ion currents, and the floating potential are obtained. However, the data obtained is not sufficient to determine other important parameters such as electron temperature, electron and ion concentrations, and plasma potential at this point. For these purposes, the data are processed, which provides a fairly complete picture of the parameters.
In order to eliminate the shortcomings of the system, it is necessary to develop a scheme for obtaining the probe current-voltage characteristic in the automatic mode. This will allow to capture data in a short period of time, thereby increasing the accuracy of the calculated plasma parameters.

The power supply 2 is replaced by a sawtooth pulse generator; the analog voltmeter and ammeter are replaced by a voltage sensor and a current sensor respectively. As the control board the Arduino scheme on the base of ATmega 328 microcontroller is used (figure 1(b)).

The basis of the laboratory model is a low-pressure gas-discharge lamp with soldered probes, shown in figure 1(c). Each probe has its own length, and therefore a different area of the receiving surface, which must be considered in the calculations. The data received from the probes is monitored using the port monitoring function in the Arduino software package. The monitored data is recorded and stored on the computer. For further data processing, the MagicPlot software package is used, in which the volt-ampere characteristics are built (figure 2).
During the processing of the graphs in the MagicPlot software package, we obtained some plasma parameters, such as plasma potential, probe current at the probe potential, as well as parameters that determine the slope of the electron current density dependence on the probe potential. Using these parameters the calculation of the electronic temperature and the concentrations of ions and electrons can be carried out.

For the experimental verification of the proposed scheme for the study of gas-discharge plasma, the current-voltage characteristics of two probes located at different points of the discharge gap for different discharge currents were obtained on a laboratory model with a standard scheme. Then the measuring devices and equipment were replaced, after which the volt-ampere characteristics of the two probes were also obtained at the corresponding discharge currents. These current-voltage characteristics are shown in figure 3(a).

![Figure 3. Volt-ampere characteristics of the probe at different discharge currents (a); logarithmic plot of current-voltage curve for the probe at $I_{\text{dis}} = 40$ mA before (b) and after (c) replacement of the measuring devices.](image)

Analyzing the obtained dependences it can be noticed that the maximum probe current increases with increasing discharge current. This is due to the fact that as the potential between the electrodes increases, the emission of electrons from the cathode also increases. With a decrease in the modulus of the potential of the probe, the probability of electrons hitting it increases, due to this, an increase in the current is observed. When the probe potential value is greater than the plasma potential, an electronic layer is formed around the probe, which determines the maximum current on it. As the discharge current increases, the layer thickness increases, thereby increasing the maximum current on the probe. After that, the obtained characteristics were processed. In the software package MagicPlot were built logarithmic dependences of the current-voltage characteristics. These characteristics are shown in figures 3(a), (b).

After the experimental verification of the proposed scheme, the following conclusions can be made: the use of this scheme increases the accuracy of the plasma parameters measurement; the use of
this scheme in the processing of data can uniquely determine the position of the tangents, which in
turn reduces the divergence of possible options in obtaining the plasma parameters.

Based on the work done, it can be concluded that this scheme greatly simplifies the experimental
work on obtaining plasma parameters, and also significantly reduces the processing time of the data.
In accordance with the experimental work done, it can be said that it has led to satisfactory results.
Despite this, there are great opportunities for further work to improve this diagnostic method.

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