MODERN PROBE METHODS OF STUDYING THE ELECTRON ENERGY DISTRIBUTION FUNCTION IN A PLASMA

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The present state of theoretical and experimental work on probe studies of the electron energy distribution function in a plasma is reviewed.

The probe method proposed by Langmuir for determining plasma parameters has been improved by many researchers, whose results have been generalized in a number of monographs [1-4]. They focus attention on the determination of the concentration and temperature of charged plasma particles.

Detailed information about the electron energy distribution function (EEDF) is necessary in practice since the electron component to a great degree determines the properties of the plasma as a whole. The probe method, we note, is the only direct experimental method of measuring the EEDF.

The exposition of methods of EEDF measurement in the well-known handbooks is in fact limited to a consideration of the collisionless case, when the electron mean free path $\lambda_e >> r_s$; $r_s = a + d$. The condition $\lambda_e >> r_s$ substantially limits the applicability of the probe method of EEDF measurement to comparatively low neutral-gas pressures $p \leq 1\text{-}5$ torr.

Progress has been made in recent years in extending probe methods of EEDF measurement to the range of intermediate and high (up to hundreds or torr) pressures [5-7]. The general theory that we developed in [7] for the electron current in probes under conditions when the electron energy relaxation length $\lambda_c >> r_s$ can uniquely relate the unperturbed EEDF to the probe current for the Langmuir ($r_s << \lambda_e$), diffusion ($\lambda_e << r_s$), and intermediate ($\lambda_e \simeq r_s$) cases. This relation is described by an integral equation and in the limiting cases of low and high pressures leads to the known proportionality of the EEDF to, respectively, the second and first derivatives of the electron current with respect to the probe potential. In the intermediate case the EEDF should be found by solving the corresponding integral equation. Complications may be caused by the need to take the potential distribution into account when the space-charge layer is thicker ($d >> a$).

Besides extending the range of pressures at which the EEDF can be studied experimentally, it is also important to eliminate the effect of systematic errors on the results of probe measurements. The main systematic errors in EEDF measurements are due to the instrumental function of the setup, the effect of the probe ion current on the results of the measurements, and the finite conductivity of the plasma between the boundary of the space-charge layer and the comparison electrode. Let us briefly consider the aforementioned errors and possible automatic (circuit) compensation or elimination by mathematical processing of the results.

The instrumental function of the setup for EEDF measurement with no oscillations of the plasma potential is determined by the shape and amplitude of the differentiating signal [8]. The results of the measurements was shown to be related to the instrumental function by a convolution-type equation, and a method is proposed for obtaining the true EEDF. There still is an urgent need, however, to develop optimum algorithms for solving the inverse problem in order to find the true EEDF from measurements.

The effect of the ion current on the EEDF measurement has been examined in a considerable number of papers, e.g. [9, 10]. In [11], we proposed and implemented an experimental technique of automatically compensating the effect of the ion current and its derivatives on the EEDF measurement. It is based on recording the difference signal from two cylindrical probes of different diameter under conditions when hydrodynamic drift of ions to the probe can occur.

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Berger and Heisen [12] suggested a circuit for compensating the effect of the plasma resistance on the EEDF measurement by means of an auxiliary probe. Our development of this scheme [13] has broader capabilities. It makes EEDF measurements possible with time resolution and simultaneous correction of the amplitude of the useful signal and the potential shift.

Let us also note important work at present on the determination of the anisotropic electron velocity electron distribution in a plasma [14] and studies of the distribution function of electrons and negative ions in the plasma of electronegative gases [15].

As the above indicates, considerable progress has been made recently in developing probe methods of EEDF analysis. Some theoretical aspects of EEDF measurement (development of highly effective regularizing algorithms for determining the EEDF from the results of measurements at intermediate and high pressures with allowance for the instrumental function of the setup; analysis of the effect of the space-charge layer thickness on the EEDF measurement at elevated pressures; and generalization of the kinetic theory of the electron current in a probe to the case of EEDF measurements in magnetic fields) have remained unresolved, however, and it is desirable to combine the individual schemes for solution, considerably improving the parameters of the experimental setup and use them in a universal automated system for probe diagnostics of the EEDF.

NOTATION

λ_e, electron mean free path; r_s, radius of the space-charge layer; a, probe radius; d, thickness of the space-charge layer; λ_ε, electron energy relaxation length.

LITERATURE CITED

1. O. V. Kozlov, An Electron Probe in a Plasma [in Russian], Moscow (1969).
2. J. D. Swift and M. J. R. Schwar, Electrical Probes for Plasma Diagnostics, Am. Elsevier, New York (1969).
3. Yu. A. Ivanov, Yu. A. Lebedev, and L. S. Polak, Methods of Contact Diagnostics in Nonequilibrium Plasma Chemistry [in Russian], Moscow (1981).
4. B. V. Alekseev and V. A. Kotel'nikov, Probe Method of Plasma Diagnostics [in Russian], Moscow (1988).
5. Yu. B. Golubovskii, V. M. Zakharova, V. N. Pasunkin, and L. D. Tsendin, Fiz. Plazmy, **7**, No. 3, 620-628 (1981).
6. A. M. Devyatov and M. A. Mal'kov, Izv. Vyssh. Uchebn. Zaved., Fiz., **27**, No. 3, 34-39 (1984).
7. N. A. Gorbunov, N. B. Kolokolov, and A. A. Kudryavtsev, Fiz. Plazmy, **15**, No. 12, 1520-1527 (1989).
8. L. M. Volkova, V. I. Demidov, N. V. Kolokolov, and E. A. Kral'kina, Teplofiz. Vys. Temp., **22**, No. 4, 757-763 (1984).
9. A. P. Ershov, V. A. Dovzhenko, and G. S. Solntsev, Vestn. Mosk. Gos. Univ., Ser. Fiz., Astron., **18**, No. 6, 25-31 (1977).
10. K. D. Asvadurov and I. A. Vasil'eva, Zh. Tekh. Fiz., **45**, No. 7, 1558-1559 (1975).
11. N. B. Kolokolov, A. A. Kudravtsev, and N. A. Khromov, Teplofiz. Vys. Temp., **29**, No. 3, 436-439 (1991).
12. E. Berger and A. Heisen, J. Phys. D, **8**, 629-639 (1975).
13. N. B. Kolokolov, A. A. Kudravtsev, and N. A. Khromov, Proceedings of the Eighth All-Union Conference on the Physics of Low-Temperature Plasma. Part II [in Russian], Minsk (1991), pp. 171-172.
14. A. P. Mezentsev, A. S. Mustafaev, and V. L. Fedorov, Zh. Tekh. Fiz., **55**, No. 3, 544-549 (1985).
15. J. Amemiya, J. Phys. D, **23**, 999 (1990).