

A STUDY OF THE ANISOTROPY OF THE ELECTRON ENERGY DISTRIBUTION FUNCTION IN LOW-TEMPERATURE MAGNETISED DISCHARGE PLASMA IN ARGON AND XENON

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Abstract

In presented measurements we used the flat Langmuir probe that can be rotated along its axis to measure the anisotropy of the EEDF in the low temperature plasma in the cylindrical DC magnetron discharge. In our measurements we varied the parameter B/p_0 from 3.3×10^{-3} T/Pa up to 2.8×10^{-2} T/Pa by varying the gas pressure from 6 Pa down to 0.71 Pa at the magnetic field 20 mT.

1. Introduction

The maxwellian electron energy distribution function is one of the basic assumptions when the Langmuir probe theories are used for evaluation of the plasma parameters. It is known that the magnetic field B can influence the anisotropy of the electron energy distribution function (EEDF). This effect does not depend on B itself, but rather on the ratio B/p_0 , where p_0 is the pressure in the discharge vessel, see e.g. [1]. The effect of pressure "compensates" the effect of magnetic field since the collisions with neutral particles randomise the movement of electrons and therefore reduce the relaxation time of the EEDF to its original state. Experimentally the anisotropy of the EEDF (in this case the difference between the electron temperature in directions parallel and perpendicular to the magnetic field) has been found by Aikawa [2] at B/p_0 in the order of several T/Pa. We attempted to measure the anisotropy of the EEDF in the low temperature magnetised discharge plasma of the cylindrical magnetron discharge in rare gases using the planar Langmuir probe, that can be rotated along the axis in the probe plane. The method has been described in detail in [3] and it consists in the expansion of the anisotropic EEDF into series of Legendre polynomials:

$$f(v, \Theta) = \sum_{i=0}^{\infty} f_i(v) P_i(\cos \Theta). \quad (1)$$

The first two coefficients f_0 and f_1 give the electron density and the mean electron energy and

together with the rest coefficients determine the angular dependency of the EEDF. The coefficients of the expansion are determined from the second derivative with respect to the probe voltage of the probe characteristic measured with the planar Langmuir probe. For these measurements the planar probe surface is oriented at three or five different angles with respect to the preferred direction, in this case to the direction of the magnetic field vector. Generally one obtains so many coefficients f_i for the into Legendre polynomials expanded EVDF as the number of probe positions is used.

2. Experimental system

The block diagram of the used experimental set-up is in detail described in [4]. The cylindrical magnetron used in this experimental study consists of a co-axial non-magnetic-stainless-steel vacuum vessel pumped by the combination of mechanical and turbomolecular pump. In measurements reported here the system worked in the flowing regime with the technical grade argon or xenon as the working gas. The pressure in the magnetron discharge vessel has been kept constant by regulating the flow of the working gas by the MKS mass-

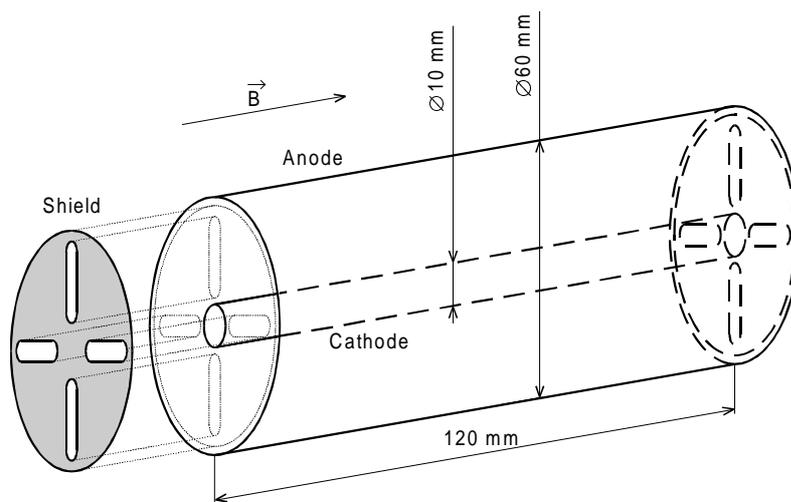


Fig. 1. Shape of the discharge vessel and the electrodes.

flow controller. The gas pressure inside the discharge vessel has been measured by means of MKS capacitance vacuummeter. The shape and dimensions of the discharge space and electrodes is seen in Fig. 1. The outer cylinder of the vacuum vessel is grounded and serves as anode. The inner stainless-steel cylinder is water-cooled, isolated from the vacuum system body and

serves as cathode of the cylindrical magnetron discharge that is connected to the negative high voltage supply. The discharge current is stabilised by the power supply that is operated in a constant-current mode. The magnetic field is created by means of a couple of Helmholtz coils placed symmetrically to the middle of the discharge vessel. The current through the Helmholtz coils is also electronically stabilised so that it is insensitive to the change of the coil resistance due to warming-up of the coils. The homogeneity of the magnetic field on the discharge axis has been checked by a Hall probe. The magnetic field strength could be varied from zero up to $8 \cdot 10^{-2}$ T. The used flat Langmuir probe depicted in Fig. 2 can be rotated along the axis of its support and can be moved in radial direction by using the micrometric screw.

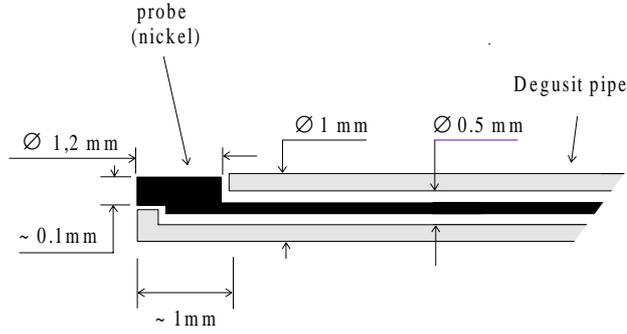


Fig. 2. Construction of the planar Langmuir probe.

3. Results and discussion

The symmetry of the EEDF around the preferred direction (probe axis) that is the supposition for using the described expansion is fulfilled since the electric field at the probe position was found to be very small. This implies the negligible $\vec{E} \times \vec{B}$ drift that might influence the EEDF symmetry otherwise. In our measurements we varied the parameter B/p_0 from 3.3×10^{-3} T/Pa up to 2.8×10^{-2} T/Pa by varying the gas pressure from 6 Pa down to 0.71 Pa at the magnetic field 20 mT. The typical results taken at two rather different values of B/p_0 are shown in Figs. 3a (lower B/p_0) and 3b (higher B/p_0). In accord with [5] at the elevated values of B/p_0 the more pronounced anisotropy of the EEDF is noticeable. The maximum amplitude of the EEDF is in Fig. 1b approximately 3 times less than in Fig. 1a. This takes place despite the fact that at higher B/p_0 the probe was positioned closer to the cathode surface and it is caused by the contraction of the discharge due to increased magnetic field. Similar results are presented in Figs. 4a,b for xenon. Also here we have chosen the magnetic field 20 mT. Fig. 4a shows the case of higher pressure 6 Pa. At this B/p the EEDF was almost isotropic. At the reduced

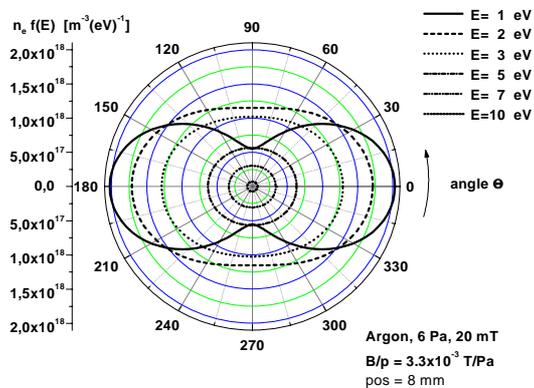


Fig. 3a. Polar plot of the EEDF in argon at 6 Pa and $B=20$ mT. Probe position 8 mm from the cathode surface, discharge current $I_d=50$ mA.

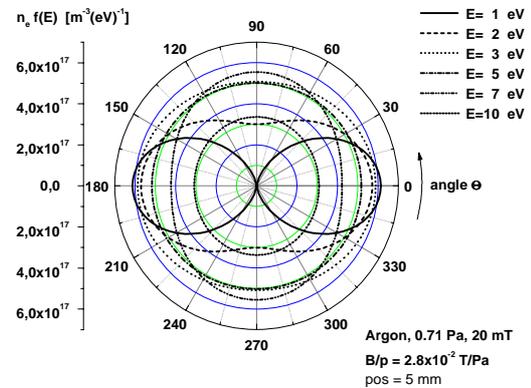


Fig. 3b. Polar plot of the EEDF in argon at 0.71 Pa and $B=20$ mT. Probe position 5 mm from the cathode surface, discharge current $I_d=50$ mA.

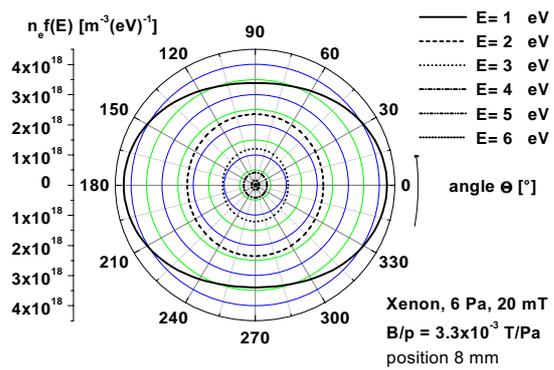


Fig 4a. Polar plot of the EEDF in xenon at 6 Pa and $B=20$ mT.

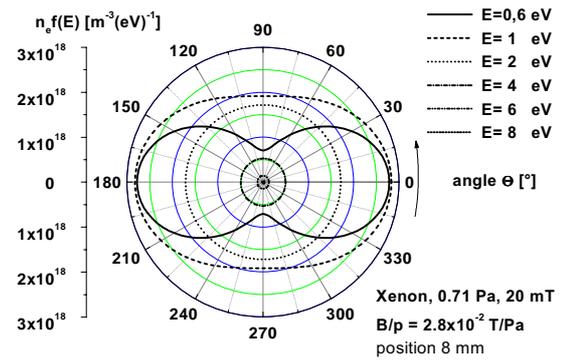


Fig 4b. Polar plot of the EEDF in xenon at 0.71 Pa and $B=20$ mT.

pressure 0.71 Pa (Fig 4b) the polar plot shows somewhat larger anisotropy of the EEDF in comparison with Fig. 4a.

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