NON-EQUILIBRIUM EFFECTS DURING PLASMA DIAGNOSTICS BY LANGMUIR PROBES

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Langmuir probes are standard tools for diagnostic of a low and high temperature plasma. Although initially they were invented to study a low pressure, stable plasma [1], later they were applied for such exotic cases as the plasma of a combustion front [2], in ablation processes [3,4] or in a Tokamak device [5]. Standard theories of Langmuir probes are based on various assumptions, i.e. a collisionless probe-sheath (ion motion determined by electric field), a Boltzmann electron profile (ne(x) = ne0 exp[-eU(x)/kTe]) and a constant electron to the ion temperature ratio, Te/Ti . Some of these assumptions were questioned and non-equilibrium effects were found in the presented work, using the results of Particle-In-Cell Monte Carlo (PIC-MC) simulations of long cylindrical probe immersed in Ar plasma. The applied PIC-MC model was described in ref. [6]. The non-equilibrium effects at the plasma-wall interface were already discussed in our previous report [7].

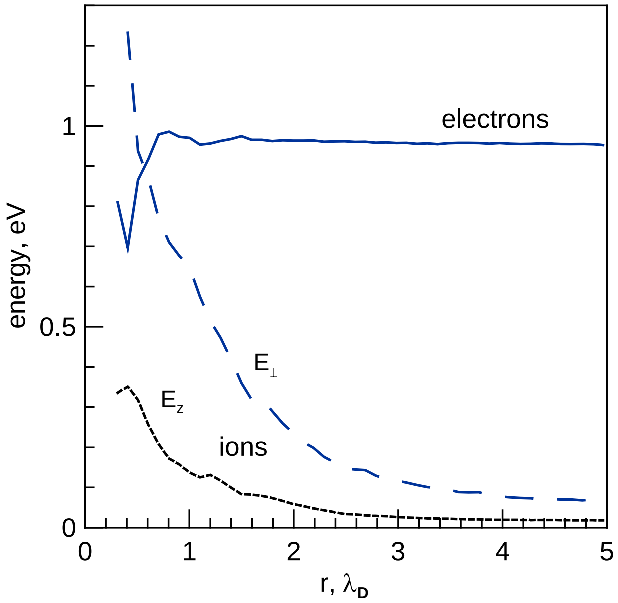

Fig. 1. Ion (dashed lines) and electron (solid line) thermal energies profiles calculated per 1D. The probe bias U_p = -20 V

The case considered here is related to a probe in a plasma under the conditions described by the parameters $r_p\backslash\lambda_D \sim 0.26$ and $\lambda_D\backslash\lambda_{mfp} \sim 0.04$, where λ_D is the Debye length and λ_{mfp} is the mean free path and r_p = 313 μm. The gas pressure was 1.3 mTorr and the ions were supposed to be in equilibrium with the gas (room) temperature T = 0.025 eV. The charged particle density (in the bulk plasma), $[Ar^+] = 7.15\times10^7 cm^{-3}$ and the electron temperature, T_e = 1.9 eV. Taking into account that the gas density (at room temperature) is of the order of 4.3×10^{13} m^{-3}, the degree of ionisation α is about 2×10^{-6} and λ_D is 1.21 mm under the present conditions.

Figure 1 presents the profiles of thermal energy of electrons (solid line) and ions (dashed lines) calculated per 1 degree of freedom. In the case of ions, we have separated the thermal energy into two parts: (a) E_z, related to the axial symmetrical z-direction and $2E_\perp$ related to the motion in the 2D manifold perpendicular to the z-axis. It is clearly seen that the ion thermal energy is not equilibrated and E_z is significantly (~3 times) lower than $E_\perp$ .This indicates that under considered conditions, collision processes are not efficient enough to couple the ion thermal-motion in the respective directions. The non-equilibrium between the electron and ion thermal energies seen in Fig. 1. is well known and understood, taking into account the difference in masses and mobilities.

Figure 2 presents the non-equilibrium ion speed distributions, for speed related to the mentioned above 2D manifold.

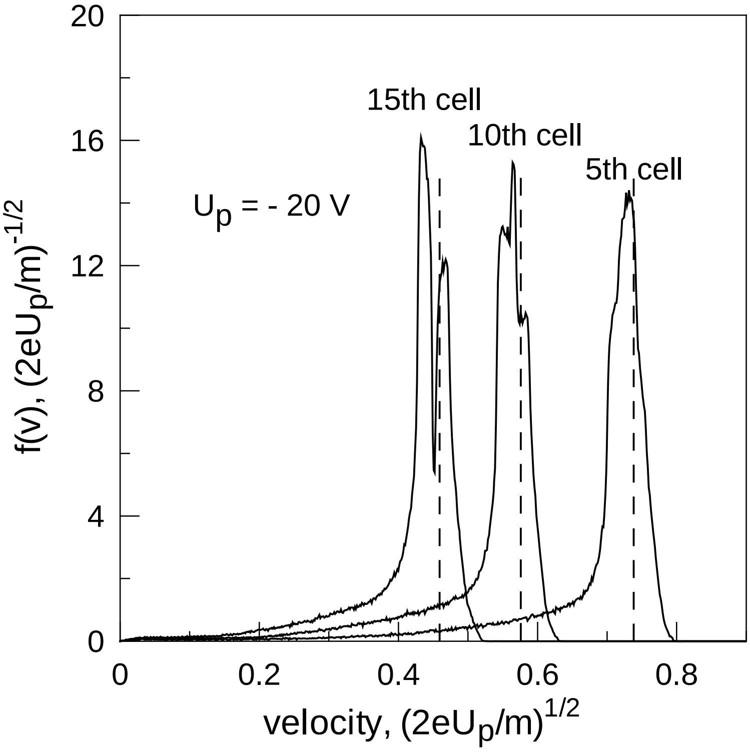

Fig. 2. Calculated ion 2D speed distributions at the 5-th, 10-th and 15-th grid elements for a probe bias U_p = -20 V. The velocity is related to that corresponding to the probe-attraction energy, eU_p; and the distribution is normalised to 1. The vertical dashed lines represent the velocities corresponding to the electric field potential in each grid

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