Ball-pen probe measurements in a low-temperature magnetized plasma

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1. Introduction

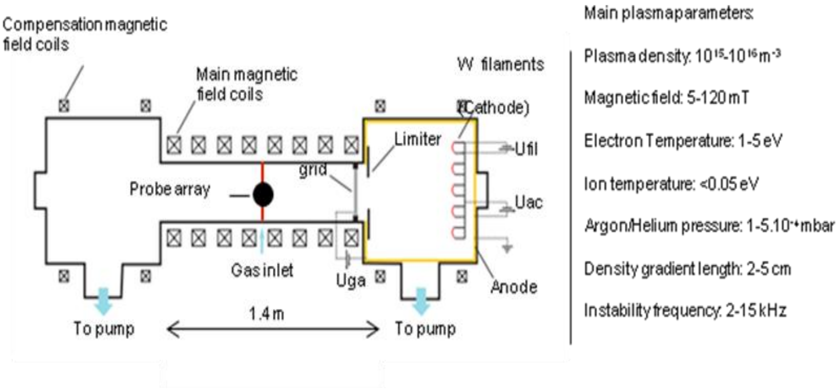
Langmuir probes are the most widely used electrostatic probes for measurements of the plasma potential in both cold and hot plasmas. From simple probe theory, the relation between the plasma potential V_p and the floating potential V_{fl} is given by:

$$V_{fl} = V_p - (k_B T_e/e)\ ln(R) \quad (1)$$

where k_B, e, T_e are the Boltzmann constant, the elementary charge and the electron temperature, respectively. $R=(I^-_{sat}/I^+_{sat})$ represents the ratio between the electron and ion saturation currents. In fusion plasma, the plasma potential is usually determined through simultaneous measurements of the Langmuir probe floating potential and electron temperature. The ball-pen probe has been recently developed [1] for direct measurements of the plasma potential in magnetized hot plasmas. It consits of a movable Langmuir probe-like metallic conductor placed inside an insulating tube. The ratio R, using the ball-pen probe, can be adjusted to one. In that case the probe characteristic becomes symmetric and the plasma potential is equal to the floating potential of the probe. The application of the ball-pen probe in low temperature magnetized plasma is still subject to investigations. In this framework, a ball-pen probe has been installed on the linear low-temperature magnetized plasma device Mirabelle [2] and comparative measurements of plasma potential, between ball-pen and Langmuir probe were performed.

2. Experimental setup

Experiments are conducted on the linear magnetized plasma device Mirabelle (Fig.1). Plasma is produced in one source chamber by thermoionic discharge and diffuses in the linear section where it is confined by an axial magnetic field up to 120 mT. A radially movable ball-pen probe is located in the central part of the column. The ball-pen probe consists of a retractable cylindrical tungsten collector (0.2 mm of diameter) inside an insulating ceramic tube of 1 mm diameter (Fig. 2). The probe is oriented perpendicular to the magnetic field. Due to a Larmor radius effect, electrons can be shielded while ions are not and the electron current reaches the ion current. According to Eq. (1), the floating potential of the probe approaches the plasma potential. A high impedance amplifier is used for potential measurements. Depending on the depth of the collector, the ball-pen probe can also be used as classical Langmuir probe.



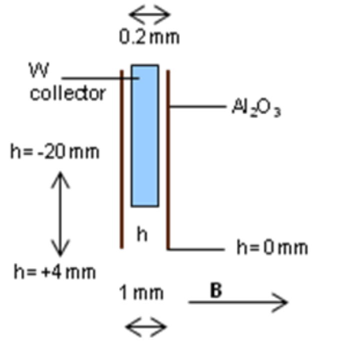


Figure 1: Scheme of the linear magnetized plasma device Mirabelle Figure 2: Scheme of the ball-pen probe

3. Results

In Mirabelle, the floating potential of the ball-pen probe was measured according to the depth h of the collector. Measurements have been performed at fixed radial position for three different working pressure P_0 = 2.10^{-4} mbar, P_1 = 4.10^{-4} mbar, P_2 = 5.10^{-4} mbar, in both Helium and Argon plasma with axial magnetic fields from 5 to 80 mT. Two floating potential h-scan are presented in Fig. 3. Current-voltage characteristics were recorded for each

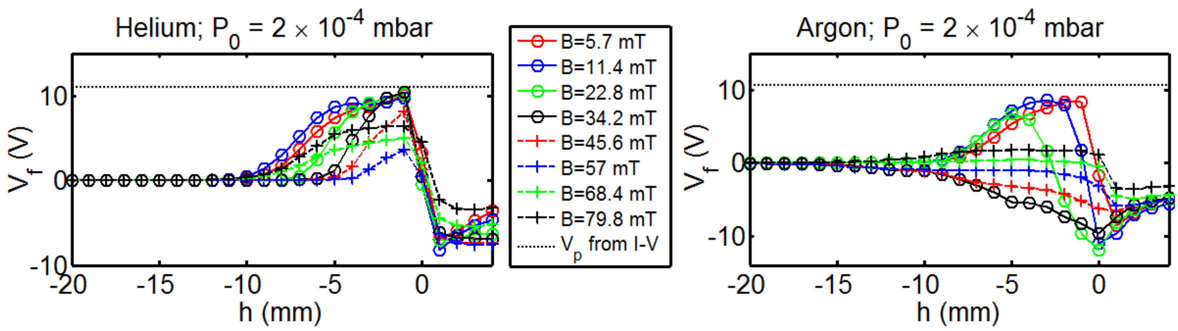


Figure 3 : Ball-pen probe floating potential with respect to the depth of the collector in Helium and Argon plasma at the working pressure P_0.

plasma conditions in order to obtain local measurements of n_e , T_e and Vp. The ratio R was calculated according to Eq. (1) using the floating potential of the ball-pen probe corresponding to the maximum of the h-scan curves and T_e , V_p from I-V characteristics. The evolution of R as a function of the magnetic field, the pressure and the gas is presented in Fig 4. Three regions of operation can be distinguished. In the first region corresponding to weak magnetic field (5 to 20 mT), the ratio R is close to one regardless to the working pressure in both Helium and Argon discharges, indicating that the ball-pen probe gives a direct and successful measurement of V_p. The second region between 20 and 35 mT is characterised by a strong increase of the ratio R and the third region from 35 to 80 mT by a weaker decrease of this same ratio.

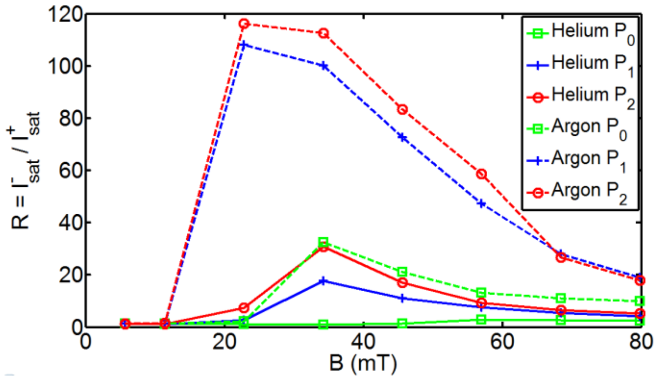


Figure 4 : Dependence of the ratio I^-_{sat} / I^+_{sat} with magnetic field for different gases and pressures.

For the whole range of parameters, the dynamic of ions is mainly governed by collisions since $\beta_i = \omega_{ci} / \nu_i \approx 1$. On the other hand, electrons are always magnetized ($\beta_e = \omega_{ce} / \nu_e \gg 1$) and their perpendicular transport is mainly driven by $\boldsymbol{E}\times\boldsymbol{B}$ drift generated by the potential structure near the tube entrance [3]. However, in the first region, the electron drift is strongly limited by the probe geometry. ρ_{ce} (Fig. 5) being on the order of the diameter d (1 mm) of the tube entrance, electrons are hitting the tube before reaching the collector. In that case the electron shielding seems to be sufficiently efficient. Moreover, the classical perpendicular conductivity σ is almost equal for both ions and electrons justifying that R is close to one.

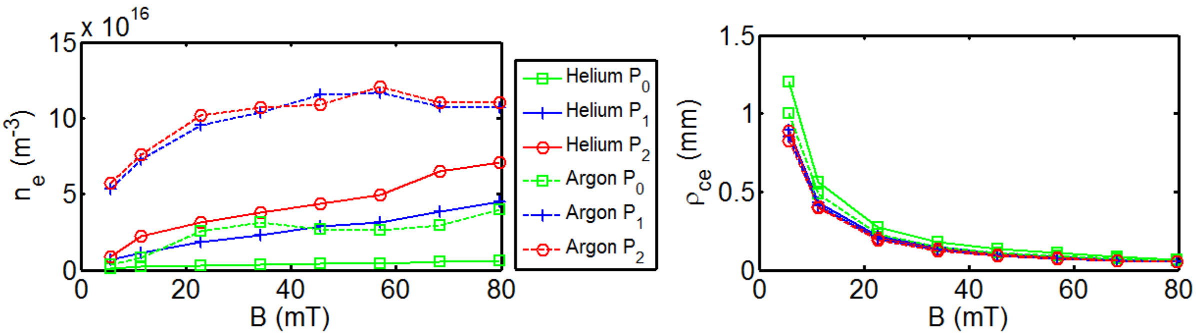


Figure 5 : n_e and ρ_{ce} as a function of B for different gases and pressures.

The $\boldsymbol{E}\times\boldsymbol{B}$ shielding is no longer effective in the second region because ρ_{ce} becomes smaller than d and electrons can flow inside the tube towards the collector. Consequently, R increases rapidly and reaches a maximum. This behaviour is due to an electron flux which is proportional to the density times the $\boldsymbol{E}\times\boldsymbol{B}$ velocity. Then, for higher density (Fig. 5) we can clearly see that the value of R is higher. This effect is similar in both Helium and Argon and the influence of the ion Larmor radius is not clear. The evolution of R is mainly governs by the electron dynamic. In the third region, the ratio R seems to follow a $1/B$ decay. This is likely due to a better filtering of the electron contribution but the reason is still not yet understood. It should be investigated in more details.

A comparison between radial profile of the ball-pen probe floating potential and plasma potential obtained from *I-V* characteristics is presented in Fig. 6. It corresponds to an Helium discharge at P_0 and B = 5.7 mT. Both profiles are in agreement with a constant deviation of 1 V corresponding to the error of V_p measurement using the first derivative of the *I-V* curve.

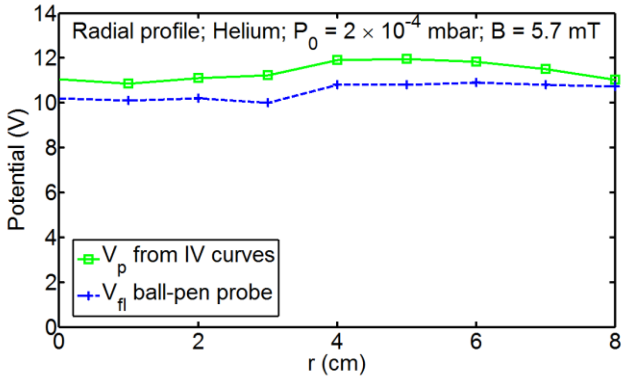


Figure 6 : Radial profiles of ball-pen probe floating potential and plasma potential from *I-V* characteristic.

4. Conclusion

Several ball-pen probe floating potential measurements have been performed in the low-temperature magnetized plasma device Mirabelle. The ratio R has been estimated using both ball-pen and Langmuir probes measurements for a whole set of plasma parameters. Different regions of operation have been observed. In this device, it seems that the electron Larmor radius should be on the order of the tube entrance diameter to better shield the $\boldsymbol{E}\times\boldsymbol{B}$ electron contribution. In that case, the ball-pen probe can be applied for direct measurement of the plasma potential. More investigations will be performed using different size of parameter d.

Acknowledgement

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