28th ICPIG, July 15-20, 2007, Prague, Czech Republic

Performance of a Langmuir probe and a hairpin resonance probe in inductively coupled low pressure plasmas

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We present a comparison between the electron densities in an inductively coupled RF-plasma (ICP) measured using a floating hairpin resonance probe and a conventional Langmuir probe. The Langmuir probe was previously verified by a microwave interferometer in the same apparatus. Electron densities are obtained in hydrogen, argon, helium and their mixtures; and the results are found to be in good agreement. This validates the reliability of the hairpin resonance probe for application in similar low pressure plasma sources. By applying an external magnetic field, the Langmuir probe showed strong dependences on the magnetic field strength and the direction of the field lines with respect to the probe tip.

1. Introduction

Langmuir probe is the most simple and inexpensive plasma diagnostic tool for obtaining wide range of plasma properties such as electron density, electron temperature, electron energy distribution function, the plasma potential and the floating potential. The electron density obtained using Langmuir probe, are sensitive to the current collection by the probe, however with appropriate sheath theories included in the interpretation of the data, accurate plasma densities can be obtained. Recently we have standardized our Langmuir probe system at the University of Augsburg, inductively coupled plasma source by benchmarking with microwave interferometer technique. The results obtained by Langmuir probe are in good agreement with the interferometer technique. Therefore this plasma set-up is now routinely used for benchmarking different plasma diagnostics.

A new approach for measuring electron density using a hairpin resonance probe is becoming very popular. [1-3]. The probe has certain advantage as compared with the Langmuir probe, in terms of measuring spatial electron densities in magnetized systems. Also in cases where the impurity contents in the plasma are significant, the surface poisoning of the probe could have dramatic effect on the reproducibility of the measurements. On the other hand, the influence of these constraints are low in case of a hairpin probe, as anticipated in recent works, however except ref [3] there has not many systematic investigation comparing the reliability of hairpin probe with other known diagnostics. The ICP source at the Augsburg University, with the standardized Langmuir probe system gives an opportunity to compare the relative performance of the probe for a wide range of experimental plasma conditions.

As mentioned before, a difficulty considering Langmuir probe measurements is the presence of a magnetic field due as used in negative ion sources [4]. A filter field of about 10 mT is applied in front of the extraction grid for the negative ions in order to reduce the extracted electron current. The influence of this magnetic field on Langmuir probe measurements was measured in the ICP with and without an applied magnetic field depending on the field strength with the probe tip parallel and perpendicular to the field lines.

2. Experimental setup

The experiments were carried out in a planar inductively coupled RF source (cylindrical setup, ∅ 15 cm, height 10 cm, f_0 = 27.12 MHz) using input powers of up to 350 W and pressures between 6 and 30 Pa. The Langmuir probe (APS3 system [5-7], passive RF compensation) was mounted at the bottom of the vacuum vessel, so the probe tip could be positioned along the axis of the cylindrical symmetric discharge.

The hairpin resonance probe is quarter wave-length parallel transmission line which has one end open while the other end is short-circuited, such that the structure resembles a hairpin. The structure resonates at a frequency, $f = c/4L\varepsilon^{0.5}$, which depends on the length L of the hairpin and the relative dielectric constant, ε, of the medium surrounding the hairpin. Here $c = 3\times10^8$ m/s is the speed of the light in air and ε =1, giving $f_{vacuum} = c/4L$. When the probe is immersed in plasma, the resonance frequency shift to a higher frequency as the plasma dielectric constant is smaller than in vacuum. From the frequency shifts the electron density can be easily determined. A detail description of a floating hairpin resonance probe can be found in ref [1-3]. The accuracy of the measurement is very high, since it depends on the relative shift of the probes resonance frequency in vacuum; which can be easily calibrated.

The hairpin resonance probe is mounted in radial direction centred in height. The plasma has a Bessel profile in radial direction; therefore the centre of the plasma, where the two probes are situated simultaneously, is identical. No measurable influence due to proximity of the probe, about 1cm apart, has been measured.

Applying up to 32 permanent magnets (CoSm, 1T, a pair of up to eight on each side of a diagnostic flange at opposing sides of the vacuum vessel, with the same orientation of polarity) leads to a magnetic field strength of 1.9 mT (4×1 magnet), 7,0 mT (4×6) and 8.2 mT (4×8) in the centre of the discharge volume respectively. These values were obtained by calculations with the Quickfield™ software. The Langmuir probe was mounted at the bottom and by kinking the probe tip, parallel and perpendicular orientation in respect to the magnetic field lines could be achieved.

3. Results

Figure 1 shows a comparison of the hairpin resonance probe and the Langmuir probe in helium plasmas with different pressures at constant input power (a) and mixtures of hydrogen and argon with varying ratio of mixture at constant pressure and input power (b). The electron densities are found in good agreement within the error range for all plasma conditions. Helium plasmas at higher pressures show a very steep density profile in radial as well as in axial direction, so the deviation at 27 Pa may be due to different plasma positions of the two probes. Other comparisons in helium, argon and hydrogen plasmas varying gas mixture, pressure and input power show similar results.

The influence of a magnetic field on the voltage/current characteristics of Langmuir probe measurements is shown in figure 2 for helium plasmas with and without magnetic field (here 8.2 mT). Solid lines represent the parallel orientation of the probe tip, dashed lines the perpendicular orientation. As expected, the influence of the orientation of the probe tip on the shape of the U/V characteristic and the plasma potential is weak without a magnetic field (grey lines), whereas the deviation between the two curves is due to slightly different plasma positions of the tip. Applying a magnetic field of 8.2 mT (black lines), the curves show a different behaviour in the electron saturation region also leading to a deviation of the plasma potential.

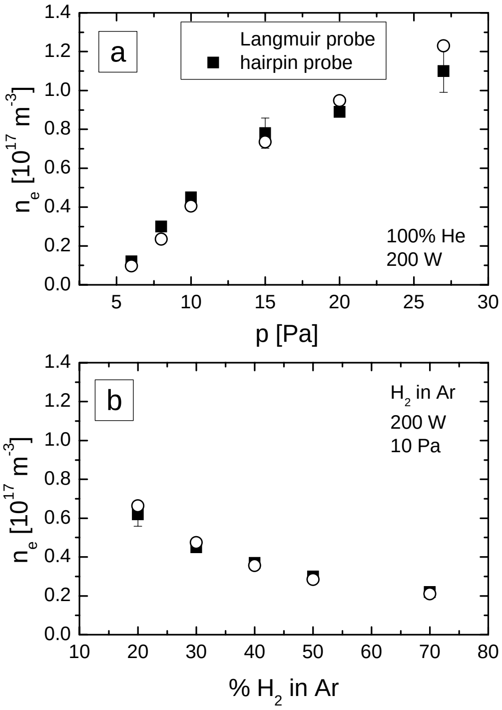

Figure 1: Comparison of the hairpin resonance probe with the Langmuir probe in Helium (a) and Argon plasmas with hydrogen admixture (b)

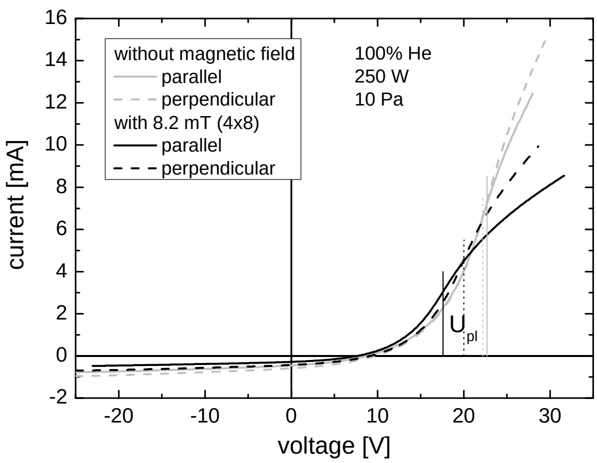

Figure 2: Voltage/current characteristics of Langmuir probe measurements with and without magnetic field in helium plasmas

In figure 3 the resulting electron densities are plotted against the magnetic field strength and show a decrease with increasing magnetic field strength. The factor between parallel and perpendicular orientation is 1.1 for 0, 1.9 and 7 mT and rises to a value of 1.4 for 8.2 mT. Spatially resolved measurements show a more steep profile of the plasma potential and the electron density in axial direction with the presence of the magnetic field. There the corresponding electron temperature (3 eV) is independent of the orientation of the probe tip without magnetic field. With magnetic field, T_e is lowered by 0.4 eV for parallel in respect to perpendicular orientation.

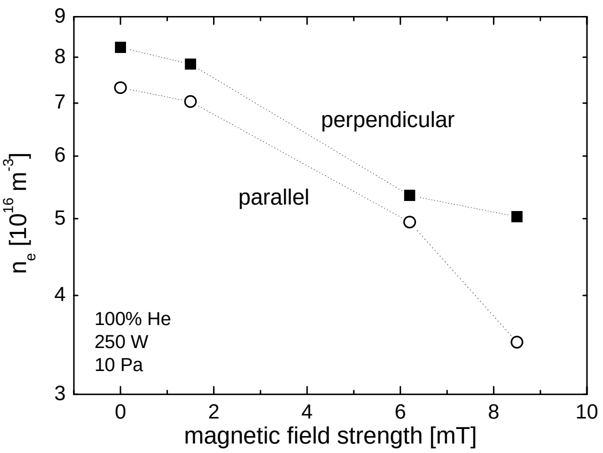

Figure 3: Electron densities in helium plasmas with increasing magnetic field strength, probe tip parallel and perpendicular to the field lines

4. Conclusions

Electron densities of the hairpin resonance probe and the Langmuir probe are found to be in good agreement. The Langmuir probe system was previously verified by a microwave interferometer, so the measurements validate the reliability of the hairpin resonance probe in similar low pressure plasma sources.

A magnetic field applied at the ICP source influences the shape of the plasma and the electron saturation current of Langmuir probe measurements and accordingly all parameters obtained out of it. The orientation of the probe tip in respect to the magnetic field lines becomes important for magnetic field strengths of 8.2 mT. There the electron density, measured with a parallel probe tip, is reduced by a factor of 1.3 in comparison to lower field strengths.

5. References

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