Evaluation of plasma density in RF CCP discharges from ion current to Langmuir probe: experiment and numerical simulation

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Probe measurements are one of the fundamental plasma diagnostic methods. The current-voltage relationship, obtained from the probe current can be divided roughly in ion and electron part. On the one hand the method of obtaining plasma parameters from the electron part is well established but there are difficulties in correct measurements of this part. The careful RF compensation and filtration of main and higher harmonics of plasma oscillation in probe current are very important. On the other hand, the value of the ion probe current is much smaller than the electron current and requirements to probe electric circuit are much lower. The ion part of i-v curve can be measured with great accuracy at different discharge conditions, but there is difficulty in the analysis of the obtained data. Mostly the analysis of experimental ion current data is carried out on the base of collisionless analytical theories. However the difficulties in experimental data treatment with using of these approaches are increased with plasma density and gas pressure. As a result, development and application of rather simple method of plasma density estimation are still a challenge. This work is aimed to the correct ways of interpreting the ion part of i-v curve by means of experimental and numerical analysis.

Experimental measurements of current-voltage relationship in 81 MHz CCP discharge in argon were performed by cylindrical Langmuir probes of two different radii: 50 and 250 μm. The discharge parameters were varied in the following range: neutral gas pressure 30 – 200 mTorr, input power 5 – 30 W, estimated plasma density: 1010 – 1011 cm-3. The usage of two probes with different radii allows us to validate the OML theory predictions about probe ion current proportionality to the probe radius.

The numerical model of ion current collection by cylindrical probe was constructed on the base of the particle-in-cell with Monte-Carlo collision method for ions motion and Boltzmann relation for electrons. The model computations are quite fast and can be used to pre-calculate data for further real time I-V curve analysis in experimental probe measurements.

The comparative analysis of different methods of I-V curve processing was done. The analytic collisionless theories of orbital and radial motion and numerical simulation of ion probe current were compared to reveal their possible range of application. The collisionless theories commonly used for estimation of plasma density could underestimate the plasma density due to the lack of collisions. However the collisionless OML theory for thin (50 μm) probe can formally give correct plasma density value even for discharge parameters where this theory is not applicable due to presence of ion collisions. The two opposite effects of ion collisions (the increase of ion probe current due to destruction of orbital motion and the decrease of ion current due to “collision drag-force” and ion path increase) are partially neutralized by each other in case of 30 and 100 mTorr argon pressures. But this neutralization can not be a reliable basement of OML theory use for any particular plasma conditions and probes. Moreover, the collisionless theories are hardly applicable for higher pressures (>150-200 mTorr) where the ion collisions should be taken into account. Also in case of different background gases, the relevant study and similar applicability analysis are needed to avoid possible mistakes in plasma density derivation by using of any simple theory.

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