Electron density measurements in highly electronegative magnetized plasma using RF diagnostics

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1. Introduction

Diagnostics of highly electronegative plasma or ion-ion plasma is a complicated task [1]. The electron density in such plasmas can be on few orders of magnitude lower than the ion density, thus contribution of the electron current to the IV curves measured by electrostatic diagnostics (as a Langmuir or planar probe, RFEA etc.) can be negligibly small. Knowing the electron density is necessary to calculate the electronegativity parameter α, which is a ratio between the ion and electron density. Though significant progress in the Langmuir probe theory for strongly electronegative plasmas, the existing or new models still need validation by other types of plasma diagnostics [1]. Direct methods of the electron density measurements such a MW interferometry cannot be easily applied since the electron density in ion-ion plasma reaches too small values ($<10^{13}$ m^{-3}). In addition, diagnostics of the ion-ion plasma created using the magnetic filters is complicated due to the strongly non-homogeneous magnetic field (~100-200 G) and the small size of plasma (< 10 cm) such that the boundary conditions can play an important role [1]. In this work we present a method of diagnostics of the low electron density (10^{12}-10^{14} m^{-3}) laboratory plasma with inhomogeneous magnetic field. The method can be used for both electropositive and electronegative plasmas, with or without the magnetic fields, and is based on the impedance measurements of a short dipole.

2. The matched dipole probe (DIM probe)

The short dipole antennas (comparing to the wavelength) are already known as a powerful instrument of magnetized plasma diagnostics [2]. The theory of short dipole impedance in plasma developed by Balmain [3], and various numerical simulations show that two main resonances on the impedance-frequency dependence are possible: the resonance at ω_p and upper hybrid resonance at $\omega_{uh}^2=\omega_p^2+\omega_c^2$. The first resonance is very sensitive to the probe orientation relatively to the magnetic field, while the second resonance is very stable and usually has highest amplitude. Due to this, the ω_{uh} resonance detection is a main method to obtain a magnetized plasma density [2]. Unfortunately, this method cannot be applied directly to the diagnostics of relatively small laboratory ion-ion plasma created with magnetic filters, because firstly the $\omega_c>>\omega_p$ and secondly the magnetic field is not constant along the reasonable dipole dimensions (few cm) [1].

We propose to use a short matched dipole with ω_p resonance detection. To enhance ω_p resonance, the dipole is oriented perpendicularly to the magnetic field. In order to achieve highest sensitivity and avoid signal decays and self-resonances, the probe is matched by miniature resistive load close to the probe tip. The probe geometry is defined from preliminary modeling such that a matched line impedance disturbance by plasma is less than a few % in all range of parameters, while the minimal frequency of the series resonance (due to “ion sheath-probe” circuit) is limited by an internal capacitor to be out of the scanning range. The matched dipole probe is calibrated in both magnetized and non-magnetized Ar plasma, and then tested in the SF6 magnetized ion-ion plasma having α>2000 [1]. One of the measured plasma impedance-frequency dependences is shown on the Fig.1. The resonance at ω_p=53 MHz is detected, and corresponding electron density is $3.5\cdot10^{13}$ m^{-3}. The plasma density resolution is better than $\pm5\cdot10^{11}$ m^{-3}.

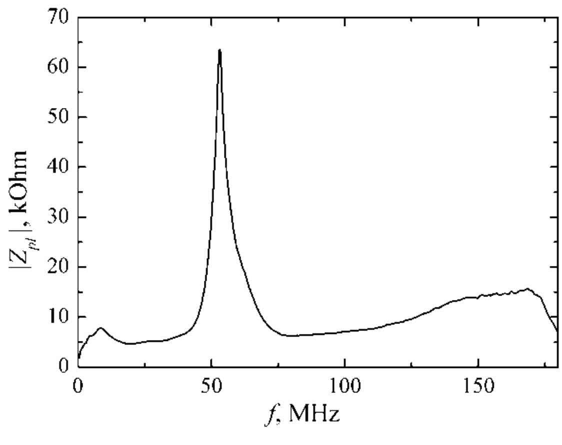

Fig. 1: *Absolute value of the plasma impedance $|Z_{pl}|$ measured as a function of the signal frequency f.*

References

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