G Model
FUSION-8762; No. of Pages 4
ARTICLE IN PRESS
Fusion Engineering and Design xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Fusion Engineering and Design
journal homepage: www.elsevier.com/locate/fusengdes

RF compensation of single Langmuir probe in low density helicon plasma

Soumen Ghosh*, Prabal K. Chattopadhyay, Joydeep Ghosh, Dhiraj Bora

Institute for Plasma Research, Bhat, Gandhinagar 382428, India

HIGHLIGHTS

- Appropriate density and temperature measurement with Langmuir probe in RF Eenvironment.
- Necessity of large auxiliary electrode for RF compensation at low densities ($\sim10^{16}$ m^{-3}).
- Measured two temperature electrons in low pressure helicon antenna produced RF plasma.
- Tail electrons are localized only at off-axis in our cylindrical plasma system.

ARTICLE INFO

Article history:
Received 19 June 2015
Received in revised form 4 May 2016
Accepted 12 May 2016
Available online xxx

Keywords:
RF compensation
Langmuir probe
Self resonance choke
Electron temperature
EEPF

ABSTRACT

Interpretations of Single Langmuir probe measurements in electrode-less radio frequency (RF) plasmas are noteworthy tricky and require adequate compensation of RF. Conventional RF compensation technique is limited only at high density (>10^{17} m^{-3}) RF plasmas. RF compensation of single Langmuir probe at low density RF plasmas ($\sim10^{16}$ m^{-3}) is presented in this paper. In RF driven plasmas, where the RF voltage is high ($\sim$50 V) and density is in the range ($\sim10^{16}$ m^{-3}), the primary RF compensation condition ($Z_{ck} >> Z_{sh}$) is very difficult to fulfill, because of high sheath impedance (Z_{sh}) at 13.56 MHz and the construction limitation of a self-resonant tiny chock (Z_{ck}) with very high impedance. Introducing a large auxiliary electrode (A_x), (A_x »> A_p), close to the small Langmuir probe (A_p) tip, connected in parallel with probe via a coupling capacitor (C_{cp}), significantly reduces the effective sheath impedance (Z_{sh}) and allows probe bias to follow the RF oscillation. Dimensional requirements of the auxiliary electrode and the role of suitable coupling capacitor are discussed in this paper. Observations show proper compensation leads to estimation of more positive floating potentials and lower electron temperatures compared to uncompensated probe. The electron energy probability function (EEPF) is also obtained by double differentiating the collected current with respect to the applied bias voltage using an active analog circuit.

1. Introduction

Apart from academics, the electrode-less RF plasma sources are widely used in semiconductor industries and material processing, coating, etching etc. And single Langmuir probe remains the most commonly used diagnostics for plasma density and temperature measurements. However, their uses in radio frequency plasmas are not very straightforward. There are primarily two issues which make the use of this diagnostics complicated; (1) there is no reference electrode and (2) the plasma potential (V_S) oscillate with the RF source with respect to the instantaneous probe bias voltage [1]. Placing a reference electrode having an area larger than probe dimension or conducting plasma enclosure may resolve the first issue. But the later one requires much more attention as it is very crucial for proper Langmuir probe data interpretation.

Significant progresses have been made since last 50 years on implementation of various techniques for removing RF modulations from the Langmuir probe characteristics in RF plasmas. In 1992, Godyak et al. [2] removed the 13.56 MHz RF modulation and its first harmonic at 27 MHz by placing a self-resonating choke [3] very close to the probe tip. In that paper they have also reported electron energy probability function (EEPF), presence of hot electrons and their bi-Maxwellian distribution in RF discharges. However, these kinds of self resonance chocks suffers limitation from high impedance side and are difficult to construct in tiny sizes to be placed very close to the probe tip. As a result this RF compensation technique is successful in high density ($\sim10^{17}$ m^{-3}) plasmas. In 1994, Sudit et al. [4] used the similar technique with

* Corresponding author.
E-mail addresses: soumen@ipr.res.in, soumen08phy@gmail.com (S. Ghosh).

http://dx.doi.org/10.1016/j.fusengdes.2016.05.019

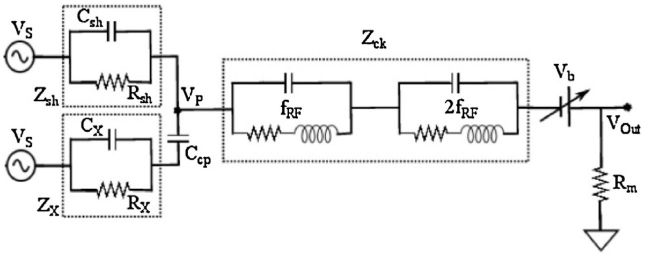

Fig. 1. Equivalent circuit for RF compensation probe.

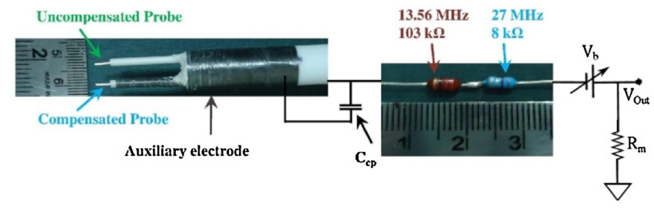

Fig. 2. Physical dimension of probe, auxiliary electrode and self resonance chokes with circuit architecture for RF compensation.

placing an additional electrode, having larger area than the probe tip. Presence of additional electrode with a coupling capacitor close to the probe together with the self-resonating chokes satisfied the necessary impedance requirement criteria for RF compensation. However, the quantitative description regarding the dimension of an additional electrode with which one can achieve RF compensation at lower densities (~10^{16} m^{-3}) is unavailable. In this paper we present quantitative description of dimensional requirements of additional electrode and successful RF compensation at low density (~10^{16} m^{-3}) RF plasmas.

2. Langmuir probe diagnostic

Radio frequency plasma is produced by applying 13.56 MHz RF power into a right helicon antenna concentrically placed on an outer surface of a cylindrical glass chamber. External magnetic field has been used for confining both electrons and ions in the source chamber. Detail description of the experimental system can be found in references [5] and [6]. Langmuir probes are used to measure the local density and temperature and EEPF of the plasma. The cylindrical Langmuir probe is made of tungsten wire and is 4 mm long and 0.5 mm in radius. The Current-Voltage (I–V) characteristics are obtained by applying a ±110 V ramp (frequency 11 Hz) bias to the probe with respect to the grounded conducting expansion chamber. The data analysis and interpretation of the raw (*I–V*) traces are discussed in references [7–9].

2.1. RF compensation

To avoid large voltage swings in probe potential, V_P, it is customary to add resonant chokes near the probe tip which offers large impedance to the RF oscillations and low impedance for low frequencies. We have used two tiny self-resonating chokes for compensating 13.56 MHz and 27 MHz having measured impedances of 103kΩ and 8kΩ respectively. Fig. 1 shows the equivalent circuit of the Langmuir probe and associated auxiliary electrode sheaths. Where, V_S is the space or plasma potential, V_P is the probe potential, V_b is the probe bias voltage and V_{out} is the output voltage across the current measuring (R_m = 1kΩ in our case) resistance. The sheath impedance (Z_{sh}) is the parallel equivalent of sheath resistance (R_{sh}) and sheath capacitance (C_{sh}). The impedance of two self-resonating chokes connected in series is represented as (Z_{ck}). Impedance (Z_X) of floating auxiliary electrode is coupled to the probe tip by a coupling capacitor (C_{CP}).

2.2. Parameter optimization

The RF compensation criteria using equivalent circuit analysis is given as [3].

$$Z_{ck} >> Z_{sh}(\frac{e|V_{RF}|}{kT_e} - 1) \quad (1)$$

$$R_{sh} = \frac{2\lambda_D^2}{\varepsilon_0 A_P U_B} \quad (2)$$

Where λ_D is the Debye length and U_B is the Bohm velocity. In our case R_{sh} ~148 kΩ, Z_0 (=1/ωc_0, c_0 (~0.054 pf) is the probe capacitance without V_{RF}) ~214 kΩ for T_e ~6 eV, n_i ~1 × 10^{16} m^{-3}, gives Z_{sh} ~ 725 kΩ for V_{RF} ~ 50 V. In this situation, without having a choke of impedance Z_{ck} > 725 kΩ, it is very difficult to block the RF modulation. Availability of tiny choke of ~103 kΩ leaves us with two options; either to reduce Z_{sh} by placing an additional electrode in parallel with the probe or to procure another tiny high impedance choke, which may not be readily available. Sheath resistance relation (Eq. (2)) shows that the sheath resistance is inversely proportional to the density and the collection area. Therefore, at low densities R_{sh} increases and takes Z_{sh} away from fulfilling the RF compensation criteria. Placing an auxiliary electrode (A_X) close to the probe having larger area than the probe area (A_X »>A_P) reduces the effective sheath impedance. The Langmuir probe used has an area (A_P) ~ 1.48 × 10^{-6} m^2 and we have chosen an auxiliary electrode with area A_X ~ 1.58 × 10^{-3} m^2. With these parameters, the sheath impedance for the auxiliary electrode in the same plasma is calculated using $R_{sh(X)}$ ~0.148 kΩ, Z_0 ~ 0.214 kΩ, giving $Z_{sh(X)}$ ~725 Ω for V_{RF} ~50 V. Hence, effective parallel equivalent sheath impedance ($Z_{sh(eff)}$ = Z_{sh} || $Z_{sh(X)}$) is reduced to 724 Ω. Which

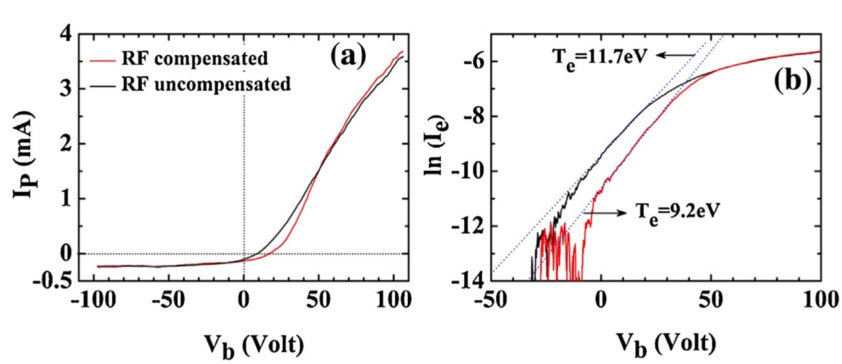

Fig. 3. (a) Represents the comparison of single Langmuir probe (I–V) traces for RF compensation and RF un-compensation at (r, Z) = (0, 60)cm, 200 W and 2 × 10^{-4} mbar pressure, (b) represents the corresponding semi-logarithmic electron current plots to determine electron temperature.

Please cite this article in press as: S. Ghosh, et al., RF compensation of single Langmuir probe in low density helicon plasma, Fusion Eng. Des. (2016), http://dx.doi.org/10.1016/j.fusengdes.2016.05.019