Topic number 6

A novel non-invasive technique for detection and analysis of harmonics in Radio Frequency plasmas

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In this work, a new plasma diagnostic technique is proposed to analyze the harmonics generated in Radio Frequency (RF) discharges accurately using a Dual Directional Coupler (DDC). A careful and complete analysis not only determines the harmonics present in plasma, but also yields accurately the power in the *forward* and *reflected* waves of the fundamental and each harmonic generated in the plasma, which makes it a valuable plasma diagnostic tool. Apart from this, one can estimate the complex impedance and reflection coefficient at the plasma end for each harmonic as well as the fundamental. This non-invasive, calibrated experimental technique may prove useful in formulating a systematic model which enhances understanding of RF plasma heating at low pressures.

1. Introduction

In Radio Frequency (RF) discharges, two mechanisms of electron heating play crucial roles: (i) Ohmic heating at high pressures, due to electron-neutral collisions and (ii) Stochastic heating at low pressures, due to electron-sheath interaction [1, 2]. Due to the non-linear sheath behaviour, harmonics are generated in the plasma, which need to be considered for understanding how the RF power is coupled at low pressures. In this paper, a novel, non-invasive harmonic probe technique is presented that characterizes the plasma-generated-harmonics of a parallel-plate RF discharge using calibrated broadband Dual Directional Coupler (DDC). This technique determines the dominant harmonics produced by the plasma and yields accurately the ***forward*** and ***reflected*** power in the fundamental and harmonics.

2. Experimental Details and Methodology

The experiment is carried out in a 13.56 MHz, RF discharge system with parallel plate electrode geometry as shown in Fig. 1. The measured plasma densities are in the range 10^9 - 10^{10} cm^{-3} and electron temperatures in the range 1 - 2.5 eV. The experimental parameters varied are the RF power (25 - 60 W) and Argon gas pressure (10 - 80 mTorr).

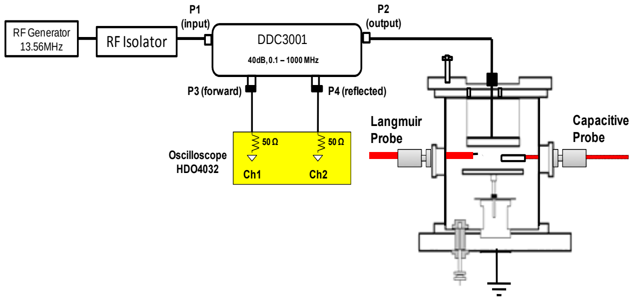

Figure 1 Experimental set up for harmonics analysis using DDC and Capacitive Probe.

A matching network was not used in the present experiments as its coupling capacitance allows the (plasma) load to develop a high DC self-bias voltage that can damage the DDC. However, an isolator has to be used to isolate the generator from the power flowing from the load to the generator.

The two DDC output signals yield the total forward (from the generator to the load) and reverse (from the load to the generator) power flow in the fundamental and the harmonics. The two output signals of the DDC are actually a superposition of the fundamental and harmonics produced by the plasma. The contribution of each frequency to the total signal is carried out by Fast Fourier Transform (FFT), from which other data like forward and reflected power, complex impedance at load etc. may also be determined for each frequency.

3. Results and Conclusions

While detailed results will be presented during the conference, the results indicate that among all the harmonics generated in the plasma, power content of the third harmonic (40.68 MHz) dominates in the present experiments. Since RF isolator absorbs all the harmonics generated from the plasma, this diagnostic gives way to characterize the different harmonics in a non-invasive manner. This precise information can be used to develop a better model for understanding power coupling in the low pressure regime.

4. References

[1] M. A. Lieberman and A. J. Lichtenberg, Principles of Plasma Discharges and Materials Processing, Wiley, New York, (1994).

[2] J. Schulze, Z. Donko, D. Luggenholscher and U. Czarnetzki, Plasma Sources Sci. Technol., **18**, (2009) 034011.