Fluctuation in a Helicon Plasma With Additional Immersed Antenna

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***Abstract*—Fluctuations in the floating potential are measured in a cylindrical magnetised plasma, as the phase between a "primary" Helicon antenna and a "secondary" immersed antenna is varied. The two antennas are powered by separate radio frequency (RF) generators of 13.56 MHz controlled by a single oscillator and phase shifter. The Helicon antenna is separated from the plasma by a glass tube, while the immersed copper antenna is in direct contact with the plasma. The image presented here shows floating potential fluctuations of ∼100 Hz where the amplitude of the fluctuations vary dramatically with the phase between the two RF generators.**

***Index Terms*—Dual antenna generated plasmas, fluctuations, radio frequency plasma.**

IN GENERAL, high-density low-pressure plasma sources are excited by radio frequency (RF) fields generated by antennas physically separated from the actual plasma. The plasma may be excited by capacitive coupling of the voltage difference across the antenna, and/or by inductive coupling of the electric fields induced by currents in the antenna. The majority of the inductively coupled plasmas have a low plasma potential of a few tens of volts, and a floating potential close to zero volts. For processing applications, an RF-biased substrate can be introduced into an inductively coupled plasma source, allowing the ion energy and the ion flux density impinging upon the substrate surface to be controlled independently.

If the plasma source frequency and the biased substrate frequency are significantly different from each other, there is little or no interaction between the two frequencies [1]. However, the substrate is sometimes biased with the same frequency as the source with a fixed phase applied between the two signals to avoid beating. In this study, the phase between an immersed antenna (or substrate) is varied with respect to the RF voltages of the "primary" plasma generating antenna in order to study the fluctuations in the floating potential. Briefly, the experiments is as follows [2]. An argon plasma at 4 mtorr is excited by a 20-cm-long double saddle type helicon antenna (H-antenna) surrounding and outside a 15-cm-diameter glass tube. A 6-cm–long bare copper antenna (S-antenna) is inserted through the aluminum source end plate and extends 8 cm into the plasma. Both antennas are fed at 13.56 MHz with separate matching networks and RF generators. The two generators are connected by

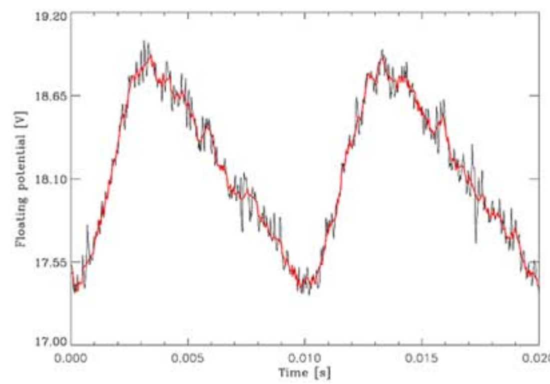

Fig. 1. Fluctuations in the floating potential at 80° phase shift between the H- and S-antenna. Black line shows original data from the oscilloscope, and red line shows the IDL filtered data used in the color image (Fig. 2).

a phase shift controller, where the RF-voltage to the H-antenna is fixed, and the RF-voltage to the S-antenna can be varied between 0° and 360°. The power on the H-antenna and S-antenna is 150 and 100 W, respectively, where the H-antenna is inductively coupled and the S-antenna is capacitively coupled to the plasma.

The fluctuations in the floating potential $\widetilde{V}_f$ are measured by a cylindrical Langmuir probe 1 cm from the immersed antenna, on the horizontal plane of the antenna. The probe is connected to a 1-MΩ oscilloscope where each time series of $\widetilde{V}_f$ consists of 2000 points in 50 ms, and acquired by a Labview acquisition program. $\widetilde{V}_f$ is measured as a function of the phase between the two RF generators, and the results of 15 time series are used to generate a filled contour image by use of Interactive Data Language (IDL) (Fig. 2). To create an aesthetically pleasing image as the one presented here, the data has to be smoothed. Fig. 1 shows one example of the data obtained from the oscilloscope, where the black line shows the original data with high frequency noise and some spikes. By smoothing the data using IDL, or by averaging using the oscilloscope, the amplitude of the random fluctuations, and perturbutations of the actual measurement can be reduced. Hence, careful filtering of the data was applied to each time series to remove the spikes and some noise, and still keep the nature of the basic fluctuations. An example of this is shown in Fig. 1, where the fluctuations at 80° is plotted. The red line shows the filtered data, which is used in the color image (Fig. 2). The colors in the image represent the amplitude of the floating potential, the purple, blue, green, yellow to red, spanning from 15 to 22 V. The image shows not only the dramatic variation in the fluctuation amplitude as a function of the phase shift, but also reveals a sinusoidal like variation in the average floating potential. This sinusoidal behavior has been discussed

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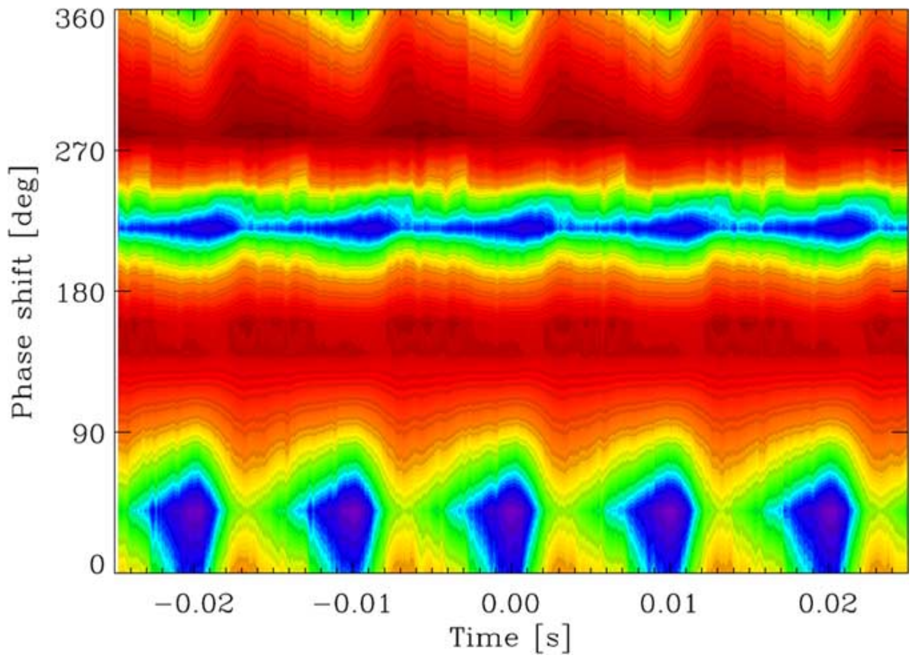

Fig. 2. Fluctuations in the floating potential as a function of the phase between the Helicon and immersed antenna. Purple to red color indicate the average floating potential in a linear scale from 15 to 22 V.

previously [2], and is out of the scope of this paper, which focus on the fluctuations.

As shown in this image, large fluctuations in the floating potential are measured at phase shifts between 0° and 90°, while in the intermediate phase range 90°–270°, the fluctuations are barely visible, and only variation in the average floating potential seen.

One possible cause of these fluctuations around 100 Hz, is that they might be due to short term gas depletion produced by ion pumping of gas from the source chamber to the diffusion chamber. This phenomenon has been observed previously and is probably typical of all systems having a source volume considerably smaller than the diffusion volume [3], [4]. The image presented here shows fluctuations measured when the immersed antenna is grounded, but it can be either electrically floating using a blocking capacitor, or grounded via the RF generator. If the ion pumping occurs, one would expect the fluctuations to appear in both the grounded and floating antenna case, however, there is insignificantly small amplitudes of the fluctuations measured in the floating case. Hence, the ion pumping theory can not be the only explanation for these fluctuations.

When the antenna is floating, the blocking capacitor charges up to a large negative bias of several 10 s to 100 V, which is imposed on the antenna, while grounding the antenna allows a current to flow from the plasma via the antenna to ground. Hence, the plasma potential builds up to prevent the electron loss to the antenna. It has been shown previously that the sheath voltage between the plasma and the antenna is the same for both the floating and grounded antenna, which means that the plasma potential can increase to hundreds of volts in the grounded case [2]. As the electron temperature is equal in the two cases, the floating potential also increase to some 10 s of V, as shown in the image. In this grounded situation, with very high plasma and floating potentials, many small pinpoint discharges could be seen in the diffusion chamber and along the probe shaft. These pinpoint discharges are presumably related to the large impedance difference between the sheath in front of the antenna and the earthed sheaths along the chamber walls and probe shaft [2]. It also seems that the pinpoint discharges occur more frequently when the fluctuations in the plasma is high, e.g., between 0° and 90° phase shift. However, the detailed physics of their appearance and evolution is not yet known, and we can only speculate if there is any relation between the measured fluctuations and the pinpoint discharges.

Dramatic changes have been measured in other plasma parameters, such as the plasma density and plasma potential as the phase shift is changed. This variations as a function of phase might be due to some nonlinear interactions between the two antennas, typically observed in multifrequency sources with commensurate frequencies [1]. Further investigations, and preferably some modeling, are necessary to obtain information that can show this kind of "antenna connection."

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