5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Observation of dominance of the 3rd and 6th harmonics at low pressures in a parallel plate capacitive discharge using a Novel Non-invasive Diagnostic for accurate RF Harmonic Characterization

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An important aspect of Capacitively Coupled Discharges (CCDs) concerns the coupling of the RF power in such discharges, particularly at low pressures. At low to moderate pressures and low RF powers, the two competing mechanisms are the stochastic mechanism and the Ohmic mechanisms. Of these, the former is a nonlinear process that is most efficient at low pressures whereas the latter is effective mainly at high pressures (up to ~1000 mTorr). Now, because the stochastic mechanism is nonlinear, it is capable of producing harmonics of the applied RF frequency. There are strong evidences in literature which suggested that these nonlinearities can enhance significantly the stochastic power coupling to electrons. Thus one may use the frequency and power spectrum of the harmonics as a tool to characterize, understand and fine-tune the models and simulations pertaining to the stochastic process, since this process is not fully understood even today.

In this regard, this work presents some new results on the measured harmonics of the fundamental RF frequency (13.56 MHz), produced in a parallel plate capacitive discharge, carried out using two separate methods. The first method involves use of calibrated probes, an Uncompensated Floating Langmuir Probe (UFLP) and a Capacitive probe (CP) [1, 2], and the second method uses a dual directional coupler (DDC) placed between the plasma load and the matching network (MN) [3, 4]. The probes were used to determine the localized RF signal levels in the plasma at the fundamental and its harmonics. Suitably normalized amplitudes of the RF signals at the fundamental and the harmonics, were recorded over a wide pressure range, 0.6–1000 mTorr (Fig. 1) and these were correlated with the estimated Stochastic and Ohmic power fed to the plasma (Fig. 2). It is found that both stochastic power absorption and harmonic production (2nd and 3rd harmonics) can be observed not only at low pressures, but also at high pressures up to ~1000 mTorr. The probes however, do not yield the actual power content of the harmonics, which is the true measure of harmonic strength.

The DDC method circumvents all the above drawbacks of probes, yielding the total power content in each harmonic. As shown Fig. 3, it identifies the 3rd as the dominant harmonic for all pressures, while the 6th is next most important harmonic after the 3rd at low to medium pressures (≤200 mTorr). At higher pressures only, the 2nd is stronger than the 6th. The latter results are completely unexpected and new, and to the authors' knowledge have not been reported to date, stressing the need not only for more careful experimentation, but also for more accurate models/simulations.

References

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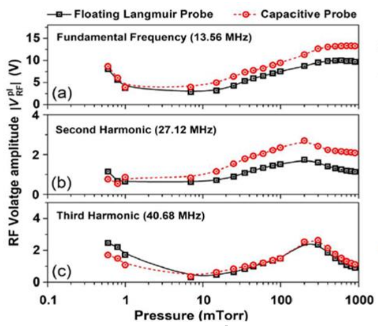

Figure 1 RF voltage amplitudes $|V_{\mathrm{RF}}^{\mathrm{pl}}|$ in the plasma determined from Floating LP and Capacitive probe.

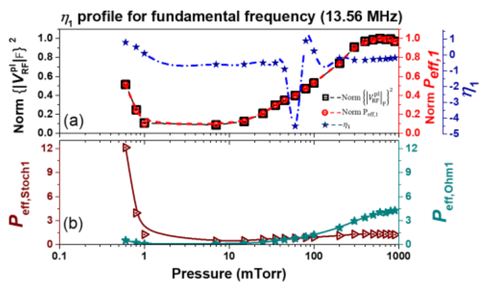

Figure 2 (a) Plot showing variation of normalized $\{|V_{\mathrm{RF}}^{\mathrm{pl}}|_F\}^2$ and normalized effective power $P_{\mathrm{eff,1}} = P_{Stoch}^{\eta_1} P_{Ohm}^{1-\eta_1}$. (b) Variations of $P_{\mathrm{eff,Stoch1}}$ and $P_{\mathrm{eff,Ohm1}}$ with the pressure.

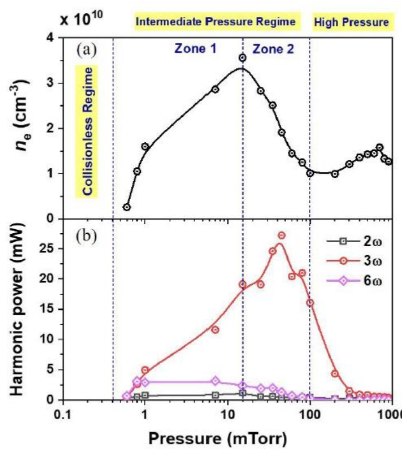

Figure 3 (a) Plasma density n_e and (b) RF harmonic power content (second, third and sixth harmonic) using DDC versus Argon gas pressure at fixed 10 W RF power.