# Triple and emissive probe measurements of plasma parameters in a magnetized capacitive coupled discharge

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In this paper a triple Langmuir probe and emissive probe have been applied to obtain spatial measurement of plasma parameters in a magnetized CCP discharge. The discharge is created between two rectangular parallel plates using a 13.56 MHz RF source. When the magnetic field is applied, a step-like density profile is found between the plates. This observation has been attributed due to **E** × **B** drift motion of electrons inside bulk plasma. The temperature *Te* in the central region shows a sharp increase towards the plates. Whereas ion current shows a M-shaped profile. The results are being compared with particle in cell simulation (PIC) developed by Dublin City University, Dublin, Ireland. A qualitative discussion has been presented to highlight the overall characteristics.

Capacitive Coupled Plasmas (CCP) are commonly used in plasma processing for etching of silicon substrate [1]. The CCP discharge is created by applying Radio-Rrequency (RF) potential between two parallel plate electrodes. The electrons respond to the time varying RF potential whereas positive ions can only respond to the time-averaged RF potential, owing to their large mass. Compared to other RF sources a CCP has simple geometry and hence low installation cost. The only disadvantage is the low etching rates and low plasma density. In order to improve the performance of CCP discharge an external magnetic field is applied. The introduction of magnetic field modifies the electron/ion dynamics adjacent to the RF sheaths and inside bulk plasma. Etching rates and plasma density can be enhanced with the help of external magnetic field. However certain studies have found plasma uniformity is compromised with imposition of magnetic field [2-3] .When a transverse field is applied the electrons motion is dominated by the cyclotron motion enhancing the electron collisions with background neutrals. Obtaining spatial distribution of plasma parameters would be very effective in understanding the dynamics of discharge. In this paper, a triple Langmuir probe (TLP) and an emissive probe have been applied along the center of discharge to obtain a spatially resolved measurement of $T_e$ and the ion saturation current. For the un-magnetized case the experimentally obtained distribution of temperature is compared with the PIC simulation results.

The experimental setup consists of a rectangular parallel plate electrodes enclosed inside a cylindrical glass vacuum chamber. The transverse magnetic field is produced by a pair of electromagnet coils which are placed outside the glass chamber. The plates are capacitively driven in a push-pull configuration using a 1:1 center-tap ferrite transformer whose primary is connected to 13.56 MHz RF generator (model no AG 1213W) via automatic L type impedance tuner (Model no-AIT-600-12-R). For measuring ion current TLP is used [4]. It consists of two same size tungsten pins biased with a fixed DC voltage. The ion saturation current is measured between these two probes across a resistor. The third pin remains floating and the difference between the positive and floating probe potential is proportional to electron temperature. Emissive probe is used to estimate the electron temperature. It consists of a tungsten filament which on heating measures the potential very close to the plasma potential [5]. Temperature can be estimated by having information of floating ($V_f$) and plasma potential ($V_p$) with given relation: $V_p - V_f = T_e ln\left(\frac{M_{ion}}{2\pi m_e}\right)^{\frac{1}{2}}$, where $M_{ion}$ is the mass of Ar ion and $m_e$ is electron mass.

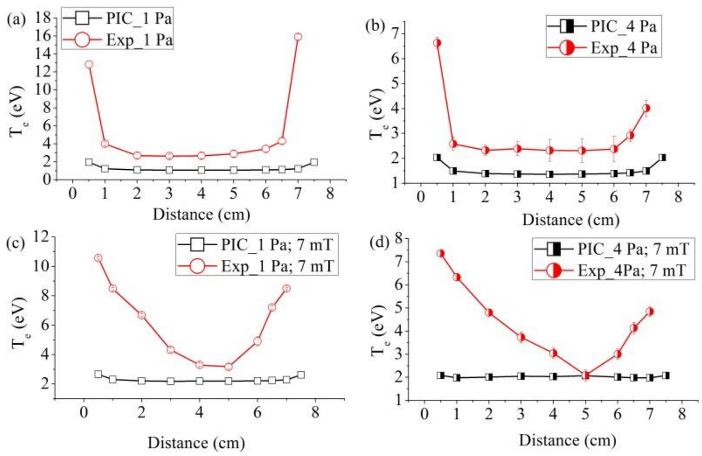


Fig-1: Graph showing electron temperature obtained experimentally with emissive probe (red circle) and electron temperature estimated by PIC simulation (black square) for given conditions: (a) P=1Pa and B=0; (b) P=4 Pa and B=0; (c) P=1Pa and B=7mT; (d) P=4 Pa and B=7mT.

In fig-1 spatial distribution of electron temperature ($T_e$) is potted along the gap of parallel plates. The plates are 8cm apart. In Fig-1(a)-(b), $T_e$ remains constant throughout the bulk and shows a sharp increase adjacent to the plates. Rise in $T_e$ near the plates can be attributed to the fact that stochastic heating is dominant near the sheaths while ohmic heating dominates in the bulk plasma. This temperature is the result of the net energy gained by the electrons experiencing oscillating electric fields. In the literature also high electron temperature near the sheath has been observed in numerical papers [2].

The PIC results are fairly in agreement with the experimental results for non-magnetized case. This can be considered as a benchmark for PIC code in the absence of B field. The experimental values are more than PIC values by a factor of 2 in the bulk. However there is a significant difference in the profile of PIC and experimentally obtained data for the magnetized case. This is due to the limitation of 1-D PIC code which considers the plasma to be uniform. However the introduction of B-field gives rise to inhomogeneity in the discharged. The reason of this inhomogeneity is the $E \times B$ drifts. The details about PIC code used are given in [6]. Nevertheless the agreement of PIC with experiments for non-magnetized case proves the correctness of emissive probe measurements.

In the presence of B-field (fig 1(c)), $T_e$ exhibits continuously falling trend from near sheath region to the center of discharge (V-shaped). The temperature profile gets slightly skewed (fig 1(d)) when pressure is increased. This indicates that the discharge is not uniform in the bulk in B-field due to drifts of charged particles and this drift is further hindered by increasing pressure.

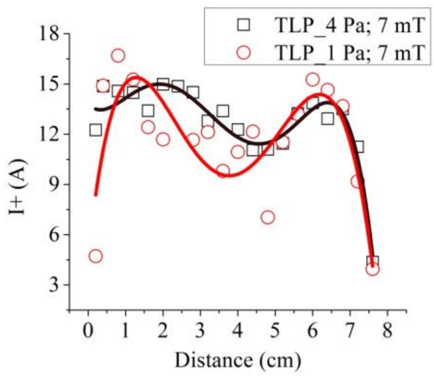


Fig-2: Ion current measured by TLP for 1 Pa and 4 Pa in the presence of B=7mT field.

Another evidence of $E \times B$ induced non uniformity is given by the ion current measurements by TLP. Fig-2 indicates that the density is higher close to the plates however the profile tends to become skewed when increasing pressure to 4 Pa. Higher densities towards the electrodes is a result of increased ionization and excitation near the sheath. Fan et al. also observed the similar density profile using a 2-D PIC Monte-Carlo-collision simulation in a symmetric CCP discharge where one plate is powered and one is grounded.

In conclusion, we have measured the $T_e$ and $I_{sat}$ current spatially between the plate gaps. The inhomogeneity in the discharge has been observed and ascribed to the EXB drifts in the discharge. The sharp temp and density near the electrode is due to collision-less heating and increased ionization near the sheath region [3].

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