Radial Characteristics of a Magnetized Plasma Column

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Abstract

The cross-field transport of electrons/ions across magnetic field is fundamentally important as it determinines the characteristics of plasma wetted area in the scrape of layer region and particle confinement in magnetically confined plasma devices. The electrically biased objects in the edge region inside tokamaks as well as in Linear plasma devices are known to influence the dynamics of charge particles. The external electrodes in magnetized column can introduce long range electric fields in the plasma column. This leads to either excitation/ suppression of the instabilities resonsible for such transport. In this paper we present experimental results on radial plasma characteristics obtained of a cylindrical plasma column produced in a Linear Device. The magnetized plasma column at one end is terminated with conducting electrodes which are deliberately biased with respct to the plasma. The nature of the long range perturbation during application of electric bias on the electrodes have been investigated using electric probes and its impact on the radial characteristics have been qualitatively explained.

1. INTRODUCTION

Low density plasma in crossed electric and magnetic field behaves differently than the other normal plasma. In some context we can call it electric-magnetic (EM) region plasma [1]. In EM region of plasma the electron gyro radius and Debye length are smaller than probe dimensions / apparatus dimensions, but the ion gyro radius and collision mean free path are bigger than probe dimensions / apparatus dimensions. In crossed electric and magnetic fields, electron motions are due to **E x B** drifts, which actually confine the electrons, while the ions will follow the electric field as they are unmagnetized. There are two different theories for the crossed-field diffusion of plasma. The first theory considering the Boltzmann equation with collision terms, which is generally applicable in large magnetic field and the diffusion coefficient is proportional to $\frac{1}{B^2}$ [2, 3]. The second theory was proposed by Bohm [4] and later it is derived by Spitzer [5], which suggests that at low magnetic field strength the crossed-field diffusion coefficient is proportional to $\frac{1}{B}$. Petschek derived this proportionality by a different assumption [6]. A cylindrical plasma column confined by axial magnetic field has been investigated numerically by different authors [7,8]. Due to the radial density gradients in magnetized plasma various types of instabilities will grow [9]. The elongated plasma column having minimum gradient in magnetic field can considered as scrape of layer (SOL) region [10,11], where the magnetized charged particles (electrons / ions) interacts with the electrode surface, like diverter/limiter in Tokamak devices [12]. In the past, several techniques have been used to produce a cylindrical plasma column in an axial magnetic field [13, 14, 15, 16]. The radial characteristics of the cylindrical plasma have been reported by many authors based on both theoretical models and experimental results [17, 18, 19]. In this paper our main intension is to investigate the type of diffusion happening in the EM-region plasma. If anomalous diffusion is happening in our system, then try to find the numerical value of Bohm coefficient from our experimental results and match with the Bohm's predicted value. There are some reported works both experimental and numerical [1, 20, 21, 22], where people have identified the anomalous diffusion in crossed-field case by introducing some fluctuations in electric field and calculated the Bohm coefficient. But there is no indication of virtual cathode formation at the centre of the plasma and ion acceleration. In this paper we have not introduce any type of fluctuations in plasma and there is a clear indication of virtual cathode formation as well as ion acceleration and ion trapping. Previously some authors reported that in EM-region plasma, the assumption of Boltzmann distribution for electron density does not hold true [23, 24, 25]. We have tried to verify the density distribution of electrons in the crossed-field direction. As by applying the axial magnetic field we have confined the magnetized electrons at the centre of the plasma column, so experimentally we have tried to identify the acceleration of the ions towards the centre of plasma column. Finally we have verified whether the ions are get trapped at the potential well at the centre of the column or not.

This paper has been organized as follows: Section 2 is devoted to the experimental set-up and brief description about the plasma diagnostics used in measurements. The experimental results have been presented in Section 3. The discussion of the results and brief conclusion of the paper has been mentioned in Section 4.

2. EXPERIMENTAL SET-UP AND DIAGNOSTIC

The experimental setup is shown in Fig. 1. There is a stainless steel cylindrical vessel having length of 50 cm and internal diameter of 16 cm. The vacuum created inside the chamber with the help of rotary and diffusion pump to achieve a base pressure of 2.1 x 10^{-6} mbar. A uniform axial magnetic field is produced by using a pair of electromagnet coils. The maximum magnetic field achieved at the axial direction is 8 mTesla. The magnetic field is uniform over 20cm axially. A filament is used at one end of the chamber to create plasma and other end of chamber grounded.

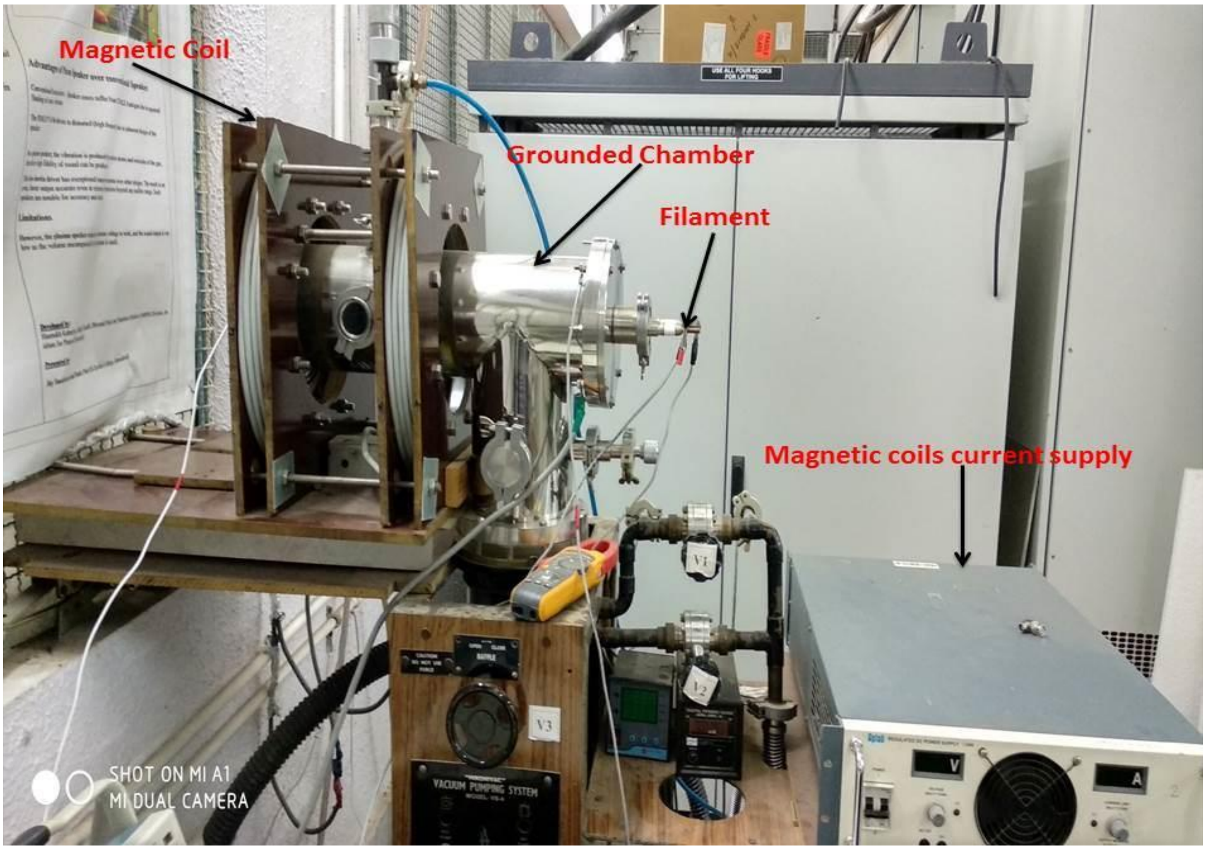

Fig.1. Image of the experimental set-up

Homogeneous argon plasma is created by applying a potential (150V) across the filament and grounded chamber. The radial plasma parameters are measured with the help of single cylindrical Langmuir probe (diameter = 0.25mm) from the side-port of the chamber.

3. EXPERIMENTAL RESULTS

3.1. Discharge Characteristic of Plasma

The variation in the discharge characteristic with the application of magnetic field is presented in Fig. 2. The potential across the filament (cathode) and grounded chamber (anode) is kept constant in the whole experiment. It is seen that with increasing magnetic field the discharge power in the plasma has increased, at the same time the central density of plasma increases with magnetic field strength increases as the ionization increases.

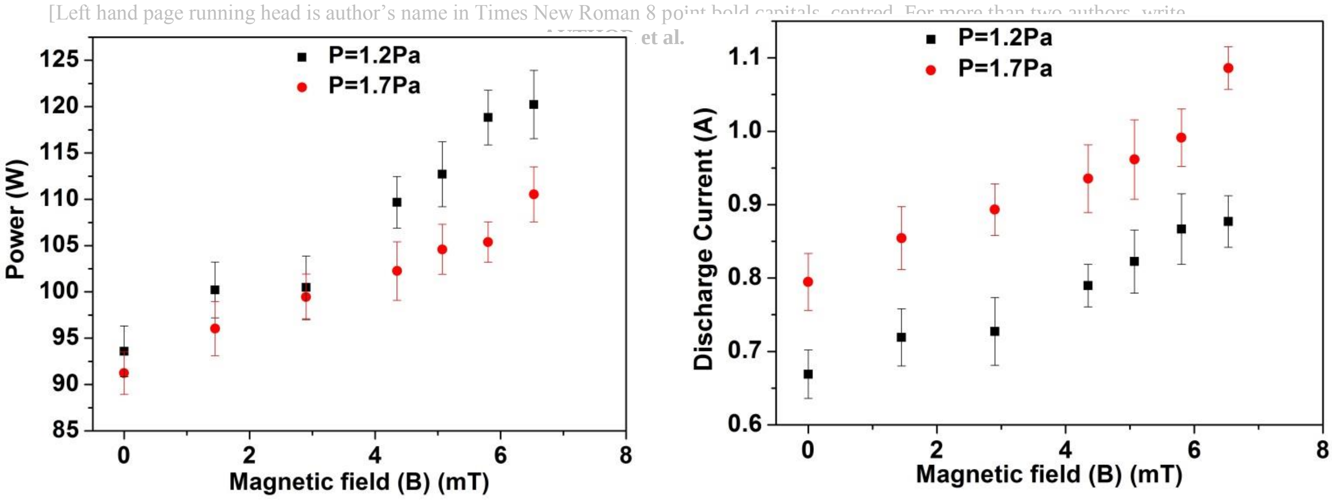

Fig.2. Discharge Power and Current as a function of axial magnetic field for pressure = 1.2Pa and 1.7Pa

3.2. Radial Characteristic of Plasma

The plot of floating potential V_f , plasma potential V_P and corresponding electron temperature T_e as a function of axial magnetic field for different radial positions are shown in Fig. 3. At lower magnetic field the plasma potential as well as floating potential is independent of position. But as the magnetic field strength increases the plasma potential and floating potential is lower near the centre and higher towards the edge of the plasma. The normalized plasma density is showing an interesting behaviour. It is independent of magnetic field strength at

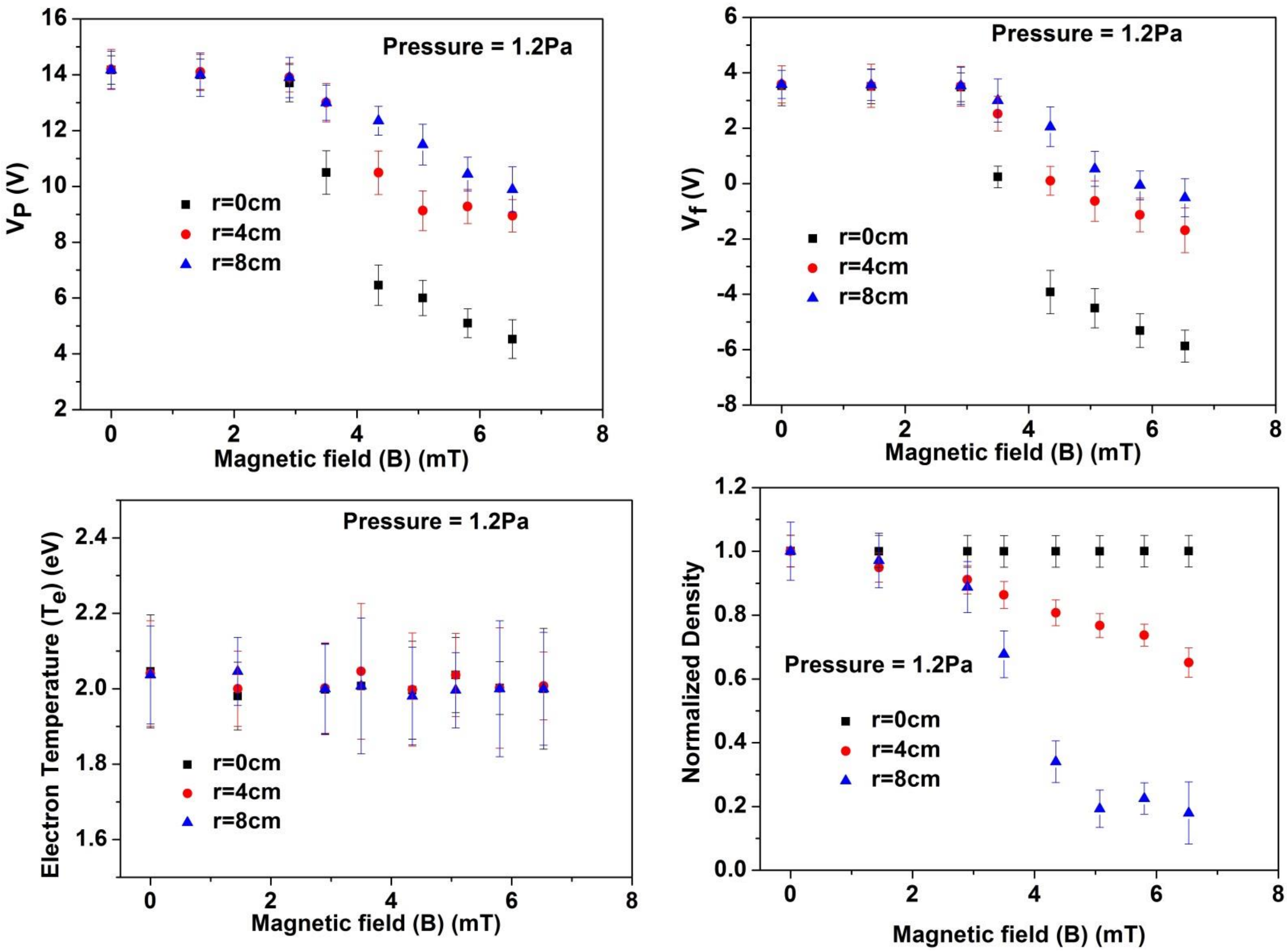

Fig.3 Different Plasma Parameters with magnetic field variation for different radial position

the center but as we move away from the center it falls rapidly with increasing magnetic field strength. As the axial magnetic field is uniform along the measurement region, there is no variation observed in electron temperature with radial positions.

4. DISCUSSION AND CONCLUSION

In the present manuscript we have tried to identify how the presence of axial magnetic field affects the plasma parameters in the radial direction or crossed magnetic field direction. Magnetic field has a direct effect in ionization frequency. In Fig.2 it is shown that with increasing axial magnetic field strength both discharge power and discharge current increases due to increment of ionization. As there is a mobility difference between electrons and ions, their crossed-field diffusion is greatly influenced by magnetic field. In the present experiment we assumed only the electrons are magnetized not the ions. So the electrons will try to gyrate around the magnetic field lines and it will be confined radially. It is observed in the present experiment that axial magnetic field confines the electrons at the center of the discharge, which makes the plasma potential as well as floating potential lower there and higher at outside. Now if we look at the normalized plasma density variation, we will found that as we move away from the center, the density falls rapidly with increasing magnetic field. This is also confirming the role of magnetic field in plasma confinement. From Fig.3, it is observed that density and potential graphs are varying oppositely with axial magnetic field; that means the electrons are not following normal Boltzmann distribution in the crossed-field direction which is also proposed by other authors. But in the present setup we have experimentally observed the Non-Boltzmann distribution of electrons. From the Fig.3 it is also observed that due to confinement of electrons at the center by axial magnetic field a negative potential wall is formed towards the center of discharge, which actually confined the ions electro-statically. So as a whole axial magnetic field is confining both the electrons and ions, this makes the plasma density higher at the center and lower in outside. Finally to find the nature of diffusion in the radial direction we have found the coefficient of Bohm Diffusion [4] equation using the experimentally found parameters. Bohm proposed value of this coefficient is 0.0625. We found this value as 0.07, which is nearly equal to the Bohm proposed value, and it is independent of magnetic field strength. Based on this result we can conclude that in the present experiment the diffusion is happening due to anomalous diffusion.

In conclusion, we have presented characteristics features of magnetized plasma column sustained by external magnetic field in linear device. The basic concept ion trapping through low density EM region plasma in crossed electric and magnetic fields have been verified. Confinement of plasma at the centre of discharge by axial magnetic field has been experimentally verified in linear device. The concept of Anomalous diffusion and ion acceleration at lower magnetic field had been reported by Janes and Lowder, and Yoshikawa and Rose in the density range of 10^{13} m^{-3} by introducing some fluctuations [1, 20]. In the present experiment, this has been achieved in the presence of axial magnetic field having density range of 10^{15} m^{-3} and without any fluctuations. In a uniform discharge the conversion of potential energy into the kinetic energy occurs by means of anomalous diffusion mechanism, which causes the ion acceleration. A more details study indicates that the bulk of the energy released by anomalous diffusion mechanism is deposited in ion thermal energy [26]. This has certain advantages while controlling the plasma interaction with substrates. The study can also be useful to understand the nature of plasma diffusion in the presence of a foreign object inside the plasma, which will either create or suppress some instability in the plasma. This has been considered for the future study.

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