Temperature anisotropy directed current profiles and effect of adiabatic invariants on plasma heating in a dipole plasma: Spatially-resolved experiments and power balance modeling

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Anisotropy in temperature prevails in natural environment such as space and astrophysical plasma, and in laboratory plasma. Temperature anisotropy being a free energy source have revealed possible explanations to heating and particle acceleration problems such as inward diffusion [1] in the radial direction, and is an intrinsic characteristic of magnetized plasmas. Yet, the transport mechanism along various directions remains to be fully understood.

Recently, we have reported electrical conductivity [2] from a table top dipole plasma device fabricated with a permanent magnet for particle confinement and uses ECR heating for plasma generation [3]. The schematic of the compact dipole plasma device is shown in Fig. 1. In this work, apart from the magnetic geometry, particle drifts arising due to curved field lines and temperature anisotropy is considered to obtain the electrical conductivity tensor.

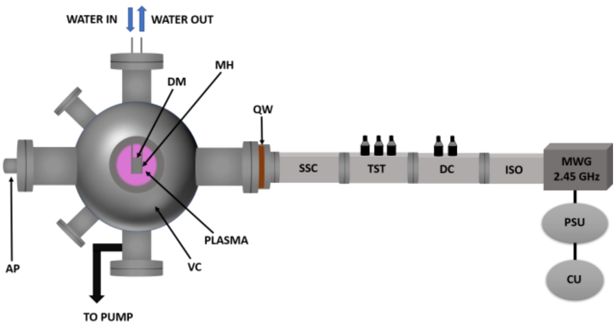

Fig. 1. Schematic of the experimental setup. CU: Control Unit, PSU: Power Supply Unit, MWG: Microwave Generator, ISO: Isolator, DC: Directional Coupler, TST: Triple Stub Tuner, SSC: Straight Section, QW: Quartz Window, MH: Magnet holder, DM: Dipole magnet, VC: Vacuum chamber, AP: Axial port.

Further, we aim to obtain electric field at every spatial position with a resolution of 5 mm in our system by measuring the space potential (to obtain electrostatic field) employing Langmuir probe and wave electric field using linear antenna. This will aid to procure current density profiles applying Ohm's law given by $\vec{J} = \bar{S} \cdot \vec{E}$, where $\vec{J}$, $\bar{S}$ and $\vec{E}$ represents the current density, electrical conductivity tensor and the electric field respectively. Moreover, the electric field measurements will be used as an input to solve the spatio-temporal power balance model to understand the heating and acceleration mechanisms contributing to the current flow.

A mathematical model is formulated from the continuity equation for energy density [4] given by,

$$\frac{d\left(\frac{3}{2}N_e k_B T_e\right)}{dt} + \vec{\nabla} \cdot \overrightarrow{Q_e} = r_e, \qquad (1)$$

where, N_e and T_e are the electron density and temperature, k_B is the Boltzmann constant, Q_e is the energy flux to the surface, r_e is the rate of energy change corresponding to source and sink of energy. On volume integration, the energy equation reduces to power balance equation. The power gain in any ECR system is due to the power deposition by the wave electric field [5]. In case of a dipole field, in addition to wave heating, particles also gain energy by betatron and Fermi heating as reported in Refs. [6] and [7]. The betatron and Fermi heating occurs due to the mirror and curvature drifts leading to the conservation of first and second adiabatic invariants respectively. The power loss mechanisms are the heat conduction [8], inelastic collision which includes ionization and electronic excitation [5], elastic collision [9] and isotropization loss [1]. The above power gain and loss mechanism contributes to the right-hand side of Eq. (1). Incorporating all these mechanisms, power balance equation will be solved.

The detailed current profile in the dipole system along with the power balance modeling results will be presented in the conference.

References

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