Abstract

Formation of toroidal non-neutral plasma (electron cloud) in a low aspect ratio (A=1.5) toroidal device having steady-state toroidal magnetic field and the effect of externally applied non-equipotential boundary conditions on equilibrium properties of toroidal non-neutral plasmas is described in the present thesis. This thesis also describe the computational work regarding development of particle simulation code for 2-D guiding centre simulation of toroidal non-neutral plasmas and its implementation to study the effect of toroidicity on equilibrium properties and L=1 diocotron mode of toroidal non-neutral plasmas.

Experimental studies of non-neutral plasmas are performed in basically two types of devices viz. linear cylindrical device and toroidal device. Chronologically, non-neutral plasma studies in toroidal devices comes first among the two. However, due to simplicity of constructing cylindrical devices and simplicity in electron injection and trapping in them, a lot of non-neutral plasma studies were done in cylindrical devices.

Malmberg and his co-workers conducted a series of elegant and thorough experiments in simple cylindrical devices which are also popularly called as "Malmberg Trap". These experimental investigations not only demonstrated the existence of non-neutral plasma equilibria, but they also showed existence of various collective phenomena that are similar to those observed in neutral plasmas. Thus, non-neutral charged clouds trapped in simple magnetic bottles have turned out to be excellent test beds for the study of many fundamental properties of confined plasmas.

The closed magnetic field lines in toroidal devices complicates the electron injection into the device for formation of toroidal non-neutral plasma because the electrons could not be injected parallel to the magnetic field lines. Toroidicity of these devices also plays major role in determining various physical properties of toroidal non-neutral plasmas which can not be studied using cylindrical devices. Literature survey shows that few attempts were made earlier to study properties of toroidal non-neutral plasmas. However, these were not sufficient and a lot more work needs to be done in this regard. Present work is a part of the initiative taken up by ***Institute for Plasma Research*** *(Gandhinagar, India) towards better understanding of the toroidal non-neutral plasmas.*

Low density toroidal electron cloud ($\mathbf{n_e \approx 10^7/cc}$) *could be formed in a low aspect ratio* ($a=87.5mm$, $R_0=132mm$, $A \equiv R_0/a=1.5$) *toroidal device having steady-state toroidal magnetic field of 500 Gauss at minor axis* (R_0) *of torus and background neutral pressure of less than* 5×10^{-7} *torr. Electron injection was achieved using toroidally symmetric cross-field diode and* $\nabla B\times B$ *drift of electrons in the torus. Electron temperature was estimated to be of the order of 10eV or less and hence corresponding Debye Length was less than 10mm. Thus toroidal electron cloud having dimensions several times larger than the Debye Length was formed. The electron injection process could maintain*

toroidal electron cloud as long as electron injector is switched ON. It is shown that electron cloud stay for minimum 500μs before switching OFF the injector due to limitation of the capacitor bank used to supply current for toroidal magnetic field generation. This indicates continuous replenishment of the electrons lost from the cloud. Moreover, the wall probe signals show minimum lifetime of 150μs after switching OFF the electron injector.

Temporal evolution of cloud potential in poloidal plane was measured using high impedance (Langmuir) probe and corresponding density profile was obtained by numerical solution of Poisson's equation. Most of the transients in potential structures were observed to decay within first few hundred microSeconds and hence 500μs time period available for the present experiments is found to be sufficient for present study. In case of electron cloud formation with equipotential potential boundary conditions, hollow potential profile was observed with potential well depth nearly same as the cathode potential. However, application of non-equipotential boundary conditions showed significant change in the potential structure. Potential well depth significantly deeper than the cathode potential could be obtained by suitable application of non-equipotential boundary conditions. It was also observed that response of electron cloud to application of external non-equipotential boundary condition after switching ON the injector is nearly same as that before switching ON the injector.

In the computational work, successful development of the 2-D guiding centre particle simulation was demonstrated by simulating toroidal electron cloud in large aspect ratio (nearly cylindrical device). Simulation runs for uniform density cylindrical column shows excellent energy and charge conservation as well as rigid body rotation. Simulation of hollow density profile in cylindrical device show strong radial transport to fill up the central hollow region.

Simulation of uniform density toroidal electron cloud in toroidal devices having aspect ratios ranging from 1.5 to 100 was carried out to study effect of toroidicity on equilibrium position and L=1 diocotron mode. With increase in toroidicity (i.e. decrease in aspect ratio of torus) the equilibrium position of toroidal electron cloud is observed to increasingly shift away from minor axis in the major radial direction. Moreover, quantitative agreement was observed between simulation results and theoretical prediction for such a radially inward shift. L=1 oscillations were observed by observing centre of charge motion. The oscillation frequency of L=1 mode was found to agree very well with the predicted empirical formula. Moreover, toroidicity is found to increase damping rate of the L=1 diocotron mode.