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Intriguing physics of plasmas confined by a dipole magnet driven at steady state

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Plasmas confined in a dipole magnetic field is a subject of interest because of its natural occurrence in planetary magnetospheres such as those of Earth and Jupiter [1]. The rather simple magnetic field holds together colossal plasmas in space, and high β (ratio of plasma to magnetic pressure) plasmas can be sustained with good confinement. Unlike most other confinement schemes where stability requires an average good curvature and magnetic shear, for a plasma confined in a dipole field, the stability is derived from plasma compressibility, which utilizes the large flux tube expansion of a dipole field. The adiabaticity condition $\delta(pV^{\gamma}) = 0$, where p is the plasma pressure, V is the differential flux tube volume and γ (= 5/3) is the adiabatic constant, defines the condition for marginal stability. Dipole magnetic fields have been considered as an alternate confinement scheme for nuclear fusion, and large devices employing superconducting coils have been built [1, 2]. We report results of a table-top dipole plasma device, fabricated with a single permanent magnet [3], and uses electron cyclotron resonance (ECR) heating for plasma generation (Fig. 1). The system offers distinct advantages for investigation of these plasmas, in terms of steady state operation which is difficult in large devices, easy plasma accessibility and characterization, and low operational costs. Voluminous plasmas (Fig. 2) can be sustained, e.g. a single permanent magnet of volume ~ 17 cm^3 and maximum surface field of ~ 0.5 T, can confine a plasma of volume ≥ 3.4×10^4 cm^3. The compact device bears promise for basic studies on dipole plasmas, simulation of magnetospheric plasmas, studying dusty plasmas or for plasma processing. Experiments and detailed modeling indicate that peaked density profiles as mentioned in earlier works [1,2], are realized as a natural outcome of the solution of diffusion equation [4]. The plasma β increases steadily from a small value near the magnet to ~ 7% in the midplane (~ 8 cm from the magnet center), and thereafter the increase is more gradual and almost levels off to ~ 10% at the chamber edge (~ 20 cm). In general, the electron temperature T_e and the plasma potential V_s are higher at the polar cusp regions, and decreases toward the equatorial plane, with the profiles becoming more spherically symmetric away from the magnet. The location of the mid-plane density peak (~ 8 cm) seems to match closely with the region where β starts to level off, and V_s starts to decrease exponentially. Particle loss cone analysis in the curved mirror fields, indicates that the percentage of particles lost near the surface of the magnet is much higher ~ 20% than that near the plasma edge ~ 0.07%, this along with the fact that the plasma retention rate is highest a little downstream from the magnet (~ 3 – 7 cm), may explain the density depletion close to the surface of the magnet [5]. Furthermore, it is found that the particle diffusion is governed by the classical scaling law (~$1/B^2$), and the recombination coefficient scales as ~$1/B^{0.5}$, as a result of its implicit dependence on the magnetic field through the electron temperature [5].

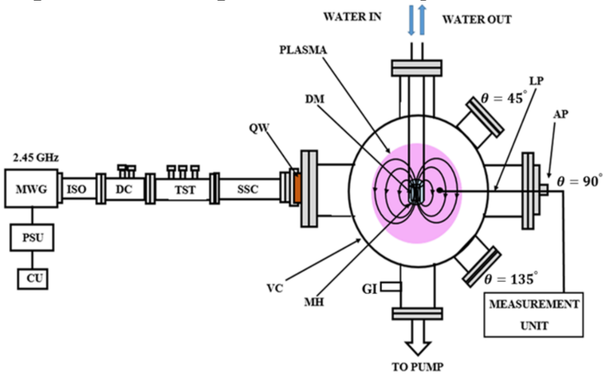

Fig. 1. Schematic of the experimental setup. VC: Vacuum Chamber, QW: Quartz Window, SSC: Straight Section, TST: Triple Stub Tuner, DC: Directional Coupler, ISO: Isolator, MWG: Microwave Generator, PSU and CU: Power Supply Unit and Control Unit for the MWG, AP: Axial Port, DM: Dipole Magnet, LP: Langmuir Probe, MH: Magnet Holder, GI: Gas Inlet.

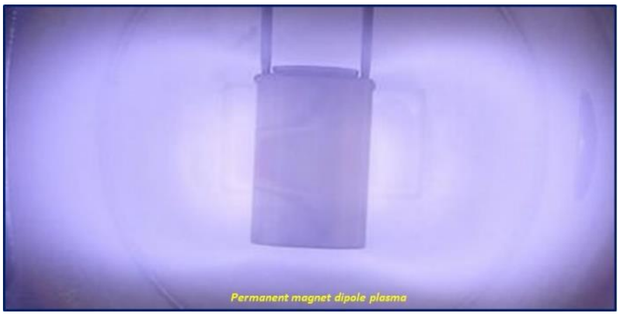

Fig. 2. Digital picture of the steady state permanent magnet dipole plasma. Note the alternate bright and dark regions, like the radiation belts of the Earth.

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