

Seminar

Institute for Plasma Research

Title: Study of ECR Plasma Relevant to Initial Phases of Discharges in Fusion Devices
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Date: 6th November 2025 (Thursday)
Time: 10:00 AM
Venue: Seminar Hall, IPR

Abstract

In a magnetized plasma, Electron Cyclotron Resonance (ECR) waves interact with electrons resonantly and thus find immense applications in fusion devices which span across pre-ionization, Electron Cyclotron Current Drive (ECCD), and Electron Cyclotron Wall Conditioning (ECWC), each vital for the reliable operation of tokamaks, stellarators, and compact fusion reactors. For example, pre-ionization creates a partially ionized seed plasma that reduces the breakdown voltage needed for plasma initiation using Ohmic Transformer (OT). This allows the flux conservation for longer plasma shots and safety of the superconducting coils. Similarly, ECCD allows for precise current profile control, contributing to improved plasma confinement and stability. ECWC further supports operational efficiency by cleaning tokamak walls, reducing impurities, and ensuring longer operational lifetimes. For example, the breakdown in Superconducting Tokamak SST-11 is achieved at toroidal loop voltage of 3 V (0.43 V/m) to produce repeatable plasma when the plasma production is assisted with ECR pre-ionization. In case of ITER, the available loop voltage² is expected to be ~ 12 V (0.3 V/m).

Owing to the limited availability of loop voltages and slow penetration of fluxes in superconducting tokamaks, repeatable plasma current start-up phases can be produced with ECR pre-ionization techniques. The basic understanding of the pre-ionization of the plasma employing ECR cannot be studied in isolation in tokamak-like configuration, therefore several basic studies have been attempted in pure toroidal devices having aspect ratio 3. However, this ECR technique becomes more crucial for tight aspect ratio machines where central Ohmic coils have limited flux or have no Ohmic coils at all due to limited span in the central bore of the machine. It is important to understand the mechanism of pre-ionization in a controlled manner in the tight aspect ratio toroidal magnetized plasmas.

Devices with aspect ratios ($A < 2$) pose unique challenges due to its geometric constraints and magnetic inhomogeneities for initiating plasma and sustaining the confinement. In this research work, an attempt has been made to study the basic understanding of pre-ionization, particularly in tight aspect ratio machine, namely 'STARMA', having the device aspect ratio (A) of 1.52. The toroidal magnetic field at the axis of the machine can be produced up to 1 kG for 0.25 s. Microwaves power up to 6 kW is used at a frequency of 2.45 GHz, which resonates with electrons where ambient toroidal magnetic field of 875

G is encountered. It is worth noting that toroidal magnetic field varies sharply in the radial direction of the plasma volume due to tight aspect ratio of the device. This allows one to accommodate two resonance locations, namely fundamental and second harmonic resonances, within the plasma volume, radially.

The STARMA device is equipped with several diagnostics to study Electron Cyclotron Resonance (ECR) produced plasmas. These diagnostics include a Langmuir probe, a Triple Langmuir Probe (TLP), 3 axis B-dot probe, a Rogowski coil, and fast imaging. Langmuir probes are essential tools in plasma diagnostics, providing measurements of electron temperature, electron density, plasma density fluctuations etc. Plasma equilibrium is obtained using a rectangular shape limiter at the periphery of the plasma cross section. Additionally, the research investigates advanced wave-plasma interaction phenomena such as O-X-B mode conversion and its role in improving plasma heating and density buildup under different wave polarization configurations. The study systematically maps the spatiotemporal evolution of the plasma, identifies fluctuation behavior, and probes charge separation effects under curved magnetic geometry. Insights gained from these experiments not only provide a deeper understanding of plasma dynamics in tight aspect ratio devices but also inform future applications in superconducting tokamaks like ITER and spherical tokamaks, where non-inductive startup methods are crucial due to geometric and operational constraints.

Keywords: Electron Cyclotron Resonance (ECR), mode conversion, tight aspect ratio, pre-ionization, STARMA device, O/X-mode propagation, superconducting tokamaks.
