Seminar

Institute for Plasma Research

Title: Experimental Investigation on Interaction of Electromagnetic Waves with Over-dense Plasmas

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Date: 04th May 2026 (Monday)

Time: 10:30 AM

Venue: Seminar Hall, IPR

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Abstract

It is well established that an unmagnetized plasma does not support propagation of low-frequency electromagnetic (EM) waves ($\omega << \omega_{pe}$, where ω and ω_{pe} are the wave and plasma frequencies, respectively). However, if the wave interacts with an inhomogeneous plasma containing the critical layer ($\omega = \omega_{pe}$), partial absorption can occur in the over-dense region under specific conditions. The exact interaction mechanism depends on various factors such as the intensity, angle of incidence and polarization of the incident wave as well as the scale length L_n of the plasma density gradient $\boldsymbol{\nabla n}$. The absorption of wave energy in over-dense plasma has long attracted interest due to its relevance in ionospheric radio-wave propagation, microwave–plasma interactions applicable to particle accelerators, magnetic fusion confinement devices and energy-loss processes in inertial fusion involving laser–plasma interactions. While numerous theoretical and simulation studies exist, experimental investigations of EM wave–plasma interaction are highly limited. The present work is aimed at experimentally addressing various unresolved questions related to the interaction of EM waves with over-dense plasmas in the system SYMPLE (System for Microwave PLasma Experiments). The work covers two parts: Part 1 - Development of a system consisting of a high power microwave (HPM, 1-3 MW) source, a plasma system and HPM-plasma coupling system that meets all prerequisites for controlled nonlinear wave–plasma interaction studies, and Part 2 - A set-up of a low power (100 W microwave power) experimental system and investigation of linear resonant absorption of wave energy in plasma. On the high power front (Part 1), limited accessibility to the HPM source during the course of this research precluded its use for experiments on non-linear plasma interaction experiments.

An integrated high power microwave (HPM) system consisting of an S-magnetron (3 GHz, 3 MW, 5μs pulse width) HPM source and a coupling system has been established consisting of several critical subsystems designed and developed indigenously as part of this work to meet the specific requirements of the experiments. The concerned tasks cover (a) design and development of a pulsed modulator to drive the magnetron, (b) design and development of a DC-Break, (c) simulation and experimental validation of a TE-TM microwave mode converter developed to have the wave electric field $E_{\mu} \parallel \boldsymbol{\nabla n}$ and (d) design and development for different microwave step transition structures (MSTSs) to launch the waves in desired modes (TM_{01}, TM_{02}, TM_{03}, etc.) in the plasma. The purpose of excitation of various modes in the plasma is to have different "effective angle of incidence," θ_{eff}, of the wave launched normally i.e. along the axis of the cylindrical plasma column. Here, $\theta_{eff} = \sin^{-1}\sqrt{(\varepsilon_{r,\,ret})}$ where $\varepsilon_{r,\,ret}$ is the value of the plasma dielectric constant at the location of wave return and is determined by the mode (TM_{01}, TM_{02}, TM_{03}, etc.) propagated and the plasma radial extent. Thus, for a given radial extent of plasma, θ_{eff} can be controlled by exciting different modes in the plasma.

Low-power experiments (100 W) on microwave reflection from plasma with various combinations of L_n and θ_{eff} have been carried out in order to systematically address the dependence of wave energy absorption on the absorption parameter " τ " which is a function of θ_{eff} and L_n. A reasonable agreement of the results with Denisov dependence of wave absorption on τ

is obtained. To the best of our knowledge, present observations form the first experimental validation of the theoretically predicted Denisov dependence of wave energy in plasma.

Thus, development of an experimental system for investigating a broad range of wave-plasma interaction phenomena, as well as in experimentally validating the theoretically predicted Denisov dependence of wave absorption in plasma form the key contributions of this thesis.

References:

[1] **Priyavandana J. Rathod** Anitha V. P, IEEE Transactions on Plasma Science (53, 1563, 2025)

[2] **Priyavandana J. Rathod**, Anitha V. P., and D. V. Giri, IEEE Transactions on Plasma Science (52, 2706, 2024).

[3] Anitha V. P., **Priyavandana J. Rathod** et al., Review of Scientific Instrument (90, 013502, 2019)
