Seminar

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Institute for Plasma Research

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Title: Experimental Investigation on Interaction of Electromagnetic Waves in an Over-dense Plasmas.

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Date: 08th September 2025 (Monday)

Time: 10:30 AM

Venue: Seminar Hall, IPR

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 ∇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 for fusion confinement 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 development of a system that meets all prerequisites for wave–plasma interaction studies, detailed characterization of plasma to identify the parametric regime suitable for wave interaction and experiments on resonant absorption of wave energy in plasma.

A microwave 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. One of the critical requirements is to have the wave electric field $E_\mu \parallel \nabla n$, which is ensured by launching the microwave in TM mode with the help of a TE–TM mode converter. Although the scheme adopts normal incidence of the wave, a concept of "effective angle of incidence $\theta_{\mu,eff}$" is introduced, given by $\theta_{\mu,eff} = \sin^{-1}\sqrt{(\varepsilon_{r,\,ret})}$. Here, $\varepsilon_{r,\,ret}$ 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, $\theta_{\mu,eff}$ can be controlled by exciting different modes in the plasma. In order to launch various TM modes, different types of microwave step transition structures (MSTSs) have been designed and developed.

The experimental results cover attainment of desired pulsed modulator parameters to drive the microwave source, validation of $E_\mu \parallel \nabla n$, and measurements of field patterns consistent with excitation of desired modes (TM_{01}, TM_{02}, TM_{03}, etc.) thereby rendering control over θ_{eff} as well as attainment of different L_n. Low-power experiments on microwave reflection from plasma with various combinations of L_n and $\theta_{\mu,eff}$ have been carried out to validate the theoretically predicted Denisov dependence of wave absorption on τ which is a function of $\theta_{\mu,eff}$ and L_n. An account of the developmental work and results is presented.
