Seminar

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Institute for Plasma Research

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Title: Deep Learning-Assisted Microwave-Plasma Interaction for Plasma Density Estimation: efficient and adequate data generation for real experimental scenario

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Date: 05th March 2025 (Wednesday)

Time: 10:30 AM

Venue: Seminar Hall, IPR

Abstract

Low-temperature plasmas (LTPs) are essential in medicine, materials processing, semiconductors, and space propulsion [1]. Accurate density estimation is crucial as electron dynamics govern LTP properties. While various diagnostic methods exist, traditional techniques face challenges such as plasma contamination, probe damage, costly optics, and hardware limitations. Microwave-based diagnostics offer affordability but rely on mathematical fitting and prior density profiles [2], prompting the use of deep learning (DL) for enhancement. A convolutional neural network (CNN)-based DL [3] approach improved density estimation from microwave reflections by analyzing reflected electric (E)-field images [1]. Using a dataset comprising high-pressure LTPs (1e18–1e19 m^{-3}) and corresponding reflected E-field (obtained using 2D FDTD simulations), the method accurately reconstructed density profiles. However, the need for sufficient E-field data in experimental setups remains unexamined.

This work explores DL-driven data generation, data adequacy for density prediction, and realistic COMSOL-simulated microwave plasmas. DL achieved a 300–500 times speedup in simulating reflected E-fields from asymmetric plasma profiles with <10% error [4]. The role of spatial E-field distribution in DL performance was assessed using masked E-field patterns, yielding MAPE of 5–10% and SSIM ~ 0.99. Accuracy remained high even when the mask was reduced from 25% to 3%. But performance dropped when mask coverage reduced to 2% , leading to false predictions and a limited density range (5e18–1e19 m^{-3}). Additionally, COMSOL Multiphysics was used to study a 500 MHz microwave plasma reactor with argon in four configurations under varying power and pressure. The accelerated data generation, effective E-field data collection, and realistic microwave plasma modeling contribute to future plasma diagnostics for validating the proposed DL methodology.

References:

[1] P. Ghosh, et al. (2023). Deep learning assisted microwave-plasma interaction based technique for plasma density estimation. *J Phys D: App Phys*, 57 (1).
[2] W. Xiao et al. (2022). Measuring Electron Density of Atmospheric Microwave Plasma Jet by Microwave Perturbation Method *IEEE Trans. Instrum. Meas.* 71, pp. 1-9
[3] M. Desai et al.(2022). Deep-Learning Architecture-Based Approach for 2-D-Simulation of Microwave Plasma Interaction. *IEEE Trans. Microw. Theory Tech.* 70 (12), pp. 5359-5368
[4] P. Ghosh, et al. (2024), *Efficient Data-Driven Simulation of Microwave Interaction with Complex Plasma Profiles.* In IEEE Microwaves, Antennas, and Propagation Conference (MAPCON), Hyderabad, India, 2024 (Accepted for proceeding)