Laser Induced Breakdown Spectroscopy (LIBS) based wall monitoring diagnostic for ADITYA-U tokamak

Bharat Hegde[1,2], K. Singh[1,2], K. A. Jadeja[1], S. Dolui[1,2], Ashok Kumawat[1,2], Ankit Kumar[1,2], I. Hoque[1,2], K. Yadav[1,2], S. Banerjee[1,2], Suman Aich[1,2], H. Raj[1], Nilam Ramaiya[1], R.L. Tanna[1] and J. Ghosh[1,2]

[1] Institute for Plasma Research, Gandhinagar, India - 382428

[2] Homi Bhabha National Institute, Anushaktinagar, Mumbai, India - 400034

e-mail (speaker): bharat.hegde@ipr.res.in

Understanding and controlling plasma-wall interactions (PWIs) is crucial for the sustained performance and operational longevity of tokamak devices. PWIs have a significant role in retention, deposition and recycling of fuel and impurities on plasma-facing components (PFCs), which can impact plasma stability and repeatability of discharge [1]. Conventional diagnostic techniques such as Residual Gas Analysis (RGA) and optical emission spectroscopy are valuable but limited. RGA helps identify composition of the bulk volume of gases in the vacuum vessel and Optical emission spectroscopy requires a plasma to be present. Neither provides direct insight into surface-bound impurities. Sophisticated surface analysis techniques like SEM, XPS, or AES offer detailed elemental profiles but are impractical for routine operation due to their need for vacuum venting and sample extraction. In light of these problems, Laser Induced Breakdown Spectroscopy (LIBS) is an excellent analytical technique for in-situ analysis of PFCs and wall of the tokamak vacuum vessel. LIBS is simple to implement, requires no sample preparation, does minimum damage to the sample and can work under various ambient pressures [2]. Because of these advantages, LIBS is used in a diverse field of studies including metallurgy, geology, space exploration and nuclear fusion [3].

We have designed and developed a Laser-Induced Breakdown Spectroscopy (LIBS) based wall-monitoring diagnostic system tailored for in-situ analysis within the ADITYA-U tokamak [5]. LIBS enables a simple, reliable, and remote detection of elemental compositions directly on PFC surfaces without the need for sample removal from the vacuum vessel. The diagnostic system features a high-energy pulsed Nd:YAG laser, beam delivery and light collection optics, a Czerny-Turner spectrograph for high-resolution spectral analysis, and a motorized sample holder.

Complementing the in-situ system, we have also developed a dedicated ex-situ LIBS experimental setup for laboratory characterization and validation. Ex-situ LIBS spectra of stainless steel, graphite and molybdenum samples exposed to the ADITYA-U plasma discharges are obtained and compared with unexposed control samples. The spatial and depth composition of the layers formed on these samples as a result of plasma wall interactions are studied.

The proposed in-situ LIBS system is scheduled for deployment in the upcoming ADITYA-U experimental campaign. Together with the ex-situ analysis facility, this work establishes a comprehensive framework for monitoring of fuel retention, impurity deposition and recycling. It further enables assessment of wall conditioning techniques like boronization and lithiumization [4], and supports the creation of a spectral database for in-vessel materials, enhancing diagnostic readiness for next-generation fusion reactors.

References

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