Laser diagnostics for negative ion source optimization: insights form SPIDER at the ITER Neutral Beam Test Facility

R. Agnello[1, 2], M. Barbisan[3], A. La Rosa[2], R. Pasqualotto[2, 3], B. Pouradier-Duteil[2, 4], R. Zagórski[5]

[1]*École Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland*
[2]*Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete S.p.A.), C.so Stati Uniti 4, 35127 Padova, Italy*
[3]*Consiglio Nazionale delle Ricerche, Istituto per la Scienza e la Tecnologia dei Plasmi, C.so Stati Uniti 4, 35127 Padova, Italy*
[4]*CEA, IRFM, F-13108 St. Paul lez Durance, France*

[5]*National Center for Nuclear Research, 05-400 Otwock, Poland*

The ITER Heating Neutral Beams (HNBs) require large, high-energy H/D atom beams (285/330 A/m² current density, and 1/0.87 MeV acceleration energy, respectively for H and D). To address the associated challenges, the SPIDER negative ion RF beam source at the Neutral Beam Test Facility (NBTF) in Padova (Italy) serves as a full-scale source prototype with a 100 kV triode accelerator, for design validation and performance verification.

SPIDER is equipped with two advanced laser diagnostics to monitor key plasma parameters. **Cavity Ring-Down Spectroscopy (CRDS)** is used to measure H^-/D^- ion densities, while **Laser Absorption Spectroscopy (LAS)** tracks caesium vapor density in the source. These measurements are essential for optimizing negative ion production and meeting ITER source targets. We present diagnostic implementation details, recent experimental results, and correlations with other machine parameters, such as the extracted ion current. Since CRDS relies on a single 4-meter-long optical cavity, the longest used in such sources, it has demonstrated sensitivity to alignment issues. Based on recent experimental experience, structural improvements are being made to enhance both stability and measurement reliability. LAS has mainly been employed as a tool to monitor the conditioning status of SPIDER. Additionally, due to its use of four lines of sight, LAS has proven effective in monitoring the caesium distribution within the source. Comparing different diagnostics is crucial for gaining a comprehensive understanding of the processes occurring within the source. However, comparison with numerical models is equally essential. In particular, plasma fluid simulations emphasize the need for experimental data, especially negative ion density, to constrain model parameters.

This work demonstrates the essential role of laser diagnostics in developing ITER-relevant plasma sources and informs ongoing efforts to improve measurement accuracy in challenging environments.