Measurement of neutral hydrogen density in a helicon plasma

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Abstract

A new diagnostic system based on two-photon absorption laser induced fluorescence (TALIF) has been developed to measure neutral hydrogen density in the edge region of fusion plasmas. 2015 nm photons from a frequency tripled dye laser are up-converted into the plasma chamber where they excite the 1s-3d transition in neutral hydrogen. The 3d state then decays emitting light at 656 nm. The emission signal intensity is directly proportional to the ground state hydrogen density. With the tabulated atomic absorption rates of the hydrogen and krypton, TALIF measurements of krypton gas provide an absolute calibration. Here we present the technical details and measured performance of the TALIF system (laser line width, pulse length, pulse energy RMS stability) and TALIF measurements of room temperature krypton gas. The krypton measurements are compared to the expectations and measured line widths are analyzed in terms of Doppler and saturation broadening. We also present TALIF measurements of the radial profile of the absolute neutral hydrogen and neutral temperature in a helicon plasma source as a function of source parameters. Work supported in part by US DOE under DE-FG02-04ER54698.

TALIF Laser System

Laser system (left) and laser specs (right). Laser system consists of a 20 Hz frequency doubled Nd:YAG with 550 mJ per pulse pumping a pulse dye laser running a mixture of Rhodamine 610 and Rhodamine 640 dyes. The 615 nm light is then frequency tripled down to 2015 nm through two non-linear stages.

Laser pulse as a function of time (top left). Pulse shape was measured using a fast photodiode. De-convolving the pulse width with the instrumental function of the photodiode (3.8 ns), allowed calculation of the temporal pulse width of the tripled beam. The F dependence of the output of the non-linear tripling crystals resulted in narrowing of the temporal pulse width.

Cartoon of injection/collection scheme (top right) and modeled beam size (bottom left) for TALIF system. A single beam path is used to inject laser light into the plasma and collect fluorescent emission. Using a translation stage the focusing lens is scanned towards and away from the plasma chamber allowing radial profiles to be constructed. As the injection and collection paths are the same no realignment is necessary between radial positions.

TALIF Calibration Theory

To accurately determine the neutral density from a measured hydrogen TALIF signal, the system must first be absolutely calibrated. This is accomplished by comparing the signal from a sample of ideal gas of known density with the signal from hydrogen, where the two-signals have been measured with nearly identical spatial, spectral and temporal laser profiles. The ratio equations for the populations of a two-state system are given by:

\[ \frac{d}{dt} n_2 = R(t)(1 - A_{pH}) \]

\[ \frac{d}{dt} n_1 = -R(t)n_1(t) \]

where \( n_2 \) and \( n_1 \) are the densities of the ground and excited states, \( A_{pH} \) is the total de-excitation rate, including both spontaneous emission and collisional quenching and \( R(t) \) is the two-photon excitation rate. Solving these under the assumption that the laser energy is far from saturation, the volume \( V \) and frequency \( \nu \) integrated signal measured by the photomultiplier tube is given by:

\[ S_{PMT} = \frac{M}{L} G_{PL} G_{PL} \int_0^{\nu_{max}} F d\nu \]

where \( M \) is the total transmission of the system, \( G_{PL} \) and \( G_{PL} \) are the quantum efficiency and gain of the detector respectively, \( e \) is the elementary charge, \( \nu = \nu_{max} - \nu \) is the cross-section for two-photon absorption and \( n_{Kr} \) is the known density of krypton.

Calibration Data

Kr TALIF signal as a function of laser energy (left) and sample calibration spectrum (right). The condition for accurate calibration is that the laser energy is below the saturation level. This dependence can be tested by measuring the TALIF signal as a function of laser energy. In an unsaturated regime, the signal will scale as \( E^2 \). To determine the calibration factor, a Gaussian lineshape is fit to the Kr spectrum, then integrated over wavelength. This gives \( M_{Kr} \), which is then used to calculate the neutral density.

References


Future Work

➢ Further investigation of plasma space, vary B, power, pressure etc.

➢ Construct and install planar Langmuir probe so that electron saturation can be reached.

➢ Installation on DIH-D tokamak and measurement of edge neutral density.