

Development of a laser-induced fluorescence system to detect densities and velocity distributions in the divertor plasma of ASDEX Upgrade

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1. Introduction

Laser-induced fluorescence (LIF) generally offers the possibility to spectroscopically determine the velocity distributions and the densities of neutrals, molecules and ions with high spatial resolution.

In order to apply laser-induced fluorescence in the divertor plasma of ASDEX Upgrade (AUG) [1] we developed LIF at the neutral deuterium wavelength of 656.107 nm as well as at the neutral helium wavelength at 667.815 nm in order to investigate the deuterium and helium velocity and density behavior, respectively, in the divertor of ASDEX Upgrade. In a later step other important species in the divertor plasma like Carbon III at 464.742 nm will be investigated. The general aim of these studies is to support the physics understanding and the modeling of divertor plasmas [2].

The laser-induced fluorescence system relies on the application of a system of quartz fibers in order to transmit the high energy laser pulses to the divertor plasma and of another system for the collection of the fluorescence photons. This is necessary, because the divertor region in ASDEX Upgrade is limited in accessibility. An important condition for exciting the desired transition is the very exact wavelength calibration.

2. Fundamentals of laser-induced-fluorescence

By tuning the laser wavelength a certain transition can be excited. The following relaxation occurs to different lower levels by allowed transitions. In this experiment the fluorescence is detected at the same wavelength as the exciting laser. If a large number of particles is excited to the required level with a very short pulse the intensity of a line starting from this level should decay exponentially: $I(t) \propto A_{ki} n_k(t) = A_{ki} n_k(0) e^{-t/\tau}$. Fig. 1 shows the allowed excitation and relaxation transitions for the deuterium and helium lines. There is only one allowed transition for helium so the lifetime of the upper level can simply be calculated by

$$\tau = \frac{1}{A_{ik}}$$

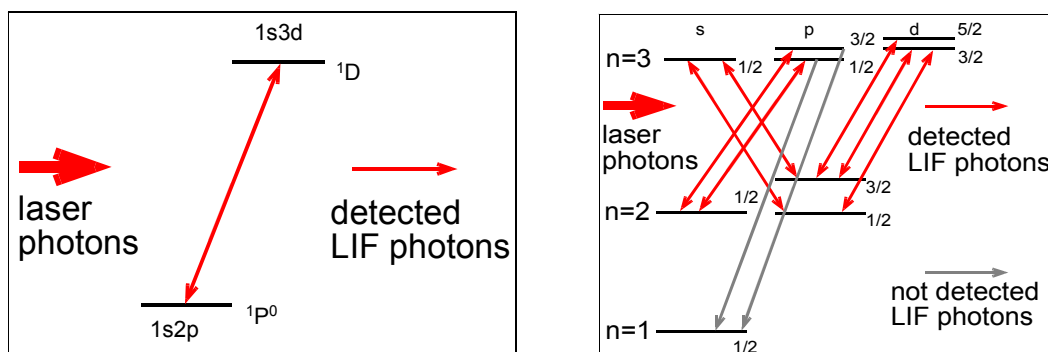


Fig. 1a: Term scheme and allowed transition for He Fig. 1b: Term scheme and allowed transitions for D

For deuterium the $D\alpha$ fine structure and the relaxation through Lyman- β has to be taken into account. An effective lifetime for the upper level is calculated assuming the population corresponds to the statistical weights. Using values from [3] the lifetimes are: $\tau_{He} = 15.7ns$ and $\tau_D = 10.0ns$, respectively.

3. Experimental setup

To excite the desired transitions a dye-laser using DCM solved in dimethylsulfoxide is used which is pumped by a frequency doubled Nd:YAG laser ($\lambda=532nm$) that produces 7ns pulses with a repetition rate of 10Hz. The laser pulses are transmitted into the divertor of ASDEX Upgrade by a quartz fiber which limits the excitation wavelength to the visible range. The coupling into this fiber is done by a system of lenses compressing the laser beam cross section which was optimized to transmit more than 5mJ into the torus. The fluorescence photons are detected by quartz fibers transmitting only visible light, too. The detection volume of $0.36cm^3$ is formed by the observed part of the laser beam (Fig 2).

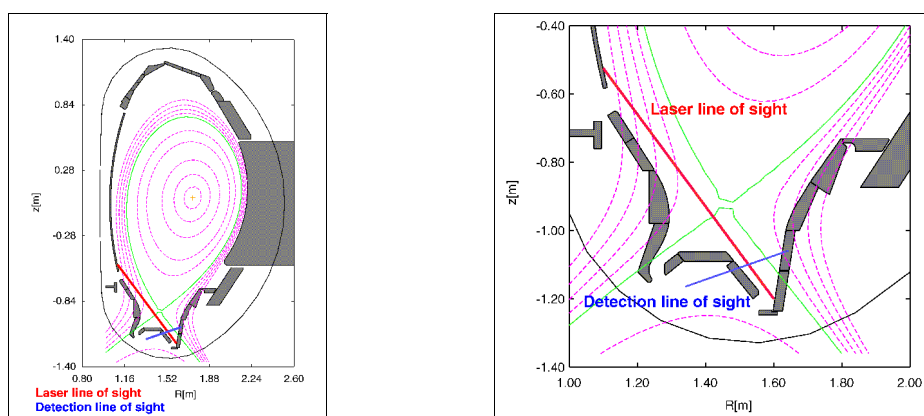


Fig 2: Lines of sight in the divertor of AUG

The detection fiber forms the entrance slit of a quarter meter spectrometer which spectroscopically selects the photons collected by this fiber. The selected photons are detected by a gated photomultiplier whose voltage signal is digitized by a 4GS/s digital storage oscilloscope and sent to the PC that controls the whole setup.

4. Wavelength calibration

Since for the determination of velocity distributions the absolute shift of the wavelength is of interest, a very exact knowledge of the exact wavelength produced by the dye-laser is indispensable. For these calibration purposes optogalvanical spectroscopy was used.

In the plasma of a hollow cathode lamp the absorption of laser photons changes the population of states which results in a current change due to different ionization probabilities of the states. This change of current leads to a periodic change in voltage measured over a resistor and a capacitor. For neon lines very small widths could be achieved which shows that this technique is applicable. Due to pressure problems in the hydrogen/deuterium lamp the plasma was unstable resulting in a very bad signal to noise ratio for the optogalvanical signal. This problem will be fixed soon.

For the neon transition the measured wavelength is 640.220nm, the measured linewidth is 4.8pm (fig. 3a). The wavelength tabulated in [3] is 640.2246nm. For $H\alpha$ the measured wavelength is 656.265nm at a linewidth of 42pm (fig. 2b). The tabulated value is 656.28nm.

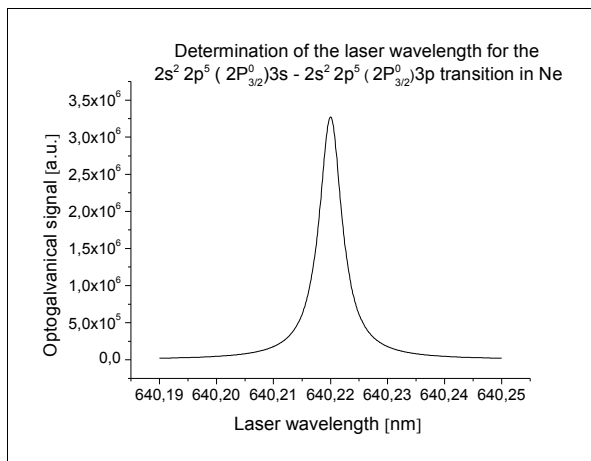


Fig. 3a: Measured Ne line at 640.22nm

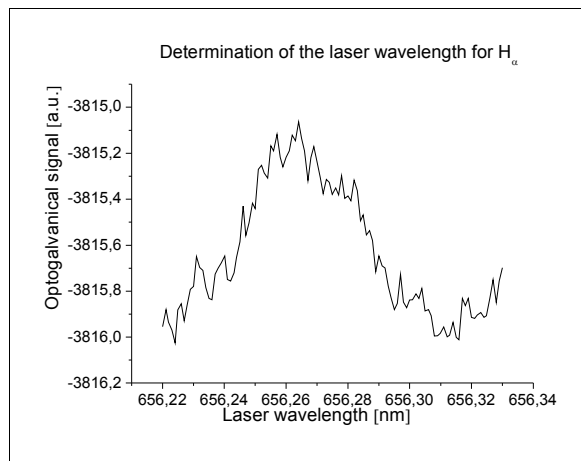


Fig. 3b: Measured Hα line at 656.28nm

Within that device’s level of accuracy of 50pm these results were validated using a Burleigh wavemeter.

5. First signals

Fig. 4a shows the averaged temporal envelope of 15 laser pulses with (red) and without (black) plasma at the deuterium wavelength. The immediate signal is obviously dominated by the stray light from the torus. Fig. 4b shows the same measurement plotted semi-logarithmically with a linear fit. The lifetime of the upper level was calculated as the inverse of this straight line’s slope to 11.3ns. The expected value calculated in chapter 2 is 10.0ns.

The averaged temporal envelope of 3 laser pulses with (red) and without (black) plasma at the helium wavelength is shown in fig. 5a. Fig. 5b again shows the semi-logarithmically plotted measurement with a linear fit from which the lifetime was calculated to be 15.4ns which is in very good agreement with the value of 15.7ns calculated in chapter 2.

The LIF signals occur infrequently and the reason for this behavior is not yet understood. The missing overlap of neutral density and electron density (since the electrons deliver the collisional excitation energy) within the observation volume may be one explanation. Another one is a possibly too low detection sensitivity which might only allow to detect LIF photons during Edge Localized Modes (ELMs).

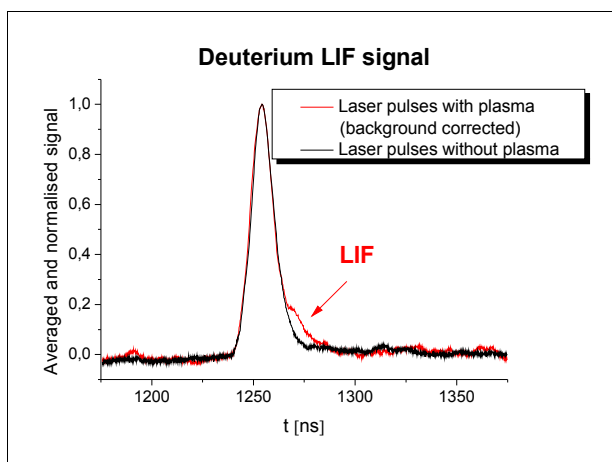


Fig. 4a: Dα LIF signal

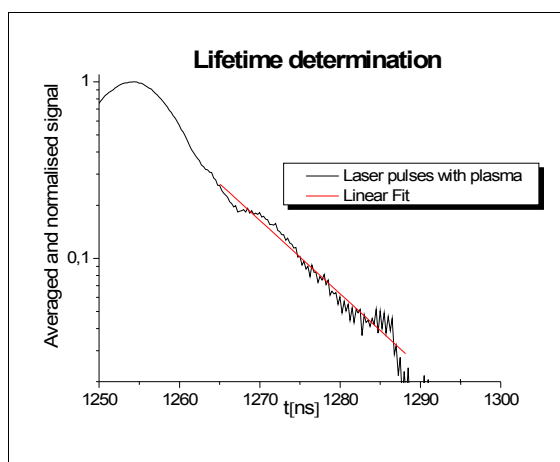


Fig. 4b: Deuterium lifetime determination

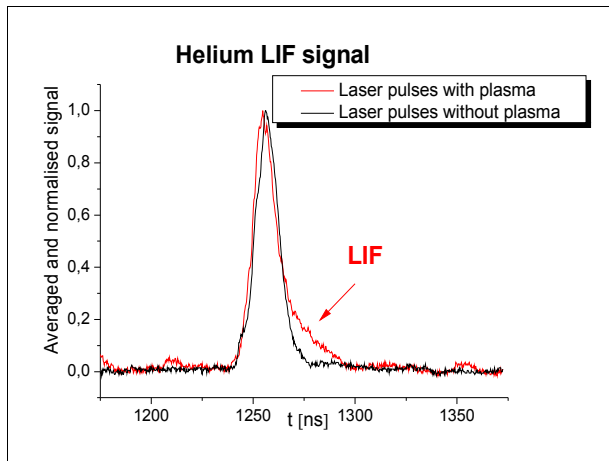


Fig. 5a: He LIF signal

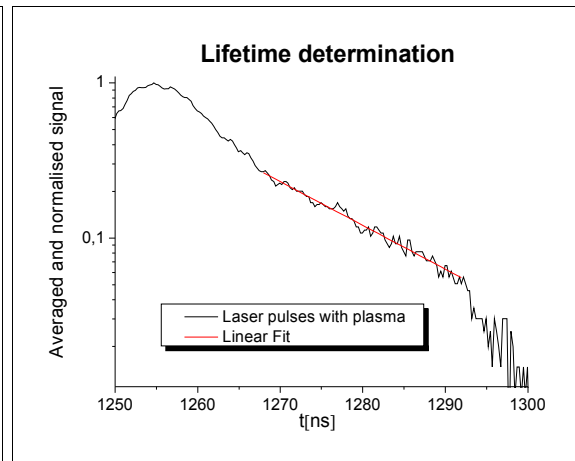


Fig. 5b: He lifetime determination

6. Conclusion and outlook

A system to detect laser-induced fluorescence in the divertor plasma of ASDEX Upgrade was installed and tested. A pulse energy of 5.3mJ which is 18% of the maximum pulse energy and 45% of the used pulse energy can be transmitted into the torus. The laser wavelength was calibrated using optical galvanical spectroscopy and a Burleigh wavemeter. First LIF signals for deuterium and helium were obtained. The lifetimes of the upper levels were determined from these measurements; they showed excellent agreement with those expected from theory. As the LIF signal occurs infrequently it is assumed that the zones with significant concentrations of the species in the excitable states are very small. To tackle this problem a new system will be available in the next experimental campaign for high time and spatial resolution observation of 16 volumes using 4 laser lines and 4 detection lines of sight (fig. 6).

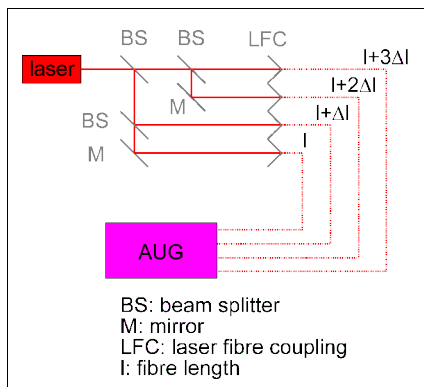


Fig. 6a: Delatation of laser pulses

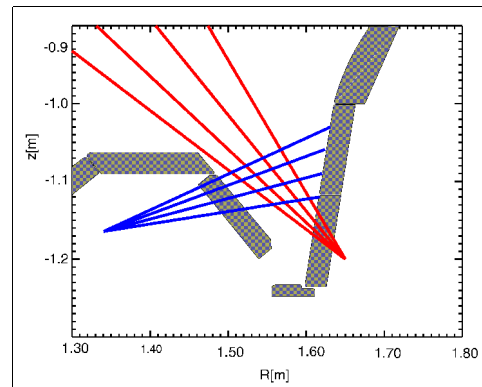


Fig. 6b: New observation volumes

Each laser pulse is divided into four equal pulses which can be delayed to each other by different lengths of the optical path (fig. 6a). Each of these laser pulses allows the simultaneous observation of four different volumes (fig. 6b). With this setup time resolved ELM-measurements may be possible.

References

- [1] A. Hermann, O. Gruber: Fusion Science and Technology, Vol. 33, No. 3 (2003) , Chapter 1
- [2] J. Neuhauser et al.: Fusion Science and Technology, Vol. 33, No. 3 (2003) , Chapter 8
- [3] NIST Atomic Spectra Database, NIST Standard Reference Database #78, <http://www.nist.gov>