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OPTICAL EMISSION SPECTROSCOPY OF H_2 IN A TOROIDAL MAGNETISED PLASMA

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Abstract. A noninvasive diagnostic technique relying on optical emission spectroscopy is used for studying plasma confined in a purely toroidal magnetic field. Visible emission lines of molecular hydrogen were specifically targeted. Bi-dimensional structures and poloidal plasma profiles were reconstructed from the emissivity distribution of hydrogen Fulcher system using tomographic method. A few details concerning the methods employed to capture different emission viewlines, data reduction and tomographic reconstruction techniques are also addressed.

1. INTRODUCTION

The quest for finding new sources of energy have generated large interest in magnetized plasmas where plasma is confined in toroidal device such as tokamaks and stellarators aiming to produce energy through controlled thermonuclear fusion (see Wagner 2007). In particular, there is an ongoing effort aimed to better understand the effect of anomalous particle transport in reducing the confinement in magnetized plasma (see Wagner 2007). This phenomenon is quite general and related to the dynamical effects due to turbulence, which arise naturally in magnetized plasmas (see Tynan et al. 2009). In particular there is evidence of drift-wave turbulence in magnetically confined plasmas and, associated to that, the appearance and build-up of large amplitude density fluctuations in the edge region of plasmas, strongly contributing to turbulent cross-field particle and energy fluxes (see Tynan et al. 2009). The turbulence measurements are generally more complicated in plasmas than in fluids due to the faster time scales and to the difficulties in measuring locally microscopic parameters such as the plasma density and temperature (see Dudok de Wit et al. 2013). Another approach is related to the use of the electromagnetic radiation emitted by the plasma state. This usually escapes from the plasma and could be collected from outside, without a direct disturbance of the system. As a tool for the study of plasma turbulence, optical diagnostics could be demanding too (see Donne' 2006). Since in plasma turbulence the associated autocorrelation times are in the range of a few microseconds to tens of microseconds, the diagnostics should be faster than these time scales. Optical emission spectroscopy (OES) is usually fast enough. For instance, in a hydrogen plasma, the lifetime of hydrogen n=3 state, emitting the H_α line, is about 10 ns. However, even in a simple hydrogen low temperature plasma, OES reveals many features arising from the complex plasma gas phase. Although atomic hydrogen dominates emission, it is common to spot emission also from the rich structure of excited levels of the H_2 molecules (see Barni et al. 2018). Such features in the emission spectra are suitable to study particular phenomena happening in the plasma, be it those arising due to presence of minority ions, the recombination or the dynamical effects induced by the collisions with neutrals (see Pierre et al. 2004). The continuous improvement in radiative collisional models also opens up the concrete possibility to relate spectroscopical data to constrain or even to measure more fundamental plasma parameters (see Capitelli et al. 2013). Here we present the application of an OES passive optical diagnostics to the study of emissivity in a simply magnetized toroidal (SMT) device using a low resolution visible spectrometer. In particular our aim will be to reconstruct the 2D pattern of emissivity of H_2 molecular states of the so-called Fulcher-α band system, the 3pπ d $^3\Pi_u$ [3c] → 2sσ a $^3\Sigma_g^+$ [2a] transitions (see Aguilar et al. 2008).

2. EXPERIMENTAL SETUP

Layout of the experimental setup is shown in figure 1. The Thorello device consists of four 90° curved and corrugated stainless steel sectors joined together to form a complete torus with a major radius of 40 cm and a minor radius of 8.75 cm. A set of 56 number of water-cooled circular coils surrounding the chamber enable us to apply a purely toroidal magnetic field (a simply magnetized torus, SMT configuration) of intensity up to 0.2 T using a 600 A DC stabilized current supply. Base pressure of less than 1×10^{-4} Pa is achieved using a couple of turbomolecular pumps backed by two rotary pumps. Experiments were normally performed by filling high purity hydrogen gas up to a pressure of a few 10^{-2} Pa. Plasma is produced by thermionic emission of three intertwined thoriated tungsten filaments bent in a 13 turns spiral shape (diameter 7 mm and length of 3 cm), placed with the axis aligned to the magnetic field about the center of the poloidal cross section. The filament is heated by passing a current of tens of ampere and discharge is struck between the hot filament (cathode) and the grounded vacuum vessel (anode) by applying a potential difference of about 150 V. More precisely a limiter, a hollow disk of 15 cm diameter, short-circuits the vertical electric field. Typical plasma parameters estimated using Langmuir probes at the radial center of the device are given by Te ~ 4 eV, Ti ~ 0.2 eV, Ne ~ 10^{11} cm^{-3} (see Barni et al. 2009).

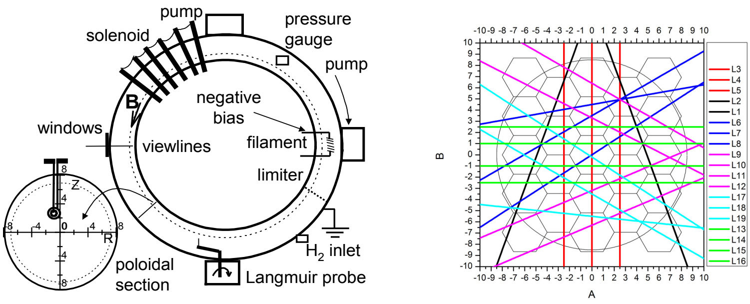

Figure 1: Left: experimental layout of the Thorello device. Right: viewline system of measurement and relation with the 2D poloidal section map of the device.

3. RESULTS AND DISCUSSION

In order to demonstrate the capabilities of the proposed diagnostics we have performed a few measurement in our magnetized plasma device. We take advantage of the steady state stable conditions of the SMT plasma. To reduce statistical uncertainty we measure three times the full set of 19 viewlines, each set with a different random order, to mitigate effects due to plasma parameters drift. Spectrometer acquisition times were optimized to each viewline, and spectra were cleaned by subtracting the relevant dark spectra (see Barni et al. 2018). The average intensity of each viewline was then evaluated, together with a statistical error. The discharge OES spectra we are discussing about were taken from plasma driven by a 70 A filament current and a 150 V cathode bias, with a magnetic field of 70 mT, starting from a 0.1 Pa pure hydrogen gas. A typical spectrum measured is shown in Figure 2. Apart from the more prominent Balmer lines, it is possible to spot the lines corresponding to the Fulcher-α diagonal bands. They are the more bright ones, at 602.0, 612.3, 622.6 and 632.9 nm [(n,n)-Q1 with n=0…3], corresponding to the transitions from subsequent excited vibrational levels of the 3c state. The reconstruction of the 2D pattern of emissivity in the SMT poloidal cross-section is then undertaken from the 19 viewline average dataset, as we have discussed in our previous works (see Barni et al. 2018). In figure3 we report the results for the first of the Fulcher-α diagonal band lines, compared with the Balmer H_α. It could be noticed that, contrary to naive expectations, the molecular line pattern is more concentrated in the central region, around the filament magnetic shadow in the poloidal cross-section.

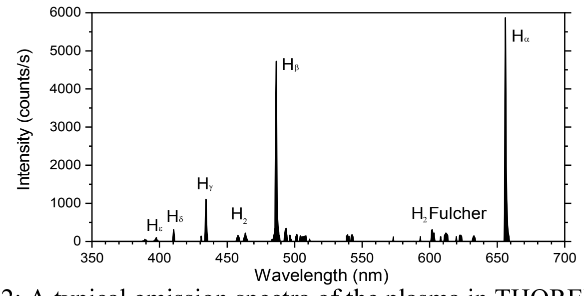

Figure 2: A typical emission spectra of the plasma in THORELLO.

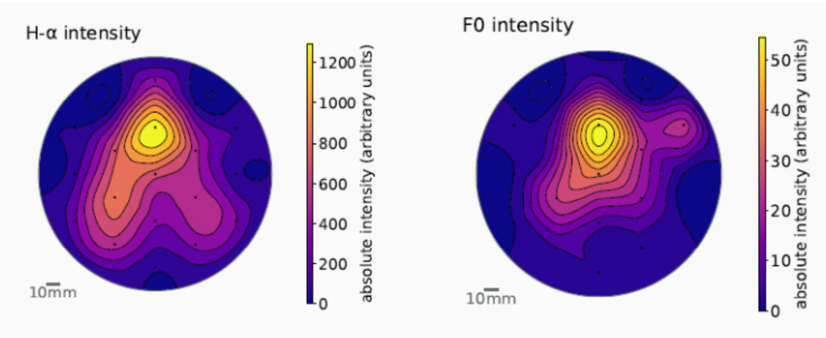

Figure 3: A reconstructed map of emissivity of the first H_2 Fulcher-α diagonal bands, compared with the Balmer H_α from the plasma.

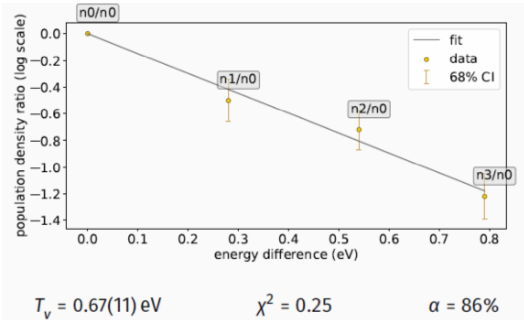

Figure 4: Extraction of the excitation temperature of the H2 3c state in the cell corresponding to the brighter spot of the plasma column.

Finally, from the reconstructed intensities of the diagonal bands, using the relevant lifetimes and branching ratios (see Fantz et al. 2006) it is possible to estimate the relative population of the first four vibrational levels of the excited H2 3c state. As it could be seen from figure 4, their distribution is roughly by a Boltzmann factor, from which it is possible to extract an effective excitation temperature or, as it sometimes referred to, a vibrational temperature, in this case T_{exc}=0.67±0.11 eV. It should be compared with a central electron temperature of 4.4 eV.

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