Plasma Spectroscopy in ISTTOK

J. Figueiredo[1], R. B. Gomes[1], T. Pereira[1], H. Fernandes[1], A. Sharakovski[2]

[1]*Associação EURATOM/IST, Centro de Fusão Nuclear, IST, 1049-001 Lisboa, Portugal*
[2]*Association EURATOM/University of Latvia, Institute of Physics, 32 Miera Str., Salaspils*

Abstract. Plasma spectroscopy is a well established technique for impurities study in fusion plasmas. A brief description of the several spectroscopic systems which have been in operation at ISTTOK is given. In ISTTOK a passive spectroscopy diagnostic system is being used to perform spectral and spatial characterization in the 300 – 850 nm wavelength range. The system used to perform that work consist essentially of a cooled CCD camera coupled to a half a meter imaging spectrograph with collection optics based on a multi-fiber set to allow for enhanced spatial resolution. Experimental data is shown underlining typical plasma fusion spectral lines and specific ISTTOK characteristics. A web based data access tool is presented that allows the spectral plasma survey in specific wavelength ranges. The information provided by this survey has been used to select suitable transmission filters for a diagnostic, currently under development, to measure Zeff parameter for ISTTOK plasmas. A description of this diagnostic is also presented.

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INTRODUCTION

Plasma spectroscopy, as non intrusive plasma diagnostic, is widely used in Nuclear Fusion[1,2] and elsewhere in science. Spectroscopic survey of elements in the plasma is essential as density and spatial distribution of impurities can greatly influence the characteristics of the tokamak discharge. Even a small amount of impurities can affect energy confinement by radiative power losses.

In plasma facing components' tests a spectroscopy survey of impurities allows control of the plasma interaction with the tested material. Spectral and spatial distributions of impurities from the recently installed gallium jet[3] in ISTTOK have been studied.

Several spectroscopic systems have been in operation at ISTTOK. The evolution of both edge ion temperature and plasma poloidal velocity was measured using a double grating high dispersion spectrometer to study carbon impurity lines[4]. H_α and CIII spectral lines time evolution are monitored and a bolometry diagnostic is currently installed. These systems are used for operation purposes and control of discharges.

This paper focuses on a spectroscopy diagnostic composed mainly by an imaging spectrograph. The implemented setup is described in detail. Experimental data is presented as well as it's usefulness for several related projects. One of those projects is the Zeff diagnostic which is under development. Future work is pointed out in the last section.

IMAGING SPECTROGRAPH

Experimental setup

ISTTOK is a copper shell tokamak with an iron core transformer and circular cross section. ISTTOK has a minor radius r = 8.5 cm, a major radius R = 46 cm and a toroidal magnetic field B_T~0.6T. This tokamak is currently being used to study the interaction of a gallium jet with the plasma. A spectroscopy diagnostic has been specifically designed to characterize the discharges produced in these conditions.

The main component of this diagnostic (Figure 1) is an ½ meter imaging spectrograph (CVI Laser DK480I) which allows resolving small areas (~4 mm^2) in the plasma. The diagnostic line of sight is installed on a tangential viewing port. This particular port has direct observation line to the gallium jet region. The plasma radiation is focused by a suitable objective on a fiber bundle, composed of 7 optical fibers, which conveys light to the spectrograph. A set of lenses is used to optimize light coupling between the fiber bundle and the spectrograph. An achromatic lens has been recently installed to avoid alignment problems when changing the system wavelength. The spectrograph is equipped with a triple-grating turret system, with gratings blazed at 300, 500 and 750 nm, 1200 groove/mm and 68×68 mm^2 area. To improve data quality the grating efficiency curves are taken into account when operating the diagnostic since each grating presents a variation of efficiency with wavelength. At the spectrometer output focal plane a spectroscopic cooled CCD (Hamamatsu S7030-1007) camera acquires the spectral line intensities from the plasma in the 300 - 850 nm wavelength range. The CCD camera has a peak quantum efficiency of 92% at 650 nm and better than 80% between 500 - 800 nm which makes it appropriate for visible plasma fusion spectroscopy. At >86 dB the camera dynamic range provides also the ability to acquire high intensity spectral lines as well low intensity ones. The pixel size is 24×24 μm^2 and the camera resolution is 1024×122.

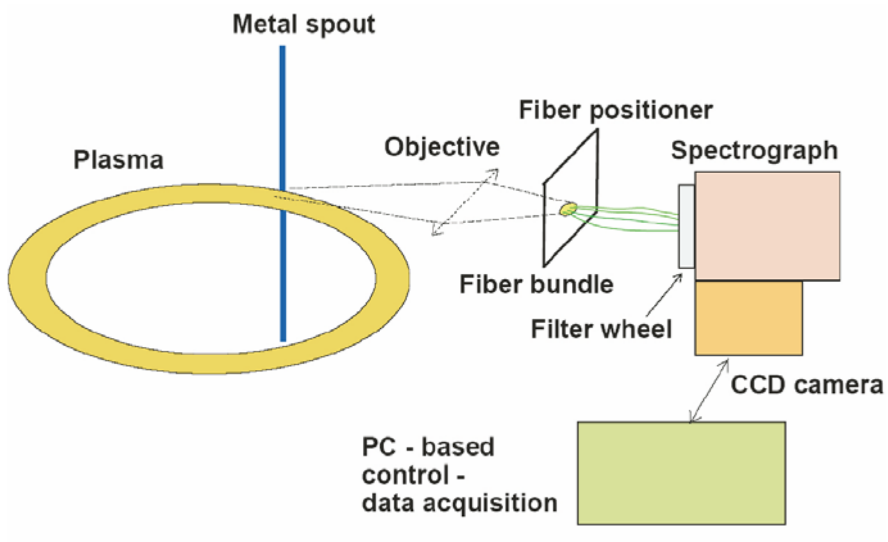

FIGURE 1. Schematic of ISTTOK's imaging spectrograph diagnostic[5]

A PC controls the operation and stores the data produced by the diagnostic. An optical trigger to the controller ensures the synchronization of exposures with tokamak discharges. To improve signal to noise ratio for each acquisition the CCD camera acquires two images. One of those images is obtained during the discharge and is subtracted by another one with only noise, by taking it without plasma in the chamber.

EXPERIMENTAL RESULTS

A survey in the 300 - 850 nm range was performed to characterize the specific plasma spectral emission of ISTTOK. That data can be accessed through a web based tool. The expected typical impurities were detected in ISTTOK plasma, such as carbon, oxygen and nitrogen. Being able to survey the entire visible spectrum but also soft UV and near IR this diagnostic has been useful for several scientific projects within ISTTOK. This system is being used in plasma facing components tests, specifically as stated in the gallium project.

Gallium Jet - Plasma Interaction

This diagnostic was designed to provide spectroscopic data during operation with gallium jet. It was demonstrated that there is an effective plasma-gallium interaction due to the fact that gallium typical spectral lines were observed exclusively during discharges with gallium in the chamber (namely GaI, II and III lines were observed).

During each discharge four spectra were obtained for four different lines of sight radially distributed* and focused on the gallium jet plane with ~1 cm of resolution. By doing a spatial scan on consecutive shots further spatial data is obtained as shown in Figure 2. The point of maximum intensity for gallium lines is in the jet vicinity for neutral gallium and moves in the direction of the plasma core for higher degrees of ionization where higher temperatures strip gallium ions. The maximum intensities in the emission profiles are not further apart due to the fact that gallium ions present low ionization potentials†. This procedure in the blue region of the spectra was repeated in the red region since several gallium lines are also present at those wavelengths‡.

Also of importance is the fact that after several gallium discharges the tokamak vessel isn't contaminated. Gallium spectral lines aren't detected in a discharge in the absence of the liquid metallic jet.

Web Data Access

To simplify public access to ISTTOK typical spectra data a web based[6] tool was created. One example of such spectrum graph is presented in Figure 3. In this spectrum the most intense line is from CIII. This is a common impurity in tokamaks which use carbon as a plasma facing component as is the case of ISTTOK limiter. The other lines are typical "atmospheric" impurities oxygen and nitrogen. The Hγ line of

* three end channels of the fiber bundle were cutoff due to the spectrograph to fiber coupling optics magnification ratio

† 6, 20.5, 30.7 eV for GaI, II and III

‡ 639.7, 633.4, 599.4 nm for GaI, II and III

the hydrogen Balmer series, which is a characteristic feature of tokamak spectra emission, appears on the lower wavelength limit of this particular spectrum at 434,047 nm.

This web based tool was developed in JAVA™ using JFreeChart open-source library. This tool currently holds experimental data from a survey between 350-800 nm. This spectral survey was acquired to guarantee that there is an ISTTOK spectral reference for future spectral data acquisitions. This means that easy detection of a new impurity source, for instance, is quicker and less time consuming.

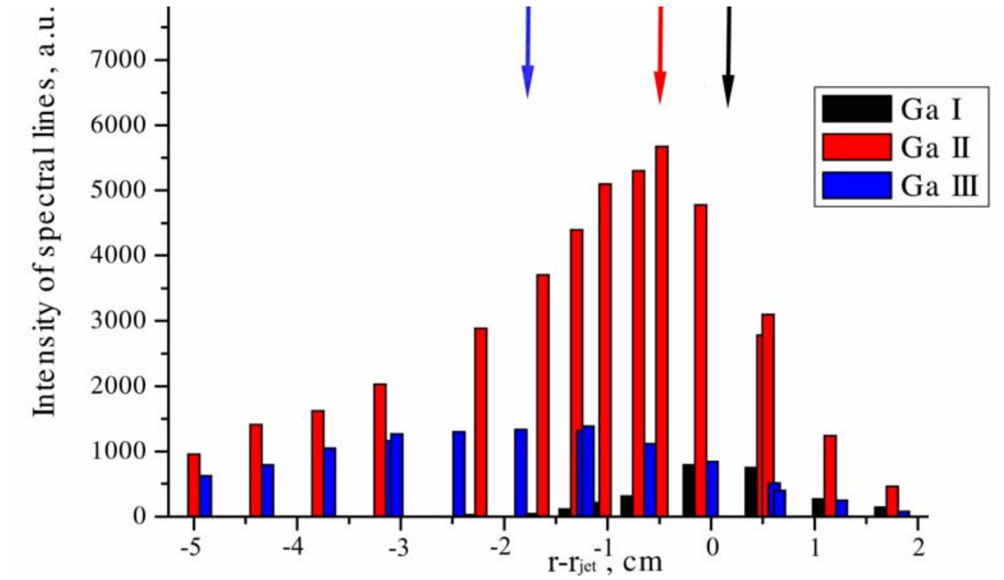

FIGURE 2. Gallium spatial distribution

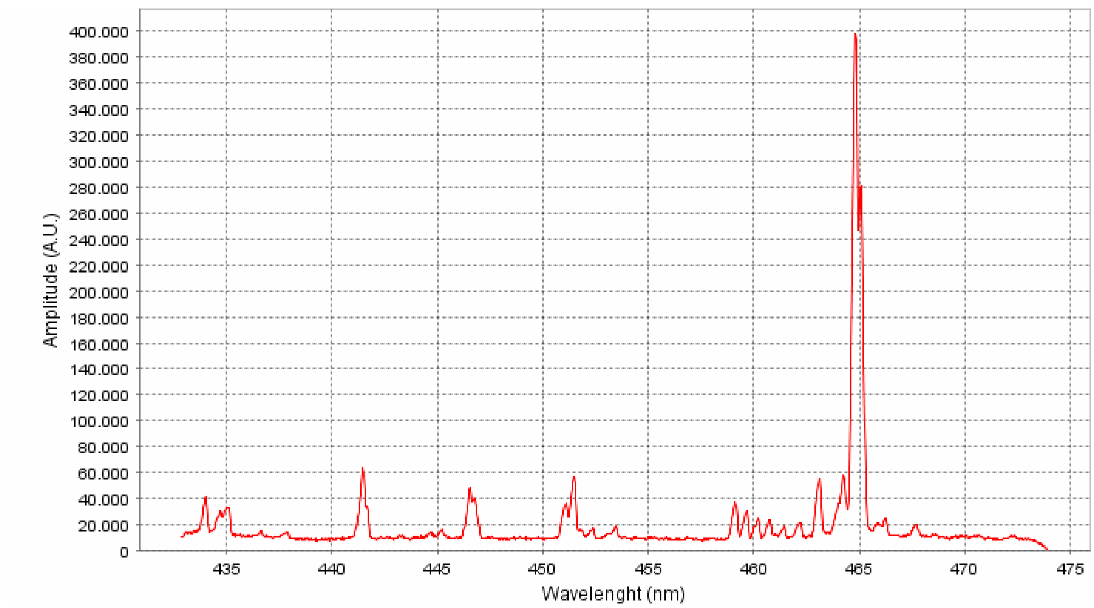

FIGURE 3. 430 - 475 nm ISTTOK spectrum

Zeff SYSTEM DEVELOPMENT

In ISTTOK a technique using a set of transmission filters (Table 1) and photodiodes is being developed to obtain Zeff data. The effective ionic charge (Zeff) is a very important parameter in nuclear fusion research that characterizes the global impurity content of plasmas. It can be derived from measurements of bremsstrahlung radiation. That set of filters has to be specifically chosen in order to avoid spectral lines and acquire only bremsstrahlung. To do so the analysis of spectroscopic data is required so that the specifications of the filters are accordingly defined. The bremsstrahlung emission can then be used to deduce the Zeff profile and electronic temperature.

Experimental data from the set of filters of the diagnostic is presented in Figure 4. Preliminary calibrations in intensity were performed with a tungsten filament. The profiles of T_e and Zeff, once the diagnostic becomes operational, are to be obtained by this diagnostic. Experimental intensity values are to be fitted to Eq. 1 in which C is a constant value and ε the plasma emissivity.

$$\varepsilon = C \cdot n_e \cdot Zeff \cdot \frac{1}{\sqrt{T_e} \cdot \lambda^2} \cdot e^{\frac{1240}{\lambda \cdot T_e}} \quad (1)$$

TABLE 1. Zeff system filters

Wavelength (nm)	FWHM (nm)
360	10
417	3
476	10
530	10
577	3
627	3
656	1,5
680	10
766	10
830	10
980	10

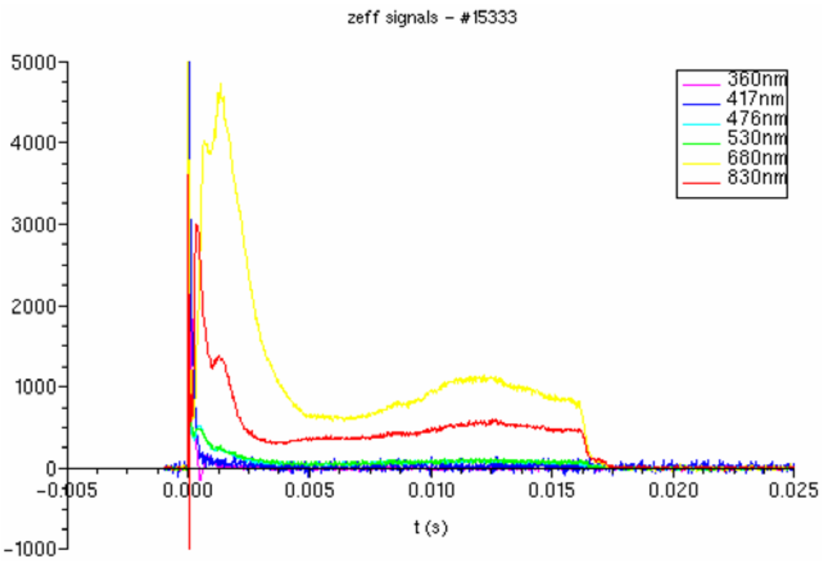

FIGURE 4. Zeff diagnostic signals for narrowband filters of specific wavelengths

FUTURE WORK

Regarding future work a CMOS camera is being evaluated for an upgrade of the diagnostic. The objective is to use a camera with time resolution capability that could replace the actual camera which integrates plasma radiation during an entire shot. Specifically Photron's® FASTCAM 1024 PCI has been studied. This particular solution would bring several enhancements to the diagnostic. This camera has a lower pixel size of 17×17 μm providing better spatial and spectral resolutions. The frame rate depends on resolution but could go from 1kfps (1024 x 1024) to ~100kfps (128 x 16). The main difficulty with this camera, or with any other CMOS based one, is that CMOS camera sensitivity is lower than that of the CCD.

Regarding the Zeff diagnostic further calibration and analysis with other diagnostics must be performed in order to obtain reliable scientific information from the data.

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