Measurements of Ion Temperature in the Edge Plasma of the COMPASS Tokamak

D. I. Naydenkova,[1,2] F. Janky,[1,2] V. Weinzettl,[2] J. Stockel,[2] D. Sestak,[2] T. Odstrcil,[3] J. Ghosh,[4] R. Gomes,[5] T. Pereira[5]

[1]Charles University Prague, Faculty of Mathematics and Physics, Prague, Czech Republic.

[2]Institute of Plasma Physics AS CR, v.v.i., Prague, Czech Republic.

[3]Czech Technical University in Prague, Prague, Czech Republic.

[4]Institute for Plasma Research, Spectroscopy diagnostic division, Gujarat, India.

[5]Associaco EURATOM/IST, Instituto de Plasmas y Fuso Nuclear - Laboratório Associado, Instituto Superior Técnico, Lisboa, Portugal.

Abstract. The ion temperature was estimated using measurements provided by optical system based on the two-grating spectrometer on the COMPASS tokamak. It was done by analysis of Doppler-broadened CIII spectral lines at about 465 nm. The ion temperature in the range of 30–35 eV was measured at the plasma edge in short low-current ohmic discharges.

Introduction

The COMPASS tokamak (R = 0.56 m, a = 0.23 × 0.38 m, I_p < 400 kA, B_T < 2.1 T and pulse length up to 1 s), with ITER-relevant plasma geometry, is operated at IPP Prague [*Panek et al,* 2006]. Currently, the COMPASS tokamak operates with plasma of the circular cross section. The divertor mode operation with additional plasma heating by the neutral beam injection is expected at the beginning of 2012.

The system for high resolution spectroscopy is based on the spectrometer, which is a part of new diagnostics installed on the COMPASS tokamak for particle transport studies. This two-grating spectrometer, which has originally been developed and operated on the ISTTOK tokamak [*Gomes et al,* 2003], was moved to Prague in 2009. Recently, the spectrometer was equipped by a new highly sensitive spectroscopic camera, which allows reaching both higher spectral and temporal resolutions. The system allows estimation of both ion temperature and poloidal velocity of the edge plasma by analysis of Doppler-shifted and broadened carbon triplet lines $1s^22s3s–1s^22s3p$ emission (≈ 465 nm) temporally integrated over the whole discharge or with temporal resolution about 10 ms. Currently, experimental results of temporally integrated measurements are presented.

Experimental setup

The system for high-resolution optical spectroscopy is located at the sector 8/9 of the COMPASS tokamak (Figure 1). Two configurations, which will be realized using three diagnostic ports spaced in one poloidal cross-section, suppose to be used for observation of plasma rotation during COMPASS tokamak experiments.

During first experiments only the horizontal and top ports were used for measurements of Doppler broadening of CIII spectral lines as a test measurement for the system. Light from the tokamak plasma was transferred by means of an optical path based on collecting lenses and few mirrors to the entrance slit of the spectrometer. The reflectance of the mirrors is more then 88% in the spectral range of ≈ 465 nm.

The two grating high-resolution spectrometer, which is used for analysis of the measured spectrum, is newly equipped with the high-speed camera iXonEM+ DU-897 from ANDOR Corporation, which has high quantum efficiency higher than 90 % in the range of interest. High readout rate allows getting required temporal resolution in the range of few milliseconds. At the same time, the new camera increases spectral resolution of the system due to a smaller pixel size of the camera sensor. The principle parameters of the spectrometer are summarized in Table 1.

Figure 2 shows the temporal evolution of main plasma parameters of the discharge such as plasma current, loop voltage measured by magnetic diagnostics [*Havlicek et al,* 2010], electron density

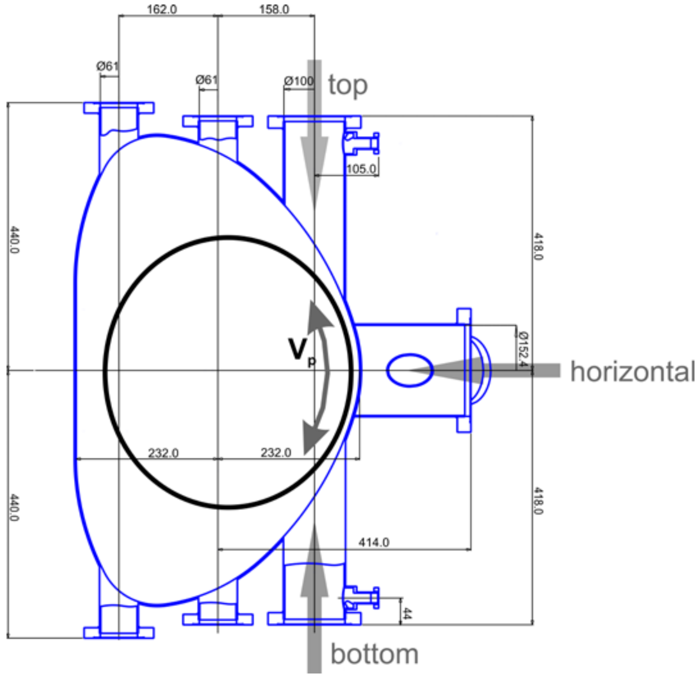

Figure 1. Poloidal view to section 8/9. Observation points, which were used for tests of concept of the method (horizontal) and which will be used during next experiments (vertical), are shown by arrows. Poloidal plasma rotation along magnetic surfaces is indicated by grey arrow.

Table 1. Main parameters of the high-resolution spectrometer.

optical resolution	0.004 nm
operation range	~8nm
readout rate	<10MHz
quantum efficiency	>90%
entrance slit width	200μm

measured by the microwave interferometer and integral visible light emitted by plasma [*Weinzettl et al,* 2011] for a typical short, low current ohmic discharge of duration ≈ 10 ms.

These discharges can be characterized by the strong plasma-wall interaction. Consequent instabilities terminate the discharge in few milliseconds after the plasma breakdown.

Results

Measurements with the high resolution spectrometer were performed using both observation positions, i.e. by collecting the light emission through the horizontal and after the top vertical ports.

Figure 3 shows spectrum recorded through the horizontal port over the whole discharge duration.

In this particular case, it was not possible to identify precisely the individual spectral lines seen in the measured spectrum. The possible reason is that the spectrum is integrated along the horizontal chord from the low field to the high field side of the plasma column and the light from different regions of the plasma column is recorded simultaneously. Moreover, the radial and vertical movement of the plasma during the discharge possibly complicates interpretation of the spectrum. Therefore, these data cannot be used for determination of the ion temperature from the Doppler broadening. Note also sharp peaks, which are superimposed to the optical signal. They probably correspond to HXR photons, generated by interaction of runaway electrons with a first wall element. Consequently, the CCD camera has to be shielded by sufficiently thick lead blocks in future experiments.

The spectrum measured from the top observation port is shown in Figure 4.

It is clearly seen, that the high spectral resolution allows distinguishing carbon triplet lines $1s^2 2s3s$–$1s^2 2s3p$ with wavelengths 464.742, 465.025, and 465.147 nm. The carbon ions appear

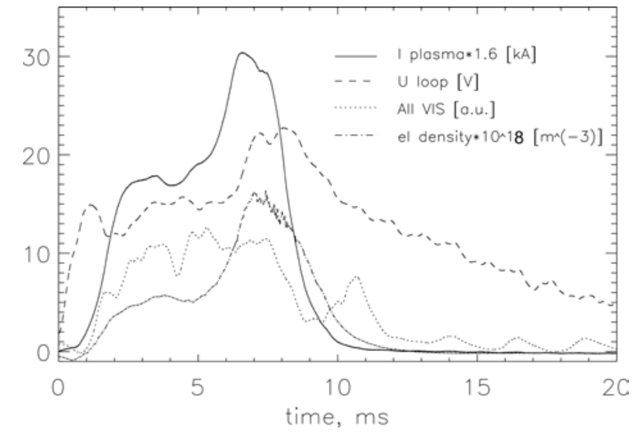

Figure 2. Evolution of main plasma parameters of a typical discharge (#1618) at the COMPASS tokamak. Temporal evolution of the plasma current (kA), line averaged electron density (10^{18} m^{-3}), the loop voltage (V) and integral visible plasma radiation (a.u.) during the discharge are shown.

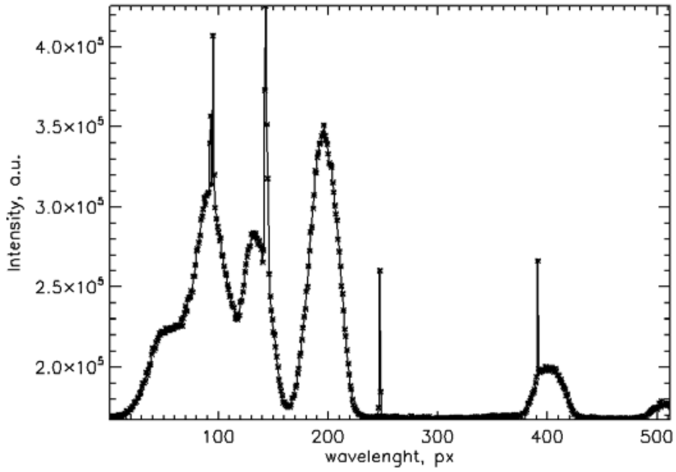

Figure 3. Spectrum recorded from the horizontal port.

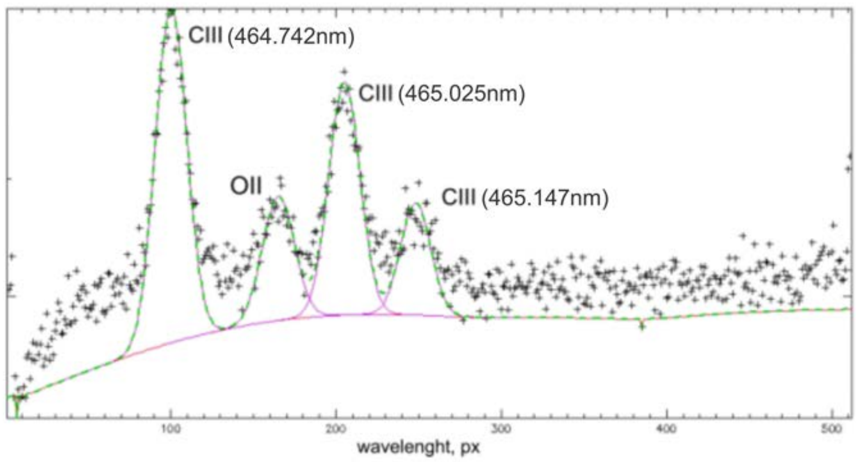

Figure 4. Spectrum recorded during the discharge #1618 from the top outer diagnostic port. The peak wavelengths for carbon triplet of double ionized carbon are indicated.

because of the plasma interaction with graphite tiles, which cover bottom of the COMPASS vessel (divertor tiles) and its central column. Another impurity line, a weak OII line (464.914 nm), is also nicely identified in the spectrum.

To isolate the individual CIII spectral lines from the non-linear background noise, the peaks are fitted by Gaussian curves. Finally, the full width at half maximum of spectral line (FWHM) of all CIII triplet lines is determined. The temperature of double ionized carbon ions can be deduced from the FWHM according formula [*Naydenkova et al,* 2009]. By the same fitting procedure, the relative intensities of the triplet lines with respect to the line 464.742 nm are determined as well.

The values of the ion temperature, given in the table, are in the range of 30–35 eV, which can be expected at the plasma edge. They are also close to those measured by the same spectrometer on the ISTTOK tokamak [*Gomes et al,* 2003]. The upper limit of the ion temperature of O II ions was estimated as ≈ 50 eV. Results shown in Table 2 are upper limits of the ion temperature of CIII ions, because a small instrumental broadening was not taken into account [*Gomes et al,* 2003].

The relative intensities of the CIII triplet lines determined from the NIST (National Institute of Standards and Technology) atomic database [*Wiese,* 2003] are also shown in Table 2. It is seen that the relative intensities measured by the spectrometer are in a good concordance with those predicted.

Table 2. Results of fitting of the CIII triplet lines. Tabulated values of relative intensities of the carbon triplet with respect to the line 464.742 nm were taken from the NIST atomic database [*Kelleher et al*, 1999]. The last column shows ion spin transitions for a given line.

Wavelength, nm	$FWHM_{Dopp+inst}$, nm	T_i, eV	Relative intensity measured	Relative intensity NIST	J_i-J_k
464.742	0.063	34.0	1	1	1-2
464.025	0.06	33.6	0.88	0.87	1-1
465.147	0.058	31.5	0.51	0.62	1-0

Conclusion

The first measurements of ion temperature from the data measured from the top outer diagnostic port were successfully performed using the high-resolution spectrometer installed on the COMPASS tokamak. Higher resolution was received thanks to the installation of a new camera with smaller pixels and higher sensitivity. The CIII edge ion temperature was estimated as 33 eV. However, for more precise measurements of Ti, the instrumental broadening of the spectrometer has to be determined in the given range of wavelengths [*Gomes et al,* 2003].

Currently, the optical system is under re-installation to make possible to measure the plasma rotation in the poloidal direction from the Doppler shift of C III line by collecting light emission from all available ports, as it is shown in Figure 1.

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