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Spectroscopic Characterisation of W7-AS Island Divertor Plasmas

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Introduction

The stellarator W7-AS, equipped with ten discrete island divertor modules and an equal number of special control coils, allows access to a new advanced operational regime, the High Density H-mode (HDH) [1]. This NBI-heated high density regime benefits from high energy confinement, good density control and low impurity confinement. Characteristics for the HDH-mode are rather flat density profiles, large edge density gradients and localised radiating zones in the edge region. For detailed studies of the processes governing the functioning of the island divertor, a number of new spectroscopy based divertor diagnostics have been installed on W7-AS.

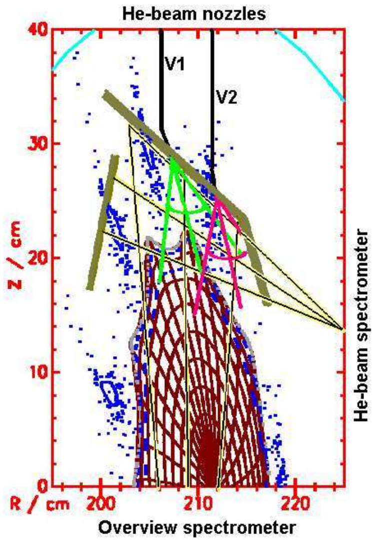

Figure 1: Line of sights for the two spectrocopic systems. 'V1' and 'V2' are the two valves for the Thermal He-beam diagnostics. Also shown are the cone-angle(42^0) expected for the He-beam

Passive spectroscopy for Island divertors

Figure 1 shows the lines of sight of two spectrocopic systems, which view the upper divertor module of W7-AS. The 'He-beam spectrometer' (optimised for the observation of the thermal He-beam, described later), viewing tangentially to the target plate in radial direction, probes the region between the target plate and the separatrix of the main plasma ($\Delta z = 9cm$). This region is imaged directly through a narrow cutout in the outer baffle onto the entrance slit of a spectrometer via two mirrors which are located inside the vacuum vessel. The detection system consists of a UV-Vis-IR achromate as imaging optic, a low resolution spectrometer (f=190 mm f/D = 4) with a triple grating, and a back-illuminated frame transfer CCD camera with 512 X 512 pixels. The time resolution of the system can be adapted to the requirements of the experiments. It is typically 25 ms (at 3 mm vert. res.) but could be increased at the expense of vertical resolution by binning larger numbers of rows on the CCD. Another spectrometer, the 'overview spectrometer', can view radially across any of the target plates in the same divertor module by tilting the imaging optic which is coupled to a linear array quartz fibre bundle. The other end of the fibre bundle is coupled to a spectrometer with a higher resolution (f=320 mm). Both spectrometer systems have been calibrated for absolute intensity measurements.

Radiation during detachment

In W7-AS, the bolometer arrays measured 10-90 % of the input power in various configurations, the highest fraction being observed in the detached discharges. From the tomographic reconstruction of bolometer signals for detached discharges, it was observed that the radiation is asymmetric in the poloidal plane [2]. The data from the bolometer array at the bottom divertor shows a highly radiating zone (Figure 2), when the magnetic field is reversed ($+B_0$). The observation of the same kind of zone, during the normal field ($-B_0$), by the spectrometers viewing the top divertor suggests that E X B drift effects might be responsible for the observed up/down asymmetry [6].

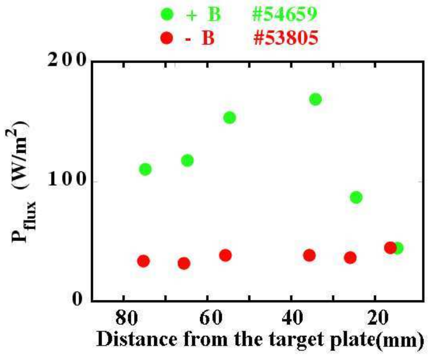

Figure 2: Radiation recorded by bolometer at bottom divertor for detached discharges

Carbon emission front

In the divertor region, where carbon is the main impurity (from graphite target plates), the spectrometers routinely record the emission lines of CII and C III. Figure 3 shows the location of the C II (5143 Å) radiation front from the He-beam view. In the case of attached plasmas (# 51040) the radiation front remains near the target plate and when the plasma detaches (# 51050) the front jumps up towards the separatrix. During the detached phase, the intensity of the line radiation from the different ionisation stages of carbon is found to be less compared to the attached cases. While the

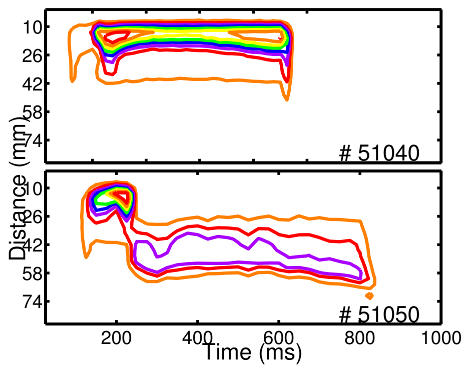

Figure 3: Emission zones of CII 5143 Å near the target plates during attached and detached plasmas

bolometers show a highly radiating region close to the target plate (<50 mm) the He-beam spectrometer surprisingly shows that the maximum C II radiation is emanating only from a region beyond a distance of about 60 mm from the target plate(see Figure 4), when the plasma is detached. This is an indication of recombination close to the target plate. The strong increase of H-β radiation in that region, as shown in the Figure 4, which follows the increase of neutral pressure [3] to very high values (compared to the bottom divertor), monitored by the manometers [4] [5] behind the target plates on the top divertor also suggest the same. Recombination requires very high densities and very low temperatures, which have actually been estimated from the Balmer series emission characteristics as shown in the next section.

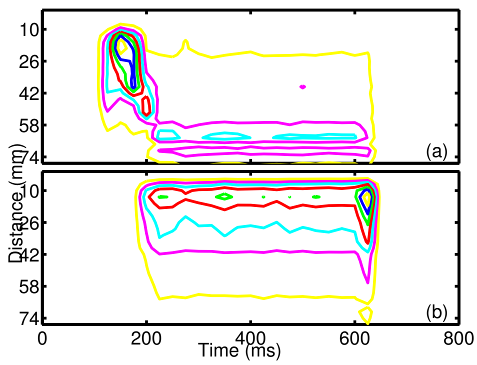

Figure 4: (a) shows C II and (b) shows H-β from # 52611.

Balmer Spectrum emission

Figure 5 shows an example of the Balmer Spectrum recorded during detached pulses. From these spectra, line-averaged densities were estimated from the Stark broadening [7] of a high quantum number (n=8) Balmer line. The values ranged between $2-8\times10^{20}m^{-3}$, with the highest being observed about 10-16 mm from the target plate. This region has been identified as a recombination zone above. The temperatures, estimated from the ratio of continuum emission near the series limit, ranged between 1.3-3 eV while from the Boltzmann Plot it was between 0.1-0.3 eV. The reason for these different values may be due to the inhomogenity of the plasma in the line of sight. During attached plasma scenarios higher quantum number ($n > 6$) Balmer lines were not seen, which is due to the prevailing high temperatures.

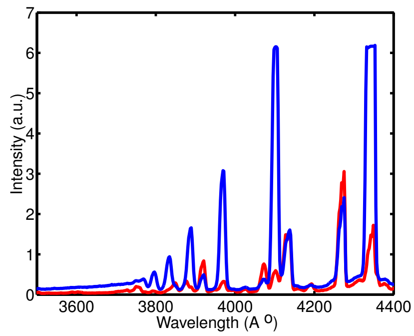

Figure 5: Typical Balmer spectrum from # 51315. red – no detachment and blue – detached.

Active Spectroscopy - Thermal He-beam Diagnostics

To explore the plasma characteristics locally in the edge island region an active thermal helium beam [8] was installed and tested in the recent experimental campaign. He-gas from a pressure controlled reservoir is puffed into the torus using two independently operable nozzles which are integrated into one of the target plates in the upper divertor module as shown in Figure 1. One of them directs the gas towards the X-point region; the other one directly into the island. The He-beam spectrometer allows simultaneous observation of three temperature and density sensitive spectral lines of He I (6678, 7061,7283 Å). From the line intensity ratios ($\frac{I_{7061}}{I_{7283}}$ for T_e and $\frac{I_{6678}}{I_{7283}}$ for n_e), the values of T_e and n_e were estimated using tabulated intensity ratios for different combinations of T_e and n_e values using the collisional-radiative model for He I [9]. From the preliminary results, the T_e and n_e profiles measured vertically below the target between two islands (X-point region) and across an island by using either of the two nozzles show a clear difference (Figure 6). The bump in the n_e values from the valve V2, which is not present in the other one, is suspected to be due to the island. The experimental results also show an increase in n_e values with an increase in the He-gas reservoir pressure (from where it is puffed into the torus), while the T_e values decrease. This suggests that the He-gas gets accumulated in the island and increases the local density by more ionisation, thus decreasing the T_e is not surprising since an increasing number of He-atoms gets ionised inside the island. A detailed modelling is still pending to explain these results.

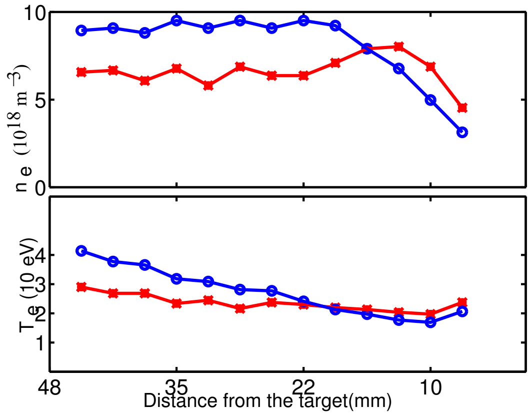

Figure 6: n_e and T_e values from Thermal Hebeam Diagnostics 'o'(blue) is from the x-point region (# 53763) and '' (red) is from the island region (# 53762)*

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