

Radiation profile measurements for edge transport barrier discharges in the Compact Helical System

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Introduction

The formation of an edge transport barrier (ETB) has recently been found in the Compact Helical System (CHS) plasmas heated by neutral beam injection (NBI) with strong gas puffing [1]. This regime is characterized by the appearance of the steep gradient of the electron density near the edge accompanied by the abrupt drop of hydrogen Balmer alpha (H_{α}) line intensity. The behaviors of impurity ions in the presence of transport barriers are of great importance from the viewpoint of the power balance. In this study we have measured the spatial profiles of the radiation power in the ETB discharges by an absolute extreme ultraviolet (AXUV) photodiode array. The impurity behaviors are discussed based on the radiation profiles and the vacuum ultraviolet (VUV) spectra measured by a grazing incidence spectrometer.

Diagnostics

CHS is a medium-size helical device whose average major and minor radii are 1 m and 0.2 m, respectively. The magnetic field strength at the axis is fixed at 0.9 T in this study. The lines of sights of the AXUV photodiode array have been arranged within a horizontally elongated cross section as shown in Fig. 1. A compact mounting module including an in-vacuum preamplifier has successfully been designed and fabricated for the photodiode array [2]. In the present data acquisition system, only 12 channels out of 20 can be measured simultaneously as numbered in Fig. 1. On the other hand, the total radiation power from the plasma is routinely monitored by a single channel pyroelectric detector with a wide viewing angle.

We have utilized an existing flat field graz-

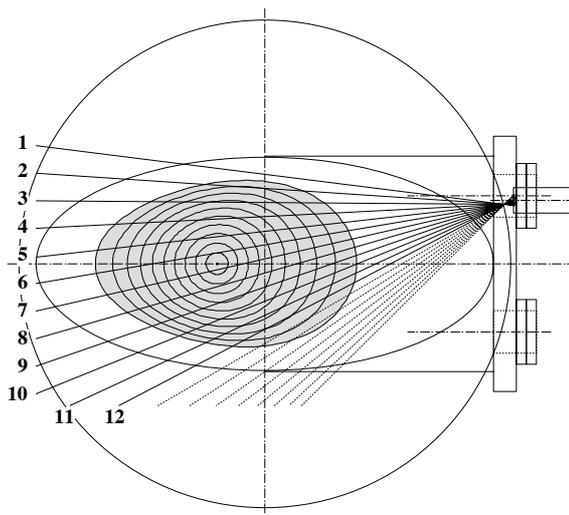


Figure 1: Lines of sights of the AXUV photodiode array and the flux surfaces of the plasma.

ing incidence spectrometer (Shinku-Kogaku, model JYF-306) for the survey of VUV spectra in the wavelength range of 10–110 nm at a spectral resolution of 0.3 nm [3]. The viewline of the spectrometer is fixed at a line passing through the plasma center within a horizontally elongated cross section. Time evolutions of the impurity line intensities can be obtained in a single shot at 10 ms intervals.

ETB discharge

The time traces of the parameters in a typical ETB discharge are shown in Fig. 2. The magnetic axis position and the toroidally averaged ellipticity in this case are $R_{ax}=92.1$ cm (in major radius) and $\kappa=1.22$, respectively. The discharge was initiated by electron cyclotron heating (ECH) followed by dual co-NBI heating at a total power of 1.24 MW. The amount of the hydrogen gas puff was ramped down so as to avoid an excessive increase in the electron density.

A spontaneous transition to the ETB phase occurred at 70 ms with an abrupt drop of $H\alpha$ intensity followed by the steeper increases in the total radiation power (Pyro) and the line-averaged electron density. The steep density buildup only near the edge ($\rho>0.5$) has been verified by Thomson scattering and other diagnostics [1]. The electron density in the core region ($\rho<0.5$) is almost kept constant. On the other hand, the profile of the electron temperature (400 eV at the center) is almost unchanged

at the transition. This density pedestal formation results in the increase in the stored energy through the improved power deposition and energy confinement time in spite of the increased total radiation power [4]. The signals of all the channels of the AXUV photodiode array also increase more steeply at the transition. The line averaged emissivity for the two lines of sights are displayed in Fig. 2 (c). A back transition occurred just after the termination of the one NBI (at 123 ms)

because the heating power was reduced below the threshold.

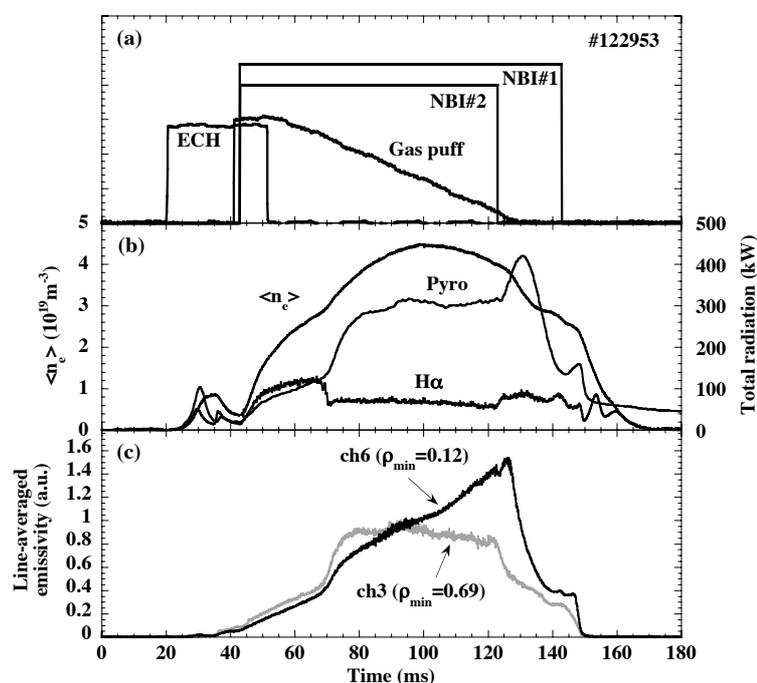


Figure 2: Time traces of the parameters for a typical ETB discharge. Line averaged emissivity measured by the AXUV photodiode array is shown in (c) for the two lines of sights.

Radiation profile

The difference between the two signals in Fig. 2 (c) indicates the change in the radiation profile immediately after the transition. The temporal variation of the spatial distribution of the line averaged emissivity is shown in Fig. 3 for channels 2–6 (see Fig. 1) at 5 ms intervals. The horizontal axis is expressed by the minimum minor radius along the line of sight. Note that the slightly hollow distribution just after the transition (at 75 ms) in Fig. 3 means that the radial profile is actually more hollow. The relatively low emissivity for channel 2 may be due to the degradation of the photodiode sensitivity for low energy photons near the boundary. This observation indicates that the radiation power tends to increase especially near the edge just after the transition. Then it gradually changes into the flattened one, which can be commonly seen even in the discharges without ETB. Since the number of the lines of sights is not enough for the Abel inversion, it is difficult to judge from this result that the impurity ion density increases due to the formation of the ETB. The time evolution of the VUV spectra described in the next section gives an answer to this question.

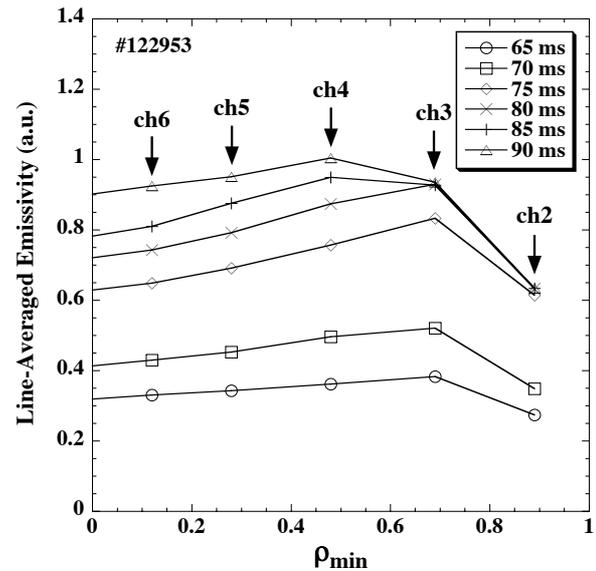


Figure 3: Spatial distribution of the line averaged emissivity in the same discharge as Fig. 2. The minimum normalized minor radius along the viewline is chosen as the horizontal axis.

Impurity line intensities

We have observed VUV spectra in the ETB discharges in order to examine the individual impurity line intensities. Several resonance lines of metallic (iron, chrome, titanium) and oxygen impurities are identified from the measured spectra. The temporal evolutions of the intensities of several representative lines in an ETB discharge of the same configuration are plotted in Fig. 4 at 10 ms intervals together with the AXUV photodiode signal for the channel 6. The transition occurred at 73 ms in this discharge, and the signals are normalized to those just before the transition (at 65 ms). The line intensities of all impurities increase more steeply just after the transition in the same way as the radiation emissivity. The energies required for the ionization into Fe XV, Cr XIII, Ti XII and O V (from the previous charged states) are 392, 298, 265, and 77 eV, respectively. Therefore three metallic impurity lines appear to represent mainly the radiation from the

core region. Since the electron density in the core does not change at the transition, the metallic impurity ion densities actually seem to increase inside the transport barrier. On the other hand, O V line appears to be emitted from the edge region where the electron density largely changes. Though changes in metallic impurity transport coefficients inside the ETB are inferred from the VUV spectra, numerical simulations of impurity transport are required for the quantitative analyses.

Summary

We have measured the spatial distributions of the radiation emissivity in the ETB discharges in CHS by using an AXUV photodiode array. The radiation profile rapidly changes into more hollow one immediately after the spontaneous transition to the ETB phase, which implies the impurity transport is reduced near the plasma boundary due to the ETB formation. This implication is supported by the observations of the time evolutions of the metallic impurity line intensities from the plasma core. Quantitative analyses of impurity transport based on numerical codes is required in the future work.

Acknowledgments

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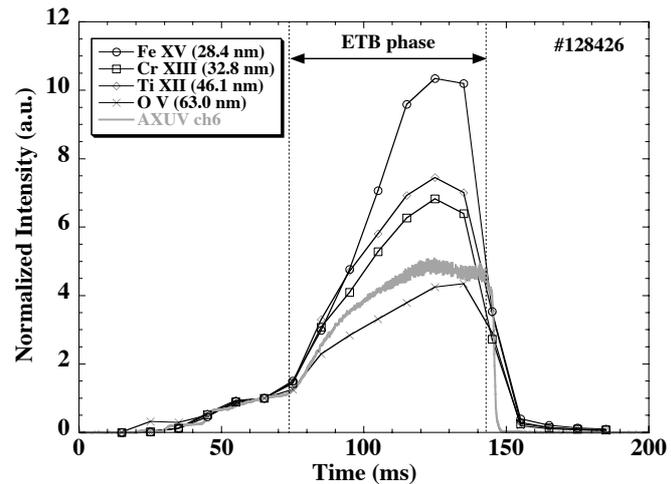


Figure 4: Temporal evolutions of several representative impurity line intensities in an ETB discharge. AXUV photodiode signal for channel 6 is also shown.