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Local emission and core concentration of tungsten in TEXTOR-94 plasmas operated with tungsten test and poloidal limiters

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Abstract

The correlation between the local WI light emission from W limiters and the W quasi-continuum light emission from the core plasma measured by the XUV spectrometer was investigated in the TEXTOR-94 limiter tokamak. The W quasi-continuum light emission showed a linear dependence against the line spectrum emission from neutral W from the metallic test limiter immersed in neutral beam (NBI) heated plasmas. The surface of the poloidal limiter made of vacuum-plasma-spray coating of W (VPS-W) was covered by a carbon layer during the time it was kept in the shadow of graphite ALT-II limiter. As a result of the carbon coating, the contribution to the W quasi-continuum intensity by the poloidal limiter was smaller than that by the test limiter, despite the fact that the surface area of the poloidal limiter facing the plasma was about seven times larger than that of the test limiter. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Limiter materials; Tungsten; TEXTOR; High-Z material

1. Introduction

Experiments with W-coated divertor plates have been done at ASDEX-U to clarify the potential problems associated with the use of W for divertors [1]. In TEXTOR-94, fundamental processes of interaction between the plasma and high-Z material surfaces have been investigated using test limiters under various edge plasma conditions [2]. High-Z test limiters were made of pure metal, and the durability of the pure material in the tokamak edge plasmas has been one of the extensively studied topics [3]. The vacuum-plasma-spray coating of W (VPS-W) on carbon realizes lighter plasma facing components than those made of metallic W, and the VPS-W has been tested for its performance as the surface of the poloidal limiter of TEXTOR-94 [4].

Plasmas were successfully maintained with the minor radius determined by the W poloidal limiters provided the plasmas were heated with neutral beam heating

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(NBI) or ion cyclotron heating. Under the ohmic heating condition with the electron density exceeding about 3.5×10^{13} cm^{-3}, the high-*Z* accumulative instability was observed like the case of a W test limiter [5]. However, the instability occurred less frequently for plasmas with the poloidal limiter than those with the test limiter positioned at the same distance from the plasma center. The reason can be the smaller release of W into the edge plasma from the poloidal limiter than that from a test limiter, but this assumption has not been verified as these limiters were used separately under some different discharge conditions.

Therefore, both poloidal and test limiters were put into TEXTOR-94 to compare their impact on the core W concentration under the identical discharge conditions. Attempts were also made to estimate the local release by spectroscopy. The relative contribution by W release from the poloidal limiter on core W concentration was estimated by comparing the difference in XUV-W signals due to the change of the positions of test and poloidal limiters.

2. Experimental setup and procedure

The toroidal belt limiter, ALT-II, was always located at the nominal minor radius of 46 cm, while the poloidal limiter was moved further into the plasma. The surface of the poloidal limiter was made of a 0.5 mm thick VPS-W coating deposited on graphite with an Re interlayer. The test limiter was made of pure solid W and its position was controlled by the LIMLOCK system [6]. The geometrical surface areas of these limiters facing the axis of the minor radius were about 3×10^4 cm^2 for ALT-II limiter, 700 cm^2 for the poloidal limiter, and 100 cm^2 for the test limiter, respectively.

In addition to the routine core plasma diagnostics, an XUV spectrometer system was installed to detect the radiation in the spectral range from 1.5 to 7.2 nm. The XUV spectra were recorded by integrating the detector signal for 0.1 s. The edge electron temperature and density were measured by He atomic beam spectroscopy [7], and the radiation profile was measured by bolometer arrays. The local emission of W neutrals from limiters was measured by spectroscopy. One spectrometer was aligned to observe the surface of the test limiter from outside of the torus. The other spectrometer was arranged to tangentially observe the surface of the poloidal limiter from the toroidal direction. CCD cameras were used to measure the spatial distributions of WI neutrals around the limiters by observing the WI emission at 400.9 nm with 1.5 nm bandwidth optical interference filters. The current flowed through the test limiter, and those through the center blocks of the top and bottom rows of the poloidal limiter were measured from the voltage drop across resistors.

TEXTOR-94 was operated with $Ip = 340$ kA and $Bt = 2.23$ T. After the discharge was established the plasma was heated with NBI at the power of 1.3 MW from 0.4 to 1.4 s. During this time, the electron density and temperature were kept constant at 0.85 keV and 4.2×10^{13} cm^{-3}, respectively. Then the plasma was sustained with ohmic heating. The test limiter was located at 46 cm minor radius from the beginning until the end of all discharges except for the case when only the W emission from the poloidal limiter was evaluated. In shots 83357 and 83358, the poloidal limiter was positioned at minor radius larger than 46 cm, and the plasma minor radius was determined by ALT-II limiter during the entire period of discharge. In the following four discharges, 83359, 83360, 83361 and 83362, the poloidal limiter was positioned at 46 cm minor radius at the start to find the contribution to the core W signal. In these shots, the poloidal limiter was moved up to 44, 43, 42.5 and 42 cm minor radii shot by shot after turning off the NBI heating at 1.4 s.

3. Results

3.1. Behaviors of highly charged ions in the core plasma

The W quasi-continuum from highly charged W ions was detected by the XUV spectrometer together with line spectra of C and O ions, as shown in Fig. 1. The background was subtracted from the spectrum and the intensities of the line and band-like spectra were calculated by integrating the signal over the wavelength regions of the corresponding spectra. For the W quasi-continuum, the signal from 4.5 to 7 nm was integrated. Fig. 2 shows the measured time history of the intensities of these signals. In this shot the poloidal limiter was kept at 48 cm, which was 2 cm outside of the LCFS

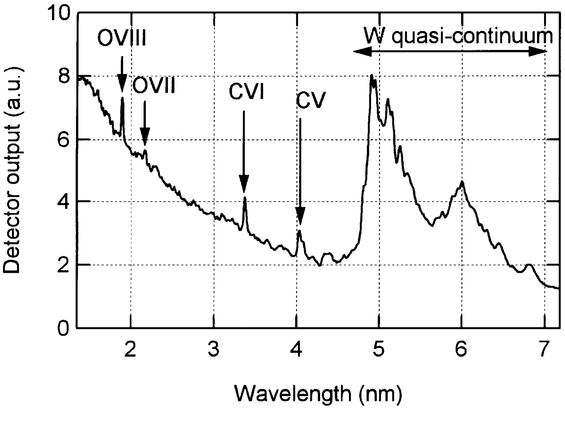

Fig. 1. A typical spectrum of TEXTOR-94 core plasma obtained by the XUV spectrometer.

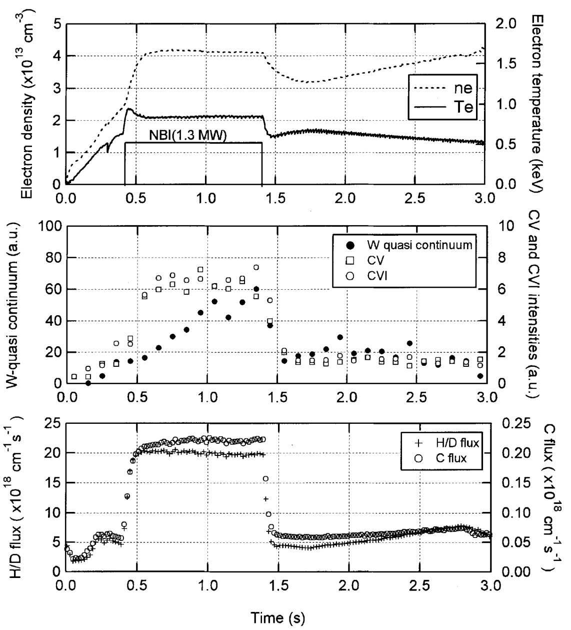

Fig. 2. Top panel: the line averaged electron density and temperature at the plasma core; middle panel: signals from the XUV spectrometer; and bottom panel: H/D flux and C flux measured at the ALT-II limiter. The flux signals were integrated along the distance of the line of sight.

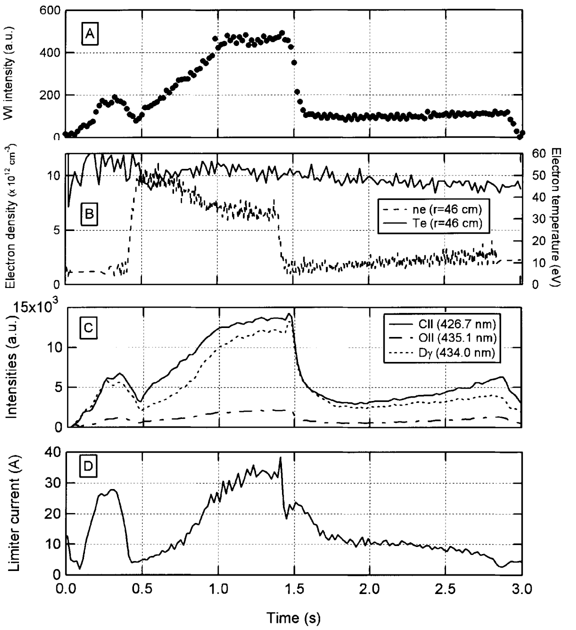

Fig. 3. A: WI light spectrum integrated in the region beyond the LCFS near the test limiter; B: electron temperature and density at 46 cm minor radius measured by He atomic beam spectroscopy method; C: line spectrum intensities of D_γ, C and O; and D: the current flowing in the test limiter.

determined by ALT-II limiter. The figure also shows the electron density and temperature of the core plasma with the NBI heating power. The signals of highly charged carbon ions increased with a short time constant as the NBI pulse was turned on. Meanwhile, the integrated signal of the W quasi-continuum showed an increase with a longer time constant.

3.2. W release from the test limiter

Penetration of W from the test limiter into the edge plasma was estimated by integrating the WI light intensity in the region beyond the LCFS. This integrated WI light intensity is plotted as a function of time in Fig. 3 for shot 83357 with the poloidal limiter withdrawn outside of the LCFS. Together with the neutral W signal, the local plasma parameters at 46 cm minor radius measured by the He beam method are plotted. The WI intensity showed a slow increase while both the electron temperature and density decreased slowly following a sharp increase at the start of the NBI heating.

In the TEXTOR discharge conditions, the plasma contains C and O impurities amounting to 1–3% of H/D fluxes, and these light impurity ions also contribute to the sputtering of W at limiter surfaces. When D_γ, CII and OII line spectra at the surface of the test limiter were measured to estimate the corresponding particle fluxes onto the limiter, they showed an increasing time dependence as shown in Fig. 3. Their behaviors were similar to that of the neutral W flux, and the current flowed through the test limiter.

3.3. Correlation between XUV signal and WI emission

The W quasi-continuum in the XUV signal was compared with the local WI emission from the test limiter with the poloidal limiter withdrawn outside of the LCFS. The result is shown in Fig. 4. Open circles in the figure show the correlation during the NBI phase of the discharge and they show a linear dependence. As the electron temperature and density at the plasma center were constant during the NBI heating, the core concentration of W should be proportional to the intensity of the W quasi-continuum. The W concentration estimated from the radiation profile and the data given by Post et al. [8] was about $n_W/n_e = 6 \times 10^{-5}$ at the maximum W quasi-continuum intensity in Fig. 4. Contrary to the case of NBI heating, neither the WI signal from the limiter nor the W quasi-continuum signal changed substantially during the ohmic phase of the discharge until 3 s.

The correlation between the WI emission and the W quasi-continuum intensities was plotted with closed circles for the case that the poloidal limiter had been

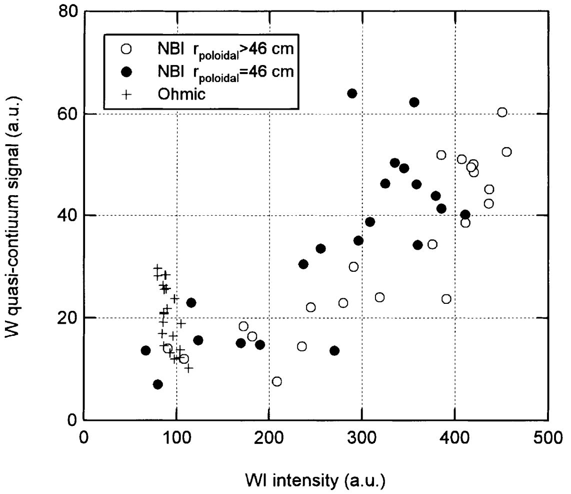

Fig. 4. Correlation between the integrated intensity of the W quasi-continuum and the neutral WI line emitted from the test limiter. The open circle data were taken with the W poloidal limiter withdrawn beyond the LCFS, while the closed circle data were taken with the W poloidal limiter positioned at the LCFS determined by the ALT-II.

moved up to 46 cm minor radius during the NBI. A small increase in W quasi-continuum intensity can be recognized in this figure indicating that some W neutrals are released from the poloidal limiter. When the test limiter was withdrawn to 48 cm minor radius and the poloidal limiter was placed at 46 cm minor radius, the W quasi-continuum signal from the plasma with similar plasma parameters was detectable during both NBI and ohmic heating phases of the discharge. The maximum intensity of the quasi-continuum signal for the plasma operated only with the poloidal limiter was estimated to be smaller than 30% of the signal with the test limiter located at 46 cm.

After turning off the NBI, the poloidal limiter was moved further into the plasma than the ALT-II and the test limiters. The W quasi-continuum intensity was plotted as a function of the poloidal limiter position in Fig. 5 with the intensity of the WI light in the region beyond the LCFS around the test limiter, and the intensity of the WI light on the center block of the top row of W poloidal limiter. Contrary to the WI light from the test limiter, the integration of WI light from the poloidal limiter has been done without the assignment of the location of LCFS, as the shape of the poloidal limiter was more complicated than that of the test limiter. As the signals were weak, they were integrated for 1 s during the ohmic heating phase. The figure shows that the release from the test limiter has affected the central W concentration more than that from the poloidal limiter.

From the comparative study, the W release from the test limiter was found more influential to the W quasi-continuum signal than that from the poloidal limiter, though the surface area of the poloidal limiter was larger and it was inserted deeper into the plasma than the test limiter. An investigation on the WI light emission from the poloidal limiter was conducted, and the formation of a C coating on the VPS-W surface on the limiter arising from the C flux from ALT-II main limiter during discharges with the poloidal limiter withdrawn outside of the SOL was confirmed [9]. The top surface of the test limiter exposed to the plasma was essentially a pure W layer even after the test limiter was positioned beyond the LCFS and then exposed to the plasma [10]. The difference in W release rate due to the surface condition between the two limiters can cause the difference in W concentration in the core plasma.

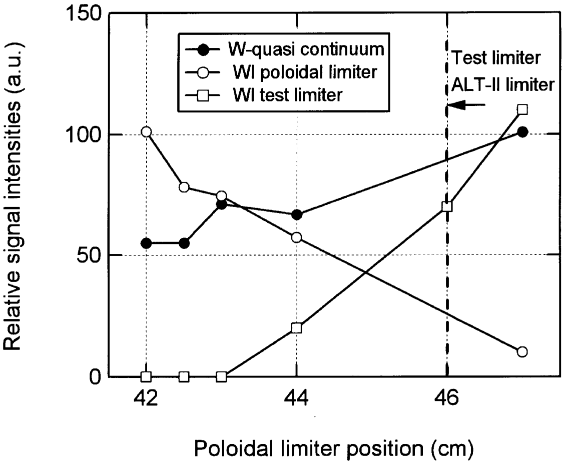

Fig. 5. Time averaged signals of WI emission from the test limiter, WI light intensity at the surface of the poloidal limiter, and the W quasi-continuum plotted as functions of poloidal limiter position. Test limiter and the ALT-II were located at 46 cm.

4. Conclusions

The correlation between the W quasi-continuum and the WI light emission near the test limiter was confirmed for NBI heated discharges. Under the condition that the core W concentration was proportional to the WI light near the test limiter, the effect to the W quasi-continuum due to the W poloidal limiter was investigated. Despite the larger surface area, the contribution by the poloidal limiter to the W quasi-continuum intensity was less than that by the test limiter. This is mostly due to a coating of the W surface with carbon from background carbon impurity in the edge released from the graphite PFC. The present result shows that the local W emission from high-Z PFC can be largely determined by the influence of the all-carbon wall surrounding. Although carbon impurity can increase the W emission by sputtering, carbon deposition on top of the W coating can effectively reduce the W source. Thus one has to be careful in drawing conclusions about the use of high-Z PFC from small-scale experiments in which surfaces are still largely determined by graphite material. When the W emission from the VPS-W PFC is reduced in C surrounding environment, it can realize more stable operation of plasmas than the metallic W PFC.

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