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Dependence of deuterium line-shape on the insertion depth of BN and C limiters in the TPE-1RM20 reversed field pinch plasma

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Abstract

Boron nitride (BN) and graphite limiters were placed in the edge region of deuterium plasma of the reversed-field-pinch machine TPE-1RM20. The limiters were attached on a linear motion feedthrough and were inserted into the edge plasma up to 40 mm beyond the plasma boundary defined by fixed limiters. The emission spectrum of deuterium atoms was measured in the vicinity of the limiters. The spectral line profile was analyzed by changing the insertion depth of the limiter. When the limiter was inserted a certain depth for the first time, the emission of hydrogen atoms was observed for both BN and carbon materials and the release of retained hydrogen was evident. The emission intensity of hydrogen was suddenly decreased within 3–5 shots for the case of BN limiter, and then, the peak was buried under noise. The broadened spectrum of deuterium was observed when the BN limiter was inserted up to approximately 30 mm. The amount of released hydrogen from the graphite limiter was 2–3 times larger than that from BN limiter and the release continued for 5–10 shots. The profile of deuterium line was changed with shot by shot compared to the BN limiter experiments. A broadened profile was observed when the insertion depth exceeded 30 mm.

1. Introduction

High heat flux experiments on plasma-facing materials provide important information for nuclear fusion reactor design [1]. In our TPE-1RM20 reversed field pinch (RFP) machine [2], a vacuum vessel (stainless steel) was protected by molybdenum (Mo) limiters. Our previous study focused on the interaction between the Mo limiter and the boundary plasma [3]. To avoid the contamination of carbon, a graphite limiter had not been inserted into the plasma. However, boron nitride (BN) and graphite limiter experiments were performed recently before the shut down of the machine. Those limiters were inserted up to 40 mm into the deuterium RFP plasma.

The strong interaction occasionally causes plasma disruption. To reveal the mechanism of disruption, the spatially resolved observation of the emission line profile is useful to analyze local phenomena. The line profile of carbon and oxygen in front of a tokamak limiter was measured [4]. For carbon atoms, chemical sputtering dominated at low boundary temperatures and physical sputtering became significant at high temperature [4].

In the present experiment, an emission spectrum around the wavelength of 656 nm was observed in the vicinity of the limiter by varying the insertion depth. The emission of hydrogen released from the limiter was apparent. A broadened spectral profile of deuterium was observed when the limiter was inserted deeply.

2. Experimental

TPE-1RM20 is a RFP plasma confinement machine. The plasma is a torus structure with a major radius of 750 mm and a minor radius of 192 mm. The minor radius was defined by molybdenum limiters attached on the inside wall of the vacuum chamber. Deuterium gas

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was used and the filling pressure was approximately 0.2 Pa. The operation condition of the plasma was set to obtain a plasma current of 130 kA. The typical plasma duration was 10–13 ms. The plasma position for the direction along the major radius was controlled by a vertical magnetic field in order to reduce the interaction between plasma and fixed limiters.

The schematic diagram of the experimental setup is shown in Fig. 1. A movable limiter was attached on a linear-motion feedthrough. A BN (Denka, N-1) limiter head was used at the first experiment. Subsequently, a graphite (Toyo Tanso, CX-2002U) limiter head was attached by opening the vacuum chamber. The limiter heads were cylindrical structures, 20 mmϕ and 35 mm in length with a hemispherical tip. The insertion depth was changed by using the feedthrough. The stroke of the feedthrough was 50 mm. When the scale of the feedthrough $X = 10$ mm, the top of the limiter was placed at the same minor radius with those of fixed limiters.

Balmer-α emission of deuterium atom (D_α, 656 nm) on the limiter surface was measured through an optical window at the opposite side of the chamber as shown in Fig. 1. Spatial resolution at the limiter surface was measured to be approximately 3 mmϕ. The monitoring area was determined by using a telescope and was fixed to the center of the limiter head. The D_α line-broadening was analyzed by a 1 m double monochrometer (JASCO CT-1000D) with a gated image intensifier and a multichannel detector (Princeton Instruments). The gate of a multichannel photodetector was set at the flat top phase of a discharge pulse; delay from the ignition of plasma: 3 ms, gate width: 3 ms. The overall wavelength resolution was approximately 0.013 nm.

3. Results and discussion

3.1. BN limiter

Observed spectra for shots #84511, #84512, #84513, #84514 and #84515 are shown in Fig. 2. These spectra were observed when the BN limiter was inserted up to 5 mm beyond the plasma surface ($X = 15$ mm). From the spectrum for #84511, a hydrogen line is apparent in addition to a deuterium line. Shot #84511 was the first experiment with the insertion depth of 5 mm. The hydrogen peak intensity decreased with shot by shot. Note that the shot #84510 was a misfire and therefore, the emission intensity of deuterium for shot #84511 was higher than for other spectra shown in the figure. When the limiter was inserted up to a certain depth for the first time, a hydrogen peak always appeared. Therefore, the release of retained hydrogen from the limiter is evident.

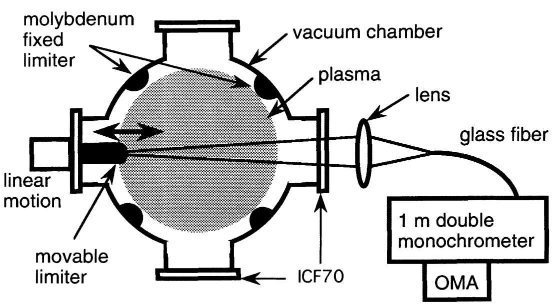

Fig. 1. Schematic of the experimental set-up.

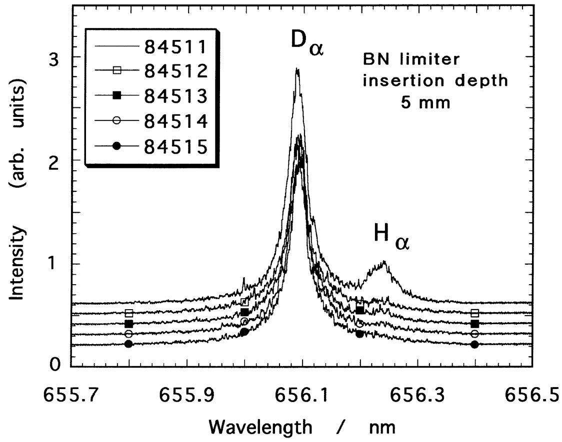

Fig. 2. Observed deuterium spectra for shots #84511, #84512, #84513, #84514 and #84515. The BN limiter was inserted 5 mm beyond the plasma surface defined by fixed limiters. The emission at the center of the limiter was observed. Shot #84511 was the first experiment with an insertion depth of 5 mm. The hydrogen peak was apparent at #84511. Its intensity decreased with shot by shot. Note that the shot #84510 was a misfire and therefore, the emission intensity of deuterium for shot #84511 was higher than the other spectra as seen in the figure.

The observed deuterium spectrum exhibited line-broadening. The line width (FWHM) is plotted versus the insertion depth in Fig. 3. The width did not broaden up to the insertion depth of ~20 mm ($X = 30$ mm), and then it increased suddenly for 20–30 mm. Further insertion led to a narrowing again. The broadening for the deeper insertion may be due to increasing charge-exchange deuterium neutrals produced from high energy deuterium ions. The intensity of the deuterium line is plotted in Fig. 4 as a function of the insertion depth. The intensity gradually increased from −10 to 20 mm, and then, suddenly decreased and increased again from 30 to 40 mm. In Fig. 5, the toroidal one-turn resistance of the plasma is plotted. The resistance increased between the insertion depth of 20–30 mm. The emission of boron was monitored and strong bloomings of boron were apparent when the limiter was inserted deeply. These results clearly shows that the interaction between the limiter and plasma affects the whole plasma. From these results,

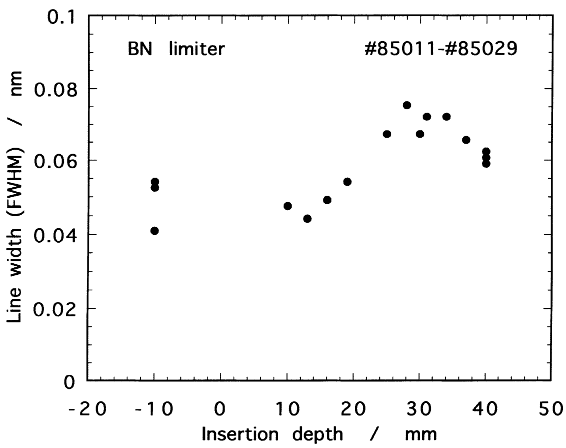

Fig. 3. The spectral line width of the Balmer-α line of deuterium as a function of insertion depth of the BN limiter. The same minor radius as the fixed limiters was regarded as the zero point of the insertion depth.

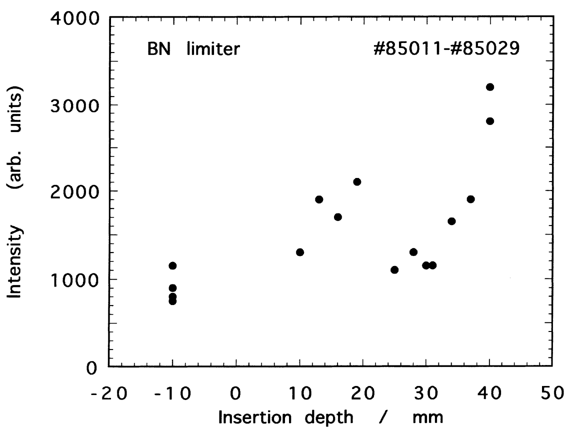

Fig. 4. The spectral line intensity of the Balmer-α line of deuterium as a function of insertion depth of the BN limiter.

we conclude that the phenomenon for the insertion depth up to 20 mm (10% of the minor radius) is local around the limiter and the tendency at 30–40 mm may be due to the cooling of the whole plasma.

3.2. Graphite limiter

The amount of hydrogen emission from the graphite limiter was larger than that from the BN limiter. This indicates that the retention of hydrogen is more significant in graphite. The release continued for 5–10 shots. Therefore, the wall conditioning is more important when graphite was used as plasma-facing materials. The

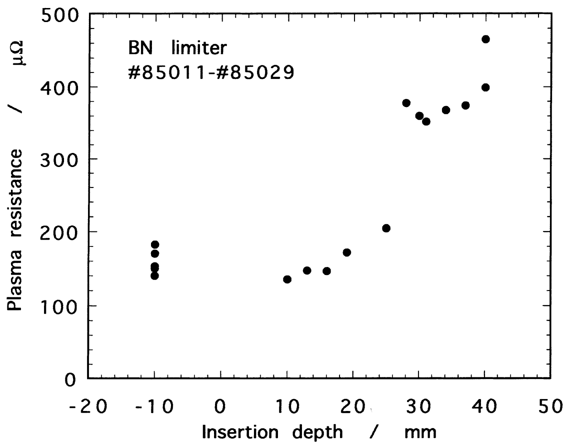

Fig. 5. Toroidal one-turn resistance of plasma at 4.5 ms as a function of insertion depth of the BN limiter.

measurement of surface temperature is needed for further analysis. The line profile of D_α changed with each shot, and a broadened profile was observed when the insertion depth exceeded 30 mm. In the present experiment for a graphite limiter, the apparent increase of the one-turn resistance of the plasma was not observed, even though the blooming of carbon was observed. To understand the mechanism, analysis of several plasma parameters such as the central electron temperature, temperature profile, impurity diffusion and etc. is needed.

4. Conclusions

BN and graphite limiters were inserted into the edge plasma of the RFP machine. The emission spectra around the Balmer-α lines of hydrogen and deuterium were observed. The spectral line width increased with the insertion depth of the limiters. Deeper insertion led to change of whole plasma when the depth exceeded 30 mm for the BN limiter.

References

[1] T. Tanabe, N. Noda, H. Nakamura, J. Nucl. Mater. 196–198 (1992) 11.
[2] Y. Hirano, Y. Yagi, T. Shimada et al., Plasma physics and controlled nuclear fusion research, Proc. 13th Int. Conf. on Plasma Phys. and Controlled Nuclear Fusion, vol. 2, IAEA, Washington, 1990, p. 717, and references cited therein.
[3] S. Sekine, Y. Hirano, Y. Yagi, T. Shimada, Y. Maejima, H. Shimizu, T. Tanabe, J. Nucl. Mater. 220–222 (1995) 1135.
[4] P. Bogen, D. Rusbüldt, J. Nucl. Mater. 196–198 (1992) 179.