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Journal of Nuclear Materials 337–339 (2005) 104–108
journal of nuclear materials
www.elsevier.com/locate/jnucmat

Tungsten limiter tests in ASDEX Upgrade

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Abstract

In order to prepare for tungsten coating to be applied to the low field side poloidal guard limiters, 1 μm W-coated CFC limiter tests have been performed in ASDEX Upgrade. The test limiters were exposed to H-mode deuterium plasmas with the neutral beam heating at maximum 5 MW for approximately 1 s. The power flux deposited on the test limiter was calculated by solving the 3-D heat conduction equation by using the measured time dependent surface temperatures as boundary conditions. The experimental results show that the heating with more radial NI beams leads to a higher local deposited power with a longer radial decay length related to banana particle loss. Strong localized W erosion was found at the tip of the test limiter due to arcing, which obviously depends on the neutral beam injection (NBI) geometry.

PACS: 52.40.Hf; 52.55.Fa
Keywords: Poloidal limiter; Tungsten coated carbon; Power flux; Erosion; ASDEX Upgrade

1. Introduction

High-Z materials such as tungsten (W) have been considered as a plasma facing material for a steady state burning plasma device like ITER [1]. To examine the feasibility of tungsten as a plasma facing material in future fusion research and reactor devices, the area of W-coated graphite tiles has been increased from campaign to campaign in ASDEX Upgrade. For this purpose a tungsten coated first wall and high heat flux components have been developed for application in ASDEX Upgrade [2]. Most of the experimental results in ASDEX Upgrade operated with large area W-coated fine grain graphite tiles indicate that there is no negative influence on the plasma performance [3,4]. For the goal of a full W machine, 12 poloidal guard limiters (CFC) on the low field side in ASDEX Upgrade will be also replaced by W coated limiters in the future. However, fast particle loss may lead to localized damage of the limiters on the low field side [5,6]. In ASDEX Upgrade the limiter glows on the low field side, as frequently observed in discharges with NBI, and/or ICRH-minority heating, and are attributed to fast ion loss resulting in high local power loads, which may become a problem with tungsten coated limiters. In order to understand better these effects, tungsten limiter tests have been performed with a W-coated CFC probe on a movable manipulator in the midplane of ASDEX Upgrade.

This paper describes experimental results on measurements of the power flux to the test limiter and the behavior of the W erosion in discharges with different

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0022-3115/$ - see front matter
doi:10.1016/j.jnucmat.2004.10.163

NI beams. It is reported that power flux in the far SOL region and the strong local W erosion due to arcing obviously depend on using NI beams related to banana particles loss.

2. Experimental methods

Test limiters were made from 3-D CFC(SEP N11) with 1 μm tungsten layer deposited by PVD. The size and the geometry of the test limiter are shown in Fig. 1. The front part of 15 mm length can be positioned in front of the ICRH protection limiter. It is shaped to have an angle of 45° to the toroidal direction for smoother deposition. The thickness of 15 mm in the vertical direction is about the size of the larmor radius of deuterons of 10 keV in a magnetic field of 2 T. To estimate the integral energy flow to the test limiter, it was designed as a calorimeter with two thermocouples mounted inside at 5 mm and 25 mm from the front surface, as shown by the dotted lines in Fig. 1(b). The test limiter was mounted on a movable midplane manipulator in ASDEX Upgrade, and positioned 15 mm in front of the ICRH protection limiter. The surface temperature distribution of the test limiter (only one side) was measured with a 2-D infrared camera. Details of the infrared camera diagnostic in ASDEX Upgrade are described in [7]. The power flux deposited on the test limiter was calculated by solving the 3-D heat conduction equation (ANSYS finite element code) by using the measured time dependent surface temperatures as boundary conditions. The test limiter is assumed to be thermally isolated during the discharge. Temperature dependent conductivity and heat capacity of the material are used, and the W thin layer was omitted in the calculation. In ASDEX Upgrade there are two neutral beam injectors (NBI-1 and NBI-2) displaced toroidally 180° to one another. Both injectors consist of two radial and two tangential beams. A more detailed description of NBI system is given in [8,9]. In order to investigate the influence of fast ion losses the same discharge parameters were repeated with neutral beam heating using NBI-1 and NBI-2, respectively.

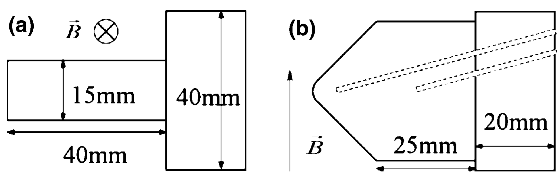

Fig. 1. The size and the geometry of the test limiter. (a) toroidal view, and (b) top view.

3. Results and discussion

3.1. Power deposition on the test limiter

Two test limiters were exposed in two similar H-mode deuterium discharges (#17428 and #17505) operated at $I_p = 1$ MA and $B_t = -2$ T with neutral beam heating by NBI-1 and NBI-2, respectively. The temporal behavior of the line averaged density, NBI heating power and $R_{sep} - R_{lim}$ of the midplane separatrix distance is shown in Fig. 2 for both discharges. In each discharge, two tangential beams were used for heating, one was operated from 1.0 s to 4.0 s at 2.5 MW, and another was added from 2.4 s to 3.3 s at 2.5 MW, therefore, there was a maximum power of 5 MW for the duration of 0.9 s. However, tangential beams used in #17428 have more central and radial injection than the one used in #17505 [8]. At the beginning of the discharge, the separatrix was moved towards the test limiter, and then quickly away from the test limiter, and finally kept at a distance of about 2.8–3.0 cm from 1.0 s to 2.9 s. The separatrix was moved radially away from the test limiter with a velocity of 0.01 cm/ms from 2.9 s to 3.3 s for measurements of the power flux decay length in the SOL.

Interesting experimental results were obtained by varying the neutral beam injection geometry with fixed heating power and duration of heating using the same plasma parameters. Shown in Fig. 3 is the temperature distribution on the surface of the test limiter at the time of 2.9 s of the maximum temperature for both discharges. The results show the presence of a maximum on the front upper part of the test limiter, around 2330 K for the case of the radial beams and 1980 K for the tangential beams. In fact, it is clearly found that there is a local erosion area on the front upper edge of the test limiter in the case of radial beams (see Fig. 6). Moreover, similar local damage was observed in the W-uncoated CFC test limiter with the same geometry. Therefore, although the local inhomogeneous heat

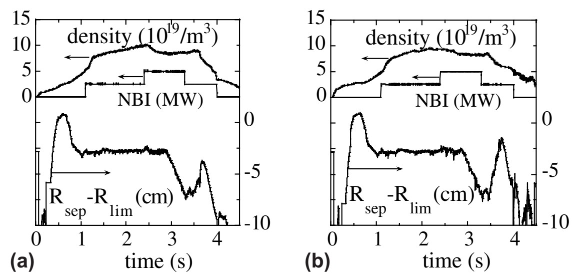

Fig. 2. The temporal behavior of the line averaged density, NBI heating power and $R_{sep} - R_{lim}$. $R_{sep} - R_{lim}$ means the midplane distance between the separatrix and the test limiter. (a) for #17428. (b) for #17505.