

**OPEN ACCESS**

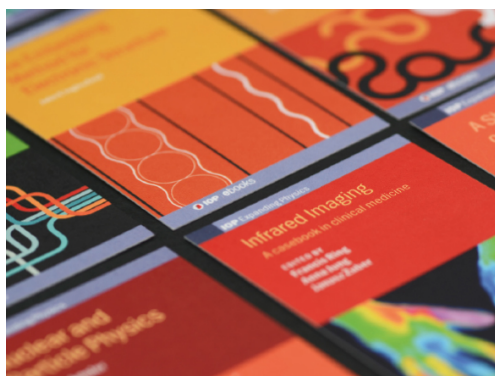
# A test of nitrogen-assisted plasma discharges for fuel removal from plasma-facing components in tokamaks

To cite this article: P Sundelin *et al* 2008 *J. Phys.: Conf. Ser.* **100** 062027

View the [article online](#) for updates and enhancements.

## Related content

- [Survey of dust formed in the TEXTOR tokamak: structure and fuel retention](#)  
D Ivanova, M Rubel, V Philipps *et al.*
- [Study of correlation of deuterium content in a-C:D dust induced by laser irradiation from the co-deposited surface with the grain size and velocity](#)  
Daniel Alegre, Henric Bergsaker, Igor Bykov *et al.*
- [12th International Workshop on Plasma-Facing Materials and Components for Fusion Applications](#)  
Arkadi Kreter, Jochen Linke and Marek Rubel



**IOP | ebooks™**

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

## A test of nitrogen-assisted plasma discharges for fuel removal from plasma-facing components in tokamaks

P. Sundelin<sup>1</sup>, M.J. Rubel<sup>1</sup>, B. Emmoth<sup>2</sup>, V. Philipps<sup>3</sup> and G. Sergienko<sup>3</sup>

<sup>1</sup>Alfvén Laboratory, Royal Institute of Technology, Association EURATOM – VR, 100-44 Stockholm, Sweden

<sup>2</sup>Department of Microelectronics and Information Technology, Royal Institute of Technology, Association EURATOM – VR, 164 40 Kista, Sweden

<sup>3</sup>Forschungszentrum Jülich, Association EURATOM – FZJ, Jülich, Germany

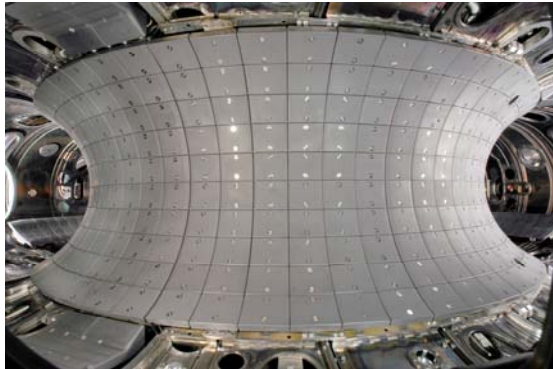
E-mail: persun@kth.se

**Abstract.** Safety regulations limit the amount of tritium accumulated in wall components of a fusion reactor to 350g. Because of this, reduction of long-term fuel inventory is one of the most urgent tasks to be resolved to ensure the safe and economic operation of a reactor-class fusion device. Several methods have been suggested and tested. The aim of this paper is to evaluate the cleaning efficiency of plasma-facing components by ICRH-assisted plasma discharges with in nitrogen-hydrogen in the TEXTOR tokamak. Three types of probes were investigated: laboratory prepared a-C:D layers on silicon; boron layers on silicon obtained by pre-boronisation in TEXTOR and not coated Inconel substrates. The main results are following: (i) laboratory prepared a-C:D layers are not affected: deuterium and carbon contents did not decrease (ii) the morphology of layers pre-boronised in TEXTOR is not affected (iii) no significant effects were noticed on Inconel probes. A comparison of cleaning methods with nitrogen and oxygen is also presented.

### 1. Introduction

Retention of fuel is one of the most important aspects of plasma-wall-interaction which must be addressed. Safety regulation limits the amount of tritium in a next-step device (e.g. ITER) to 350 g. Since fuel is deposited together with carbon in a device with carbon plasma-facing components (PFC), this level may be reached after less than 100 ITER pulses [1]. Therefore, development of techniques for fuel removal is of key importance. Several methods have been tried and evaluated: sweeping the strike point over an area with carbon co-deposits, glow discharge cleaning or pulses with electron cyclotron radiation heating which may clean the main chamber, warming up in-vessel cryo-pump panels or baking of water cooled components [2], photo-cleaning using lasers [3-5] or ultra-intense bursts of visible or near-IR light [7,6]. Another group of tested methods is based on oxidation [8-10]. A broad overview of methods has been presented by Counsell [11]. The main issues in evaluation of various techniques for reduction of fuel content are: (i) efficiency of fuel removal, (ii) modification of the surface and (iii) dust formation related to disintegration of co-eposited layers.

The aim of this paper is a preliminary evaluation of a nitrogen-based fuel removal experiment where different layers were exposed to discharges in the TEXTOR tokamak; its vacuum vessel is shown in figure 1a.



**Figure 1a.** View of the interior of the TEXTOR tokamak.



**Figure 1b.** Holder used for exposure.

## 2. Experimental

The study was carried out with three types of probes: silicon substrates coated with amorphous deuterated carbon films (a-C:D), silicon with pre-boronised layers and bulk Inconel. The a-C:D layers were deposited under laboratory conditions, whereas the boronised films were prepared in TEXTOR during a regular boronisation process carried out with hydrogenated diborane ( $B_2H_6$ ). All three types of probes were mounted on holders, as shown in figure 1b, and inserted into the tokamak using the limiter lock system into the TEXTOR vacuum vessel. One set of probes were inserted using limiter lock system 1 in the bottom of the vessel, and one set using limiter lock system 3 at the top. The probes were exposed to discharges in hydrogen-nitrogen ( $H_2-N_2$ ) glow discharge plasma assisted by ion cyclotron radiation heating (ICRH). The experiment used 25 discharges with a total time of about 40 s.

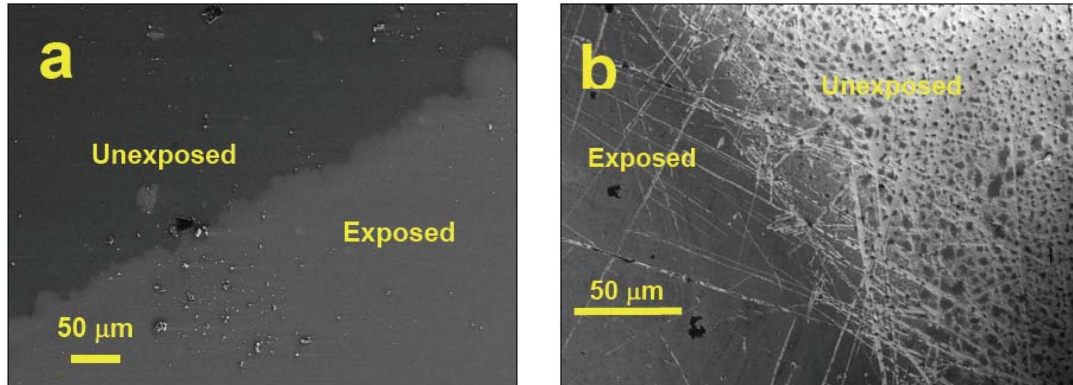
Following the exposure, surface studies were performed by means of scanning electron microscopy (SEM), wavelength dispersive X-ray spectroscopy (WDS) and accelerator-based ion beam analysis (IBA) methods. The IBA methods were nuclear reaction analysis (NRA) with a 2MeV  $^3He^+$  beam and enhanced proton scattering (EPS) with a 2MeV  $H^+$  beam. The objective of NRA was mainly to quantify deuterium, while EPS was used to study the boron and carbon content.

## 3. Results

### 3.1. Surface morphology

Images of the Si probes taken with electron microscopy show smooth surfaces both before and after exposure. As seen in figure 2a, there is no change in morphology can be seen. A slight contrast may be due to the small amount of deposited carbon. On the Inconel samples, there is a thin layer formed on the exposed part, as indicated in figure 2b.

The composition was determined using wavelength dispersive X-ray spectroscopy (WDS). The analysis of the layer formed on the Inconel samples show a small increase in carbon, which was deposited during the experiment. No other change could be detected with WDS. The amount of boron in the exposed and unexposed parts is very similar. Notable is also that no nitrogen was detected, despite exposure in the nitrogen environment. The exception from this is a small amount of nitrogen in the Inconel samples. This is probably related to the presence of TiN and TiNbCN compounds which are usually found in the original (not exposed) material.



**Figure 2.** (a) Pre-boronised silicon probe. Original surface (top) compared to exposed surface (bottom). (b) Inconel probe. On the exposed part (right), the carbon layer formed during the experiment is visible.

### 3.2. Ion beam analysis

The results obtained with IBA are collected in Table 1. The data present the deuterium, carbon and boron contents in the initial and exposed probes. Previous results [9] for oxygen-assisted cleaning are given for comparison. During this experiment, the probes were positioned at limiter lock 3. After the H<sub>2</sub>-N<sub>2</sub> treatment, there is no significant decrease in deuterium content due to the exposure. In the a-C:D probes, all differences are within the variations of the non exposed layer. In the pre-boronised probes, no change is observed at all. If we compare these results to the results from the experiment with oxygen-assisted cleaning, the difference is significant. While 98 – 99.5 % of the deuterium was removed using oxygen-assisted cleaning, almost no effect is achieved with nitrogen. The carbon layer is also effectively removed by He-O<sub>2</sub> glow, while the amount of carbon increases slightly during the nitrogen-assisted cleaning experiment, indicating deposition of carbon eroded from plasma-facing components by the H<sub>2</sub>-N<sub>2</sub> treatment. The significant difference in deposition between the pre-boronised probed and the a-C:D probes is possibly explained by the difference in position on the holder, i.e. some probes may be shadowed by the holder.

For one of the pre-boronised samples, one can see an increase in boron of around 30 %. This change is small enough to possibly be explained by variations in the original layer thickness, but it might also be a real effect because boron is present in TEXTOR and could be deposited.

In general, the analysis show no certain decrease of boron, carbon and deuterium when initial and H<sub>2</sub>-N<sub>2</sub> treated samples are compared. In some cases, there are indications of some decrease, but these changes are quite small.

**Table 1.** Content of D, B and C before (**in**) and after exposure (**ex**). Oxygen cleaning data from [9]. All results in [ $10^{15} \text{ cm}^{-2}$ ]. (1) and (3) denote limiter locks in TEXTOR.

Cleaning method	Sample	D <sub>in</sub>	D <sub>ex</sub>	B <sub>in</sub>	B <sub>ex</sub>	C <sub>in</sub>	C <sub>ex</sub>
H <sub>2</sub> -N <sub>2</sub>	Inconel 1	0.1-1.9	0.4	-	-	-	-
ICRF-assisted plasma	Inconel 3	0.1-1.6	0.4	-	-	-	-
	Boron 1	1.3-1.9	1.2-2.8	36	49	108	113-142
	Boron 3	2.1-2.9	2.8	50	51	54-55	75
	a-C:D 1	629-679	660-677	-	-	884-983	1030-1100
	a-C:D 3	364-395	375	-	-	606	710-771
He-O <sub>2</sub> glow	a-C:D	411-638	3-9	4-12	4-8	790-980	2-37
	Boron	17	1-3	290-318	221-255	12	12-45

#### 4. Concluding remarks

The experiment aiming at the evaluation of co-deposit and fuel removal efficiency was carried out in the TEXTOR tokamak using a hydrogen-nitrogen ICRF-assisted plasma. The results of surface studies show that this type of treatment has little influence on the surface morphology. The amount of carbon on pre-carbonized probes is even somewhat (5 - 30 %) increased during the exposure, thus indicating carbon deposition on probes in the tokamak. This statement is supported by microscopy and WDS studies of the Inconel probe where thin carbon coating was found (figure 2 b) after the exposure. Experiments in laboratory plasmas lead to the conclusion that nitrogen significantly increase the erosion rate of a-C:H layers [12], or that the cleaning efficiency of H<sub>2</sub>-N<sub>2</sub> glow discharges is comparable to those of He-O<sub>2</sub> glow discharges [13]. Previous results from the JET tokamak [14] indicate a decreased deposition. In the experiment reported in this paper, the results do not indicate that carbon deposition and/or co-deposit formation is reduced in the presence of nitrogen-containing plasma. This may be related to the migration and re-deposition of carbon eroded in another location, e.g. from the inner bumper of toroidal belt limiter. It is also important to note that the deuterium content in the probes is not affected by the H<sub>2</sub>-N<sub>2</sub> discharges. Much stronger effects in the surface structure and composition have been found after oxygen-assisted cleaning [9]. The comparison of both approaches indicates that oxidation is more efficient in removing fuel than discharges in hydrogen-nitrogen plasma. However, definitive conclusions should not be drawn from these preliminary results, since the effects of plasma cleaning may be strongly dependant on the position of the probes.

#### References

- [1] Federici G *et al* 2001 *Nucl. Fusion* **41** 1967
- [2] Andrew *et al* 1999 *Fusion Eng. Des.* **47** 233
- [3] Skinner C H *et al* 2003 *J. Nucl. Mater.* **313–316** () 496
- [4] Shu W *et al* 2003 *Appl. Phys. A* **76** (2003) 421
- [5] Gasior P *et al* 2006 *Phys. Scr. T* **123** (2006) 99
- [6] Widdowson A *et al* 2007 *J. Nucl. Mater.* **363–365** 341
- [7] Coad J P *et al* 2007 *J. Nucl. Mater.* **363–365** 287
- [8] Davis J W and Haasz A A 2001 *Phys. Scr. T* **91** 33
- [9] Rubel M J *et al* 2007 *J. Nucl. Mater.* **363–365** 877
- [10] Hopf C *et al* 2007 *J. Nucl. Mater.* **363–365** 882
- [11] Counsell G *et al* 2006 *Plasma Phys. Control. Fusion* **48** B198
- [12] Schwartz-Selinger T *et al* 2007 *J. Nucl. Mater.* **363–365** 174
- [13] Ferreira J A *et al* 2007 *J. Nucl. Mater.* **363–365** 888
- [14] Tabares F L *et al* 2005 *J. Nucl. Mater.* **337–339** 867