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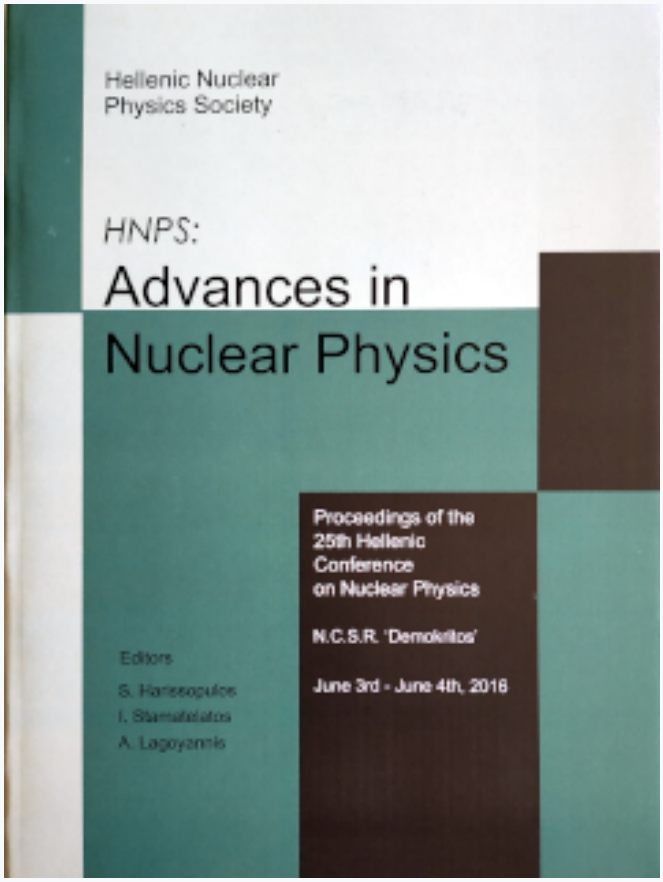

Investigation of tungsten-coated divertor tiles at the JET tokamak with the ITER-Like Wall

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Investigation of tungsten-coated divertor tiles at the JET tokamak with the ITER-Like Wall

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Abstract Materials migration in fusion plasma devices and fuel retention in plasma-facing components are issues of great importance for the safe operation of fusion devices. The underlying mechanisms require a good understanding in order to make predictions regarding the lifetime of wall components and to assess the amount of fuel retained in the machine mainly in co-deposited layers. To reduce fuel inventory and to investigate plasma-wall interactions a large-scale experiment at the JET (Joint European Torus) tokamak is realized: operation with the ITER-Like Wall (JET-ILW) which comprises beryllium and tungsten.

The current work reports on the post-mortem analysis of W/CFC tiles retrieved after the first deuterium-deuterium campaign at JET-ILW. Specimens from different areas of the divertor have been analyzed by means of several techniques including nuclear reaction analysis and Rutherford backscattering employing a deuterium beam. In addition, X-ray fluorescence spectroscopy and scanning electron microscopy with energy dispersive X-ray analysis are used to assess the sample surface morphology and analyze the stoichiometry of the surface of the samples in order to compare with the results from the ion beam analytical techniques.

Keywords plasma-facing material, divertor, RBS-NRA, XRF, SEM

INTRODUCTION

In 2010/11 the plasma facing components (PFC) of the Joint European Torus (JET) were replaced by beryllium in the main chamber and tungsten in the divertor, so that JET can be used as a test bed for ITER since this material combination (Be and W) is foreseen for the activated phase of ITER [1]. Material migration and fuel retention were studied during the JET-ILW experimental campaign 2011–2012 using in-situ [2] technique and post mortem analysis [3]. The current work refers to the surface analysis of samples retrieved from the JET-ILW tokamak divertor Tiles after the first campaign. Specimens from four tiles of the divertor have been analyzed at NCSR "Demokritos", using ion beam analysis (Rutherford backscattering (RBS) and nuclear reaction analysis (NRA)), scanning electron microscopy (SEM) with energy dispersive analysis (EDS) and X-ray fluorescence spectroscopy (XRF).

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** *See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia*

EXPERIMENTAL DETAILS

The samples originate from the JET tokamak divertor after an 18.9 hour exposure. The tile number, description and position as S-coordinate are given in Table **1** [4]. In the presentation of the results the samples are denoted by the three letters containing the Tile number, i.e. G4D, for simplicity.

Divertor Tile number	S-coordinate	Sample Code	Sample description (as fabricated)
4	904	14BN G4D/1a	CFC/Mo(3 μm)/W(12 μm)/Mo(4 μm)/W(4 μm)
6	1360	2BN G6C/2a	
7	1699	2ON G7A/4a	
8	1892	2ON G8B/4a	

Table 1: List of samples.

The RBS/NRA technique was carried out at the 5.5 MeV Tandem accelerator of NCSR "Demokritos". The samples were irradiated with a 1.7 MeV deuterium beam, the current was around 1 nA and the backscattered-produced particles were detected at 170 and 120 degrees with respect to the beam axis by two silicon surface barrier detectors. The beam diameter at the target was around 1 mm.

SEM measurements were carried out using a FEI Quanta Inspect electron microscope coupled with EDS. For the EDS analysis a voltage of 12.5 kV was used in order to enhance the contribution from the top layers of the samples. The XRF spectra were measured employing Amptek's XRF system using an Ag X-ray tube, a high voltage of 30 kV and a silicon drift detector [5]. Elements with Z>11 were detected with a detection limit of the order of ppm. A collimator with 1 mm diameter was used. Spectrum quantitative analysis was performed using NIST stainless steel 316 standard [6].

RESULTS AND DISCUSSION

The experimental spectra of the NRA measurements of the samples are presented in Figure 1. The concentration of the various elements as a function of depth was determined from the simulation of the data using SIMNRA software [7].

The elemental depth profiles of the RBS/NRA analysis are depicted in Figure 2. It is noted that a flat surface is assumed in data analysis which is not the case for the samples under investigation due to the roughness of the CFC substrates. It may be that the derived depth profiles do not reflect the exact layered structure of the sample. Tables 2 and 3 present the results of the EDS analysis and XRF spectroscopy, respectively. These results should be viewed with respect to the limitations of each technique, regarding detection sensitivity and depth penetration. It is pointed out that XRF can only provide information for elements with Z>11 but has a higher sensitivity than EDS. Also XRF probes larger depths than EDS.

From the RBS/NRA, EDS and XRF measurements, we conclude that the elements migrated into the divertor are: D which is the fuel, Be which constitutes the element of the main tokamak chamber, Ni, Cr, Fe and Mo from the Inconel 625 of the radio frequency

antenna inside the tokamak, C which was the former JET plasma facing component, O as impurity and N which is used for plasma edge cooling in the divertor area.

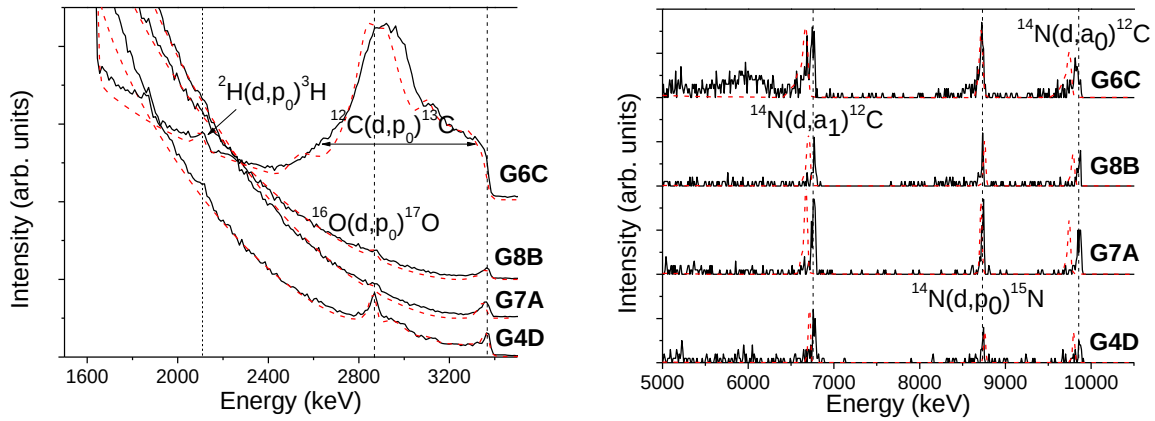

Figure 1: The experimental NRA (solid line) and simulated (dashed line) spectra of the samples from low (left) and high (right) energy regime.

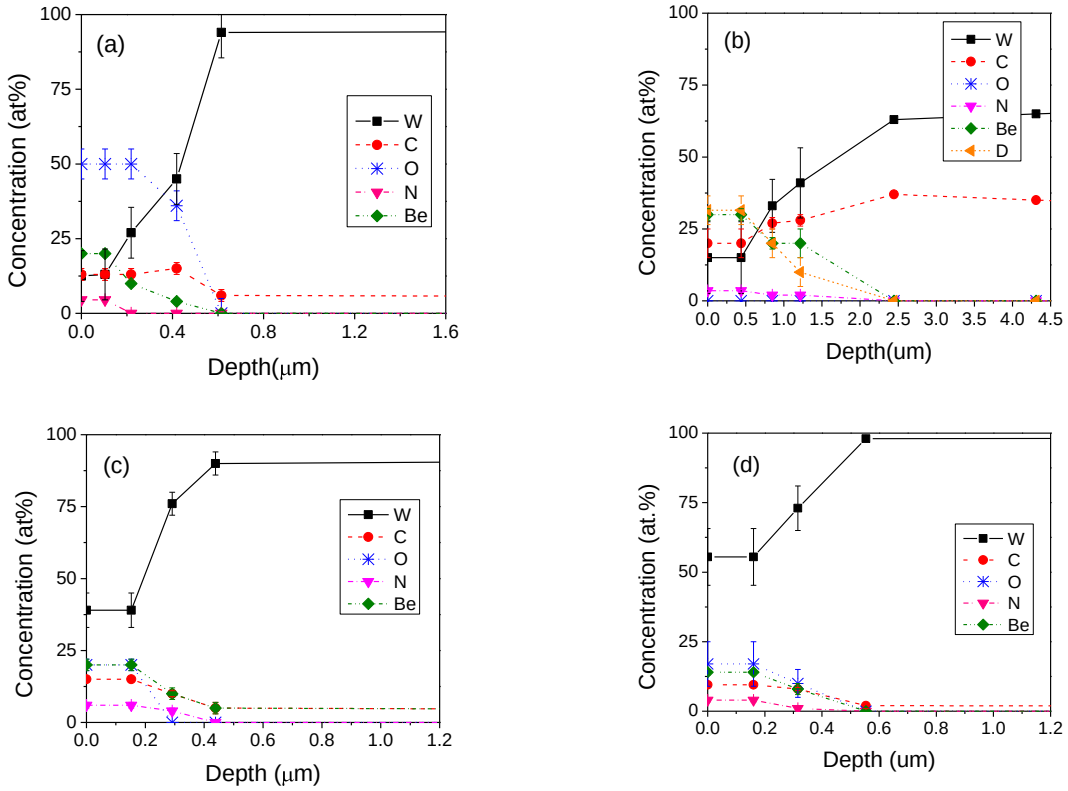

Figure 2: Depth profile of the samples: a) G4D, b) G6C, c) G7A and d) G8B.

Specifically, for the sample from Tile 6, the deposited elements, except for C, can be traced up to a thickness of 2.5 μm; this sample presents the highest surface concentration of Be (30.5 at%) and significant concentration of D (31.5 at%) and Ni (6.6 at%); C is detected in deeper layers (above 4.5 μm); Mo (0.4 at%) is detected on the surface. For the sample from Tile 4, the thickness of deposition is 0.5 μm; it presents high surface concentration of O (50 at%) and the lowest concentration of Fe (0.036 at%) and Cr (0.054 at%); Mo (0.9 at%) is

detected on its surface. Regarding the samples from the Tiles 7 and 8, the thickness of deposition is 0.4 and 0.6 μm, respectively; they present low surface concentration of light elements (O, C, Be) and, in the Tile 7, the highest concentration of Fe (0.54 at%) is observed. Ni cannot be quantified by XRF in the samples from Tiles 4, 7 and 8 because the $K_{\alpha 1}$ peak (7.48 keV) from Ni overlaps with the L_l peak (7.39 keV) from W. The fact that D is not detected on the samples from Tiles 4, 7 and 8 is due to the masking of the $^{2}H(d,p)^{3}H$ peak by the high pile-up. The use of kapton foil before the detector eliminates the high pile-up observed in the low energy regime and makes the quantification of ^{2}H possible [8].

	G4D	G6C	G7A	G8B
C	42(3)	28.0(3)	33.1(7)	29(2)
N	-	1(1)	-	-
O	16(1)	16.0(4)	5.1(7)	4(1)
Ni	0.1(2)	6.6(3)	-	-
Mo	0.9(1)	0.40(3)	-	-
W	41(2)	48.0(2)	61.8(3)	67(1)

Table 2: Surface elemental concentration (at%) using EDS analysis.

	G4D	G6C	G7A	G8B
Cr	0.054(9)	0.60(1)	0.07(1)	0.047(2)
Fe	0.036(6)	0.41(2)	0.54(1)	0.043(1)
Ni	n.q.*	2.32(1)	n.q.	n.q.
Mo	23.07(7)	23.50(5)	24.59(8)	16.20(7)
W	76.84(7)	73.17(5)	74.80(8)	83.71(7)

*n.q.: non-quantifiable

Table 3: Elemental concentration (at%) as determined by XRF spectroscopy.

CONCLUSIONS

In the present work, various analytical techniques (RBS/NRA, SEM with EDS and XRF) were combined to obtain an integrated view of the elemental deposition on samples from different tiles of the ILW JET tokamak divertor which had been exposed to an 18.9 hour plasma operation. The elements that were detected on the surface of all Tiles are: Be, N, O, C, Cr and Fe. Mo was detected only on the surface of the samples from Tiles 4 and 6. Furthermore, D and Ni were detected only on the surface of the sample from Tile 6. The presence of D on the other tiles is hindered by the large pile-up at low energies. For that reason, a kapton foil will be placed before the detector in future measurements [8].

AKCNOWLEDGMENTS

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