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Boron deposition on the graphite tiles of the RFX device studied by secondary ion mass spectrometry

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Abstract

We report on a systematic surface analysis of the graphite tiles coming from different locations on the first wall of the reversed-field pinch device RFX by secondary ion mass spectrometry. Both boron and the main contaminant species were investigated. The largest values of the total boron intensity are found for tiles positioned in front of the injection valve, the lowest for those at the gap. The in-depth profiles of the normalized boron signals are interpreted as signatures of a plasma–wall interaction, namely of the plasma coming in contact with the wall in restricted regions, mainly determined by the magnetic field configuration, during its lifetime.

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1. Introduction

Wall erosion and re-deposition are major effects of the interaction of a plasma with the surrounding wall, a clue issue in nuclear fusion technology. To keep the radiative losses low, the plasma impurities must be limited to low-Z elements, i.e., the effective charge must approach $Z_{\mathrm{eff}} \cong 1$ as far as possible, which implies that low-Z materials must be used for the first, plasma-facing wall. To this purpose, boronization of the graphite tiles covering the inner wall of the vacuum vessel is adopted in several fusion relevant devices. Another important feature, mostly related to the magnetic field structure, is that the effects of erosion and re-deposition on the tiles are generally expected to be inhomogeneous (localized). Due to this, measurements on a variety of tiles selected from different parts of the vessel wall are required in order for a significant insight in these effects to be achievable. An additional complication comes from the fact that the fusion experiments are carried out in different magnetic configurations, e.g., tokamaks and stellarators, and in vacuum chambers with very different shapes, e.g., with either circular or elongated cross-sections. As a consequence of this each system must be investigated quite individually [1,2] and the general conclusions one can draw are bound to be only qualitative or otherwise to be applicable at best to a limited number of devices.

In this work we report a systematic investigation based on secondary ion mass spectrometry (SIMS) of a series of graphite tiles of the inner wall of reversed-field fusion device RFX after a long exposure to the plasma in the first phase of RFX operation. A point worth being stressed is that during this early phase the dynamic evolution of magneto-hydrodynamic (MHD) perturbations, in particular the so-called tearing modes and plasma disruptions, may have significantly contributed to the plasma–surface interactions.

To reveal the expected correlations between the effects detectable on the tiles and the underlying plasma–wall interactions, SIMS analysis of the tile surfaces and near-surfaces has been performed on a set of tiles coming from

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different toroidal and poloidal positions in the vacuum vessel of RFX. The main criterion in the selection of the tiles was that of correlating their positions with the known inhomogeneities of the passive stabilizing shell. The major target of our investigation was characterizing the boron distribution in the tiles and its dependence on the poloidal and toroidal coordinates.

2. Tile composition, experimental set-up and measuring procedures

The vacuum vessel of RFX is made of Inconel 625 and the first wall of the device includes 2016 graphite tiles that completely surround the last closed magnetic surface. While basically polycrystalline, the graphite of the tiles, produced by Carbon-Lorraine as PT5890 [3,4], also included amorphous carbon. The boron film was deposited on the tiles via glow discharge cleaning (GDC) in a He atmosphere. The average thickness of the hydrogenated boron film deposited on the tiles has been estimated, over a range of the order of hundred nanometers, using a mechanical profilometer [4]. Extensive investigations of the quality of the boron coatings prior to the exposition to the plasma were performed by a number of groups [5,6] including that of RFX [7,8]. Further, all samples are currently analyzed via Rutherford backscattering [9]. Besides the boron, these analyses reveal the presence of both metallic and non-metallic impurities, such as V, Cr, Mn, Mo, Fe, Co, Ni, Cu, Zn and Se, in almost all the samples.

The samples used in our analysis by the SIMS were cut out from tiles selected from different toroidal rows (A1, A38, A44, A59, A60, A68) and different poloidal positions (T1, T8, T15, T22) (see Fig. 1). The total amount of samples was 24 and their typical size ca. $15 \times 10 \times 1.5\ mm^3$. The SIMS measurements were carried out by a dedicated SIMS set-up based on standard commercial components [10–12]. The equipment was completed by a Hiden EQS 1000 Mass Energy Analyser made of a combination of an electrostatic energy analyser and a quadrupole mass filter. The mass spectra were collected using 6 keV mass-filtered $^{16}O_2^+$ ions generated by a duoplasmatron ion gun (model DP50B by VG Fison). The spectra were produced in sequence, which required no more than 70 s per each. The in-depth elemental distributions were evaluated from the mass spectrometric data just after the end of the related measurements. The primary beam was raster-scanned. The 'crater effect' was avoided by recourse to electronic gating of the registration system. Thanks to this, only secondary ions coming from the limited central area of the crater were collected. The depth of the sputter craters and the surface topography were determined by a Tencor Stylus Profiler P-10. Finally, roughness measurements were also made from three different areas of the samples, each of $600 \times 600\ \mu m^2$ size, randomly chosen on their surfaces. The identification of the ion species in the measured spectra was obtained using the numerical code DECO [13].

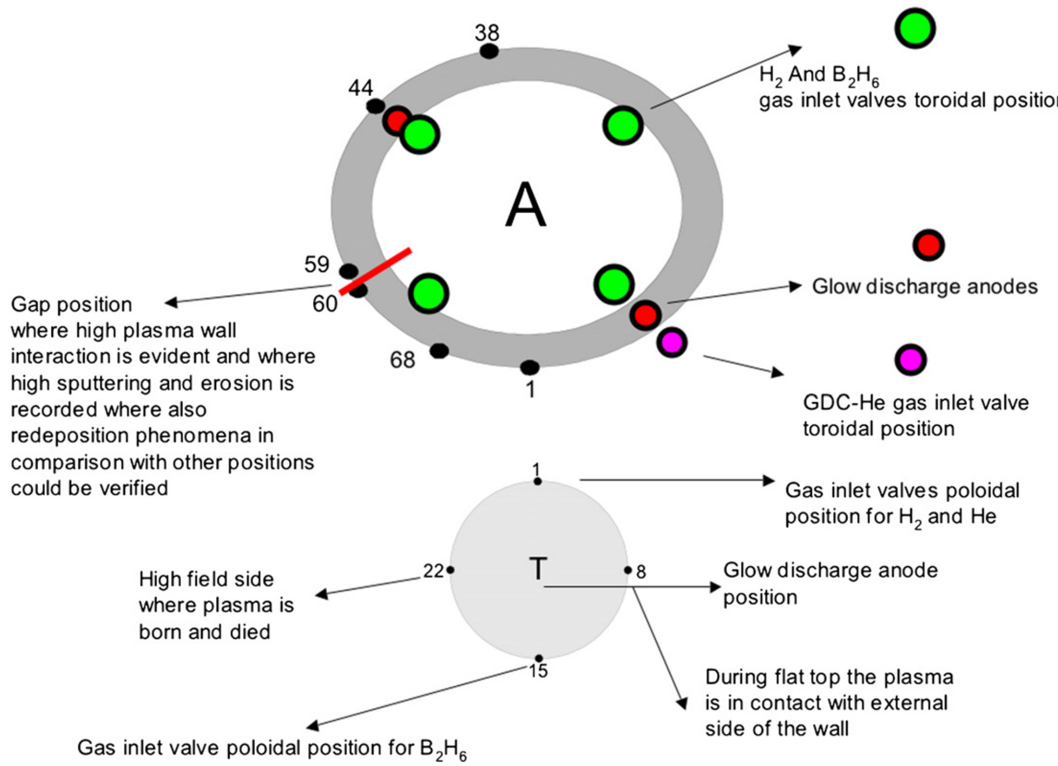

Fig. 1. Schematic view of the sample positions selected for the SIMS measurements (letter A denotes the toroidal rows and letter T the poloidal positions).