Boronisation research plan

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1 Short overview

Amount	kind of samples	need	project	TOMAS days
12	hydrogen doped graphite	Test ICWC vs ECWC	W7-X	18
12	hydrogen doped boron-coated graphite			
56	Boronized tungsten, doped with deuterium	Test efficiency of IC and GD	ITER	≈35

Note that these samples don't include the five ITER-contract mentioned "test depositions and characterization of the layers,...to make sure D content can be produced reliably."

2 Scientific relevance and reasoning

W7-X

Glow discharge in H_2 plasma and ECWC in He plasma have been actively used on W7-X to condition the wall and it's effects have been reported ([1],[3] and EUROFUSION WPS1-PR(16) 16175) while it is possible for stellarators to have homogeneous EC wall conditioning, ICWC may provide a more efficient cleanup [2]. As preparations for the possible usage of ICWC in W7-X it should be investigated how ECWC and ICWC compare both in removal from pure graphite and from boron-coated graphite (as both are possible PFMs in W7-X). To this end baseline ECWC experiments need to be carried out on TOMAS, as well as comparative ICWC experiments, both in W7-X relevant plasmas.

As mentioned in EUROFUSION WPS1-PR(16) 16175, ECWC outgassing follows a time power law ($\propto t^{-0.7}$), a similar law for removal needs to be observed on TOMAS to show that it is equipped to compare IC and EC, after which similar experiment needs to be carried out to determine the IC time power law and scale difference between EC and IC on TOMAS.

To obtain W7-X relevant conditions in TOMAS, the IC frequency will be set to 38MHz, mimicking the W7-X minority heating and the second harmonic heating scenarios (which we of course don't have due to the low magnetic field).

Both the electron density, temperature and ideally ion energy distribution will be kept as close as possible to the one observed at W7-X (reflectometer + langmuir probe measurements + modelling on W7-X, LP , interferometer and RFEA on TOMAS), the plasma species will be Helium.

During experiments the QMS, the MW interferometer and optical spectroscopy will be acquiring data.

ITER

Following the ITER contract [ADCYGE] the 2 ITER available wall conditioning schemes GDC and ICWC will be tested on deuterium-doped boronized tungsten. To this end ITER relevant plasmas need to be created in the TOMAS machine on the sample holder position, after which the necessary exposures are carried out. To this end NPA measurements need to be carried out to find a fluence relevant to a 20-minute ICWC procedure at 10-20% duty cycle (as layed out in the contract). During experiments the QMS, the MW interferometer and optical spectroscopy will be acquiring data.

3 TOMAS setup and days estimate

3.1 W7-X

The exposures will all keep the previously mentioned plasma characteristicx to make a time-removal relation possible. As W7-X boronizes their walls (monthly), EC and IC experiments will be carried out on 24 hydrogen-doped boronized graphite samples, grouped 4 per shot 3 per WC scheme (2: EC and IC). This should give insight into the de-trapping efficiency of boron in W7-X. As the rapidity of boron erosion under plasma operation is still an open question, this will also be measured post-mortem.

3.2 ITER

ICWC: 8*4 = 32 samples (8 per exposure, 4 exposures out of which 2 are test exposures and 2 are final, performed at 70°C and 240°C).

GDC: 8*3 = 24 samples (8 per exposure, 3 exposures out of which 1 is a test and 2 are final, one at 70°C and one at 240°C).

TOMAS time estimate: the ITER plan gives a maximum of 2 months, this is reasonable, a full exposure of 8 samples may take up to 5 days (3 day of preparation such as finding the ideal setting and cleaning the wall, 1 day of pumping down and 1 day of exposure) as there are 7 such exposures we estimate 35 days of experiments.

4 Sample analysis

Most of this will probably be outsourced to experts within FZJ whom will be credited appropriately. The primary goal on all exposed samples is to measure the fuel removal, nevertheless it is possible to extract additional information like roughness before and after exposure and erosion of the boron layer. As such the plan is:

1. sample preparation
2. roughness measurement
3. (if adequate)ellipsometry
4. TOMAS exsposure
5. roughness measurement
6. De-trapping measurements
7. (if adequate) ellipsometry
8. FIBSEM

Here will follow a short overview of the analysis methods.

4.1 fuel removal estimates

The elemental concentrations need to be inferred for the samples, this will be accomplished using Thermal Desorption Spectroscopy (TDS) and Nuclear Reaction Analysis, whereby we assume homogeneous impurity doping during initial boron coating and homogeneous removal or negligible erosion of the coating, as such we may draw direct conclusions regarding the wall conditioning effectiveness.

4.2 Roughness measurements

The exposure to the plasma may give inhomogeneous sputtering which might be of interest, as such a simple 1D profilometry measurement may be made before and after exposure, or, if needed, a full 2D surface map. Both of the needed devices are located in the mirror lab overseen by dr. Litnovsky.

4.3 Thickness estimate

Thickness estimates may be made using ellipsometry on the doped specimens prior to the exposure and after exposure prior to being analysed using TDS, as it is non-destructive , if the method is deemed adequate. Post-mortem (i.e after exposures and TDS) the sample thickness may (also) be found using FIBSEM (dr. Rasinski).

References

[1] A Goriaev, T Wauters, R Brakel, S Brezinsek, A Dinklage, J Fellinger, H Grote, D Moseev, S Sereda, O Volzke, and W7-X team. Wall conditioning at the wendelstein 7-x stellarator operating with a graphite divertor. *Physica Scripta*, 2020(T171):014063, mar 2020.

[2] T. Wauters, H. P. Laqua, M. Otte, M. Preynas, T. Stange, P. Urlings, Y. Altenburg, D. Aßmus, D. Birus, and F. Louche. Ion and electron cyclotron wall conditioning in stellarator and tokamak magnetic field configuration on wega. *AIP Conference Proceedings*, 1580(1):187–190, 02 2014.

[3] Tom Wauters, Andrei Goriaev, Arturo Alonso, Juergen Baldzuhn, Rudolf Brakel, Sebastijan Brezinsek, Andreas Dinklage, Heinz Grote, Joris Fellinger, Oliver P. Ford, Ralf König, Heinrich Laqua, Dmitry Matveev, Torsten Stange, and Lilla Vanó. Wall conditioning throughout the first carbon divertor campaign on wendelstein 7-x. *Nuclear Materials and Energy*, 17:235–241, 2018.