9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Efficiency of glow discharge boronisation in ASDEX Upgrade and WEST

K. Krieger[1], V. Rohde[1], S. An[1], M. Diez[2], A. Gallo[2], B. Guillermin[2], M. Mayer[1], T. Wauters[3],
ASDEX Upgrade[1] Team, WEST[2] Team and EUROfusion Tokamak Exploitation Team
[1] Max-Planck-Institut für Plasmaphysik, Garching, Germany,
[2] CEA, IRFM, Saint Paul Lez Durance, France
[3] ITER Organization, Saint Paul Lez Durance, France
e-mail (speaker): karl.krieger@ipp.mpg.de

With the recent ITER rebaseline decision introducing a full-tungsten first wall configuration [1], the efficacy of wall conditioning via boronisation has become a high-priority issue in ITER operational planning. ASDEX Upgrade (AUG) and WEST, both equipped with full-W first walls, have extensive experience with glow discharge boronisation (GDB) to facilitate plasma startup and extend the plasma operational space [2,3]. To assess the efficiency and persistence of GDBs under ITER-relevant wall conditions, detailed experiments were carried out during the 2025 AUG and WEST campaigns [4,5]. These also served to validate a simulation code [6] predicting the lateral distribution of B deposited by GDB.

GDBs were performed in both tokamaks using various configurations of active glow anodes and gas inlets. Glow discharges (GD) were monitored by residual gas analysis (RGA) to quantify the dissociation of diborane (B_2D_6) and the fraction converted into deposited B. In AUG, quartz micro-balances (QMBs) provided in-situ measurements of GDB layer deposition rates and their toroidal variation. For accurate quantification of deposited B and co-deposited D, witness samples of various plasma-facing materials (W, Mo, steel plus Si and graphite as reference) were exposed during GDBs in the main chamber of both devices using manipulator systems. Samples were retrieved via airlocks; AUG samples were stored in an argon atmosphere to prevent reactions of the deposited layers with oxygen and water, while WEST samples were coated with a protective Au layer and shipped in sealed bags. B and D area densities were measured by nuclear reaction analysis (NRA) with a ^{3}He ion beam using the reactions D(^{3}He,p)^{4}He and ^{10,11}B(^{3}He,p)^{12,13}C. Deposited B areal densities were found to be in the range of (1–5)×10^{17} cm^{-2}, with variations attributed to GDB parameters and material of the witness samples. The AUG sample results were consistent with the in situ QMB measurements and estimates based on the 95% B_2D_6 dissociation fraction, derived from RGA analysis [4], assuming uniform B deposition. D/B ratios were typically in the range of 0.1–0.2 for metallic samples, with higher values up to 0.4 for Si and graphite samples, attributed to retention of D deeper in the substrate.

To assess the stability of the B/D layers in air, the samples were repeatedly reanalysed while being stored in air in between measurements. The AUG samples showed a factor ~2 reduction in D over four months, with the strongest drop (~40%) occurring within the first two weeks, followed by a slower decline to the final ~50% loss, while the Au-protected WEST samples lost only ~10% D over one month. Deposited B declined by 10–20% in both cases. These results confirm that B layers deposited via GDB are relatively stable in air, with D and B loss likely resulting from the formation of volatile compounds with ambient oxygen and water vapour.

The variation in B deposition on the AUG samples between different glow anode configurations – full set of anodes activated versus half – was only within a factor ~2–3 depending on the sample substrate material. A higher variation by a factor ~7–12 was found between deposition on QMBs installed in the same port as glow anodes compared to one QMB in a port without a glow anode and confirmed by NRA analysis of QMB crystals retrieved during an interim repair vent of AUG. Surprisingly, B deposition on the samples was ~30% higher when the GD anode adjacent to the AUG sample holder was inactive during a GDB, indicating possible re-erosion of B close to active anodes. In WEST, samples exposed further away from the active GD gas inlets, though equally distant from glow anodes, showed ~40% less B deposition than those close to the active valves. The modest spatial variations seen on samples and QMBs contrast sharply with pre-experiment simulations, which predicted strongly localised B deposition near anodes, decreasing by 2–3 orders of magnitude in regions between them. The discrepancy suggests that the sticking probability of B reaching the wall surface is significantly below the value of unity assumed in the simulations. This indirect conclusion could be confirmed by exposure of a dedicated sticking monitor sample to a GDB in AUG using the mid-plane manipulator, which revealed a B sticking fraction of ~0.2 [7]. The results are highly relevant for ITER, alleviating concerns that the limited number of available installation positions for glow anodes might severely constrain GDB efficacy.

Moreover, these results motivate further development of the predictive simulation code, incorporating revised B sticking fractions and an improved deposition model to refine the interpretation of AUG and WEST data and to enhance confidence in predictive modelling of ITER GDB performance, supporting the design of an optimal boronisation strategy for ITER.

References

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[7] M. Mayer, PFMC 2025, subm. to Nucl. Mat. Energy