

antenna

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1 Introduction

1.1 Boronization

The interior of a fusion reactor is extremely hostile, as such a refractory material needs to be chosen for plasma facing components (PFC), tungsten is increasingly favoured over other materials due to its unique combination of properties such as low erosion rate, low tritium retention and resistance to heat-induced stress [1][2]. But there are two big drawbacks to using tungsten as a PFC: As it has a very high Z-value, if it does get sputtered, high amounts of radiation loss may occur due to brehmstrahlung [3] and second it's a very bad oxygen getterer which is the most deleterious of all impurities encountered in a fusion device. We can get the "best of both worlds" by coating our tungsten with a small ($<100\text{nm}$) layer of a low Z-material. Previously Beryllium was considered the main candidate but due to it's high toxicity and difficulty of handling the now most favored candidate is boron. Boronization (the deposition of a thin film of boron) has a proven track record of causing better confinement times and ELM (Edge Localized Mode) control [4][5][6][7]. There is however, at the time of writing, no direct research to the rapidity of Boron erosion under wall conditioning techniques such as ICWC, that gap is what this paper tries to fill.

1.2 Experimental setup

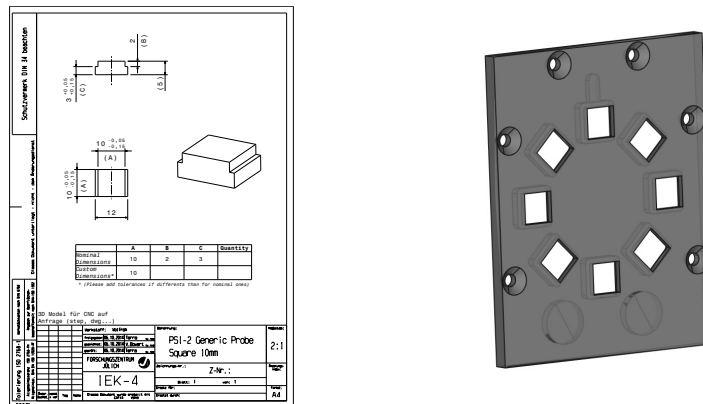


Figure 1: The mask (right figure) is made out of tungsten and can contain 8 samples (left figure), the 10x10mm top of the samples are coated with boron and attached in the mask such that it is facing towards the plasma in the vessel

One may analyse boron-tungsten erosion by using neutral and ion beams, mimicking ICWC, the obvious advantage being that the experiment is simpler with easily chosen and controlled parameters. But the disadvantage is that co-operative effects, which may occur only when a plasma is present, will not be observed [8]. The TOMAS machine [9] will be used as it is capable of forming a full plasma during an ICRH discharge and thus introducing these co-operative effects. It is equipped with a monopole ICWC antenna which will be set to operate at 50MHz, closely mimicking the 53MHz that will likely be used at ITER. The mask containing the samples (see figure 1) is mounted on a movable arm which we'll position on top of the vessel. We'll modify the pressure in such a way that the neutrals pressure (i.e the observed pressure during the discharge) is 10^{-5} mbar, closely mimicking what was the case in JET and will likely be the case in ITER [10].

2 Erosion estimation using neutrals

2.1 Explanation of the theory

Sputtering due to ICWC is said to be mainly caused by high energy neutrals (citation needed), as such our main estimate of sputtering will be the neutrals we measure in the vessel using the ToF-NPA, as mentioned in Daniels work (citation needed), for our experimental setup.

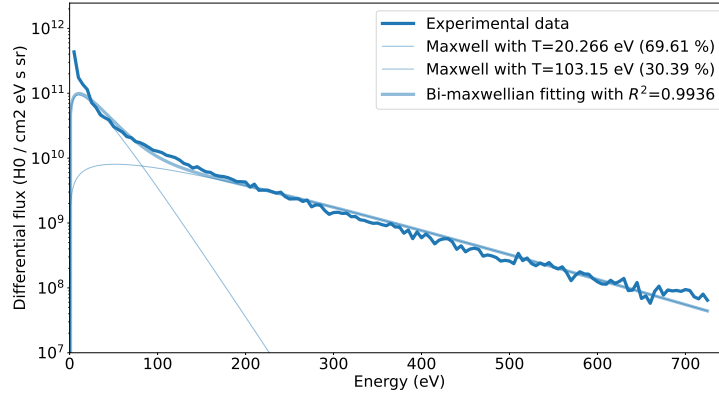


Figure 2: The assumption behind the bi-maxwellian distribution is that we have the conversion of heated ions to neutrals resulting in the high temperature maxwellian, and ions indirectly heating neutrals due to collisions, resulting in the low temperature maxwellian. There is, however, no verification of this notion yet. Note that the R^2 of the fitting is defined with the logarithmic difference to better emphasize the shape.

An example measurement made with the NPA is shown in figure 2. As the data is expressed as differential flux, it lends itself to be easily manipulated into other quantities. One such manipulation is using the following formula to transform it into an erosion rate:

$$S = \frac{2\pi}{N} \int_E Y(E) \mathcal{F}(E) dE \quad (1)$$

With $Y(E)$ the yield of the neutrals on the material (i.e how many atoms of the material get sputtered for every incoming neutral), $\mathcal{F}(E)$ the experimental differential flux as previously shown and N the number density. The validity of this formula is quite straightforward to see as:

- The NPA covers a certain solid angle, this has been accounted for as can be seen in the unit of the example experiment (/sr meaning per steradian), we can get an approximation for the average flux in the vessel by assuming homogeneity and thus multiplying this data by 2π steradians.

- The differential flux of particles in an energy bin surrounding E causes sputtering, to get this sputtering rate we multiply by the yield Y at that energy as it's defined to be the outgoing atoms per incoming, we integrate over all energies to get the full contribution.
- The number density of the target N dictates how the amount of outgoing atoms relates to the decrease in thickness, this can be seen from the units.

In the software we use equation 1 in the finite form, summing over the energy bins:

$$S = \frac{2\pi}{N} \sum_{E_0}^{E_{\max}} Y(E) \mathcal{F}(E) \Delta E \quad (2)$$

Where we may get the yield $Y(E)$ using the software RustBCA[11], assuming ions to behave the same as neutrals (as the samples aren't charged, this should give a negligible discrepancy) with parameters from Wolfgang Eckstein's book [12], assuming perpendicular impingement¹.

2.2 Calculated estimates

References

- [1] Philipps V 2011 *Journal of Nuclear Materials* **415** S2–S9 ISSN 0022-3115 proceedings of the 19th International Conference on Plasma-Surface Interactions in Controlled Fusion URL <https://www.sciencedirect.com/science/article/pii/S0022311511001589>
- [2] Neu R, Dux R, Kallenbach A, Pütterich T, Balden M, Fuchs J, Herrmann A, Maggi C, O'Mullane M, Pugno R, Radivojevic I, Rohde V, Sips A, Suttrop W, Whiteford A and the ASDEX Upgrade team 2005 *Nuclear Fusion* **45** 209 URL <https://dx.doi.org/10.1088/0029-5515/45/3/007>
- [3] Winter J 1996 *Plasma Physics and Controlled Fusion* **38** 1503 URL <https://dx.doi.org/10.1088/0741-3335/38/9/001>
- [4] The ASDEX Team, The ICRH Team, The LH Team, The NI Team, Schneider U, Poschenrieder W, Bessenrodt-Weberpals M, Hofmann J, Kallenbach A, Krieger K, Müller E, Niedermeyer H, Ryter F, Roth J, Söldner F, Stäbler A, Steuer K, Vollmer O and Wagner F 1990 *Journal of Nuclear Materials* **176-177** 350–356 ISSN 0022-3115 URL <https://www.sciencedirect.com/science/article/pii/002231159090071T>
- [5] Jackson G, Winter J, Burrell K, DeBoo J, Greenfield C, Groebner R, Hodapp T, Holtrop K, Kellman A, Lee R, Lippmann S, Moyer R, Phillips J, Taylor T, Watkins J and West W 1992 *Journal of Nuclear Materials* **196-198** 236–240 ISSN 0022-3115 plasma-Surface Interactions in Controlled Fusion Devices URL <https://www.sciencedirect.com/science/article/pii/S0022311506800383>
- [6] Xu W, Sun Z, Maingi R, Zuo G, Yu Y, Li C, Guan Y, Zhou Z, Meng X, Huang M, Zhang L, Gao W and Hu J 2023 *Nuclear Materials and Energy* **34** 101359 ISSN 2352-1791 URL <https://www.sciencedirect.com/science/article/pii/S235217912200240X>
- [7] Winter J, Esser H, Könen L, Philipps V, Reimer H, Seggern J, Schlüter J, Vietzke E, Waelbroeck F, Wienhold P, Banno T, Ringer D and Vepřek S 1989 *Journal of Nuclear Materials* **162-164** 713–723 ISSN 0022-3115 URL <https://www.sciencedirect.com/science/article/pii/0022311589903528>
- [8] McCracken G and Stott P 1979 *Nuclear Fusion* **19** 889 URL <https://dx.doi.org/10.1088/0029-5515/19/7/004>

¹note that assuming a distribution such as $\cos(\theta)^2$ doesn't change the result by more than 10%

- [9] Gorjaev A, Wauters T, Möller S, Brakel R, Brezinsek S, Buermans J, Crombé K, Dinklage A, Habrichs R, Höschen D, Krause M, Kovtun Y, López-Rodríguez D, Louche F, Moon S, Nicolai D, Thomas J, Ragona R, Rubel M, Rüttgers T, Petersson P, Brunsell P, Linsmeier C and Van Schoor M 2021 *Review of Scientific Instruments* **92** 023506 ISSN 0034-6748 (*Preprint* https://pubs.aip.org/aip/rsi/article-pdf/doi/10.1063/5.0033229/10050393/023506_1_online.pdf) URL <https://doi.org/10.1063/5.0033229>
- [10] Douai D, Kogut D, Wauters T, Brezinsek S, Hagelaar G, Hong S, Lomas P, Lyssoivan A, Nunes I, Pitts R, Rohde V and de Vries P 2015 *Journal of Nuclear Materials* **463** 150–156 ISSN 0022-3115 pLASMA-SURFACE INTERACTIONS 21 URL <https://www.sciencedirect.com/science/article/pii/S0022311514009763>
- [11] Drobny J T and Curreli D 2021 *Journal of Open Source Software* **6** 3298 URL <https://doi.org/10.21105/joss.03298>
- [12] Eckstein W 2013 *Computer Simulation of Ion-Solid Interactions* Springer Series in Materials Science (Springer Berlin Heidelberg) ISBN 9783642735134 URL <https://books.google.de/books?id=4h3rCAAAQBAJ>