

Boron erosion on a tungsten substrate using the TOMAS ICWC antenna

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1 Introduction

1.1 Boronization

The interior of a fusion reactor is extremely hostile, as such a good 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 is one big drawback of 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], we'd also like good hydrogen recycling by wall pumping for density control, a way of capturing impurities like oxygen in the plasma and easy cleanup afterwards through wall conditioning. 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 its 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

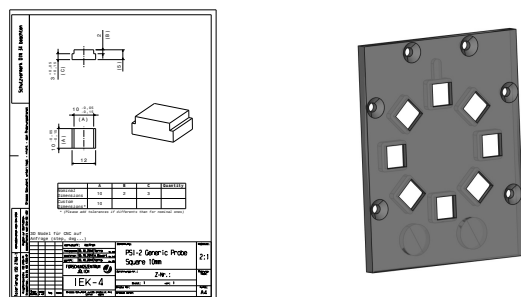


Figure 1: The mask (right figure) is made out of tungsten and can contain 8 samples (left figure), the 10x10mm top of the samples are coated with boron and attached in the mask such that it is facing towards the plasma in the vessel

The TOMAS machine [8] is equipped with a monopole ICWC antenna which will be set to operate at 50MHz, closely mimicking the 53MHz that will be used at ITER. The mask containing the samples (see figure 1) is mounted on a movable arm. 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 used in JET and will be used in ITER [9].

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.

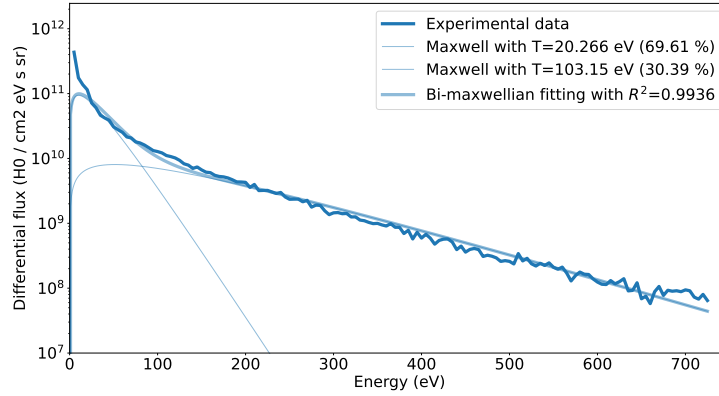


Figure 2: The assumption behind the bi-maxwellian distribution is that we have the conversion of heated ions to neutrals resulting in the high temperature maxwellian, and ions indirectly heating neutrals due to collisions, resulting in the low temperature maxwellian. There is, however, no verification 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[10], 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 [11], assuming perpendicular impingement¹.

2.2 Calculated estimates

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

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