Research plan

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1 Thickness and density estimation

We wish to know how the various wall conditioning schemes affect the boronized PFM, to this end we need to know both the thickness of the boron layer before and after the exposures, as well as it's density. We want to know the density as to see how it is dependent on the substrate and to infer how many atoms got sputtered.

1.1 Boronized Tungsten

My proposal for measuring the thickness of the boron layer is to use three methods, the first two methods concern a general estimate of the thickness whilst the third would be sample-specific. We first half-coat one sample by applying sticky tape during coating and peeling it off afterwards, enabling the first method: the use of a profilometer to determine the jump in height. The second method which we'll also apply on this half-coated sample is the use of a SEM either by drilling small holes in the coated surface and determine the thickness that way or looking at the side of the sample. The third method is to use the ellipsometer in the mirror lab, this last method is also what we'll be using for the normal samples, it is however good to have many thickness estimates of the half-coated sample as we'll need it later and as it's a good check to see if the ellipsometry measurements are accurate. Note that most of these techniques (especially the ellipsometry) will only be possible if the tungsten surface is polished properly.

To now measure the density we'll perform ion beam analysis on the half coated sample. To see how this works, please allow the following train of thought: After analysing the experimental data from the IBA (ERDA) we'd know that there are x amount of B^{10} atoms per cm^2 and y amount of B^{11} atoms per cm^2 on the surface of the sample, using the mass of both of these isotopes and the measured thickness (of which we have 3 independent measurements), we can infer the density:

$$\rho = \frac{1}{d \times 1cm^2}\left(x \times \text{massa } B^{10} \text{ isotope} + y \times \text{massa } B^{11} \text{ isotope}\right) \tag{1}$$

Assuming this density to hold for the other samples, we can infer how many atoms were sputtered from the change in thickness which we'll measure using ellipsometry.

1.2 Boronized Graphite

My proposal for measuring the thickness of the boron layer on graphite would be to use two methods, we'll also be using the half-coated sample enabling the use of a profilometer. The second method which we'll apply in conjunction is by using the ellipsometer in the mirror lab, note that the SEM wouldn't be able to see the difference between carbon and boron and is thus not possible to use here. We then proceed as mentioned for tungsten, inferring the density using IBA.

2 Doping estimation

As we'd later want to measure the outgassing efficiency of the various wall conditioning systems, we'd like to dope the samples with some atoms (e.g deuterium) and measure the concentration before and after the various wall conditioning schemes. We'll probably measure these concentrations using ERDA.

3 Exposure: Erosion rate

We'd like to expose the samples to either hydrogen, helium or mixed hydrogen and helium. Each under different wall conditioning regimes, either Glow Discharge, Ion Cyclotron Wall Conditioning, Electron Cyclotron Wall Conditioning or ICWC and ECWC at the same time. We'll first do some spectroscopy to see the amount of impurities in our plasma (if any are visible, our spectrometer is quite low-resolution). And then expose the pure boron to test the erosion rate with different powers.

3.1 ICWC

In TOMAS the IC creates both neutrals and ions, mostly with energies below 1keV. The frequency at which we may couple is still uncertain, ideally we'd like to go as high as possible which would be a 50MHz plasma, but for now we were only able to go up to 42MHz. As magnetic field we will use 0.114T (2000A input current) and power-wise we'd like to do a ramp, with values 1500W, 3500W and 5500W of injected power. Limiting the pressure to 10^{-4} mbar during the discharge of the 1500W, maintining the same base pressure (not the neutrals pressure) for the higher powers. I.e when the penning gauge indicates 10^{-3} mbar without IC and 10^{-4} mbar with IC at 1500W, we'll be doing 5500W for the same 10^{-3} mbar gas (however this system is still under consideration). Whilst the powers we'll use are very small compared to larger devices, due to the way everything is measured, as will be mentioned, it might be possible to extrapolate to bigger devices. ICWC at TOMAS is a monopole working in a mode conversion scheme, as such most of the particles evenly spread to the wall. This enables us to extrapolate measurements performed by the RFEA (retarding field energy analyser,able to measure the ion distribution) and ToF-NPA (Time of Flight Neutral Particle energy Analyser, measure neutral distribution) to the full vessel and use it as a prediction on how the sample will be eroded. Unfortunately the retarding field energy analyser (RFEA) seems to have some hickups for the moment when doing IC discharges which we'll try to fix over the next couple of weeks. If it's not properly fixed when experiments are carried out, we will have to either rely on simulations to determine the amount of ions and their energies in the plasma or correlate the electron density and temperature to the ion density and temperature (if at all possible) or correlate the neutrals to the ions (e.g assuming pure charge exchange).

3.2 ECWC

Efficiency of ECWC for fuel removal has been less investigated in current devices but as it will be used for conditioning in JT-60SA and W7-X, there is an upsurge in interest. We don't expect any 10eV$<$ energy neutrals, as such the main player of outgassing and erosion will be ions. As mentioned we either need some kind of RFEA measurements to estimate the erosion rate/simulate or somehow correlate the electron density and temperature to the ion density and temperature.

3.3 ECWC+ICWC

These sometimes are used in conjunction, so we'll also do exposures with these, note that the erosion rate will drastically increase. The max combined power should be around 11kW of injected power, we may scale as: 1.5kW EC + 1.5kW IC, 3.5kW EC + 3.5kW IC, 5.5kW EC + 5.5kW IC, or total = 3kW, 7kW and 11kW of power. We have tested 10kW already so this all seems possible. I'd do the combined erosion after the IC and EC as we'll have a more concrete idea of what to expect.

3.4 Glow Discharge

Even though GD is falling out of favour due to superconducting magnets not being easy to turn off, we'll do some exposures if time permits, with the same pre-measurements as IC.

4 Extrapolation to larger devices

If we can simulate the particle flux, using e.g a modified version of the tomator code, and the thus implied erosion using a BCA (Binary Collision Approximation) code such as rustBCA, we might be able to verify the erosion prediction and have confidence that this kind of code may work on bigger devices.

It is also possible that some mechanisms are dominant and easily scalable, for example, it might be that the IC sputtering is mainly caused by the RF sheath formed in front of the antenna. The RF sheath induced sputtering may scale logaritmically with power, if this is also the case with the sample erosion, we can be confident that it's the main sputtering candidate and thus easily scalable to other antenna's (by simulating their sheath).

5 Exposure: Outgassing efficiency

This is for much later, after all the erosion estimations have been done, but under all the previously mentioned techniques, we'll use the same measurements and estimate the outgassing rate by constructing a sample with the same amount of doping in the BCA simulation.