Plasma-surface interaction, blister formation and hydrogen retention on ITER relevant materials

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In this contribution we present a coupled approach diagnostics/modelling dealing with laboratory simulations of plasma-surface interactions in the frame of the ITER project. We made a focus on studying interaction between an hydrogen plasma and a surface of aluminum used as a surrogate to beryllium. In particular, the formation kinetics of blisters onto the surface was studied. The corresponding amount of hydrogen which diffused and is trapped in the material was quantified using a Molecular Rate Equation model.

1. General

Plasma-wall interactions present a serious concern in existing fusion reactors. Surface modification of PFC (Plasma Facing Components), dust formation and hydrogen retention are some of the problems that have to be resolved before achieving sustainable nuclear fusion. Beryllium (Be) is has been chosen as a first wall material due to its high thermal conductivity, low neutron activation, low Z and its affinity to oxygen. However it is a highly toxic material and it has to be handled with great caution. As proposed by [1,2] aluminum (Al) is a non-toxic proxy material to Be, which presents a similar behavior after plasma exposure. Its studies can therefore provide useful information that can be transposed to Be. However, their hydrogen isotope (HI) retention mechanisms are different. In this article, experimental and model results are first predicted for hydrogen retention and blister formation in Al. Next a numerical comparison between Al and Be retention will be exposed.

2. Experiments

The plasma reactor CASIMIR (Chemical Ablation, Sputtering, Ionization, Multi-wall Interaction and Redeposition) is used to partially simulate plasma wall interactions processes. This reactor relies on the ECR (Electron Cyclotron Resonance) principle to produce low pressure (10^3 mbar) and high-density plasmas (10^{11} cm^{-3}) [3]. Al samples were exposed to hydrogen plasma at different fluences with a flux of ~ $1.7\text{x}10^{20}$ ions/m^{2}s. After 6h of plasma exposure, corresponding to a fluence of ~$3.6\text{x}10^{24}$ ions/m^2, the Al surface shows a high density of blisters of approximately $2.9\text{x}10^{-4}$ blisters/µm as presented in Fig.1. The density of blisters doubles after the sample is exposed during 12h. The cross section images of these samples show large voids, of about 25-100 µm, under the blisters. These voids reach a depth of about 150 µm. There are also smaller voids, with a size of 1-5 µm, close to the surface of the sample.

3. Modelling

A macroscopic rate equations code has been used to simulate hydrogen retention in materials and bubble formation [4,5]. This code simulates the depth profile of hydrogen isotopes, the hydrogen concentration in the material and the temperature distribution in the exposed material. The code was initially developed to simulate HI retention in tungsten (W), however it has been extended for Al and Be and used to simulate the plasma conditions of CASIMIR. Three types of traps were used to simulate the experimental results on Al: vacancies, dislocations and bubbles. This numerical approach has been extended to Be and some differences on HI retention with Al are presented.

4. References

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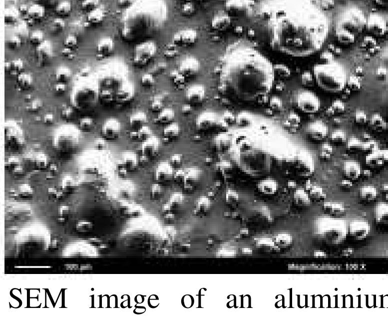

Fig. 1 SEM image of an aluminium target exposed to hydrogen plasma