Sputtering and electrical characteristics of lithium surfaces exposed to a plasma.

F. L. Tabarés, E. Oyarzabal, A.B. Martín-Rojo, D. Tafalla and J.A Ferreira.

As. EURATOM/CIEMAT, Madrid Spain

1.Introduction.

Lithium is becoming a material of high potential for Plasma Facing Components in a Fusion Reactor [1]. The reasons for this are its low atomic number, high capability of particle and power handling, in particular in its liquid form, and its low melting point, thus opening the possibility of developing liquid PFC concepts at moderate temperatures. To date, a direct relation between the enhanced performances of Li based plasma devices and the associated low recycling of cold Li surfaces (T<400ºC) has been postulated [2]. However, tritium inventory control in a reactor calls for a high recycling wall. It is expected that D and T recycling in liquid lithium could become unity at high enough temperatures (450 ºC), so that a compromise between high recycling and low vapor pressure in the range 400-500 ºC must be achieved. However, it is unknown whether the positive effects on plasma confinement will be lost under high recycling conditions.

In the present work, the search for positive effects of Li coatings other than low recycling has been addressed. First of all, the anomalous low sputtering yield observed in TJ-II experiments [3] has been investigated by inserting a fresh lithium bar in the plasma. Secondly, the sputtering yield and I-V characteristics of lithium covered metallic electrodes have been recorded in a He plasma. It has been found that at low negative potentials of the electrode, an apparent excess of ion current is driven, must larger that the one corresponding to a pure secondary electron emission from the lithium surface Details about these phenomena, its dependence on lithium surface conditions and the impact on reported observations in Li-based plasma devices are here presented.

2.Experimental.

Two kinds of experiments are described here. First, the sputtering characteristics of lithium coated first wall and that of a lithium bar inserted into the edge of TJ-II plasmas were obtained from the space resolved observation of the Li emission at 671 nm and normalized

to the Hα emission. According the previous analysis, a recycling coefficient of r=0.1 [3] has been assumed for evaluating the true absolute particle fluxes. Values of the corresponding S/XB coefficients for both emissions were taken from the bibliography [4]. The edge electron density and temperature profiles were evaluated from the supersonic He beam diagnostic, which show reasonable agreement with the Langmuir probe data if the errors for the effective probe area are accounted for.
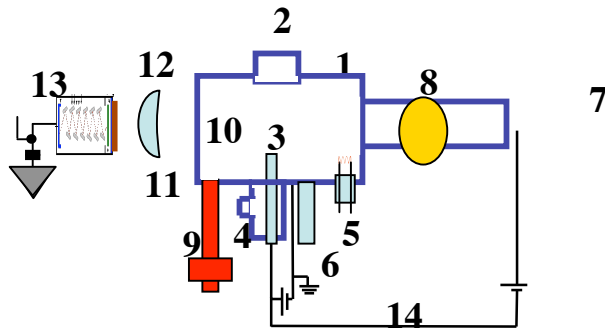

Figure 1. *Schematic drawing of the set up used for sputtering experiments in a GD discharge.1: Vacuum chamber; 2: Vacuum system; 3: anode; 4: Gas input; 5: tungsten filament; 6: Double Langmuir probe; 7: SS bar covered by Teflon; 8: Lithium oven; 9: orto-carborane oven; 10: Window; 11: Lens; 12: IF Filter; 13: Photomultiplier, 14: Bias.*

Secondly, an experimental set-up was envisaged for the laboratory tests. It is sketched in figure 1. Basically, a SS bar, which tip is the only part exposed to the plasma, is covered in a separated chamber by Li or Li/B (the B overlayer produced from a GD of o-carborane) and then inserted in a GD plasma at pressures of P<1 Pa and 300 mA current. A photomultiplier/ Interference Filter (filterscope) system looks for emission of neutral lithium, at λ=671 nm, sputtered by the plasma ions accelerated by the plasma sheath. The potential of the bar is varied from negative to near the plasma potential of the discharge (~+220 eV) while the current driven by the bar is recorded (i.e., the bar I/V characteristics). A double Langmuir probe directly inserted into the He plasma is used for the recording of the microscopic parameters, n_e, T_e, of the main discharge and to check for any possible perturbation of the bar biasing on the plasma parameters. The ion current in the I/V characteristic is tentatively ascribed to the flux of ions impinging on the bar, i.e., no secondary electron or ion effects are considered at this stage. The energy of the ions is also ascribed to the direct potential difference between the plasma and the bar, as no inelastic collisions at the sheath are expected for the low pressures here involved (ref). In this way, a direct plot of the Li line emission normalized to the ion current *vs* the difference V_p-V_{bar}

provides a first approach to the characteristic sputtering yield *vs* E ion curve for each sample.

3. Results

Figures 2 and 3 shows the evolution of the Li sputtering yield obtained in TJ-II for the wall coatings and for the fresh bar, respectively. The expected dependence from the Bohdansky formula is also shown for reference. Both values have been normalized to their respective maxima, although absolute values for the experimental yield are in the order of 6-8 times lower than predicted from the simple binary collision models and surface binding energy of Li.
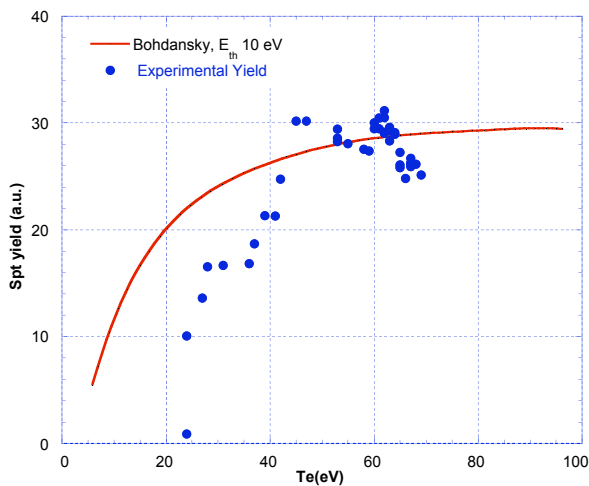
Figure 2. Li sputtering yield (a.u.) versus electron temperature at r=0.95 with a fresh lithium wall. The continuous curve represents the behavior expected according to the Bohdansky expression with Eth =10 eV normalized to the maximum experimental value and assuming E_{ion}= 5kTe.

The radial distribution of excited Li atoms in front of the bar, corrected for the background signal, was also recorded together with the edge parameter profiles. These profiles are shown in

Figure 3. Radial profile of excited Li in front of a fresh Li bar inserted into the plasma edge. Top ECRH plasmas, bottom NBI plasmas.

figure 3 for the ECRH and NBI phases of the discharge. Fitting of these profiles to a simple attenuation/excitation model allows for the evaluation of the mean velocity of the sputtered Li atoms. It must be pointed here that fast attenuation of the possible evaporated Li, at thermal energies, should not interfere in the evaluation of the Li penetration at typical, much higher, sputtering velocities. From the profiles shown in Fig 3, we obtain a radial
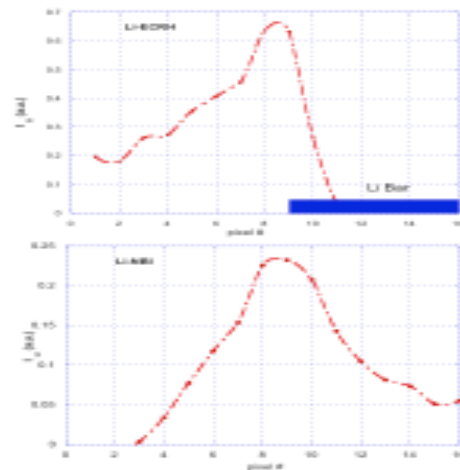
(projected) velocity of 3 Km/s for both cases, in good agreement with previous measurements [4] and the simple Thomson model.
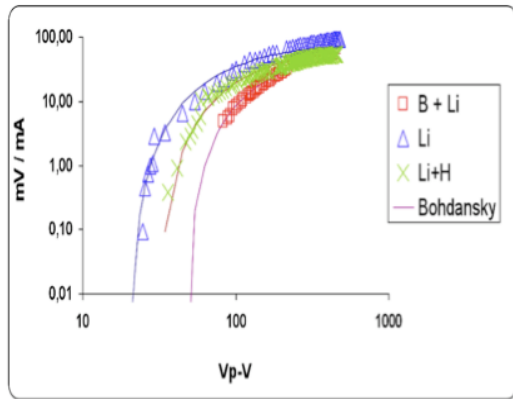

Figure 4. *Deduced curves for the sputtering yield of Li, Li-H and B-Li coatings in He GD and fittings to the Bohdansky expression for the threshold energy values of 20, 30 and 45 eV, respectively*

Lithium experiments were also performed in the GD setup shown in figure1. The results for a He plasma and three different tip coatings are shown in figure 4. Please note that the extrapolation of the data to threshold energy value is very large in the case of B coatings and therefore not reliable value can be extracted from it. However, it is worth noting that the inferred E_{th} values scale as Li < LiH < B/Li, thus supporting the assumption of surface contamination playing an important role in the observed low sputtering yield values in TJ-II. Finally, the I/V characteristics of the coated bar are shown in figure 5 for some of the explored systems. As seen, a dip in the ion saturation current, particularly conspicuous near the V_{float} value is systematically obtained. The fact that the dip, in H plasmas, is more intense in the case of clean metal, while for He plasmas that happens for the Li coated bar suggests the combined effect of secondary electron emission and metastable ionization as responsible for this effect [5]. Since secondary electron emission leads to a decrease in the sheath voltage, governing the actual energy of the impinging ions, this effect cannot be ruled out as responsible of the decreased sputtering yield observed in hot plasmas.
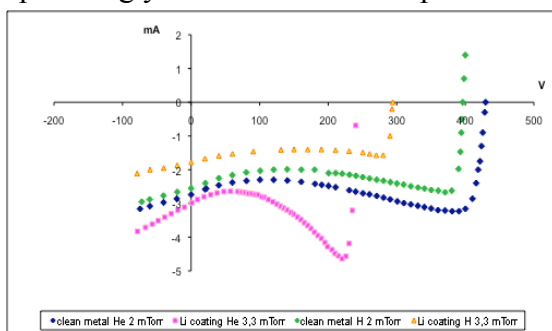

Figure 5. *I/V characteristic signal of a biased bar with/w.o Li coated tip exposed to He and H GD plasmas*

References

[1] Y. Hirooka et al. Nucl. Fus **50** (2010) 077001 [2] L.E. Zakharov et al. J. Nucl. Mater **363-365** (2007) 453.

[3] F. L. Tabarés, et al. Plasma Phys. Control. Fusion. **50,** (2008) 124051.

[4] J P Allain et al. Nucl. Fus. **44** (2004) 655.

[5] M.R. Talukder, J. Bangladesh Ac. of Sci. **31**(2007) 33-44