Testing the compatibility of lithium elements with a hot plasma: studies of solid lithium insertion in TJ-II

F. Tabarés[1], D. Tafalla[1], A. B. Martin-Rojo[1], E. Oyarzabal[1]
and J.A. Ferreira[2]
[1]*As Euratom/Ciemat.Av Complutense 22, 28040 Madrid Spain*
[2]*TE/VSC CERN, CH-1211 Geneva 23, Switzerland*

1.Introduction.

The selection of plasma facing materials for future Fusion devices, aiming at steady state operation of a burning plasma, remains challenging. Solid materials are known to be prone to disintegration, dust formation and neutron-induced permanent damage, among other deleterious effects. Therefore, liquid metals, and lithium in particular, have been proposed as alternative to more conservative concepts. One of the main concerns, however, is the survival of these elements to disruptions and type I ELMs, in particular associated to the development of strong MHD forces and massive evaporation. For liquid lithium elements, it has been claimed that self-screening driven by evaporation effectively protects them against the huge heat loads present at the plasma-solid interface [1]. However, little experimental evidence of such effect has been documented to date [2,3].

In the present work, a solid bar of lithium with biasing and displacement capabilities has been exposed to the plasma edge in TJ-II under lithiated wall conditions [4]. Heating powers up to 0.8 MW (ECRH and NBI) were injected into the plasma, leading to unmitigated power densities at the bar tip up to 30 MW/m^2. Edge parameters were characterized by a supersonic He beam diagnostic and Li I, LiII and Hα emissions at the bar and its proximity were recorded. A 16-channel photomultiplier array allowed for the monitoring of the attenuation of these signals in the toroidal and radial directions, thus enabling transport studies. In spite of the very large power loads underwent by the bar, which ultimately melted down and fell into the plasma, it survived for more than 20 shots, implying the nominal deposition of ~50 kJ on its 2g mass. Evidence of self-screening by strong localized radiation was not obtained during the present experiments, although a short ionization mean free path of the evaporated lithium into the local plasma was deduced form the attenuation analysis, thus implying the possible development of a high density local plasma near the bar.

2.Experimental.

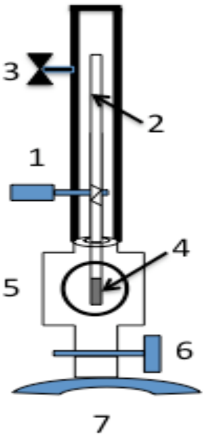

Figure 1. Schematic drawing of the set up used for the exposure of a solid Li bar into the TJ-II plasma edge. 1: Manipulator; 2 hollow shaft with teeth; 3:pulsed valve for gas input; 4 lithium bar 5: preparation chamber; 6:isolation valve; 7:TJ-II vacuum chamber.

An experimental set-up was envisaged for the exposure of solid lithium to TJ-II plasmas. It is sketched in figure 1. Basically, a pinion-and-drive manipulator with a hollow stem is used to transport the lithium bar (4 cm long, 1 cm diameter) from the preparation chamber to the plasma, typically up to the LCFS. The bar is isolated from the manipulator and it can be biased to ± 150 V respect to ground. The hollow shaft is used to flow He near the Li tip for local plasma characterization through the three-line ratio diagnostic. However, no such experiments were possible this time.

A 16 multichannel photomultiplier/ Interference Filter system looks for emission of neutral lithium, at λ=671 nm, singly ionized Li at λ= 548.6 nm and Hα from a side window. The array can be oriented, either vertically for radial propagation studies, or horizontally for toroidal ones. Hydrogen plasmas, heated by 600 kW ECRH or by 800 kW of NBI, were generated in TJ-II. Edge parameters were determined from the supersonic He beam diagnostic, located almost toroidally opposed to the Li bar location.

3. Results and discussion

Experiments were performed at different insertions of the bar into the SOL at floating potential. Only a few experiments were carried out under bias of the Li tip. Unfortunately, no visual observation of the Li bar was possible in this campaign. However, a highly spiky emission of neutral Li was eventually detected at maximum insertion. This was ascribed to the possible ejection of droplets from the solid, as this behaviour was not seen in the Li signal taken from the main wall, almost toroidally opposed to the location of the bar. No perturbation on main plasma parameters was seen upon insertion of the bar up to the LCFS.

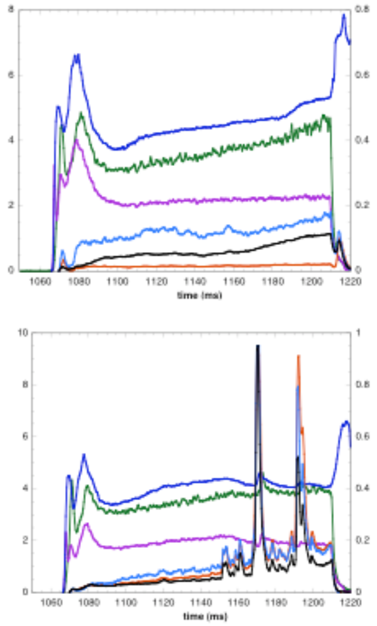

Figure 2. Traces of density, Ha and Li signals in a ECRH plasma. From top to bottom: electron density (10^{13} cm-^{3}, right scale), Li I and Hα at mid plane and local LiI signals: central(blue), SOL (black) and in-plasma (red): bottom: same but showing LiII signals with spikes

Typical signal traces during a plasma discharge are shown in figure 2. The time dependence of the electron density, lithium and Hα signals at mid plane and 180° toroidally away from the bar and the local emissions of Li (top) and LiII (bottom), from a toroidal array on which channel 8 represents the bar centre and channels 4 and 14 represent the in-plasma and SOL emissions, respectively, are shown. Note that spikes of the LiII signal in the bottom are not reflected into the main plasma traces unless a critical level is achieved. Then, a small increase of the electron density and Li signals together with a concomitant decrease of Hα, indicating enrichment in Li of the plasmas, takes place. This behaviour was systematically recorded in low-density plasmas, on which strong contribution of runaway electrons was produced. The bar was held at ground potential in these shots. From the 16-channel photomultiplier array, the toroidal profile of the LI and LiII emissions can be reconstructed. The results are shown in figure 3. As seen, two different degrees of attenuation into the plasma are seen, according to the tilting of the plasma with respect to the bar at this location. Also, a clear broadening of the Li ion emission due to plasma transport is observed. Interestingly, these profiles didn't significantly change when a ± 150V bias was applied to the bar. However, melting of the tip of the bar led to a broadening of both profiles (see below). From figure 3 top and the edge plasma parameters deduced from the He beam diagnostic, located 180 ° away in the toroidal direction, the attenuation of Li atoms ejected from the bar can be calculated. For typical values of ne= 1.10^{12} cm^{-}

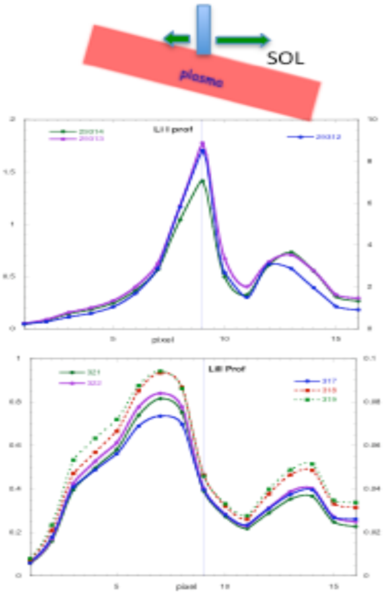

Figure 3. Toroidal profiles of LiI (top) and LiII (bottom) emmision. On top: sketch of the observation geometry (5 cm span, ~25 º tilt angle)

^{3} and Te=40 eV at the LCFS, a mean free path for Li atoms of >35 mm should be observed. The value deduced, however, is only 7 mm. This discrepancy points to the presence of a local plasma with higher density near the Li bar. The production of such local plasma has been reported elsewhere [2,3], and future experiments aimed at its characterization are presently in progress.

From the edge parameters one can also estimate the local power flux hitting the bar. For an arbitrary bias potential, V, the normalized heat flux to a probe is given by [5]

$$\frac{Q(V)}{kTe(j+/e)} \equiv \gamma(V) = -\frac{eV}{kTe} + \frac{2.5Ti}{Te} + 2\left[\left(1+\frac{Ti}{Te}\right)\left(\frac{2\pi m_e}{m_i}\right)\right]^{-1/2} \exp\left(\frac{eV}{kTe}\right) \qquad 1)$$

In the absence of external bias, the probe stays at floating potential, which in the presence of secondary electron emission (SEE) reads:

$$\frac{eV_f}{kTe} = 0.5\ln\left[\left(1+\frac{Ti}{Te}\right)\left(\frac{2\pi m_e}{m_i}\right)\right](1-\delta_e)^{-2} \qquad 2)$$

The SEE coefficient was recently evaluated in a separate experiment for solid lithium [6]. In the presence of high-energy (>100eV) electrons it can as high as 2.5, yielding a floating potential value of 1.3 Te, instead of the customary value of 3 Te. The maximum power flux to the bar deduced from eq.1 is 58 MW/m^2, so that ~2kJ would be deposited into the bar each shot. This is higher that the required energy to melt the 2g bar (1.5kJ). However, it was found that only after 12 repetitive shots, the tip of the Li bar was melted. A shielding effect by enhanced local radiation associated to the development of a local dense plasma has been claimed for plasma-exposed Li previously [1]. This issue however requires further study in TJ-II.

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