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Energy balance of FTU discharges with lithizated walls

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INTRODUCTION

At the end of 2005 a Liquid Lithium Limiter (LLL) with capillary porous system (CPS) was tested for the first time on the high field medium size tokamak, FTU. LLL has been used as plasma facing material and as a wall conditioning technique to deposit a lithium film on the chamber walls (lithization). Liquid lithium could represent a good solution in the future fusion machines to control high heat loads and to ensure the self-regeneration of the plasma facing surface. Moreover lithium is a low Z material with very good getter properties for light impurities (oxygen and carbon) and for working gas particles, as required to minimize plasma contamination and particle recycling. The innovative concept tested on FTU and developed by Russian Federation is based on the effect of capillary forces to counteract the action of JxB forces on tearing molten lithium off the container and to refill the lithium surface faced to the plasma from an underlying liquid lithium reservoir.

In this paper, after a brief description of the CPS liquid lithium limiter and lithization procedure, the physical effects of lithization on plasma characteristics and in particular those related to the energy transport analysis are described including a comparison between lithization, boronization and full metallic walls conditions. Then the conclusions are drawn.

Fig. 1. Photograph of the three units of Liquid Lithium Limiter installed on the support used for the LLL introduction inside FTU.

LLL SYSTEM AND LITHIZATION PROCEDURE

The prototype of LLL used on FTU [1] employs the same CPS configuration just successfully tested on T-11M [2]. This structure is realized as a matt from wire meshes of stainless steel 304, with pore radius 15 μm and wire diameter 30 μm that lead liquid lithium to the side faced to the plasma from a liquid lithium reservoir. The LLL system, composed by three similar units showed in Fig. 1, is installed on a vertical bottom port of FTU and can be exposed to the edge plasma up to 2 cm inside the last closed magnetic surface (LCMS) defined by the contact with a TZM (an alloy with 98% of molybdenum) toroidal limiter. Lithization is performed by using LLL during plasma discharges as a source of lithium atoms produced by sputtering plus evaporation processes induced by plasma interaction. Three shots at B_T=6T, I_p=0.5 MA, linear average density n_e =0.7x10^{20} m^{-3} with LLL inserted at a distance of about 2 cm from LCMS are needed to form a lithium film thickness of about 10 monolayers, by assuming an uniform distribution of Li atoms on the chamber walls.

PLASMA RESULTS

In the first experimental campaign the LLL has been tested in ohmic discharges at B_T=*6T*, I_p=*0.5-0.9MA* and n_e from 0.15 up to 2.7x$10^{20}m^{-3}$. Lithization has allowed obtaining very clean plasma with a strong reduction of medium-high Z impurities such as Fe and Mo and with a prolonged gettering effect on oxygen due to the Lithium accumulation on the surfaces not directly exposed to the plasma. These results have produced low effective ion charge mostly maintained below 2.0 during all the experimental campaign (about 200 shots). As a consequence of the reduction of Z_{eff}, the resistive loop voltage was lower than for purely metallic walls conditions and even lower than for discharges after boronization [3]. Also the radiated power was reduced to the lowest values ever reached on FTU, between 40% -20% for all the explored plasma conditions (Fig. 2).

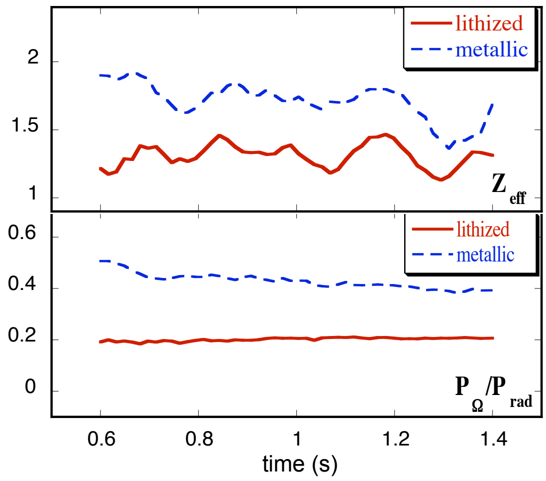

Fig. 2. In the first frame the effective ion charge for a lithizated (continuos) and a metallic discharge (dotted) is shown. In second frame the ratio between ohmic and radiated powers for the same discharges.

Another effect of lithization has been the strong modification of the recycling characteristics due to the pumping effect of Li on D_2 particles, resulting in a better control of plasma density and in a higher density limit than for boronized walls [4]

ENERGY TRANSPORT ANALYSIS

Transport and energy balance analysis was performed for lithizated, metallic and boronized discharges with B_T=*6 T*, I_p=*0.5 MA* and linear average n_e=*0.6x*$10^{20}m^{-3}$. In particular, a clean metallic discharge (i.e. oxygen-free) and a fresh boronized discharge without saturated walls were chosen for comparison with lithizated discharge. The analysis was made using the transport code JETTO [5] in interpretative mode as concerning electron energy transport. Experimental magnetic equilibrium, electron density profile and temperature profile were used as input of the code. Radiation profile was calculated from impurities concentrations by the cooling rate factor for each single impurity, while effective ion charge was obtained from bremsstrahlung measurements which within the error bars is consistent with the experimental resistive loop voltage. Due to the fact that ion temperature is not measured on FTU, ion temperature profile was calculated assuming neoclassical ion transport augmented by an anomaly factor of about 2.5 needed to reproduce the experimental neutron rate in ohmic discharges before lithization.

As a result of our analysis it was found out in lithizated and boronized discharges an improvement of the energy confinement time τ_E by a factor of 1.3 in comparison with metallic ones (Fig. 3). On the other hand, the transport analysis shows a reduction, even though not so remarkable, of electron thermal diffusion coefficient χ_e for lithizated discharge [3]

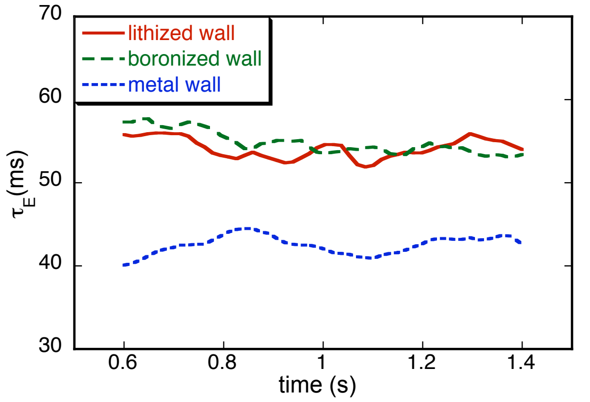

Fig. 3. Energy confinement time for lithizated (continuos), boronized (dashed) and metallic (dotted line) discharge.

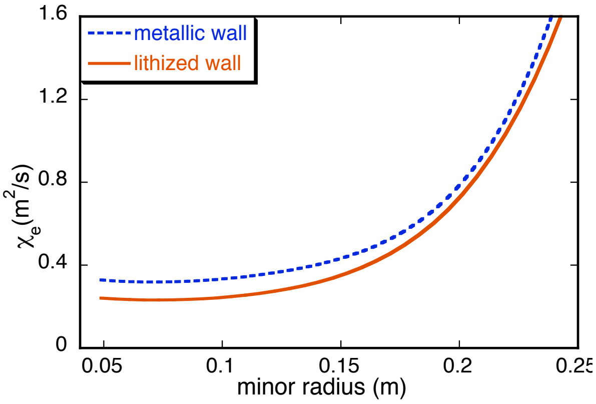

Fig. 4. Electron thermal diffusion coefficient χ_e for lithizated (continuos) and metallic (dotted) discharges.

as well as in boronized discharge in comparison to the metallic one (see Figure 4). This small reduction cannot be considered an indication of any substantial evidence of an ameliorated transport regime. This is due to the fact that the major responsible for the increase of the energy confinement time is the strongly reduced ohmic power in lithizated and boronized discharges as a consequence of reduction of the effective ion charge, Z_{eff}. A lower value of Z_{eff} causes reduction both in ohmic input power and in output radiated power, so that the two terms contribution balance each other in the calculation of χ_e.

The energy confinement time τ_E as resulting from energy balance analysis, was compared with ITER97 L-mode scaling [6] and found higher by a factor between 1.19 and 1.25 for the lithizated discharge (Figure 5). The fresh boronized discharge shows an increment by about the same factor, while the metallic discharge has a value of $\tau_E/\tau_{ITER97L}$ of about 1.1, a value sensibly higher than theaverage for the standard FTU ohmic discharges, which is equal to 0.92 [7]. This fact is essentially due to the particularly good cleaning state of the analyzed metallic discharge where oxygen is almost completely absent.

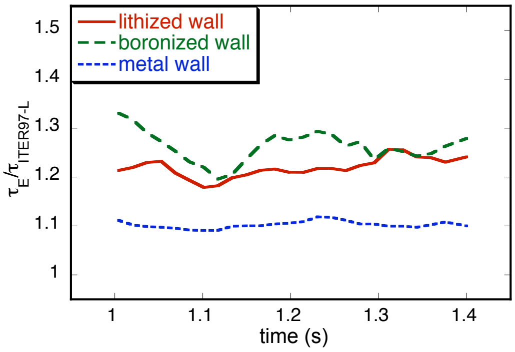

Fig. 5. The energy confinement time enanchement over ITER97L mode scaling as predicted by JETTO for the lithizated (continuos), boronized (dashed) and metallic (dotted) discharges.

CONCLUSIONS

Transport energy balance analysis has been performed among lithizated, boronized and purely metallic ohmic plasma discharges. For all these cases, values of $\tau_E/\tau_{ITER97L}$ greater than one have been found and up to 1.25 in lithizated and boronized discharges. However, it is to point out that, for boronized discharges, differently to lithizated discharges, this behaviour is observed only for the best wall conditions, i. e. a few shots after boronization with not saturated walls. In the case of metallic oxygen-free discharges this behaviour is obtained only after old lithization and/or boronization when the gettering effect of Li and B on oxygen is still present.

REFERENCES

[1] M.L. Apicella et. al. *First experiment with Lithium Limiter on FTU*. 17° International Conference on Plasma Surface Interaction in Controlled Fusion Devices, 22 – 26 May 2006, Hefei Anhui, China.

[2] V.B. Lazarev et al.,30th Conf. On Con. Fus. Pla. Phys., ECA2003, v.27A, P - 3.162.

[3] M.L. Apicella et al., *Nucl. Fusion*, **45** (2005), 685.

[4] O. Tudisco et al., this Conference.

[5] G. Cenacchi, A. Taroni, in Proc. 8th Computational Physics, Computing in Plasma Physics, Eibsee 1986, (EPS 1986), Vol. 10D, 57.

[6] S.M. Kaye et al., *Nucl. Fusion*, **37,** No. 9 (1997), 1303.

[7] B. Esposito et al., 2004 *Transport Studies in the FTU Tokamak*, ch. 6, pp. 370-86 (special issue on FTU) Fusion Sci. Technol. 45 297-520.