Radiative layer with a Liquid Lithium Limiter on FTU

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INTRODUCTION

On FTU the use of a Liquid Lithium Limiter (LLL) with a capillary porous system (CPS) has produced original and promising results, as described in ref [1, 2]. Sputtered and evaporated Li is able to produce a radiating layer acting as a protective thermal shield on the exposed surfaces. This has been clearly observed and analysed in FTU, when the LLL leading edge was inserted in the FTU vacuum chamber at a distance of ≈2 cm behind the last closed magnetic surface (LCMS) and was exposed to a thermal load of 2 MW/m^2. A toroidal ring of bright green light due to single ionized Li atoms (λ = 548.4, 548.6 nm) was formed in the bottom side of the vacuum chamber, indicating that the radiative behaviour of the Scrape Off Layer (SOL) was mostly governed by lithium. This paper is focused on the results obtained with LLL inserted more inside the SOL (up to 1.5 cm from the LCMS) in order to produce more evident "shielding" effects by means of a strong Li efflux from LLL surface. Total plasma radiation and its poloidal distibution were monitored by horizontal and vertical bolometric arrays and by CCD diagnostic. In fig. 1 it is shown a simplified scheme of the FTU lithium experiment. Here LLL is installed in one lower port and consists of three separated modules (molybdenum rods coated by lithium-impregnated CPL). The schematic view of the horizontal bolometric arrays that are shifted 120^0 in toroidal direction from the LLL location is shown in fig. 2.

EXPERIMENTAL RESULTS

The first discharges (##29860 ÷ 29867) with a high level of lithium injection into the FTU plasma were performed in autumn 2006 when LLL was inserted up to a distance of 1.5 cm from the LCMS to test the limits of LLL operations. The strong Li flux onto the chamber walls during these sequence of shots resulted in a definite drop of deuterium recycling. The usual limit of D_2 puffing rate was not high enough for the stabilization of plasma density to the pre-programmed value of $0.8x10^{20}m^{-3}$ and the plasma density decreased almost by a factor 2 from the first to the last shot. This fact produced a plasma with a higher electron temperature. The most interesting features were related to the radiative characteristics of these shots that resulted strongly modified. This is clearly evidenced in fig. 3 by comparing the last two discharges of this sequence (#29866, #29867) characterized by very similar electron density ($0.4x10^{20}m^{-3}$) and temperature (2.5keV). From the figure it results evident for shot 29867 the decrease of the signal from the horizontal bolometric chord BolH01 looking at the toroidal limiter and the simultaneous increase of the signal from the vertical bolometer chord BolV05 looking at the LLL. This behaviour indicates the loss of radiation spatial symmetry and the vertical shift of the radiation from the center of the plasma column towards the bottom side where the lithium limiter is located as supported by the VC image (fig. 4). Looking at the line integrals of the horizontal bolometric array (P_{RADH}) for plasma discharges with different dominant impurities, the following results were obtained: a) a nearly symmetric radiation profile with P_{RADH}/P_{OHM}= 20% (*with Mo as dominant impurity and absence of oxygen concentration),* b) an asymmetric radiation profile with P_{RADH}/P_{OHM} = 10% (*with Li as dominant impurity and with LLL inserted)*, c) a partially recovered symmetric radiation profile with P_{RADH}/P_{OHM} = 14% (*with Li as dominant impurity but after LLL extraction)*.

The analysis of the spatial distribution of the radiation resulting from the sixteen horizontal chords (see the schematic view of fig.2) is shown in fig. 5 for the cases with LLL inserted (#29867) and immediately after LLL extraction (#29871)

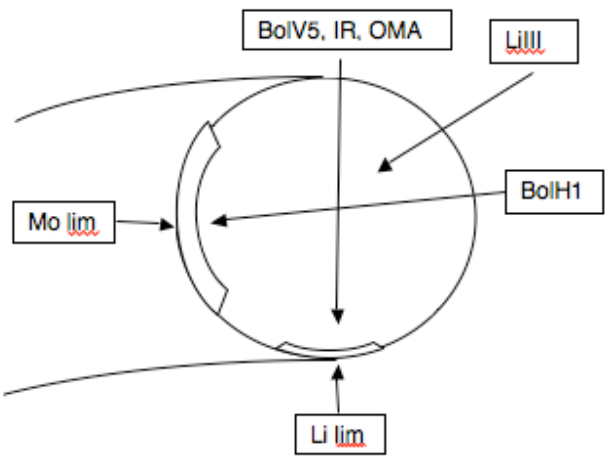

Fig.1 Schematic view of LLL experiment:BolH1, BolV5: horizontal and vertical bolometer chords, IR: infrared sensors for the measurement of lithium surface temperature, OMA: Optical Multi-channel Analyzer looking at the LLL

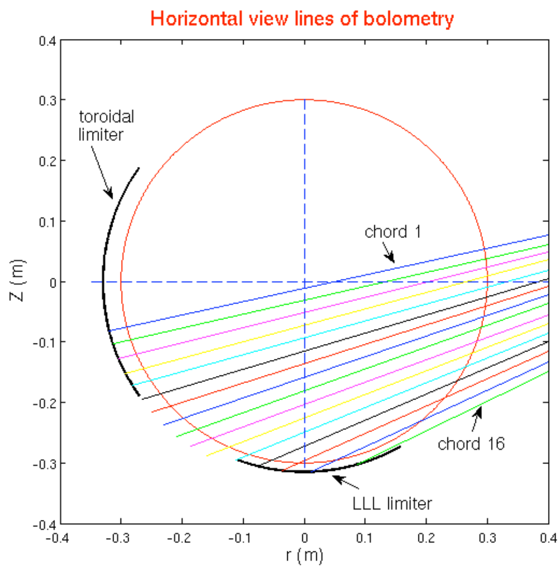

Fig.2 Schematic view of the horizontal bolometric chords on FTU looking at the lower part of the plasma

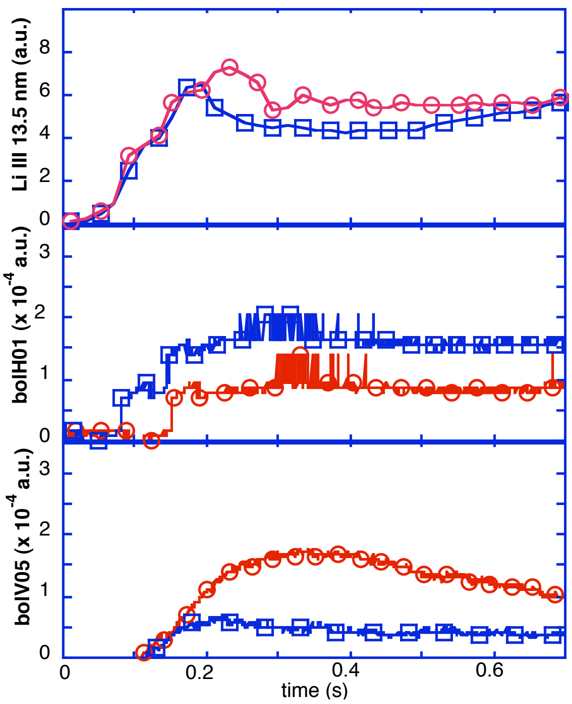

Fig.3 Comparison of the discharges #29866 (squares) and #29867 (circles). Starting from the top: LiIII line emission, bolH01 (horizontal) and bolV05 (vertical) bolometric signals.

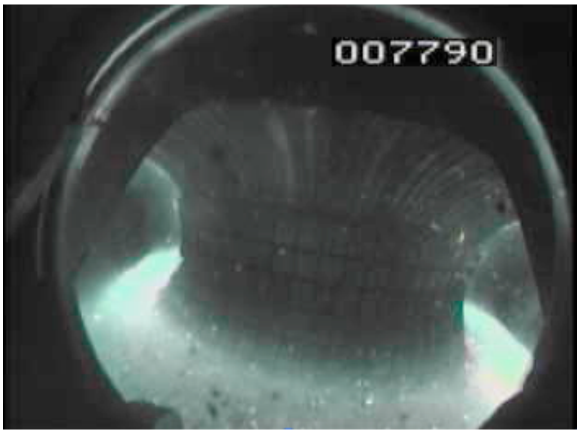

Fig.4 Enhanced Li injection forms a "radiative" toroidal Li limiter when LLL is well inserted in the SOL (shot 29867)

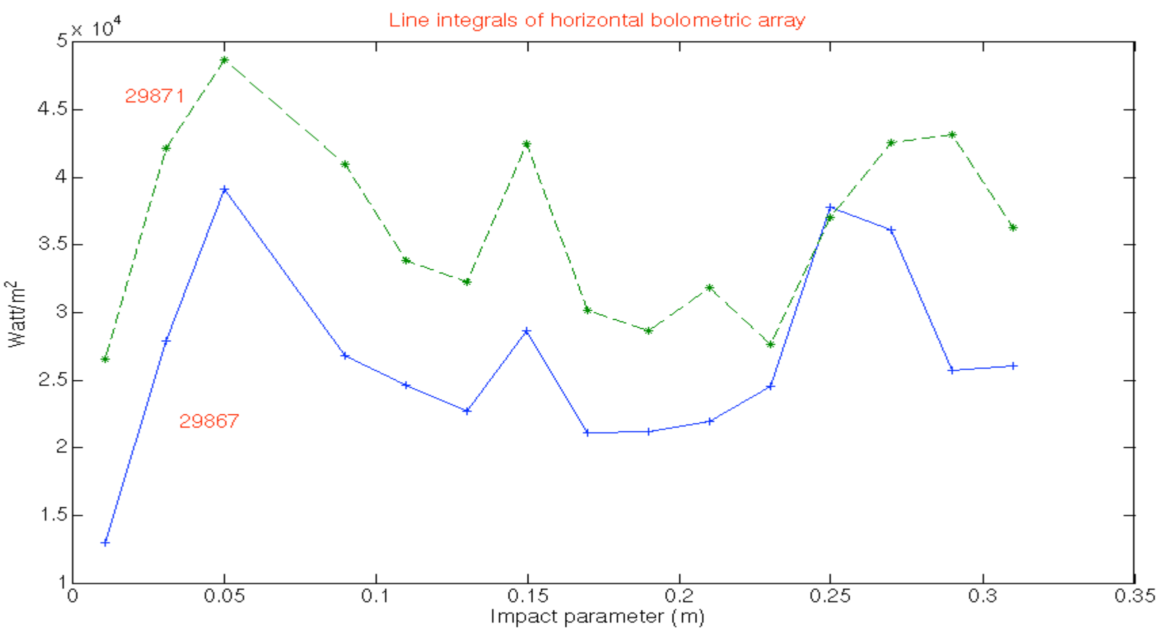

Fig. 5 Line integrals at 0.5s of horizontal bolometric signals for shot with LLL inserted (#29867 full line) and for shot with LLL extracted (#29871 dashed line)

Here the impact parameters vary from -1cm (chord 1) up to -31 cm (chord 16) with a radial resolution of 2 cm. The absolute values of shot 29867 for the chords looking directly at the toroidal limiter from -1 cm (chord 1) to -11 cm (chord 6) were found well below than for shot

29871. For impact parameters from - 23 cm (chord 12) to – 29 cm (chord 15) both shots displayed an increase of the radiation signals, but the relative contribution to the total radiation for shot 29867 resulted higher than for shot 29871. As deduced by the value of the impact parameter of chord 12, this radiation is surely bounded at radii larger than 0.23 m that is in the plasma periphery at r/a=0.79, where a=0.29 m is the radius of the main Mo limiter. According to the 2D multifluid edge transport code TECXY [3] for the LLL modelling, the production of lithium atoms from LLL surface (50 cm^2) is too small to result in the Li coating of the full toroidal Mo limiter ($1m^2$) even with the LLL in the closest position to the LCMS tested up to now. Under these conditions, the level of BolH01 signal of fig. 3 can be considered as representative of heavy ion emission from the Mo limiter due to physical sputtering. From the experimental results, its value for shot 29867 is lower than for shot 29866, that is compatible with the effect of Li radiation on the decrease of edge electron temperature, and consequently of the thermal load on the limiter surface.

It is to point out that with LLL inserted and Li as the only impurity, plasma dilution defined by the ratio of deuterium to lithium+deuterium concentrations $n_D/(n_D+n_{Li})$ was as low as 85% at the low density $0.4x10^{20}m^{-3}$ here examined. It was deduced by the value of the effective ion charge Zeff (0) in the plasma centre, as given by Spitzer resistivity and assuming q(0)=1, and that was equal to 1.7 for the discharge here examined.

CONCLUSIONS

The first FTU results with a strong Li efflux from LLL surface support the idea of a "radiative" Li lithium limiter that transforms and re-radiates the plasma energy flux to the tokamak vessel surface and decreases the heat load on the Mo limiter. Then, the well-known problem of high heat removal rate from the plasma facing components could be much facilitated in the fusion reactor, if the lithium shielding mechanism is proved to be universal. These experiments give a contribution for the investigation of a more complex scenario aiming at the innovative project of a liquid lithium divertor.

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