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Experiments on FTU with a liquid lithium limiter

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INTRODUCTION

During the year 2007, experiments have been carried on to test a Liquid Lithium Limiter (LLL) with capillary porous system (CPS) on the high field medium size tokamak FTU. Previous results [1] with LLL have shown that plasma discharges with lithized walls are remarkably cleaner than those with purely metallic or boronized ones: Z_{eff} in ohmic discharges is well below 2 in a wide line-averaged density range $0.15<\bar{n}_e<3.0\times10^{20} m^{-3}$. Due to the strong reduction of oxygen and molybdenum concentration inside the plasma, Li becomes dominant impurity resulting in radiation losses lower than 30% of the ohmic input. Moreover, as a consequence of the strong pumping effect of Li, with LLL up to 10 times more gas than in boronized or fully metallic discharges has to be injected to get the same electron density, These plasmas are characterized by electron temperature in the scrape off layer (SOL) higher by a factor 1.5 than those normally measured [2]. Operations near or beyond the Greenwald limit are easily performed. Plasma operations are more reliable with good plasma reproducibility and allowing for easier recovery from plasma disruptions.

The LLL used on FTU employs the same CPS configuration previously tested successfully on T-11M [3]. 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 the liquid Li, from a reservoir, to the side facing the plasma.

Fig. 1. Photograph of the three units of LLL

The LLL system, composed by three

similar units shown in fig. 1, is installed on a vertical bottom port of FTU. In this paper we present the most interesting experimental results. Very high peaked density profiles are obtained in ohmic (OH) conditions and described here together with additionally heated discharges, with LH and ECRH when the LLL is inserted in the SOL, about 2 cm away from the LCMS in the shadow of the main TZM toroidal limiter.

EXPERIMENTAL RESULTS

The LLL has been exposed to the plasma in OH discharges at B_T=6T, I_p=0.5-0.7MA and $\overline{n}_e$ from 0.15 up to 3.0·$10^{20}$$m^{-3}$. New plasma regimes with highly peaked density profiles (peaking factor $pk_n=n_{e0}/\langle n_e\rangle > 2$ [2]) can form spontaneously for $\overline{n}_e$>1.0·10^{20} m^{-3}. Plasma densities near or beyond the Greenwald density limit are achieved and easily reproduced. Higher electron temperatures at the plasma periphery and in the SOL are generally observed in the whole density range as a consequence of the strong pumping capability of lithium. The associated quasi-quiescent MHD activity points out the importance to have low recycling and high T_e at the edge [4]. Further investigations on this crucial issue are under way on FTU [5].

The evidence of strong peaking density profile with low-recycling plasmas is shown in fig.2. The temporal evolution of $\overline{n}_e$ on the central and a peripheral chords of the interferometer is plotted for two high-density discharges with B_T = 6T and I_p 0.5MA. The strong increase of the density peaking factor starts with MARFE oscillations that are visible on the signals at about 0.6 s. Remarkably, the higher density shot (#30583, $\overline{n}_e$~2.8·10^{20} m^{-3}) also shows a stronger peaking (pk_n~2.3 and n_{e0}~4.5·10^{20} m^{-3}) contrarily to the common experience with gas fuelled discharges. This is evident from the fact that the peripheral chords are almost unchanged for the two discharges, while the central ones are strongly different. Consistently, the SOL density profiles are very much similar, see fig. 3 where they are plotted versus the distance from the LCMS.

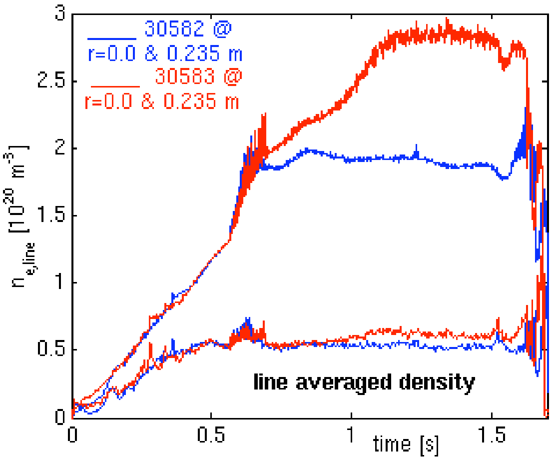

Fig.2-Time traces of central and peripheral density

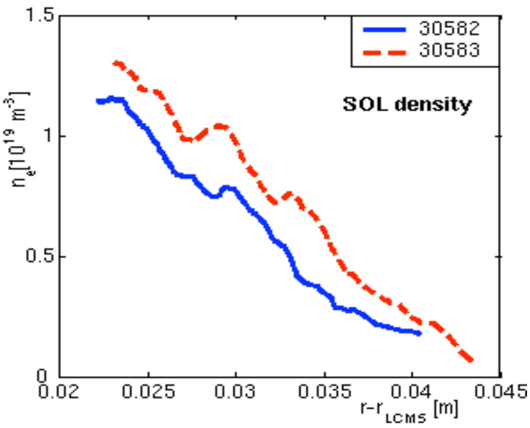

Fig.3-SOL density profile for the shots of Fig. 2

The small increase in #30583 is well below that expected from the scaling law holding for FTU, according to which $n_{eSOL} \propto \bar{n}_e^{1.46}$ [6].

The common feature of the high density lithized plasmas is the steeper radial density profiles, with respect to those obtained with other wall conditions, suggesting that the pumping effect of lithium leads to a particles depletion of the outermost plasma region. This effect on the density profile is also observed after a fresh boronization but it lasts only for a few shots.

Plasma discharges with LHCD and ECRH at total power levels up to 1.5 MW have been performed at B_T=5.3T, I_p=0.5MA and $\bar{n}_e$ in the range from 0.5 up to $0.8 \cdot 10^{20}$ m^{-3}. Respect to 'metallic' walls conditions both the particle recycling and the Z_{eff} value are kept considerably lower even with non-negligible additional power exhibiting only minor changes in the edge parameters when moving from the ohmic to heated phase. Preliminary results also indicate that strong internal transport barrier (ITB) can be obtained with lower additional power than for pure metallic or boronised walls. Investigations are going on to assess the role of Z_{eff} reduction, that increasing the LH current drive efficiency could facilitates the formation of a proper current radial profile, as well as the role of the reduced recycling.

In fig, 4 two discharges have been compared with lithized (#30620) and metallic (#27923) walls characterized by similar main plasma parameters. In both cases additional power has been applied during the plateau of the plasma current. For #30620, P_{LH}=0.75 MW and P_{ECH}=0.8 MW starting respectively at 0.5 s and 0.45 s, while for #27923 P_{LH}=1.5 MW and P_{ECH}=1.2 MW respectively starting at 0.5 s and 0.55 s. For #30620, obtained with LLL, a strong ITB with very high central temperature of 8 keV develops to be compared with the lower value of 6 keV reached in the metallic case, in spite of the higher additional power injected.

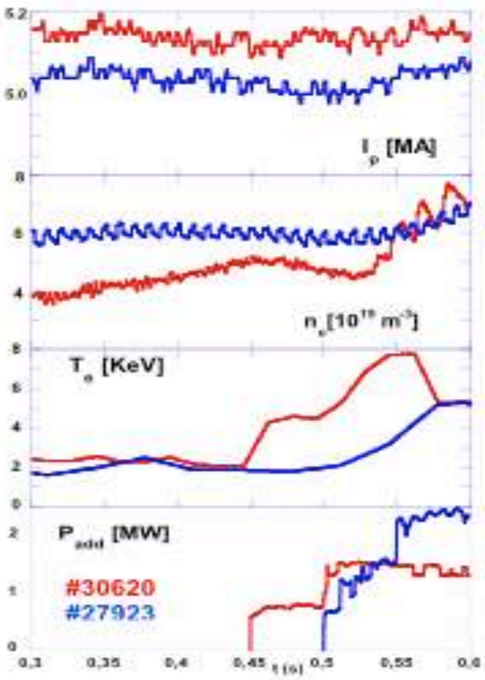

Fig.4 Comparison between plasma discharges

Although it is short leaved, the barrier is quite high, since its strength, as given by the normalized temperature gradient, $\rho^*_{T,Max}$ [7], is about 0.026, well above the ITB threshold of 0.014. Its radial width exceeds half the minor radius, similarly to what previously obtained in FTU for the same current and field [7]. The large dilution of the plasma with lithium particles up to 50% accounted for by the partial decrease of neutron rate signal, is a consequence of the too low plasma density operations, where higher Li flux is expected into the plasma. The dilution effect has not been observed for medium and high-density discharges by comparing the neutron production of similar shots with different wall conditions.

CONCLUSIONS AND PERSPECTIVES

Experiments with the liquid lithium limiter exposed to the plasma have confirmed that a strong peaking of the electron density occurs above the density value, $\overline{n}_e$~$1.0 \cdot 10^{20}$ m^{-3}. Peaking factors greater than 2, quite similar to those obtained in pellet fuelled discharges, are achieved.

These effects occur in presence of low recycling and high electron temperature at the edge as a consequence of the strong pumping capability of lithium. The underlying physics connecting the modified edge conditions and the generation of peaked density profile needs to be further investigated.

In presence of both ECH and LHCD additional power, electron temperature up to 8 keV are achieved when an internal transport barrier is developed. Comparison with previous discharges at comparable plasma parameters, has shown that about half the additional power is sufficient in lithium discharges to establish the barrier. This power threshold reduction could be partly explained by the Z_{eff} reduction (at least of a factor 2), while the connection between the lower recycling conditions and better plasma performance need to be further investigated.

The results so far obtained have encouraged starting the design of a new liquid lithium limiter able to withstand high heat loads and to act as main limiter on FTU. This limiter will be actively cooled and equipped with a system for the lithium refilling thus pioneering a work for a conceptual prototype of a divertor panel.

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