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Peaked density profiles and MHD activity on FTU in lithium dominated discharges

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ABSTRACT

Density profiles become broader, as the line averaged density is increased. At higher density, change of the trend is associated with the appearance of the MARFE. Lithium coated wall extends the maximum density accessible at low current (well above the Greenwald density limit) and can produce profiles with very high density gradient. At higher current the effect on the density limit can be exceeded only if the magnetic field is raised too. A comparison of successive similar discharges before and after wall conditioning with lithium showed a reduction of the MHD activity.

1. Introduction

Lithium is becoming a very interesting element to be used as first wall material in fusion devices. Its retention capability of large amount of hydrogen reduces the wall recycling allowing a better control of the plasma density [1–4]. Some positive effects on the plasma core have also been observed in the presence of lithium coated wall [5,6], and whether this is related to the drastic change of the edge parameters is under investigation in many devices. In Frascati Tokamak Upgrade (FTU) the better performances are ascribed to the peaking of the density profiles at very high density [6,7]. In this paper a detailed presentation of the density profile behavior in FTU under different wall conditions is reported.

FTU is a middle size machine ($R_o = 0.935$ m, $a = 0.3$ m) with circular poloidal section and metallic first wall. It is a compact Tokamak with high magnetic field (up to 8 T) and plasma current up to 1.6 MA [8]. The stainless steel liner is covered internally, by a toroidal limiter made by 2 cm thick tiles of molybdenum. A molybdenum poloidal limiter is also used to protect the external side of the vessel. No carbon tiles have ever been inserted in FTU, even though small carbon contaminations have occurred in the FTU, for the outgassing of MHD coils insulator. Recently, a poloidal Liquid Lithium Limiter (LLL) has been installed in a vertical port [2].

Oxygen is usually the main light impurity when operating with high Z material wall. In order to reduce the oxygen content, FTU walls are usually conditioned with boron at the beginning of any experimental campaign. Walls can also be conditioned with lithium, inserting LLL into the scrape-off layer (SOL), and using the plasma discharges to spread the lithium on the walls [6]. The effects of the lithium persist for several discharges after the LLL has been extracted from the SOL. We will refer to both kinds of discharges (with LLL inserted and followings) as "lithium conditioning discharges". An extensive study of the density behavior in ohmic discharges is presented in this paper, comparing wall conditioned with boron and lithium.

2. The scanning interferometer

As FTU is a compact high magnetic field machine, the port area is rather limited both in toroidal and in radial direction. The vertical port, where the interferometer is located, is 40 cm wide in the radial direction so that the plasma can be probed from the edge (+30 cm), at the low field side (LFS), to −10 cm that is 1/3 of the radius at the high field side (HFS). However, this port is split in two by a mechanical reinforcement of the vacuum vessel, each of which is scanned by a beam of the CO_2/CO interferometer. The two color interferometers use a CO_2 laser (10.6 μm) as main wavelength and a CO laser (5.4 μm) for compensation of the mechanical vibrations [9,10]. Each of the two scanning beams are produced by a fast tilting mirror that oscillates in the focus of a parabolic mirror, so two vertically translating beams are obtained. The beam is then reflected back to the original direction by a second passage through the same

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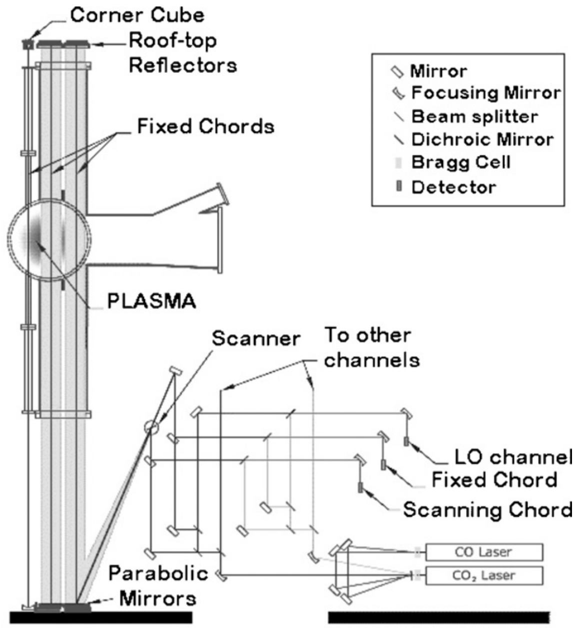

Fig. 1. Sketch of the scanning interferometer. Two scanning chords are used to cover the 2/3 of the plasma diameter.

optics thus allowing the use of a fixed detection line. Some fixed chords are also installed which, however, are not relevant for the purpose of this paper (Fig. 1).

Scanning mirrors oscillate at 8 kHz, and provide a density profile every 62.5 μs. Such time is short enough for most of the plasma phenomena. Density rise produced by slow pellets in 0.5 ms has been resolved [11]. The spatial resolution of the interferometer is given by the beam width that is about 1 cm in the plasma. The CO_2 interferometer is not very sensitive due to its short wavelength, but on the other hand it is strongly immunized with respect to the fringe jump problem. The noise on density measurements is about $2 \times 10^{18}\ m^{-2}$.

The typical line integrate density profile of FTU is shown in Fig. 2 (dots), together with the Abel inverted profile (solid line).

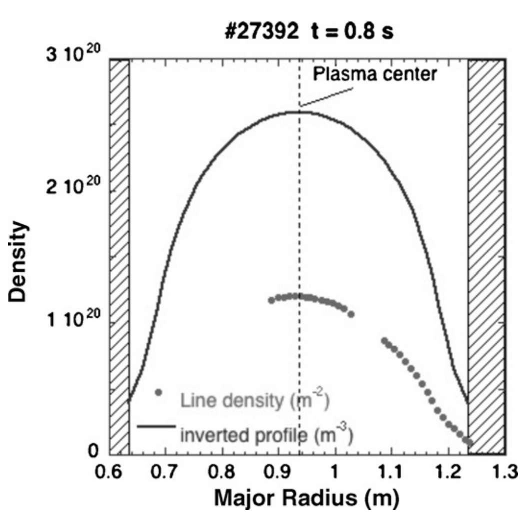

Fig. 2. Typical density profile of FTU. The measured line averaged density (dots) and the Abel inverted density profile (full line). Plasma boundary is shown as dashed area.

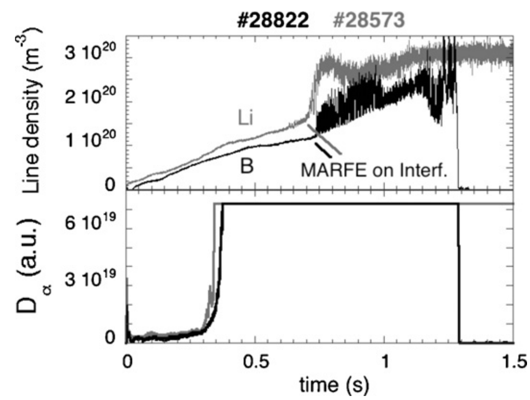

Fig. 3. Two FTU discharges, with boron conditioned wall (dark line) and lithium conditioned wall (gray line). MARFE appears on D_α at about 0.3 s, and is observed on interferometer later (0.8 s) at higher density. In boron conditioned discharges MARFE usually appears at lower density with respect to lithium conditioned ones.

3. Abel inversion of density during MARFE

At high density and low current, and especially in the presence of low Z impurities like lithium and boron, a radiative instability known as MARFE [12,13] occurs at the plasma edge, inside the last closed surface. The instability is caused by a reduction of the parallel thermal conductivity at the edge caused by a drop of the edge temperature. It is not our intention to give here a complete analysis of the MARFE instability, that can be found elsewhere [14–16], but it is important to give the main phenomenological characteristics to understand its effects on density profiles.

The MARFE appears at the high field side edge, just above or below the toroidal limiter. The visible camera shows a toroidal ring of strong emission in this zone and the D_α emission from this zone increases by orders of magnitude. The MARFE emission is poloidally asymmetric and is radially confined within few centimeters. The small ring observed by the camera, expands poloidally increasing the intensity till the camera is completely saturated. When the MARFE is well developed it is also observed on the CO_2/CO interferometer starting from the HFS chords. In Fig. 3, it is shown the line density (upper box) from the inner chord of the interferometer ($R = 0.88$ m) and the D_α emission along a line looking horizontally into the toroidal limiter, for two discharges: #28822 (conditioned with boron) and #28573 (conditioned with lithium). The sharp rise of D_α at 0.3 s is the signature of the MARFE formation. With increasing density the MARFE expands poloidally towards the low field side until it fully enters the interferometer view giving rise to fast density oscillations. The oscillations can be large and regular, as in shot #28822 (B), or small and chaotic as in shot #28573 (Li). As the MARFE is poloidally asymmetric the line integrated density profile is strongly affected by its presence and the inversion problem cannot be solved using only the interferometer information. This problem is common to boron and lithium wall conditioning, and the main difference is the density at which the MARFE appears.

In Fig. 4, the line density of discharge #28808 (conditioned with boron) with a strong density oscillations during the MARFE is shown.

One of these oscillations is expanded in the small box on the left. The oscillation period is about 6–7 ms and is well resolved by the scanning interferometer. The line density profiles at four different times during the oscillations, are shown in the lower box (profiles 1 and 4 are at the minima, 2 during the ramp up and 3 at the peak of the oscillations). We can make the following observations: (i) profiles 1 and 4 are almost identical and symmetric with respect to the plasma centre; (ii) the peripheral LFS chords are not affected by the MARFE at any time; (iii) at the top of the oscillations the central