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Journal of Nuclear Materials 313–316 (2003) 734–737

journal of nuclear materials

www.elsevier.com/locate/jnucmat

Observations with a mid-plane reciprocating probe in MAST

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Received 27 May 2002; accepted 17 September 2002

Abstract

A fast reciprocating probe has recently been installed on MAST. It has been used to measure the outboard, mid-plane scrape off layer (SOL) of L-mode plasmas, and to study the intermittent fluctuations in the SOL in L-mode and ELMy H-mode discharges. In this paper, the system and the experiments are introduced.

PACS: 52.25.Gj
Keywords: SOL; Reciprocating probe; Fluctuation

1. Introduction

An experimental database of the upstream scrape off layer (SOL) is fundamental for extrapolating from existing spherical tokamaks (ST) to divertor and target condition in future large devices. This forms an important part of SOL modeling [1] (OSM2/EIRENE) validation work on MAST. In addition, the ST geometry of MAST leads to a low field (typically 0.25 T) at the outboard mid-plane allowing the physics of the SOL in regimes where the ion gyro radius, ρ_i^* is a significant fraction of the heat flux width, Δ_h (ρ_i^*/Δ_h up to 1 compared to $\ll 1$ in conventional devices) to be explored. A reciprocating probe (RP) is installed on the outboard, mid-plane of MAST for SOL physics researches. It is also found to be an invaluable tool for exploring the characteristics of ELMs in the far SOL.

The probe head is equipped with a range of diagnostics for studying the upstream edge plasma (up to and slightly inside the separatrix) including radially spaced triple probes, a Mach probe and an array of fast mirnov coils. These allow it to be used for measurements of the upstream SOL parameters, SOL flows and both electrostatic and electromagnetic fluctuation levels.

This paper reports RP work providing mid-plane parameters and profiles for the outboard mid-plane SOL of L-mode plasmas with a mid-plane RP in MAST, and focuses on the observations of the intermittent fluctuations in the SOL. In Section 1, the RP system is introduced. Section 2 gives the experimental setup. In Section 3, the results are discussed.

2. Reciprocating probe system

The RP system is attached radially to MAST through an outboard flange in the equatorial plane. Its driving system consists of a motor drive unit and a pneumatic drive unit. The motor drive unit moves the probe head, its supporting tubes and the pneumatic drive unit from outside of the vessel (allowing access to the probe for maintenance) over a distance of around 1 m to the 'standby' position in the vessel. The pneumatic drive unit can then reciprocate the probe head with a maximum speed of about 0.9 m/s over a distance of 10 cm. The probe reciprocates towards the MAST axis in around

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0022-3115/03/$ - see front matter
PII: S0022-3115(02)01574-X

0.2 s and returns in 0.4 s typically interacting with the edge plasma for less than 150 ms.

The probe head is made of boron nitride, and the pins are made of POCO graphite. There is a coating of carbon on the probe head to prevent sputtering of boron nitride from contaminating the pins. Three identical probe groups classified as group A, B, and C are installed in the probe head. Groups A and B are at the same radial position, but separated by a 5 mm high barrier, to allow measurements of plasma flow. Group C is 5 mm radially separated from the other probes, further from the plasma. Each group consists of three pins with a diameter of 1.5 mm, protruding for 3 mm from the probe head.

3. Experimental set-up

In the experiments reported in this paper, the probes are mainly configured as triple probes. The sampling rate of the RP data acquisition system is set to 1 MHz for the study of fast events. At maximum probe velocity, 1 ms represents a radial movement of <1 mm, so at least 1000 data points are obtained per millimetre of movement. In L-mode discharges, the probe has been used to measure the SOL in disconnected double null discharges, the most common configuration for MAST, in which there are two X-points, lying on different flux surfaces with the gap between these at the mid-plane being greater than ρ_i^* but less than Δ_h. The plasma current in the reported experiments is about 0.6 MA, and the line averaged density is between 1×10^{19} and 3.3×10^{19} m^{-3}. In ELMy H-mode discharges, the probe is positioned outside the plasma to observe the intermittent bursts of particle flux during the ELMs.

4. Results and discussion

In the L-mode discharges, T_e close to the separatrix is typically measured to be around 30 eV, and n_e ranged between 0.5×10^{19} and 1.5×10^{19} m^{-3}. In the SOL, the measured temperature scale length λ_{Te} ranges from 10 to 60 mm, and λ_{ne} is always smaller, from 7 to 40 mm.

It has been reported [2] that significant particle fluxes during ELMs (characterised by an increase in the ion saturation current density at the probe, j_{sat}) can be detected even when the probe is remote (~20 cm) from the plasma edge (Fig. 12 in Ref. [2]). During inter-ELM periods midplane D_α emission is roughly Gaussian (determined by Abel inversion of data from a D_α linear camera), whilst during the ELMs the emission broadens and skews towards the outboard side.

The amplitude of burst in j_{sat} during ELMs could vary significantly, even for ELMs with a similar divertor D_α signal (see Fig. 1). This can possibly be explained by the existence of a toroidally or poloidally localized structure generated during ELMs, expanding radially outwards from the plasma edge. From the time difference between the j_{sat} bursts and the rise in D_α, the speed of radial expansion was preliminarily reported to be around 300–500 m/s [2]. However, with a better time resolution now available (the sampling rate was previously 50 kHz), it is observed that the speed is, in fact, typically somewhat higher around 1 ± 0.5 km/s (see Fig. 2).

The burst of j_{sat} corresponding to an ELM varies with the distance of the probe from the last closed flux surface of plasma, Δ_r between about 2 kA/m^2 at 25 cm to 100 kA/m^2 when the probe is around 3 cm from the plasma edge. It is difficult to determine a clear functional relationship between the amplitude of j_{sat} and Δ_r due to a considerable scatter in the data. However, it can be

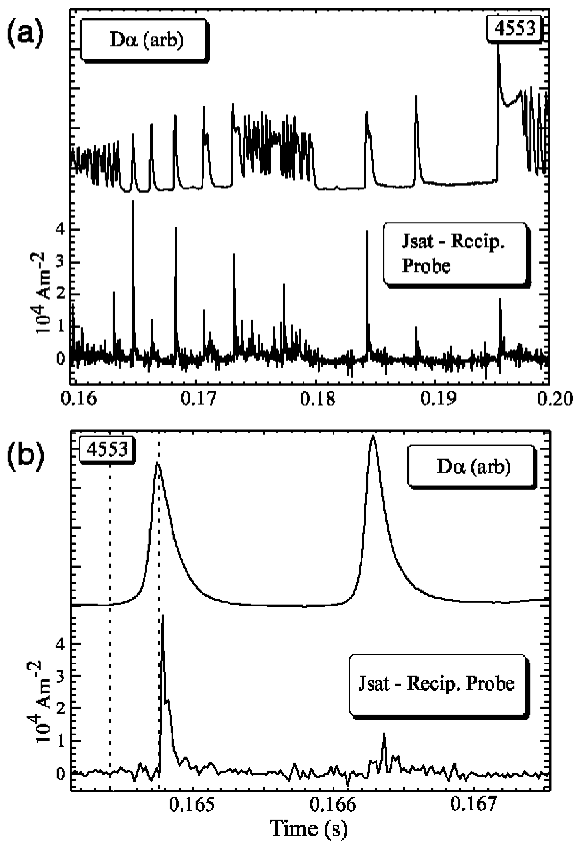

Fig. 1. Comparision of divertor D_α emission together with j_{sat} from the RP about 15 cm from the outboard separatrix in an ELMy H-mode plasma (reproduced with permission from [2]). ELMs with similar D_α signals can have different j_{sat} response (a), and burst of j_{sat} corresponding to ELM is later than that of D_α (b).

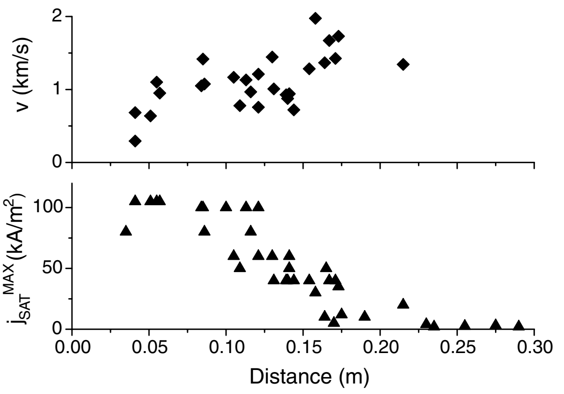

Fig. 2. Variation in the magnitude of j_{sat} bursts on the RP during ELMs in H-mode shots together with calculated radial expansion velocities. The x-axis is Δ_r. The y-axis of the upper graph is the radial expansion speed V (equals Δ_r/Δ_t, where Δ_t is the time between the rising of D_α signal viewing the divertor region and the burst of j_{sat} signal). The y-axis of the lower graph is the amplitude of the maximum j_{sat} value corresponding to one ELM.

seen that the smaller Δ_r is, the bigger the chance of observing higher j_{sat} (see Fig. 2).

It was reported for PISCES and L-modes in Tore Supra, that intermittent bursts give rise to j_{sat} in the SOL as high as inside the plasma [3]. This is also observed in the L-mode discharges on MAST. However, the j_{sat} fluctuations are different in ELMy H-mode both in amplitude and profile. Fig. 3 compares an ELMy H-mode discharge with an L-mode discharge. In the shown period for both discharges, Δ_r is about 4 cm. In ELM-free periods, the intermittent burst of particle flux outboard of the separatrix is suppressed significantly compared to L-mode but rises to a similar level during the H–L transitionary period. When the plasma confinement returns back to H-mode, j_{sat} fluctuations are again almost completely suppressed.

Fig. 4 compares measurements of SOL profiles in an L-mode discharge and an ELMy H-mode pulse. The discharges have similar plasma current (~0.6 MA) and power flow across the separatrix (~1 MW). The electron density of the L-mode shot (~2.6×10^{19} m^{-3}) is a little lower than the ELMy one (~3.7×10^{19} m^{-3}). The burst of j_{sat} corresponding to the ELMs could be more than 100 kA/m^2 up to at least 10 cm from the plasma edge. Whilst in L-mode, j_{sat} is commonly less than 40 kA/m^2 in the region near the plasma edge, and decays quickly away from the edge, similar to T_e profile. More detailed characterisation of the structure of fluctuations in the L-mode SOL will be the subject of future experiments.

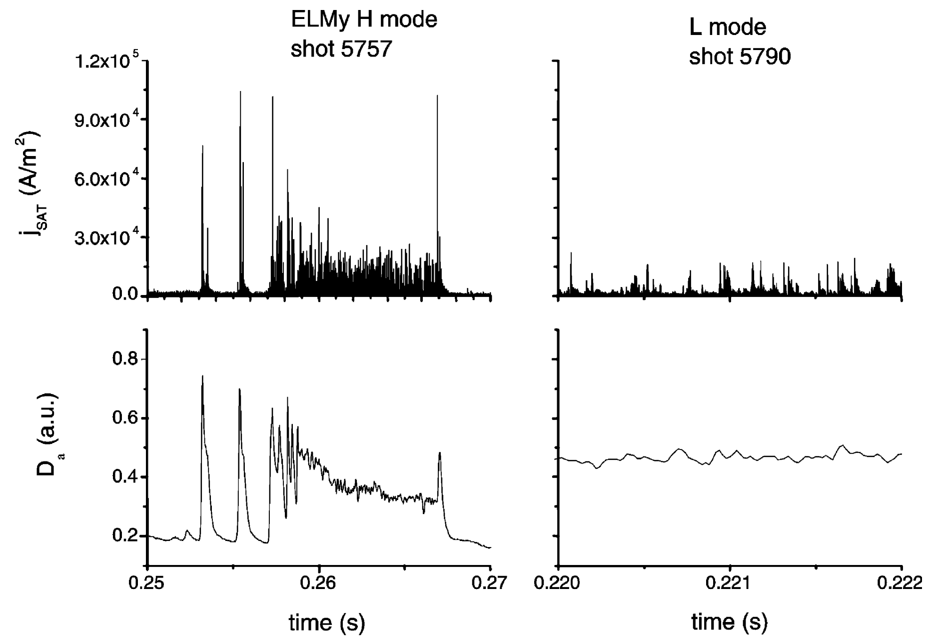

Fig. 3. j_{sat} at the RP in different confinement regimes together with D_α views of the divertor region. In these two pulses, Δ_r is almost the same (about 40 mm). It should be noticed that the time window shown here is different, being 200 ms for the ELMy case and 20 ms for the L-mode case.

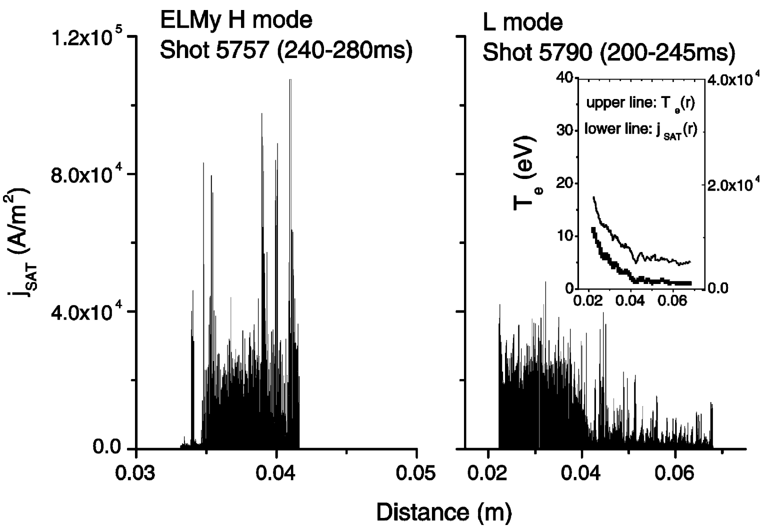

Fig. 4. SOL profiles of j_{sat} in ELMy H-mode (left plot) and L-mode (right plot) discharges. For the L-mode discharge, smoothed T_e profile and smoothed j_{sat} profiles show similar trends (small plot in the right plot).

5. Conclusion

The newly installed RP is introduced in this paper. It has been used to measure the SOL characteristics of both L- and H-mode discharges in MAST. In L-mode at the outboard mid-plane, λ_{Te} is of similar magnitude but larger than λ_{ne}. During ELMs, even in the region 3–25 cm outboard of the separatrix, bursts of j_{sat} from 2 to 100 kA/m^2 are observed and seem to be associated with the radial expansion of a poloidally or toroidally localised structure at the plasma boundary at about 1 ± 0.5 km/s. The characteristics of the intermittent bursts of particle flux during ELMs are very different from those observed in L-mode.

Acknowledgements

This work is jointly funded by Euratom and UK Department of Trade and Industry. One of the authors (Y. Yang) is supported by a Royal Society fellowship award, and is very grateful to Dr S.K. Erents, Joon-Wook Ahn and Eric Arends for helpful suggestions.

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