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Filamentary heat deposition to the first wall in ASDEX Upgrade

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Introduction

The investigation of heat deposition to in vessel components in present tokamak experiments and its extrapolation to a next step device as ITER is an essential issue of research. Power balance investigation reveals that a fraction of the power crossing the separatrix is not received by the divertor but is distributed to non-divertor components. This fraction of non-divertor heat load can be up to 50% of the energy ejected during an Edge Localized Mode (ELM) [1]. Although the contributions of this heat flux to the overall power balance is below 10% it can cause serious damage to components not designed for receiving high heat loads. Independent measurements of different high temporal resolution diagnostics reveal that the nature of the heat transport is of high dynamic. In present models it is described as a non-linear evolution of MHD-modes with toroidal mode numbers in the order of n=10 which causes a filamentary or 'blobby' transport of particles and energy in the plasma edge. The investigation of the temporal evolution of the transport during ELM events has at least two aspects: First, the understanding of the mechanism of ELM formation with the goal to avoid ELMs completely or to reduce the amount of energy associated with an ELM. Second, the parameterisation of the heat deposition and the extrapolation to ITER like conditions. Recent measurements with high resolution thermography, Langmuir and magnetic probes, as well as Thomson scattering and ICRH antennae coupling measurements reveals that turbulent transport dominates the first raising phase of an ELM whereas the decay is quiescent. This paper reports on combined measurements of these diagnostics. It presents measurements of ion saturation currents to a Mach-type Langmuir probe exposed to the scrape-off layer (SOL) plasma in combination with thermographic heat flux measurements during a scan of the SOL width.

Diagnostics and Experiments

The plasma edge and the SOL in ASDEX Upgrade are diagnosed by different diagnostics with ELM relevant temporal and spatial resolution. The Thomson scattering system running in burst mode measures electron density and temperature on a 2 µs time scale [2]. Mach-type Langmuir probes mounted on the mid-plane manipulator are used to measure the Ion saturation current and floating potential with 2 µs time resolution. The temperature can be derived from single probe characteristics measured with 1 ms resolution. Alternatively the mid-plane manipulator can be used to expose a fast ion detector to the edge plasma allowing the detection of pitch angle and energy of fast ions penetrating deep into the limiter

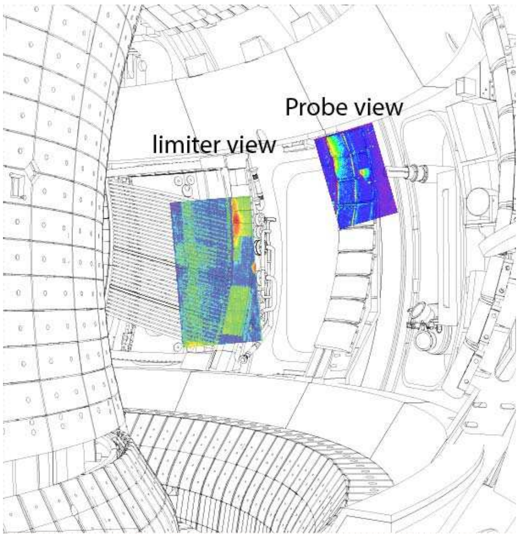

Fig 1 CAD view into the ASDEX Upgrade vessel. The two viewing geometries of the ir-camera are indicated.

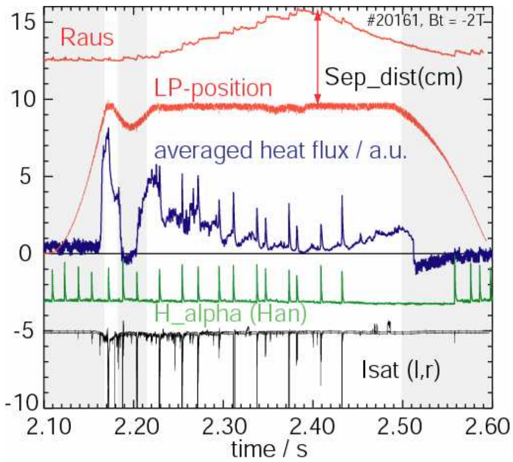

Fig 2 Time traces of probe position, the plasma sweep as well as signals of H_α, maximum heat load to the probe head and I_{sat} from LPs. Gray background - The period where the LP is in the limiter shadow.

shadow[3]. Optical access to the vacuum vessel is used either to measure the heat load to the mid-plane manipulator and the adjacent protection limiter or to the ICRH antennae limiter as shown in Fig 1. The probe view was used to measure the ELM heat flux e-folding length in the SOL outside the limiter shadow for two different magnetic fields, B_t = -2 T and -3 T, respectively, by watching the load to the carbon shielding of a Mach-type Langmuir probe at the mid-plane manipulator by thermography. For these experiments, the Langmuir probe was positioned 5 mm in front of the leading ICRH limiter during two strokes per discharge lasting about 600 ms each with about 300 ms in front of the ICRH limiter. During this hold phase of the fast stroke, the plasma was moved away, increasing this way the distance between separatrix and Langmuir probe from 3 to 8 cm (see Fig 2). The temperature and density distribution as measured by the Thomson scattering system during this phase of the discharge is shown in Fig 3.

Results and Conclusions

The temperature and density distribution in the plasma edge which is smooth in between ELMs becomes strongly structured during an ELM and show a clear separation between field line bundles of high temperature and density as shown as blobs in the poloidal cross section in Fig 3. Single ELM evolution can not be resolved by the Thomson scattering system due to the snapshot like measurement with a repetition rate of 50 ms [4]. Fast measurements but with limited spatial resolution (Langmuir and magnetic probes, ICRH antenna coupling, fast ion detector) show a pronounced temporal variation of the measured signal which has to be interpreted as a movement of such an electron temperature and density structure as observed by Thomson scattering [5-7]. Whether or not the movement is a toroidal or poloidal rotation is not unambiguously predicted, yet. However, heat flux measurements in the upper divertor [8] and at the limiters of ASDEX Upgrade show no delay between near and far separatrix signals on a time scale of the measurement of a few 100 µs. A comparison of Langmuir probe signals measuring with a

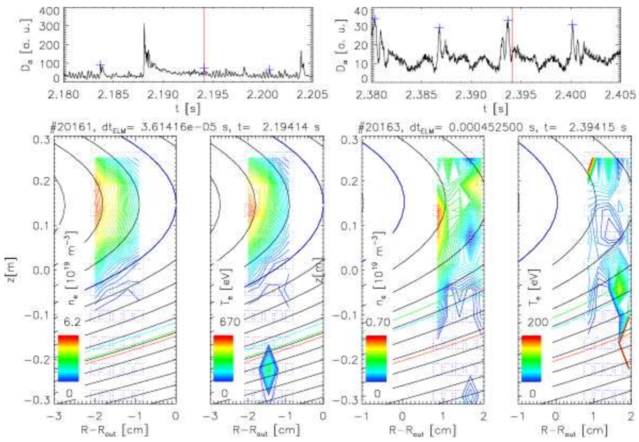

Fig 3 Temperature and density as measured by Thomson scattering in between ELMs (left) and during an ELM (right). During an ELM a 'blob' like structure with distinct positions of the maxima of temperature and density is found.

much faster time resolution of 25 μs show also no delay for signals far away from the separatrix. The radial propagation velocity of the ELM signal should be at least 1 km/s. Despite this short response on the mid-plane ELM energy release remote from the separatrix, a significant part of energy is lost parallel field lines into the divertor. The resulting radial e-folding length is about 2.5 cm during the ELM phase and slightly shorter (2 cm) in between ELMs. This holds for both values of the magnetic field strength as shown in Fig 4. The expected stronger decay due to a shorter connection length into the divertor for a lower magnetic field ($\sqrt{5m/8m}$) is not obvious and might be hidden in the scatter of the data. A slightly longer e-folding length during an ELM is consistent with the similarity between ELM and inter ELM heat flux profiles found in the outer divertor in most of the tokamaks, which show only a weak broadening ($\lambda_{ELM} / \lambda_{between} = 1 \div 2$) during an ELM [9]. It is also consistent with the finding that the fraction of energy deposited by an ELM outside the divertor (about 60% of the non-divertor load) is higher than the ELM transported power of about 20% [10]. The heat flux decay with increasing distance to the separatrix follows an e-folding behaviour up to the maximum distance to the separatrix of about 8 cm for both magnetic field strength. The signal drops strongly if the probe head is in the limiter shadow (see Fig 2), where the e-folding length is a few millimetres. Only a few high energetic ions on banana trapped orbits can penetrate deep into the limiter shadow as measured by the fast ion detector [3].

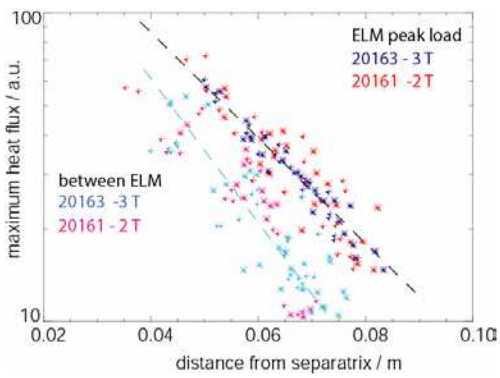

Fig 4 Heat flux to the head of the Langmuir probe vs. the distance to the separatrix for ELMs (dark colored) and in between ELMs (light colored) for two different magnetic field strength (red - 2 T, blue -3 T)

The ELM heat flux to the probe is measured very local at the head of the Langmuir probe with a diameter of about 5 cm. Nevertheless, each ELM is detected with a significant heat flux following an exponential radial decay. This fact and the short exposure time of 10 μs compared to 250 μs frame rate means that the probability for a rotating filament/blob to hit the probe is unity either because the velocity is high or the ELM structure is significant

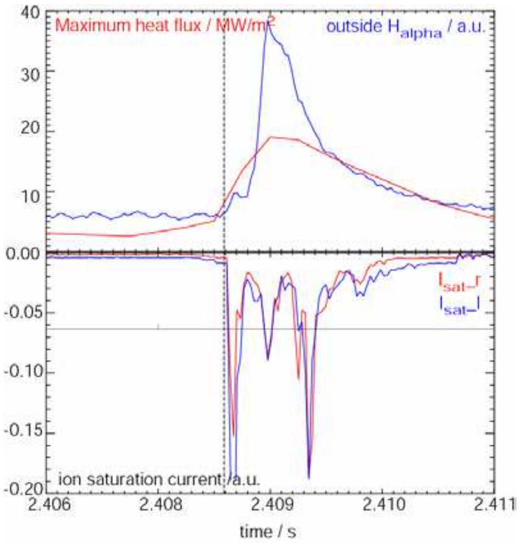

Fig 5 Top: D_α signal and maximum heat flux to the LP probe head. Bottom: Ion saturation current to the ion and electron drift side of the Mach probe.

broadened. The temporal evolution of the ion saturation current on the ion and electron drift side shows a comparable structure with clearly separated peaks (Fig 5) with a width of about 10 µs. The measured heat flux signal shows no pronounced structure but a broad deposition (Fig 5) not only for the maximum heat flux but also for the spatial distribution at the probe head. Ion saturation currents to the electron and ion drift side of the LP are identical in its main structure (Fig 5) with the same order of magnitude. This means that the toroidal velocity is not dominating the intrinsic flow in the filament.

Summary

Combined measurement of thermography, Langmuir probes and Thomson scattering reveals a structured pattern of electron temperature and density in the pedestal and SOL region. The midplane heat flux decays radialy with an e-folding length of a few centimetres for a wide range (2 – 3 T) of magnetic field strength. The ion saturation pattern measured at the ion and electron drift side of a Mach-probe in the mid-plane is correlated and has to be explained by a dominating radial and/or poloidal velocity of the moving structure.

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