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A high resolution Thomson scattering system at W7-AS

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1. High resolution Thomson scattering

A new ruby Thomson scattering system with high spatial resolution for plasma edge and gradient investigation on the high field side in the triangular plane of W7-AS stellarator has been installed. The detection system consists of a Littrow-type spectrometer and an intensified CCD camera. Similar diagnostic systems are known from other fusion laboratories using combinations of a grating spectrometer and an intensified CCD camera (ICCD) for Thomson scattering [1-3]. Our goal is to investigate the gradient and edge region of the W7-AS plasma with high spatial resolution, which is important for core-edge studies with boundary island configurations [4]. As light source a ruby laser with high pulse energy (up to 15 J) is used. The scattering geometry is shown in Fig.1. The scattered light is imaged upon a new set of thirty fiber bundles providing a spatial resolution of 4 mm, which is improved by a factor of five compared to the original fiber guides used for the interference filter polychromator detection system [5]. At the output the fiber bundles form the entrance slit of the Littrow-type spectrometer.

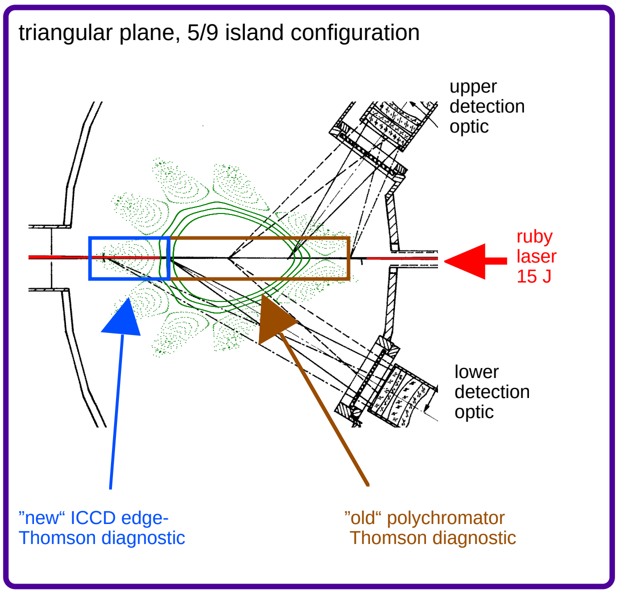

Fig. 1: Partitioning of the view chord. The total length of the view chord is 420 mm.

The total view chord (420 mm) of the ruby Thomson diagnostic is observed by two different detection systems (see Fig. 1). The section near the inner torus wall (120 mm) is observed by the presented CCD edge system. The rest of the viewing chord is covered by the existing interference filter polychromator system. By means of a two-pulse Pockels cell driver the ruby laser pulse is divided into two single pulses with different energy (energy ratio 10:1). The stronger pulse (up to 13 J) is needed for the new system, because the improved spatial and spectral resolution leads to a lower signal. The new system includes one CCD-based detector, therefore only one Thomson scattering profile can be measured per plasma discharge. In order to get more temporal data it would be necessary to use more CCD-based detectors [6]. In contrast to the detectors in periodic multipoint Thomson scattering systems [7] the ICCD cameras cannot be operated at high repetition rate. The spectrometer setup of the CCD edge system is shown in Fig. 2. The lens inside the Littrow–type spectrometer has a focal length of 50 cm. The f-number (f/#) of the polychromator is 4. The ICCD includes an image intensifier (40 mm diameter) with a S25 photocathode and a P43 phosphor. The CCD chip with 512 x 512 pixels is

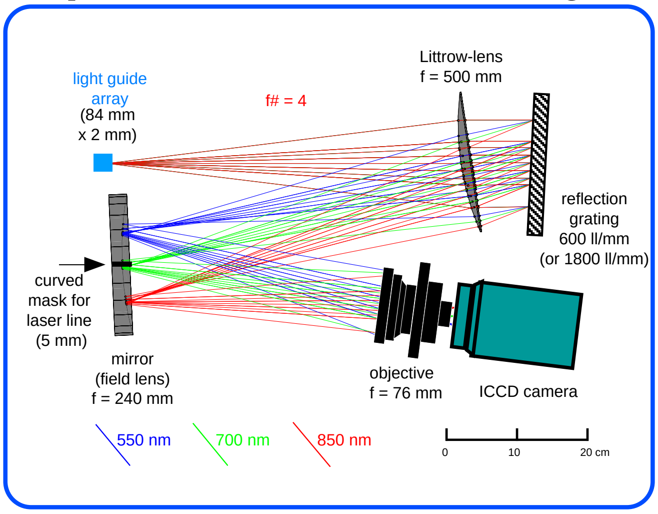

Fig. 2: Setup of Littrow-type spectrometer

cooled by means of a Peltier element. Depending on the installed diffraction grating (1800 ll/mm or 600 ll/mm) a total wavelength range of 80 nm (suitable for plasma edge investigations) or 320 nm (suitable for gradient investigations) can be surveyed. The laser line is blocked by a curved black mask (width 5 mm) on the spherical mirror in the focal plane, which serves as a field lens. The spectral image is demagnified by a factor of 4 and projected on the detector cathode by means of an objective (f=76mm, f/#=0.87).

2. Calibration and data analysis

Electron temperature and density profiles are derived by fitting the measured spectra by an analytical 2nd order approximation of the relativistic Thomson scattering profile [8]. As the entrance slit (slit height = 84 mm) of the Littrow-type spectrometer has no curvature, the slit image in the focal plane is curved. Therefore the geometrical position of the spectra on the CCD chip has to be measured for each fiber bundle. The wavelength calibration of the investigated spectral range has to be done separately. In addition an intensity calibration has to be performed to determine both the spectral ($\rightarrow T_e$) and absolute ($\rightarrow n_e$) efficiency of the diagnostic setup.

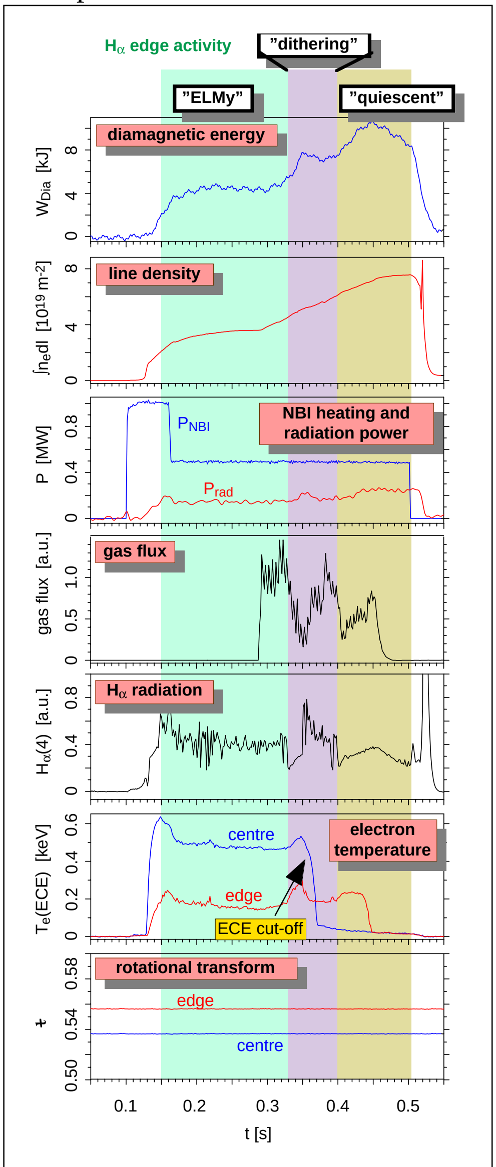

Fig. 3: Overview of discharge parameters for the investigated H-mode discharges.

The spectral, intensity and geometrical calibration of the presented diagnostic setup can be done in situ. Radiation of different light sources can be imaged on every fiber bundle by means of an additional bundle. It consists of the same kind of quartz fibers used for the fiber bundles forming the entrance slit of the Littrow-type spectrometer. Radiation of a calibrated tungsten strip lamp serves for both spectral intensity calibration and determination of the geometrical position of the light from each fiber bundle on the CCD chip.

A neon spectral lamp is used for wavelength calibration. Absolute intensity calibration is done by means of Raman scattering of hydrogen (λ = 723.8 nm, p_H<100 mbar) [9]. In spectral direction 20 pixels are binned for noise reduction, therefore every evaluated spectrum consists of 25 measured data.

In the following two chapters an example of use for each grating configuration is shown.

3. NBI-heated "H-mode" discharges

For gradient region investigations the Littrow-type spectrometer was equipped with the 600 ll/mm grating. Thomson profiles were measured during different phases of NBI-heated H-mode discharges. As the ruby Thomson scattering diagnostic provides profiles only at one time per discharge the laser time has to be varied during a discharge series with sufficient reproducibility. Different H_α activity indicates different transition behaviour to the quiescent H-mode phase. Fig. 3 shows an overview of the discharge parameters. The discharge starts with an "ELMy" H-mode phase, followed by a "dithering" Phase, before the "quiescent" H-mode is established.

The measured Thomson scattering profiles are compared with electron temperature and density profiles from ECE [10] and Nd:Yag Thomson scattering diagnostics [7] at W7-AS. The electron density n_e during the "ELMy" phase is lower than the ECE cut-off density. Therefore this phase is a good candidate for comparison, because each diagnostic provides a complete electron temperature profile. Fig. 4 shows profiles from shot

No. #48145 at 200 ms. The temperature profiles of the different diagnostics agree very well. The Nd:YAG Thomson diagnostic leads to smaller density values than the ruby Thomson system, which is probably due to a nonlinear detector characteristic of the Nd:YAG system. Please note that all ruby Thomson profiles are derived from two different detection systems (see chapter 1).

In Fig. 5 ruby Thomson scattering profiles are shown during a "dithering" and a "quiescent" H-mode phase.

In the latter phase with low H_α activity the electron density profiles show steep gradients about the separatrix. Even with the new CCD edge Thomson system (4 mm spatial resolution) these gradients cannot be resolved. The other Thomson scattering systems at W7-AS (old ruby system on the low field side and Nd:YAG system) do not offer sufficiently high spatial resolution to detect such steep gradients. Therefore these diagnostics lead to another interpretation of profile gradients. As shown by the electron density profiles of the new diagnostic the rising of the gradient is restricted to a small spatial area and does not affect the whole gradient region of the plasma.

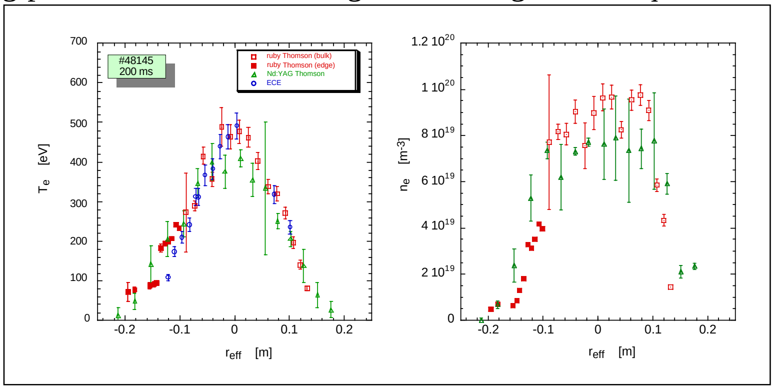

Fig. 4: Electron temperature and density profiles measured by ruby Thomson scattering (red squares), Nd:YAG Thomson scattering (green triangles) and ECE diagnostic (blue circles).

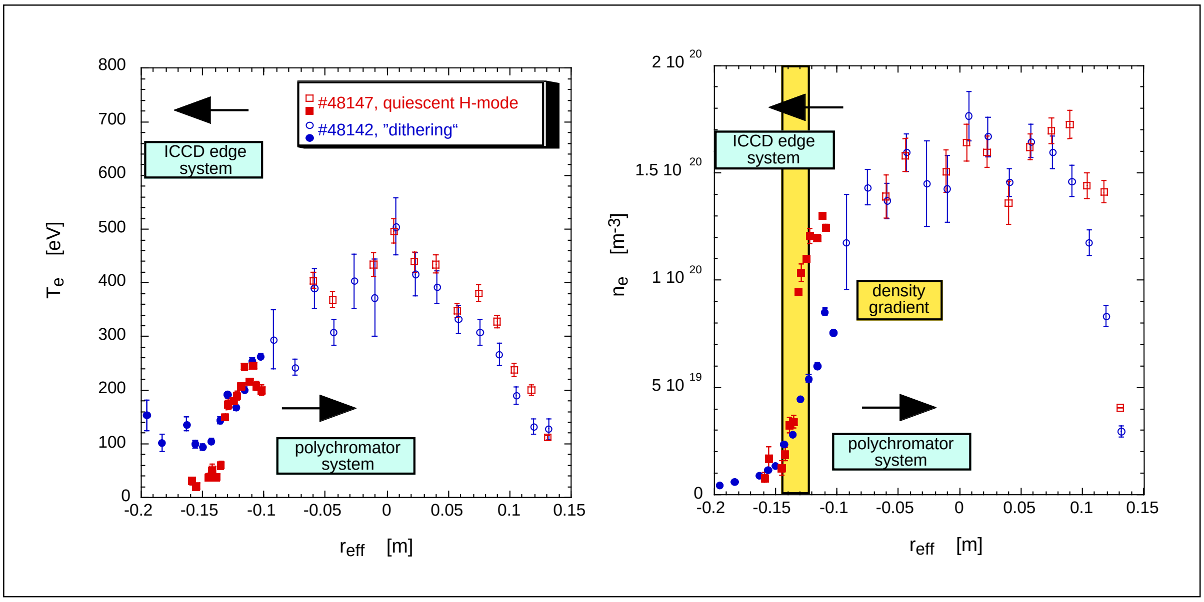

Fig. 5: Electron temperature and density profiles in a dithering (blue circles) and a quiescent H mode phase (red squares). Measured by ruby Thomson scattering diagnostic (full symbols denote data from the new CCD diagnostic).

Compared to the "dithering" phase the corresponding electron temperature during the "quiescent" H-mode drops to lower values outside the density gradient region, but the precision of measuring temperatures below 100 eV is not sufficient with the used grating (600 ll/mm) of the spectrometer. As described in chapter 1 the laser line is blocked by a curved black mask on the spherical mirror in the focal plane. For that reason the inner part of the Thomson spectrum (approx. 15 nm) is blocked, too, so that narrow spectra ($\rightarrow$ low T_e) cannot be fitted as well as broader ones.

Due to cut off of the microwave radiation there are no ECE temperature profiles available for the "quiescent" H-mode phase.

4. High electron densities near the edge

In order to study edge and scrape-off-layer plasma behaviour of an $(\iota_a/2\pi)=5/9$ boundary island configuration [4] with high electron densities near the edge, the new Thomson scattering diagnostic was equipped with the 1800 ll/mm grating, providing a higher spectral resolution.

The electron temperature and density profiles in Fig. 6 show clearly that this diagnostic equipment is especially suited to measure electron temperatures below 100 eV. As indicated the transition region from boundary island to core plasma can be investigated with high accuracy. At higher temperatures (above 200 eV) the observed spectral region of the diagnostic system does not cover the entire Thomson scattering profile leading to inaccurate fitting parameters. That results in an enhanced scattering of the profile data, especially the electron temperatures.

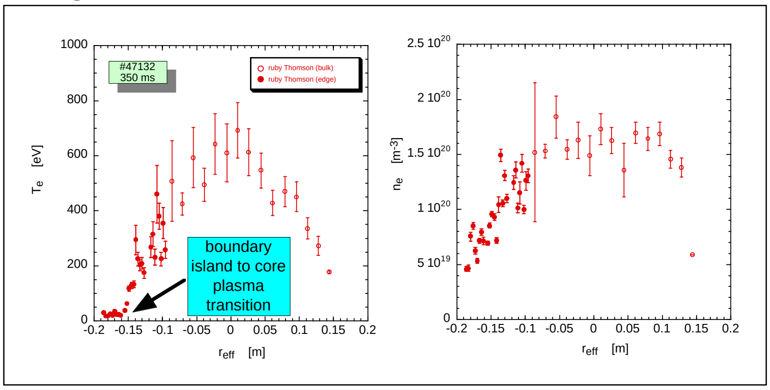

Fig. 6: Electron temperature and density profiles in a discharge with high edge density

5. Discussion

It has been shown to be possible to measure electron temperature and density profiles with an enhanced spatial resolution of 4 mm on the high field side of the plasma. Both examples of Thomson profile measurements mentioned in chapter 3 and 4 show the benefit of profile diagnostics with high spatial resolution for plasma edge investigation.

As emphasized in chapter 3 the interpretation of profiles with an enhanced spatial resolution causes another picture of particle transport physics. The important processes are restricted to very small spatial areas. This affects e.g. the value of the radial electric field E_R. Tentatively estimating the radial electric field from ambipolarity condition by using the profiles with steep density gradients (see Fig. 5) lead to strong negative E_R-values. This remains to be investigated in detail to clarify to what extent our understanding of particle transport phenomena in the gradient region is still valid**.**

After installation of the new island divertor at W7-AS in the year 2000 it will be of prime importance to be able to study the behaviour of profile parameters in the island and separatrix regions with high spatial resolution.

In the coming experimental campaign more experimental data will have to be collected for the presented scenarios and further effort will be spent to obtain a consistent picture in comparison with other diagnostics. In 2000 a third neutral beam injector is build up at W7-AS stellarator claiming space of the existing ruby Thomson interference filter polychromator system which will be replaced by a second CCD-based system similar to the presented one.

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