First Measurements with the re-installed accelerated Lithium beam diagnostics on TEXTOR

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Introduction

Diagnostic alkali beams are standard diagnostics in many fusion devices as they are capable of measuring plasma electron density profile in the edge and SOL plasma [1]. In these experiments the Doppler shifted emission of the collisionally excited beam particles is measured. Since the beam is weakened by the plasma, the light emission is not local function of the density. To reconstruct the density profile the populations of the different atomic states has to be followed along the beam using a collisional-radiative model [2].

With a fast detection system the high frequency density turbulence can also be characterized from the SOL to the outer part of the core plasma [3], which is the primary goal of the recent studies. The beam width is about 2 cm, which defines the poloidal localization. The radial resolution is determined by the finite lifetime of the excited 2p-2s atomic state. In the case of the TEXTOR 35 kV Li beam the smearing is about 2 cm. The ITG turbulence, thought to be responsible for the anomalous transport at the plasma edge, has similar spatial scale, therefore the major aim of this diagnostic is to characterize density fluctuation in TEXTOR.

The precision of the reconstructed density profile is influenced by the background light level. As a solution the beam can be chopped to measure the actual background. The frequency of the chopping system can be adapted as needed in a wide range (10Hz - 200kHz).

The TEXTOR Li-beam diagnostic was upgraded with the following main components: newly designed high throughput optics with in-vessel elements, two parallel observation systems containing a scientific CCD camera and a 16 channel Avalanche Photodiode (APD) fast camera unit, fast deflection system, data acquisition system and control unit of the diagnostic.

This paper describes the upgrades of the TEXTOR Li-beam diagnostics and demonstrates the capabilities through the first measurements.

The Li gun and the deflection system

Positively charged thermal Li ions are emitted (~1mA) continuously during the tokamak discharge from a resistively heated ion emitter and accelerated by an ion optic to 35 keV. The Li ions are neutralized in Sodium vapour. The beam is fired at the midplane horizontally at section 9/10. A pair of deflection plates is located between the ion optic and the neutraliser, which can either chop or poloidally deflect the beam a few cm in the plasma. If the beam is removed from the plasma, the background light level can be continuously monitored. This way the light profiles can be accurately reconstructed from the camera frames. If the beam is periodically deflected only a few cm in the plasma (with up to 200 kHz frequency) two virtual beams are present in the observation area in slightly different time. Calculating the cross-correlation between fluctuations measured in the two beam phases poloidal flows can be deduced directly [4]. The timing of the observation and deflection system is synchronized.

The upgraded optics and observation system

The optics of the new observation system consists of two parts: a 'periscope' - containing two mirrors and the first focusing element – built into the tokamak and the outside optical system – containing a field lens, a beam-splitter and the components for two branches of observation, see Figure 1.

The first focusing element in the periscope – made from a pair of quarz plano-convex lenses (combined focal length ≈ 355mm) – collects the light, transfers it through the vacuum window and makes an about 1:1 image at the field lens from an approximately 150mm long section of the beam. The outer part of the new observation system starts with this field lens – made from a pair of BK7 plano-convex lenses (combined focal length ≈ 325mm) – followed by a 20/80 beam-splitter that divides the light between the CCD camera (for density profile measurement) and APD detector (for fluctuation measurement) branches, see Figure 2. The APD camera unit still has a specialty: at the image plane – in front of the sensors – are a row of rectangular bi-convex lenses (f=25mm) – one for each APD channel. It is used to convey the light from the image plane (15x8mm^2 area corresponds to one channel) to the sensors (5x5mm^2). This arrangement enhances the light collection by a factor of ~4.

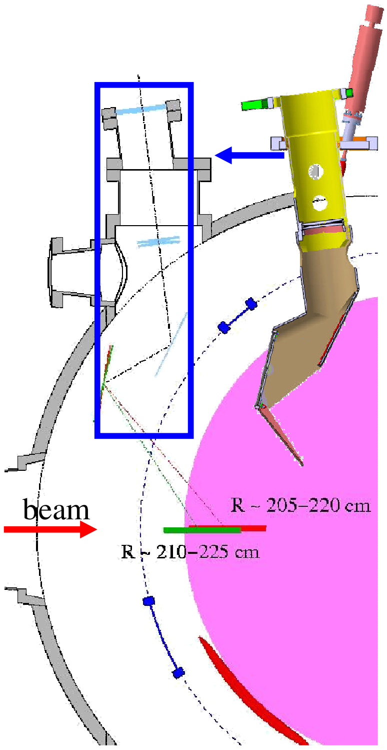

Fig. 1. Optical arrangement and a section view of the 'periscope' for TEXTOR Li-beam observation system.

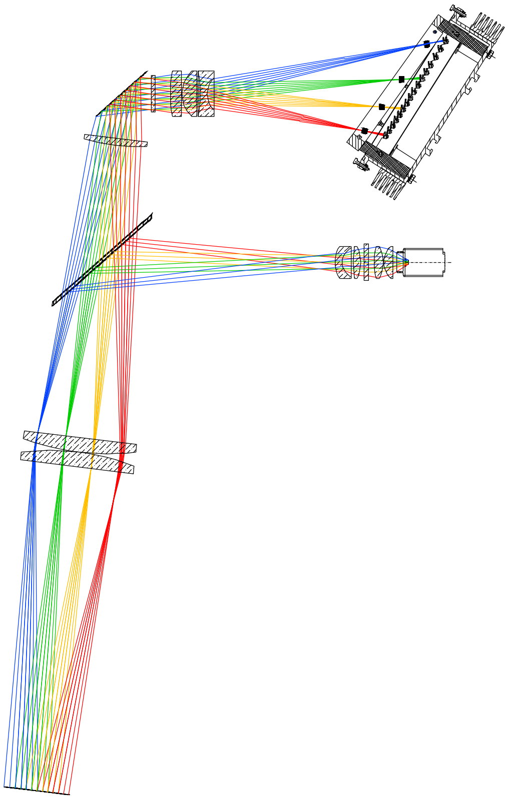

Figure 2. Schematic view of the outside optics. Rays from the beam are shown only for four points (corresponding to the middle of APD channels: 1, 6, 11 and 16). A front view of the APD camera (without the cover and the lenses in the image plane) is also shown.

The high optical throughput and the high quantum efficiency of the APD (85%) is crucial to maximize the SNR.
The minimum level of detectable plasma fluctuations is limited by the statistical photon noise, with $\delta n_e/n_e \propto 1/N^{1/2}$ where N is the number of photons detected in the integration period. The system was designed for 10^{10} photon/sec incident light, which corresponds to a photon noise level of ~ 2.2 % at 500 kHz bandwidth. The APD detectors have an internal gain of ~ 50 at 360 V bias voltage and custom, high-frequency, ultra-low-noise amplifiers are used in a temperature-stabilized housing. The photon statistical noise dominates over the electronic noise at incident photon rates above 5×10^9 photon/sec. The data acquisition system utilises two 8 channel, 2 MHz ADC with 14 bit resolution. This detector type is not sensitive to the magnetic field, therefore the camera unit can be close to the tokamak and no fibre optic coupling is needed.

Results

The Li2p emission profiles can easily be calculated from the pictures of the CCD camera. The above described deflection system synchronized with the camera frames is used for measuring the background light precisely. The edge and SOL electron density profile is basic information for the different plasma scenarios. The time evolution of the density profile can be followed during the whole discharge up to 100 Hz. A series of light profiles is shown in Figure 3. along the beam path in a limiter H-mode scenario, where the transition can clearly be identified at 1.75 sec. After the transition the light profile has higher maximum and appears radially outer, which is caused by the steeper edge density profile. For the density reconstruction the IPP "Absolute" code is used [2]. An example of reconstructed density profiles closely before and after the transition is shown on Figure 4.

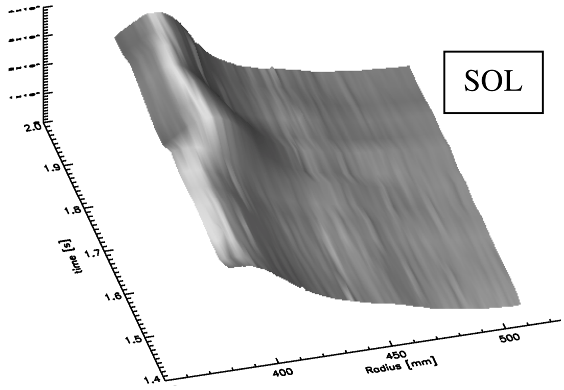

Figure 3. Series of light profiles.

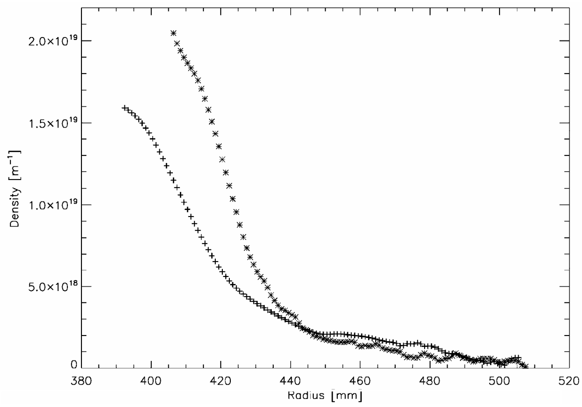

Figure 4. Density profiles before and after an L-H transition.

The fast APD camera unit has 1 cm spatial resolution along the beam path and detects typically 10^{10} photons/sec/channel at the maximum of the profile resulting in 2-3% photonic noise. Higher amplitude transient events and waves can be observed directly, which gives an excellent tool to resolve Edge Localised Modes (ELM).
As an example on Figure 5. 14 kHz growing nonsinusoidal MHD mode is presented before an ELM. It has to be noticed that this mode is often seen in the pedestal region.

The growing of this mode does not necessarily cause ELMs and can not be found before every ELM. The understanding of this behaviour needs further investigations.

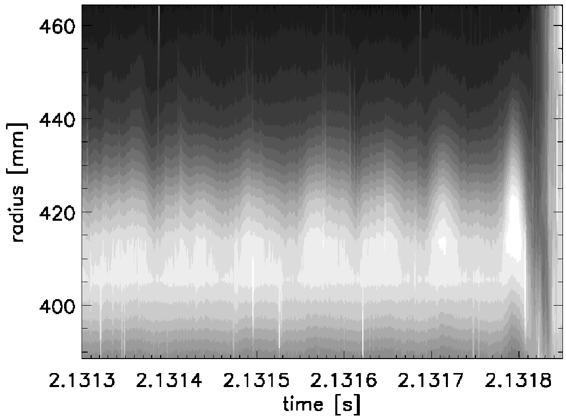

Figure 5. Series of light profiles showing the 14 kHz mode before an ELM.

To identify the core turbulence below the statistical noise correlation technique can be used [3,4,5]. The definition of covariance:

$$C^S(R_1,R_2,\tau)=\frac{1}{T}\int_0^T \tilde{S}(R_1,t)\tilde{S}(R_2,t+\tau)dt$$

where the light intensity can be written as a sum of an average and a fluctuating part: $S(R,t)=S^0(R)+\tilde{S}(R,t)$

With this method the exact temporal behaviour of the signal is lost but fluctuations below the statistical noise can be detected. Characteristic decorrelation time, relative fluctuation amplitude levels and the radial propagation can be examined in different plasma scenarios and can be used to characterize the transport. In the outer channels relatively high amplitude structures are observable with long (50 µsec) decorrelation time. These edge structures were seen on other devices as well and can be identified as SOL and edge turbulence. The relative level of fluctuations drops as we look deeper into the plasma. In the core 0.5% fluctuation can be identified as the detection limit is 0.1% in a sufficient long integration time (~10 msec). Different high frequency radially localized MHD modes were also observed up to 100 kHz frequency.

Conclusions and outlook

The upgraded TEXTOR Li beam BES diagnostic can routinely measure the density profile (20-100 Hz) and the density fluctuation profile (up to 500 kHz frequency). Transient measurements with fast beam chopping in SOL and edge plasma (1D) are also possible. As the next step the fast beam deflection system will be operated for poloidal flow velocity measurements, which can be used to identify velocity modulations up to the kHz frequency range.

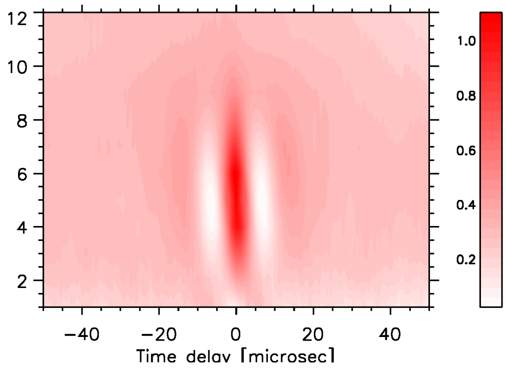

Figure 6. 2D correlation function in an ohmic discharge. The reference channel is inside the LCFS. The colour scale corresponds to the relative fluctuation amplitude (%).

References

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