Novel high speed spectrally resolved imaging system for simultaneous 2-D Te and ne edge plasma measurements with temporal resolution up to 100 kHz

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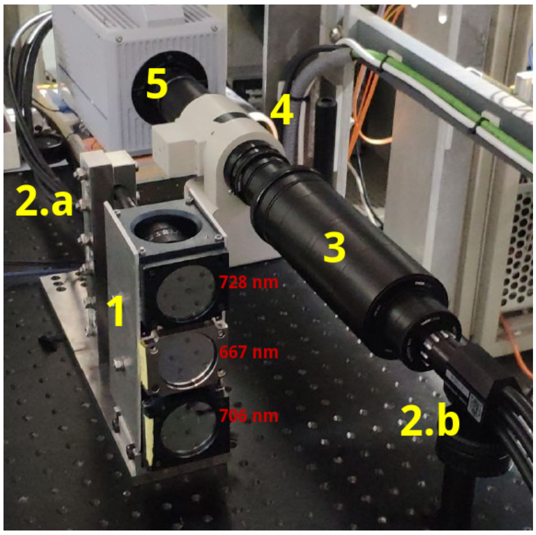
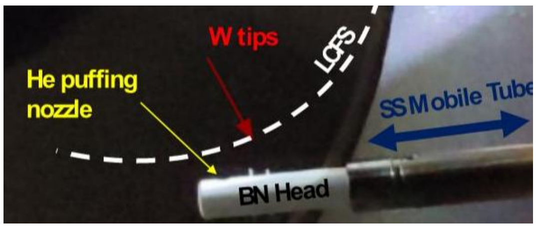
Introduction

A better understanding of turbulence in the edge and SOL regions of fusion plasmas is important as it determines edge transport and sets the boundary condition for the core plasma. To make progress in this direction, simultaneous measurements of turbulent fields are needed in order to understand their interaction. It is known that filamentary plasma structures play a major role in this region, a fact that is exploited here to explore the perpendicular turbulent structure. This contribution describes a novel diagnostic approach that combines 2D spectral measurements with Gas-Puff Imaging (GPI). Using this technique, density and temperature fields can be determined independently in a poloidal cross-section of the plasma edge with an exposure time of $\tau_{exp} \geq 5\mu$s and a frame rate of $f_{acq} \leq 20$kHz.



(a) *Optical system of SGPI: 1) Lens block with interference filters installed, 2) Opto-fiber triple-bundle image transmission line, 3) Relay lens coupling, 4) Hamamatsu C10880 image intensifier and 5) Photron SA1.1 fast camera*



(b) *Movable puffing injector assembly*

Figure 1: Optical and puffing systems

Spectrally-resolved Gas Puff Imaging

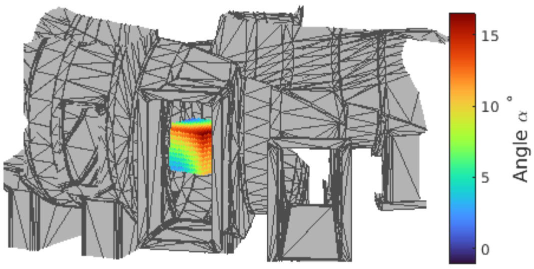
Common applications of the spectral GPI technique only recover a correlate to one field, e.g. the electron density. The present Spectrally-resolved GPI (SGPI) [1, 2] system allows simultaneously determining both the electron density, n_e, and temperature, T_e, from spectral images of a poloidal plasma cross-section, based on the He-I line ratio technique [3].

Experimental set-up

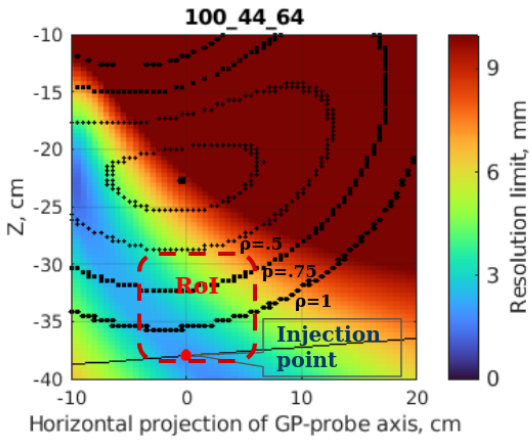
SGPI consists of optical and puffing systems: the optical system (Fig. 1a) consists of three 50 mm lenses with interference filters (667 nm, 706 nm and 728 nm, FWHM = 1 nm); the received light is combined into a single image by means of a triple opto-fiber bundle, projected onto a 2-stage (GEN-II + GEN-I) image intensifier; after amplification, the image is recorded by a fast camera. The puffing system consists of a retractable stainless steel tube with a Boron-Nitride injector head fitted with tungsten pins (by way of spatial reference), as shown in Fig.1b.

The injection location was carefully chosen to minimise the angle α between the local magnetic field and the line of sight (LoS) within injection volume (Fig. 2a). This maximizes the spatial resolution, as the filamentary turbulent structures are extended mainly along the field lines.

The spatial resolution corresponding to a given LoS is limited among others by the non-tangential component of the projection, which in first approximation can be estimated as $\sin(\alpha)\Lambda$, where Λ is the characteristic length of the plume along the field line ($\sim$5 cm). Additional errors arise from the parallax of the viewing angle between the separate lenses. The resulting resolution map is shown in Fig. 2b.



(a) *Angle α (colour coded) calculated in vicinity of chosen injection point with vacuum vessel of TJ-II*



(b) *Estimation of maximal potential spatial resolution from angle α, including difference in viewing angles of lenses (Black dotted lines depict flux surfaces, the red dashed square indicates the region of interest viewed by the camera)*

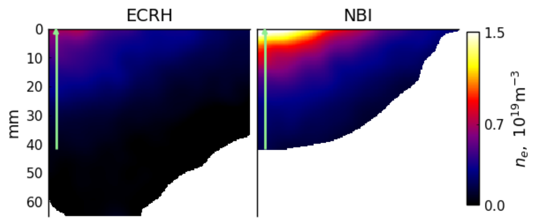
Figure 2: Puffing system design

Analysis

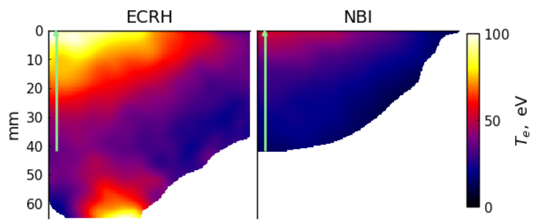
In order to calculate pixel-wise line intensity ratios from the images, they have to be precisely aligned. To achieve this, tungsten tips were added to the injector, see above, which glow when heated by the plasma, emitting sufficient black body radiation to be seen through the filters and serving as reference points for alignment. When satisfactory alignment is achieved, the image ratios are calculated.

The interpretation of the obtained line ratio maps is based on a collisional-radiative model (CRM) that estimates light emission spectra as a function of electron temperature and density. The CRM therefore serves to map the line intensity ratios to plasma parameters and vice-versa. By using line ratios instead of the direct emission amplitude of a given line, the impact of the neutral density on absolute intensity is cancelled, so that the intensity ratios only depend on n_e and T_e.

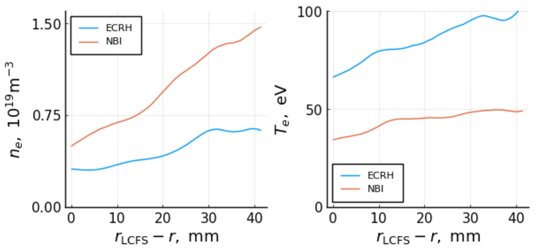
Currently we are using data from a CRM developed in Julich [4, 5], which has also been used for a supersonic Helium beam diagnostic [6] at TJ-II. However, data from other CRMs can also be used to provide the relation between the plasma parameters and the line intensity ratios. We will address this possible improvement in future work.



(a) *Density maps of typical ECRH and NBI plasmas*



(b) *Temperature maps of typical ECRH and NBI plasmas*



(c) *1D profiles along the green arrow in Figs.3a,3b*

Figure 3: 2D n_e and T_e maps of TJ-II plasmas

Results

The commissioning of the new SGPI diagnostic was concluded successfully and has yielded promising results like the ones presented in Fig. 3, corresponding to shot 53541 of TJ-II. It was confirmed that the light levels obtained in TJ-II discharges, combined with with image intensification, are sufficient to achieve exposure times as low as 5 μs, which are relevant for turbulence studies. Measurements were performed in both ECRH and NBI heated plasmas, yielding a sufficiently large dataset for further analysis.

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