Thomson Scattering Measurements of Helium Recombining Plasmas in the Divertor Simulator MAP-II

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Laser Thomson Scattering (LTS) measurements of Electron Ion Recombining (EIR) Helium plasma were performed in the divertor/edge simulator MAP-II. Upgrades of our LTS system, in the stray-light level and in the notch filter, allowed the measurement of electron temperatures as low as 0.1 eV and further investigation of EIR processes. Electron temperature and electron density profiles of EIR He recombining plasmas with different background neutral pressures have been measured.

Keywords: Thomson scattering, divertor, detached plasma, recombining plasma, electron ion recombination (EIR) processes

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The volumetric recombination process is regarded as important in achieving divertor detachment, which can reduce the heat flux onto the divertor plate [1]. MAR (Molecular Activated Recombination) processes (2-3 eV), induced by H_2 puffing, as well as conventional EIR (Electron Ion Recombination) processes ($<$ 1 eV) can contribute to volumetric recombination, but their reaction rates strongly depend on the electron temperature.

It has been pointed out in several devices, both in tokamak divertors and in divertor simulators, that in recombining plasmas the electric probe characteristic exhibits an anomaly which disturbs the measurements [2]. On the other hand, spectroscopy for the Rydberg series in a partially local thermal equilibrium condition, such as EIR plasmas, always reflects the brightest point.

From this point of view, Laser Thomson Scattering (LTS) can be a solution, offering reliable and spatially resolved electron temperature and density measurements [3].

We have developed an LTS system and applied it to the H_2-MAR plasmas of a few eV, as reported in [4]. The laser source is a frequency-doubled Nd:YAG Laser (7 ns, 532 nm, 10 Hz, 500 mJ). The light is collected at 90° with respect to the laser path by means of a lens (150 mm in focal length and 100 mm in diameter). The optical fibers, 0.2 in the N/A and 0.1/0.125 mm in the core/clad diameter, are assembled in a 64-channel array. In the present experiment, the central 24 channels, corresponding to 4.5 mm in the radial scattering length, were used to obtain electron temperature and density. On the other hand, the spatial resolution along the magnetic field is 0.13 mm (single fiber channel).

With the aim of applying it to low temperature plasmas, a double monochromator system (composed of camera lenses, holographic gratings, Rayleigh block, and an ICCD camera) is used to measure narrow Doppler broadening and to suppress stray light of the laser wavelength. It has to be noted that the use of filter spectroscopy in this temperature regime requires the assumption of the Boltzmann distribution and careful sensitivity calibration [5]. The Rayleigh block is a carbon rod 0.35 mm in diameter, located at the laser wavelength position in the image plane of the first monochromator. Reciprocal linear dispersion of the monochromator was determined to be 0.02 nm per pixel of the ICCD. Wavelength resolution, evaluated in FWHM, was 0.15 nm for a slit width of 0.11 mm.

In order to measure EIR plasmas, however, further upgrades were required. Specifically, we reduced the dimensions of the physical block by replacing the carbon rod with a copper wire about 0.2 mm in diameter. Although the temperature corresponding to that thickness is 0.07 eV, the edge region of the wire becomes dulled, possibly due to the finite instrumental function. Therefore, for safer estimation of the temperature, the region excluded from the fitting is set to about 0.9 nm which determines the practical lower measurable temperature of 0.13 eV. However, reducing the dimensions of the block, at the same time, degrades the stray-light suppressing capability. In order to compensate for this effect, we optimized the system (optics, windows, laser path, and beam dump) by reducing the level of stray light from about 10 torr of equivalent N_2 Rayleigh scattered light of the previous setup to about 1 torr. Experiments were conducted in the steady state linear

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divertor/edge plasma simulator MAP-II [6]. The discharge conditions were as follows: $V = 65\,\mathrm{V}$, $I = 30\,\mathrm{A}$, with He as discharge gas. Since in our setup the position of the laser was fixed, in order to measure a spatial profile of the recombining plasma along the plasma column, as shown in Fig. 1, we needed to move the recombination "front" by controlling the gas pressure. The shape of the recombining front did not change throughout this operation; thus the spatial profile can be expressed as the dependence on the neutral pressure, as in Fig. 1. The constancy of the shape of the plasma recombining front can be seen from Fig. 2 where two pictures of the plasma column are taken at different neutral pressures, respectively 108 mtorr and 129 mtorr. In the pictures, the shape of the front is highlighted; the cone indicating the recombination front in the figure exhibits the same angle throughout the present conditions in this work. The movement of the front with changing the neutral pressure can be regarded as mainly due to the effect of neutrals in the upstream part of the plasma column (about 1 m in length).

Doppler-broadened Thomson scattered spectra at the neutral pressures of 140 mtorr (a) and 145 mtorr (b), after the subtraction of the residual stray light, are shown in Fig. 3. The central notch-filtered part of the spectrum is excluded in the fitting procedure.

In Fig. 4, the measure of electron temperature and density is shown as a function of the neutral pressure from 80 to 145 mtorr.

The electron temperature monotonically decreased with increases in the neutral pressure. In these conditions, the electron collisions are dominated by elastic collisions with neutrals and ions with a mean free path that varies from the order of 1 mm in the ionization dominated region

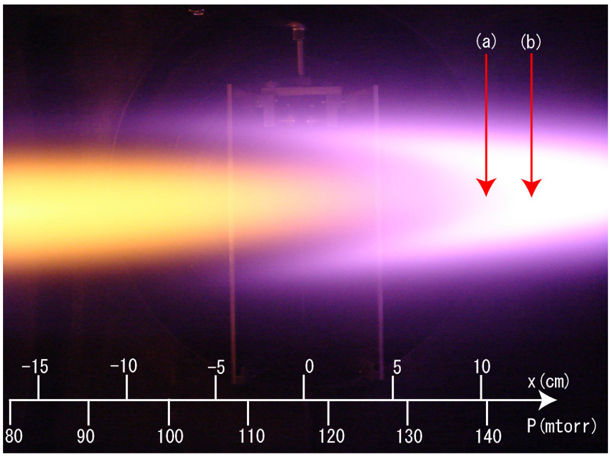

Fig. 1 Typical camera picture of the plasma with the equivalent measured spatial position's dependence on the neutral pressure. The red arrows indicate the positions of the measurements shown in Fig. 3.

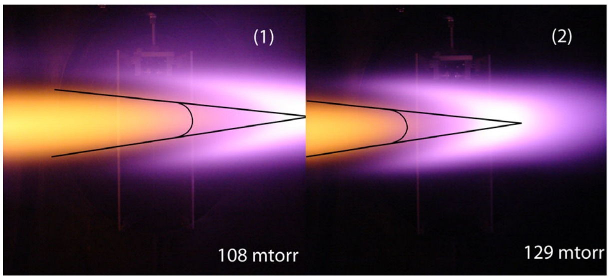

Fig. 2 Plasma pictures at the neutral pressures of (1) 108 mtorr and (2) 129 mtorr; the highlighted cones indicating the recombination fronts exhibit the same angle.

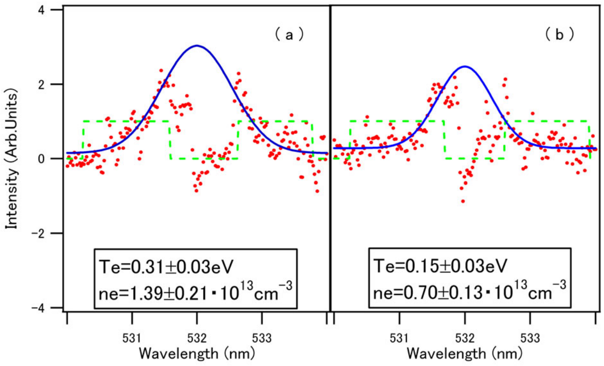

Fig. 3 Examples of Thomson spectra (dots) with Gaussian fitting (continuous line) and mask (dashed line).

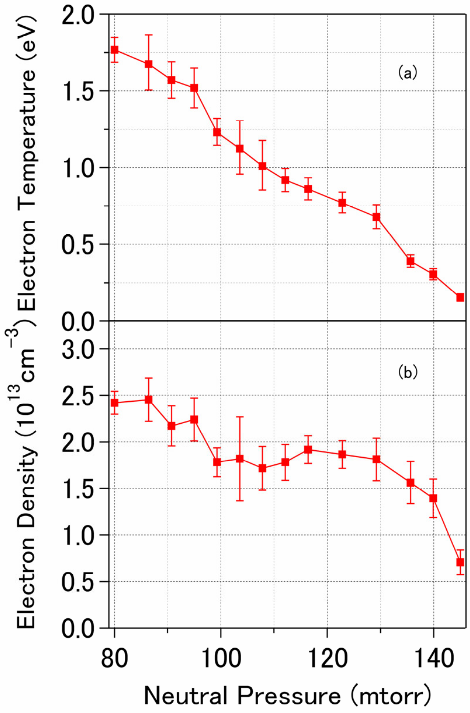

Fig. 4 Profiles of (a) electron temperature and (b) electron density as a function of neutral gas pressure.

(around 80-100 mtorr in Fig. 1) to the order of 0.1 mm in the recombination dominated region (> 130 mtorr).

We can see that the lowest measured temperature (0.15 eV) is close to the lower limit of our LTS system (0.13 eV). The steeper slope in electron temperature and the beginning of the decrease in electron density between neutral pressures 130 mtorr and 135 mtorr suggest the beginning of EIR, confirmed also by camera pictures taken at the different positions, indicating this interval of pressures as the start of the brightest region (recombining front) of the plasma.

Spectroscopic analysis based on the He I CR model will give us information about the consistency of both measurements, which is quite useful in using passive spectroscopy as a simple method for monitoring the divertor/edge plasmas from a limited observation chord.

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