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Development of a Near-Infrared Interference Spectrometer for Measurements of the Local Helium Atomic Emission Lines in the Spherical Tokamak QUEST

球状トカマクQUESTにおけるヘリウム原子発光線局所計測のための
近赤外干渉分光器の開発

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In tokamak plasmas, the atomic spectra of the inboard and outboard scrape-off layers (SOLs) can be separated by using the difference in the magnitudes of the Zeeman splitting. From the separated spectra, it is possible to determine the local emission intensity and velocity of atoms. In order to apply this method to the QUEST spherical tokamak, we have developed a near-infrared interference spectroscopy system for the HeI 2^3S-2^3P emission. By observing the spectra of helium discharge lamps and a diode laser, we confirmed that the instrumental function is represented by the Lorentz function with a FWHM of 18.7 pm.

1. Introduction

In the SOL of the tokamak plasmas, complex ion flow structure, which is relevant to the improvement of the plasma confinement and impurity screening, is generated. Since the ion flow is partly driven/dissipated by atoms through the pressure gradient induced by the ionization and the friction, investigation of not only ions but also atoms is essential for the comprehension of the driving mechanism of the ion flow structure. In this paper, we measure the spatial distributions of the atomic density and velocity as traces of the ion source and ion momentum loss along the SOL of the QUEST spherical tokamak.

We measure the local atomic emission intensity and the velocity relative to the core plasma in the SOL. The measurement method of passive near-infrared emission spectroscopy with observation of the Zeeman effect on spectral shapes is adopted. The magnetic field strength in the tokamak device depends on the major radius, when the field strength and its gradient are sufficiently large, the spectra which originate from the inboard and outboard SOLs can be separated by using the difference in the magnitudes of the Zeeman splitting (Fig.1). The emission positions can be identified from the magnitudes of the Zeeman splittings and the emission intensities and velocities at those positions can be determined from the areas and the Doppler shifts, respectively [1-3].

For a given magnetic field strength, the magnitude of the Zeeman splitting is approximately proportional to the square of the wavelength. Observation of spectra in a longer wavelength range is advantageous for the separation of the spectra. In order to apply the method to the QUEST spherical tokamak [4] and improve temporal resolution of the measurements, we have developed a near-infrared interference spectroscopy system for the HeI 2^3S-2^3P emission (1083 nm).

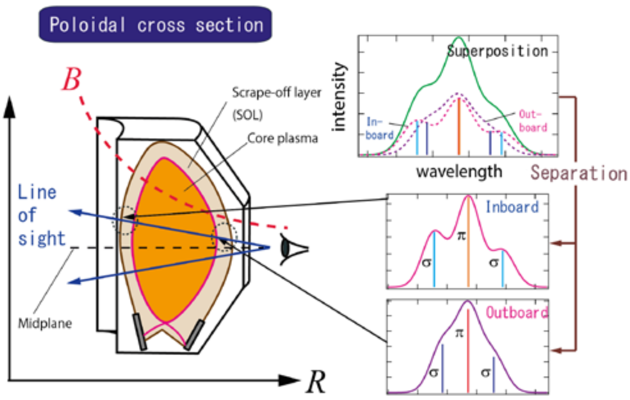

Fig.1 A schematic illustration about principle of local measurements of emission spectra using the Zeeman splitting

2. Near-infrared interference spectrometer

2.1 *Design*

We designed a spectrometer which utilizes a Fabry-Perot interferometer (FPI). For the inboard (0.50 T) and outboard (0.15 T) SOLs of the QUEST, we determined the required FWHM of the interferometer by calculating a spectrum expected to be observed with a radial line-of-sight on the midplane. In the calculation, radially localized emissions with the same intensity and the Doppler broadening equivalent to the atomic temperature of 0.2 eV were assumed based on experimental results obtained in a similar plasma [3] (Fig.2). From the results of the spectrum calculation, we confirmed that the two spectra can be separated by analyzing the short-wavelength shoulder shape of the superposed spectrum when the FWHM is smaller than 20 pm.

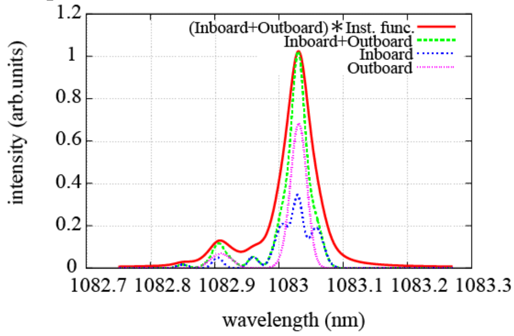

Fig.2 The calculated He I 2^3S-2^3P spectra expected to be measured by using the midplane viewing chord of the QUEST (Purple: outboard SOL spectrum; Blue: inboard SOL spectrum; Green: summation of the both curves; Red: convolution of the instrumental function of the interferometer into the green curve)

The spectrometer (Fig.3) consists of a collimation lens (Mitutoyo M Plan Apo NIR 10×), an aperture (Sigmakoki IH-30), a tunable FPI (Light Machinery OP-1986-64: peak wavelength 1083 nm, Finesse ~30, FSR 0.6 nm), and a band pass filter (Omega Optical XB173-1080BP10: peak wavelength 1080 nm, FWHM 20 nm). The cavity length of the FPI is adjustable by applying voltage to the piezo-actuator. For the present measurements, a low-frequency triangular voltage (20 $V_{p\text{–}p}$, ~1 Hz), which corresponds to about two FSRs, was fed to the piezo-actuator. The transmitted intensity of the light is detected by a cooled photomultiplier tube detector (PMT; Hamamatsu Photonics R5509-43). The PMT current is converted into voltage by a transimpedance amplifier, and recorded by a digitizer (National Instruments USB-4431: ±10 V, 24 bit, 102.4 kHz sampling). In order to improve the S/N ratios of the measured spectra, 11 spectra were averaged for the all experiments shown in this paper.

2.2 *Wavelength calibration and evaluation of instrumental function*

Fig.4 (a) shows the HeI spectrum measured with a glow discharge lamp (the discharge pressure 20 Pa, the current 3.0 mA, under no magnetic field). The measured scanning voltage of FPI was converted to the wavelength, by using the wavelengths of the observed large and small peaks, which originate from the three fine structure transitions [5], under an assumption of the linearity between the scanning voltage and the cavity length of the FPI. The validity of the assumption was confirmed by comparing the calculated spectra with the observed ones of a discharge tube installed in a superconducting magnet, where the magnetic field strength is up to 0.5 T.

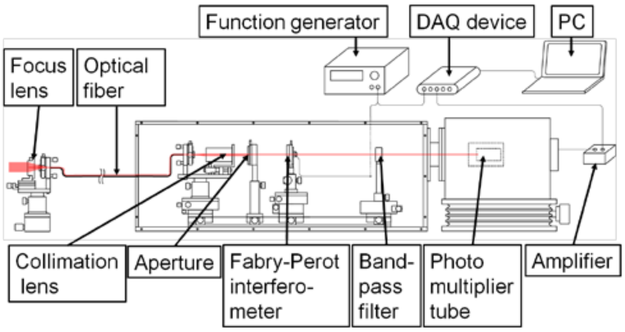

Fig.3 A diagram of the NIR interference spectrometer

By using the determined voltage-wavelength relationship, the instrumental function was evaluated by measuring the Fabry-Perot diode laser light (peak wavelength 1060 nm, temperature 293 K) with negligible broadenings (Fig.4 (b)). We have confirmed that the instrumental function is represented by a Lorentz function with a FWHM of 18.7 pm.

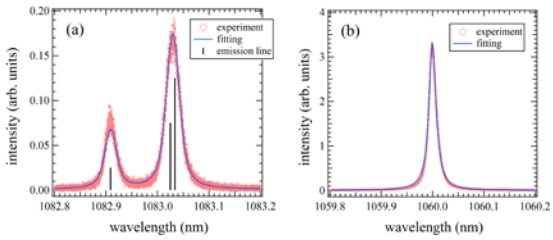

Fig.4 the HeI spectra measured using two kinds of light source ((a) the helium glow discharge lamp (b) the Fabry-Perot diode laser light) and the fitting results

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