Development of the Ultrasoft X-Ray Diagnostic for Impurity Transport Studies with a Tracer-Encapsulated Solid Pellet Injection on LHD

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A prototype ultrasoft X-ray polychromator for impurity transport studies using a tracer-encapsulated solid pellet (TESPEL) has been recently developed at Johns Hopkins University and tested on the Large Helical Device. The system has high throughput with good spatial (a few cm) and spectral (0.1~0.2 nm) resolution and millisecond time response for measuring faint charge-exchange recombination emissions from the fully stripped low-Z tracer impurity. The signals from the magnesium tracer deposited locally by TESPEL injection have been successfully obtained with the prototype polychromator.

Keywords:

TESPEL, CXRS, multilayer mirror, ultrasoft X-ray polychromator

The local properties of impurity transport can be obtained with fairly high-accuracy by means of Tracer-Encapsulated Solid PELlet (TESPEL) injection [1]. TESPEL consists of polystyrene (-CH (C_6H_5) CH_2-) as an outer shell (typically 0.5~0.9 mm diameter) and tracer particles as an inner core (~0.2 mm size). The flexible choice of the tracer particle is one of the important characteristics of TESPEL. The local diffusion properties, especially in the radial direction, of tracer impurities deposited locally in the core plasma by TESPEL injection can be obtained by the observation of line emissions arising from the process of the charge exchange recombination (CXR) of tracer ions with neutral hydrogen atoms, which originated from Neutral Beam Injection (NBI) [2]. In TESPEL experiments involving low-Z impurities, such as lithium, magnesium (Mg), and fluorine (F), on the Large Helical Device (LHD), the signal to noise ratio of the CXR emissions in the visible range was very low, since the charge exchange cross-section decreased substantially due to the high LHD NBI energy (~180 keV) [3]. One of the alternatives for obtaining the CXR emissions from TESPEL tracer impurities on the LHD is a shift of the range of measurement from the visible domain to the ultrasoft X-ray (USXR) range. Mg or F is expected to be an optimal tracer for USXR CXR Spectroscopy (CXRS) measurement [4]. The brightness values of the CXR emissions with the optimal tracers are estimated to be about 4.2×10^{12} (photons/cm^2sr s) for F IX at 8 nm and about 1×10^{13} for Mg XII at 4.5 nm at an NBI energy of 150 keV (NBI Port-through power, 3 MW) and with the amount of tracer particles at 2.5×10^{18}. Although these values are more than one order of magnitude larger than those in the visible domain, the local USXR CXRS measurement using the TESPEL tracer is still challenging and needs the strong rejection of the background level to distinguish the faint CXRS signal.

For such a challenging measurement with the TESPEL tracer, a one-channel USXR polychromator with a high photon throughput has been recently developed by the Johns Hopkins University (JHU) Plasma Spectroscopy Group [5] and tested in a recent LHD experiment. The device consists mainly of a toroidally aligned stacked-grid collimator for the angular collimation of radiation, two planar Ni/C multilayer mirrors (MLM) as a dispersive element, and two high-sensitivity photodetectors. A titanium foil 0.3 μm in thickness on a Parylene-N film of 0.7 μm in thickness is applied for reducing scattered VUV and visible lights. The filters are optimized for a maximal background rejection rather than the largest transmission. Such configuration using a grid collimator [6] in combination with MLM and foil filters [7], which provides a high throughput having 2 cm radial and 0.1~0.2 nm spectral resolution, has been used for the first time in magnetic fusion experiments. The light emissions from the plasma are collimated on the MLM, and the Bragg reflected beam propagates through the filters and is registered by a new, highly sensitive, compact and efficient high-gain micro-channel plate (MCP). The MCP a detectors, which are coated with 150 nm CsI for photocathode, are used in a photon

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counting mode. In the experiments, the applied voltage for the MCPs was set at 1250 V and the gain of the preamplifiers (FEMTO DLPCA-200) at 10^8 V/A.

In the experiments, one MLM (Line MLM) was optimized for the measurement of the CXR emission of the Mg H-like n = 2–3 ($\lambda_{\rm Line}$ = 4.5 nm). In order to eliminate the contribution from the background (BKG) noise as shown in Fig. 1, the other MLM (BKG MLM), which was set at a nearby wavelength ($\lambda_{\rm BKG}$ = 5.1 nm), was also installed at the same toroidal location. The system response of a combination of the MLM reflectivity and the filter transmission is shown in Fig. 1.

The Line and BKG represent the system with the Line MLM and the one with the BKG MLM, respectively. Here we assumed that the background level is the same for the window of wavelength from 4 nm to 6 nm.

For a correct background measurement of CXRS, it would be preferable to use a channel with the same wavelength as for the Line MLM but at a different toroidal location without NBI. This is intended as the measurement system's final form. In the polychromator, to monitor the progress of the tracer ionization in front of the device, a photodiode with the MLM, which is optimized for the Mg Li-like line ($\lambda_{\rm PD}$ = 5.8 nm), is also installed. The signals from the photodetectors are transmitted to the FEMTO preamplifiers, amplifiers, and a digitizer board.

A clear Mg contribution after the TESPEL injection has been observed by the one-channel prototype USXR polychromator in collaboration with the JHU Plasma Spectroscopy Group. A TESPEL with the Mg tracer, the total amount of which was about 7×10^{17} atoms, was injected into the LHD plasma heated by NBI with line-averaged density of n_e= 1.7×10^{19} m^{-3} and a central electron temperature of T_{e0} ~ 2 keV. As shown in Fig. 2, the signal with the Mg tracer obtained by the Line channel shows exponential decay, which may suggest no accumulation of Mg impurity in the core plasma. Preliminary analysis indicates that the signal obtained from the Line channel with the Mg tracer essentially contains the CXR emissions and other contributions, such as those of electron impact excitation and from continuum. Therefore, as mentioned above, the background measurement using a channel with the Line MLM at a different toroidal location without NBI or a shot without NBI at the same toroidal location is expected to obtain a pure Mg H-like CXR emission from the core plasma.

Nevertheless, this experimental result suggests that the TESPEL technique in combination with the novel USXR polychromator could be a powerful tool for local transport measurement on the LHD. However, the single-channel measurement can provide only the averaged property of tracer impurity transport at a certain location. Based on the results from the one-channel prototype polychromator, a multi-channel polychromator with MLM will be applied to the LHD in conjunction with the JHU Plasma Spectroscopy Group. This will enable us to study local impurity transport on the LHD.

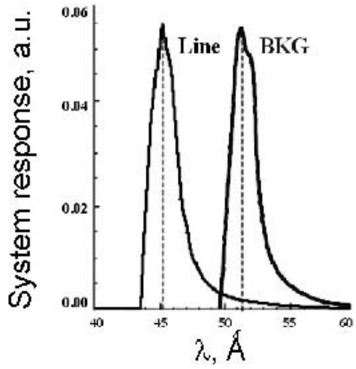

Fig. 1 The system response of a combination of MLM reflectivity and the filter transmission for the Line and BKG channel as a function of wavelength.

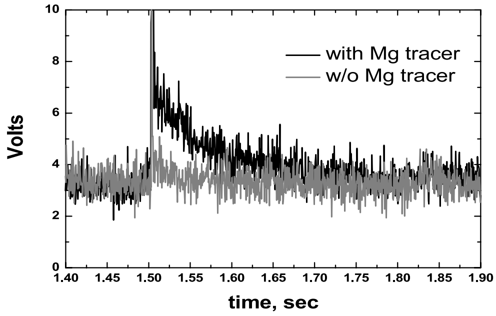

Fig. 2 Comparison of the signals obtained from the Line channel with (LHD#48640) and without (LHD#48648) the Mg tracer. TESPEL was injected at 1.5 s.

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