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Determination of tungsten and molybdenum concentrations from an X-ray range spectrum in JET

JETにおけるX線帯スペクトルからのタングステン及びモリブデン密度の決定

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W^{45+} and W^{46+} 3p-4d inner shell excitation lines in addition to Mo^{32+} 2p-3s lines have been identified from the spectrum taken by an upgraded high-resolution X-ray spectrometer. It is found from analysis of the absolute intensities of the W^{46+} and Mo^{32+} lines that W and Mo concentrations are in the range of ~10^{-5} and ~10^{-6}, respectively. For the purpose of checking self-consistency, it is confirmed that the W concentration determined from the W^{45+} line is in agreement with that from the W^{46+} line within 50% and that the plasma effective charge determined from the continuum of the first order diffracted spectrum is also in agreement with that from the second order within 50%. However, it is still required to check quantitative validity by comparing these quantities with those from other diagnostics.

1. Introduction

It has been decided that ITER will be operated from day one with a W divertor and Be first wall. In such a wall configuration, one of the most significant issues is impact of W accumulation on plasma fusion performance. In order to investigate the impact, in JET, experiments with ITER-like wall configuration have been performed with an upgraded high-resolution X-ray crystal spectrometer. This X-ray spectrometer originally monitored the spectral line from He-like Ni ion [1], and has now also started monitoring W concentration since installation of a second crystal and detector [2]. Coincidentally, Mo spectral lines are found in the same wavelength range as the W spectral lines. Hence, from the measured absolute intensities of the W and Mo spectral lines, it is possible to evaluate W and Mo concentrations simultaneously.

2. Spectrometer setup

The X-ray spectrometer is built in Johann mounting with a Rowland circle radius of 12.5 m [1] and new Gas Electron Multiplier (GEM) detectors [2]. The measurable spectral band for the W channel is 0.0043 nm with 256 strips of the detector at a wavelength of 0.52 nm, and an inverse linear dispersion of 2.1 x 10^{-5} nm/mm. The sensitivity is calculated as a product of photon-throughputs at each component of the spectrometer such as X-ray reflectivity of the crystal, resulting in 1.6 x 10^{-11} [counts ph^{-1} m^2 sr] [2]. The diagnostic line-of-sight is tangential to the plasma current and 0.2 m below the magnetic axis

of typical diverted plasmas.

3. Line identification

One of the difficulties in high resolution spectroscopy is line identification due to the difficulty in determining the wavelength; slight misalignments of the instrument result in large uncertainties in wavelength and also known lines rarely fall in a very narrow spectral band, making the experimental wavelength calibration uncertain. To overcome these drawbacks, we employed the following two methods:

i) Laser-blow-off experiments and

ii) Validation of the modelled spectrum using Flexible Atomic Code (hereafter, FAC) [3], by comparing it with published spectra. Mo laser-blow-off experiments confirm that two of the central spectral lines in Fig. 1 are from Mo ions. Furthermore, comparison with the calculated spectrum indicates that the two lines are due to Mo^{32+} 2p - 3s lines. The remaining lines are well reproduced by the validated W spectrum, resulting in the following identification: W^{45+} 3p-4d lines and a W^{46+} 3p-4d line. Note that difference of the calculated Mo^{32+} lines from the measured ones is due to different Doppler shift of the Mo^{32+} ion from the W^{45+} and W^{46+} ions.

4. W and Mo concentrations

From the measured intensities, W and Mo concentrations, $c_W = n_W/n_e$ and $c_{Mo} = n_{Mo}/n_e$, respectively, are determined from the following equation (a similar equation for c_{Mo}):

$$c_W = I^{W46+} \Big/ \int FA^{W46+}(R)\cdot PEC^{W46+}(R)\cdot n_e(R)^2\, dR$$

, where I^{W46+} [ph m^{-2} s^{-1}] is the measured W^{46+} intensity, PEC^{W46+} [ph m^3 s^{-1}] the photon emission coefficient calculated by FAC, FA^{W46+} ($=n_{W46+}/n_W$) the fractional abundance under coronal ionization equilibrium calculated with ADAS ionization/recombination rates [4], R [m] the major radius along the line-of-sight of the X-ray spectrometer. Below an electron temperature of ~5 keV, the term inside the integral, $FA^{W46+}(R)\cdot PEC^{W46+}(R)\cdot n_e(R)^2$, is peaked at the very centre of the plasma, indicating that the W concentration determined from the W^{46+} line is a good measure for the core W concentration, although the line-of-sight of the X-ray spectrometer does not pass through the very centre but up to a normalised poloidal magnetic flux of Ψ_{pol} ~0.05.

As shown in Fig. 2, the determined W and Mo concentrations are in the range of 10^{-5} and 10^{-6}, respectively, both in non-seeded and in N_2 seeded ELMy H-mode plasmas, respectively, with a central electron temperature and density of 4 and 3.5 keV, and 6 and 9 x 10^{19} m^{-3}. The ratio of Mo to W concentration is ~5%. Mo materials are used only for some Mo marker tiles, W/Mo interlayers on CFC divertor tiles, some structural elements made of Inconel 625 (9% Mo included) with a possibility as a contaminant over the Be-coating on the central column [5]. Although they might be sources of Mo ions, the Mo source is not yet identified. Further comparison of the W concentrations and plasma effective charges will be given to show self-consistency within the X-ray spectrometer.

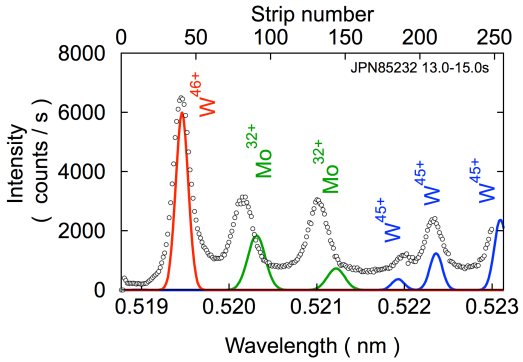

Fig.1.Spectrum measured by the X-ray spectrometer and that calculated by FAC at 4 keV and W^{45+}, W^{46+} and Mo^{32+} density ratio of 1.0:0.3:0.7.

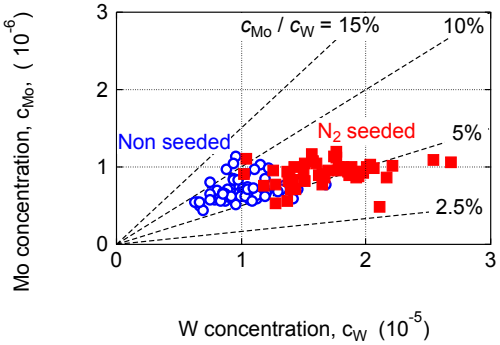

Fig.2. Mo Concentration as a function of W concentration from non and N_2 seeded plasmas.

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