S15-2

Spectroscopic modeling for high Z impurities with their atomic processes and transport from wall to core plasma in LHD

LHDにおける壁からコアでの高Z不純物の原子過程と輸送の分光モデル

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Qunatitative tungsten study with reliable atomic modeling is important for successful achievement of ITER. We have developed tungsten atomic modeling for understanding the tungsten behavior in fusion plasmas. The modeling is applied to the analysis of tungsten extreme ultraviolet (EUV) spectra observed from plasmas of Large Helical Device (LHD) and compact electron beam ion trap (CoBIT). We found EUV emission peaks at 1.5-4 nm of W^{22+} - W^{33+} ions are useful to determine the charge state distribution. Unresolved transition array (UTA) feature are reproduced by our model. Transport calculation helps to understand tungsten behavior in LHD plasma. We obtained mean velocities of sputtered tungsten atom by ion beam experiments and the result indicates importance of atomic structure for tungsten kinetics.

1. Introduction

Tungsten is used as plasma-facing material in ASDEX Upgrade [1] and JET [2] to support ITER project because of high melting point and low sputtering yield by hydrogen. However, tungsten is sputtered by impurities from limiter [3] or divertor plates and accumulated in core plasma. Tungsten causes large radiation power loss and cools plasma. It is important for stable operation of ITER to study the influx and transport of tungsten ions with a spectroscopic method. Previous studies on tungsten atomic modeling have not fully explained the tungsten EUV spectra, e.g. an unresolved transition array (UTA) seen at 4.5-7.0 nm in plasma with electron temperature T_e <1.5 keV [4], which corresponds to edge plasma temperature for ITER. Since the UTA is composed of numerous transitions, it has been difficult to analyze the UTA. We need a reliable atomic model for tungsten over wide temperature range.

We have developed a tungsten atomic model with detailed atomic structure, and we applied the model to analyze EUV spectra measured from CoBIT plasmas [5] with tungsten hexacarbonyl vapor and from the LHD plasmas with tungsten pellet injection. The CoBIT experiments well control the charge distribution of tungsten ions. The information from the CoBIT spectra is helpful to understand EUV spectra in the LHD.

2. Tungsten Atomic Model

We have constructed a collisional-radiative (CR) model for tungsten ions. Atomic data in the CR model are calculated with the HULLAC atomic code [6]. We consider electron configurations with principal quantum number *n* up to 6 including inner-shell excited states for atomic structure and up to 20,000 J-resolved fine-structure levels are included for one ion in the CR model. As atomic processes, electron-impact ionization, excitation and de-excitation processes, and radiative decay are included. Recombination processes are ignored. Here we examine W^{q+} ions with q = 20-45, which are N-shell ions with outermost electron in n = 4 shell for the ground state, and they are seen in LHD plasma with T_e < 3 keV.

3. EUV Spectroscopic Measurements

Tungsten EUV spectra at 1.5-4 nm wavelength region were measured in CoBIT with various electron beam energies. The charge states of observed emission peaks were determined. Using the CR model, we calculated EUV spectra with the physical condition of CoBIT, i.e., $n_e = 10^{16}$ m^{-3} and mono-energy electron distribution and identified emission peaks as 6g–4f, 5g–4f, 5f–4d, and 5p–4d transitions of W^{19+}–W^{33+} ions [7]. The peak wavelengths shift shorter for higher charge states and they are useful to determine the charge state distribution in LHD plasmas.

For LHD plasmas, tungsten was injected as an impurity pellet or a tracer-encapsulated solid pellet (TESPEL) in NBI heated discharges. A pellet was ablated in the vicinity of normalized minor radius ρ~0.8, and tungsten was ionized and transferred into a core plasma region. After pellet injection electron temperature dropped due to large radiation loss by tungsten at the central region and recovered with NBI heating. Tungsten EUV spectra at 1.5-4 nm were measured in LHD, which were similar to the spectra measured in CoBIT. We calculated spectra using the CR model with the plasma condition of LHD and synthesized spectra with ion abundances determined to match with the measured spectra. Obtained charge distributions are shown in Fig. 1 for two cases. Our model calculations well reproduce the LHD spectra. We also synthesized spectra at 4-7 nm with the determined ion abundance and the two-peak UTA feature is obtained as shown in Fig.2.

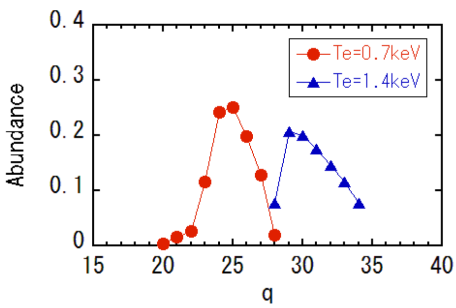

Fig.1 Obtained charge distribution for tungsten ions in LHD plasma discharge 112880 at t = 4.64 s (T_e = 0.7 keV) and t = 4.80 s (T_e = 1.4 keV).

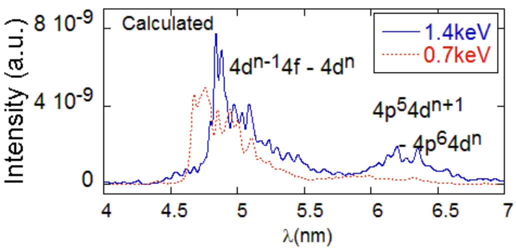

Fig.2. Synthesized spectra using obtained charge distributions for LHD plasma.

4. Tungsten Behavior in LHD

We performed tungsten transport calculation with the STRAHL code [8] for the discharge analyzed above to demonstrate tungsten behavior in the LHD plasma. In this calculation we use ionization and recombination rates from ADAS [9], since we need complete sets of these rates from neutral to fully ionized tungsten ion. Constant diffusion coefficient D=0.1m^2/s and spatial dependent inward convection velocity up to -2 m/s at ρ=0.5-1.0 are assumed. Obtained spatial and temporal distributions of tungsten ions reasonably explain the obtained charge state distributions.

5. Mean Velocity of Sputtered Tungsten Atom

We measured tungsten velocity sputtered from tungsten target irradiated by ion beam to understand behavior of sputtered tungsten atom [10]. The mean normal velocities are dependent on energy difference between the work function and ionization potential of the excited states. This indicates that detailed atomic structure of sputtered tungsten atom influence tungsten kinetics and need to consider this effect in particle simulations for divertor plasmas.

6. Summary

We have developed tungsten atomic modeling to understand tungsten behavior in fusion plasma and analyze EUV spectra measured in LHD plasmas.

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References

[1] R. Neu *et al*: Plasma Phys. Control. Fus. **49** (2007) B59.
[2] G. F. Matthews *et al.*: J. Nucl. Mater. **438** (2013) S2.
[3] R. Dux *et al.*: J. Nucl. Mater. **390-391** (2009) 858.
[4] T. Pütterich *et al.*: AIP Conf. Proc. **1545** (2013) 132.
[5] N. Nakamura *et al.*: Rev. Sci. Instrum. **79** (2008) 063104.
[6] A. Bar-Shalom *et al.*, J. Quant. Spectr. Rad. Transfer **71** (2001) 169-188.
[7] H. A. Sakaue *et al.*, AIP Conf. Proc. **1438** (2012) 91.
[8] K. Behringer, Rep. JET-R(87)08, JET Joint Undertaking, Abingdon (1987).
[9] H. P. Summers, http://www.adas.ac.uk/
[10] K. Nogami *et al.*, submitted to Nucl. Instr. Meth. B (2014).