Assessment of W density in LHD core plasmas using visible forbidden lines of highly charged W ions

National Institute for Fusion Science
kato.daiji@nifs.ac.jp

ABSTRACT

- Total tungsten (W) density in core plasmas of LHD is assessed with the measurement of visible magnetic-dipole (M1) lines emitted from W26+ and W27+ in the ground states.
- Hollow radial profile of W density in LHD core plasmas with a line-averaged n_e ~ 4×10^{19} m^{-3} and central T_e ~ 1 keV is found.
- Rapid decrease of W density in the whole core region is observed during reheat mode with elevated electron temperatures.

OUTCOME

- Observation of visible M1 lines from W26+ and W27+ in LHD core plasma
  - Line 1: 4f⁷2F_{7/2} → 2F_{5/2} of W27+ at 337.73 nm
  - Line 2 and 3: 4f⁷23F₄ → 1G₄ and 3F₄ → 3F₃ of W26+ at 335.73 and 333.70 nm

- Radial profiles of W26+ and W27+ densities
  - Density ratios of W27+ to W26+ approximately agree with transport-free ionization equilibrium model. This result is validated by tungsten radial transport simulation using STRAHL code.

- Radial profile of total W density
  - Hollow radial profile of W density in LHD core plasmas with a line-averaged n_e ~ 4×10^{19} m^{-3} and central T_e ~ 1 keV.
  - Rapid decrease of W density in the whole core region during reheat mode with elevated electron temperatures.
  - Total W density obtained with the present PECs of the M1 lines is assessed to be overestimated (at least factor of 3).

BACKGROUND

- W transport and its density control are key issues for ITER with W divertor, because it is well known that W has a strong radiation cooling power.
- Quantitative understanding required for predicting effects of MHD mode activity, turbulent transport, and neoclassical transport are still limited.
- Direct measurements of W cooling factors have a large uncertainty as independent measurements of total W density in plasmas are inaccurate.
- Until now, only a few direct measurements of W ion density with spectroscopic diagnostics of emission lines in the extreme-ultraviolet (EUV) range.

CHALLENGES / METHODS / IMPLEMENTATION

- W pellet injection experiment at LHD
  - Pellet consists of polyethylene tube containing a tungsten wire (0.6 mm long and 0.15 mm diameter, 6.8×10^{17} W/pellet).
  - Time-resolved (38 ms exposure at every 100 ms) emission spectra at 44 LOS along the vertical direction of a horizontally elongated poloidal cross section measured using a Czerny-Turner visible-UV spectrometer (grating 1200 gr/mm, slit width 50 μm).

Collisional-Radiative (CR) model for PEC of M1 line

- CR model for fractional populations of excited levels n_{q+1}^{i} of W^{q+} ions:
  \[ \sum_{j \neq i} n_{e} C_{j}^{i} n_{q+1}^{i} + n_{p} C_{j}^{p} n_{q+1}^{i} + \sum_{j < i} A_{j} n_{j} n_{q}^{i} = \sum_{j > i} A_{i} n_{j} n_{q+1}^{i} \]
  where n_e and n_p electron and proton densities, C_{j}^{i} and C_{j}^{p} (de-)excitation rate coefficients, S_{i}^{q+1} ionization rate coefficients, A_{j} transition rates.

CONCLUSION

- Visible W M1 lines are useful for assessment of W density and quantitative understanding of W transport in core plasma.
- For precise assessment, accurate PEC calculations of the M1 lines are crucial. Further improvement of CR models for W spectra is necessary.
- Usage of W visible M1 lines at ITER has a potential advantage because mirrors and optical fibers are available to avoid direct neutron irradiation on detectors.

ACKNOWLEDGEMENTS

JSPS KAKENHI 18H01201, NIFS20KLPF075, NIFS21KLPF083, and the NINS program of Promoting Research by Networking among Institutions (grant No. 01411702)