Contribution of Quantitative Spectroscopy to Fusion Plasma Research

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In fusion plasmas, different roles are required for impurities in terms of atomic number, Z; in low temperature peripheral (divertor) plasmas, enhancement of low Z impurity radiation is of importance for mitigating plasma heat load onto plasma-facing walls, while in high temperature core plasmas, suppression of impurity radiation, particularly by high Z impurity ions, is essential for maintaining high temperature. This talk discusses a mechanism, which enhances low Z impurity radiation in divertor plasmas and a method available for validating ionization and recombination rates of high Z impurity, tungsten (W) based on quantitative spectroscopy.

In the divertor plasma of JT-60U tokamak, we successfully provided a comprehensive picture of the carbon radiative cooling process [1]. In high-density divertor plasmas, typically an electron density above $1\times10^{20}$ m$^{-3}$, strong radiation zone appeared, and intense line emissions from carbon ions, originating from the carbon divertor targets, were observed. It was found, in this radiation zone, that the C III line emission contributed 30% of the total radiation power, and C IV 60%, and that the C IV ions were produced by ionization of C III ions and at a higher rate by recombination of C V ions (He-like). These indicate that C III and C V ion flowed into the radiation zone, and were converted into the biggest radiator, C IV. In particular, a newly discovered channel [2], conversion of an inefficient radiator C V into an efficient C IV contributed to enhance the radiative cooling more than that of C III to C IV. Interestingly, in Ne-seeded plasmas, recombination of Ne IX (also, He-like ion) was observed in the Ne radiation zone [3], suggesting recombination of impurity He-like ion is one of common key processes to enhance the impurity radiation.

In the core plasma of JT-60U tokamak, W density was determined from the intensity of W$^{45+}$ spectral line (4s-4p: 6.2 nm). The determined W density over electron density ranged from $1\times10^{5}$ up to $1\times10^{7}$ [4]. In addition, to investigate the validity of W$^{44+}$ ionization rate and W$^{45+}$ recombination rate, a density ratio of W$^{45+}$ to W$^{44+}$ calculated with an ionization equilibrium model was compared to that determined from an intensity ratio of W$^{45+}$ to W$^{44+}$ 4s-4p lines. One of the advantages of this method is cancellation-out of electron temperature dependence of excitation rates of 4s to 4p by taking the intensity ratio. This is due to similar transitions in simple systems: closed 3d shell + 4s electron, exciting to 4p level for W$^{45+}$ and one additional 4s for W$^{44+}$. This analysis resulted in agreement between measurement and calculation within experimental uncertainty (~30%), showing the validity of the ratio of W$^{44+}$ ionization rate to W$^{45+}$ recombination rate. Similar analysis performed in the JET tokamak [5], but for the density ratio of W$^{46+}$ to W$^{45+}$ determined from the intensity ratio of W$^{46+}$ to W$^{45+}$ 3p-4d lines (0.52 nm), showed the measured W$^{46+}$/W$^{45+}$ ratio was systematically higher by 16% than that calculated. This indicates a possibility that the calculated W$^{45+}$ recombination rate is overestimated or the calculated W$^{45+}$ ionization rate is underestimated. The reason for this deviation is not yet clear.


