2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Multipleionization on Cl-Kα Spectra from Hot Dense Plasma Produced by Ion Beam Irradiation

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Kα spectroscopy is one of useful diagnostics to estimate density and/or temperature of plasma generated by an ion beam [1]. Kα lines are emitted from K-shell vacant ions, and a K-shell vacancy is created by incident ion impacts. Charge states of Kα lines are mainly determined by ionization of outer-shell, which is usually caused by plasma electrons. Plasma conditions can be deduced according to the charge states of the spectra. In plasma creation by ion beam irradiation, K-shell ionization of target atoms is accompanied by outer-shell ionization by incident ion impacts. This process is called multipleionization. In the case that multipleionization processes by incident ions are comparable to single ionization by plasma electrons, ionization of target atoms is enhanced, and plasma temperature estimated with Kα spectra can be lower compared with the case that the processes are neglected.

Not only K-shell vacant states but also L-shell ones are mainly created through inner-shell ionization by incident ion impacts. In population kinetics calculation, such non-radiative processes as KLL-, KLM-, KMM- and LMM-Auger transitions are considered [2] to estimate net Kα intensity. The LMM transitions are related to L-shell vacant states and others are for K-shell vacant states. The corresponding population kinetics is solved under a collisional radiative equilibrium (CRE) condition.

The cross sections of K- and L-shell ionizations by ion impacts are referred from Refs. [3],[4]. Probability of the multipleionization can be expressed by single electron ionization probabilities with the assumption that the multipleionization is regarded as simultaneous single ionization of binding electrons. If all the electrons in same shell have same ionization probability, a cross section $\sigma_{\mathrm{K,nM}}$ for ionizing a single K-shell and n M-shell electrons has a binomial distribution [5]:

$$\sigma_{\mathrm{K,nM}} = \sigma_{\mathrm{K}} \binom{N_{\mathrm{M}}}{n} P_{\mathrm{M}}^{n} (1 - P_{\mathrm{M}})^{N_{\mathrm{M}}-n}, \qquad (1)$$

where σ_{K} represents a cross section for ionizing a single K-shell electron, N_{M} and P_{M} stand for number of M-shell electrons and probability for ionizing a single M-shell electron respectively.

Fig. 1 shows an example of Cl-Kα spectra with and without multipleionization obtained by numerical simulation. Chlorine is often used as a tracer for plasma diagnostics, and doped in target material, for instance, C_2H_3Cl [1]. In the calculation, it is assumed that target atoms are chlorine and an incident ion-beam is C^{6+}. The multipleionization processes for a single K-shell and up to seven M-shell electrons are considered. In the figure, it can be seen that Kα lines with multipleionization at photon energy ~ 2625 eV are enhanced compared with those without multipleionization. According to Ref. [1], Kα lines from Cl^{2-4+} have peaks there, the enhancement thus may be due to such charge states of the Kα lines.

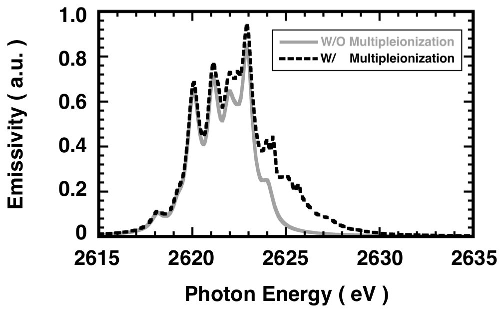

Fig. 1 Calculated Cl-Kα spectra at electron temperature T_e = 10 eV, and target ion density $\varrho \sim 8.1 \times 10^{12}$ cm^{-3} with and without multipleionization.

In this study, we will discuss plasma conditions where the multipleionization processes have an apparent contribution to the Kα spectra.

References

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