§28. EUV Spectra by Xe^{q+} + Xe Charge Transfer

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Recently, Xe and Sn ion spectra produced by laser are studied as EUV light sources for lithograph for the wavelength 13.5nm, where reflection of multilayer mirror is high. In low-ionized Xe and Sn ions, many lines including satellite lines are emitted around 13.5nm. Atomic processes related to Xe or Sn ions should be studied to extract the radiation power efficiently from plasma.

For identification of complicated EUV spectra from these high Z ions, spectra by charge transfer Xe^{q+} + Xe [1] are useful. In these experiments, a Xe ion beam are taken out from an ECR ion source and injected to the neutral Xe gas target with kinetic energy of *20q* keV. Spectra emitted by charge transfer were measured from vertical direction of the collisional crossing point.

Correct identification of spectral lines needs modeling to calculate line intensities by charge transfer processes. In this report, we constructed a collisional-radiative model including charge transfer processes, which assumed an intuitive function as equation (1) for charge transfer rates to an excited state *i*.

$$C_i^x \propto F_i \exp\left\{-\left[(E_i - E_c)/\sigma\right]^2\right\}, \qquad (1)$$

where F_i is a coefficient to each energy level *i*, E_i is an energy of *i* state, E_c is a captured energy measured from the ground state, and is captured energy width in Gaussian type distribution which we assumed for the energy dependence by electron transfer. If a charge transfer is a dominant process in collision system Xe^{q+} + Xe and collisional processes by electron impact are negligible, complicated rate equations are reduced to a simple equation as follows,

$$dN_i/dt = -\sum_j A^r_{ij} N_i + \sum_j A^r_{ji} N_j + C_i^x N_{Xe}, \qquad (2)$$

where A^r_{ij} is a radiative transition rate from an *i* state to a *j* state, and N_i and N_{Xe} are population densities of an i state of Xe^{q+} ions and the ground states of neutral Xe atoms. The numbers of energy levels depend on ion species. For Xe^{8+} + Xe processes, energy levels $4d^{10}nl$ and $4d^9 4fnl$ of Xe^{7+} ions are included and the total number of the levels is 277. For Xe^{18+}+ Xe processes, energy levels 4s24p6nl, $4s^2 4p^5 4dnl$, 4s4p64dnl, $4s^2 4p^4 4d^2 nl$, $4s4p^5 4d^2 nl$, $4s^2 4p^5 4f^2$ and $4s4p^6 4f^2$ of Xe^{17+} ions are included, and the total number is 8831. A quasi-steady state solution of equation (2) is written as

$$N_i = r_i^{Xe} N_{Xe}. \qquad (3)$$

Population densities are populated by charge transfer only.

Figure 1 shows the measured and theoretical spectra. A Gaussian type line profile is assumed in theoretical spectra. The measured spectra are emission spectra from charge transfer of Xe^{8+} + Xe. The theoretical spectra are obtained from equation (1) - (3) with E_c = 79.5eV and σ = 1eV. These parameters in equation (1) are very sensitive to line spectra. The values F_i in equation (1) are assumed to be unity.

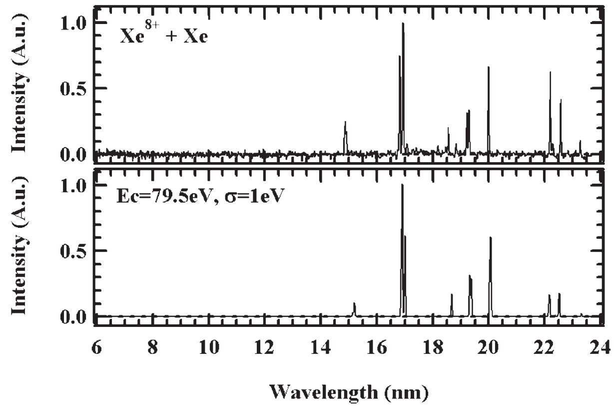

Figure 1 The measured spectra by Xe^{8+} + Xe processes (Top panel) and the theoretical spectra with E_c = 79.5eV and σ = 1eV, respectively.

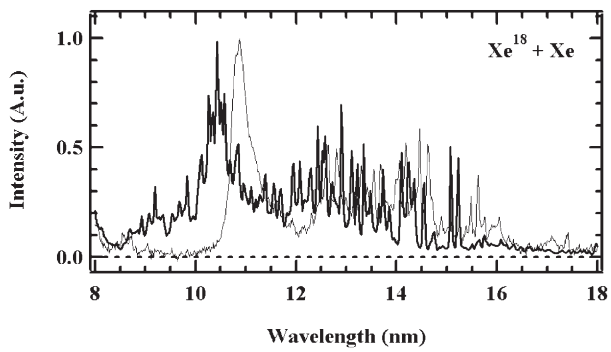

Figure 2 Comparison with the measured (thin line) and theoretical spectra (bold line) from charge transfer processes of Xe^{18+} + Xe. The theoretical spectra are calculated for E_c = 420eV and σ = 1eV, respectively.

Comparison with the measured and theoretical spectra by Xe^{18+} + Xe is shown in figure 2. The theoretical spectra roughly agree with the measured spectra if the wavelengths are shifted about 0.5nm to longer wavelength side. We found that a broad feature around 10.5-11.0 nm is produced by 4p-4d and 4d-4f transitions between various configurations and the comb-like spectra in 12.0-16.0 nm are produced by 4p-4d transitions of $4s^2 4p^6 4d$ - $4s^2 4p^5 4d^2$. Forbidden lines are generally strong in a case of charge transfer or recombining plasma where radiative cascade processes are dominant. However, we found that lines from metastable states are not measured in the spectra in ref [1]. It means that emissions from excited states with a long life time can not be measured in experiments. Measurable spectral lines from an ion beam are limited by a velocity of ions, an extension of target neutral Xe gas and a focal spot size of a spectrometer.

References

[1] Tanuma, H. et al., NIMB 235 (2005) 331-336.