§16. Plasma Atomic Processes Explored by Optical Emission Spectroscopy of Excited Atoms Sputtered from the Metal Surface by Ion Bombardment

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Cooling processes of the plasma due to radiation from excited neutral atoms sputtered from the wall surface is an important atomic process in fusion plasma, because neutral atoms penetrate into the plasma across the magnetic fields. In particular, it is very important to know the kinematics of the excited atoms produced in the sputtering processes. We measured the mean velocity of excited tungsten(W) atoms in direction normal to the surface by observing ion induced light emission.

The experiments were carried out in the National Institute for Fusion Science (NIFS). When ion beam entered onto the surface at normal incidence angle, a number of visible emission spectra were observed through a monochromator with a CCD detector, which was set in direction parallel to the surface. We measured the intensity of light emission from sputtered atoms on tungsten surfaces under the irradiations of Kr^+ ion and Ar^+ ion, as a function of the perpendicular distance from the surface. Using the analysis of decay curve, we estimated the mean vertical velocity component in direction normal to the surface. The decay of the photo emission intensity I as a function of z provides an information on the mean velocity with normal direction of the excited atoms. In general, this intensity decay follows the well-known relation,

$$I = \sum_k I_{0k} \exp\left(-\frac{z}{< v_\perp > \tau_k} \right) \quad . \qquad (1)$$

Where I_{0k} is the intensity from a particular transition k at the surface (z=0), $v_\perp$ is the vertical velocity component normal to the surface, τ_k is the lifetime of the excited state.

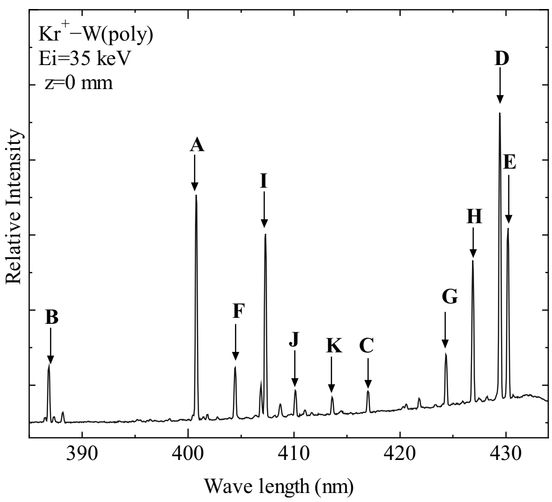

Fig. 1. A typical survey optical emission spectrum obtained at z=0 mm

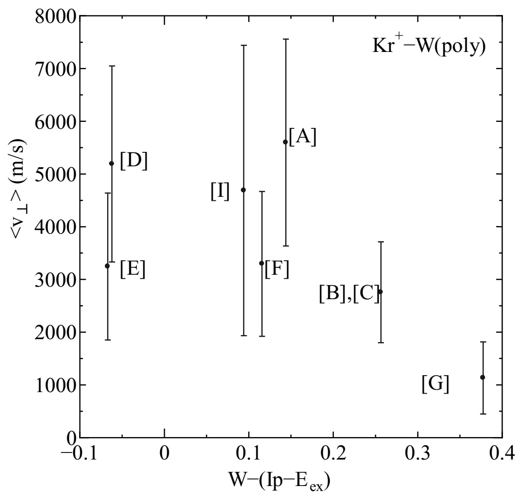

Fig. 2. The mean vertical velocity of various excited states of W as a function of the energy gap between the work-function E_f and I_p minus excitation energy E_{es}.

Figure 1 shows an typical optical emission spectrum obtained at z=0. Several strong lines from sputtered W atoms were observed in the wavelength of 380-440 nm. Every line appears on the successive state considered to be surface luminescence. Even if projectile energies were different, the intensity ratio of each peak in a spectrum did not change in essence for both Kr^+ and Ar^+ irradiation. Although all WI lines belong to 6p→6s/5d transitions, they are classified into four types of transitions that consist of a combination of two upper and two lower states: $5d^56p \rightarrow 5d^56s$ (A, D, H, I), $5d^56p \rightarrow 5d^46s^2$ (K), $5d^46s6p \rightarrow 5d^56s$ (B, E, F), and $5d^46s6p \rightarrow 5d^46s^2$ (C, G, J).

The estimated mean vertical velocities are 5.6 ± 1.7 km/s on average for the "A" line[1)], 2.8 ± 1.0 for "B" and "C" lines, and 1.2± 0.7 for "G" line. In any case, we confirmed that the obtained mean vertical velocities had no projectile energy dependence[2)]. However each average value was different as expected. Therefore, we tried to draw the mean vertical velocity graphs as a function of the energy gap between the work-function E_f and I_p minus excitation energy, as shown in Fig.2. In spite of a small excitation energy difference, it seems that the mean vertical velocity depends on the energy gap between the work-function E_f and I_p minus excitation energy E_{ex}. For example, compared with others, the case of "G" has lower velocity, and its energy gap is large. Therefore, we can build hypothesis. Only the atom which escaped the non-radiative transition near the surface is observed. So, observed excited W atoms are the survivors. When the energy gap is small, the interaction occurs with the surface, and slow excited atoms may be eliminated.

1) K. Motohashi et.al.: Nucl. Instrum. Meth.B, **283**,(2012) 59.
2) Y.Sakai et al.: Book of Abstracts, The 4th China-Japan Joint Seminar on Atomic and Molecular Processes in Plasma (AMPP2012), (2012) 1.