§17. Improved Beam Transport System and Atomic Processes Relevant to a Heavy Ion Beam Probe for LHD

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The HIBP system requires the stable beam output and operation during plasma experiments. Therefore the extraction electrodes and Einzel lens system of the ion source have been improved to avoid their insulation break down, which is caused by cesium adhesion. The other improvements inside the ion source include reduction of the cesium metal and the gold target consumptions. Throughout LHD experiments, the consumptions of cesium and gold target are characterized for practical operations and plasma experiments.

In the basic design phase of LHD-HIBP system, the ratios of primary beam current to secondary beam current are predicted by taking into account only the electron-impact ionization processes [1]. The recent LHD experimental results, however, suggest that a diagnostics appropriate for high temperature (~10 keV) and high density (~10^{20} m^{-3}) plasmas is required in order to study the plasma confinement and transport in LHD. Under such plasma conditions, it is expected that the role of charge exchange and ionization (i.e. electron loss) processes of Au^+ and Au^{2+} ions with the plasma protons could also be important in the calculations of beam attenuation in the plasma.

In absence of experimental cross section or calculations with more sophisticated theoretical methods for the electron-impact ionization processes

$$Au^{q+} + e \rightarrow Au^{(q+1)+} + 2e, \quad q=1, 2 \qquad (1)$$

A reasonable (and widely adopted) approach to estimate the cross sections of these processes is to use the Lotz formula [2]. The ionization cross sections for Au^+ and Au^{2+} are calculated by the Lotz formula. We note that the outer 5*d* subshell almost exclusively determines the cross sections in the entire energy region investigated.

The simplest of these processes are the charge exchange and ionization of the beam ion on plasma protons, i.e.,

$$Au^{q+} + H^+ \rightarrow Au^{(q+1)+} + H, \qquad q = 1, 2 \qquad (3)$$

$$\rightarrow Au^{(q+1)+} + H^+ + e \qquad (4)$$

The combined effect of these two processes is called electron loss. These processes have not been included in the beam attenuation analysis of HIBP diagnostics so far.

We have performed cross section calculations for the electron loss cross section of Au^+ on protons in a broad energy range by using the CAPTURE [3] and LOSS [4] computer codes, with inclusion the contributions from 5d, 5*p*, 5*s*, 4*f* and 4*d* subshells, as shown in Fig. 1.

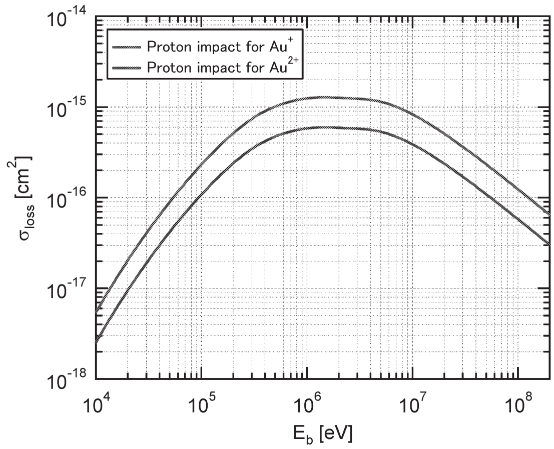

Fig. 1 Electron loss cross sections for Au^+ and Au^{2+} by proton impact.

The beam attenuation has been carried out the calculations for the simplified model of LHD plasmas. The secondary ion beam current I_{B2} at the exit point $l = l_2$ from the plasma boundary is given by

$$I_{B2} = \frac{2\kappa_{mcp} I_{B1} \delta l}{v_B}\left(n_e\left\langle\sigma_{ei}^{1,2} v_e\right\rangle + n_{H^+}\left\langle\sigma_{loss}^{1,2} v_B\right\rangle\right) \times \exp\left(-n_e\frac{\left\langle\sigma_{ei}^{2,3} v_e\right\rangle}{v_B} l_2 - n_{H^+}\frac{\left\langle\sigma_{loss}^{2,3} v_B\right\rangle}{v_B} l_2\right), \qquad (5)$$

where the detection efficiency of the micro-channel plate κ_{mcp}= 0.3 is extrapolated from that in the lower energy region of the datasheet and $\delta\ l$ is the effective observation length. The ratio $(I_{B2} / I_{B0})_{\rm cal}$ is calculated using the effective observation length $\delta\ l$ = 0.6 mm, and $l_1 = l_2 = 1$ m. We have found that the ion-ion collision processes reduce the ratio $(I_{B2} / I_{B0})_{\rm cal}$, and calculated signals become closer to experimental ones. Still the disagreement between calculated and measured signals remains large. For the plasma with $n_e = 1\times10^{19}$ m^{-3} and T_e = 1.5 keV, and beam energies of 1.62 MeV and 5.33 MeV, for the ratio $\chi \equiv (I_{B2} / I_{B0})_{\rm exp} / (I_{B2} / I_{B0})_{\rm cal}$ we obtain the values 8.7×10^{-3} and 5.4×10^{-3}, respectively.

As the next step, more detailed atomic and molecular processes and plasma density profiles would be treated for the above estimation of primary and secondary beam attenuations.

References

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