§10. Study of Heavy-metal-ion-beam Production with Tandem Accelerator for LHD-HIBP System

Taniike, A., Shinobu, T., Mochizuki, S. (Kobe Univ. Mar. Sci.), Ido, T., Nishiura, M., Shimizu, A.

The heavy ion beam probe (HIBP) is one of a method of plasma diagnostics, which can measure the potential profiles in plasma. An HIBP system has been installed at the Large Helical Device (LHD-HIBP) [1]. In recent HIBP diagnostics, the current of the heavy ion beam is sufficient for the electron density of 10^{19} m^{-3}. Since the attenuation of the probe beam is severe in higher density plasma, larger Au^{+} current is necessary. Some studies investigating how to increase the current have been done [2, 3]. These objectives are to increase the negative ion beam current and to improve the charge exchange efficiency in the gas cell of the tandem accelerator, the beam transport efficiency, and the detection efficiency of ejected ions and so on. Especially, the experimental study to optimize the gas cell for high charge exchange efficiency is not easy using LHD-HIBP because it takes much time to change gas species in the gas cell. We have studied on the subject using a tandem accelerator at Kobe University[3]. The accelerator has a gas cell, and the terminal voltage is up to 1.7 MV. In this fiscal year, the charge fractions of Au beam generated by the tandem accelerator were measured, and some ionization cross sections for Au ions or neutral atom were obtained.

To obtain the charge fraction, measurements of the ion current are necessary. The current can be measured with a Faraday cup (FC). Since the initial state of the ion is negative in the present work, measurement of neutral atom is also necessary. We consider the use of MCP because the *initial* secondary-electrons can be produced by ions or neutral particles at the entrance section of the MCP. Two stages micro channel plate (Hamamatsu photonics Inc.) was used and set on *x-y* movable stage. Entrance of MCP was biased at 1800 V, and exit was biased at 300 V. The collector has ground potential. The current detected by MCP have been calibrated with several tens percent error.

A charge fraction was measured with the MCP system at 0 beam line. Accelerated Au^{-} is ionized in the gas cell, and becomes Au^{0}, Au^{+}, Au^{2+}, and so on through a direct or sequential process. As MCP is installed at a straight position, all species ions/atoms are entered. Neutral atom can be easily measured by deflecting away other charged particles with a SW Magnet. Ions can be also selected with SW Magnet. Since other *unfocused* charge state ions or neutrals are also detected, the detected current needs some corrections. The ion beam is focused on the MCP entrance and the current is measured. As the MCP is movable in the *x-y* direction of ±5 mm, the beam profile is obtained. We assume the profile is a Gaussian distribution, the total current is estimated with the peak current. The measured current profiles indicate that some ion species overlap. The ion current is corrected as removing this overlapping current.

Fig. 1 shows the dependence of Au charge fractions on Ar target thickness. The impact energy of Au^{-} is 500 keV. Neutral Au^{0}, Au^{+} and Au^{2+} are measured with MCP. The output was corrected by a calibration factor. The Au^{-} current was measured by FC. The origin of horizontal axis needs a small correction, because an influence of residual gas.

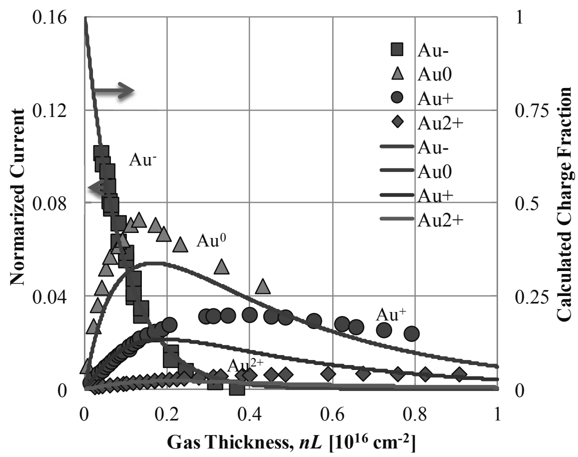

Fig. 1 Comparison of the charge fraction calculation and the experimental data.

Some ionization cross sections are estimated from the experimental results. When a very small amount of gas is introduced into the gas cell, Au^{0}, Au^{+}, Au^{2+} other highly charged ions do not exist. Three ionization cross sections, $\sigma_{-1,0}$, $\sigma_{-1,1}$ and $\sigma_{-1,2}$ are estimated using the gradient at $nL = 0$. The values are listed in table 1, and compared with calculated cross sections. The calculation is based on Firsov's model. The model explains the energy transfer between two atoms. The values for heavy ions have an uncertainty by a factor of two, and the cross sections are calculated at large values. Therefore the calculated values become larger than our experimental results. The rate equations are solved with the cross sections obtained from our experiment, and the solutions are plotted in Fig. 1. Some cross sections are obtained from the curve fitting. Because the gain calibration for MCP has not high precision, precise gain calibration is essential to obtain the cross sections in our experimental system.

Table 1. Ionization cross section for negative ion. The unit is in 10^{-16} cm^{2}.

	$\sigma_{-1,0}$	$\sigma_{-1,1}$	$\sigma_{-1,2}$	$\sigma_{-1,3}$
Exp.	7.0	1.3	0.15	
Calc.	23	9.9	5.4	3.3

[1] T. Ido *et al.*, Rev. Sci. Instrum. 77 (2006) 10F523.

[2] M. Nishiura *et al.*, Rev. Sci. Instrum. **79** (2008) 02C713. 675-678.

[3] A. Taniike *et al.*, Plasma Fusion Res. 5, S2087 (2010).