OPTIMUM THICKNESS OF CARBON STRIPPER IN TANDEM ACCELERATOR IN VIEW OF TRANSMISSION

K.Shima, Tandem Accelerator Center, University of Tsukuba, Ibaraki 305-8577, Japan

Abstract

Optimum thickness of charge stripper foils installed at the terminal of 12UD Pelletron tandem accelerator has been investigated from the view of (1) charge stripping effect, (2) transmission of ions through accelerator, (3) lifetime of foils for the irradiation of heavy ions. For this purpose, measurements have been done for (a) transmission of H, Li, O, Br and Au ions, passing through a tandem accelerator for carbon stripper of 1.8-19.5 μg/cm^2 thickness, at terminal voltages of 5MV and 10MV, and (b) lifetime of 2-15 μg/cm^2 thick Tanashi foils developed by Sugai by irradiating Au ions at the terminal voltage of 10MV. Obtained results are as follows: (a) From the view of above items of (1) and (2), the optimum thickness of foils is 10 μg/cm^2 for ions of Z=1, several μg/cm^2 for Z=8, and less than a few μg/cm^2 for heavier ions. (b) From the view of item (3), the lifetime of Tanashi foils of a few μg/cm^2 is about 2.4 times longer than that of commercial foils.

1 INTRODUCTION

The requirements for the charge stripping carbon foils placed at the terminal of tandem accelerator are (1) high transmission of beam through acceleration tube, (2) high charge stripping effect, (3) long lifetime for the irradiation of beam, and (4) easy to make and install. These requirements are all closely related to the foil thickness.

Considering above features, the transmission of H, Li, O, Br, Au ions passing though 12UD-pelletron tandem accelerator, the charge stripping effect and the lifetime of foils have been investigated by changing the carbon stripper thickness. The object of this work is to find optimum thickness of carbon strippers as well as their way of making. It is shown that the optimum thickness is not unique but strongly depends on ion species and ion energies.

2 CHARGE EXCHANGE PROCESS

The fraction of ions, F_q, with charge state q, at the penetration depth x in matter is given by the following rate equation,

$$dF_q(x) / dx = \Sigma_k (F_k\sigma_{kq} - F_q\sigma_{qk}) , \qquad (1)$$

where $_{kq}$ stands for the charge exchange cross section of ions from charge state k to q. If we apply Eq.(1) to the incidence of H$^-$ ions colliding with a carbon stripper placed

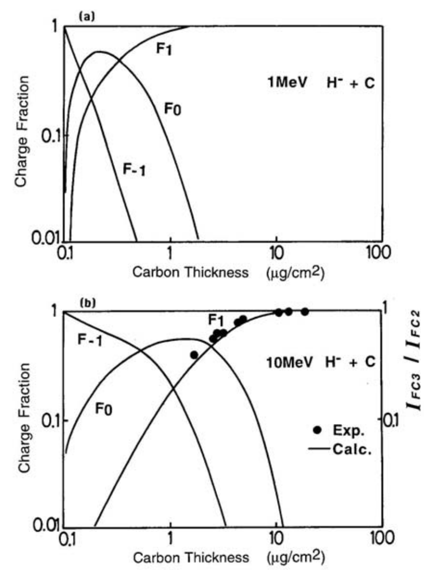

Figure1: Calculated charge fractions of hydrogen $F_{-1}(x)$ for H$^-$, $F_0(x)$ for H and $F_1(x)$ for H$^+$. (a) 1 MeV H$^-$ + C, (b) 10 MeV H$^-$ + C. The dots in (b) mean the observed beam current ratio between I_{FC3} of H$^+$ ions at FC3 to I_{FC2} of H$^-$ ions at FC2. An explanation for the experimental data is given in section 3.

at the terminal of tandem accelerator having the terminal voltage greater than 1 and 10 MV, then calculated values of F_q of hydrogen for the cases of 1 MeV H$^-$+C and 10 MeV H$^-$+C are drawn in Fig.1, where the theoretical electron loss cross sections by Gillespie [3] are adopted. Fig.1 indicates that the thickness of carbon foil for the attainment of charge equilibration is about 1.5 and 10 μg/cm^2 for the incidence of 1 MeV and 10 MeV H$^-$ ions, respectively. The explanation for the experimental data points plotted in the figure is given in the following section.

3 MEASUREMENT

3.1 Transmission vs. foil thickness

The transmission of ions in tandem accelerator versus stripping foil thickness has been measured by installing commercial foils (Arizona Carbon) at the terminal of 12UD Pelletron tandem accelerator. Here, the transmission, T_r, is defined to be the ratio of number of ions before and after the passage through the tank of accelerator, i.e.,

$$I_{FC3} = I_{FC2}\, F_1(x)\, Tr , \quad \textit{for hydrogen ions} \quad (2)$$

$$I_{FC3} = I_{FC2}\, q_b\, Tr , \quad \textit{for heavy ions} \quad (2)'$$

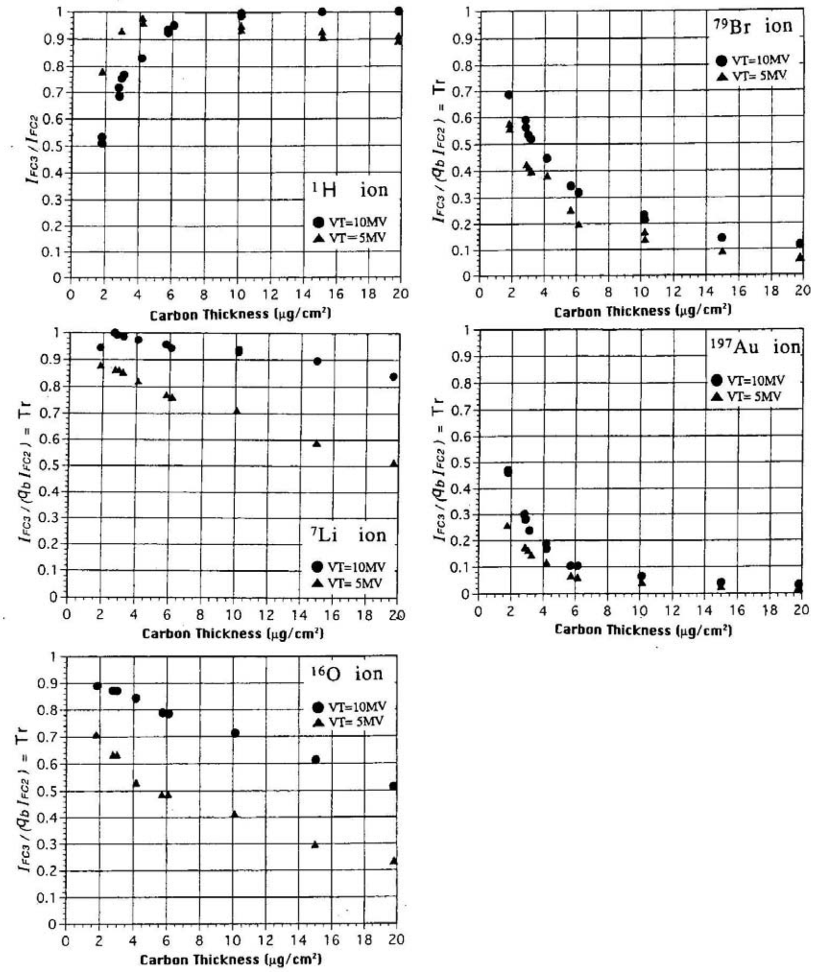

Figure 2: Observed transmission of H, Li, O, Br, and Au ions passing through 12UD tandem accelerator for terminal voltage of V_T= 5MV and 10 MV. The definition of transmission, Tr (ordinate), is given by Eq. (5) for hydrogen ions and by Eq (5)' for other ions.

where, I_{FC3} and I_{FC2} are the beam currents measured at the downstream (Faraday Cup 3, *FC3*) and upstream (Faraday Cup 2, *FC2*) of the tank, respectively, and q_b indicates the mean charge of ions after the passage through a carbon foil at an incident energy of eV_T where V_T is the terminal voltage. The value q_b is given by,

$$q_b=\Sigma_q\{qF_q\}. \quad (3)$$

Measurements of I_{FC3} and I_{FC2} have been done for ^{1}H, ^{7}Li, ^{16}O, ^{79}Br and ^{197}Au ions, at V_T = 5MV and V_T =10MV for stripper foil thickness ranging from1.8 to 19.5 μg/cm^2.

Firstly, observed results of $I_{FC3} / I_{FC2} = F_1(x)\ T_r$ in Eq.(2) of H ions in the case of V_T =10MV are shown in Fig.1 (dot mark) as a function of carbon foil thickness. These values correspond to the ratio of H^+ beam currents at FC3 to H^- beam currents at FC2. A good agreement between the calculated $F_1(x)$ values for H^+ ions (solid curve) and observed I_{FC3} / I_{FC2} values (dots) indicates that the transmission *Tr* is almost 100% in our accelerator at V_T=10MV, and that the variation of I_{FC3} / I_{FC2} versus *x* observed at less than 10 μg/cm^2 is due to the variation of charge fraction of H^+ component at a charge non-equilibrium region of carbon thickness. In the case of V_T=5MV, a good agreement was also obtained in the values of I_{FC3} / I_{FC2} between calculation and observed, and it was found that at least 4 μg/cm^2 thick carbon foil is necessary to attain charge equilibrium (see Fig.2).

Secondly, observed values of *Tr* in Eq.(2) for Li, O, Br and Au ions at V_T=5MV and 10MV are shown as a function of carbon foil thickness in Fig.2. The hydrogen data of I_{FC3} / I_{FC2} at V_T=5MV and 10MV, already shown in part in Fig.1, are again presented.

Fig.2 shows a characteristic feature that for such light and high velocity ions like H, the values, $I_{FC3} / I_{FC2}=F_1(x)\ T_r$, first increase with increasing foil thickness, *x* , and then show saturating or decreasing feature. On the other hand, for heavy ions such as O, Br or Au, observed *Tr* values simply decrease with increasing foil thickness, and this trend becomes more significant with heavier and slower ions.

The increasing behavior of $I_{FC3} / I_{FC2} = F_1(x)\ T_r$ values with x for light ions is due to the variation of $F_1(x)$ in charge non-equilibrium region as was already mentioned above. However, for 5 MeV or 10 MeV heavy ions in carbon foils, charge equilibration is already attained at a few μg/cm^2, which presents the behavior that the T_r values simply decrease with increasing x. This trend is caused by the increasing effect of energy straggling and multiple scattering processes. Observed results of T_r versus ion velocity and ion mass are consistent with the trend of these processes.

From the view of ion beam transportation under the high transmission condition, the optimal stripper foil thickness is not unique. It is important to prepare stripping foils with various kinds of thickness, and to select them in accordance with the accelerated ion species and velocities. In summary, optimal carbon foil thickness in various cases of ion species at V_T=5 and 10 MV, is tabulated in Table 1.

3.2 Lifetime versus foil thickness

Previously we reported that the lifetime of Tanashi foils developed by Sugai [1] by means of *new arc-discharge method* is longer than that of commercial foils by 30-40 times for 10-15 μg/cm^2 thick region [2]. This method is essentially to use both AC- and DC-arc-discharge in the preparation of carbon foils.

Since the use of much thinner foils than 10-15 μg/cm^2 thick is desirable in view of transmission, and since the lifetime of carbon foils would depend on the foil thickness, the lifetime of Tanashi foils has been measured at various thickness by the bombardment of 600 nA Au^- ions at V_T=10MV. The lifetime of commercial carbon foils (Arizona carbon) was also measured for comparison.

Results are shown in Fig.3 together with the previous results [2] obtained at the thicker foil region. The ordinate indicates the lifetime ratio between Tanashi foils (new ark-discharge) and Arizona Carbon foils. It is seen that the characteristics of Tanashi foils being extremely long lifetime at the thickness region above 10 μg/cm^2 gradually fades away with decreasing foil thickness. In fact, in the region of 1.7-2.2 μg/cm^2, the lifetimes of Tanashi foils are on an average 2.4 times longer than the commercial foils.

4. SUMMARY

The optimal carbon foil thickness used at the terminal of tandem accelerator has been investigated. The results are listed in Table 1 and Fig.3. An important fact is that an optimal foil thickness depends on the ion species and velocity. For the efficient acceleration of heavy ions such as Br or Au at V_T = 5 or 10 MV, carbon foils as thin as 2 μg/cm^2 or less than that are optimal. Their installation and evacuation at the terminal of a tandem accelerator is easily attained if a tentative supporting material is used on a carbon foil. The Tanashi foils made by means of new arc-discharge method, in the thin region of 2 μg/cm^2, demonstrated to have long lifetime compared with that of commercial foils, but their superiority observed at the thicker than 10 μg/cm^2 region is not so remarkable.

REFERENCES

[1] I.Sugai, T.Fujino, K.Yamazaki, T.Hattori and M.Ogawa, *Nucl. Instr. Meth.*, A236, 576 (1985).

[2] K.Shima, S.Ishii, T.Takahashi, I.Sugai, M.Oyaizu and T.Ishihara, *Nucl. Instr. Meth.*, B139, 451(1998).

[3] G.H.Gillespie, *Phys. Rev.* A16, 943 (1977), *Phys. Rev*. A18, 1967(1978).

Table 1: Optimum thickness of carbon strippers in view of transmission. V_T stands for the terminal voltage.

Ions	V_T = 5 MV	V_T = 10 MV
H	≈ 5 μg/cm^2	≈ 10 μg/cm^2
Li	≈ 3	≈ 4
O	‹ 2	≈ 2
Br	‹ 2	‹ 2
Au	‹ 2	‹ 2

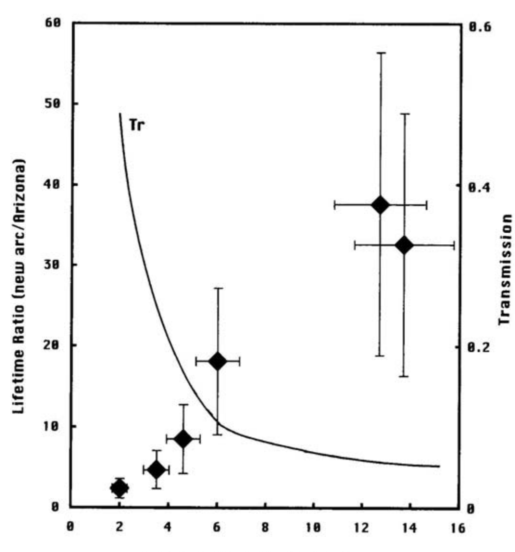

Figure 3: Observed ratio of stripper foil lifetime between Tanashi foils (new arc) and commercial carbon foils (Arizona) for the incidence of 10 MeV (V_T=10 MV) 600 nA Au^- ions. The mean lifetime of commercial carbon foils was 2.9 minutes.