DEVELOPMENT OF HYBRID TYPE CARBON STRIPPER FOILS WITH HIGH DURABILITY AT >1800K FOR RCS OF J-PARC

I. Sugai, Y.Takeda, M.Oyaizu, H.Kawakami, A.Takagi, High Energy Accelerator Research Organization, Oho 1-1, Tsukuba, Ibaraki 305-0801, Japan
Y.Irie, Japan Atomic Energy Agency, Tokai, Naka, Ibaraki 319-1195, Japan
H,Hattri, K.Kawasaki, Tokyo Institute of Technology, Ookayama, Meguro, Tokyo 152-8550, Japan

Abstract

The Japan-Proton Accelerator Research Complexes (J-PARC) requires thick carbon stripper foils (200-300 μg/cm^2) to strip electrons from the H$^-$ beam supplied by the linac before injection into the RCS of J-PARC. High-intensity H$^-$ beam and circulating bunched beam give much energy depositions to conventional carbon stripper foils. Thus carbon stripper foils with high durability at 1800K are urgent and indispensable for this accelerator.

Recently, we have developed Hybrid type Boron mixed Carbon stripper foils (HBC-foil). Namely, the lifetime measurement of the foils was tested by using a 3.2 MeV, Ne$^+$ DC beams of 2.5μA, in which a significant amount of energy was deposited in the foils. We have investigated double- layered effects on the lifetime of the HBC-foils.

The maximum lifetime was found to be extremely long , 30-and 250 –times longer than those of Diamond and commercially available best carbon foils (CM-foil). It was also found that the foils show free from shrinkage, and an extremely low thickness reduction rate even at a high temperature of 1800K. In this poster the foil preparation procedure and lifetime measurements with a 3.2 MeV Ne$^+$ beam is reported.

INTRODUCTION

Fig.1 shows the layout of the RCS with the injection and extraction beam transport line. A 180 MeV (first stage) H$^-$ beam from the J-PARC linac is stripped directly to H$^+$ by a 200±20 μg/cm^2 thick carbon foil Before injection into the RCS. The unstripped H$^-$ and H^0 beams are post-stripped by a couple of carbon foils placed at downstream. The unstripped beams are then converted to protons and are transported to the beam dump. The lifetime of the carbon stripper foils strongly depends on the beam current intensity and density. Due to the energy loss of the H$^-$ beam in the carbon foil at the injection stage and due to collisions with the circulating bunched beam, which is much more intense than the H$^-$ injection beam, the temperature of the stripper foils become very high.

For comparison, we calculated the energy deposition of foil thickness for energy depositions as function of foil thickness for a low energy Ne$^+$ DC beam of 3.2 MeV and high-energy proton beams of 200 MeV and 400 MeV.

The results are shown in Fig.2. The energy deposition

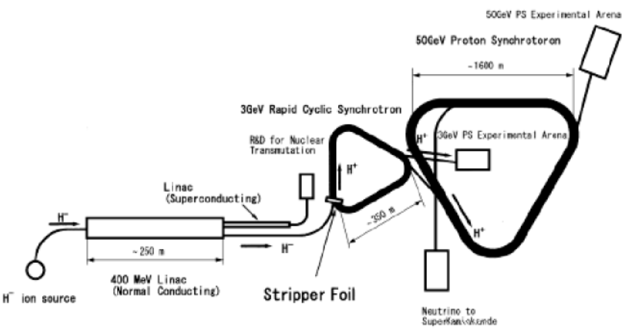

Figure.1 Schematic layout of the accelerator complex of J-PARC

of the H$^-$ injection beam is only about 0.5 W/ cm^2. Hence, most of energy deposition is originating from the circulating bunched beams.

As can be deduced from Fig.2, the thermal power of the 3.2 MeV Ne$^+$ DC beam is nearly same as those by 200 and 400 MeV proton beams. Therefore, it can be justified to use a 3.2 MeV Ne$^+$ DC beam in the lifetime measurements of the stripper foils.

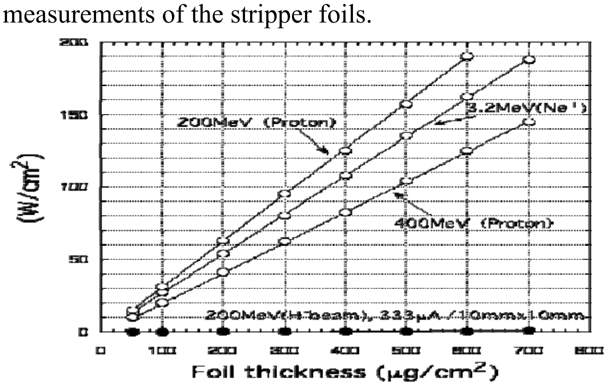

Figure.2 Energy deposition as a function of foil thickness for 200 MeV, 400MeV and Ne$^+$ DC beam.

During irradiation of carbon stripper foils with pulsed 200 MeV and 400 MeV H$^-$ ions of high current density, the peak temperature of the foils with 250-500 μg/cm^2 thick may rise above 1800K and the limiting effect on the lifetime might be shrinkage, thinning and occurring of pinholes due to evaporation and sputtering until burning of a hole. In order to solve these problems, there are mainly two ways. The one is to use a diamond foils and the other is to apply the new laser stripping techniques. The diamond foil is a very attractive method for ion stripping due to its drastically high thermal conductivity.

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Here, it should be noted the diamond foil has about five times higher conductivity than the copper material.

In our investigations, however, the diamond foil ruptured by changing into graphite structure above 1800±100K. The laser stripping technique is also an very attractive method. It is, however, in a development stage and far from practical use.

Hence, the development of long-lived type of carbon stripper foil with high durability at 1800K is one of the key technologies for the 3 GeV proton beam at the RCS of J-PARC.

EXPERIMENTAL RESULTS

The cluster carbon stripper foils have a long lifetime, which are prepared by developing of the controlled AC/DC arc-discharge (CADAD) method [1-2]. Although the foils had a very long lifetime, we found that the foil thickness reduced to about 25% of the original thickness and pinholes were observed also at the irradiated area. In addition, the maximum obtainable foil thickness turned out to be 130±20 μg/cm^2 due to lack of adhesion to the substrate. So, in order overcome these issues, we succeeded in developing a boron mixed type of carbon stripper foil of 250 to 500 μg/cm^2 accessible thickness.

Comparative lifetime measurement and properties of the HBC-foils as well as of the diamond foils and of the best CM-foils were performed with a 3.2 MeV Ne^+ DC ion beam. The carbon arc evaporation source was installed as show in Fig.3.The distance between the evaporation source and the substrate was 230 mm. As mentioned in ref.[1-3],

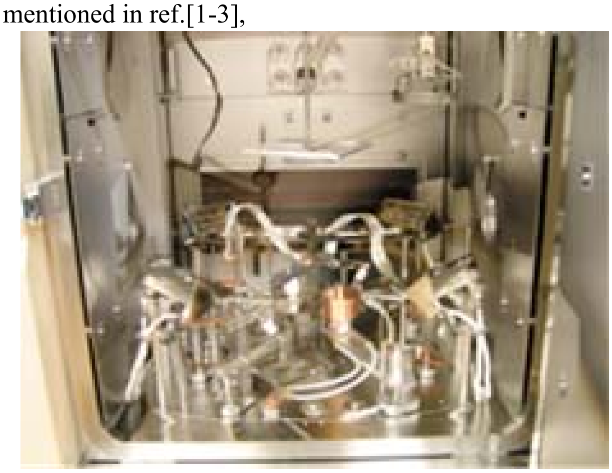

Figure.3 Arc-discharhe evaporation-source in EBX-2000C cryo-vacuum pump apparatus.

the approximately lifetime of the foil was found to be correlated to the expression R= Wc/ (Wc + Wa) calculated in %, where Wc and Wa are the carbon source weight losses due to ablation from the cathode and the anode electrodes. We used the foils made at R = 60 to 70 %. Fig.4 (a) shows the HBC-layer, which shows strong adherence to the substrate even exposure in atmosphere. On the other hand, (b) cluster layer was made by the

(a)

(b)

Figure.4 Photographs of carbon layers on slide glasses. Represent an HBC-foil of 370 μg/cm^2 and is for a Cluster–foil of 140 μg/cm^2 made by the CADAD method.

CADAD method and the layer showed always floating from substrate after taking out in the atmosphere from the evaporation source.

Self-supporting foils were obtained by applying an annealing technique (600K for 7h). However we can see pinholes in some part of foils. This is very serious problem to be solved.

The lifetime measurements were performed with a 3.2 MeV Ne^+ DC beam of 2.5±0.5 μA and 4.0 mm beam spot. In this case, the lifetime was determined as a total integrated irradiation dose (mC/cm^2) until foil rupturing occurred. We investigated double layered effect on not only the lifetime but also pinhole formation and thickness reduction. We used two HBC-foil of 400±50 μg/cm^2. Two diamond foils (DM-foil) of 360 and 540 μg/cm^2 etched within 18 mm in hole diameter except for Si frame, which are obtained from Kobe-steel company and two CM–foils of 414 μg/cm^2, for a comparison.

In this lifetime measurement, we used ribbon type foils of 20 mm x 30 mm and the foils were supported 10 mm SiC fibers except the DM-foils. We observed the state of shrinkage, brittle and rupture from a viewing port. Table 1 shows the results of the lifetime measurements.

Table 1: Maximum and average lifetime of HBC-foil, DM-foil and CM-foil measured with a 3.2 MeV Ne^+ ion beam of sabout 3 μA.

Type of foils	HBC-foil	DM-foil	CM-foil
Max. lifetime (mC/cm^2)	11150	310	26
Average (mC/cm^2)	8200	180	23

From Table 1, the double layered HBC-foil did not show any noticeable shrinkage and pinholes even after a long time irradiation of approximately 1100 mC/cm at the temperature of1600±200K.

(a)

(b)

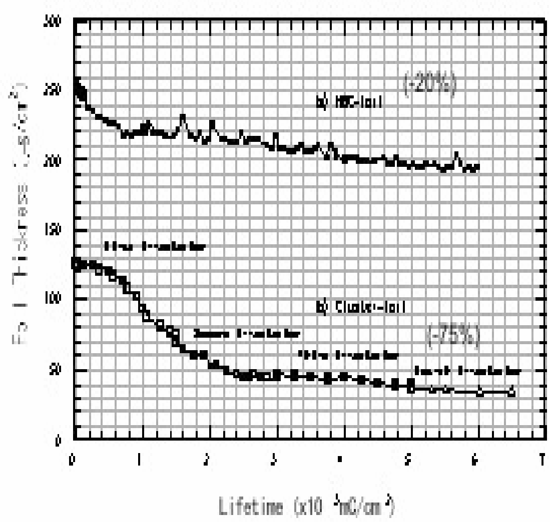

Figure.5 Thickness changes of the single layered HBC-foil of 240 μg/cm^2 and Cluster-foil of 130 mg/cm^2 during irradiation

Fig.5 shows thickness changes of the single layered HBC-foil of 240 μg/cm^2 and Cluster-foil of 130 μg/cm^2 during irradiation although both foils are single-layered.

Fig.6 shows photographs of a double layered HBC-foil (a), a DM-foil and a CM-foil at different stages of irradiation. The thickness reduction of the foil was reduced to within only 20% of the original thickness, as measured with an α-thickness gauge [4]. The tested DM-foils in Fig.6(b) showed a little dark color after a few minutes of irradiation, and it become a deeply dark color with more than irradiation time, and then it was broken approximately 205mC/cm^2 The CM-foil showed a strong shrinkage after only 20 mC/cm^2.

(a)

(b)

(c)

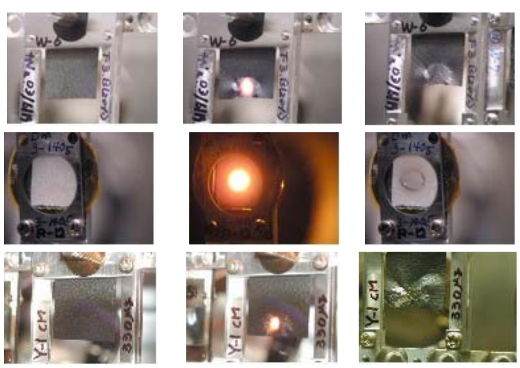

Figure.6 Photographs of (a)a double-layered HBC-foil, (b)a DM-foil and (c) a CM-foil at different stages of irradiation.

SUMMARY

We prepared the HBC-foil and investigated the effects of double layered HBC-foil on the lifetime, pinhole and thickness reduction compared with the single layered HBC-foil, the DM-foil and the CM-foil. The double layered HBC-foils showed extremely long lifetime of 11150 mC/cm^{2}in maximum, which corresponds to 36 and 484 times of the single DM–foil and the double one CM-foil. The pinholes were not observed even at after long time irradiation at 1600±200K and the thickness reduction of the double one was within 20 % of original thickness.

From these results, the double-layered HBC-foils are very practically useful and promising for use in J-PARC.

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