LIFETIME COMPARISION OF DOUBLE AND SINGLE LAYERED HBC-FOILS USING 3.2 MEV NE$^+$ ION

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Abstract

The Japan-Proton Accelerator Research Complexes (J-PARC) requires thick carbon stripper foils of 300-500 μg/cm^2 thick to strip electrons from the H-beam supplied by the linac before injection into the RCS (Rapid Cycling Synchrotron). The energy deposition upon foil by the intense circulating proton bunched beam as well as H$^-$ beam result in the foil temperature of ~1800K.Thus, conventional carbon stripper foils (CM-foil) are ruptured in a very short time and even a high quality diamond (DM) foil is also broken at around 1800 K. Therefore, thick carbon stripper foils with high durability even at 1800K are indispensable for such accelerator. For this purpose, we have developed HBC (**H**ybrid type **B**oron mixed **C**arbon)-foil by the controlled DC arc-discharge method. We have measured the lifetime of a double and single layered HBC-foils, high quality diamond foils and commercially available best carbon (CM) foils for comparisons using 3.2 MeV Ne$^+$ ion beam in which a significant amount of energy loss was deposited in the foils due to low energy heavy ion. The double layered-foil (180 μg/cm^2 x 2) was found to be long 23 and 484 times longer than those of DM-foils (360μg/cm^2 x 1) and double-layered CM-foil (207μg/cm^2 x 2), respectively.

INTRODUCTION

Due to the energy loss of H$^-$ beam in the carbon foil and the collisions with circulating bunched beam, the temperature of the stripper foils becomes 2000 K at peak temperature. Hence, conventional CM-foils ruptured in very short time due to the thickening and shrinkage, caused by high power energy deposition of the ion beam.

To overcome this problem, we have developed HBC-foils [1], which is based on using boron mixed graphite rod. We found that the foils has strong adhesion to the substrate and thus the foils could be made with thickness up to maximum 680μg/cm^2, and also lifetime showed rather long. The high temperature damages of the shrinkage, the thickness reduction and the pin-hole productions were also mitigated significantly even at the high temperature of approximately 1700 K. However, when the foil temperature was higher than 1700K, the damages of foil were always observed at the irradiated area and its around of the foils. In order to investigate the possibilities to lower the temperature rise, a single-and double-layered foils were prepared while keeping the total thickness the same. By using 3.2 MeV Ne$^+$ beams, we have investigated the temperature difference and the damage of the double and single layered HBC foils. Also, high quality Diamond and commercial carbon foils were tested for comparison.

EXPERIMENT

Foil Preparation

The preparation method of the HBC-foils was almost the same with the previous one in ref. [1]. We have used the Controlled DC Arc-Discharge (CDAD) method [3] .

The cathode used a boron-doped(20%) carbon rod of 10 mm diameter while the opposite electrode was a pure graphite rod of 15 mm diameter. The carbon discharge arc-evaporation source was installed in a new vacuum chamber (EBX-2000C).

The distance between the evaporation source and the substrate was 220 mm. The deposition thickness onto the substrates was monitored with a quartz thickness gauge and the weight was measured after deposition. The self-supporting foils were obtained by applying an annealing technique. Namely, the deposited layer with substrate was heated at 300℃ for 6h using Ta filament heater in vacuum chamber. Then, foils were peeled off from the substrate, keeping a flat shape. The pinholes were observed in some parts of the annealed foils. This pinhole formation is not yet clear and it is very serious problem to be solved in near future. For the beam test, we used the foils having no pinholes which could be identified by watching the foils through a light.

Lifetime Measurement

The experimental set up for measuring the lifetime was shown in Figure.1.

The profile of beam spot with 5 mm in diameter was checked and the uniformity was adjusted by watching the beam spot on a quartz disk of 1 mm thick and 20 mm in diameter. The vacuum was 8 x 10^{-5}Pa without beam irradiation and 2 x 10^{-4}Pa during beam irradiation. The lifetime in this paper is defined as the integrated ion current per unit area (mC/cm^2) on the foils until the foil is ruptured. We also monitored the foil thickness by detecting elastically scattered Ne$^+$ particles with a silicon solid-state-detector during irradiation. We observed the

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surface condition of the foils and ruptured state by means of a VIDEO camera through a viewing port.

The lifetime measurements were performed with a 3.2 MeV Ne^+ beam of 2.5±0.5 μA and 4.0 mm beam spot diameter, supplied from the Van de Graff accelerator at Tokyo Institute of Technology. The energy deposition of 3.2 MeV Ne^+ ion beam is nearly close to that of the RCS of J-PARC, as shown in Figure.2 of Ref. [1]. We investigated the following foils; double layered foils (180 μg/cm^2 x 2) and single layered foils (373 μg/cm^2) of the HBC-foil, one thin and one thick DM-foils of approximately 360μg/cm^2 and 540μg/cm^2 each, one double-layered (nominal thickness of 207 μg/cm^2 x 2) and one single layered (nominal thickness of 402 μg/cm^2) foils of CM-foil. The diamond films were obtained from Kobe-Steel Company in Japan for a comparison since DM foil has much higher thermal conductivity. We tested the diamond foils without removing Si frame.

In this lifetime measurement, we used the ribbon type (or rectangular) foils of about 20 mm x 30 mm sandwiched at one edge with two Al holder (38 mm x 58 mm). The other part of the foil is also sandwiched by SiC fibers of 10 mm diameter in steps of 3 mm distance. The DM-foils prepared by chemically etching the Si substrate except the Si frame was also sandwiched by two target holders, where the SiC fibers were not used for fixing.

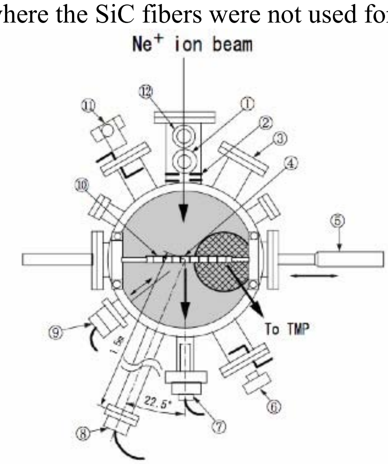

Figure1: Experimental apparatus for lifetime measurement of various carbon stripper foils at Tokyo Institute of Technology. (1) Quadrupole-mass-spectrometer, (2) Aperture 5 mm ∅, (3) View port, (4) Carbon test foil., (5) Transfer rod, (6) TV camera (7) Faraday-cup, (8) Solid state detector, (9) Thermo couple, (10) Target ladder, (11) Radiation thermometer, (12) Vacuum ion gauge.

RESULTS AND PROPERTIES

Table-1 shows the results of the lifetime measurements. The temperature of the foils tested was measured on the hot beam spot of the foils with two infrared ray radiation thermometers during the lifetime measurements. The thermometers were IR-306 of the KONICA-MINOLTA Company and PM 174 of the YOKOKAWA Company of Japan. The values obtained by both thermometers were consistent with each other. In this measurement, the emissivity of carbon was used 0.3-0.4, based on a calibrated thermocouple obtained from our measured data [1].

Figure. 2 (a), (b), (c) and (d) show pictures of the double and single layered HBC-foils, the DM-foil and the double layered CM-foil before beam irradiation, under irradiation and the survived or ruptured. Figure 2 (a) and (b) show the surface behaviours of double (a) and single (b) layered HBC-foils before irradiation, after irradiation and survived.

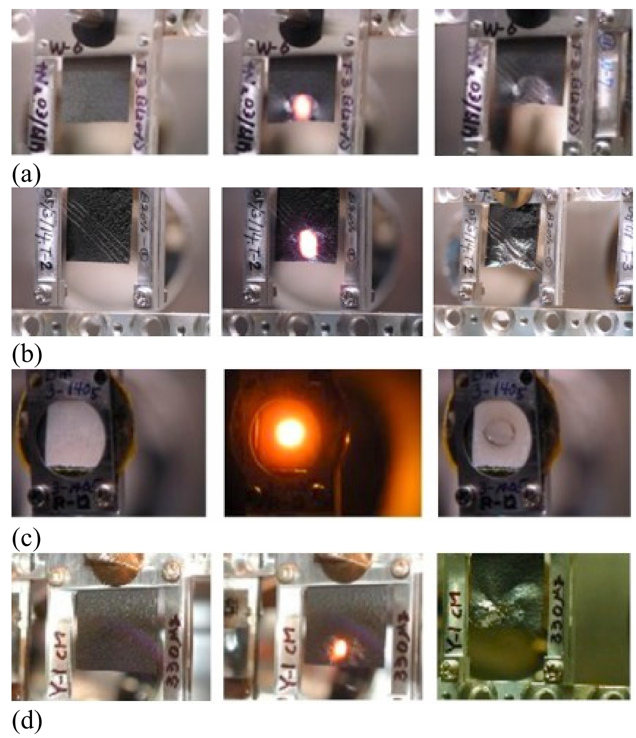

Figure 2: Photographs of foils at different stages of ion irradiation: (a) double layered of HBC-foil (180 μg/cm^2× 2). (b) single layered of HBC-foil of 373 μg/cm^2. (c) DM-foil of 360 μg/cm^2 (d) double layered of CM-foil (207 μg/cm^2.× 2).

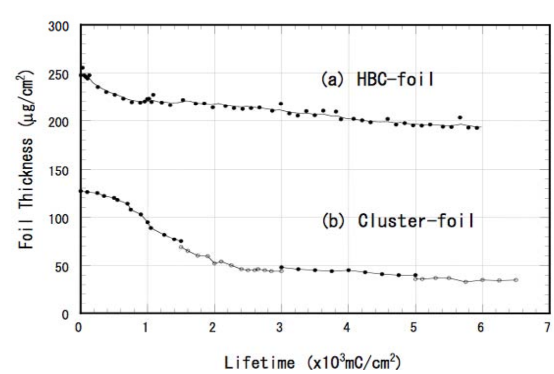

Figure 3: Thickness changes of the single layered HBC-foil of 240 μg/cm^2 and Cluster-foil of 130 μg/cm^2 during ion irradiation, for a comparison.

Table 1: Lifetime results of various foils

Type of foil	double and single HBC-foils (180 μg/cm^2 × 2 and 373 μg/cm^2),		thin and thick DM-foils (360 μg/cm^2 and 540 μg/cm^2)		double and single CM-foils (207 μg/cm^2 × 2 and 402 μg/cm^2)	
Max. lifetime (mC/cm^2)	11150	8000	484	175	23	26

From the figure (a), the double layered HBC-foil (180 mg/cm^2 x 2) did not show noticeable shrinkage even after a long time irradiation of approximately 11150 mC/cm^2 at temperature of 1500±200K. This foil was irradiated in six separated sessions because a long beam-time was not available. The foil thickness of the irradiated area was measured with a-ray thickness gauge [4]. Then the foil thickness showed reduction only 10 % of the original thickness. Also, we could not identify pinholes if seen through a light.

The lifetime of the double layered HBC-foil (180 μg/cm^2×2) showed extremely 11150mC/cm^2,which corresponded to 484 times compared to that of the double-layered CM-foil. On the other hand, as shown in figure (b), the single HBC-foil (373 μg/cm^2) showed small shrinkage and the thickness reduction at the irradiated area was about -27 % of the original thickness. We could look clearly many pinholes of the foil through a light. However, the foil was not yet ruptured.

The high quality of the thin DM-foil of 360 μg/cm^2 showed considerably long lifetime of 484mC/cm^2 as shown in Figure.2 (c), which is corresponding to about 20 times of the CM-foils, but thick one showed only 175 mC/cm^2. The DM-foils did not show any shrinkage pattern during irradiation. The temperatures of the thin and thick DM-foils were approximately 1700±100K and 1800 ±100K,respectively.

The CM-foils, however, showed a strong shrinkage within a short irradiation of 25 mC/cm^2, as shown in Figure. 2 (d) and the lifetime was only 25±5 mC/cm^2 at the rupture.

The thickness change of the single layered HBC-foil with 240 μg/cm^2 during irradiation was plotted in Fig.3 (a). In the figure, the thickness change of the cluster foil of 130 μg/cm^2, which is shown in Fig. 2 of Ref. [2] was added for a comparison. The lifetime measurement of the single layered HBC-foil was stopped at the 6000 mC/cm^2, due to the limited beam time. The cluster foil in shown in Figure 3 was also irradiated in four sessions and the foil lifetime showed significantly long lifetime of 6500 mC/cm^2. However, the reduction of the foil thickness was -93μg/cm^2 or -73 % of the initial thickness in the irradiated area at the approximately 1300±200K for long tome irradiation. We observed many pinholes at the irradiated area. On the other hand, the thickness reduction of the HBC-foil showed considerably low -19 % of the initial thickness, which is corresponding to nearly 1/4 of the cluster foil. However we observed small pinholes from the irradiated HBC-foil (a).

SUMMARY AND CONCLUSION

1. The double layered HBC-foils (180 μg/cm^2×2) showed extremely long lifetime of 11150 mC/cm^2 , which correspond to 23 and 484 times of the single DM-foil (360 μg/cm^2) and the double layered CM-foil(207 μg/cm^2 ×2).
2. The temperature of the double layered HBC-foils (180mg/cm^2×2) showed lower approximately by 200K than that of the single layered HBC-foil (373μg/cm^2) of the nearly same foil thickness.
3. The pinholes of the double layered HBC-foils were not observed seen though a light even after long time irradiation at high temperature of 1500 ± 200K. However, the fine pinholes were observed for the single layered HBC-foils at the irradiated area in the same irradiation condition as that of the double-layered foil. The thickness reductions of the double and the single layered one were approximately -10 % for the double and -33 % for the single ones of their original thicknesses. Hence, the thickness reduction of the double layered HBC-foil is corresponding to approximately 1/3 of the single one.
4. Noticeably big shrinkage formation of the double-layered foils was not observed as well as the single layered HBC-foils.

From these results, the double layered HBC-foil is very useful and promising for use in J-PARC and MW class accelerators with high creditability

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