DEVELOPMENT OF THE THIN ROTATED CARBON-DISK FOR URANIUM ACCELERATION

H. Hasebe†, H. Okuno, H. Imao, N. Fukunishi, M. Kase, O. Kamigaito
Nishina Center for Accelerator-Based Science, RIKEN, Wako, Japan
A. Tatami, M. Tachibana, M. Murakami
Material Solutions New Research Engine, Kaneka Corporation, Settsu, Japan

Abstract

Highly oriented graphite sheets provided by Kaneka Corporation have been applied as charge stripper disks for heavy-ion acceleration at RIKEN RI Beam Factory since 2014. The graphite sheets have a 10-µm-order thickness and have withstood the heat load of the increasing beam intensity. Kaneka Corporation has also developed the graphite thin film (GTF) disks and has successfully provided larger GTF disk with a thickness of 1.5 µm. We applied them to the first stripper in uranium acceleration and investigated after beam irradiation by SEM. Their performance during beam operations and the lifetime will be discussed.

INTRODUCTION

RIKEN RI Beam Factory has two charge stripping sections for the uranium (U) acceleration. The first stripping section is essential because the incident U^{35+} beams are stripped into the greatly enhanced charge state around two times higher. The conventional carbon foil (C-foil) stripper can efficiently enhance the mean charge state up to U^{71+}, however, the radiation damage of the increased beam intensity shortened its lifetime in several hours. We developed the carbon nanotube sputter deposition carbon (CNT-SDC) foils [1] for the rotating cylinder stripper device to extend the lifetime by enlarging the irradiated area. The foils successfully worked for the beam operations until 2011, and the lifetimes of the CNT-SDC foils were 2~5 C representing by the total irradiated charge, which was 100 times longer than static C-foils. However, unavailability of the CNT sheet and the continuously increasing beam intensity forced us to replace the CNT-SDC foil stripper to the He gas stripper device in 2012 [2]. The He gas stripper has both longer lifetime and better thickness uniformity. But, if we can solve the lifetime issues, C-foil stripper has a lot of advantages in terms of 1) higher charge states, 2) higher beam transmission because orifices are unnecessary, 3) less residual radiation, 4) easier maintenance and replacement, and 5) shorter system length.

GRAPHITE THIN FILM DISK FOR ROTATING STRIPPER

We have applied the high-density highly oriented graphite sheets to the rotating stripper device at the second charge stripping section for U acceleration since 2014. We have successfully supplied high intensity U beams for long-term operations. The sheets after the beam operation had no significant damage in appearance, however, microscopic damages was observed by SEM [3]. Kaneka Corporation also developed thinner graphite thin film (GTF) disks [4] the thickness less than 10 µm for the second stripping section.

Characteristics of the GTF

The GTF are prepared from the heat-treated polyimide films at temperatures up to 3000 °C. The GTF characteristics are listed in Table 1. A prominent feature of the GTF is the very high thermal conductivity of 1500 $W\cdot m^{-1}\cdot K^{-1}$ in the plane direction. In addition, the GTF has a higher thermal diffusivity than copper or aluminum, and has a high density and uniform thickness.

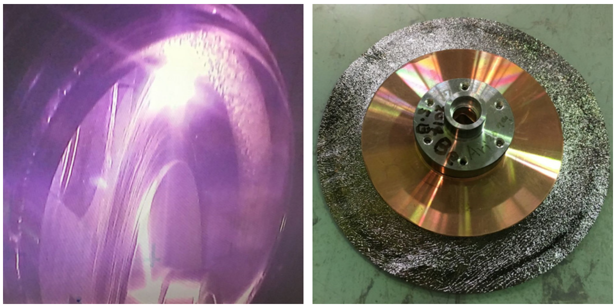
Table 1: Characteristics of the Kaneka GTF

		Units	Typical values
Thermal conductivity	In plane (XY axis)	$W\ m^{-1}\ K^{-1}$	**1500**
	Normal to plane (Z axis)		5
Thermal diffusivity		$cm^2\ s^{-1}$	9.0
Density		$g\ cm^{-3}$	**2.0**
Tensile strength		MPa	40
Bending		Cycles	>10000
Electrical conductivity		$S\ cm^{-1}$	13000

GTF disk at the first stripping section in U beam time

We installed the rotating stripper device just upstream of the He gas stripper device. The dimensions of the GTF disk were 110 mm in diameter and 0.36 $mg\cdot cm^{-1}$ in thickness (about 1.5 μm^t). We used this GTF disk as the first charge stripper for the U beam operation in October 2018 (Fig. 1 (a)). The operation period was four days with the maximum U beam intensity of 45 eµA (U^{35+}). The disk rotation speed was 160 rpm and totally 5.8×10^{16} particles were irradiated. The used GTF disk was shown in Fig. 1 (b). No significant damage was observed, while slight deformations were observed in the irradiated area.

† hasebe@riken.jp



(a) (b)

Figure 1: (a) GTF disk during U beam irradiation. The irradiated spot was brilliant. (b) The GTF disk after the beam operation.

Charge distribution

The charge distribution of the U beam after the passage through the GTF disk was shown by solid squares in Fig. 2. The energy of the incident U beam was 10.75 MeV/u. The mean charge state was 71 with its fraction of 16%. The distribution obtained with the He gas stripper was also plotted in Fig. 2 (by solid diamonds). The mean charge using He gas was 64 with the fraction over 20%, owing to the closed shell effect in U ion.

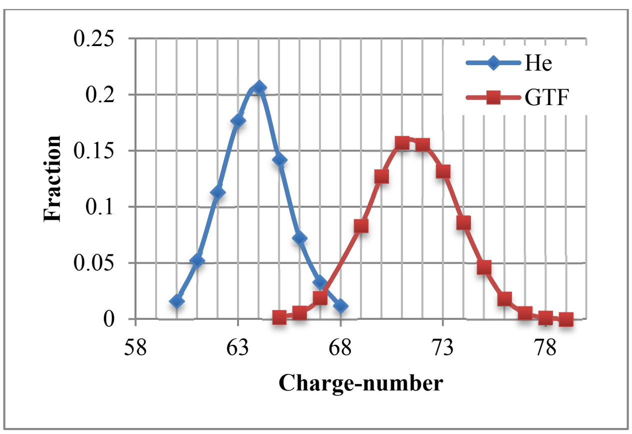


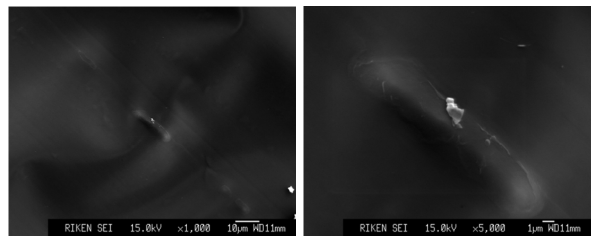
Figure 2: Charge distributions of the U beam at 10.75 MeV/u after passing through the GTF disk (solid squares) and the He gas stripper (diamonds).

OBSERVATION SCANNING ELECTRON MICROSCOPY

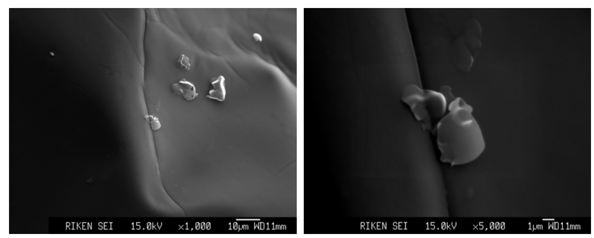
The GTF disks was observed by a scanning electron microscope (SEM) with the electronic scanning micro analyzer (EPMA). A part of the beam irradiation mark was cut off with scissors and was placed onto the SEM sample stage. The surface and the cross section of the GTF disks were observed in two cases where the beam was irradiated or not. To observe the cross section, a GTF disk piece was attached onto an Aluminum block and was placed upright. As shown in Fig. 1 (b), we couldn't observe any visible damage in the GTF disk.

SEM images of the GTF disk surface

Figures 3 (a) and (b) show the no-irradiated part and the beam-irradiated part, respectively. The magnification factors are 1000 times (left) and 5000 times (right). We found that many bumps and some peeled areas in the beam-irradiated surface in Figure 3 (b).



(a)

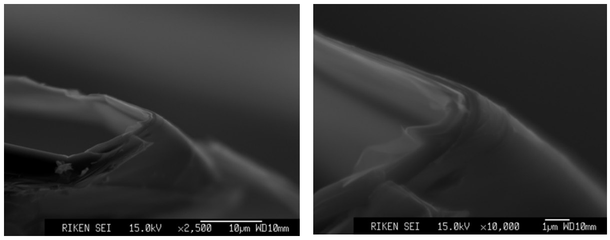


(b)

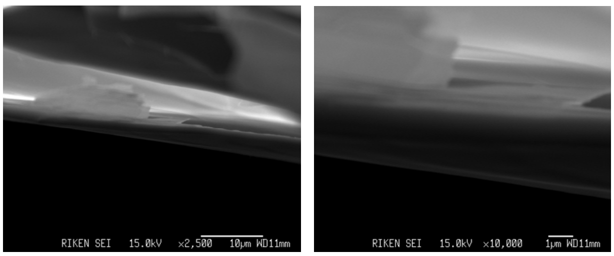
Figure 3: SEM images of the GTF disk surface. (a) no-irradiated part and (b) beam-irradiated part.

SEM images of the GTF disk cross section

Figure 4 shows the SEM images of the GTF disk cross section. The upper (a) and lower (b) images show the no-irradiated part and the beam-irradiated part, respectively. The magnification factors are 2500 times (left) and 10,000 times (right). The thickness did not change after the irradiation. While many fine layers can be observed at the no-irradiated part, the structures become hard tobe distinguished at the beam-irradiated part.



(a)



(b)

Figure 4: SEM images of the GTF disk cross-section: (a) no-irradiated part and (b) beam-irradiated part.

SUMMARY

The U acceleration at RIBF has applied Kaneka GTF disk as the first charge stripper. This GTF disk stripper has successfully worked and provided stable high-intensity beams for a long operation period. We couldn't observe any visible beam-irradiation damage in the GTF disk. The surface and the cross section of the GTF disks were observed by SEM. The fine layer structures became hard to be distinguished at the beam-irradiated part. The reason for the damage seems to be weakening of the bond strength or the lattice defects caused by the beam irradiation. It is noticed that the GTF disk thickness did not change by beam irradiations. Further analysis by Raman spectroscopy or TEM may make them clear in details. It is concluded that Kaneka's GTF disk is suitable for the charge strippers.

REFERENCES

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