HISTORY OF SOLID DISK IMPROVEMENT FOR ROTATING CHARGE STRIPPER

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Abstract

In 2007, we installed a rotating disk stripper device in the final charge stripper section for acceleration of U beam. At first, we selected a carbon disk stripper. However, the quality of the beam after it passed through the stripper was unusable because of the non-uniform thickness and unexpected low density of the stripper. In 2012, the rotating stripper using a Be-disk successfully realized the stable U beam operation. However, the thermal load of the increasing beam intensity caused deformation of the Be-disk even after a short irradiation period. In 2015, highly oriented graphite sheets of high density were used as the disk stripper, which had the longest lifetime. The graphite sheet exhibited improved stripping and transmission efficiencies.

INTRODUCTION

A charge stripper is an essential device used to strip U beams to produce the high-charge state of U^{86+} at 50 MeV/nucleon before acceleration by a subsequent cyclotron at the RIKEN RI Beam Factory (RIBF). A 17-$mg \cdot cm^{-2}$ thick static-type carbon foil (C-foil) was used as the stripper at the RIBF because of its high melting point. As the intensity of the U beam was expected to increase, a rotating carbon disk (C-disk) stripper device was constructed in 2006[1]. A C-disk of diameter 120 mm was installed and tested in 2007. However, the C-disk could not be used as the stripper because of its non-uniform thickness and unexpected low density. Other C-disks, which were commercially available or originally fabricated, were tested, but none met our requirements. Therefore, until 2011, the only alternative was to use polycrystalline graphite foils fabricated by Arizona Company[2]. These foils were used as the static-type C-foil stripper and needed to be replaced every time their lifetime was over in order to accomplish the U beam time. However, the lifetime of these static C-foils decreased to 9 h as the beam intensity increased. Hence, providing stable U beams was difficult.

BERYLLIUM DISK STRIPPER

In October 2012, other materials were tested as alternatives to C-disks: low-density C [2], Ti [3], and Be [3]. Each disk had a thickness of 19 $mg \cdot cm^{-2}$. A U^{64+} beam at 50 MeV/nucleon was irradiated on the C/Ti/Be disk at rotating speeds ranging from 300 to 1000 rpm. The charge states at the peak were 82+ and 86+ for the Ti- and Be-disk, respectively. The charge distribution of Be was almost the same as that obtained for the static C-foil. Therefore, Be-disk could be used instead of the C-foil stripper. The charge distribution of the C-disk could not be obtained because of non-uniformity in its thickness.

The Be-disk was used during the beam-time operation from November to December, 2012. We successfully delivered a stable U beam during the long-term operation. Totally 1.18×10^{18} U particles were irradiated on the Be-disk over a period of 37 days[4]. The number of irradiated particles and the disk conditions are summarized in Table 1 along with other disks described below. The first Be-disk is denoted as Disk 1 in Table 1. For Disk 1, the emittance of the beam increased after the stripper exceeded the accepted levels for subsequent cyclotrons because of the non-flatness of the disk. To obtain flatter disks, we fabricated a Be-disk that was subjected to diamond polishing (Disk 2) in March 2013[5]. In addition, the disk thickness was reduced from 0.1 mm (19 $mg \cdot cm^{-2}$) to 0.085 mm (16 $mg \cdot cm^{-2}$), which was suited for the injection energy of the subsequent cyclotron. Therefore, transmission efficiencies of the downstream cyclotrons were improved. The Be-disk seemed still usable after irradiation with 9.29×10^{17} U particles during the 30-day beam-time operation[6]. Therefore, the Disk 2 was used again for the U beam-time operation in March 2014. Although the disk was already distorted, it survived for 21 days more. During the beam time of 51 days (including the 30 days in 2013) as mentioned in Table 1, a total of 1.68×10^{18} U particles was irradiated on the disk. Figure 1 shows the photographs of the Be-disks before (left) and after usage (right). As shown in Figure 1 (Disk 2), many cracks were observed along the beam irradiation traces, and the beam transmission efficiency decreased as well, thus, indicating that the lifetime of the disk was over. The Be-disk was replaced with a new disk (Disk 3), which was identical to Disk 2 (0.085-mm-thick, diamond polished), for the remaining beam time. In addition, a total of 8.83×10^{17} U particles was irradiated on the new Be-disk over a period of 17 days. The beam transmission efficiency was improved owing to the diamond polish. However, as the upstream beam intensity increased, the thermal load increased from 90 W to 230 W, resulting in deformation of the disk. In October 2014, we introduced a Be-disk with a special design (Disk 4) to reduce the thermal deformation. Because of this improvement, Disk 4 survived even after the 20-day U beam time with radiation of approximately 9×10^{17} U particles. The main changes were as follows. 1) The outer diameter of the disk was changed from 120 mm to 110 mm; 2) Small cuts

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were made at 12 positions around the circumference of the disk; 3) The disk holder was made of copper (changed from aluminum) with an outer diameter of 65 mm; 4) Twelve holes of 2-mm diameter were made around the holder. Beam availability was improved because the beam fluctuation was suppressed by reducing the deformation. Disk 4 is still usable without any degradation[7].

The lifetime of Be-Disk is approximately 140 times longer than that of the static type C-foil.

Table 1: Summary of the Four Be-disks

	Irradiation current Total beam particle	Days	State
Be Disk 1 Not polish 0.1-mm thick	4 - 5 eμA 1.18×10^{18}	37	Many cracks Still usable Slight beam fluctuation
Be Disk 2 Diamond polish 0.085-mm thick	4 - 12 eμA 1.68×10^{18}	51 30+21	Distortion and Many cracks Not usable Slight beam fluctuation
Be Disk 3 Diamond polish 0.085-mm thick	12 eμA 8.83×10^{17}	17	Distortion, Slightly cracked Still usable No beam fluctuation
Be Disk 4 Diamond polish 0.085-mm thick φ110 mm Special processing	8 eμA 9×10^{17}	20	Slightly Distorted No crack Still usable No beam fluctuation

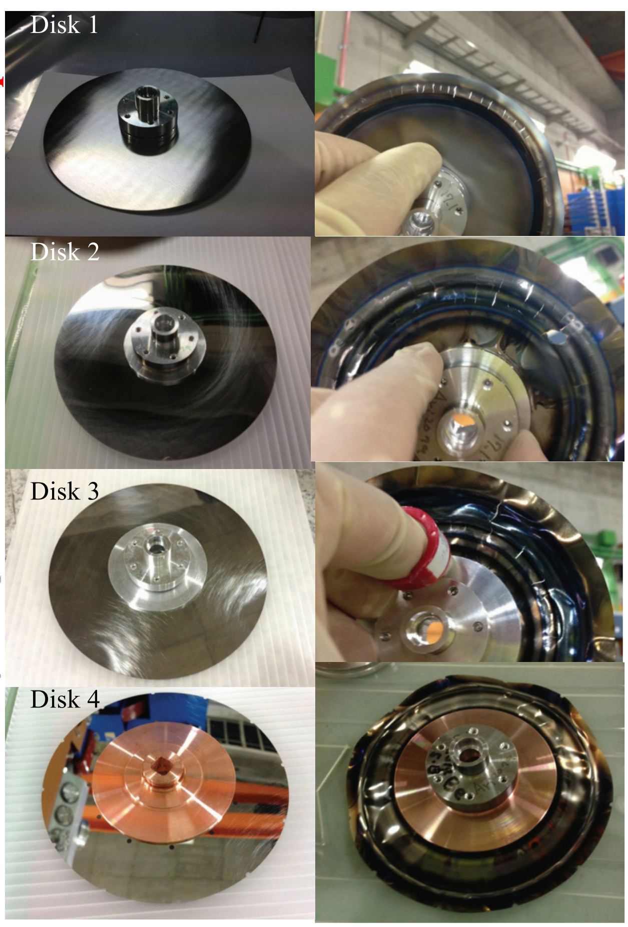

Figure 1: The four Be-disks: before usage (left) and after usage (right).

GLASSY CARBON DISK STRIPPER

In the autumn of 2014, we tried to polish a glassy carbon (GC) disk by using the polishing technology applied for the Be-disk. The main characteristics of GC are good heat resistance, high mechanical strength, and fine-grained structure. The model number of GC was F-22, and the density was 1.93 g·cm^{-3}. This GC-disk was fabricated from a 1-mm thick disk. Both sides of the disk were processed using diamond polishing, and the thickness was reduced up to 0.085 mm. The material manufacturer was Tanken Seal Seiko Co. LTD[8], and machining was carried out by Crystal Optics Inc.[9] The fabricated GC-disk had uniform thickness. In Figure 2, the disk at the upper left is the new GC-disk.

GRAPHITE SHEET DISK STRIPPER

In the autumn of 2014, a 0.035-mm (7.1-mg·cm^{-2}) thick sample of highly oriented graphite sheet (GS) having high density was tested by Kaneka Corporation[10] as a stripper material. This GS was made from a polymer sheet under the high-temperature and high-pressure condition. The characteristics of GS are listed in Table 2. A prominent feature of the GS is the very high thermal conductivity of 1500 W/mK in the plane direction. In addition, GS has a higher thermal diffusivity than copper or aluminum. Therefore, the rise in temperature at the beam spot position is suppressed. The other features include high density and uniform thickness. The fluctuation in thickness for the GS is approximately half of that for the Be-disk. In addition, the GS is mechanically strong and can be handled easily by using scissors or a cutter knife. The disk at the lower right side in Figure 2 is the new GS-disk. The GS-disk has two layers roughly cut to have an outer diameter of 110 mm.

Table 2: Characteristic of Kaneka GS

		Units	Typical values
Thermal conductivity	In plane (XY axis)	W/mK	**1500**
	Thru plane (Z axis)		5
Thermal diffusivity		cm^2/s	9.0
Density		g/cm^3	**2.0**
Tensile strength		MPa	40
Bending		Cycles	>10000
Electrical conductivity		S/cm	13000

BEAM TESTS OF GC AND GS DISK

In October 2014, the two new carbon disks were tested with U beam. Figure 3 shows the results of the charge distribution for the Be-, GC-, and GS-disks. Blue, red, and green plots indicate the distribution of the Be-, GC-, and GS-disks, respectively. It was observed that the charge distributions of the GC- and GS-disk were similar to that of the Be-disk. Moreover, as observed from the profile data measured at the downstream of the charge

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stripping section, the thickness uniformities of the GC- and GS-disk were similar to that of the Be-disk.

Figure 2: New GC-disk (upper left) and new GS-disk (lower right).

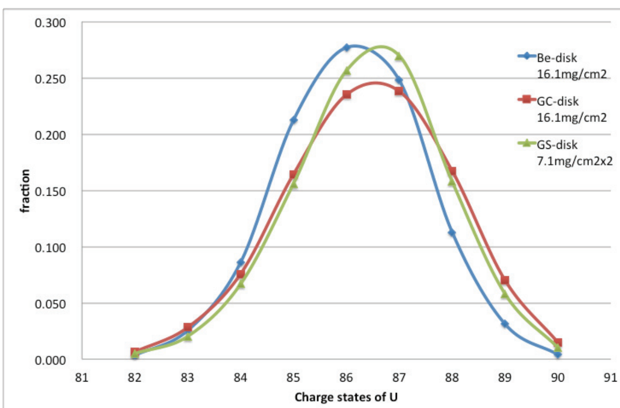

Figure 3: Charge distributions of Be-, GC-, and GS- disks.

GS DISK IN BEAM TIME

We successfully obtained two types of C-disks, and the GS-disk was used during the U beam time from March to May, 2015. A total of 1.4×10^{18} U particles with an intensity of 15 eμA, which corresponds to a thermal load of 205 W, was irradiated on the GS-disk. A total of 1.4×10^{18} U particles corresponds to the amount irradiated during the Be-disk lifetime. However, the GS-disk was still usable. Figure 4 shows the photograph of the GS-disk after usage. No change in the appearance of the new GS-disk was observed except for a slight color change. The lifetime measurement of the GS-disk is still in progress. The maximum temperature of the GS-disk was estimated to be about 600K according to the ANSYS[11] calculation. It was also observed that the thickness uniformity of the two-layer GS-disk is equivalent to that of the single-layer GS-disk. Hence, thickness can be tuned by combining multiple sheets of different thickness.

CONCLUSION

The U beam intensity has been increasing continually. We have developed foil and disk strippers with very long lifetime (the lifetime of the GC-disk has not been measured yet.). Moreover, the cost for the stripper materials has decreased because of the use of C-disks. The performance of the GS-disk as the stripper is excellent and it has the longest lifetime. The GS is also applicable for constructing multilayer disks with variable thickness for acceleration of other ion beams. The three-layer GS-disk was used for the krypton beam operation after the U beam time, and it successfully provided high-intensity beam with good stability. Thus, the problem related to the final stripping section was solved.

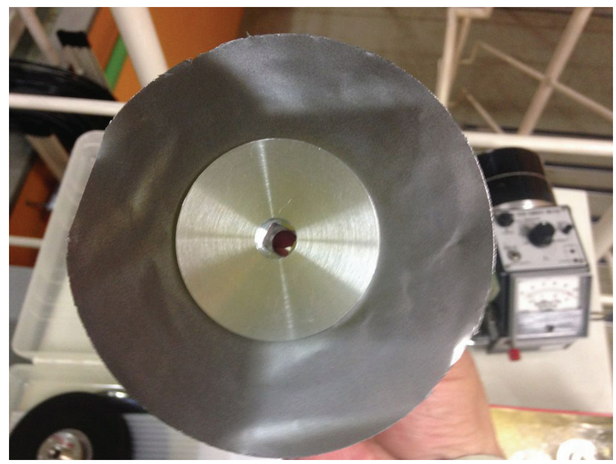

Figure 4: GS-disk after usage.

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