Uranium Beam Interaction with Materials in Charge Stripper and Target

Hiroki Okuno¹, Hiroshi Imao¹, Hiroo Hasebe¹ and Koichi Yoshida¹

¹RIKEN Nishina Center for Accelerator-Based Science, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

E-mail: okuno@riken.jp

(Received June 15, 2019)

The Radioactive Isotope Beam Factory (RIBF) is a cyclotron-based accelerator facility that uses fragmentation or fission of high-speed heavy ion beams. Charge strippers in the accelerator system, and target for RI beam production, were successfully developed, although they have risk to be a bottleneck.

KEYWORDS: Heavy ion accelerator, Uranium ion, Charge stripper, Target and beam dump, ...

1. Introduction

The Radioactive Ion Beam Factory (RIBF) is a cyclotron-based accelerator facility that uses fragmentation or fission of heavy ion beams to produce intense radioactive ion (RI) beams over the entire atomic range [1]. The RIBF facility consists of four cyclotron rings (RRC, FRC, IRC, and SRC) with three injectors, including two linacs (RILAC and RILAC2) and one AVF cyclotron (AVF), as shown in Fig. 1. Cyclotron cascades can provide heavy ion beams from H⁺² to uranium ions, at more than 70% of the speed of light, to efficiently produce RI beams. Three acceleration modes are available, as shown in Fig. 1. The first mode is primarily used for mid-heavy ions, such as Ca, Ar, and Zn. The second mode is used for light ions, such as O and N. The third mode is used for very heavy ions such, as Xe and U. Production of the first successful beam occurred approximately twelve years ago. The facility has been operating since then, with continuous efforts to increase the beam intensity; especially for very heavy ions such as Xe and U. The current beam intensity for uranium ions is 71 pnA: the world record. The beam availability has improved significantly, exceeding 90% since 2013. Development of charge strippers greatly contributed to the upgrade of beam intensity of uranium ions.

BigRIPS is the in-flight fragment separator which produces an intense RI beam by using the projectile fragmentation and in-flight fission of ²³⁸U. A major feature of BigRIPS is large acceptance. This is accomplished by using superconducting quadrupoles with large bores. BigRIPS has a two-stage separator. The first stage is used for production and separation of the RI beams, and the second stage is used for particle identification and/or further separation. Four hundred types of RI beam have been produced to supply the experiment so far. Fourteen hundred production yields were measured, and one hundred and forty kinds of new isotope have been identified. Targets and beam dumps are important devices which are irradiated by the strong primary beams.

2. Charge strippers for uranium beam acceleration

Figure 1 shows the acceleration scheme for uranium ion acceleration at the RIBF, with the two charge strippers. The first stripper enhances the charge state, from 35+ to 64+, while the second strip-
per enhances from 64+ to 86+. Degradation of conventional carbon foils can become significant for short operation periods with high intensity uranium beams. Therefore, a new stripping system, based on helium gas [2] and a rotating disk stripper—using highly-oriented graphite sheet from Kaneka [3]—were developed as shown in Fig. 2.

The advantage of using helium gas is a higher equilibrium charge state of 65+ at 11 MeV/u. This is due to suppression of the capture process, while the equilibrium charge state is 56+ with high-Z gases, such as neon and nitrogen. 0.7 mg/cm² of helium gas was successfully accumulated, without window, with a 5-stage differential pumping system. Twenty six pumps were used to reduce the pressure by 8 orders of magnitude; from 7 kPa to 10⁻⁵ Pa, as shown in Fig. 2. This system started operation in 2012. The rotating disk stripper is used as the second stripper. It is crucial to have uniform thickness for beam stability. The Be disk was used for the initial operation. However, beam irradiation with high current deformed the disk. Now, a highly oriented graphite sheet from Kaneka is used without any problems. This sheet has uniform thickness because it is made from a polyamide thin film with highly pressurized heat-up. Thermal conductivity of the Kaneka sheet, in the plane direction, is three times higher than that of Cu.

Fig. 1. Acceleration modes for the RIBF.

Fig. 2. Charge strippers for uranium beam acceleration.

3. Target and beam dump for RI beam production

The beam power—82 kW—is dissipated in the target and the beam dump. At the target, beam spot size is as small as 1 mm in diameter; the target thickness is roughly 1/3 of the stopping range of
the primary beam; and the material is Be, C, W or Pb. A water-cooled rotating target is used due to the large heat density: 5.67 kW/mm$^3$ [4]. The target is attached to the cooling disk and water is supplied through the rotating shaft, as shown in Fig. 3. Because of the difficulty in placing the rotating joint in vacuum, the motor and rotating joint are placed in a small box in the vacuum chamber. This box is at atmosphere and is sealed off, from vacuum, by ferromagnetic seals.

The primary beam for the BigRIPS separator stops at the first dipole magnet, where the primary beam and desired RI beam are separated. The beam stop position was determined by the Bohr ratio of beam and separator. This cannot be changed once the desired RI beam is fixed. Therefore, the beam stop positions are spread widely around the the first dipole (D1) magnet. The beam size varies depending on where the primary beam stops, and heat load deposited by the beam changes from 10 to 200 MW/m$^2$ accordingly. Since this value is not high compared with those for the target, and wide coverage is necessary, we decided to build a stationary system with highly efficient water cooling as shown in Fig. 3 [5]. Screw and swirl tubes are used to attain a higher heat transfer coefficient. Critical heat flux is around 55 MW/m$^2$ under the conditions of high pressure of 1 MPa and high water velocity of 10 m/s.

Fig. 3. Structure of the rotating target and beam dump for BigRIPS.

4. Outlook

We have a plan to reach the goal intensity of 1pA of uranium beam. This plan will be realized by increasing output from the ion source and stripping efficiency at the two strippers. Charge stripper rings will be installed to increase the total stripping efficiency from 5% to 50% [6].

References

[1] Y. Yano, Nucl. Instrum. Methods Phys. Res., Sect. B 261 (2007) 1009.
[2] H. Imao, et al., Phys. Rev. ST Accel. Beams 15 (2012) 123501.
[3] H. Hasebe, et al., Proc. of 28th World Conf. of the International Nuclear Target Development Society, INTDS 2016., AIP Conference Proceedings 1962, 030004 (2018)
[4] A. Yoshida, et al., Nucl. Instr. Meth. A590(2008)204.
[5] K. Yoshida, et al.,Nucl. Instr. Meth. B317(2013)373.
[6] H. Imao, Proc. of 9th International Particle Accelerator Conference, Vancouver, (2018) MOZGBE1.