High mass resolving power and isomeric state separation at SLOWRI/ZD-MRTOF system

W. Xian,[*1,*2] M. Rosenbusch,[*2] S. Chen,[*1,*2] Y. Hirayama,[*2] D. Hou,[*3,*2] S. Iimura,[*5,*4] H. Ishiyama,[*4] Y. Ito,[*6] S. Kimura,[*4] J. Liu,[*3] H. Miyatake,[*2] S. Nishimura,[*4] T. Niwase,[*7,*4,*2] P. Schury,[*2] A. Takamine,[*4] M. Wada,[*2] Y. X. Watanabe,[*2] H. Wollnik,[*8] and S. Yan[*9]

With high precision and accuracy, as well as short measuring times, the multi-reflection time-of-flight mass spectrograph (MRTOF-MS) has become competitive with Penning traps for measuring masses of short-lived nuclei.[1)] In 2013, the first MRTOF built at RIKEN was tested online by measuring ^{8}Li ions. The mass excess of ^{8}Li was accurately reported to be 20947.6(15)(34) keV ($\Delta m/m \sim 6.6 \times 10^{-7}$). The mass resolving power achieved at that time was $R_m > 150$k.[2)] In 2020, a next-generation device of similar design has been put into operation at the ZeroDegree spectrometer of RIBF with the goal of measuring very exotic nuclides and their isomers with a higher resolving power.

In the MRTOF reflection chamber, ions are confined and reflected back and forth between a pair of ion reflection mirrors, allowing the ions to have a flight path of up to or beyond one kilometer. In any field-free drift region, more energetic ions have a shorter time-of-flight, but in the reflection region inside the ion mirrors, this can change because of the shape of the potential distribution. It is possible to make more energetic ions penetrate deeper into the mirrors to achieve a longer flight path that compensates for their higher energy and equilibrates the time-of-flight with that of less energetic ions. The better this compensation works, the narrower the final TOF distribution can be as ions with different energies can simultaneously reach the detector.[3)] However, this requires a non-trivial search for complex mirror potentials and those of ion-optical focusing elements located in the central drift tube section. In our case, this would require a search in 11-dimensional parameter space.

In a first-order approach, every possible potential distribution is the generator of a function mapping the TOF of an ion to a kinetic energy TOF(E). In recent offline experiments using the new ZD-MRTOF system, by use of a pulsed drift tube between the ion trap and MRTOF, we measured these response functions in a much wider energy range than done before. This measurement was repeated after changing some voltage of each ion mirror. In this manner, the effect of changing each mirror potential on this function could be studied. This allowed for an improved local search around the present conditions to fulfill the condition $\partial \mathrm{TOF}(E)/\partial E \approx 0$ for a particular number of reflections. The different shapes of the TOF(E) functions have been added in an appropriate manner, which resulted in a new voltage configuration with excellent energy compensation.

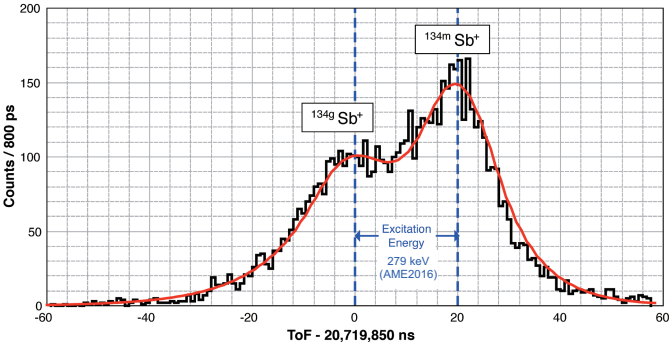

Fig. 1. TOF spectrum of ^{134g}Sb^{+} and ^{134m}Sb^{+} in the online experiment of the ZD-MRTOF system.

In the corresponding offline tests, by using ^{39}K^{+} ions from a thermal ion source to perform the procedure mentioned above, a mass resolving power $R_m \sim 700$k was achieved for the first time at RIBF, with a flight time of ~9 ms after 490 laps.

The first online commissioning experiment of the MRTOF at ZeroDegree terminal was conducted at the end of 2020. Even under online conditons, we were generally able to maintain a mass resolving power in excess of 500k during the commissioning. This high mass resolving power allowed us to demonstrate an isomeric separation of ^{134m,g}Sb^{+}, which has an isomeric state with an excitation energy of 279(1) keV [$T_{1/2}$ = 10.07(5) s] above the ground state [$T_{1/2}$ = 0.78(6) s]. As shown in Fig. 1, we could successfully identify the ground state (^{134g}Sb^{+}) and the isomeric state (^{134m}Sb^{+}) in the TOF spectrum owing to the very high mass resolving power that the ZD-MRTOF system achieved.

*1 Department of Physics, The University of Hong Kong
*2 Wako Nuclear Science Center (WNSC), IPNS, KEK
*3 Institute of Modern Physics, Chinese Academy of Science
*4 RIKEN Nishina Center
*5 Department of Physics, Osaka University
*6 Advanced Science Research Center, JAEA
*7 Department of Physics, Kyushu University
*8 Dep. of Chem. and Biochem., New Mexico State University
*9 Institute of Mass Spectrometry and Atmospheric Environment, Jinan University

References

1) Y. Ito *et al.*, Phys. Rev. C **88**, 011306(R) (2013).
2) P. Schury *et al.*, Nucl. Instrum. Methods Phys. Res. B **335**, 39 (2014).
3) R. N. Wolf *et al.*, Int. J. Mass Spectrom. **313**, 8(2012).