Research Facility Development Division
Instrumentation Development Group
SLOWRI Team

1. Abstract

SLOWRI is a universal low-energy RI-beam facility at RIBF that provides a wide variety of short-lived nuclei as high-purity and low-emittance ion beams or stored ions in a trap, including a parasitic operation mode. The SLOWRI team develops and manages the facility and performs high-precision spectroscopy experiments. The construction of the SLOWRI facility began in FY2013 and commissioning work is ongoing. From FY2019, SLOWRI has been started to be co-operated under RNC and WNSC/KEK collaboration.

High-energy radioactive ion beams from the projectile fragment separator BigRIPS are thermalized in a large He gas catcher cell (RFGC) or in a small Ar gas catcher cell (PALIS cell). From these gas cells, the low-energy ion beams will be delivered via mass separators and switchyards to various devices: such as an ion trap, a collinear fast beam apparatus, and a multi-reflection time of flight mass spectrograph. A multi-reflection time-of-flight mass spectrograph (MRTOF) has been also developed.

Two mass measurement projects using MRTOF mass spectrographs have been started: one is for trans uranium elements at the GARIS facility and the other is for r-process nuclides at SLOWRI facility. At GARIS-II, we installed second prototype RFCG combined with MRTOF, which is a medium-sized cryogenic RF-carpet He gas cell. Using second prototype RFGC, more than 80 nuclear masses have been measured including first mass measurements of Md and Es isotopes. In FY2020, we have started mass measurements for neutron rich unstable nuclei using a fission source installed in the second prototype RFGC. At SLOWRI facility, third prototype RFGC has been installed at F11, the downstream of ZeroDegree spectrometer, which is a 50-cm-long RF-carpet-type He gas cell combined with MRTOF. In November and December of FY2020, we have successfully performed the on-line commissioning, symbiotically by using RIs provided for HiCARI campaign. The extraction efficiency in total has been achieved at 1% in maximum and the masses on more than 70 nuclei have been measured using RIs provided with BigRIPS.

Parallelly, the on-line commissioning for PALIS has been continuously performed at F2 of BigRIPS. In FY2020, the extraction of I-emitter Bi Isotopes by the gas flow without a laser ionization has been confirmed from PALIS gas cell.

2. Major Research Subjects

(1) Construction of the stopped and low-energy RI-beam facility, SLOWRI.
(2) Development of a multi-reflection time-of-flight mass spectrograph for precision mass measurements of short-lived nuclei.
(3) Development of collinear laser spectroscopy apparatus.
(4) Development of a parasitic slow RI-beam production method using resonance laser ionization.

3. Summary of Research Activity

(1) Construction of stopped and low-energy RI-beam facility (SLOWRI)

SLOWRI consists of two gas catchers (RF carpet gas cell and PALIS gas cell), mass separators a 50-m-long beam transport line, a beam cooler-buncher, an isobar separator, and a laser system. The RF carpet gas cell (RFGC) will be installed at the exit of the D5 dipole magnet of BigRIPS. The gas catcher contains a large cryogenic He gas cell with a large traveling wave rf-carpet. The PALIS gas cell is installed in the vicinity of the second focal plane slit of BigRIPS. It will provide parasitic RI-beams from those ions lost in the slits during other experiments. In this gas catcher, thermalized RI ions quickly become neutral and will be re-ionized by resonant laser radiations. Off- and on-line commissioning is underway.

Based on test experiments with the prototype setups, the RF-carpet gas cell contains a three stage rf-carpet structure: a gutter rf carpet (1st carpet) for the collection thermal ions in the cell into a small slit, a narrow (about 10 mm) traveling-wave rf-carpet (2nd carpet) for collection of ions from the gutter carpet and for transporting the ions towards the exit, and a small rf carpet for extraction from the gas cell. The off-line test has been completed in FY2019.

A 50-cm-long RFGC, which is a prototype for final version RFGC with 1.5 m length, has been installed at F11 of ZeroDegreee spectrometer of BigRIPS in FY2020. In November and December of 2020, the on-line commissioning has been successfully performed symbiotically using RIs provided with BigRIPS during HiCARI campaign. The extraction efficiency in total has been achieved at 1% in maximum.

(2) Development of a multi-reflection TOF mass spectrograph for short-lived nuclei

The atomic mass is one of the most important quantities of a nucleus and has been studied in various methods since the early days of modern physics. From among many methods we have chosen a multi-reflection time-of-flight (MRTOF) mass spectrometer. Slow RI beams extracted from the RF ion-guide are bunched and injected into the spectrometer with a repetition rate of ~100 Hz. A mass-resolving power of 170,000 has been obtained with a 2 ms flight time for ^{40}K and ^{40}Ca isobaric doublet. This mass-resolving power should allow us to determine ion masses with an accuracy of $\leq 10^{-7}$. A new MRTOF has been assembled in FY2019 to be coupled with the third prototype of RFGC and has been installed at F11 of BigRIPS in FY2020. Mass measurements using RIs provided with BigRIPS during HiCARI campaign have been symbiotically performed. As the result, atomic masses on more than 70 nuclei have been successfully measured. Among them, 11 isotope masses improve the present uncertainty significantly and 3 isotope masses have been measured for the first time.

(3) Development of collinear fast beam apparatus for nuclear charge radii measurements

The root-mean-square charge radii of unstable nuclei have been determined exclusively by isotope shift measurements of the optical transitions of singly charged ions or neutral atoms by laser spectroscopy. Many isotopes of alkali, alkali-earth, and noble-gas elements in addition to several other elements have been measured by collinear laser spectroscopy since these ions all have good optical transitions and are available at conventional ISOL facilities. However, isotopes of other elements, especially refractory and short-lived ones, have not been investigated so far.

In SLOWRI, isotopes of all atomic elements will be provided as well collimated, mono-energetic ion beams. This should expand the range of nuclides available for laser spectroscopy. An off-line mass separator and a collinear fast beam apparatus with a large solid-angle fluorescence detector was built previously. A 617-nm transition of the metastable Ar^+ ion at 20 keV was measured with both collinear and anti-collinear geometry, which allowed determination of the absolute resonant frequency of the transition at rest with a relative accuracy better than 10^{-8}. A new setup is under preparation at the SLOWRI experiment area in collaboration with the Nuclear Spectroscopy Laboratory.

(4) Development of parasitic slow RI-beam production scheme using resonance laser ionization

More than 99.9% of RI ions produced in projectile fission or fragmentation are simply dumped in the first dipole magnet and the slits. A new scheme, named PALIS, meant to rescue such precious RI using a compact gas catcher cell and resonance laser ionization, was proposed as a part of SLOWRI. The thermalized RI ions in a cell filled with Ar gas can be quickly neutralized and transported to the exit of the cell by gas flow. Irradiation of resonance lasers at the exit ionizes neutral RI atoms efficiently and selectively. PALIS has been installed at F2 at the downstream of BigRIPS. and off- and on-line commissioning is under progress.

At F2, due to high radiation from a beam dump, it is not easy to handle ions using electric ion guides. Therefore, a 70-cm-long gas pipe from the Ar gas cell was newly installed to transport RIs to relatively low radiation area thanks for the Ar gas flow. In FY2020, we have confirmed the transportation of RIs through the gas pipe to the relatively low radiation area using -emitting Bi isotopes provided with BigRIPS. In FY2021, an on-line test for resonant laser ionization is planned using α-emitting Bi isotopes.

Members

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List of Publications & Presentations

Publications

[Original Papers]

Y. Hirayama, P. Schury, M. Mukasi, H. Choi, S. Iimura, Y. X. Watanabe, M. Wada, H. Watanabe, and H. Miyatake, "Three-dimentional tracking multi-segmented proportional gas counter for beta-decay spectroscopy of unstable nuclei," Nucl. Instrum. Methods Phys. Res. A **997**, 165152 (2020).

M. Rosenbusch, P. Schury, M. Wada, S. Iimura, Y. Ito, and H. Wollnik, "Accurately accounting for effects on times-of-flight caused by finite field-transition times during the ejection of ions from a storage trap: A study for single-reference TOF and MRTOF mass spectrometry," International Journal of Mass Spectrometry **456**, 116346 (2020).

M. Mukai, Y. Hirayama, P. Schury, Y. X. Watanabe, M. Ahmed, H. Haba, H. Ishiyama, S. C. Jeong, Y. Kakiguchi, S. Kimura, J. Y. Moon, M. Oyaizu, A. Ozawa, J. H. Park, H. Ueno, M. Wada, and H. Miyatake, "Development of a multi-segmented proportional gas counter for β-decay spectroscopy at KISS," Nucl. Instrum. Methods Phys. Res. B **463**, 423–424 (2020).

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M. Mukai, Y. Hirayama, Y. X. Watanabe, S. Schiffmann, J. Ekman, M. Godefroid, P. Schury, Y. Kakiguchi, M. Oyaizu, M. Wada, S. C. Jeong, J. Y. Moon, J. H. Park, H. Ishiyama, S. Kimura, H. Ueno, M. Ahmed, A. Ozawa, H. Watanabe, S. Kanaya, and H. Miyatake, "In-gas-cell laser resonance ionization spectroscopy of ^{196,197,198}Ir," Phys. Rev. C **102**, 054307 (2020).

M. Rosenbusch, M. Wada, P. Schury, Y. Ito, H. Ishiyama, S. Ishizawa, Y. Hirayama, S. Kimura, T. M. Kojima, H. Miyatake, J. Y. Moon, T. Niwase, T. Sonoda, A. Takamine, Y. X. Watanabe, and H. Wollnik, "A new multi-reflection time-of-flight mass spectrograph for the SLOWRI facility," Nucl. Instrum. Methods Phys. Res. B **463**, 184–188 (2020).

Presentations

[International Conferences/Workshops]

A. Takamine (invited), "SLOWRI rf gas catcher development toward symbiotic mass measurement," RIBF Users Meeting 2020, on-line, Wako, Japan, September 8–10, 2020.

H. Ishiyama (invited), "Present status of SLOWRI," SSRI-PNS collaboration meeting, on-line, Wako, Japan, September 3, 2020.

[Domestic Conferences/Workshops]

飯村俊, 高峰愛子, M. Rosenbusch, 和田道治, S. Chen, J. Liu, W. Xian, D. Hou, S. Yan, P. Schury, 園田哲, 小島隆夫, 渡辺裕, 小田原厚子, 石山博恒, 「理研 BigRIPS SLOWRI における RF カーペットガスセルの開発～オンライン試験と質量測定」, 日本物理学会第 76 回年次大会, on-line, 2021 年 3 月 12 日.

M. Rosenbush, M. Wada, P. Schury, Y. Hirayama, H. Miyatake, Y. X. Watanabe, S. Iimura, H. Ishiyama, T. Kojima, T. Sonoda, M. Mukai, S. Nishimura, S. Naimi, T. Niwase, A. Takamine, Y. Ito, D. S. Hou, J. Liu, S. Chen, J. Lee, and W. Xian, "New mass measurements of exotic nuclides by the first MRTOF setup at BigRIPS/RIKEN," 日本物理学会第 76 回年次大会, on-line, 2021 年 3 月 12 日.
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