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On-line experimental results of an argon gas cell-based laser ion source (KEK Isotope Separation System)

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ABSTRACT

KEK Isotope Separation System (KISS) has been developed at RIKEN to produce neutron rich isotopes with $N = 126$ to study the β-decay properties for application to astrophysics. The KISS is an element-selective mass-separation system which consists of an argon gas cell-based on laser ion source for atomic number selection and an ISOL mass-separation system. The argon gas cell of KISS is a key component to stop and collect the unstable nuclei produced in a multi-nucleon transfer reaction, where the isotopes of interest will be selectively ionized using laser resonance ionization. We have performed off- and on-line experiments to study the basic properties of the gas cell as well as of the KISS. We successfully extracted the laser-ionized stable ^{56}Fe (direct implantation of a ^{56}Fe beam into the gas cell) atoms and ^{198}Pt (emitted from the ^{198}Pt target by elastic scattering with a ^{136}Xe beam) atoms from the KISS during the commissioning on-line experiments. We furthermore extracted laser-ionized unstable ^{199}Pt atoms and confirmed that the measured half-life was in good agreement with the reported value.

1. Introduction

The elements heavier than iron are considered to be produced in a rapid neutron capture process (r-process), which goes through very neutron-rich nuclei. However, details of the production process and the astrophysical site of the r-process are not fully understood. The β-decay properties of nuclei with $N = 126$ are considered to be critical for understanding astrophysical sites for the production of the heavy elements such as gold and platinum [1].

We plan to measure the half-lives of ^{200}W, ^{201}Re, ^{202}Os and ^{203}Ir ($Z = 74$–77, $N = 126$) produced by multi-nucleon transfer (MNT) reaction [2] between a ^{136}Xe beam with energy of around 10 MeV/nucleon and a ^{198}Pt target [3]. The reaction system is considered to be one of the best candidates to produce the nuclei around $N = 126$ [4]. In order to accumulate the reaction products efficiently and select the interesting nuclei with high purity while suppressing the unwanted species, we have constructed the KEK Isotope Separation System (KISS) at RIKEN RIBF facility [5]. KISS is a thin-target, gas-cell based on-line isotope separator (ISOL) facility designed for the production of beams of neutron rich isotopes near $N = 126$ for β-decay studies. Resonance laser ionization inside the argon gas cell [6–11], followed by mass separation of the ion beam results in the production of isotopically pure, low-energy, mono-energetic ion beams.

In the report, we introduce the KISS setup and the gas-cell system in Section 2, the results of the KISS commissioning on-line experiments in Section 3, development of ion extraction system for increasing the extraction efficiency in Section 4, and the summary in Section 5.

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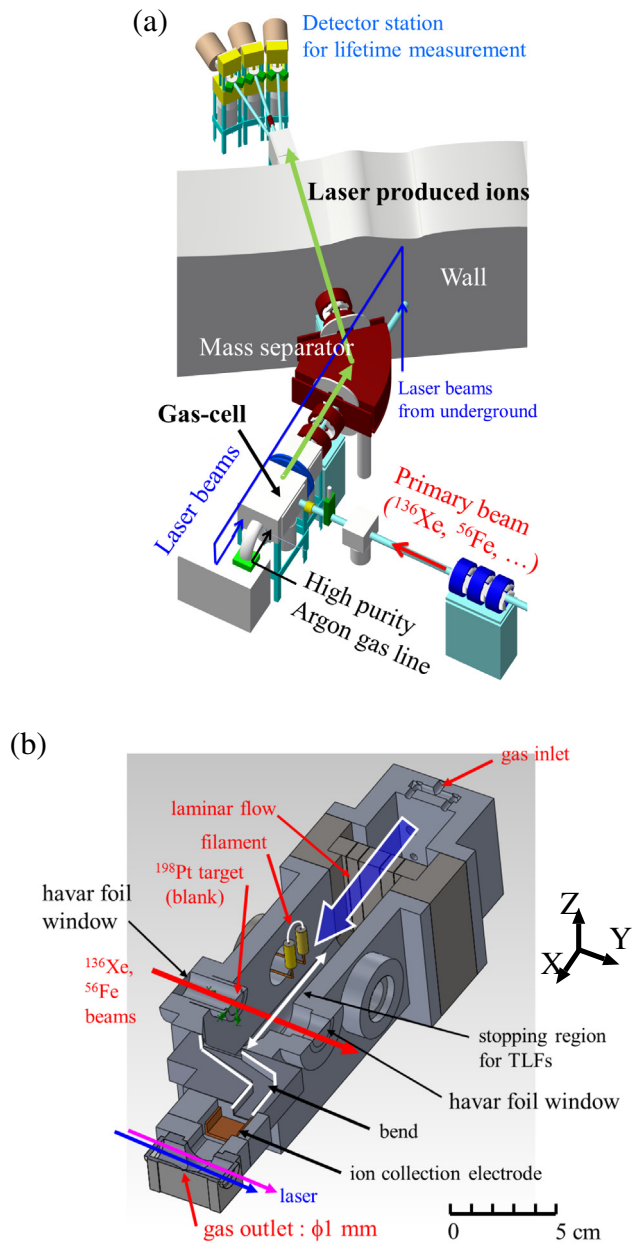

Fig. 1. (a) Schematic view of KISS. (b) Schematic cross sectional view of the gas cell.

2. Overview of KISS and gas cell system

Fig. 1 shows a schematic layout of KISS, which was constructed at the RIBF facility in RIKEN. It consists of a laser system, a mass-separator system, β-decay measurement station and a gas-cell system. An overview of KISS is introduced in this report, and the details of KISS can be found in Ref. [5].

Primary beams are accelerated by using RIKEN Ring Cyclotron (RRC). $^{56}Fe^{24+}$ and $^{136}Xe^{20+}$ beams with an energy of 90 and 10.75 MeV/nucleon and a maximum intensity of 4 and 20 pnA were used for the on-line tests, respectively. The energy of the ^{56}Fe beam was degraded to 1.5 MeV/nucleon by using an aluminum energy degrader, which was placed at 100 mm upstream of the gas cell entrance, in order to implant at the center of the argon gas cell. The ^{136}Xe beam was directed onto the ^{198}Pt target placed in the gas cell, and was stopped at a tungsten beam dump after passing through the gas cell.

The laser system consists of two frequency-tunable dye lasers pumped by two excimer (XeCl, 308 nm) lasers and is installed in a separate room below the KISS gas cell system. A repetition rate of up to 200 Hz is available and the linewidth of the dye laser is typically 0.15 cm^{-1}. Depending on the ionization schemes of heavy elements, the laser radiation from the dye laser can be frequency-doubled using a BBO crystal. The distance between the laser system and the gas cell is about 15 m. Both laser beams with the size of about 8–10 mm in diameter are transported to the gas cell with a small angle, and are overlapped at the ionization region in the gas cell for resonance ionization, spatially and temporally by maximizing the number of laser ionized atoms. A search for efficient ionization schemes of heavy elements [12,13] are in progress using a newly developed test chamber [14].

The mass-separator system has a QQDQQ configuration, in which Q and D denote quadrupole and dipole magnets, respectively. The deflection angle and pole gap of the D magnet are 45° and 70 mm, respectively. The measured mass resolving power is 900, which is sufficient for our project.

The detector station has a tape transport device for decay measurements using a pulsed beam from the separator. Plastic scintillator telescopes followed by germanium γ-ray detectors cover the implantation point in the tape transport device. In order to measure the lifetime of nuclei produced with low reaction rate, the background rate of β-ray telescopes should be lower than the β-ray counting rate of the nucleus of interest. New β-ray telescopes with a background rate of 0.1 cps were developed and installed in the KISS detector station. The details and future plan to reduce the background rate down to a few cph will be reported in Ref. [15].

As shown in Fig. 2, the gas-cell system includes an argon gas feeding line with a gas-purification device (Monotorr Phase II 3000), a gas-catcher cell, and a sextupole ion-guide (SPIG) [16] which is used to transport ions from high pressure region to low pressure region. The beam emittance can be cooled by the collision with the random thermal motion of argon gas in the SPIG. To enable extraction of isotopes as an ion-beam with sufficiently low emittance and high efficiency, the gas-cell system employs differential pumping to reduce the pressure in the vacuum chamber from 50 kPa to several 10^{-4} Pa. When the ions leave the gas cell, their transit through the SPIG is supported by the gas jet, though the gas jet may cause electrical discharge between the SPIG and an extraction electrode and hence make it difficult to apply the necessary acceleration voltage (e.g. 28 kV). Therefore, the vacuum chamber of the gas-cell system is separated into three rooms for the differential pumping. The first, second and third rooms are pumped down by a 175 l/s screw pump, two 800 l/s turbo molecular pumps (TMPs) and a 1500 l/s TMP, respectively. The three neighboring rooms are connected by the SPIG with an aperture of 3 mm diameter and 200 mm length. The conductance between two adjacent rooms was calculated to be 0.15 l/s. The gas cell filled with argon gas at a pressure of 50 kPa is placed in the first room. The conductance of the gas cell exit, which has an aperture of 1 mm diameter and 0.5 mm length, was calculated to be 0.095 l/s. The second room is important for differential pumping and ensures that the vacuum conditions in the third room are sufficient for applying a high voltage to the first and second rooms (several 10^{-4} Pa). Typical pressure values in the three rooms are $P_1 = 8.7$ Pa, $P_2 = 0.9$ Pa and $P_3 = 3 \times 10^{-4}$ Pa, for $P_G = 50$ kPa [5].

Fig. 3 shows the calculated stopping distribution of $^{202}_{76}Os_{126}$ in argon gas with a pressure of 50 kPa. Here, the energies and emission angles of the ^{202}Os nuclei were calculated by the GRAZING code [17,18] and the stopping power was calculated by the