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Progress report of the innovated KIST ion beam facility

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ABSTRACT

The Korea Institute of Science and Technology (KIST, Seoul, Republic of (S.) Korea) ion beam facility consists of three electrostatic accelerators: a 400 kV single ended ion implanter, a 2 MV tandem accelerator system and a 6 MV tandem accelerator system. The 400 kV and 6 MV systems were purchased from High Voltage Engineering Europa (HVEE, Netherlands) and commissioned in 2013, while the 2 MV system was purchased from National Electrostatics Corporation (NEC, USA) in 1995. These systems are used to provide traditional ion beam analysis (IBA), isotope ratio analysis (ex. accelerator mass spectrometry, AMS), and ion implantation/irradiation for domestic industrial and academic users. The main facility is the 6 MV HVEE Tandetron system that has an AMS line currently used for ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{41}Ca and ^{129}I analyses, and three lines for IBA that are under construction. Here, these systems are introduced with their specifications and initial performance results.

1. Introduction

Korea Institute of Science at Technology (KIST, Seoul, Republic of (S.) Korea) was founded in 1966 and was the first multi-disciplinary research institute in Korea. As a national research institute, KIST research facilities perform both basic research and provide services for industry and other academic users. The KIST ion beam facility consists of three electrostatic accelerators, each with beamlines dedicated to different applications. The oldest is a 2 MV Pelletron system purchased from National Electrostatics Corporation (NEC, USA) 20 years ago, in 1995. It has been used for thin film analysis using Rutherford backscattering spectrometry (RBS), particle induced X-ray emission (PIXE) analysis and elastic recoil detection (ERD) analysis. The other two systems, based on a 6 MV Tandetron accelerator and a 400 kV Cockroft-Walton type accelerator, respectively, were procured through the "KIST Tandem Ion Accelerator" government project that commenced in March 2006. They were purchased from High Voltage Engineering Europa (HVEE, the Netherlands) in 2010.

A two-story building was built to house all three accelerators on the first floor and includes office space and sample preparation laboratories on the second floor. The 2 MV system was re-located to this building, and installation and commissioning of the two new systems were completed in the spring of 2013 [1] after factory testing had been completed at Amersfoort, the Netherlands. Fig. 1 is a scale layout of the building. Fig. 2 is a sketch of the three accelerator systems indicating the basic ion-optical components.

These accelerators function as basic research infrastructure to provide traditional ion beam analysis (IBA) and ion implantation/irradiation services. Due to the broad range of ion species available from the various ion sources and wide energy ranges of the accelerators, researchers have access to a wide range of analytical techniques. Besides material probing techniques such as RBS, PIXE, and ERD, medium energy ion scattering (MEIS) analysis [2] using up to 100 keV proton or 400 keV He ion beams is available on one of the 400 kV implanter lines. Ion beam material modification (IBMM) using high and low energy ion implantation/irradiation is also available on all three of the accelerator systems. However, the main application of the KIST 6 MV accelerator system to date has been accelerator mass spectrometry (AMS). This technique has been steadily developing since its first application to radiocarbon analysis in the 1970s [3,4]. Among the AMS applications at KIST, bio-medical applications based on ^{14}C labeling [5] have so far been the area of most intense research and represent a burgeoning field in Korea.

The following presents the accelerator systems, their principle specifications, and the initial performance results from on-site acceptance tests performed in 2013. Finally, some of the current work being done at KIST is briefly introduced.

2. System specifications

The KIST ion beam facility and the ion optical components of the three accelerator systems it houses are shown in Figs. 1 and 2.

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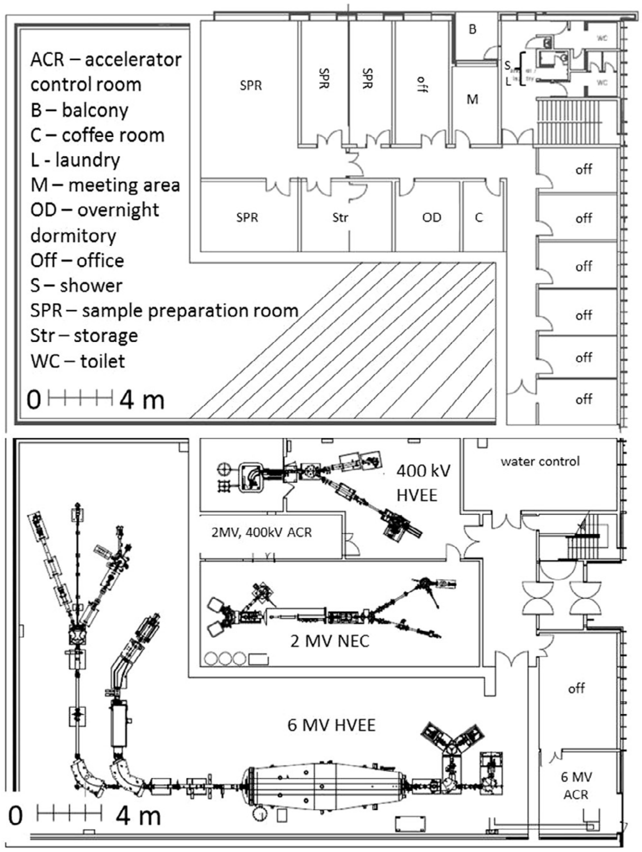

Fig. 1. Scale layout of KIST ion beam facilities. Top panel shows second floor, bottom panel shows ground floor. The accelerators are described in more detail in Fig. 2.

2.1. 6 MV Tandetron accelerator

The main facility at the KIST accelerator laboratory is the 6 MV Tandetron system. The accelerator tank holds up to 7.8 bar SF_6 gas for spark suppression, but for normal operation it is filled to 6–6.5 bar. During tank evacuation, gas is transferred to a large tank located outside of the building. The high voltage terminal is rated for 0.3–6.0 MV operation, charged by a Dynamitron high voltage generator that is driven by a 30 kHz RF power supply. During early testing, the accelerator was conditioned up to 6.6 MV and was stable at the rated 6.0 MV terminal voltage for 8 h. A summary of the accelerator performance during commissioning is given below:

① Terminal voltage: 8 h at maximum rated voltage (6 MV).

② Terminal voltage stability: ±6 V/h at a terminal voltage of 922.5 kV, measured after a warm up of one hour. Ion beam energy drift was monitored using the $^7Li(n,p)^7Be$ reaction at 1.88 MeV [6] monitored at the exit of the 90° port of the IBA switching magnet (μ-probe line in Fig. 2). Results are shown in Fig. 3.

③ Terminal voltage ripple: less than 30 V_{RMS}, measured after one hour of warming up at 75% of the maximum terminal voltage (4.5 MV) by reading the capacitive pick-off (CPO) output.

As shown in Fig. 2, there are two main functions for this system, AMS and IBA, and these have separate ion sources and analysis lines.

2.1.1. 6 MV Tandetron AMS

For AMS analysis, there are two SO-110 Cs sputter negative ion sources that can hold 50 and 200 samples respectively. The negative ion beams are accelerated to 35 keV and energy analyzed in a 54° electric analyzer (ESA) that can be rotated by 90° depending on which ion source is used. The beams are then momentum analyzed by a 90°, 9.8 MeV·amu "low energy" (L.E.) magnet for injection into the accelerator.

At the accelerator positive high voltage terminal, the negative ions undergo electron stripping either by passage through a gas column or a thin foil and are converted to positive ions. This facilitates a "second acceleration" as they are then accelerated towards the exit terminal held at ground potential. To date, all stripping has been performed using Ar gas and pressure is measured directly at the terminal.

Ions are then momentum analyzed in a high energy (H.E.), 90°, 185 MeV amu magnet. The larger beams from stable isotopes are then measured in off-axis Faraday cups. The much less intense rare isotope ion beams are further analyzed by a 35° ESA and then by another 30°, 185 MeV amu magnet for injection into a gas-ionization detection chamber (GIC). For some applications (ex. ^{10}Be and ^{36}Cl), a Si_3N_4 thin (1 μm) foil is inserted before the ESA for differential energy loss and/or further electron stripping in order to enhance the isobar separation in the GIC.

The L.E. magnet is housed in a cage that can have up to ±5000 V applied at a variable frequency. By varying the applied voltage, ion momenta are changed, and this is used to select different isotopes for sequential isotope injection into the accelerator. This technique, known as fast bouncing, avoids having to wait for a relaxing of hysteresis that would accompany switching of the magnetic field for isotope selection. Depending on the application and isotope ratio, each sample is measured for two or three "runs" that consist of 20–30 "blocks". Each block is a 20–30 s measurement where the rare ion beam is injected for 10 ms, followed by 100 μs injection of the stable isotope beam. This is repeated over the block time in order to obtain rare to stable isotope ratios corrected for ion beam current fluctuations. The isotope ratio of the sample is calculated as the average of the runs. Between sample runs, standard and background sample materials are analyzed for corrections and performance monitoring.

The system was commissioned for the routinely measured isotopes ^{14}C, ^{10}Be, ^{26}Al, ^{36}Cl, ^{41}Ca and ^{129}I. Table 1 lists the current AMS measurement conditions and ion beam transmissions as defined by the ratio of the stable isotope beam current measured after the H.E. magnet, $I_{H.E.}$, to the stable isotope current measured at the accelerator injection Faraday cup, $I_{L.E.}$. This accounts for both ion optical and electron stripping efficiencies. As can be seen in Table 2, the background values of the six major isotopes measured at KIST are consistent with other 6 MV AMS systems around the world (Dresden [7], Cologne [8] and Tsukuba [9]).

2.1.2. 6 MV Tandetron IBA

For IBA work, there are two negative ion sources – a Duoplasmatron with a lithium charge exchange cell (SO-358) and a sputter ion source (SO-860C) – that can produce most of the ion species requisite for IBA and IBMM studies. The ion source beam current performances were measured during commissioning at the 0° exit port of the IBA line switching magnet by addition of a temporary Faraday cup. Results are given below:

Model 358 Duoplasmatron:

$^4He^{2+}$: 1.03 μA at 6.0 MV for one hour

$^1H^+$: 6.8 μA at 6.0 MV for one hour (ref: original spec. 15 μA at 6.0 MV for one hour)

(Due to the high level of gamma rays and neutrons, the injected beam current was reduced from 25 μA H^- to 10 μA H^-. The output after the accelerator was reduced from 16 μA H^+ to 6.8 μA H^+)

Model 860C Sputter ion source:

$^{28}Si^{4+}$: 31 μA at 6.0 MV for 1 h

After acceleration to 35 keV at the ion source, ions are momentum analyzed in a 90° magnet for injection into the accelerator. The high energy IBA line consists of a 90°, 185 MeV·amu magnet