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160 keV ^{26}Al-AMS with a single-stage accelerator mass spectrometer

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ABSTRACT

Proof-of-principle ^{26}Al-AMS analysis is achieved with a single-stage accelerator mass spectrometer (SSAMS) utilising very low ion energy. The SSAMS operates by discriminating against atomic isobar interference in a negative ion source and suppressing molecules with thick gas stripper. Resulting 1+ ions counting is with a surface barrier detector. The NEC designed SSAMS for ^{14}C analysis is a popular model accelerator mass spectrometer and the developed further capability might be a significant addition to established ^{26}Al-AMS capacity. Measurements at these energies should also be sufficient for alternative ^{26}Al positive-ion mass spectrometry (PIMS).

1. Introduction

^{26}Al is a cosmogenic and anthropogenic radionuclide with diverse applications in geological, environmental and biological sciences [1–6]. Highly sensitive accelerator mass spectrometry (AMS) is able to detect ^{26}Al as low as 1 atom in 10^{16} total sample Al atoms, but the technique sufferers from the low electron affinity of aluminium. The resulting difficulty in producing large Al^- currents from the caesium sputter ion sources used makes these measurements slow and expensive with limited accuracy.

The MV tandem accelerator mass spectrometers typically employed in ^{26}Al measurements will also be capable of ^{10}Be detection. This measurement of in situ produced terrestrial cosmogenic radionuclides is normally preferred because of the correspondingly larger ions beams that can be made from common sample material. Nevertheless Al-AMS is needed in additional to Be-AMS to understand complicated exposure history, and for the other applications. Accordingly, developing aluminium AMS on small radiocarbon spectrometers could promote Al-AMS and it applications by expanding the installed base of capable instruments, with implications for analysis cost reductions.

Carbon and aluminium AMS rely on negative-ion atomic isobar suppression. The ^{14}N and ^{26}Mg interferences to ^{14}C and ^{26}Al do not form stable anions and are suppressed in the negative ion source. The remaining molecular interference can in principle be removed with relatively little energy in a compact system. Our single-stage accelerator mass spectrometer (SSAMS) destroys molecular interferences to ^{14}C with ion energy of <300 keV, and such low energy ^{26}Al-AMS has now been demonstrated too.

2. Experiments

Fig. 1 is of the SUERC SSAMS featuring a caesium sputter ion source which accommodates a carousel of up to 134 prepared samples including reference standards, etc. The source is biased to produce negative ions of energy up to 45 keV at ground potential. The resulting ion beam is momentum analysed by a 90° double focusing bending magnet rated to a mass energy product of 1 (a.m.u. MeV) and injected into the accelerator. The magnet vacuum manifold is electrically isolated to allow a switchable bias, known as the magnet bias sequencer (MBS), to be applied. The MBS locally increases ion energy such that lower-mass isotopes can match the rigidity of higher-mass atoms and can selectively be injected into the accelerator in turn. An off-axis multi-channel Faraday cup is aligned on the inside radius of the magnet to measure the ^{13}C and ^{12}C during the ^{14}C and ^{13}C MBS injection cycles respectively. The following accelerator is a single-stage, air insulated, 250 kV deck that houses all of the high ion energy diagnostics at potential. Once there the negatively charged ions enter a 1 m long stripper canal with a 1 cm inside diameter that is at a relatively high pressure, or gas thickness, compared to those in high-energy accelerators, using nitrogen with a input flow rate of 0.85 sccm. The thick stripper gas destroys molecules through multiple low energy collisions but only significantly produces a 1+ charge-state ion beam [7]. Post stripper ion beam analysis is with a second 90° double focusing magnet rated to a mass energy

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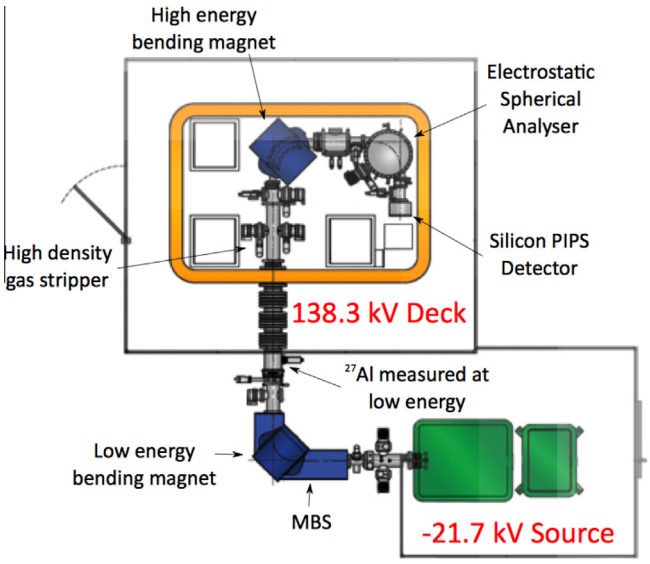

Fig. 1. Schematic of the SSAMS used for ^{26}Al-AMS (courtesy of NEC).

product of 5, to separate out the fractions of a molecule from the beam of interest. Two further off-axis Faraday cups are aligned to measure the ^{12}C and ^{13}C ions on the inside radius of the magnet. The rare isotope is transmitted on-axis to a 90° pre-detector electrostatic spherical ion energy analyser (ESA) and then, through a bounced deflector (SPAD) to the detector. The SPAD stops scattered particles damaging the detector during the stable isotope MBS injection periods. The detector is a silicon Canberra PIPS detector.

To measure aluminium the SSAMS was modified from its standard carbon set-up. ^{14}C is the maximum mass the dipole magnets are designed to transmit at full energy with the current power supplies and so the energy of the ion beam was approximately halved on both the low-energy and high-energy side of the spectrometer in order to transmit aluminium ions, which are almost twice as massive as carbon atoms. Samples were biased to −6.5 kV within the ion source and the source biased to 15.2 kV from ground for a total accelerator injection energy of 21.7 kV. The ion extraction cone in front of the sputtered sample surface was biased to 19.8 kV for efficient ion collection, but this did not add to the total beam energy in the configuration employed. The source typically produced ~1 μA of ^{27}Al$^-$. Similarly, the deck potential was required to be reduced to 138.3 kV, which gave the aluminium ions a total energy of 160 keV. This was the maximum energy of ^{27}Al that the high-energy magnet could transmit to an off-axis cup. The beam focusing of the acceleration tube was poor at this reduced potential resulting in decreased ion optic transmission. In addition, the stable isotope of aluminium, ^{27}Al, is heavier than the rare isotope and therefore would ordinarily be measured by an off-axis Faraday cup on the outside of the magnet radius, which the SSAMS does not have either at ground or on the high-voltage deck. Therefore the first two time-states of the MBS were used to inject ^{26}Al and ^{27}Al into the accelerator in repeated sequence and a third state pulled the ^{27}Al into the low-energy off-axis cup on the inside of the injection-magnet radius. The MBS was used to generate the ratio of high-energy ^{26}Al to low-energy ^{27}Al as the measure of high-energy to low-energy stable isotope ratio was stable. Several Al_2O_3 samples mixed with silver in 1 part Al_2O_3 to 2 parts Ag were used to tune and test the new configuration. Three Nishiizumi standard material (Al01-4-1, Al01-4-2 and Al01-5-3) [8] and commercial blank Al_2O_3 from Fisher and Assure were normalised to Purdue Z92-0222 primary standard (nominally ^{26}Al/^{27}Al = 4.11 × 10^{-11}).

3. Results

Repeated sample measurements were consistent, which limited sample measurement precision to Poisson counting statistics. The two secondary standard materials, Al01-4-2 and Al01-5-3, were each measured as multiple samples and their distributions are shown in Fig. 2a and b respectively. These show a normal or Gaussian distribution due to statistical variation, with no systematic error or addition scatter beyond the average measured error. Table 1 is a table of the average results of several samples for the three types of standard material used normalised to the primary standard. All of the results are within one standard deviation of the nominal values.

The under-gradient acceleration tube limited the focusing of the ion optics and the reduced velocity ion interaction with the thick stripper gas resulted in a combined accelerator and stripper ion transmission of only ~1%. The low aluminium current, although high by AMS standards, and the low transmission resulted in low counting statistics and relatively large error for the low ratio standard, Al01-5-3. The solid-state detector employed has a higher

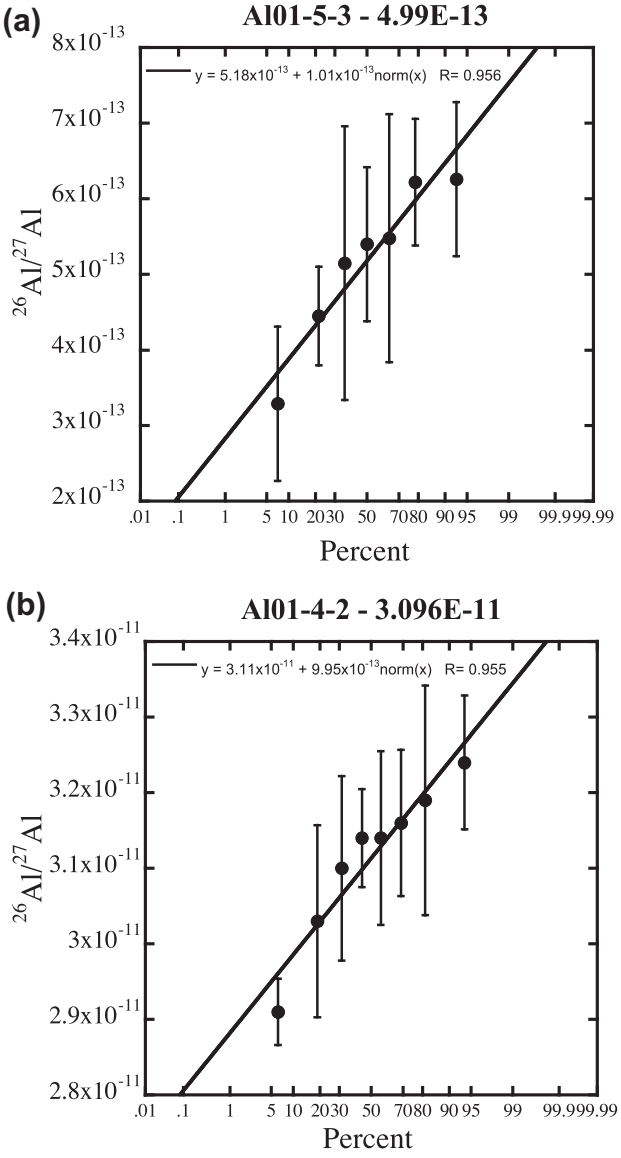

Fig. 2. Probability distribution plots of standard material (a) Al01-5-3 and (b) Al01-4-1 measured at 160 keV on the SSAMS.