ACCELERATOR MASS-SPECTROMETER FOR SIBERIAN DIVISION OF RAS

M. Petrichenkov, N. Alinovsky, V. Klyuev, E. Konstantinov, S. Konstantinov, A. Kozhemyakin, A. Kryuchkov, V. Parkhomchuk, A. Popov, S. Rastigeev, V. Reva, B. Sukhina, BINP, Novosibirsk, Russia

Abstract

The project of the first Russian accelerator mass-spectrometer at BINP is described. The scheme of AMS includes two types of ion sources (sputter and gaseous ones), low energy beam line with analyzers, electrostatic tandem accelerator with terminal voltage up to 2 MV and magnesium vapor stripper. Also it includes the high-energy beam line with analyzers and final detector. The results of first experiments with ion sources are given also.

INTRODUCTION

It is proposed to build the first Russian Accelerator Mass-Spectrometer (AMS) in Novosibirsk. It is designed for measurements of ultra low isotopes (^{14}C, ^{10}Be) concentrations with relative sensitivity $\sim 10^{-15}$ (abundance ratio).

AMS LAYOUT

The scheme of the AMS is shown in Fig 1.

The facility consists of three main parts: low-energy part, tandem accelerator and high-energy part. In the first part the sample material is converted into negative ions $^{14}C^-$, $^{13}C^-$, $^{12}C^-$ and analyzed in the double focusing magnet (#11, Fig.1) at low energy. In the tandem accelerator the ions are accelerated up to 2 MeV and stripped to 3+ state on charge exchange target. After that the ions pass 180° combined bend separator (CBS) and are accelerated in the second part of the tandem. In the high-energy section ions are separated in the magnetic spectrometer (#10, Fig.1) and analyzed in the final detector and multi-Faraday cups.

The specific feature of this facility is additional filtration of the ion beam in CBS (crossed electric and magnetic fields) after stripper. It should additionally decrease the background.

It is also proposed to use magnesium vapor stripping target instead of the gaseous one usually applied for AMS. Gaseous target requires an additional pumping system to reduce gas flux into high-vacuum part of spectrometer. The use of magnesium vapor stripper allows to have the vacuum level in accelerating tubes being comparable with systems with solid (foil) targets. The ion beam on residual gas scattering in accelerating tubes increases the energy spread in the beam and resulting in background growth, thus, limiting the sensitivity and accuracy of spectrometer. Solid targets in this beam energy region have a short lifetime and therefore are not applied usually. The magnesium vapor pressure is $\sim 10^{-10}$ Torr at room temperature and rises up to $\sim 5{\cdot}10^{-2}$ Torr at ~500°C. The operational temperature range of the target is 450-500°C. The diameter of stripping target is 3 mm small in order to decrease the magnesium flux from the target tube and its deposition on high voltage elements of the accelerator. The previously developed analogue of such a target have worked more than 500 hours on the electron cooling investigation facility. [1]

The AMS main systems are considered below.

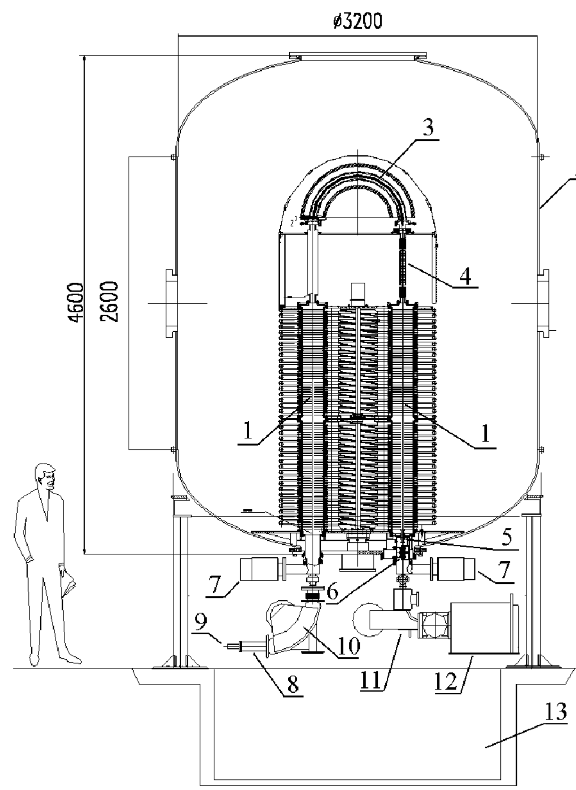

Fig. 1: AMS layout.

1 – accelerating tube, 2 – accelerator vessel, 3 – 180° combined bend separator, 4 – magnesium vapor stripping target, 5 – steerer, 6 – electrostatic three-electrode lenses, 7 – vacuum pump, 8 – final detector channel, 9 – final detector, 10 – high energy double focusing magnetic spectrometer, 11 – low energy double focusing magnetic spectrometer, 12 – ion source, 13 – service pit.

Ion Sources

It is proposed to use the gas and sputter type ion sources for different samples analysis. The optical scheme of low energy section is designed correspondingly. The use of negative ions allows avoiding the influence of isobars (^{14}N for ^{14}C) whose negative ions are too unstable to reach the final detector. The analysis time per sample depends on average ion beam current ~ 1-40 μA, which depends on isotope being measured. For current range mentioned above it is from one to several samples per hour.

One of two ion sources (the gas one, for instance) can be used if necessary as a reference for system calibration.

Sputter Ion Source

The following design of the sputter ion source was chosen (See Fig. 2.).

The source main parts are vacuum-tight body, cathode assembly with carbon sample, ionizer, forming the flux of cesium ions to the cathode and device for cesium vapors delivery to the surface of ionizer. The working surface of ionizer is a spherical-shape cup. The titanium made vaporizer is loaded with $CsCr_2$ pellets.

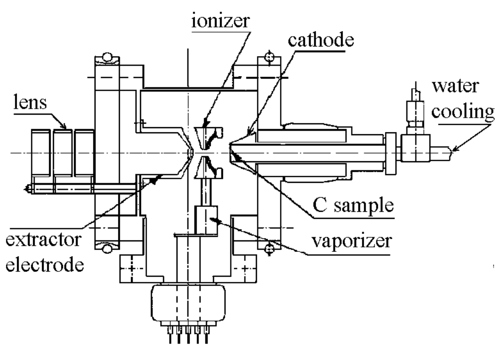

Fig. 2: Scheme of the sputter negative ions source.

The cesium ions beam is focused on the carbon sample placed on the cathode.

Special test bench was created for testing of sputter ion source. Some experiments have been carried out with this ion source in continuous regime. One-day testing was performed (See Fig. 3).

The negative ion beam current was ~ 50 μA, energy 5.5 kV and temperature of vaporizer 290^{0}C. The maximal C^- current in experiments was 150 μA. The experiments of emittance measurements are planned for future.

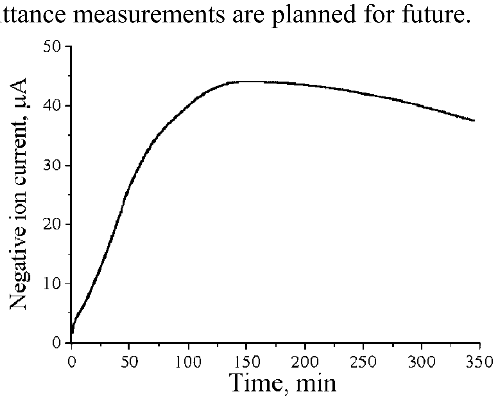

Fig. 3: Time dependence of the output negative ions current from the sputter source.

Gas Negative Ions Source.

It is proposed to use H^- ion source [2] modified for C^- ions generation (CO_2 gas supply instead of H_2O vapor and some other design modifications). It is a Penning cell with ions extraction across the magnetic field through 0.6 mm hole in anode wall. The plasma-forming gas is injected through the needle leak.

The experiments proving the possibility of getting enough negative carbon ions current from plasma of electric discharge in carbonic gases (CO_2, C_3H_8 C_2H_2, CH_4) have been carried out. The 2 μA maximal current of C^- ions was obtained (Fig. 4). It is enough for analysis of gas samples. The increase of discharge power results in the rise of heavier negative ions (O^-, OH^-, OH_2^-) current, mainly.

The typical mass-spectrogram of negative ion beam from the gas ion source (CO_2 supplied) is shown in Fig. 5.

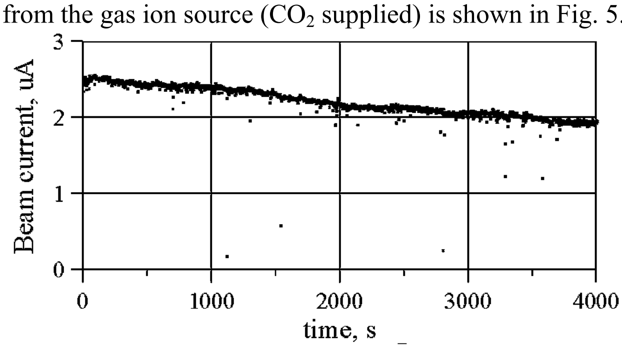

Fig. 4: Time dependence of C^- current from gas source in experiment.

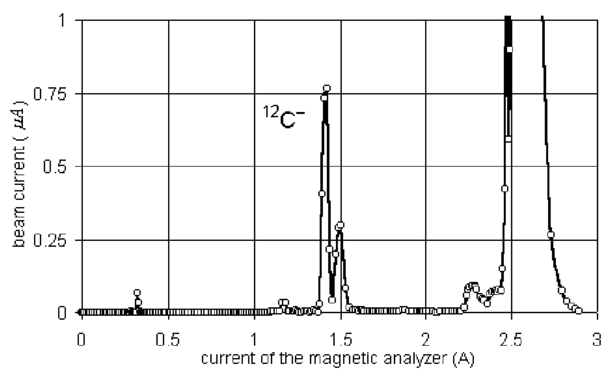

Fig. 5: Typical mass-spectrogram of negative ion beam from gas ion source (on CO_2 gas).

Low Energy Beam Line

The initial filtering of ion beam is realized in transport channel from ion sources to tandem accelerator. The double focusing magnet (with n = 0.5) is used for this aim. The impurity ions are deflected in magnetic field and then analyzed by sectionized Faraday cup. The transport channel includes three-electrode lenses, also.

One of the main requirements for AMS optics is the limitation of the beam size in the stripping tube 3 mm in diameter. The special three-electrode electrostatic lens is used for compensation of strong accelerating tube aperture lens. It provides less than 3 mm beam size in the stripping target. Two lenses are used for operation in 1 ÷ 2 MeV range of terminal voltage. See Fig. 6

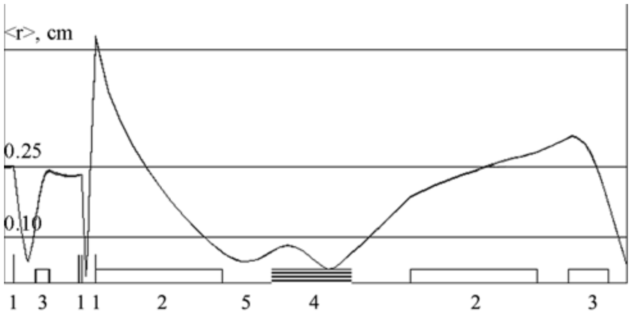

Fig 6: RMS beam size in AMS tract (calculations for $W_0 = 15$ keV – initial energy, $U_T = 1$ MV – terminal voltage), 1 – electrostatic lens, 2 – accelerating tube, 3 – double-focusing magnet, 4 – 180° combined bend, 5 – place of magnesium stripper.

Tandem Accelerator

Two 2 m length accelerating tubes are used in tandem accelerator for AMS. The cascade generator is applied as a high voltage source. The terminal voltage can be adjusted up to maximal value of 2 MV, thus the energy of $^{14}C^{3+}$ ions on the output of accelerator reaches 8 MeV value.

The specific feature of this accelerator is 180° bend of particles after their passage of first accelerating tube and stripping target. The additional beam separation from the fragments of molecules ($^{12}CH_2^-$, $^{13}CH^-$ in ^{14}C measurements) destroyed in magnesium vapor stripper of ~ 1 μg/cm² density and separation from other impurities occurs in it. It consists of double focusing electrostatic plates placed inside the flat poles bending magnet. The forces of crossed electric and magnetic fields are acting in the same direction. By the focusing properties this bend is close to spherical electrostatic deflector due to relatively small magnetic field necessary for separation of $^{14}C^{3+}$ ions from $^{12}C^{3+}$ and $^{13}C^{3+}$ ions on its output (~ 400 Gs is necessary for 1 MeV C^{3+} ions and 40 cm bending radius).

Hi-Energy Beam Section

The beam after tandem accelerator is separated in double-focusing magnet and then analyzed by final solid-state detector. (See Fig 1, 5). The impurity ions deflected by the magnet are analyzed by sectionized Faraday cup. It is proposed to equip the final detector with ΔE-E system on the second stage for measurements of energy losses of incident particles in thin layer of matter and for total energy measurement (by full absorption counter). Such a design of the final detector will allow the separation of isobaric interferences with necessary precision; the inaccuracy of energy measurement will be 3-5 % on the first stage. The detector will be equipped in future with one-coordinate position-sensitive full absorption detector (PSD) for more precise ions separation. The size of sensitive area of the chosen PSD "Sitek 1L30" detector is 4x30 mm².

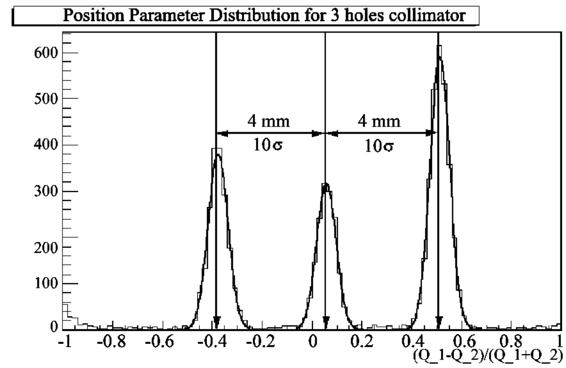

Fig. 7: Results of space resolution test of silicon PSD detector with alpha particles and three-hole collimator.

The result of space resolution test of PSD is given in Fig. 7. The alpha-particles source was used together with 3-hole collimator. The holes were separated by 4 mm. The background observed at 10 Hz typical count rate is low. The space resolution achieved σ ≅ 0.4 mm.

CURRENT STATUS

The preliminary calculations of AMS optics have been done and layout of main elements defined.

The operating model of sputter ion source has been manufactured and the development testing passed.

The possibility of C^- generation in the existing Penning gas source has been proved in experiments. 2 μA maximal current was obtained.

The model of magnesium vapors stripper was produced and thermal tests for its heating up to the required temperature carried out.

The assembly of low-energy section and accelerator tandem has started.

The fast isotopes cycling system is now under consideration.

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