RADIOCARBON MEASUREMENTS AND BACKGROUND INVESTIGATION AT SD RAS ACCELERATOR MASS SPECTROMETER

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Abstract

Present status of the accelerator mass-spectrometer facility (AMS) is described. The main parts of AMS facility have been manufactured and installed at BINP. The most distinguishing features of our AMS machine are the use of the middle energy separator of ion beams and magnesium vapors target as a stripper. The results of first experiments for beam selection and background measurements are presented.

INTRODUCTION

The accelerator mass spectrometry is an ultra-sensitive method of isotopic analysis. The ratio between isotopes ^{14}C and ^{12}C in sample can be less than 10^{-14}. So, the counting methods are used for detection of such low radiocarbon concentration. The precision of radiocarbon measurement is limited by ion background and statistical errors. The background ions can overcome the electric and magnetic filters by interaction with the molecules of the residual gas.

The AMS system consists of the ion source, low energy (LE) channel, tandem accelerator and high-energy (HE) channel [1,2]. The tandem accelerator is a folded type vertical machine. The low energy beam line is used for initial isotopes selection. The tandem accelerator is applied for rejection of the molecular ions and of course for obtaining necessary beam energy for radioisotopes detector. The HE beam line is used for the subsequent ions selection and for radioisotopes detection.

The negative ions beam is horizontally extracted from the ion source [3]. Then the beam is vertically injected into the LE accelerating tube through injection channel with 90° LE magnet. The negative ions are accelerated to the positively charged high voltage terminal and stripped to plus charge state in magnesium vapors stripper. Then they pass through the 180^0 electrostatic bend and then again are accelerated vertically into the high energy accelerating tube to the ground potential. The extracted radioisotope ions are horizontally put to the final detector through high-energy channel with 90° HE magnet.

The most distinguishing features of our AMS machine are the use of the middle energy ions separator. The middle energy electrostatic separator is located inside the tandem terminal. It can essentially decrease the ion background. Interfering isobaric molecules are destroyed by collisions in the stripper into terminal and are selected immediately after stripping process by this separator. It is important to decrease the background from molecular fragments before the second stage of acceleration, because otherwise they can acquire big energy spread by recharging on residual gas into electric field. The next important distinguishing feature is the magnesium vapors stripper instead of the gaseous one. So, it is not necessary to use additional turbo-molecular pump for good vacuum conditions on the outlets of the magnesium vapors stripper (inside the accelerating tubes).

PRESENT STATUS

Now the preliminary tests of the AMS facility at low beam energy (250 kV tandem accelerator voltage) have been completed.

The main parts of tandem accelerator were installed at BINP. The 500 kV terminal voltage was achieved in air medium (without insulating gas). The previous experimental results have demonstrated, that the negative carbon ions beam can be accelerated and stripped in magnesium target. The charge state fractions of carbon beam stripped in the magnesium vapors stripper was obtained [4]. The accelerated beam was measured at the exit of HE magnet [5].

In this paper the first tests for mass-14 isotope selection are presented. During the experiments, the injection energy of carbon beam was 15 keV. The sputter ion source was used for negative carbon ions production from graphite sample. The carbon beam current was 3 uA. The terminal voltage was 250 kV. The ion energies at the exit of AMS facility were 765 keV for 2+ state and 1015 keV for 3+ charge state. The ions transmissions of AMS system at these energies are about 3% and 0.05% for 2+ and 3+ charge states, respectively. The vacuum in the beam line was about 10^{-6} Torr.

The assembling of the AMS complex in specialized building for AMS (Dating Center) has begun this year. The accelerator will be placed into underground room with radiation shielding. The inner size of the room is 6 x 6 x 7.5 meters. We plan to use ~ 2MV tandem voltage for optimum 3+ charge state transmission in this Center equipped with radiation shielding.

The multi-cathode sputter ion source is now being manufactured. It's necessary for synchronous analysis of the forty samples and for comparison of the tested samples with the reference one.

RADIOCARBON MEASUREMENTS

The time of flight (TOF) telescope has been manufactured for ions detection. Then ion passes through collodion foil of the TOF detector, the secondary electrons are accelerated and bended by electrostatic mirror onto the microchannel plate (MCP) assembly. The signals from the MCP anodes of TOF telescope are

transformed to logical NIM pulses by discriminators. The pulsed signals arrive at coincidence circuit and at the delay lines. This coincidence signal was used as a start signal for the time-to-digital converter (TDC). The delayed signals were used as a TDC stop signals. The digital modules were earlier produced by our institute for high energy physics experiments (CAMAC standard). Each TDC channel width is about 500ps. The TOF distance is 32 cm. The maximum rate of TOF measurements is about 10 Hz. The signals from discriminators and coincidence circuit are measured by multi-channel trigger counter at frequencies up to 100kHz.

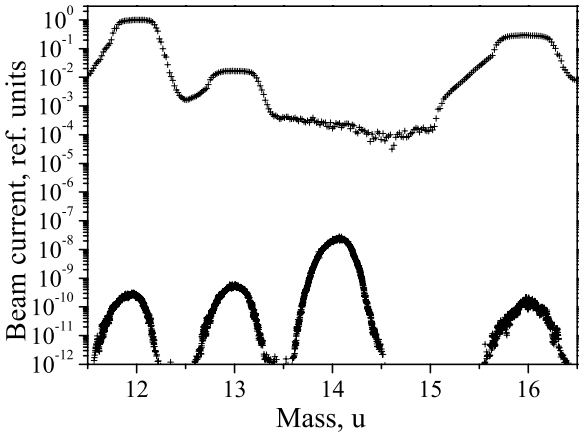

Figure 1: Mass spectrums of the injected (upper curve) and accelerated (lower curve) beams.

The Fig. 1 (upper curve) shows the typical mass spectrum of the graphite target at the exit of LE magnet. The current was measured by Faraday cup. The intensity of the mass-13 peak is about 2% of stable carbon isotope one, but the natural abundance of ^{13}C is 1.1%. It is because the ^{13}C and $^{12}CH_1$ ions can not be separated by LE magnet. The mass-14 is nearly invisible. The intensities of the molecular beams change in time. It depends on vacuum conditions in ion source and sample quality. The beam spectrum at the exit of HE magnet is also shown in Fig. 1. The ions count rate was measured by TOF telescope. Scanning was carried out with mass 14 injected into tandem accelerator with AMS settings appropriate for charge state 2+. The magnesium vapors stripper was heated for obtaining the equilibrium charge state distribution, but not more. The mass 12,13,16 peaks are reduced by 7-9 orders of magnitude. Therefore the mass-14 is clearly visible and separated. At these settings, the mass-14 ions are mainly the isobaric molecular ions.

The molecular background can be suppressed by many orders of magnitude by the stripping process in the magnesium target. For this aim the target thickness must be increased by increasing temperature of magnesium stripper. The test of the molecule destruction process was carried out earlier [6]. The graphite sample used in the ion source was a “dead” sample with low radiocarbon concentration. Thus, the magnesium vapors target thickness necessary for molecular ions destruction is about ten times more than for ion stripping. The achieved 10^{-13} level of mass-14 to ^{12}C ratio is about one order smaller then the radiocarbon concentration in modern sample. The primary beam current decreased by two times by angular scattering of the ions on the denser target.

The intensity of ion background peak mass-13 consists of two parts [6]. One of them is due to HE tails from mass-13 peak energy distribution from ion source, which have the same momentum as mass-14 for injection magnet passing. This part of the unwanted particles can be removed by Wien filter at LE channel. The second part of peak mass-13 is generated between the LE magnet and the LE accelerator tube, by breaking of the mass 14 molecules. The energy of mass-13 beam is smaller than of mass-14 beam energy by an amount of 1/14 of injection energy. This part of the ion background depends on vacuum conditions in LE channel. It's can't be filtered by electrostatic tandem bend, because the energy difference is small. But the fragments of the destructed molecular ions at tandem terminal are filtered by this 180° bend.

The ions in charge state 3+ will be used for isotope analysis because the molecules in charge state 3+ are unstable. The output of charge state fraction of 3+ is small at low beam energy, but first radiocarbon detection was carried out recently despite it. The pressed charcoal target was used in these measurements. The beam spectrum by scanning HE magnet is shown in Fig. 2. The TOF telescope channels are given on the abscissa axis. The mass is calculated from the magnet’s current. Scanning was carried out with mass 14 injected into tandem accelerator. The mass-14 is invisible in Fig. 2., because the scanning time is several minutes. For radiocarbon detection, the HE magnet current is fixed at a value corresponding to the mass 14 passing. The three-hour collection of the detected ions is presented in Fig.3.

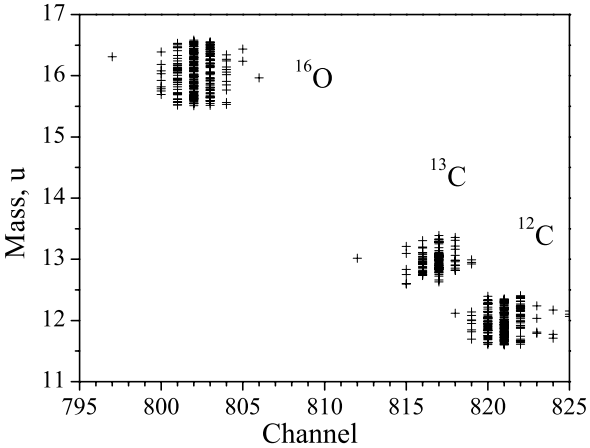

Figure 2: TOF ion spectrum for HE magnet scan.

The nitrogen ions have the same mass as radiocarbon ones, but they are filtered by our AMS complex. The negative nitrogen ions are unstable, but the negative molecular NH^- ions can rich high voltage terminal. Such ions can be produced in the ion source or from residual gas near the entrance of the accelerating tube [7]. The

NH^- ions produced inside the ion source can be significantly filtered in low energy channel, because they have another mass than radiocarbon ions. The NH^- ions from residual gas are accelerated at LE tube without filtration. The positive nitrogen ions are produced from the breakup of NH^- ions after passing through the stripper. The energies for nitrogen from NH molecules are always less than the radiocarbon ions energy into tandem terminal, because nitrogen ion gets only a part of the molecule's energy. Our AMS complex have the electrostatic filter into tandem terminal for effective filtration of the different energy ions. All the AMS complexes existent now have no filter after the first stage of beam acceleration. If the nitrogen ions are accelerated in the HE tube, the ion energy deficit into tandem terminal can be compensated in the HE tube. The particles passed through the tandem with charge state 4+, but recharged into 3+ state at the HE accelerator tube will have a larger energy, than particles passed the whole HE tube with charge state 3+. The recharging takes place by electron capture from residual gas. For typical values: electron capture cross section -10^{-15} cm^2 (1MeV N^{4+}ions on H_2 target [8]), vacuum condition – 10^{-6} Torr, recharging length – 1 cm, the recharging probability will be equal to $3.5 \cdot 10^{-5}$. Such nitrogen ions and measured radiocarbon ions will have a similar energy, mass, charge state and it is difficult to separate them by electric and magnetic filters at the exit of tandem accelerator. They can be selected only by nuclear detector. Such nitrogen ions are filtered in our AMS complex by energy filter into high voltage terminal.

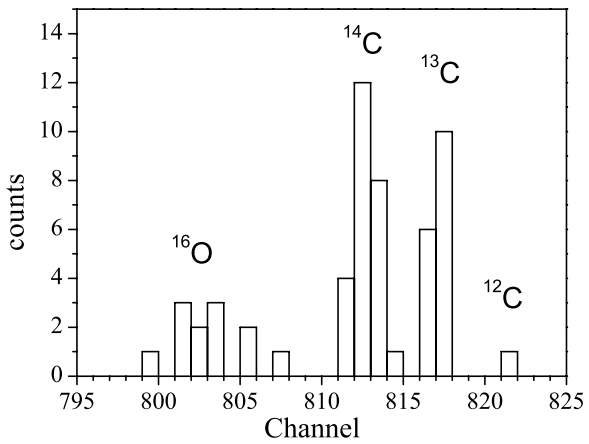

Figure 3: TOF ion counts with fixed HE magnet setting for ^{14}C passing.

We plan to use the TOF telescope with two TOF distance for more accurate radiocarbon identification. The first test of such system with ^{10}B and ^{11}B is presented in Fig. 4. The HE magnet was switched for both isotope collection. The energy of the boron ions was 1015 keV. The TOF distances are 32 cm and 22 cm. Such a system, but with thicker foils, can be used for the ion nuclear charge analysis.

The work on the AMS complex with higher tandem terminal voltage will be started in the 2009 year at Dating Center after the AMS assembly.

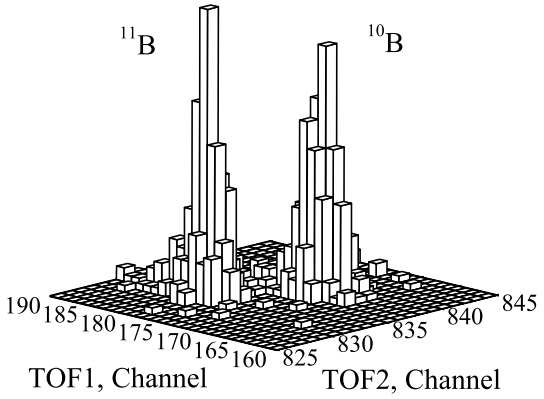

Figure 4: The two-dimensional TOF distribution for the boron ions.

SUMMARY

The main parts of AMS facility have been installed and tested at BINP. The ion background was sufficiently removed from radiocarbon beam. The first experiments for radiocarbon detection was carried out with low beam energy at 250 kV tandem accelerator voltage.

ACKNOWLEDGMENTS

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REFERENCES

[1] N. Alinovsky et al., The project of accelerator mass – spectrometer at BINP., EPAC 2004, Lucerne, Switzerland, 2004, p.2386-2388.C.

[2] N. Alinovsky et al., Status of an accelerator mass–spectrometer project for SD RAS.// Problems of Atomic Science and Technology: Nuclear Physics Invastigations.2006,. #2(46), p34-36.

[3] N. Alinovsky et al., The negative carbon ion sources for accelerator mass–spectrometer.// Problems of Atomic Science and Technology: Nuclear Physics Investigations.2006,. #3(47), p72-74.

[4] N. Alinovsky et al., Status of the Russian accelerator mass spectrometer., EPAC 2006, Edinburgh, Scotland,2006,p.2391-2393.

[5] A. Goncharov et al., Status of BINP AMS Facility., APAC 2007, Indore, India,2007.

[6] N. Alinovsky et al., Recent Results in Accelerator Mass Spectrometer Construction at BINP, IWCPA 2007, Alushta, Ukraine, 2007.

[7] J. Southon, G. Santson, K. Druffel-Rodriguez et al., RADIOCARBON. 2004.Vol. 46, N 2. P. 0.

[8] R.A. Phaneuf, F.W. Meyer, R.H. McKnight, Phys. Rev. A. 1978. Vol. 17. N 2. P. 534.

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