RECENT RESULTS IN ACCELERATOR MASS-SPECTROMETER CONSTRUCTION AT BINP

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Present status of the accelerator mass spectrometry facility at BINP is described. The results of first experiments for ^{14}C selection and background measurements are presented.

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1. INTRODUCTION

The accelerator mass spectrometry is an ultra-sensitive method of isotopic analysis for archaeology, environment science and another fields. It's based on measurements of the ratio between isotopes.

The AMS system consists of the ion source, low energy channel, tandem accelerator and high-energy 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 high-energy beam line is used for the subsequent ions selection and for radioisotopes detection.

The negative ion beam is horizontally extracted from the ion source [3]. Then the beam is vertically injected into the low energy 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.

Now the AMS facility is being constructed at BINP. The construction works in specialized building for AMS (Dating Center) will be finished next year. The accelerator will be placed into underground room with radiation shielding. The inner size of the room will be 6x6x7.5 m. In this Center equipped with radiation shielding, we plan to use ~2MV tandem voltage for optimum 3+ charge state transmission.

The most distinguishing features of our AMS machine is the use of the middle energy separator of ion beams and the magnesium vapors target as a stripper. The aim of this innovations was described in details earlier [1].

2. PRESENT STATUS

The main parts of tandem accelerator have been installed and in operation. The 500 kV terminal voltage was achieved in air medium (without insulating gas). The electrical power required in the HV terminal is generated by the 500 W gaseous turbine.

The previous experimental results have demonstrated, that the negative carbon ion beam can be accelerated and stripped into high voltage terminal of BINP AMS facility. The charge state fractions of carbon beam stripped by the magnesium vapors stripper was obtained [4]. Recently, the first accelerated beam was observed at the exit of HE magnet [5]. The beam was focused to a spot diameter of about 3 mm on the detector surface. The photo from CsI crystal and two transverse profiles from single wire monitor of carbon beam after HE magnet are presented in Fig.1.

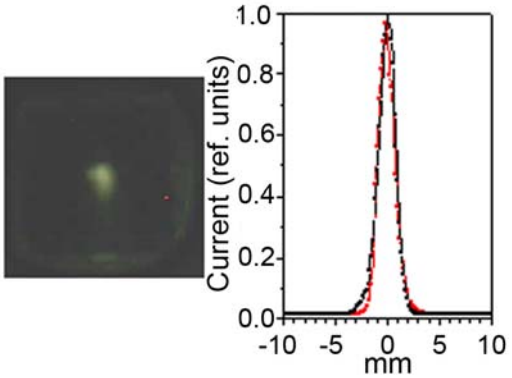

Fig.1. Beam profile at the exit of AMS

In this paper the first tests for mass-14 isotope selection are presented. During the experiments, the injection energy of carbon beam was 10 keV. The sputter ion source was used for negative carbon ions production from graphite sample. The carbon beam current was 1 uA. The terminal voltage was 250 kV. The ions transmissions of AMS system at this energy are about 10%, 1% and 0.02% for 1+, 2+ and 3+ charge states, respectively. The current of accelerated beam was measured by a silicon surface barrier detector or by Faraday cup placed at the exit of HE magnet. The vacuum in the beam line was about 10^{-6} Torr.

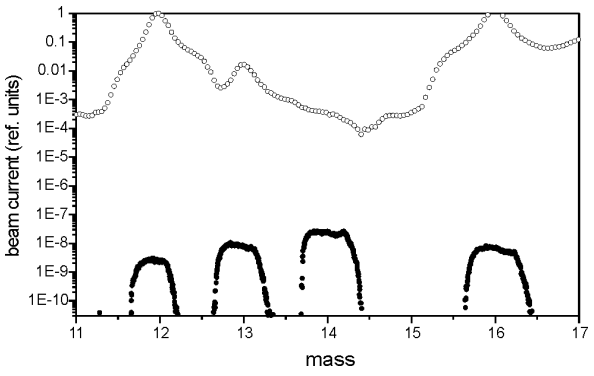

Fig.2. Mass spectrums of the injected (upper curve) and accelerated (lower curve) beams

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3. RESIDUAL BACKGROUND INVESTIGATION

The scattering and charge exchange processes allow the unwanted particles to pass through electrostatic and magnetic filters. The ions can interact with molecules of residual gas and parts of vacuum chamber.

The Fig.2 (upper curve) shows the typical mass spectrum of the graphite target at the exit of LE magnet. It is seen that the intensity of the mass 13 peak is about 2% per stable carbon isotope, 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 are changed 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.2. 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 basic peaks have the same order values, but masses 12,13,16 peaks are reduced by 6…8 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 peaks have a flat-top intensity profiles, because the beam spot size was about ten times smaller than detector window.

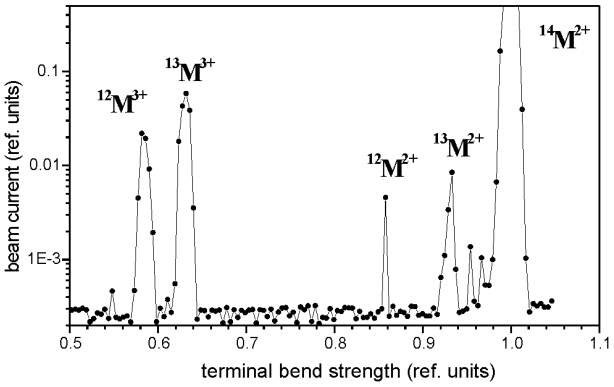

Fig.3. The scan of the tandem bend

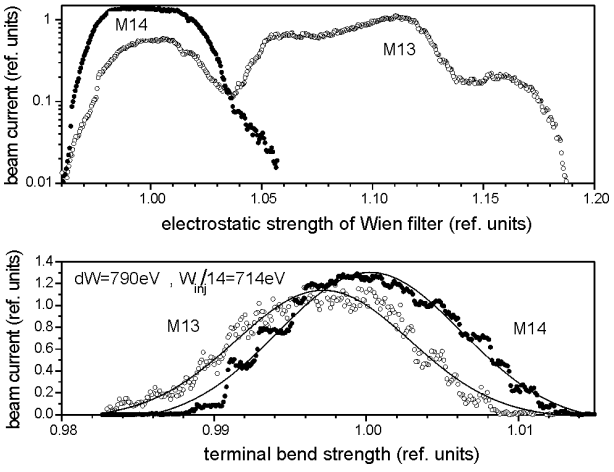

Fig.4. The scan of the electrostatic field of Wien filter (upper part) and of the180° tandem bend (lower part) for mass-13 and mass-14

To test the terminal 180° bend selection, the mass-14 beam was accelerated and passed through HE magnet which was set for ions with mass-14 and charge state 2+. Main ion peak $^{14}M^{2+}$ and peaks from the fragments of molecules is presented in Fig.3 by tandem bend scanning. The velocities of fragments and primary ions are equal in tandem terminal position. So the fragments should be filtered by HE magnet, but after the second stage of acceleration they pass through HE magnet at settings appropriate for mass-14 by recharging into electric field. These fragments of the destructed molecular ions are filtered by tandem bend at operational bend value "1", and can not take part in charge-exchanging process in HE accelerator tube. The primary ions with charge not equal to 2+ are also filtered by tandem 180° bend system. We also have noted, that this bend is very important for the isobaric background filtration, because the positive nitrogen ions are generated from negative NH^- ions, while negative nitrogen ions are unstable.

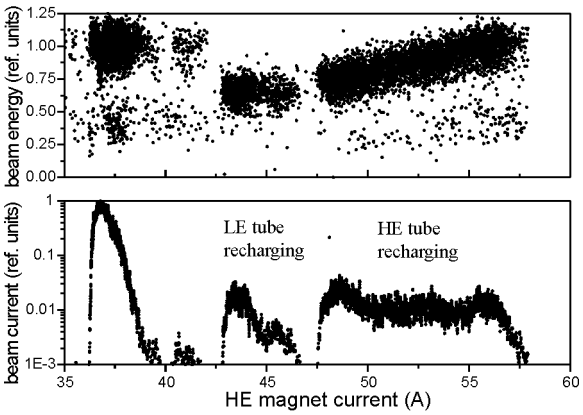

Fig.5. The ions energy (upper part) and detector count rate (lower part) for different HE magnet settings

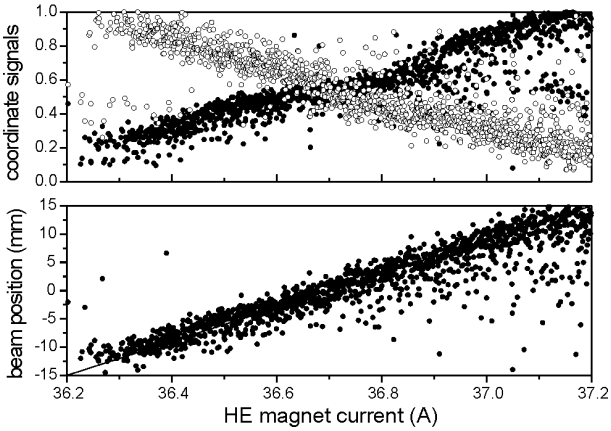

Fig.6 The coordinate signals (upper part) and ions position (lower part) for different HE magnet settings

To investigate the background nature, the Wien filter was added to the injection line. The intensity of peak mass-14 and mass-13 as functions of the electrostatic field in Wien filter are shown in Fig.4 (top part). The field value "1" corresponded to optimal mass-14 passing. The settings of HE magnet corresponded to measured mass. It is seen that mass-13 background consists of two parts. The HE part can be filtered by Wien filter. This background is due to HE tails from mass-13 peak

energy distribution, which have the same momentum as mass-14 for injection magnet passing. With using of the Wien filter set to mass-14, the mass-13 ions are 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, as it is shown in Fig.4 (in lower part). The energy difference is about 1/14 of injection energy. Experiments, when the pump after LE magnet was turned off, showed, what mass-13 current increased by two times, while the vacuum worsened by five times.

The ions energy can be measured by silicon detector. Fig.5 shows the measured ions energy (upper part) and detector count rate (lower part) for different HE magnet settings. The three reference energy points can be selected:

$$W_1 = (1+3)\cdot e\cdot V_t + W_{inj} = 1010\ keV$$
$$W_2 = \left(\tfrac{2}{3}+2\right)\cdot e\cdot V_t + W_{inj} = 677\ keV$$
$$W_3 = (1+2)\cdot e\cdot V_t + W_{inj} = 760\ keV, \qquad (1)$$

where V_t is the terminal voltage, W_{inj} is the beam injection energy. The system was adjusted for charge state 3+ transmission. The primary beam is located at magnet settings of 37 A, with average beam energy W_1. The ions corresponding to 44 A current in HE magnet have the energy W_2. These particles pass through the system with charge 2+, but in front of terminal bend they should have a smaller energy for bend passing. They are recharged from "1–" to "0" state in the LE accelerator tube. The ions of 48-57A range have energy from W_3 to W_1. These particles passed through the terminal bend with charge 3+, but recharged into 2+ state along the HE accelerator tube. All these peaks which are resulted from one step recharging in accelerator tubes are clearly visible in experiments. These peaks with large energy difference are filtered easily by HE magnet. The ions background can pass through the HE magnet by two steps recharging process, but it is below our detectable level. If the background decreasing will be required, the vacuum in the accelerator tubes will be improved by tube heating, or by additional pumps. The magnesium vapors stripper had no the observable influence on vacuum condition.

The position of each ion can be measured by the detector being used. Fig.6 shows the coordinate signals from detector (upper part) and ions position (lower part) for different HE magnet settings. This data is presented without selection particles by their energy by silicon detector. The data in Figs.5,6 are obtained in the same scan. Previously, the 0.4 mm space resolution was achieved in tests with the alpha-particles source [1].The space resolution information will be used for additional particle identification.

The background in AMS with middle energy separator, located in tandem terminal is filtered below our current detectable level. When we'll work with higher terminal voltage (~2 MV) the AMS sensitivity will be improved. The background investigations based on the described results will be continued.

4. MOLECULES DESTRUCTION

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. In test of the molecule destruction process, the target was heated up to 500^0C. During target surface heating the temperature inside the magnesium target reaches its preset value after some delay time. The effective inner temperature (T_{in}) of target and the target surface temperature (T_{out}) as a functions of time are presented in the upper part of the Fig.7. The surface temperature is controlled by thermocouples. The inner temperature was obtained by numerical solution of the thermal equation:

$$\frac{dT_{in}}{dt} = (T_{out} - T_{in})/\tau \qquad (2)$$

The left part of the equation is a heat required to raise temperature, and the right part of the equation is a heating by thermal conduction from the target surface. The delay time τ is obtained from ion stripping efficiency by using experimental data, which are presented in the lower part of the Fig.7. There the beam current curves as a functions of the T_{out} (curve 1) and T_{in} (curve 2) with 430 s delay time are given. During the experiments, the temperature increased from 430^0C to 500^0C within ~ 15 minutes and then dropped again during the same time. One can see that the beam current dependence function on T_{out} have a hysteresis form, but the beam current dependence function on T_{in} have the same form with increasing and decreasing temperature. It is implied that T_{in} is a temperature of magnesium vapor. The delay time is nearly independent on the temperature increase rate.

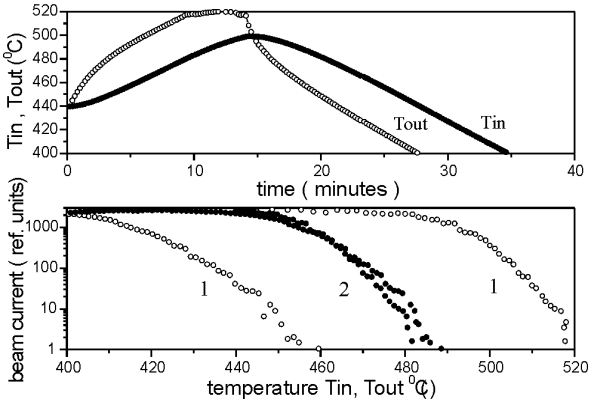

Fig.7. The time dependence of the temperatures of the magnesium vapor and of the container (upper part), the beam current (lower part) as functions of the container temperature (1) and of the vapor temperature (2) during heating and cooling

The molecular destruction process is presented in the Fig.8. The 2+ charge state mass-14 ions were used. The target thickness is obtained from the temperature by use of temperature-pressure data [6], with 30 cm target length. The $5.5\cdot10^{-16}$ cm^2 destruction cross section is used for fitting in Fig.8. The equilibrium charge state distribution of ions passing through the target is reached with about $4\cdot10^{15}$ 1/cm^2 (430^0C) target thickness.

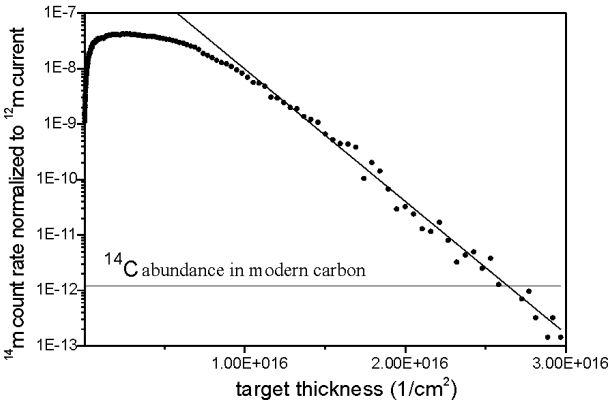

Fig.8 The destruction of the molecules

Thus, the magnesium vapors target thickness necessary for molecular ions destruction is about ten times more than for ion stripping. The primary beam current is decreased by two times by angular scattering of the ions on the denser target. The graphite sample used in the ion source was a "dead" sample with low radiocarbon concentration. The achieved 10^{-13} level of mass-14 intensity is about one order smaller then the radiocarbon concentration in modern sample.

SUMMARY

The main parts of AMS facility have been installed and in operation. Initial research was focused on background filtration. The different components of the ion background were considered. The ten percent background level was achieved at 250 kV tandem accelerator voltage.

ACKNOWLEDGMENTS

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РЕЗУЛЬТАТЫ ПО СОЗДАНИЮ УСКОРИТЕЛЬНОГО МАСС-СПЕКТРОМЕТРА В ИЯФ СО РАН

С.А. Растигеев, Н.И. Алиновский, А.Д. Гончаров, В.Ф. Клюев, С.Г. Константинов, А.М. Крючков, В.В. Пархомчук, М.В. Петриченков, В.Б. Рева

Рассмотрено текущее состояние работ по созданию в ИЯФ им. Г.И. Будкера ускорительного масс-спектрометрического комплекса (AMS). Приведены результаты первых экспериментов по выделению ^{14}C и измерению фона.

РЕЗУЛЬТАТИ ПО СТВОРЕННЮ ПРИСКОРЮВАЛЬНОГО МАС-СПЕКТРОМЕТРА У ІЯФ СВ РАН

С.А. Растигєєв, Н.І. Аліновський, А.Д. Гончаров, В.Ф. Клюєв, С.Г. Константинов, А.М. Крючков, В.В. Пархомчук, М.В. Петриченков, В.Б. Рева

Розглянуто поточний стан робіт з створення у ІЯФ ім. Г.І. Будкера прискорювального мас-спектрометричного комплексу (AMS). Наведено результати перших експериментів по виділенню ^{14}C і виміру фону.