Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 565 (2006) 686–690
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

A gas-multiplication telescope detector for low-energy ions

Rosa G. Liberman[a,*], Ulrich J. Becker[b], Paul L. Skipper[a]

[a]BEAMS Lab, Biological Engineering Division, Massachusetts Institute of Technology, 77 Massachusetts Ave., Room 56-731, Cambridge, MA 02139, USA
[b]Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Received 7 March 2006; received in revised form 31 May 2006; accepted 1 June 2006
Available online 3 July 2006

Abstract

A new detector has been designed and built for the accelerator mass spectrometry (AMS) system at the MIT BEAMS Laboratory. This gas ionization detector uses the common segmented-anode design to measure energy loss in two sectors. It differs from existing designs in having wire grid anodes rather than flat plates in order to permit gas multiplication of the signals induced by drift electrons from initial ionization of the gas. The detector output for 2.5 MeV ions is easily sufficient to feed conventional pre-amplifiers and is without interfering levels of electronic noise. Initial testing indicates that this detector resolves $^{14}C^{2+}$ from all other well-defined signal clusters in the E_r vs. ΔE spectrum at the level required for operation of the AMS instrument.

PACS: 7.75.+h; 28.41.Rc; 29.40.Cs; 41.75.−i

Keywords: Accelerator mass spectrometry; Biological AMS; Segmented anode ionization chamber; ^{14}C labeling; Biomedical samples

1. Introduction

The accelerator mass spectrometry (AMS) instrument at the MIT BEAMS Lab was designed to be a very compact system for analysis of ^{14}C or tritium, as these isotopes are used in biomedical studies. Since the more commonly used isotope, ^{14}C, is naturally present in living organisms (Modern isotope ratio $^{14}C{:}^{12}C = 1.2 \times 10^{-12}$), the instrument design criteria were relaxed as compared to instruments used for radiocarbon dating [1]. In the original design, the detection system used a solid-state detector, which provided only an energy spectrum to resolve ^{14}C from other particles. As reported earlier [2,3], the approximately 1 amol (1 amol = 10^{-18} mol) limit of detection[1] of the system could only be achieved with samples having isotope ratio greater than 100 Modern. To some extent, this limit derived from the lower current that can be achieved with a gas-fed ion source, but the high background from isoenergetic particles was also a major contributor to the detection limit.

The most abundant ^{14}C isobar, ^{14}N, is not a contaminant in radiocarbon AMS because the instruments use negative ion sources and $^{14}N^-$ is so unstable that it does not survive long enough to be detected [4]. However, mass-14 particles, such as $^{12}CH_2$, ^{13}CH and Li_2 molecules, are transparent to mass selection in the injector magnet and therefore are injected into the accelerator along with $^{14}C^-$. Their break-ups at the stripper may undergo subsequent charge-exchange collisions and, as a result, acquire the same magnetic rigidity as $^{14}C^{2+}$ and fail to be completely filtered out before reaching the detector. There is another possible source of contaminations intrinsic to AMS instruments, such as ours, that use a gas-fed ion source to produce carbon ions from CO_2: some CO_2^- may form instead of C^-. Oxygen ions produced from CO_2^- break-ups in the injector can acquire the same magnetic rigidity as $^{14}C^-$ if the breakup occurs at the right point in the ion's acceleration through the electrostatic field within the source and be injected into the accelerator. Since such O^- ion current could be very large relative to the $^{14}C^-$ current, even a very low fraction thereof that scattered through the

*Corresponding author. Tel.: +1 617 258 0417; fax: +1 617 252 1787.
E-mail address: liberman@mit.edu (R.G. Liberman).

[1]Results produced from this AMS system correspond to the total amount of ^{14}C in a sample rather than the isotope ratio.

0168-9002/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2006.06.010

high-energy analyzer to reach the detector could contribute significantly to background. Finally, lithium is always a concern in radiocarbon AMS when the instrument is operated so as to select the carbon charge state 2+ in the high-energy sector since Li^{+1} has the same m/z.

Resolution of isoenergetic ions that reach the detector of an AMS instrument is routinely achieved through the use of a gas ionization detector that records energy loss in two or more sectors, an arrangement often referred to as a telescope. Resolution is achieved because ions of different atomic number or that differ because of molecular structure lose energy at different rates. The ratio of energy loss in one sector to the loss in another sector is thus an identifying characteristic of a specific ion.

Our AMS instrument produces relatively low-energy ions. In typical operation, the terminal voltage is about 775 kV and the selected charge state is 2+, so the final particle energy is about 2.3 MeV. Several factors combine to present significant challenges to designing a telescope gas ionization detector for use with ions at this energy. One is the energy loss in the detector window. Another is the low yield—relative to ion-implanted silicon—of ion pairs produced by incoming particles. Distribution of the total particle energy loss among multiple sectors further reduces the signal produced in each sector.

Reduction of energy loss in the detector window has been accomplished very successfully [5] through use of silicon nitride (Si_3N_4). Framed membranes of this material in thicknesses of 50–100 nm and suitable rectangular dimensions are now commercially available (Silson, Ltd.). Membranes of 100 nm have ample strength for the pressures used to stop 1–3 MeV carbon ions and produce energy losses of only ~200 keV.

The low abundance of drift electrons produced by ionizing particles in a gas detector, which is further reduced in each sector of a multi-anode detector, increases the performance requirement at the pre-amplification stage of the signal processing. One approach to achieving higher pre-amplification performance is to install it within the detector chamber, thereby reducing the total capacitance of the circuit between the anode and the amplifier and providing more effective shielding for all the electronics. Our original detector design—which included flat-plate anodes—did not lend itself readily to internalizing the pre-amplifications. We therefore investigated the possibility of simply replacing the original anodes with continuous-wire grids biased to higher potential in order to achieve gas multiplication of the detector signals. We report here the successful implementation of this approach and describe the performance of the final design as it is used with our AMS system.

2. Design

The original design was that of an ionization chamber with a Frisch grid [6]. The entrance window was a 100 nm-thick silicon nitride membrane, 5 × 10 mm, supported on a 200 μm-thick frame. In order to ensure the uniformity of the electric field across the particle trajectory, the window was mounted onto a separate piece that projects into the detector box, positioning the window 1 cm into the ionization region defined by the cathode and Frisch grid, which were 5 cm apart. Between them were placed a set of five guard electrodes, connected by a resistor divider chain composed of 100 MΩ resistors, to improve uniformity of the electric field near its edges. The anode plate, made of alodined aluminum, was divided into two sectors 55 and 45 mm long for measurement of energy loss (ΔE) and residual energy (E_r), respectively. The distance between the anode plates and the Frisch grid was 2 cm. The whole arrangement was placed inside a Faraday cage in order to have a defined ground reference. This Faraday cage was electrically isolated from the outer box that provided the gas enclosure. Electrical connections were made by means of high-vacuum electrical feedthroughs located in the back plate of the external box of the detector.

Initial tests of this design were conducted using α-particles with an estimated energy of 4.3 MeV generated by an uncalibrated ^{241}Am source and with the two anodes connected together. After electronic noise had been reduced to the minimum achievable, the observed signal-to-noise ratio (SNR) was still too low for the detector to be useful for 2.3 MeV ^{14}C particles, especially considering that as little as 25–30% of that energy might be deposited in one of the two sectors.

With the goal of increasing the signal without producing a corresponding increase in noise, we reconfigured the anode region to accommodate a pair of wire grid anodes that could be biased to a sufficiently high potential to induce gas multiplication. The Frisch grid was retained in its existing location. The two anode plates were replaced by a single printed circuit board frame that holds two continuous grids of gold-plated tungsten wires (28 μm thick, 2 mm spacing) electrically isolated from each other. This board sits at equal distance between the Frisch grid and a grounded backplane, placed 1 cm apart. Although we did not perform exhaustive measurements, we observed that the amplified signals produced by 4.3 MeV α-particles were close to the electronic noise, then about 5 mV. After the modification, the α-particles yielded signals of 2–8 V depending on pressure and voltage used. We estimate the gain of the detector obtained by multiplication to be in the range of 500–2000.

All the other physical characteristics of the detector (i.e., entrance window, distance between cathode and Frisch grid, guard electrodes, Faraday cage and external box) remained unchanged. Minor changes in connectors needed to be done, in order to have the ability of working with high voltage (between 500 and 1000 V). Fig. 1 shows a schematic of the detector as it is in this final design. The detector is mounted on the analyzing magnet chamber, but it is electrically isolated from it and the rest of the accelerator in order to have a good voltage reference and reduce interference noise. A gate valve placed just in front