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ScienceDirect
Nuclear Instruments and Methods in Physics Research B 259 (2007) 213–216
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

The development of a gas-filled time-of-flight detector

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Available online 12 March 2007

Abstract

A gas-filled time-of-flight (GF-TOF) detector system for isobaric identification has been developed at the AMS facility of the China Institute of Atomic Energy (CIAE). The newly built GF-TOF detector was tested by using a ^{36}Cl standard sample (^{36}Cl/Cl = 2.88×10^{-11}) with the ^{36}Cl ion energies of 64, 49 and 33 MeV. Time resolutions of 350 ps, 580 ps and 920 ps were obtained for 64, 49 and 33 MeV ^{36}S, respectively, without gas. ^{36}Cl and ^{36}S particles were successfully separated in the TOF spectra from the GF-TOF detector at the three different incident energies. The dependence of time resolution and separation power of GF-TOF method on the incidence energy and the residual energy is discussed. The comparison of separation power for isobars between the GF-TOF method and the ΔE–E method is described. A combination of GF-TOF method and ΔE–E method may further improve the separation power for isobars. The results show that the sensitivity for ^{36}Cl AMS measurements is 10^{-14} at the energy of 33 MeV. Some results obtained with the GF-TOF method are given.

PACS: 29.40.Cs; 34.50.Bw; 07.75.+h; 29.30.Ep; 05.45.Tp

Keywords: Isobaric identification; GF-TOF detector system; Accelerator mass spectrometry

1. Introduction

A gas-filled time-of-flight detector was built to identify the isobars in AMS measurements in 1999 by Jiang et al. [1]. The time resolution of that GF-TOF system was about 1.3 ns without gas, which is not as good as expected. Later, a new GF-TOF detector was built and tested using ^{36}Cl ions with the energy of 28 MeV in 2002, but the experimental results were still not satisfactory [2]. ^{36}S and ^{36}Cl could not be well separated by either detector due to the large energy straggling caused by the thick entrance window. A new GF-TOF detector system has now been established with a time resolution of 350 ps or better without gas. The improvement in time resolution was brought about by using a thinner entrance window, an optimum flight length and a low resistance surface barrier detector (SBD) as the stop detector. With this newly built detector system, it is possible to separate ^{36}Cl and ^{36}S by using the GF-TOF method at the ion energy of 64 MeV, 49 MeV and 33 MeV. A similar technique has been developed using highly homogeneous low stress silicon nitride foil instead of gas-filled chamber by Vockenhuber [3]. For ^{36}Cl measurements at 0.5 MeV/amu a reduction of ^{36}S by 10^4 was achieved.

2. Structure of GF-TOF detector

The structure of the new GF-TOF detector system is schematically shown in Fig. 1. It consists of a micro-channel plate (MCP), a SBD and a gas-filled chamber. The 50 cm long gas-filled chamber with an entrance window of 16 mm in diameter and sealed with a Mylar foil of 0.9 μm thickness is filled with P10 (argon plus 10%

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doi:10.1016/j.nimb.2007.01.310

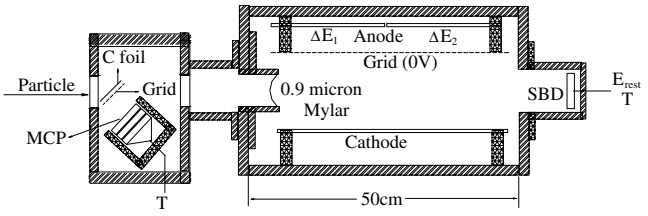

Fig. 1. Schematic diagram of GF-TOF detector system.

methane). A low resistance SBD (400 Ω cm) with 26 mm diameter is located at the rear of the chamber and insulated from the chamber. The distance between the entrance window and the SBD detector is 60 cm. The MCP detector and the gas-filled chamber have been described in detail previously [2]. A ^{36}Cl standard sample ($^{36}Cl/Cl = 2.88 \times 10^{-11}$) was used to test the detector system at the ^{36}Cl ion energies of 64, 49 and 33 MeV. Time resolutions of 350 ps, 580 ps and 920 ps, respectively, were obtained without gas.

3. Theoretical analyses

In the GF-TOF method, the time resolution is mainly limited by the energy straggling caused by the gas and the Mylar foil. The total contribution from other factors to the time resolution is about 200–300 ps. The contribution of time resolution (δ_t) is from the intrinsic resolution of the detector system (δ_{inst}) and the energy spread of ions (δ_{E-spr}), as expressed in Eq. (1)

$$\delta_t^2 = \delta^2_{inst} + \delta^2_{E-Spr} \quad (1)$$

where the term of energy spread δ_{E-spr} is expressed by

$$\delta_{E-spr} = \frac{1}{2}\frac{\delta E}{E}t \quad (2)$$

where E is the effective energy (MeV), δE is the effective energy spread (MeV) and t is the flight time (ns). The effective energy and energy spread of the ions passing through the absorber, E and δE is given by approximate formulae (3) and (4), respectively.

$$E = 0.25(E_i + E_r + 2\sqrt{E_i E_r}) \quad (3)$$

$$\delta E = 0.25[(1 + E_r^{1/2}E_i^{-1/2})\delta E_i + (1 + E_i^{1/2}E_r^{-1/2})\delta Er] \quad (4)$$

where E_i and δE_i are the energy and the energy spread measured by the SBD for the chamber without gas. E_r and δE_r are the energy and the energy spread expected at the SBD for the chamber filled with gas. Energy loss is estimated by the code SRIM [4]. The energy straggling is predicted by Shapira's semi-empirical formula [5]. The energy spread for ^{36}Cl ions with the energy of 64 and 48 MeV passing through different pressure have been measured. Satisfactory agreement has been obtained between calculated and experimental data for the energy spread.

The TOF difference (ΔT) between the isobars is dependent on the incident energy, residual energy and the flight length. Fig. 2 shows the calculated ΔT between ^{36}Cl and ^{36}S for different gas media and pressures for 60 cm flight length. The results indicate that ΔT increases with increasing incident energy and the with increasing energy loss in the gas. But the dependence of ΔT on the kind of gas is not obvious.

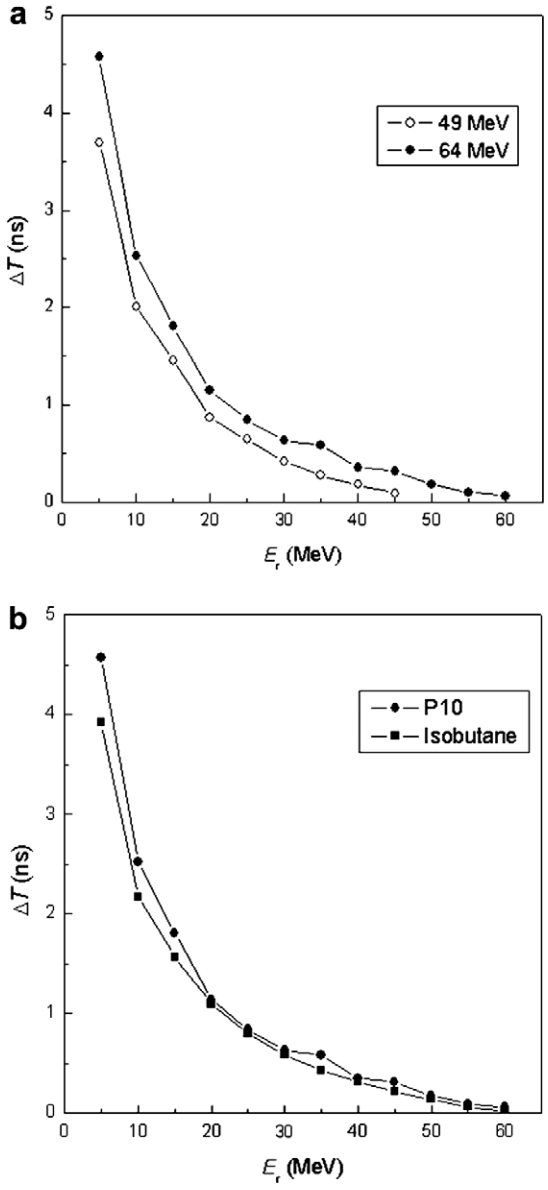

Fig. 2. Calculated TOF difference versus residual energy: (a) ^{36}S and ^{36}Cl particles passing through P10 gas with incident energies of 64 and 49 MeV, (b) ^{36}S and ^{36}Cl particles passing through P10 and isobutane with 64 MeV incident energy.

4. The isobar identification for ^{36}Cl and ^{36}S

The isobars ^{36}S and ^{36}Cl were chosen for testing the identification power of the GF-TOF detector system. ^{36}Cl standard samples of $^{36}Cl/Cl = 10^{-9}$, 10^{-11} and 10^{-13} were measured at energies from 33 to 64 MeV. Fig. 3a shows one of the GF-TOF spectra for 64 MeV ^{36}Cl and ^{36}S ions passing through the chamber filled with 40.2 mbar P10 gas, and