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Annular gas ionization detector for low energy heavy ion backscattering spectrometry

M. Mallepell, M. Döbeli *, M. Suter

Ion Beam Physics, ETH Zurich and Paul Scherrer Institute, IPP HPK H32, Schafmattstrasse 20, CH-8093 Zurich, Switzerland

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ABSTRACT

A gas ionization chamber for use in backscattering spectrometry has been built. It has the shape of a hollow cylinder and can be placed in-line with the incident ion beam. The entrance window for detected particles is composed of a circular array of silicon nitride membranes. A low noise preamplifier with cooled FET is used for charge amplification. The detector resolution has been measured for a variety of ions in the mass range from He to Si and for energies between 0.5 and 8 MeV. The energy resolution of the ionization chamber surpasses the one of a state-of-the-art silicon charged particle detector for all ions heavier than Li. For Si ions the improvement in resolution is more than a factor of 2. The device does not suffer from any radiation damage. For He particles around 1 MeV the resolution is between 13 and 16 keV (FWHM). Therefore the new detector is not only well suited for heavy ion backscattering spectrometry but can also be applied for standard He RBS, allowing the use of a single detector for all types of projectiles in a wide energy range.

1. Introduction

Rutherford Backscattering Spectrometry (RBS) is usually performed for the compositional analysis of surfaces with ^{4}He ions of energies around 2 MeV [1]. Under these standard conditions, mass resolution is clearly limited for heavier target masses even when high resolution detectors are applied. This restriction can be overcome by using ions heavier than helium as projectiles [2,3]. The simple silicon charged particle detectors normally applied for RBS are a bad choice in this case due to enhanced radiation damage and reduced energy resolution. Silicon PIN diodes are a cheap option for occasional measurements but suffer from the same disadvantages as dedicated charged particle detectors. Alternatively, high resolution electromagnetic or time-of-flight spectrometers can be used [4,5,3]. These detectors may offer ultimate depth and mass resolution, however at the expense of increasing complexity, reduced usability and cost. Considerable care has to be taken concerning, e.g. charge state of the ions and energy dependent detection efficiency. In addition, the limited solid angle of high resolution spectrometers has a negative impact on measurement time and beam damage to the sample.

At very high projectile energies, gas ionization chambers have been used as simple alternatives to Si detectors [6]. For particle energies higher than approximately 0.5 MeV/u conventional gas detectors can reach an energy resolution well below 1%. However, due to variable energy loss in the entrance window and low charge output compared to silicon detectors, the energy resolution of gas ionization detectors with plastic windows deteriorates fast for ions below about 0.3 MeV/u. A few years ago, thin silicon nitride foils [7] became available as entrance foils for gas ionization chambers [8,9]. In addition, considerable progress has been made in electronic noise suppression in charge sensitive preamplifiers used for the measurement of the very small signals produced by low energy ions in gases [10]. This has led to a situation where gas ionization detectors can maintain an energy resolution of a few percent down to particle energies of 0.1 MeV/u and below. They now outperform silicon detectors for particles heavier than lithium even at energies of a few hundred keV. For low energy protons (0.1–0.4 MeV) an energy resolution of approximately 11 keV has been obtained, corresponding to the electronic noise level of the preamplifier [10]. Following a tremendous impact of this type of ionization chamber in low energy Accelerator Mass Spectrometry (AMS) the same technique has been successfully used to build a detector telescope for low energy heavy ion ERDA [9].

* Corresponding author. Tel.: +41 1 633 2045; fax: +41 1 633 1067.
E-mail address: doebeli@phys.ethz.ch (M. Döbeli).

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Since the energy resolution of such a device is approaching the values obtained with silicon detectors even for low energy protons and helium, they have the potential to become universal detectors for charged particles in ion beam analysis experiments. In this paper we describe the details of a hollow cylindrical gas ionization detector optimized for particles in the low MeV range. The device has been tested in backscattering experiments with projectiles from ^{4}He to ^{28}Si, yielding very promising results.

2. Experimental

2.1. Design considerations

To obtain optimum energy resolution and to allow practical application of the ionization chamber in backscattering experiments a number of design conditions have to be considered. First of all, the use of silicon nitride entrance windows and CoolFET® preamplifiers [10,11] are key features of high resolution gas ionization chambers. While the replacement of conventional plastic windows by silicon nitride membranes is essential for all particle types below about 0.5 MeV/u the use of low noise electronics becomes important for light ions with atomic numbers below approximately 6 [10]. Secondly, kinematic broadening due to the finite solid angle of the system has to be taken into account in order to be able to take full advantage of the intrinsic energy resolution of the detector. Since kinematic broadening becomes more serious for heavy projectiles [2] it is important to reduce the variation $\Delta\theta$ of the scattering angle across the active area of the detector as much as possible and to keep the scattering angle θ close to 180°. At this angle, the dependence of the kinematic factor on θ is smallest. Because gas ionization detectors are generally bulkier than silicon charged particle detectors it is a design challenge to place the device close enough to the incident beam axis. An optimum way to obtain the maximum solid angle for a given $\Delta\theta$ is offered by an annular detector window centered on the beam axis [12]. Our ionization chamber is therefore of cylindrical geometry with the incident beam passing through the central axis of the device.

The optimum noise performance of charge sensitive preamplifiers can only be obtained by keeping the input capacitance as small as possible. By properly selecting the distances of the anode to the Frisch grid and the detector housing and by minimizing the length of the signal cable, the total detector capacitance was limited to less than 50 pF.

Silicon charged particle detectors can be accommodated in a scattering chamber with ease and only one single electrical connection is necessary. Ionization chambers however are bigger and need additional voltage and gas supply feedthroughs. A large vacuum vessel with gas seals inside the high vacuum is therefore required. In order to simplify the construction and to allow the use of the detector with small scattering chambers we chose a design where the ionization chamber is in-line with the incident beam tube and is attached to the outside of the scattering chamber. This also facilitates the transfer of the device from one analysis chamber to the other. However, a careful mechanical adjustment of the detector to the beam axis is necessary due to the relatively small opening of the inner beam tube. The reduction in pumping speed between the beam line and the sample chamber has to be taken into account as well.

2.2. Construction details

A complete view of the gas ionization detector is shown in Fig. 1. The incoming particle beam is guided through the middle of the device by a metal tube with 4 mm inner diameter. All electrodes are of cylindrical shape. In order to minimize the capacitance and to keep the electronic noise as small as possible, the anode is put on the inner part of the detector. It has an outer diameter of 14 mm and a length of 165 mm. The Frisch grid is placed around the anode and is formed by 80 gold-covered tungsten wires of 20 μm thickness stretched along the long side of the detector forming a cylinder of 24 mm diameter with a distance of 0.9 mm between wires. The outermost electrode is used as cathode and has a diameter of 90 mm. The applied bias voltages are −160 V (grid) and −250 V (cathode). The anode is kept at ground potential which allows to connect it directly to the FET of the preamplifier without capacitive AC coupling. The signal cable is only a few cm long and the low noise Amptek CoolFET® preamplifier is placed directly outside of the rear flange of the detector.

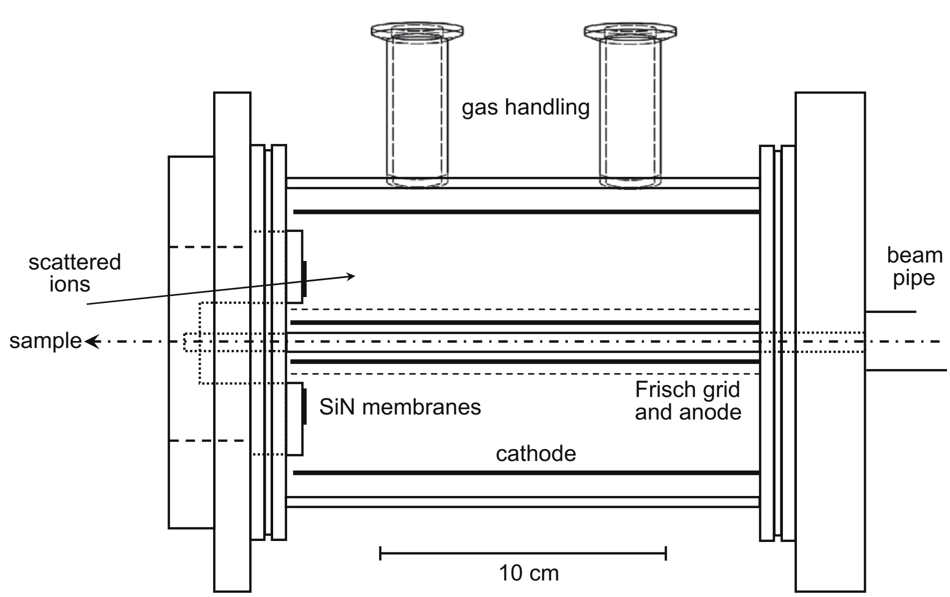

Fig. 1. Schematic view of the annular gas ionization detector with main components.