Nuclear Instruments and Methods in Physics Research B 540 (2023) 262–264

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, B

journal homepage: www.elsevier.com/locate/nimb

Nitrogen gas scintillation counter for high-intensity heavy ion beams with negligible radiation damage

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ARTICLE INFO

Keywords:
N_2 gas
Gas scintillation counter
Particle identification
High-intensity heavy ion beam
Radiation damage

ABSTRACT

We developed an N_2 gas scintillation counter as a time-of-flight counter for particle identification of radioactive isotope beams. Radiation damage, which often becomes a problem for high-intensity heavy ion beams, can be prevented by a continuous flow of N_2 gas. The scintillator, with a volume of 60 mm × 60 mm × 100 mm, was filled with N_2 gas at a pressure of approximately 100 kPa. Photons were detected using photomultiplier tubes attached to both sides of the vessel. The main emission wavelength of photons produced in the detector was 300–400 nm. Performance tests confirmed that the detector had sufficient detection efficiency, intrinsic time resolution, and short decay time. Additionally, the detector was demonstrated to be effective for particle identification.

1. Introduction

Recent developments in heavy ion accelerators and in-flight fragment separators have increased the intensity of available radioactive isotope (RI) beams [1–4]. Particle identification (PID) of RI beams is often performed by measuring time-of-flight (TOF), energy loss, and magnetic rigidity in the in-flight fragment separator. Increasing beam intensities requires these PID detectors to be resistant to radiation damage [5]. When developing new radiation-tolerant detectors for high-intensity RI beams with finite emittance, they should be easy to handle, and have a sufficient effective area, high detection efficiency, and adequate resolution, similar to existing detectors.

Several characteristics of N_2 gas scintillation counters make them suitable for use as TOF counters. N_2 gas, which is relatively inexpensive and non-flammable, can be flowed continuously to prevent radiation damage, and the purity can be easily and safely kept constant. The scintillator volume can also be determined easily. Additionally, the range of wavelength region in which scintillation photon yield is high coincides with the range in which a photomultiplier tube is sensitive [6]. Finally, although the scintillation decay times depend on the gas pressure, they are of the order of nanoseconds [6]. Despite these advantages, it is not certain whether an N_2 gas scintillation counter has sufficient detection efficiency and time resolution for heavy ion RI beams. Hence, we evaluated these quantities by building a new detector.

2. Nitrogen gas scintillation counter: NIGASCI

Fig. 1 shows the N_2 gas scintillation counter (NIGASCI) that we built. It was designed to fit in the vacuum chamber at the focal plane of the superconducting in-flight separator BigRIPS in RIKEN. The specification is shown in Table 1. The scintillation unit is made of stainless steel and is 60 mm wide, 100 mm long, and 60 mm high. N_2 gas is supplied and exhausted through 3.175 mm tubes connected to the container. The energy loss of a 300 MeV/u ^{132}Sn beam in the container

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https://doi.org/10.1016/j.nimb.2023.04.027
Received 23 February 2023; Accepted 14 April 2023
Available online 8 May 2023

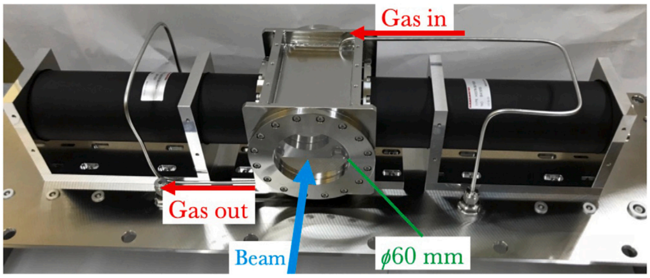

Fig. 1. Photograph of the N_2 gas scintillation counter (NIGASCI).

Table 1
Specification of the NIGASCI.

Material (container)	Stainless steel
Volume	60 (W) × 60 (H) × 100 (L) mm^3
Gas	N_2 (≥ 99.9999 Vol%)
	100–200 kPa, 50 cm^3/min, 20 °C
Effective area	60 mm in diameter
Reflective material	Aluminum foil
	MIRO 3 UV
Optical window	1-mm-thick silica glass
	SUPRASIL-P20
PMT	H3377

filled with N_2 gas at 100 kPa is about 100 MeV. The container has 60 mm apertures at the front and back that act as beam entrance and exit windows. There are also windows on both sides of the container to allow the scintillation photons to escape. They are made from 1 mm-thick silica glass (Shin-Etsu Quartz Products, SUPRASIL-P20), the transmittance of which is about 99% in the wavelength range of 300–400 nm. Emitted scintillations are detected with photomultiplier tubes (PMT, Hamamatsu, H3377). In order to increase the light collection efficiency, the windows and the inner wall of the container are covered with aluminum foil (ALANOD, MIRO 3 UV), which has a reflectance of about 90% in the wavelength range of 300–400 nm.

3. Performance evaluation

First, we confirmed the scintillation lights from N_2 and impurities by measuring the fluorescence emissions in the container with a 270 MeV ^{14}N beam. Next, we measured the number of photons produced by α particles as a function of pressure since the detection efficiency and time resolution depend on the number of photons detected. Finally, we measured the detection efficiency and intrinsic time resolution with a 270 MeV ^{14}N beam. The outcomes of these trials are described in the remainder of this section.

3.1. Nitrogen fluorescence emission

The experiment was performed at the 41 course in the Cyclotron and Radioisotope Center (CYRIC), Tohoku University. The NIGASCI was irradiated with a 270 MeV ^{14}N beam. A Faraday cup placed behind the NIGASCI stopped the beam. The beam current was 2 nA and the beam diameter was 10 mm. Emitted photons were transmitted from the container to a spectrometer (Ocean Optics, FLAME-S) via optical fibers. The emission spectrum measured at a pressure of 100 kPa is shown in Fig. 2. No pressure dependence was evident from 100 kPa to 200 kPa. Transitions in the first negative system bands and second positive system bands were observed between 300 and 400 nm. During measurement, background emissions from nitric oxide were observed below 300 nm [7]. However, the background is negligible owing to its long lifetime [8].

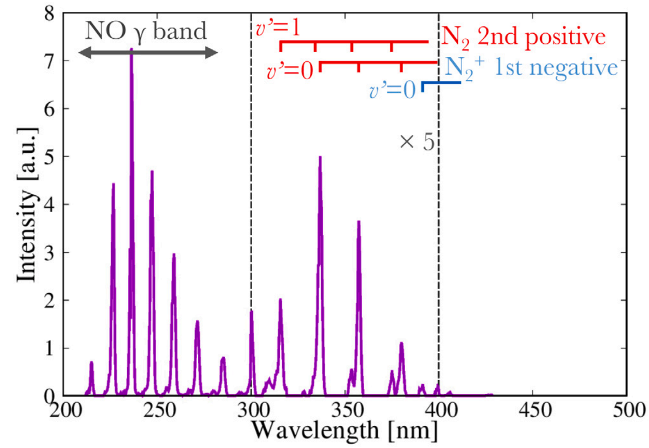

Fig. 2. The emission spectrum of N_2 gas at a pressure of 100 kPa.

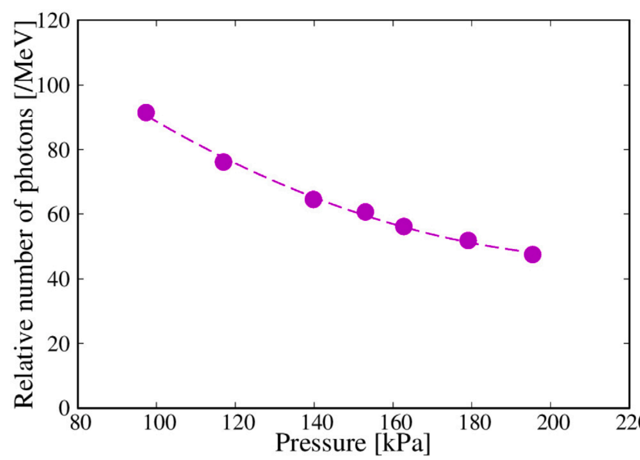

Fig. 3. Relative number of photons produced in the container as a function of pressure.

3.2. Photon yield

The dependence of the number of photons on pressure was measured using an ^{241}Am α source placed inside the gas container. The range of the α particle was shorter than the height of the container. Charge from the PMT was corrected using a light-emitting diode. Fig. 3 shows the estimated relative number of photons produced in the container. The number of photons increased as N_2 gas pressure decreased [9,10]. However, the beam of interest in this study penetrates the NIGASCI, and the energy loss in the container increases with an increase in pressure. Therefore, the difference in the number of photons detected in this pressure range is considered to be small.

3.3. Detection efficiency and intrinsic time resolution

The experiment was performed at the 41 course in CYRIC. The NIGASCI, filled with N_2 gas at a pressure of 100 kPa, and two plastic scintillation counters were aligned in the beam line. A 1 mm diameter, 270 MeV ^{14}N beam passed through these detectors, and the intrinsic time resolution was obtained from time-difference measurements between the detectors. The intrinsic time resolution of the NIGASCI was 165 ps. This value is sufficient to identify a mass number (A) around $A = 100$ using TOF measurements between the BigRIPS focal planes.

Fig. 4 shows a typical signal from the PMT when an ^{241}Am α source was placed inside the container. Both the measured decay and rise times are short. We increased the beam intensity to 10^6 particles/s, but

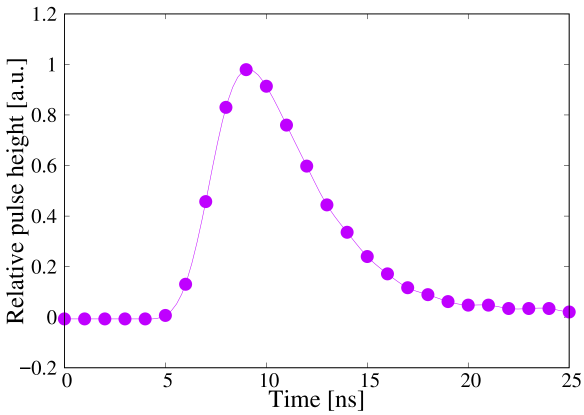

Fig. 4. Typical signal from the PMT when the ^{241}Am α source was placed inside the container. The pressure of N_2 gas was 130 kPa.

the resolution barely changed. These characteristics are advantageous for increasing RI beam intensity.

The detection efficiency is 100%. The energy loss of the ^{14}N beam in the NIGASCI is approximately 14 MeV. This value is similar to the energy loss of a 300 MeV/u Ca beam. Therefore, it has a sufficient detection efficiency for medium and heavy nuclei.

Because the NIGASCI has a high detection efficiency and sufficient time resolution, its use as a timing counter for beam PID was investigated at the RIKEN RI Beam Factory (RIBF). The NIGASCI filled with N_2 gas at a pressure of 150 kPa and two diamond detectors [11] were placed at F12, F3, and F7 of the BigRIPS, respectively. 300 MeV/u ^{48}Ca and 300 MeV/u ^{132}Sn beams were generated by irradiating a ^{9}Be target with a 345 MeV/u ^{238}U beam.^{48}Ca and ^{132}Sn from the cocktail beams were clearly identified. The details will be described elsewhere.

4. Summary

We developed an N_2 gas scintillation counter, NIGASCI, as a TOF counter for the PID of heavy-ion beams. Radiation damage can be prevented by flowing N_2 gas, continuously. Scintillations corresponding to the transitions in the first negative system bands and second positive system bands were observed between 300 and 400 nm. The number of photons produced in the scintillation counter increased with a decrease in pressure from 200 kPa to 100 kPa. The time resolution and detection efficiency were 165 ps and 100%, respectively, for a 270 MeV ^{14}N beam. The time resolution was almost constant up to a beam intensity of 10^6 particles/s. Based on these results, the developed NIGASCI was used as a TOF counter for PID around $A = 50$ and $A = 100$ at the RIBF.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to express their thanks to the crew of CYRIC for their support and skillful beam delivery. We express our gratitude to the accelerator staff at the RIKEN Nishina Center and the Center for Nuclear Study, University of Tokyo, for their excellent beam delivery.

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