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LIQUID-HELIUM SCINTILLATION DETECTION WITH GERMANIUM PHOTODIODES

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LIQUID-HELIUM SCINTILLATION DETECTION WITH GERMANIUM PHOTODIODES

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Abstract

Special high-purity germanium photodiodes have been developed for the direct detection of vacuum-ultraviolet scintillations in liquid helium. The photodiodes are immersed in the liquid helium, and scintillations are detected through one of the bare sides of the photodiodes. Test results with scintillation photons produced by 5.3MeV α particles are presented. The use of these photodiodes as liquid helium scintillation detectors may offer substantial improvements over the alternate detection method requiring the use of wavelength shifters and photomultiplier tubes.

Introduction

Liquid helium scintillation counters are widely used in neutron polarimeters,[1] and they have also found applications in various other physics experiments.[2] However, detection of the helium scintillation light is difficult because it lies in the vacuum ultraviolet (VUV) with wavelengths in the range of 600–1000Å,[3] a region where there are no suitable window materials with good transmission. The traditional detection method is to apply wavelength shifters on the inside wall of the liquid helium container to convert the VUV scintillations into visible light. This is then collected and transmitted through a window or light pipe to a photomultiplier tube. This method is also widely used with other gaseous and condensed noble gas scintillators which also emit in the VUV. Some of the major disadvantages of this method are: a) Losses in the wavelength conversion and light collection processes and the low photocathode quantum efficiency of the photomultiplier often result in a large reduction in the number of photoelectrons emitted from the photocathode compared to the number of scintillation photons. This, in turn, gives rise to an increase in statistical fluctuations in the output signals, i.e. a decrease in resolution. b) Construction of the liquid helium dewar is often complicated by the need for close optical coupling and good thermal isolation between the scintillation volume and the photomultiplier tube. c) There are additional problems associated with photomultiplier tubes, e.g. instability, sensitivity to magnetic field and bulkiness.

Many of these problems can be alleviated by using a semiconductor photodiode as the scintillation detector. We have recently demonstrated the feasibility of using a high-purity germanium photodiode for the detection of liquid helium scintillations.[4] The photodiode was immersed in the liquid helium to detect the VUV scintillations directly without using any wavelength shifters.

Germanium Photodiodes

Fabrication and operation of our germanium photodiodes is similar to that of high-purity germanium nuclear radiation detectors which are commonly used in gamma-ray and charged-particle spectroscopy.[5] The scintillation light enters the photodiode through one of its bare sides (i.e., parallel to the diode junction). The use of high-purity germanium enables a thick depletion layer which translates into a large sensitive area.

A side-entry mode of operation is used because of the extremely high absorption coefficient of VUV. If detection is through one of the contacts, the sensitivity of the photodiode will be much degraded due to two processes. First, a large portion of the light will be absorbed by the contact (e.g., a 100Å Au barrier contact will absorb ~50% of the incident VUV photons). Second, the transmitted photons are absorbed and electron-hole pairs are generated within only a few hundred Å from the surface, and subsequent diffusion of carriers to the contact before collection by the electric field results in a reduced signal.

To enable operation at liquid helium temperature (4.2K), the contacts of the photodiodes must be degenerately doped. This was achieved by ion implantation of boron (p^+ contact) ($2\times10^{14}cm^{-2}$, 25keV, room temp.) and phosphorus (n^+ contact) ($1\times10^{15}cm^{-2}$, 25keV, 77K) followed by thermal annealing.[6]

Experimental

The apparatus for testing the photodiodes consists of a metal liquid helium dewar into which photodiodes can be mounted. Scintillations were generated by a movable ^{210}Po α source (5.3MeV) facing one of the bare sides of the photodiode. Signals from the photodiode were processed by a charge-sensitive amplifier followed by a pulse shaping amplifier. These are located external to the dewar. The amplitude of the signal, i.e. the amount of the charge collected in each pulse, depends on the number of VUV photons intercepted by the photodiode during each scintillation. This, in turn, is determined by the solid angle subtended by the photodiode at the source (the range of 5.3MeV α particles in liquid helium is only ~0.2mm).

Results

Our first test was made using a photodiode with a contact area of $1\times1cm^2$ and thickness of 3mm.[4] The sensitive area is therefore $10\times3mm^2$ when the photodiode is fully depleted (120V). Spectra taken with the α source at a distance of 4 to 6mm from the photodiode showed that the signal is well separated from the noise. Signal rise time was <0.1μsec with a bias of 500V. The use of a large area (4mm diameter) source and the relatively small sensitive area of the photodiode resulted in significant broadening of the spectrum at small distances.

We have since then fabricated and tested photodiodes with a larger sensitive area because this will be required in a practical scintillation counter, and it will also enable us to determine the resolution of the photodiodes without additional contributions from geometrical effects.

Three photodiodes, each having a contact area of $20\times5mm^2$ and thickness of 5mm were stacked as shown in Fig. 1 to give a combined sensitive area of $20\times15mm^2$. The photodiodes were electrically connected in parallel. Each photodiode depletes at a bias of 200V. A ^{210}Po α source with a 2mm diameter active area was used in this test.

Spectra taken with the source at a distance d of 12mm and 8mm from the photodiodes are shown in Fig. 2. The number of electron-hole pairs collected in each pulse (top scale) is obtained by calibration with signals from the ^{241}Am 60keV gamma-rays detected directly by the photodiodes.[4] It can be seen that the FWHM

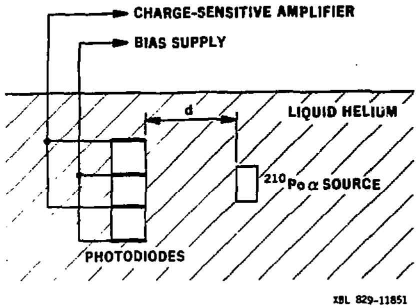

Fig. 1. Arrangement of the photodiodes and the α source.

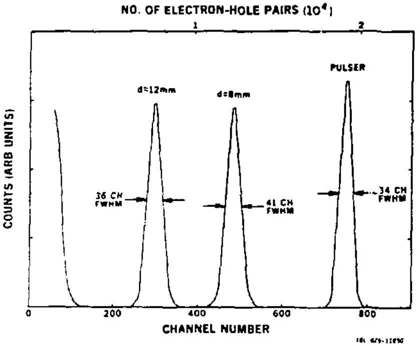

Fig. 2. Pulse height spectra of 5.3 MeV α particles taken with a photodiode bias of 200V and a 4μsec peaking time.

of both scintillation peaks and the pulser are roughly equal, which means that the energy resolution of the present setup is mostly limited by electronic noise. For d=12mm and 8mm, the resolutions (FWHM) are 12% and 8.5% respectively. The contribution to the resolutions from fluctuations in the number of photons arriving at the photodiodes, assuming a 6% scintillation efficiency for liquid helium[4] and normal statistics, are estimated to be 5% and 4% FWHM, much smaller than the electronic noise contribution.

The quantum efficiency of the photodiodes, i.e. the number of electron-hole pairs collected per photon arriving at the photodiode, is ~3.5, assuming again a 6% scintillation efficiency. This value is consistent with that obtained for the smaller photodiode (~4).[4]

Discussion

We have shown that side-entry germanium photodiodes can be used to detect scintillations in liquid helium. The direct detection and high sensitivity of the photodiodes make them very efficient scintillation detectors, competing favorably with the usual wavelength shifter-photomultiplier approach.

The energy resolution presently obtained for 5.3MeV α particles is limited by the electronic noise of the experimental set-up. This, together with the fact that the photodiodes saw only a small fraction of the scintillation photons, suggests that a substantial improvement in resolution can be expected by covering a larger solid angle with photodiodes to gain a larger signal, and by further optimization of the electronics. Coverage of a large solid angle is also required to obtain a uniform response for events occurring at different parts of the counter. On the other hand, spatial information of events may be obtained by weighing signals from each (or groups of) photodiode(s).

Other possible applications of these photodiodes include liquid ^{3}He scintillation counters which can be used as neutron spectrometers,[7] and liquid Ne or Ar scintillation counters which are useful as high energy charged-particle detectors.

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