Nuclear Instruments and Methods in Physics Research A 612 (2010) 345–348

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

The silicon photomultipliers for inelastic neutron scattering at high energy transfers

Antonino Pietropaolo *

CNISM Milano-Bicocca and Università degli Studi di Milano-Bicocca, Dipartimento di Fisica "G. Occhialini", Piazza della Scienza 3, 20126 Milano, Italy

ARTICLE INFO

Article history:
Received 7 September 2009
Received in revised form
19 September 2009
Accepted 8 October 2009
Available online 25 October 2009

Keywords:
Silicon photomultiplier
Neutron instrumentation
Neutron scattering

ABSTRACT

The silicon photomultiplier (SiPM) is a photo sensor of recent technology. It is mostly used in particle physics, for example in the detection of minimum ionizing particles and/or Cherenkov radiation. Its performance is comparable to that of photomultiplier tubes (PMTs), but with advantages in terms of reduced volume and magnetic field insensitivity. In the present study, the performance of a SiPM as a readout for a γ-ray detector made of a yttrium–aluminum–perovskite (YAP) scintillation crystal is assessed for use in time of flight inelastic neutron spectroscopy at high energy transfers. This was done by performing explorative measurements at the Italian Neutron Experimental Station (INES) beam line at the ISIS spallation neutron source. The measurements, carried out in the so-called resonance detector (RD) configuration, demonstrate the suitability of the SiPM for this kind of application.

1. Introduction

The silicon photomultiplier (SiPM) is a novel photo sensor made by an array of pixels electrically decoupled from each other by polysilicon resistors (typically of 0.5 MΩ) located on the same substrate [1–4]. The operational bias voltage is higher (about 10%) than the breakdown voltage, so that each pixel operates in a limited Geiger mode with a gain determined by the charge accumulated in the pixel capacitance (typical value of about 100 fF). In this mode, a photoelectron created in a pixel of the SiPM that reaches the high field region initiates a Geiger discharge confined to that pixel. The pixel discharge is quenched by limiting the current to about 10 μA by means of the polysilicon resistor. The independently operating pixels are connected to the same readout line. Thus, the combined output signal is the sum of all the so-called fired pixels, which is a measure of the light flux impinging on the SiPM. The main SiPM advantages, as compared to the conventional photomultiplier tubes (PMTs) are insensitivity to magnetic fields, low operation voltage, and compact size. Moreover, they exhibit a high peak photon detection efficiency (more than 50% in some cases) and good time response. These devices are very promising as readouts of detectors for different purposes, e.g. particle physics [5–7] or space applications [8,9]. Very recently a new application of the SiPM was investigated at the ISIS spallation neutron source [10] in a detector test for Neutron Resonance Capture Analysis measurements [11]. The compactness and effectiveness of these photo sensors allow to conceive their possible use for other kind of neutron-based techniques as well.

In this report, an explorative measurement is presented relative to the use of the SiPM as a compact readout for detectors used in inelastic neutron scattering measurements at high energy transfers. This technique, known as deep inelastic neutron scattering [12–14] allows one to measure the single particle dynamics, for example in hydrogen containing systems, in terms of the momentum distribution $n(p)$ and its second moment, i.e. the mean kinetic energy $\langle E_k \rangle$. The paper is organized as follows: in Section 2, the experimental setup is described, while in Section 3 the experimental results are presented and discussed and compared with Monte Carlo simulations. In Section 4, the conclusions are presented.

2. Experiment

The test was performed at the ISIS spallation neutron source (Rutherford Appleton Laboratory, UK) on the INES beam line [15,16]. The measurement was done parasitically during another kind of detector test on the instrument. Despite being used as a neutron diffractometer, the INES beam line provides a white neutron beam produced by the primary high energy neutrons that pass through a poisoned water moderator at room temperature. The primary flight path, L_0, from the moderator to the sample position is about 23 m. The neutron spectrum on the instrument is characterized by a thermal component (a Maxwell–Boltzmann distribution) peaked at about 30 meV and a E^{α} ($\alpha \approx -0.9$) epithermal component. This region of the spectrum was used

* Fax: +39 02644 82367.
E-mail address: antonino.pietropaolo@mib.infn.it

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doi:10.1016/j.nima.2009.10.064

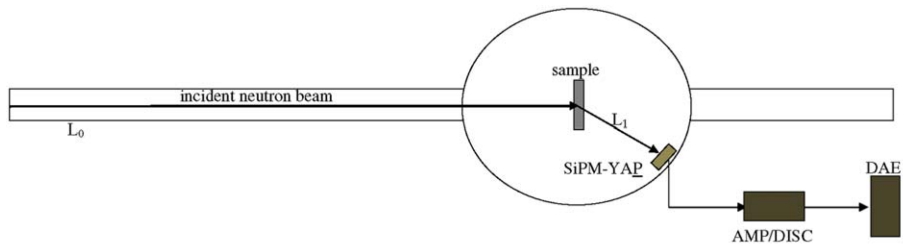

Fig. 1. Layout of the experimental setup used on the INES beam line at ISIS for the inelastic neutron scattering measurement on liquid water in the resonance detector (RD) configuration: AMP/DISC is the amplifier discriminator, while the DAE is the data acquisition electronics that stores the time of flight spectra. The gold analyzer foil was attached on the YAP surface.

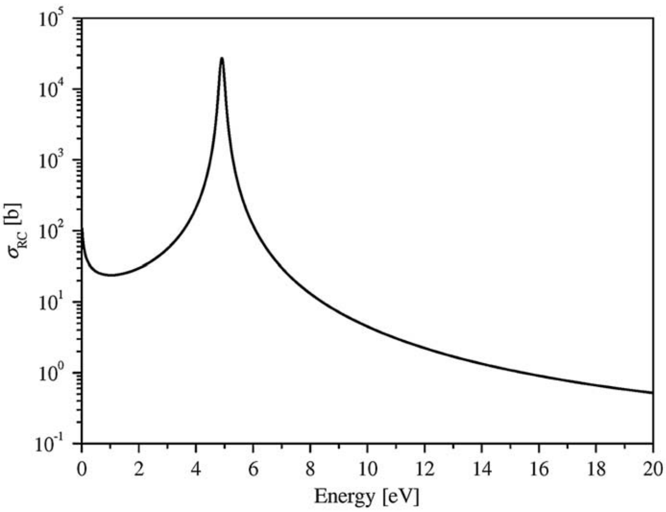

Fig. 2. Radiative capture cross-section $\sigma_{RC}(E)$ for ^{197}Au up to 20 eV.

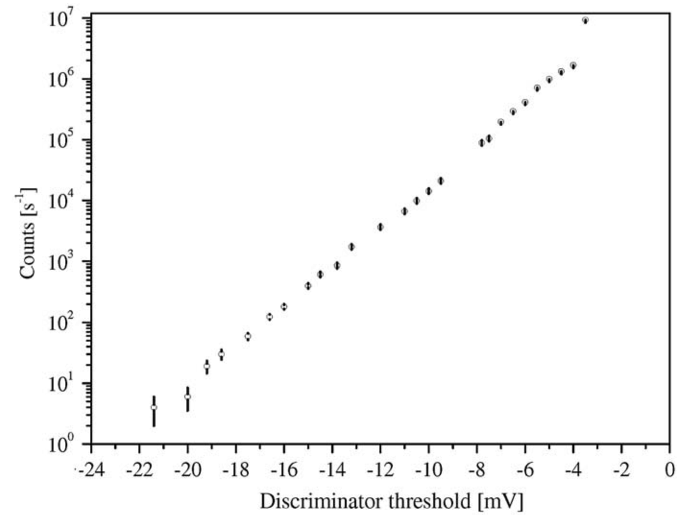

Fig. 3. Intrinsic noise rate as a function of the discrimination level for the SiPM from Hamamatsu used in the experiment.

for the inelastic scattering measurements aiming at testing a detection system made of a yttrium–aluminum–perovskite (YAP) scintillation detector coupled to a SiPM from Hamamatsu (series S10362-11-025U). The SiPM was 1 mm^2 active area and 1600 pixels. The YAP crystal was $0.6 \times 0.6 \times 2.0\,cm^3$ size. In order to perform the DINS measurements, the INES beam line was setup as an inelastic neutron spectrometer in the indirect geometry configuration [17]. The latter relies upon the selection of the energy of the scattered neutrons for example by means of nuclear resonances, using metallic foils as energy analyzers. In the present case, a ^{197}Au (n,γ) metallic foil a, 16 μm thick and $2.0 \times 0.5\,cm^2$ surface area was placed in proximity of the YAP surface and used as a (n,γ) converter/analyzer. The setup for the test measurements is shown in Fig. 1.

The neutron detection proceeds in two steps: (i) the scattered neutrons pass through the analyzer (the Au foil) which has a large resonance at 4.908 eV as shown in Fig. 2, where the radiative capture cross-section is shown in an extended range around the resonance energy E_r=4.908 eV; (ii) upon neutron absorption, a γ-rays cascade is produced with energies up to the neutron binding energy (about 7 MeV in the case of Au), the strongest transition being at E_γ=214.97 keV. This neutron counting technique is known as the resonance detector (RD) configuration [18–21]. The scattering sample was 2.0 mm thick distilled liquid water contained into an aluminum cell. The secondary flight path from the sample to the detector was $L_1 \approx 0.35$ m, the YAP–SiPM device being placed inside the INES sample tank at a scattering angle $\vartheta \approx 45^\circ$. The signal from the SiPM was sent to an amplifier/discriminator electronic module set with a lower level discrimination (LLD) threshold of 200 mV, corresponding to about 600 keV equivalent photon energy, optimized for good signal to background ratio [22]. The LLD used during the measurements was well above the intrinsic noise level characteristic of the SiPM, which was measured before the experiment. Fig. 3 shows the intrinsic noise rate measured by an analog scaler from CAEN as a function of the LLD, set by a low level discriminator from ORTEC.

Fig. 4 shows a raw time of flight spectrum collected by the YAP–SiPM system over a time period represented by an integrated accelerator current of 2451 μAh. The large bump peaked at 590 μs is the hydrogen recoil peak and the lower feature at about 750 μs is the $^{27}Al+^{16}O$ recoil signal, both measured at a final neutron energy E_1=E_r and convoluted with the instrument resolution. As noted below, there is a continuum background beneath the peak structures that can be removed by fitting a polynomial function. In order to complete the detector test, a simulation was performed by using a modified version of the DINSMS code [23], as explained in the following section. This aimed at making a direct comparison of the experimental spectrum with the one obtained using the proton momentum distribution at room temperature as measured in a previous experimental work [24].

3. Results and discussion

The Monte Carlo code, employed to simulate the TOF spectra, is a modified version of the DINSMS code, developed by Mayers et al. [23] for DINS measurements on the VESUVIO spectrometer at ISIS