Nuclear Instruments and Methods in Physics Research A 776 (2015) 98–106

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Temperature gain correction for CsI(Tl) detection systems based on digital pulse shape analysis

J. Silva [a,b,*], E. Fiori [a,b], J. Isaak [a,b], B. Löher [a,b], D. Savran [a,b], M. Vencelj [c], F. Wamers [a,b]

[a] ExtreMe Matter Institute EMMI and Research Division, GSI Helmholtzzentrum für Schwerionenforschung, Planckstr. 1, 64291 Darmstadt, Germany
[b] Frankfurt Institute for Advanced Studies FIAS, Ruth-Moufang-Str. 1, 60438 Frankfurt am Main, Germany
[c] Jožef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 20 October 2014
Received in revised form
14 December 2014
Accepted 15 December 2014
Available online 24 December 2014

Keywords:
Caesium iodide
Digital pulse shape analysis
Gain temperature dependence
Scintillation detectors
Photomultiplier
Avalanche photodiode γ-ray spectroscopy

ABSTRACT

In this paper we propose a pulse shape based method for monitoring the interior temperature of a CsI (Tl) crystal in order to correct the temperature dependence in the energy calibration of the corresponding detector system. The gain dependence on temperature of the CsI(Tl) detector was measured using both, a photomultiplier tube (PMT) and an avalanche photodiode (APD) readout photosensor. The analysis shows that the gain shifts due to temperature variations can be corrected to a precision of better than 1% with both the PMT and the APD, well below the CsI(Tl) intrinsic energy resolution for ~1 MeV γ-rays.

1. Introduction

Thallium-activated caesium iodide (CsI(Tl)) crystals have been used as a scintillation detector in many scientific and commercial applications, ranging from nuclear physics to outdoor radiation environment studies. They show a rather high luminescence intensity and a high cross-section for γ-ray interactions, and are easy to handle.

The scintillation light yield per MeV energy deposited in the CsI(Tl) crystal is known to be a function of the temperature [1,2]. Also, commonly used light sensors such as photomultiplier tubes (PMTs) and avalanche photo diodes (APDs) are intrinsically temperature-dependent devices. For accurate energy measurements in γ-ray spectroscopy using a CsI(Tl) detectors, temperature variations have to be precisely monitored in order to correct possible detector gain shifts.

CsI(Tl) has been observed to have at least two relevant scintillation light components (see e.g. [3,4]). The decay time and relative intensity of those components were measured to be also dependent on the ambient temperature when excited by γ-rays. Therefore, the scintillation characteristics of CsI(Tl) and consequently the pulse shape of the detector signals are correlated to the temperature of a CsI(Tl) crystal.

As an example, Fig. 1 shows the γ-ray energy spectra of a ^{22}Na radioactive source measured using a CsI(Tl) crystal coupled to a PMT (upper frame) and coupled to an APD (lower frame) at different ambient temperatures. The effect of the temperature in the system gain is reflected by the position shift of the 511 keV and 1275 keV peaks, respectively.

The change of the pulse shape with temperature is an observable independent of the scintillation light yield. The use of pulse shape analysis (PSA) to classify the pulse shape, considering the actual internal temperature of the crystal, provides a way to directly compensate for the gain shift due to the CsI(Tl) temperature dependent light yield. And, assuming thermal equilibrium between the crystal and the temperature sensitive part of the photosensor, it allows us to correct the gain shift of the entire detector system.

A technique of gain stabilisation considering the scintillator temperature by analysing the detector pulse shape has been already presented in Ref. [5] for a different kind of scintillator. There, they estimate the single light decay time of a NaI(Tl) scintillator coupled to a PMT from digitised signals. Then, using the decay time as a temperature parameter, they perform gain stabilisation under changing ambient temperature. An other method described in [6] uses an automated adaptive filtering approach that in effect deconvolves the information from the pulses using a temperature-dependent Ansatz; though without discussing the stability of the method or proving resolution optimality, they show excellent results from climate chamber test. Both articles show that the information contained in

* Corresponding author at: ExtreMe Matter Institute EMMI and Research Division, GSI Helmholtzzentrum für Schwerionenforschung, Planckstr. 1, 64291 Darmstadt, Germany, Tel.: +49 6159711804; fax: +49 6159713475.
E-mail address: j.silva@gsi.de (J. Silva).

http://dx.doi.org/10.1016/j.nima.2014.12.064
0168-9002/

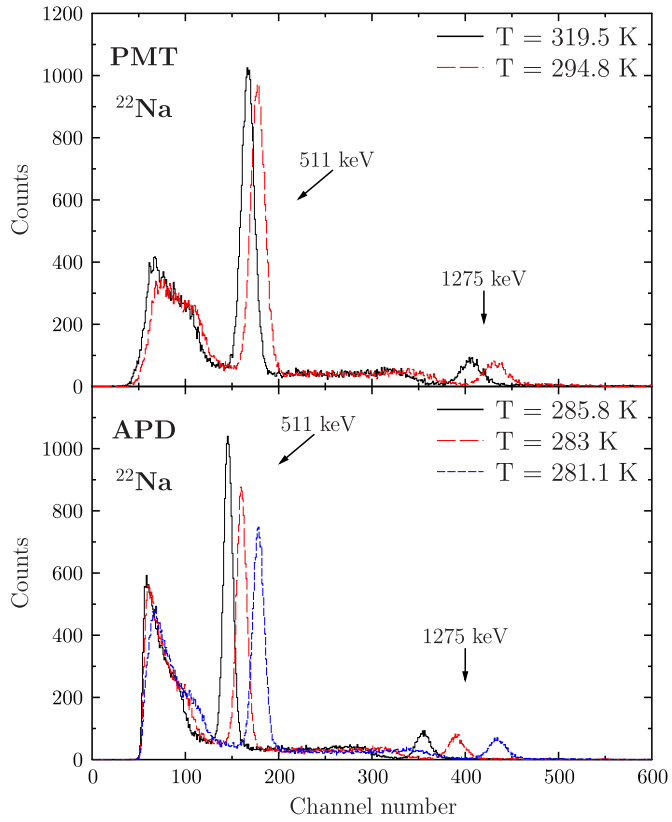

Fig. 1. Upper frame: Energy spectra measured at different temperatures using as detector a CsI(Tl) crystal coupled to a PMT sensor. The spectra are not calibrated to illustrate the temperature gain dependence. Lower frame: Energy spectra measured at different temperatures using as detector a CsI(Tl) crystal coupled to an APD sensor.

the pulse shape can be used to improve the stability of scintillators based detection systems.

In this paper we present a method that uses PSA to correct temperature-dependent gain drifts of CsI(Tl) detectors. The suitability of the method is tested using both a PMT and an APD as readout photosensors. The latter one has started to be frequently used in connection with CsI(Tl) crystals, as its spectral response better matches the scintillator emission spectrum, offering a higher quantum efficiency compared to a PMT, which finally yields a better overall energy resolution. However, the APD shows a very strong gain dependence on temperature (compare Fig. 1). In the present work the detector signals are digitised allowing us to record a large part of the signals' shape and perform different algebraic operations on the same signals. The next section gives an overview of the experimental setup used to record signals at different temperatures. Section 3 focuses on describing the PSA algorithms and steps adopted to process the raw signal in order to achieve the best pulse shape determination. In Section 4, we evaluate two differently defined quantities that parametrise the mean pulse shape of detector signals. The first uses the ratio of integrals over two parts of a signal, the second considers the sampled signal as a multi-dimensional vector and by means of vector calculation measures the current pulse shape variations relatively to a reference mean shape. In Section 5 the correlation of the peak position in the spectrum with the shape parameter is used to derive a correction factor that was then employed to correct the gain changes in a second data set obtained later using the same setup.

2. Experimental setup

To produce the experimental data two identical setups differing only in the photosensors were individually prepared using the same $15 \times 15 \times 30$ mm^2 CsI(Tl) crystal. For the first setup – the PMT setup – the crystal was coupled to a R1464 Hamamatsu PMT with a photocathode of diameter 15 mm. A high voltage of 1200 V was applied to the PMT. For the second setup – the APD setup – a Hamamatsu S8664-1010 APD detector with an area of 10×10 mm^2 was used to measure the crystal light yield. A Mesytec MPBR-16 charge sensitive pre-amplifier, which also provides the bias voltage of 425 V for the APD, was utilised to obtain the APD detector signals. The signals from both detectors were sampled by a Struck SIS3316 VME digitiser at a frequency of 250 MSPS, resolution of 16 bit and an input range of 5 V. The two setups were employed separately and two measurements per setup were successively performed under induced temperature changes. While the data from the first measurement was used to develop our method, the data from the second measurement was used to test the method and produce the results. Since the APD is a much more temperature dependent device than the PMT, we expected the gain of the APD to be strongly affected by the induced temperature changes relatively to the gain of the PMT setup.

The diagrams of the two experimental setups for the present study are illustrated in Fig. 2. Apart from detectors and respective readout electronics, both experiments were conducted identically. The crystal was wrapped in a thin layer of reflective plastic to enhance the light output and thus sharpen the full energy peaks. The back side was kept uncovered and was coupled with a silicone grease to the photosensor. The crystal was additionally wrapped in black electric tape to ensure light isolation and attached to two PT100 resistance thermometers (RTD) on the side faces of the crystal (one close to the bottom and other close to the top of the crystal, see Fig. 2). The RTD were read with a NI6217 module by National Instruments, which allow us to register and monitor temperature while conducting the experiment. A ^{22}Na source was placed about 2 cm from the crystal's front face on the side opposite to the photosensor. Photosensor, crystal and source were immersed inside a vacuum flask filled up with an antifreeze liquid solution. The temperature of the liquid was slowly increased in steps of approximately 1.5 K using a heating wire placed at the bottom of the flask that dissipated 60 W min per step. For the PMT setup, a temperature range between 261.6 K and 319.5 K was covered. For the APD setup, due to its strong gain dependence on the temperature causing this detector to quickly saturate the pre-amplifier, a narrower temperature range from 276.6 K to 307 K was covered. The temperature of the crystal was assumed to be correlated to the average value of the two thermometers. A maximum difference of 0.3(5) K was registered between the two thermometers during the measurements. Air was pumped into the liquid to facilitate thermal uniformity of the liquid and reduce stratification. The high heat transfer coefficient of the liquid (compared to air) allowed quickly to reach thermal equilibrium between the crystal and the liquid within about 10 min.

Data was taken in acquisition runs of 3 min after achieving thermal equilibrium. The temperature change during data acquisition was observed to be less than 2×10^{-2} K/min, and therefore assumed to be constant. The Multi Branch System (MBS) data acquisition software [7] was used to record to disk an amount of 80,000 traces per run, each consisting of 5000 and 8000 samples from the PMT and APD setup, respectively.

3. Signal preparation

Before PSA was applied, in a first step, every trace was prepared by performing baseline correction and time alignment. Piled-up signals were also removed from the data set. The individual steps are described in the following.

The base line is estimated by taking an average over the first 850 samples (3.4 μs) of the trace, where no signal is present, and then subtracted from the signal. For timing and triggering a different approach was used for each of the two detector systems.