

Miniature gamma detector based on inorganic scintillator and SiPM

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Abstract. The miniature gamma counter based on a cylindrical LaBr₃(Ce) crystal (5 mm diameter and 10 mm length) and SensL FC30035 silicon photomultiplier (SiPM) is introduced. The main counter characteristics such as relative efficiency, LaBr₃(Ce) self-radioactivity and energy resolution are presented. Capability of using such detector for gamma spectrometry applications is discussed.

1. Introduction

Nuclear technologies have a wide application in many different fields of science and technique, from power industry and extractive industry to medicine. Portable scintillation detectors are widely used in medical diagnostics. NaI(Tl), CsI(Tl), BGO are the most commonly used scintillators. High effective charge and density cause of their widespread use for charged particle and gamma-ray registration. The main characteristics of several inorganic scintillators are presented in the table 1.

Table 1. Basic characteristics of scintillation crystals.

| Scintillator | NaI(Tl) | CsI(Tl) | BGO | LaBr ₃ (Ce) |
|--------------------------------------|---------|---------|-----|------------------------|
| Z_{eff} | 51 | 54 | 74 | 45 |
| ρ , g/sm ³ | 3.67 | 4.51 | 7.1 | 5.08 |
| λ_{max} , nm | 415 | 550 | 480 | 365 |
| Hygroscopicity | yes | weak | no | yes |
| 50% attenuation length, mm (662 keV) | 25 | 20 | 10 | 18 |
| $\Delta E/E$, % (662 keV) | 7 | 6 | 10 | 3 |
| Light yield, phot/keV | 38 | 54 | 9 | 63 |
| τ , ns | 250 | 1000 | 300 | 16 |

Vacuum photomultipliers (PMTs) are commonly used for the scintillation light detection. But their size and HV power supply requirements reduce their practical applicability. Silicon photomultipliers (SiPMs) are more preferable to use in miniature portable counters. SiPMs have a relatively small size (thickness is usually less than 3 mm). Bias voltage lies in a range of 20 – 80V which is enough to

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obtain gain coefficient $\sim 10^4 - 10^6$. Photon detection efficiency (PDE) of SiPMs depends on cell size and bias voltage, and achieves 30 – 50% [1].

2. Detector

The detector consist of $\text{LaBr}_3(\text{Ce})$ cylindrical scintillator with diameter 5 mm and length 10 mm and SiPM FC30035SMT manufactured by SensL (its characteristics are presented at table 2). Developmental prototype of scintillation crystal was fabricated in the Institute of Solid State Physics RAS. As it is shown in the table 1, light yield and energy resolution of $\text{LaBr}_3(\text{Ce})$ are higher in comparison with other common inorganic scintillators. $\text{LaBr}_3(\text{Ce})$ also has a relatively short primary decay time. Main negative attributes of $\text{LaBr}_3(\text{Ce})$ are its hygroscopicity and self-radiation due to ^{138}La [2].

Table 2. Characteristics of the used SiPMSensL FC30035.

| | |
|--------------------------------------|---------------------|
| Active area, mm^2 | 9 |
| Number of cells | 4774 |
| Cell size, μm^2 | 35 |
| Gain* | $\sim 2 \cdot 10^6$ |
| PDE*, % ($\lambda=365 \text{ nm}$) | 25 |

*at a chosen bias voltage.

The main feature of the detector is that SiPM and scintillator are put together into the single duraluminium housing. On the one hand the housing is watertight, and on the other hand it decreases the light loss between crystal and SiPM boundaries. Scheme of the scintillation package is shown in the figure 1. Amplitude of the SiPM signal is $\sim 10 \text{ mV}$ at 31 keV gammas (from ^{133}Ba), $\sim 400 \text{ mV}$ for gammas with energy of 662 keV (^{137}Cs) and the pulse width (FWHM) is around 300 ns. Thus it is not necessary to use a preamplifier and a shaper to adapt the signal for further processing. Waveforms of SiPMs output signals for 31 keV and 662 keV gammas are presented in the figure 2. They were measured by oscilloscope LeCroy 640Zi (50Ohm load) directly without amplifier.

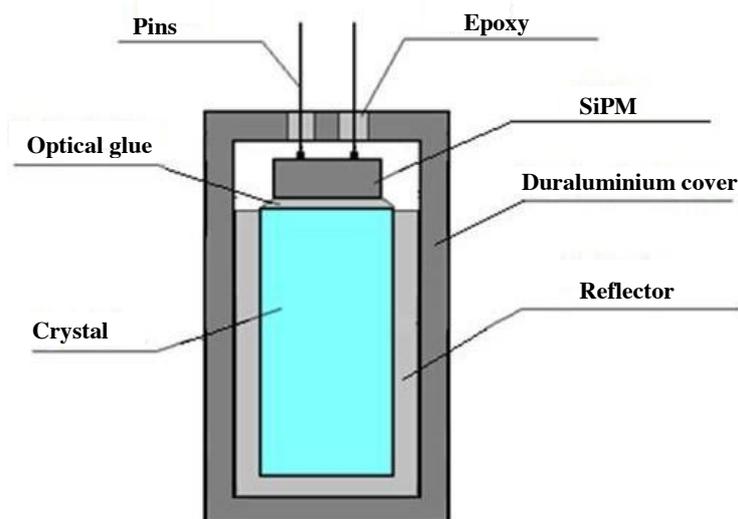


Figure 1. Scintillation unit.

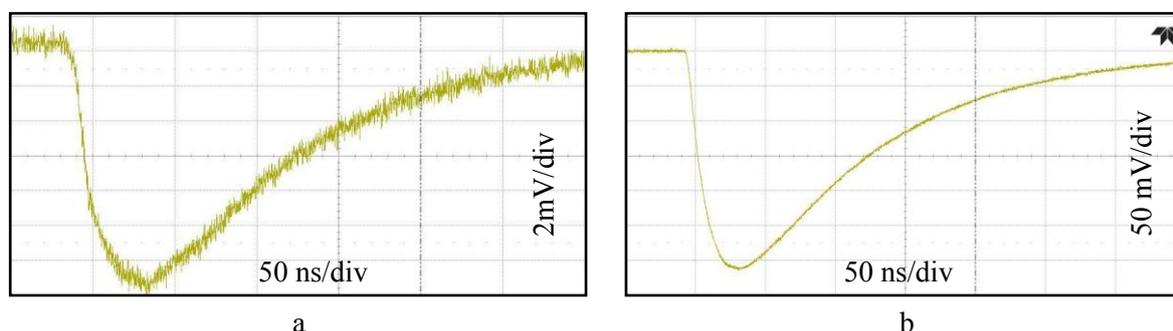


Figure 2. Waveforms of the signal from 32 keV gammas (a) and 662 keV gammas (b). (Oscilloscope LeCroy 640Zi (50Ohm load) without amplifier).

3. Self-radioactivity

Background events caused by self-radioactivity decrease the counter sensitivity. Background count rate determines the minimal activity of a radioactive source that could be registered by the detector.

In order to estimate the level of background radiation of the detector measurements of count rate without sources were provided. Detector was biased with a Polon 1904 power supply, voltage and dark current were controlled by multimeters AM1097 and CHA300. In order to count pulses from the detector discriminator Lecroy 623b and scaler CAEN 145 were used. The threshold of discriminator was set at such level to select signals with an amplitude higher than ones caused by 60 keV gammas from ^{241}Am .

Experimental results showed that the mean value of background count rate is equal 1.13 ± 0.09 pulses/sec.

4. Energy resolution

Due to the high energy resolution and high light yield of the $\text{LaBr}_3(\text{Ce})$ and the relatively high photon detection efficiency and low noise of the SiPM, the detector under discussion can be used for spectrometry. ^{137}Cs and ^{241}Am charge spectra obtained with the $\text{LaBr}_3(\text{Ce})$ -SiPM detector are presented in the figures 3 and 4.

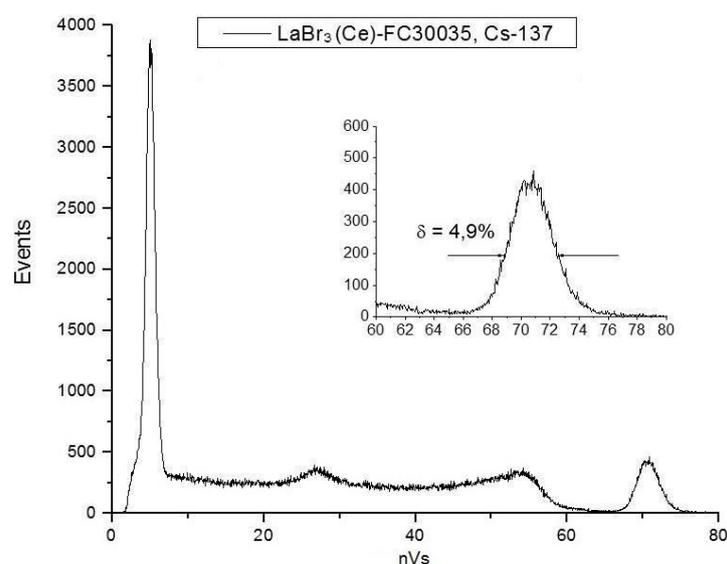


Figure 3. Spectrums of ^{137}Cs obtained with the $\text{LaBr}_3(\text{Ce})$ -SiPM unit with relative energy resolution $\delta=4.9\%$ for 662 keV with absolute statistical error 0.005%.

Scheme of power supply consisted of Polon 1904 power supply and multimeters AM1097 and CHA300. Pulses from the detector were directly sent to the oscilloscope Lecroy 640Zi having an inbuilt QDC analyzer. The Gate was around 250 ns for both measurements.

As an energy resolution was used the value $\delta = \frac{FWHM}{N_{max}}$ (relative energy resolution), where FWHM is the Full Width at Half of the Maximum of Gauss distribution fitting the peak in pulse spectra, and N_{max} is the position of Maximum. According to obtained data energy resolution at energy 662 keV (source ^{137}Cs) equal to 4.9% with absolute statistical error 0.005%, at 60 keV (source ^{241}Am) the resolution equal to 16.7% with absolute statistical error 0.05%.

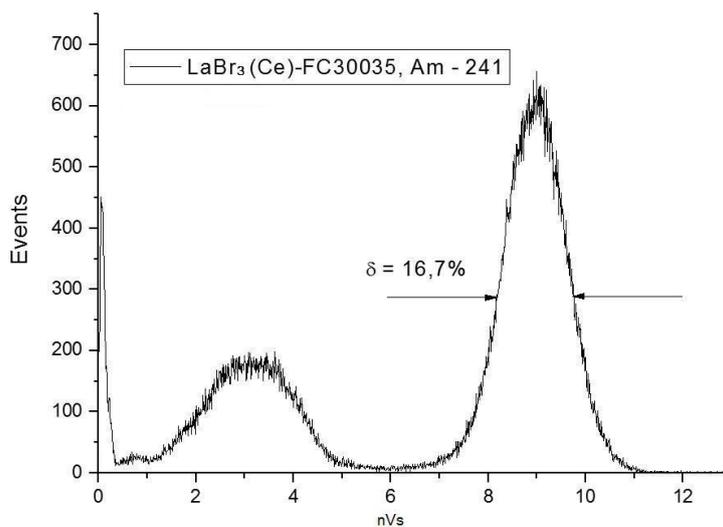


Figure 4. Spectrums of ^{241}Am obtained with the $\text{LaBr}_3(\text{Ce})\text{-SiPM}$ unit with relative energy resolution $\delta=16.7\%$ for 60keV with absolute statistical error 0.05%.

5. Conclusion

The possibility of the usage of a scintillation detector based on $\text{LaBr}_3(\text{Ce})$ crystal and SiPM as a miniature gamma counter was considered. Scintillator's self background rate was measured to be 1.13 ± 0.09 pulses/sec. Energy resolution of the detector was measured to be about 4.9% for 662 keV gamma rays. Obtained results show that the detector serve as a good alternative for well-known gamma counters based on $\text{NaI}(\text{Tl})$, $\text{CsI}(\text{Tl})$, BGO.

Acknowledgments

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References

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