Size dependence for $Gd_3Ga_3Al_2O_{12}$:Ce,B single crystal scintillator on pulse-height spectra generated by GEANT4 simulation with optical photon transport

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Introduction

Ce^{3+} doped and B^{3+} co-doped gadolinium gallium aluminum garnet ($Gd_3Ga_3Al_2O_{12}$:Ce,B or GGAG:Ce,B) single crystal is a relatively new scintillator material with several attractive properties [1], aiding its use in gamma spectrometry in conjuncture with silicon photodiodes. The present study aims at the modeling of the crystal by incorporating accurate physical, scintillation, optical and surface properties, in order to carry out GEANT4 based Monte Carlo simulation that includes radiation transport as well as optical photon generation and transport, leading to the generation of a pulse-height spectrum. Pulse-height spectra generated by simulations are presented and compared for different sizes of the crystal.

GEANT4 Simulation

The yz-projection of the simulation geometry, along with the reference coordinate axes, for the 10×10×10 mm^3 crystal coupled to a photodiode of active area 10×10 mm^2 and thickness 0.3 mm, is shown in Fig.1. The size of the crystal was changed for subsequent simulations, keeping the active area of the photodiode always equal to the crystal surface area. A parallel beam of photons emulating the decay of ^{137}Cs (6% 32 keV, 1% 36 keV and 85% 662 keV) was modeled to be incident on the top surface of the crystal along the negative z-direction and always entirely covering the surface. Table 1 presents the important simulation parameters.

After energy deposition by the primary gamma photons and subsequent generation and transport of optical photons up to the crystal-photodiode interface, a fraction of their number, equal to the detecting efficiency of this surface, are detected. This number (n_{ph}) of detected optical photons is converted to pulse-height by using the formula,

$$Pulse\ height\ (V) = \frac{n_{ph} \times e \times G}{C} \quad \text{(i)}$$

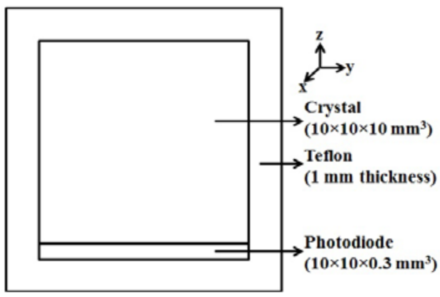

Fig. 1 Simulation geometry (not to scale)

Each simulation was performed for a total of 7×10^4 primary events. A tally of pulse-height for each event was generated. This was used to draw the pulse-height histogram.

Results and Discussion

Fig.2 presents the comparative pulse-height spectra for different sizes of the crystal, whereas Table 2 presents the corresponding values of energy resolution at 662 keV. It is clear from Fig.2 that the pulse-height corresponding to the 662 keV peak is slightly higher for the 18×18×10 mm^3 crystal compared to the 10×10×10 mm^3 crystal. This may be attributed to the fact that the greater detection volume offered by the larger crystal results in more gamma energy deposition, and, consequently, in a larger pulse-height. On the other hand, as the dimension of the crystal along the primary beam direction, i.e. its height, is increased, the peak pulse-height is gradually decreased. This can be inferred to be due to the larger distance the optical photons need to travel, and, consequently, more loss in their number due to bulk absorption and reflection at the surfaces, before being detected at the photodiode surface.

Table 1: Important simulation parameters

Parameter (Unit)	**Value**
Doping concentration (at%)	0.2 each of Ce and B, both w.r.t. Gd
Density (g/cm^3)	6.67 (Crystal), 2.2 (Teflon)
Scintillation emission spectrum	Implemented as a function of photon energy as experimentally measured, peaking at nearly 550 nm
Refractive index	1.90 (Crystal), 1.35 (Teflon), 1.00 (Air)
Optical photon absorption length (m)	5
Mie scattering length (m)	5000
Absolute light yield (photons/MeV)	46000
Resolution-scale	1.0
Decay time (ns)	61 (77%), 488 (23%)
Birks' constant (mm/MeV)	1.52×10^{-3}
Surfaces: **1.** Crystal-Teflon (dielectric-dielectric) **2.** Crystal-Photodiode (dielectric-metal) (Model used: UNIFIED)	**Type:** ground-front-painted (1), polished (2) **Reflection type:** Lambertian (1), Specular Lobe (2) **Reflectivity:** 0.98 (1), 0.00 (2) **Roughness:** 0˚ (1), 0˚ (2) **Detecting efficiency:** 0.00 (1), 0.90 (2)
Photodiode gain, G	1.0
Overall circuit capacitance, C (nF)	1.0

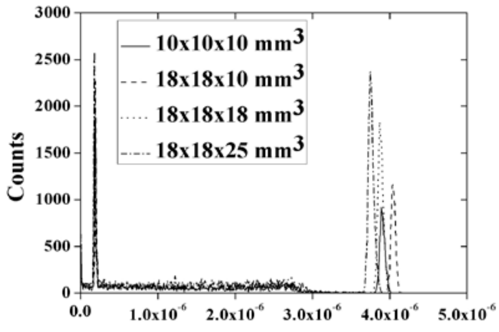

Fig. 2 Simulated pulse-height spectra for different sizes of GGAG:Ce,B crystal

Table 2: Energy resolution at 662 keV for different crystal dimensions

Size (mm^3)	**Energy resolution (%) at 662 keV**
10×10×10	2.02
18×18×10	1.70
18×18×18	2.01
18×18×25	2.02

It is evident from Table 2 that the energy resolution slightly improves when the height of the crystal is less compared to its other dimensions. This is due to better light collection at the photodiode for the shorter crystals. It is to be noted that the values of energy resolution of Table 2 are those due only to the generation and transport of optical photons, and does not include other contributions [2].

Conclusion

GEANT4 based Monte Carlo simulation of GGAG:Ce,B scintillator, incorporating optical photon generation and transport, is presented. Effects of variation of crystal dimensions on pulse-height spectra and energy resolution are reported. It is seen that the increase in surface area of the crystal with respect to its height improves the energy resolution and also increases the pulse-height.

References

[1] Rawat S., *et al.*, Nucl. Instrum. Methods A, **840**, 186-191 (2016).

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