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■ 論 文 ■

A Study of the Inorganic Scintillator Properties for a Phoswich Detector

Woo Gyo Lee · Yong Kyun Kim · Jong Kyung Kim* · V. Tarasov† · O. Zelenskaya†

Korea Atomic Energy Research Institute
*Dept. of Nucelar Engineering, Hanyang University
† STC Institute for Single Crystals of National Academy of Science of Ukraine

Phoswich 검출기 제작을 위한 무기 섬광체 특성 연구

이우교 · 김용균 · 김종경* · V. Tarasov† · O. Zelenskaya†

한국원자력 연구소
*한양대학교 원자력공학과
† STC Institute for Single Crystals of National Academy of Science of Ukraine

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Abstract - CsI(Tl), $CdWO_4$(CWO), $Bi_4Ge_3O_{12}$(BGO) and Gd_2SiO_5:Ce(GSO) scintillators were studied to manufacture a phoswich detector. The maximum wavelengths of the CsI(Tl), CWO, BGO and GSO scintillators are 550 nm, 475 nm, 490 nm and 440 nm for the radioluminescence, and the absolute light outputs of the CsI(Tl), CWO, BGO and GSO scintillators are 54890 phonon/MeV, 17762 phonon/MeV, 8322 phonon/MeV and 8932 phonon/MeV with a neutral filter, and the decay time of the CsI(Tl), CWO, BGO and GSO scintillators is 1.3 μs, 8.17 μs, 213 ns and 37 ns by a single photon method. The phoswich detector which was manufactured with plastic and CsI(Tl) scintillators could separate the β particle and γ ray. The phoswich detector could also measure the pulse height spectra of the β particle and γ ray by a PSD method.

Key words : phoswich, inorganic scintillator, PSD(pulse shape discriminator), decay time, absolute light output

요약 - Phoswich 검출기를 제작하기 위하여 무기 섬광체인 CsI(Tl), $CdWO_4$(CWO), $Bi_4Ge_3O_{12}$(BGO)와 Gd_2SiO_5:Ce(GSO)의 특성을 연구하였다. CsI(Tl), CWO, BGO 및 GSO 섬광체의 radioluminescence 중심파장은 550 nm, 475 nm, 490 nm 및 440 nm이였고, neutral filter를 사용하여 측정한 CsI(Tl), CWO, BGO 및 GSO 섬광체의 절대광량은 각각 54890 phonon/MeV, 17762 phonon/MeV, 8322 phonon/MeV 및 8932 phonon/MeV이였으며, single photon method로 측정한 형광감쇠시간은 각각 1.3 μs, 8.17 μs, 213 ns 및 37 ns이였다. 플라스틱 섬광체와 CsI(Tl) 섬광체를 사용하여 phoswich 검출기를 제작하였고 PSD(pulse shape discriminator) 방법으로 β 입자와 γ 선을 구별하으며 각각의 방사선에 대한 파고 스펙트럼을 측정하였다.

중심어 : phoswich, 무기섬광체, PSD(pulse shape discriminator), 감쇠시간, 절대광량

Introduction

The radiation field is generally the mixed more than two radiations, but the phoswich detector will be able to measure the type and energy of the radiation in such a mixed radiation field[1-4]. The phoswich detector consists of more than two kinds of scintillators and can distinguish the radiation type by the decay time and the scintillation efficiency of the radiation. Generally, ZnS(Ag) is used to detect α particles, the plastic scintillator for the β particles and inorganic scintillators for the γ ray. Although various scintillators like CsI(Tl), $CdWO_4$(CWO), $Bi_4Ge_3O_{12}$(BGO) and Gd_2SiO_5:Ce (GSO) are used commercially, the scintillator in this study was selected for a proper objective. The CsI(Tl) scintillator has a good detection efficiency and light yield per unit volume for γ ray, but must be sealed due to dampness. The CWO scintillator is an intrinsic scintillation material and it has a high atomic number, and a high density, but its decay time is very long at room temperature. The BGO scintillator has a high density and high atomic number, and its decay time is a few hundreds of ns at room temperature, its afterglow is about 0.005% after 3 ms. The GSO scintillator is doped with Ce in Gd_2SiO_5, its decay time is several tens of ns at room temperature, its radiation hardness is very strong.

In our study, the physical properties, scintillation properties and time properties of the CsI(Tl), CWO, BGO and GSO scintillators were studied, the phoswich detector was manufactured with the plastic and CsI(Tl) scintillators. The spectra of the β and γ radiations were measured with the phoswich detector by a PSD(pulse shape discriminator) method[5-7].

Experiment

1. Radioluminescence

The radioluminescence provides the exact wavelength of the scintillation when the radiation energy is absorbed. The radioluminescence wavelength was measured with a 59.6 keV energy of the ^{241}Am radioactive isotope, its activity was 6.66×10^{10} Bq. The spectral range of the radioluminescence of the CsI(Tl) scintillator was from 300 nm, and its maximum radioluminescence intensity appeared at 550 nm, as shown in Fig. 1. The spectral ranges of the radioluminescence of the CWO and BGO scintillators was from 370 and 350 nm, and their maximum radioluminescence intensity appeared at 475 and 490 nm, respectively. And the spectral range of the radioluminescence of the GSO scintillator was from 400 nm, and its maximum radioluminescence intensity appeared at 440 nm. The maximum wavelength of the radioluminescence spectrum agreed with the that of the photoluminescence spectrum.

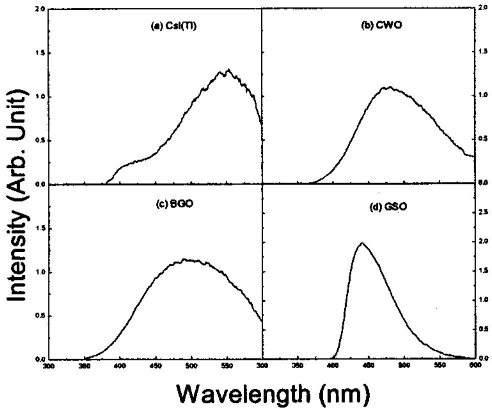

Fig. 1. Radioluminescence spectra of theCsI(Tl), CWO, BGO and GSO scintillators.

2. Scintillation property

The pulse height spectra were measured with the five energies of the radioactive isotopes, as shown in table 1. The PMT was R1307 (Hamamatsu). Table 1 shows the energy resolutions calculated from the pulse height spectra of the CsI(Tl), CWO, BGO and GSO scintillators. The energy resolutions of the CsI(Tl), CWO, BGO and GSO scintillators were 6.45 %, 8.30 %, 9.90 % and 9.20 %, respectively, when exposed to ^{137}Cs γ-ray and they improved according to the increase the radiation energy. The channels of the energies were corrected from the 1st function which was plotted regarding the radiation energy and the channel of the photo peak obtained from the pulse height spectra which were measured. Fig. 2 shows the energy calibration curves of the CsI(Tl), CWO, BGO and GSO scintillators. The calibration curves of the CsI(Tl), CWO, BGO and GSO scintillators were E_γ=0.7532(ch)+4×

10^{-13}, $E_\gamma=0.7501(ch)$, $E_\gamma=0.7428(ch)-4\times10^{-13}$ and $E_\gamma=0.7487(ch)-4\times10^{-13}$, respectively. Their slope means the energy per 1 channel and the linearity was good.

3. Absolute light output

The absolute light output is the principal characteristic of a scintillator and it is constant no matter what the size or shape of it is. Optical oil was used to eliminate the air between the surface of the scintillator and the window of the PMT and the scintillator was covered with a cylindrical reflector which was made of PTFE to receive the window of the PMT when the absolute light output was measured. The scintillators were positioned at the same position on the window of the PMT when the pulse height spectra were measured with a neutral filter and without a neutral filter[8]. Table 2 includes the inverse of the

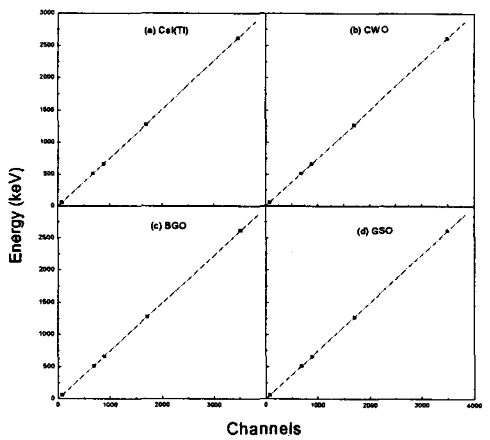

Fig. 2. Energy calibration curves for the CsI(Tl), CWO, BGO and GSO scintillators.

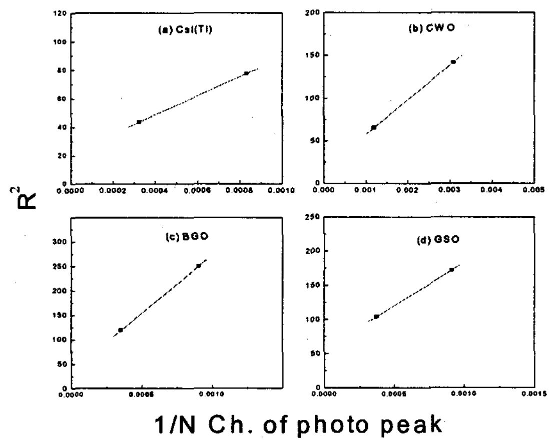

Fig. 3. Measurement of the intrinsic resolutions of the CsI(Tl), CWO, BGO and GSO detectors with a neutral filter.

Table 1. Energy resolutions and the maximum channels obtained from the CsI(Tl), CWO, BGO and GSO scintillators coupled to the PMT.

Energy (keV)	CsI(Tl)			CWO			BGO			GSO		
	Peak ch.	FWHM	R(%)	Peak ch.	FWHM	R(%)	Peak ch.	FWHM	R(%)	Peak ch.	FWHM	R(%)
2614	3470.2	144.8	4.17	3463	189.0	5.46	3494	194.5	5.57	3476	139.3	4.01
1275	1657.5	83.6	5.04	1651	107.0	6.48	1667	126.2	7.57	1700	113.4	6.67
662	857.9	55.3	6.45	843.0	70.0	8.30	841.5	83.3	9.90	866.5	79.7	9.20
511	666.8	46.0	6.90	646	58.5	9.06	649	70.0	10.79	671	62.8	9.37
59.6	83.7	11.30	13.50	64.4	18.90	29.35	65.9	23.75	36.04	65.6	20.40	31.10

Table 2. Measurement of the energy resolutions and the maximum channels obtained from the CsI(Tl), CWO, BGO and GSO scintillators without and with a neutral filter.

MeV	Measurement Condition	CsI(Tl)		CWO		BGO		GSO	
		R^2	1/N	R^2	1/N	R^2	1/N	R^2	1/N
0.662	Without filter	43.56	0.00032206	65.61	0.001184133	118.81	0.00035386	104.04	0.000372024
	With filter #1	77.44	0.00083333	141.61	0.00308642	249.64	0.00090498	171.61	0.000909918

photo peak channel and the resolution square of the CsI(Tl), CWO, BGO and GSO detectors. Fig. 3 shows the graph for obtaining the intrinsic resolutions of the CsI(Tl), CWO, BGO and GSO detectors. The formulas of the linear lines are Y=66266X+22.218, Y=39952X+18.30182, Y=237389X+34.808 and Y=125619X+57.307, where the intercept value of Y is the intrinsic resolution square of the detector. The intrinsic resolutions of the CsI(Tl), CWO, BGO and GSO detectors are 4.71 %, 4.28 %, 5.90 % and 7.57 %, respectively. Tables 3 and 4 show the intrinsic resolutions and the calculated absolute light outputs of the CsI(Tl), CWO, BGO and GSO detectors. The absolute light outputs of theCsI(Tl), CWO, BGO and GSO scintillators were 54890 phonon/MeV, 17762 phonon/MeV, 8322 phonon/MeV and 8932 phonon/MeV, and they are given in Tables 3 and 4.

4. Time property

The decay time of an inorganic scintillator is the natural characteristic of a scintillator with various values. The decay time of the scintillator was measured with a single photon method at room temperature. The scintillator was excited by the γ ray of ^{137}Cs and the time interval of the data is from 0.5 ns to 2 ns.

The decay time of the CsI(Tl) scintillator is 1.3 μs, which is slower than that of the known CsI(Tl) scintillator and that of the CWO scintillator has a very slow component and 8.17 μs, which is slower than that of the known CWO scintillator. The decay time of the BGO scintillator is 213 ns and is faster than that of the known BGO scintillator and that of the GSO scintillator is 37 ns, which is similar to that of the known GSO scintillator.

5. Phoswich detector

The phoswich detector is constructed with two different scintillators materials, which can discriminate and detect two different radiations. The phoswich detector consists of a 2.2 mm thick layer of a plastic scintillator for a β particles detection, followed by a 50 cm CsI(Tl) scintillator for a γ detection, with all the scintillators having a diameter of 50 mm, in an arrangement similar to that shown in Fig. 4. Its window consists of a 17 μm thick layer of aluminium foil and an Al-coated mylar film for the prevention of α particles and dampness. To discriminate and detect the β and γ radiation, the experimental measurement was carried out by a pulse shape discrimination(PSD) which consisted of a timing filter amplifier, constant

Table 3. Calculation of the resolutions and the technical and absolute light output from the CsI(Tl) and CWO scintillators without and with a neutral filter.

CsI(Tl)				CWO			
Detector resolution	PMT resolution	Technical light output	Absolute light output	Detector resolution	PMT resolution	Technical light output	Absolute light output
R_d(%)	R_{PMT}(%)	N_p(P/MeV)	N_p(P/MeV)	R_d(%)	R_{PMT}(%)	N_p(P/MeV)	N_p(P/MeV)
4.71	4.62	2306	54890	4.28	6.88	1770	17762

Table 4. Calculation of the resolutions and the technical and absolute light output from the BGO and GSO scintillators without and with a neutral filter.

BGO				GSO			
Detector resolution	PMT resolution	Technical light output	Absolute light output	Detector resolution	PMT resolution	Technical light output	Absolute light output
R_d(%)	R_{PMT}(%)	N_p(P/MeV)	N_p(P/MeV)	R_d(%)	R_{PMT}(%)	N_p(P/MeV)	N_p(P/MeV)
5.90	9.17	997	8322	7.57	6.84	1792	8932

fraction discriminator and a time to pulse height converter, which is shown in Fig. 5.

The rise time of the plastic scintillator was measured for the β particles and that of the CsI(Tl) scintillator was measured for the γ ray. The signals from the pulse height spectrum

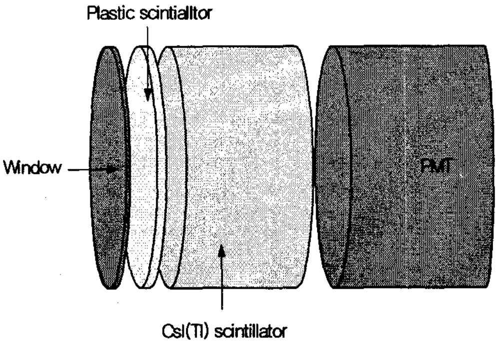

Fig. 4. Phoswich detector with plastic and CsI(Tl) scintillators.

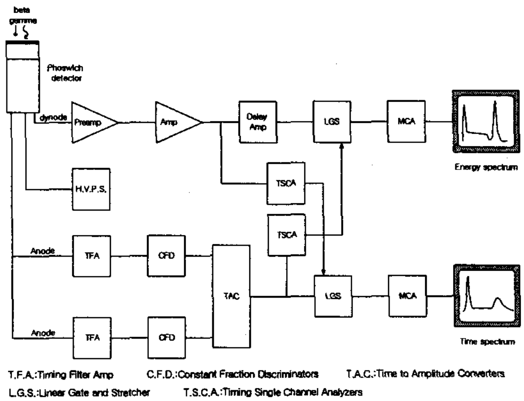

Fig. 5. Block diagram of the PSD circuit for the phoswich detector.

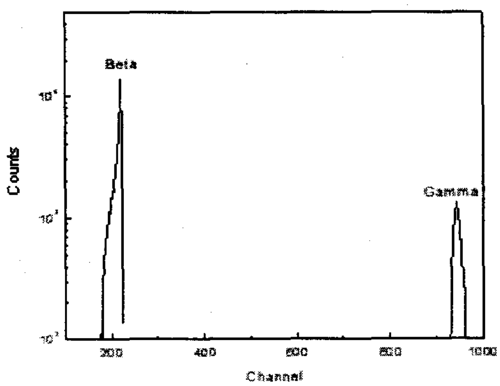

Fig. 6. PSD time spectrum of the phoswich detector.

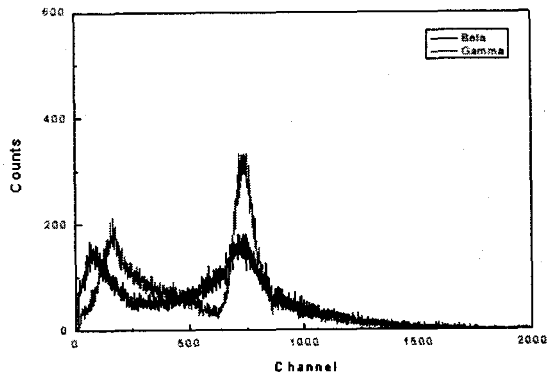

Fig. 7. Pulse height spectra of the β and γ rays measured with the phoswich detector.

inputs to the gate signal of the time spectrum are as shown in Fig. 5. The two peaks of the time spectrum separated and the former is the peak of the β particles, the latter is the peak of the γ rays. The time interval of the two peaks is 1.3 μs, as shown in Fig. 6. The spectrum of the β particles was measured when the β peak of the time spectrum inputs at the gate of the pulse height spectrum and the spectrum of the γ ray was measured when the γ peak of the time spectrum inputs at the gate of the pulse height spectrum, as shown in fig. 7. The pulse height spectrum of the γ ray has a good shape for ^{137}Cs and that of the β particles appeared that of Fig. 7, because the β peak of the time spectrum includes the γ signal in the base line of the time spectrum.

Conclusion

The properties of the CsI(Tl), CWO, BGO and GSO inorganic scintillators were studied to manufacture a phoswich detector, which was made with plastic and CsI(Tl) scintillators. The maximum radioluminescence intensity of the CsI(Tl), CWO, BGO and GSO scintillators appeared at 550 nm, 475 nm, 490 nm and 440 nm, their energy resolutions were 6.45 %, 8.30 %, 9.90 % and 9.20 %, respectively, and when exposed to a ^{137}Cs γ-ray, their calibration curves were $E_\gamma=0.7532(ch)+4\times10^{-13}$, $E_\gamma=0.7501(ch)$, $E_\gamma=0.7428(ch)-4\times10^{-13}$ and $E_\gamma=0.7487(ch)-4\times10^{-13}$, respectively. and their absolute light outputs with a neutral filter were 54890 phonon/MeV, 17762 phonon/MeV, 8322 phonon/MeV and 8932 phonon/MeV, respectively, and their decay time was 1.3 μs, 8.17 μs, 213 ns and 37 ns, respectively. The manufactured phoswich detector could discriminate between the β and γ radiations, and the time interval of the two peaks was 1.3 μs.

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