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Scintillation Light Output of 3D Printed Plastic Scintillators

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1. Introduction

Digital Light Processing (DLP) 3D printing technique can facilitate to manufacture plastic scintillators with different shapes in innovatively fast time (10 minutes to 4 hours). However, low scintillation light output of 3D printed plastic scintillator is a major problem with a practical use in radiation detection systems. Our previous study has reported that the application of new wavelength shifter ADS086BE can improve scintillation light output of 3D printed plastic scintillator up to 51% (relative to BC408 plastic scintillator, Saint-Gobain Crystal) [1].

In this study, we focused on improving the scintillation light output of existing 3D printed plastic scintillator by adding α-methyl-naphthalene as an activator. 3D printed plastic scintillators were fabricated with the different amounts of α-methyl-naphthalene. Scintillation light output derived from the pulse height spectra measured with a PMT and 662 keV gamma ray of ^{137}Cs radiation source. Additionally, the relative light output was determined and compared to the commercial plastic scintillator BC408 that produces light output 10,000 photons/MeV [2].

2. Methods and Results

2.1 Wavelength Shifter

Wavelength shifter, one of the scintillating components, affects characteristic emission wavelength spectrum of a plastic scintillator. In our previous study, we confirmed that the wavelength shifter ADS086BE (American Dye Source [3]) showed better scintillator's performance (51% relative to BC408 plastic scintillator, Saint-Gobain Crystal), compared to other wavelength shifters, e.g. POPOP. Thus, the material was selected as the wavelength shifter in this study. 3D printed plastic scintillator added with ADS086BE is a blue-emitting scintillator that has the characteristic emission wavelength spectrum with the range of 410-650 nm (λ_{max} = 460 nm).

2.2 Activator

Activator in organic scintillator affects some properties of materials, such as light conversion efficiency, the spectrum of the emitted light, and the light attenuation coefficients. As such, activator can improve scintillation light output of plastic scintillator.

In this study, α-methyl-naphthalene was selected as the activator. The main characteristics of α-methyl-naphthalene are as follows: one of naphthalene series, liquid at room temperature, high solubility, and volatility.

2.3 Plastic Scintillator Formulation and Fabrication

An UV-polymerizable resin was designed by adding photo-initiator to scintillating components to fabricate plastic scintillators with 3D printer. The resin formulation is composed of existing 3D printed plastic scintillator components (e.g. monomer, primary dye, and new wavelength shifter) with the different amounts of α-methyl-naphthalene. Each resin was stirred for 10 minutes in a water bath at 40℃ because of the volatility of α-methyl-naphthalene. Pico2 HD DLP 3D printer (ASIGA) was used, and the size of the fabricated plastic scintillators is 20 × 20 × 10 mm^3. Figure 1 shows the fabricated plastic scintillators.

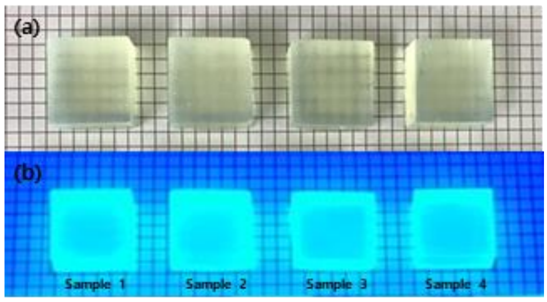

Figure 1. Fabricated plastic scintillators (a) before and (b) after 385 nm ultraviolet irradiation

2.4 Scintillation Light Output of Plastic Scintillator

Scintillation light output were measured on the commercial plastic scintillator BC408 and the fabricated plastic scintillator. Figure 2 shows the block diagram of the measurement devices consisting of the radiation source, detector, and photomultiplier tube (PMT) coupled to specimen. ^{137}Cs Compton spectrum and single photoelectron spectrum of the plastic scintillators were measured as presented in Figure 3. Light output is calculated by the following equation [4] :

$$N_{ph} = \frac{PP_e}{PP_{1phe}} \frac{K_{1phe}}{K_e} \frac{1}{E_\gamma} \frac{1}{Q.E._{eff}} \text{ [photons/MeV]} \qquad (1)$$

K_e, K_{1phe} : Amplifier's gains
PP_e : Specific point of energy spectrum
PP_{1phe} : Peak point of single photoelectron spectrum

E_γ : 0.477 MeV of ^{137}Cs Compton electron energy
$Q.E._{eff}$: Effective quantum efficiency of PMT

This can be achieved through a comparison between the peak position of a single photoelectron spectrum (PP_{1phe}) and the specific point of energy spectrum, e.g., Compton edge (PP_E). PP_{1phe} and PP_E are measured under amplifier's gain K_E and K_{1phe}, respectively. Effective quantum efficiency of PMT ($Q.E._{eff}$) is the number of photoelectrons emitted from the photocathode. $Q.E._{eff}$ of Sample 1, 2, 3, and 4 ranged from 18.6% to 19.6%, and $Q.E._{eff}$ of BC408 was 23.5%

Table 1 shows the calculated scintillation light output of BC408 and the fabricated plastic scintillators. Sample 4 showed the best light output 7,720 ± 90 photons/MeV (74% relative to the light output of BC408, Figure 4). We speculated that the characteristics of α-methyl-naphthalene such as high solubility and the chemical composition with other scintillating components affect this improvement of scintillation light output when compared with the existing activator naphthalene.

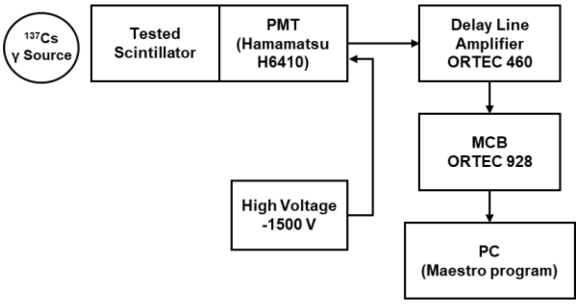

Figure 2. Block diagram to measure pulse height spectrum from ^{137}Cs with plastic scintillators

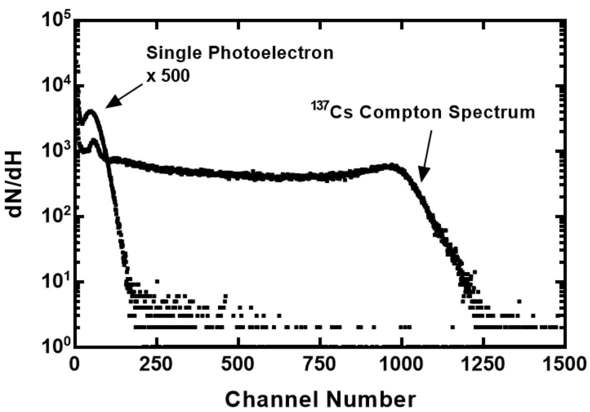

Figure 3. Measured pulse height spectra of BC408 plastic scintillator (Single Photoelectron amplifier gain: 1,000; ^{137}Cs Compton spectrum amplifier gain: 20)

Table 1. Light output of the fabricated plastic scintillators and BC408

Sample #	Light output (photons/MeV)
1	4,020 ± 130
2	4,900 ± 80
3	6,040 ± 70
4	7,720 ± 90
BC408	10,470 ± 40

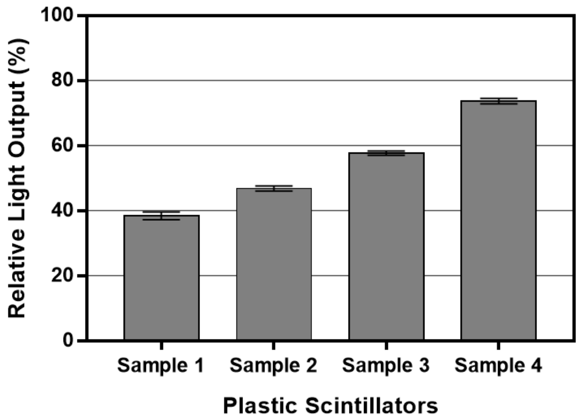

Figure 4. Relative light output of the fabricated plastic scintillators to BC408

3. Conclusions

Scintillation light output of 3D printed plastic scintillators with the different amounts of α-methyl-naphthalene was measured and compared. Using the measurement system with a PMT, light output of 7,720 photons/MeV was observed for Sample 4. To practically use this plastic scintillator in radiation detection systems, further researches on decay time and energy resolution should be performed.

REFERENCES

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