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Light Output Analysis of 3D Printed Plastic Scintillator

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1. Introduction

3D printing technique based on additive manufacturing can facilitate to manufacture plastic scintillators in innovatively fast time (10 minutes to 4 hours). For a practical use in radiation detection systems, 3D printed plastic scintillator has been studied to improve scintillation light output.

In the previous study [1], it was confirmed that the amounts of 1-methyl-naphthlane in the composition of plastic scintillator improves light output of the scintillator. Given that the addition of naphthalene can improve a transmission of plastic scintillator [2], in this study, 3D printed plastic scintillators with different amount of 1-methyl-naphthalene (0-70%) were fabricated and analyzed for the relationship between light output and transmission. The measured data were compared to that of BC408 commercial plastic scintillator (Saint-Gobain Crystal).

2. Methods and Results

2.1 3D Printed Plastic Scintillator

3D printed plastic scintillators were fabricated with the plastic resins developed in the previous study [1]. The resin formulation is composed of existing 3D printed plastic scintillator components (e.g. monomer, primary dye, and wavelength shifter) with the different amounts of 1-methyl-naphthalene (0 – 70%) as a secondary monomer.

2.2 Light Output Measurement

For evaluating light output of the fabricated plastic scintillators, a measurement system [3] using a large area avalanche photodiode (LAAPD) was constructed. Figure 1 shows the experimental setup for light output measurement. LAAPD (Advanced Photonics, SD 630-70-74-500) was used, and it was calibrated by using Gaussian peak ($P_{X\text{-}ray}$ = 456.5 ch) for 5.9 keV X-ray from ^{55}Fe source. The tested plastic scintillators (BC408 and 3D printed plastic scintillators) were coupled to the calibrated LAAPD with BC-630 optical grease for a good optical coupling, and wrapped with Teflon tape. The detector signal produced by the irradiation of 662 keV γ-ray from ^{137}Cs source was properly amplified through preamplifier (CAMBERRA 2006) and main amplifier (ORTEC 460), and the events were acquired by MCA (ORTEC 928). Figure 2 shows the measured pulse height spectra of the tested plastic scintillators.

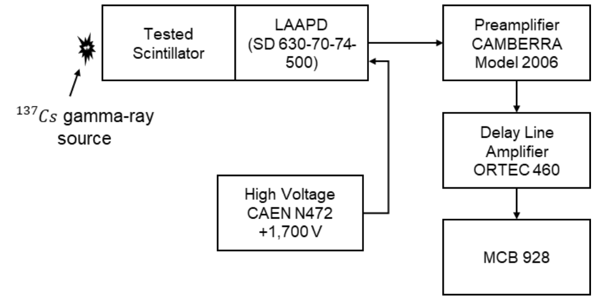

Fig. 1. Systematic diagram of measurement system for light output

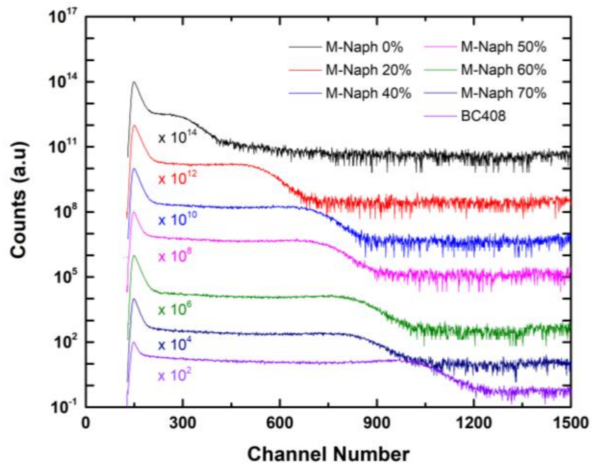

Figure 2. Pulse height spectra of the tested plastic scintillators for 662 keV γ-ray from ^{137}Cs source.

To calculate light output of the tested plastic scintillator, effective quantum efficiency ($Q.E._{eff}$) should be required, and it was calculated by the below equations:

$$Q.E._{eff} = \frac{\int I(\lambda) \times Q.E.(\lambda)\, d\lambda}{\int I(\lambda)\, d\lambda} \quad (1)$$

I(λ) is emission intensity [a.u.] of characteristic fluorescence lights emitted from the tested plastic scintillators, and Q.E.(λ) is the values for the LAAPD provided in Advanced Photonics.

Light output of the tested plastic scintillators was calculated by the below equation:

$$N_{ph} = \frac{E_{X-ray}}{E_{ion}} \frac{P_{Peak}}{P_{X-ray}} \frac{1}{E_c} \frac{1}{R_{PTFE}} \frac{1}{Q.E._{eff}} \quad (2)$$

Table I: Position of half of Compton maximum (P_{Peak}), effective quantum efficiency ($Q.E._{eff}$), light output (N_{ph}), and effective transmission (T_{eff}) for the fabricated plastic scintillators (1-methyl-naphthalene 0 – 70%) and BC408

Plastic Scintillator	P_{Peak} [ch]	$Q.E._{eff}$ [%]	N_{ph} [ph/MeV]	T_{eff} [%]
BC408	1,040 ± 30	87.20	9,970 ± 300	74.28
1-methyl-naphthalene 0%	320 ± 10	89.61	2,946 ± 50	28.11
1-methyl-naphthalene 20%	540 ± 10	89.65	5,040 ± 110	33.0
1-methyl-naphthalene 40%	730 ± 50	89.64	6,830 ± 480	38.25
1-methyl-naphthalene 50%	780 ± 20	89.56	7,250 ± 230	46.43
1-methyl-naphthalene 60%	820 ± 50	89.60	7,650 ± 430	51.85
1-methyl-naphthalene 70%	830 ± 30	89.50	7,750 ± 280	10.87

where $E_{X\text{-}ray}$ is 5.9 keV, E_{ion} is 3.6 eV the energy to make one e-h pair in the LAAPD, R_{PTFE} is the reflectivity (90%) of the wrapped Teflon tape, P_{Peak} is the position of half of Compton maximum for 477 keV Compton electron energy (E_c). Table I and Figure 3 show the calculated light output [ph/MeV] for the fabricated plastic scintillators with different amounts of 1-methyl-naphthalene. Light output 7,750 ± 280 ph/MeV was achieved for the 1-methyl-naphthalene 70% scintillator (77.7% relative to BC408 light output 9,970 ± 300 ph/MeV).

2.3 Transmission Measurement

Transmission relative to air was measured using Cary 300 UV-vis Spectrometer (Varian). Using the measured transmission spectrum for the tested plastic scintillator, effective transmission (T_{eff}) for the emission wavelength spectrum of the tested plastic scintillators was calculated by the below equation.

$$T_{eff} = \frac{\int I(\lambda) \times T(\lambda)\, d\lambda}{\int I(\lambda)\, d\lambda} \quad (3)$$

Figure 3 shows the T_{eff} for the 3D printed plastic scintillators. It was confirmed that T_{eff} was improved with the amounts of 1-methyl-naphthalene in the composition of the scintillator, while the scintillator added with 1-methyl-naphthalene 70% showed very low effective transmission 10.87% because of its unstable surface.

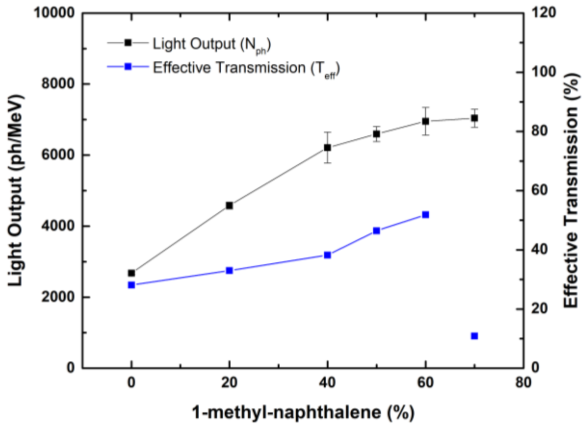

Figure 3. Light output and effective transmission for the 3D printed plastic scintillators with amounts of 1-methyl-naphthalene.

3. Conclusions

Light output and transmission of the 3D printed plastic scintillators with the different amounts of 1-methyl-naphthalene were measured and analyzed. The measured light output and transmission was improved with the amounts of 1-methyl-naphthalene, but the saturation of light output began above 1-methyl-naphthalene 60%. Given the above fact, it is expected that the additional effect factors on light output other than transmission should be considered such as the number of benzene rings in the composition of the scintillator and oxygen quenching effect.

REFERENCE

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