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Development of 3D-Printed Plastic Scintillators with Long Emission Wavelength

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1. Introduction

Plastic scintillators are used in various industries for radiation measurement. In recent years, 3D printed plastic scintillators, which can be produced quickly and inexpensively in various shapes, are being actively researched and their versatility is highly anticipated.[1]

Typically, measurement devices that use plastic scintillators include photomultiplier tubes (PMTs) or silicon photomultipliers (SiPMs) within their housing, along with the scintillator. However, in high-dose environments, accurate dose measurement becomes challenging due to noise, including electromagnetic interference.[2] For medical measurement equipment that requires real-time high radiation dose measurements, a method is used where the light signals generated by the plastic scintillators are sufficiently transported via optical fibers before being amplified by the multipliers. It is known that longer wavelengths of the transported light signals result in lower loss rates.[3]

This study developed 3D printed plastic scintillators with different emission wavelength regions to explore the possibility of creating scintillators that offer advantages in signal transmission.

2. Methods and Results

This section discusses the fabrication and characterization of 3D-printed plastic scintillators with different emission wavelengths.

2.1 Fabrication of 3D-Printed Plastic Scintillator

The resin compositions used for manufacturing plastic scintillators with different emission wavelength regions are shown in Table I. A DLP-based 3D printer (IMD-C, Carima) was used for the photopolymerization of the resins. To adjust the emission wavelengths of each plastic scintillator, different types of wavelength shifters (WS) were blended, although the component ratios of the base materials remained the same. Specifically, for RMPS540, the proportion of the Wavelength-shifter (WS) in the original mixture was increased fivefold to enhance the shifting of the emission wavelength region, resulting in the production of RMPS540_WS. The four types of manufactured plastic scintillators are as shown in Figure 1.

Table I: Composition of Plastic Scintillator (PS) Resin

PS	Monomer	Primary dye	Photo-initiator	Wavelength shifter
RMPS470	D0241 (Ethoxylated bisphenol fluorene diacrylate (OPPEA 40%))	PPO (Diphenyloxazole)	TPO (Diphenyl phosphine oxide)	ADS086BE
RMPS540 RMPS540_WS				ADS081BE
RMPS580				ADS076RE
BC408	Commercial PS (Saint-Gobain)			

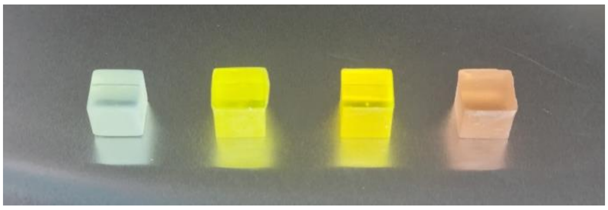

Fig. 1. 4types of 3D-printed plastic scintillator (RMPS470, RMPS540, RMPS540_WS, RMPS580)

2.2 Emission Wavelength & Transmittance

The emission wavelengths of four types of manufactured scintillators and one type of commercial scintillator were measured using a UV-visible spectrometer (Cary 300, Varian) with excitation at 340 nm. Additionally, to evaluate the self-absorption effects of the scintillators in the emission wavelength region, transmittance analyses were conducted using a spectrophotometer (Lambda 650S, Perkin Elmer).

The emission wavelength measurements resulted in peaks at 470 nm, 530 nm, 539 nm, and 580 nm, as shown in Figure 2. Additionally, RMPS540 exhibited a peak in the 380 nm region. This peak is due to the primary scintillation emitted at 374 nm from PPO in the scintillator resin, which was not absorbed by the wavelength shifter and was instead emitted directly.

As shown in Figure 3, the transmittance of the manufactured scintillators was about 77% across their respective emission wavelength regions, which is due to the use of the same monomer in all samples. This indicates that the self-absorption effect was approximately 10% higher compared to BC408.

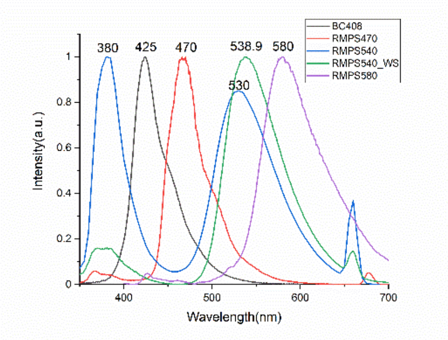

Fig. 2. Emission wavelength of each plastic scintillator

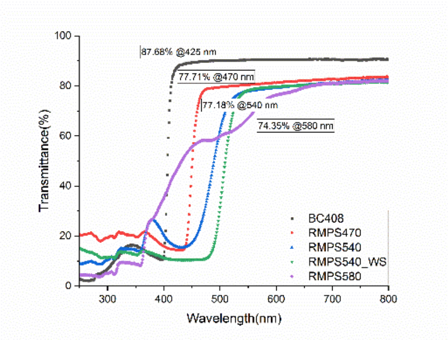

Fig. 3. Transmittance of each plastic scintillator

2.3 Light yield

To assess the light yield of each plastic scintillator, the energy spectrum was measured using a Cs-137 source (9.54 μCi), a PhotoMultiplier Tube (PMT H6410, Hamamatsu), a delay amplifier (ORTEC 460), a MultiChannel Analyzer (MCB ORTEC 919E), and a high voltage power supply (ORTEC 556). The relative and absolute Light Yields (LY) of each sample compared to BC408 were derived using Equation (1), considering the Compton-Edge (C.E) from the measured spectrum, the wavelength-specific quantum efficiency (Q.E) of PMT photocathode [4], and the gain values of the amplifier.

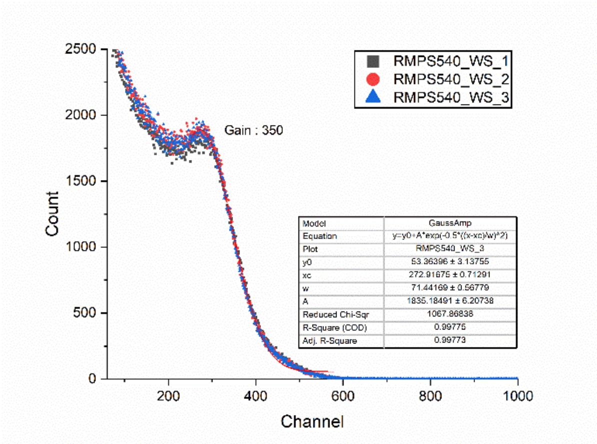

Fig. 4. Measurement Spectra of RMPS540_WS and Gaussian fitting of Compton edge

$$(1)\ Relative\ LY[\%] = \frac{C.E.sample}{C.E.\,BC408} * \frac{Q.E.BC408}{Q.E.samp} * \frac{gain.BC408}{gain.samp} * 100\%$$

The light yields of the scintillators are as indicated in Table II. RMPS540, which exhibits significant color-quenching effects, showed a lower light yield, whereas RMPS580, despite having the lowest relative transmittance, displayed a higher light yield. This can be attributed to the multiple benzene rings and absorption wavelength characteristics of ADS076RE. It is anticipated that using this scintillator could reduce signal loss in applications requiring long-distance transport of scintillation signals.

Table II: Light Yield (LY) of Plastic Scintillator

PS	BC408	RMPS 470	RMPS 540	RMPS 540_WS	RMPS 580
Relative LY [%]	100	66.9	36.7	43.3	115.8
Absolute LY [MeV /Photons]	10,000	6,689.5	3,666.5	4,326.4	11,578.8

3. Conclusions

This study developed and characterized long-wavelength 3D-printed plastic scintillators, demonstrating the potential to create scintillators with excellent performance and extended wavelengths. Future work optimizing the specific formulations and print parameters could enable the production of sophisticated 3D-printed plastic scintillators. When applied to real-time high-dose radiation measurement systems, these scintillators could reduce signal loss and ensure precise measurements.

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