

Effect of Wavelength-Shifter Concentration on the Emission Characteristics of DLP 3D-Printed Plastic Scintillators

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1. Introduction

Plastic scintillators can be fabricated in a wide range of geometries and sizes, making them suitable for use in various radiation detection systems. However, conventional fabrication methods based on thermal polymerization require long processing times, as well as shape machining and post-processing. Accordingly, digital light processing (DLP) 3D printing, which enables precise geometric control and rapid fabrication, has been applied to the fabrication of plastic scintillators. In addition to its geometric flexibility, DLP fabrication allows the scintillator formulation to be tailored by adjusting the composition of the photocurable resin, providing a means of controlling its optical characteristics. Among these characteristics, the emission spectrum is an important factor affecting the spectral response of a photomultiplier tube (PMT) and photon detection efficiency; therefore, spectral matching with the high-sensitivity region of the PMT is desirable. In this study, this compositional flexibility of DLP fabrication was utilized to develop a 3D-printed plastic scintillator with an emission wavelength of approximately 410 nm.

2. Materials and Methods

2.1 Scintillator Fabrication

The emission wavelength of a scintillator is governed by the wavelength shifter, which absorbs lights emitted from the primary dye, undergoes excitation, and subsequently re-emits light at a characteristic wavelength. Table I presents the absorption and emission peak wavelengths of the primary dye and wavelength shifters used in this experiment. The primary dye absorbs light at approximately 310 nm and exhibits emission peaks at 356 and 374 nm. [1] To ensure efficient absorption of the emitted photons, wavelength shifters with absorption region in the range of 350–380 nm were selected. Among these candidates, Acridine was selected because its emission peak at approximately 414 nm is close to the target wavelength of 410 nm. [2]. A monomer was incorporated to preserve the overall shape and mechanical strength of the scintillator. TPO was added as a photoinitiator, producing radicals under UV irradiation and thereby initiating monomer solidification. The emission peak was examined at

different Acridine concentrations using 0.0075 wt% as the reference (C_{ref}), with concentrations of $0.5 \times C_{ref}$ (0.00375 wt%), $1.67 \times C_{ref}$ (0.0125 wt%), and $2.67 \times C_{ref}$ (0.02 wt%). The overall material ratios were adjusted based on previous studies. [3]

Table I. Peak absorption and emission wavelengths of the primary dye and wavelength shifters used in this study

Peak Wavelength	Primary dye	Wavelength shifter
	PPO [1]	Acridine [2]
Solvent	Cyclohexane	Ethanol
Absorption [nm]	310	360
Emission [nm]	356	396
	374	414

2.2 Experimental setup for measuring emission spectra

The emission spectra were acquired using a fluorescence spectrometer (Varian Cary Eclipse, Agilent Technologies). An excitation wavelength of 310 nm was used, corresponding to the absorption characteristics of PPO. The emission intensity was measured across the range of 355–600 nm. For BC408, the emission spectrum was measured at a PMT bias voltage of 500 V. However, due to the low emission intensity observed for the Acridine-containing scintillator at 500 V, the PMT bias voltage was increased to 600 V for the emission-spectrum measurement. All plastic scintillators were prepared with dimensions of 2 cm × 2 cm × 1 cm. For each scintillator, the emission spectrum and peak wavelength were measured three times.

3. Results and Discussion

Fig. 1 shows the plastic scintillator fabricated with Acridine, while Fig. 2 presents the emission spectra measured at different Acridine concentrations. The peak wavelengths obtained from three repeated measurements for each condition, together with their average values and FWHM, are summarized in Table II. At $0.5 \times C_{ref}$ (0.00375 wt%), the emission peak was observed at approximately 392 nm, close to the Acridine emission reported near 396 nm under solid-state conditions. At this low concentration, reabsorption of the shorter-wavelength emission is limited, allowing

this emission component to remain relatively prominent. At the reference concentration, C_{ref} (0.0075 wt%), the peak shifted to approximately 401 nm. This shift may be attributed to a reabsorption-induced red shift, as the probability of reabsorbing shorter-wavelength photons increases with Acridine concentration. When the concentration was increased to $1.67 \times C_{\text{ref}}$ (0.0125 wt%), the emission peak shifted toward approximately 410 nm. This behavior is consistent with enhanced reabsorption of shorter-wavelength emission and a greater contribution from the Acridine emission near 414 nm. However, a further increase to $2.67 \times C_{\text{ref}}$ (0.020 wt%) caused the peak to shift back toward approximately 400 nm. At this higher concentration, reduced intermolecular distances may promote excitation migration and concentration-dependent quenching, increasing non-radiative deactivation and altering the relative contributions of the Acridine emission components [4]. Consequently, the longer-wavelength contribution observed at $1.67 \times C_{\text{ref}}$ may no longer be maintained, making the shorter-wavelength component relatively more prominent. Therefore, among the concentrations investigated in this study, $1.67 \times C_{\text{ref}}$ provided the most suitable condition for achieving an emission wavelength near 410 nm.



Fig. 1. BC408 and Acridine-containing scintillator with dimensions of 2 cm $\times$ 2 cm $\times$ 1 cm

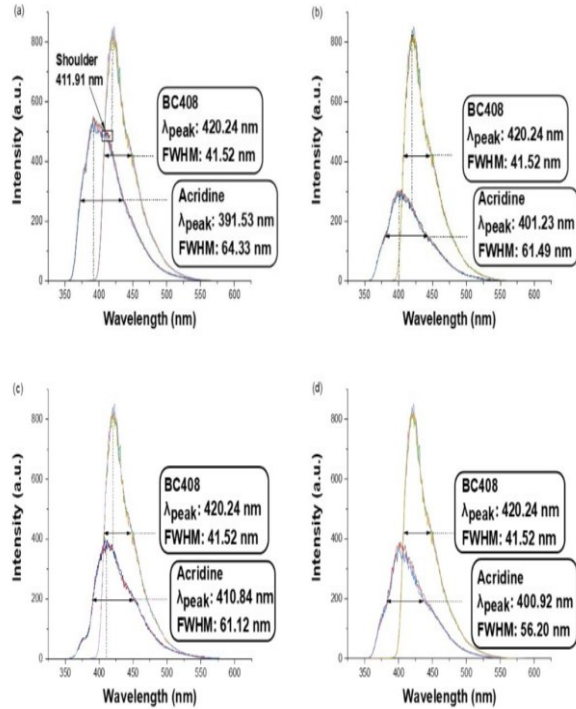


Fig. 2. Spectral characteristics of acridine at (a) $0.5 \times C_{\text{ref}}$, (b) reference concentration (C_{ref}), (c) $1.67 \times C_{\text{ref}}$, (d) $2.67 \times C_{\text{ref}}$.

Table II. Peak wavelength and FWHM of BC408 and Acridine-containing scintillator at varying concentrations

Unit [nm]	Trial 1	Trial 2	Trial 3	Mean $\pm$ Unc.
BC408	419.84	421.96	418.93	420.24 $\pm$ 0.90
FWHM	42.26	40.64	41.65	41.52 $\pm$ 0.67
$0.5 \times C_{\text{ref}}$ (0.00375 wt%)	391.84	391.84	390.92	391.53 $\pm$ 0.31
FWHM	64.36	63.81	64.83	64.33 $\pm$ 0.44
C_{ref} (0.0075 wt%)	399.84	402.92	400.92	401.23 $\pm$ 0.90
FWHM	62.97	59.30	62.19	61.49 $\pm$ 0.48
$1.67 \times C_{\text{ref}}$ (0.0125 wt%)	407.84	409.84	414.84	410.84 $\pm$ 2.08
FWHM	58.60	62.14	62.63	61.12 $\pm$ 1.10
$2.67 \times C_{\text{ref}}$ (0.02 wt%)	400.92	402.92	398.92	400.92 $\pm$ 1.15
FWHM	56.54	54.66	57.39	56.20 $\pm$ 1.31

4. Conclusions

Emission spectra were obtained and compared by varying the concentration of the wavelength shifter, which directly affects the final emission wavelength of the plastic scintillator. Among the tested conditions, an Acridine concentration of $1.67 \times C_{\text{ref}}$ (0.0125 wt%) appeared to be optimal for achieving an emission peak near 410 nm. However, the peak remained broad, as shown in Table II, and the emission intensity was lower than that of BC408 even though a higher PMT bias voltage was applied. Because the material formulation referenced in this study had been optimized for a wavelength shifter other than Acridine, future work will focus on identifying a formulation suitable for Acridine to improve scintillation performance.

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