Fabrication and characterization of a 3D-printed plastic scintillator

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Introduction

Composed primarily of hydrogen, oxygen, and carbon—elements similar to those in human tissues—plastic scintillators are particularly valuable for volumetric dose monitoring in modern radiation therapy [1]. Precise modeling of organs affected by cancer is critical to optimizing radiation dose delivery. However, fabricating small active volumes from thermally polymerized plastic scintillators requires specialized skills and advanced equipment. Three-dimensional (3D) printing offers a promising solution to these challenges by enabling the rapid and cost-effective production of complex designs with high reproducibility.

Since plastic scintillators are inherently polymeric, additive manufacturing techniques like Digital Light Processing (DLP) is well-suited for their fabrication. However, conventional plastic scintillator formulations based on Polystyrene or Polyvinyl toluene are not directly compatible with DLP due to limited photo-polymerization capabilities. Previous efforts to fabricate 3D-printed plastic scintillators using non-aromatic monomers with high naphthalene loading as an intermediate solvent have demonstrated performance degradation over time, primarily due to the solvent's volatility [2].

In this study, we present the formulation, fabrication using a DLP-based 3D printer and key properties of a plastic scintillator composed of a high concentration of aromatic monomer combined with acrylic monomers and fluorescent dyes.

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Fabrication of 3D-printed plastics

Vinyl toluene, 2,5-Diphenyloxazole (PPO), 1,4-Bis(5-phenyl-2-oxazolyl)benzene (POPOP), and Phenylbis(2,4,6-trimethylbenzoyl)phosphine oxide (BAPO), were purchased from Sigma Aldrich and Dipentaerythritol Hexaacrylate (DPHA) was purchased from the Tokyo Chemical Industry (TCI). 100 ml solution was prepared with vinyl toluene and DPHA in 1:1 ratio by mass, 2 wt% PPO 0.2 wt% POPOP, and 0.1 wt% BAPO. A Computer Aided Design (CAD) sliced model was fed to a DLP-based 3D printer which cures each layer using a 405 nm UV light-based screen. 3D-printed samples were washed with IsoPropyl Alcohol (IPA) and post-cured in a curing chamber operating at 50 W for 4-5 minutes. The samples were then polished with various grit sandpapers and an alumina slurry. A Ø20 mm × 10 mm cylindrical sample was selected to study the optical and scintillation properties.

Results and Discussion

Figure 1 shows the absorption and transmission spectra of the prepared plastics. The figure shows an absoption edge at around 400 nm. The sample exhibits an emission peak at

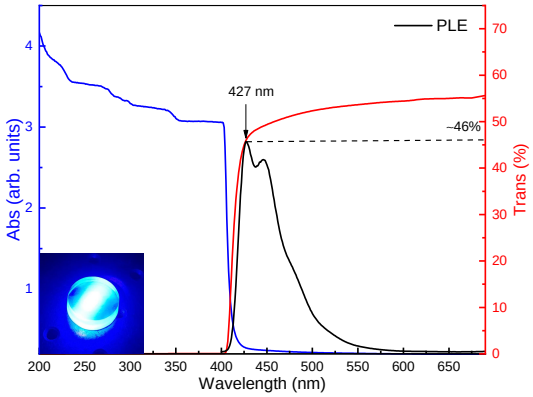

FIG. 1: Absorption, photoluminescence and transmission spectra of the 3D-printed plastic scintillator. Inset in the figure shows the scintillator under UV-illumination.

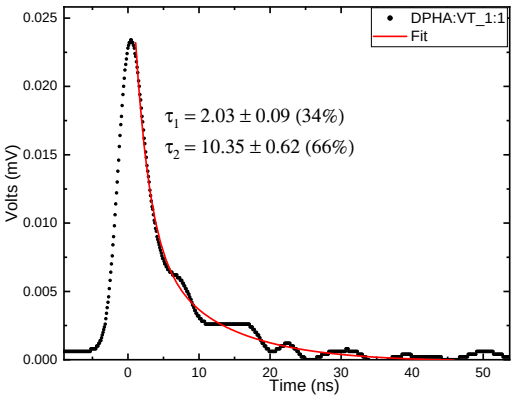

FIG. 2: Decay curve of the plastic scintillator

427 nm and a transmission of 46% at wavelength of maximum emission.

Scintillation properties were also studied out using γ-rays. The sample was optically coupled to a 2″ Hamamatsu PMT, operated at −1400V. A ^{137}Cs source was used to measure the decay time and light output of the developed plastic scintillator. A decay pulse was recorded using a 5 GSam/s Digital Storage Oscilloscope (DSO) and fitted with two-component exponential decay function. As shown in figure 2, the fast component of the decay time was measured at 2.03 ns, comparable to that of EJ-200 commercial plastic scintillator (2.1 ns) [3]. Light output was measured by comparing the compton edge position recorded in case of 3D printed plastic to that recorded with EJ-200 of simliar shape and size (Figure 3). Compton edge was fitted using Guassian peak fitting function and its position was marked at 50% of the edge maximum. Considering the light output of EJ-200 as 10000 ph/MeV [3], the light output of the prepared sample was calculated to be ∼3600 ph/MeV.

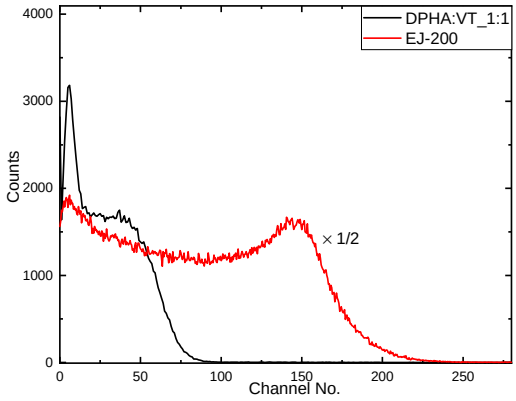

FIG. 3: Relative light output of the scintillator with EJ-200 taken as a reference

Conclusion

Plastic scintillators were fabricated using 3D printing technique with a mixture of aromatic and acrylic monomers. The optical characterization suggested that the emission peaks at 427 nm, compatible with most photosensors. However, the transmission ability needs further improvement. The developed scintillator showed a fast decay time of 2.03 ns, showcasing potential uses in fast timing applications. The light output was recorded at 36% of that of EJ-200. Efforts are going on to improve the light output and transmission by optimizing the concentration of vinyl toluene and PPO in the formulation.

References

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