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Original Article

Characteristics of Plastic Scintillators Fabricated by a Polymerization Reaction

*Cheol Ho Lee, Jaebum Son, Tae-Hoon Kim, and Yong Kyun Kim**

Department of Nuclear Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, South Korea

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ABSTRACT

Three plastic scintillators of 4.5 cm diameter and 2.5-cm length were fabricated for comparison with commercial plastic scintillators using polymerization of the styrene monomer 2.5-diphenyloxazole (PPO) and 1,4-bis benzene (POPOP). Their maximum emission wavelengths were determined at 426.06 nm, 426.06 nm, and 425.00 nm with a standard error of 0.2% using a Varian spectrophotometer (Agilent, Santa Clara, CA, USA). Compton edge spectra were measured using three gamma ray sources [i.e., cesium 137 (^{137}Cs), sodium 22 (^{22}Na), and cobalt 60 (^{60}Co)]. Energy was calibrated by analyzing the Compton edge spectra. The fabricated scintillators possessed more than 99.7% energy linearity. Light output was comparable to that of the BC-408 scintillator (Saint-Gobain, Paris, France). The fabricated scintillators showed a light output of approximately 59–64% of that of the BC-408 scintillator.

1. Introduction

A wide range of scintillation materials are used in various fields of medicine and security and for scientific purposes in research institutions. Examples of such purposes are medical imaging, ionizing radiation detection, and spectroscopy. Scintillators can be composed of organic or inorganic materials in combination with solvents. Gaseous materials can also be used for scintillation counting [1]; the most common example is helium 3 (^{3}He) counters used for neutron detection [2]. Scintillation materials are typically liquid, plastic, or crystal. Plastic scintillators are more durable than liquid scintillators and can be machined into nearly any shape. They have many advantages such as fast rise and decay times, high optical transmission, ease of manufacturing, low cost, and large available size. Because of these characteristics, there has been an increased interest in developing plastic scintillators and an interest in their many applications in nuclear physics and radiation detection, and particle identification [3]. The most common preparation method for plastic scintillators is thermal polymerization of a solution containing a liquid monomer. The polymerization techniques vary with the composition and size of the desired sample. The polymerization is initiated slowly at a low temperature and then completed at a high temperature. In this study, three plastic scintillators 4.5 cm in diameter and 2.5 cm in length were

* *Corresponding author.*
E-mail address: ykkim4@hanyang.ac.kr (Y.K. Kim).
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fabricated by the polymerization of the styrene monomer 2.5-diphenyloxazole (PPO) and 1,4-bis benzene (POPOP). Gamma ray spectra were measured using standard gamma ray sources such as cesium 137 (^{137}Cs), sodium 22 (^{22}Na), and cobalt 60 (^{60}Co). Energy was calibrated by analyzing the pulse spectra. The purpose of the energy calibration was to convert the channels in the pulse spectra into gamma ray energy. Relative light output was estimated to compare the fabricated scintillators with a commercial scintillator (BC-408 scintillator; Saint-Gobain, Paris, France).

2. Materials and methods

2.1. The plastic scintillator preparation process

Three plastic scintillators were fabricated through polymerization to compare properties such as emission wavelength and scintillation efficiency with those of commercial plastic scintillators. The recipe used in this study requires three components. The first component is a liquid monomer, which is the transparent liquid. A commercially available styrene monomer with 99.5% purity was the solvent. The second component is commercially sold as 2.5-diphenyloxazole (i.e.,. PPO) in the form of a white powder and is a scintillating chemical whose peak emission wavelength is 303 nm, which lies within the UV spectrum. The third component is POPOP {i.e., 1,4-bis[2-(phenyloxazolyl)]-benzene} which is a light yellow secondary scintillating material. The POPOP component acts as a scintillator and as a wavelength shifter, which means that it converts the shorter wavelengths emitted from the PPO into longer wavelengths. Its wavelength peak is at 410 nm, which is a visible violet light. The styrene monomer was mixed with PPO and POPOP. Table 1 shows the masses of the components used for the preparation of plastic scintillators, as measured by an electronic scale. With a density of 0.906 g/mL, 100 g of styrene are equivalent to 110.375 mL. Approximately 80 mL of the styrene monomer are needed to create a plastic scintillator of 2.5 cm in length. The reference denotes the masses of the additives (i.e., PPO and POPOP) for 80 mL of styrene. The mixed solution was poured into 100-mL beakers to create plastic scintillators of 4.5 cm diameter and 2.5 cm length, as shown Fig. 1A. The solution was stirred with a stirrer for 6 hours, and was then stirred inside a 60°C water bath. The solution was afterwards placed in a high temperature heater to induce the polymerization reaction. For complete dissolution, the temperature of the heater had to be maintained at 100°C for 2 hours because stirring alone was insufficient. After this procedure, the temperature of the heater was increased to 120°C for 150 hours while polymerization occurred. After the polymerization reaction had ended, a cooling process was allowed for 60 hours inside the heater. The temperature of the heater was gradually decreased to prevent generating air bubbles caused by internal stress inside the polystyrene material. Fig. 2 shows the temperature profile of the heater. A plastic scintillator that was fabricated using this method is in Fig. 1B. The plastic scintillator was cut by a cutting machine (Minisaw; GLP Korea, Gwangmyeong, Korea) to remove air bubbles generated on the top and bottom surfaces. The surfaces were then polished with 800–4000 grit sandpaper using a high-speed rotating machine (twin variable speed grinder-polisher; Buehler, Lake Bluff, IL, USA). Figs. 1C and 1D show the plastic scintillator after polishing and the scintillator wrapped in Teflon tape as a reflector for protection, respectively.

Table 1 – The Masses of the Ingredients Used for the Preparation of the Three Plastic Scintillators.

	Styrene (mL)	PPO (g)	POPOP (g)
Mass ratio	100 g (110.375 mL)	1 g	0.05 g
Reference[a]	80.00	0.727	0.0364
#1 beaker	79.88	0.728	0.0367
#2 beaker	80.24	0.726	0.0370
#3 beaker	80.44	0.727	0.0390

POPOP, 1,4-*bis* benzene; PPO, 2.5-diphenyloxazole.
[a] The reference denotes the mass of the additives (i.e., PPO and POPOP) for 80 mL of styrene.

2.2. Experimental setup

Various experiments were conducted to evaluate the key characteristics of fabricated plastic scintillators such as emission wavelength, linearity, and light output. First, a fluorescence spectrophotometer manufactured by Varian Cary Eclipse (Agilent, Santa Clara, CA, USA) was employed to measure the emission wavelength of the scintillator. After being placed inside the spectrophotometer, the scintillator was irradiated with an excitation beam to induce it to emit light, the intensity of which was recorded as a graph by the Cary Eclipse software (Agilent). Second, three gamma ray sources (^{137}Cs, ^{22}Na, and ^{60}Co) were used to evaluate the linearity of the scintillators through energy calibration. The purpose of the energy calibration was to convert the channels in the pulse spectra measured by the multichannel analyzer (MCA) module into gamma ray energy; the linearity was subsequently estimated, based on the calibration. Third, the relative light output of the scintillator was calculated by using the Bertolaccini method [4, 5]. Four parameters are necessary to use the method. Section 3.3 provides a detailed introduction.

3. Results and discussion

3.1. Emission wavelength

In general, typical commercial plastic scintillators have a peak emission at a wavelength of 425 nm [6, 7]. Fig. 3 shows the emission wavelength intensities of the three plastic scintillators measured with the fluorescence spectrophotometer. The beam wavelength of the spectrophotometer was set to 310 nm (i.e., the plastic scintillator absorption wavelength) to the emission wavelength spectra, and the beam was aimed at the plastic scintillator. Absorption of the beam inside the scintillator induced photoluminescence and this photoluminescence was recorded by the spectrophotometer. The results are presented for plastic scintillators #1–#3 at the peak emission wavelengths of 426.06 nm, 426.06 nm, and

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