Decay Time Measurement for Different Energy Depositions of Plastic Scintillator Fabricated by High Temperature Polymerization Reaction

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1. Introduction

Scintillators are transparent materials that emit light upon excitation by energetic charged particles. There are in general three kinds of scintillators, inorganic, organic and gaseous. Plastic scintillators are based on organic fluorite. They have many advantages such as fast rise and decay time, high optical transmission, ease of manufacturing, low cost, and large available size. For these reasons they are widely used for particle identification [1]. Also, protection of people against a variety of threats (such as nuclear, radiological, and explosive) represents a true challenge along with the continuing development of science and technology. The plastic scintillator is widely used in various devise, which serves for nuclear, photonics, quantum, and high-energy physics [5]. Thus, the plastic scintillator detector was developed to apply various industrial fields in this study. The plastic scintillator is probably the most widely used organic detector, and polystyrene is one of the most widely used materials in the making of the plastic scintillator detector. Thus, a styrene monomer as a solvent was used to fabricate the plastic scintillator by using high temperature polymerization reaction, and then the emission wavelength and the decay times for different energy depositions were measured by using the fabricated plastic scintillator.

2. Methods and Results

2.1 Fabrication of Plastic Scintillator

One plastic scintillator was fabricated through a high temperature polymerization reaction to measure variation of decay time constant for different energy depositions. Styrene monomer with purity 99.5% as a solvent was mixed with PPO, POPOP to produce the plastic scintillator. The PPO (2.5-diphenyloxazole) is used as a first solute in the form of a white powder. The POPOP as a second solute (1,4-bis[2-(phenyloxazolyl)]-benzene) is tinged with yellow is in the form of powder as in the PPO. The solution was added to the 100 ml beaker for producing the plastic scintillator with 4.5 cm diameter and 2.5 cm length and stirring operation of the solution was performed for 6 hours by using a stirrer as a shown Fig. 1(a). The solution was placed in a high temperature heater to induce the polymerization reaction. The temperature of the heater for the complete dissolution was maintained at 100℃ for 2 hours because it cannot be completely dissolved solute in the stirring operation. After complete dissolution, the temperature of the heater for 150 hours was raised and maintained up to 120℃ which the polymerization reaction occurs. After the polymerization reaction ended, the cooling process was carried out for 60 hours inside the heater. The heat supply of the heater was gradually lower to prevent a generation of air bubbles due to the internal stress of the polystyrene. Fig. 1(b) shows a plastic scintillator that was fabricated by the polymerization reaction. The plastic scintillator was cut by using a cutting machine in order to remove the air bubbles generated on the top and bottom surfaces, and then the polishing operation of the surfaces was carried out in the order of sandpaper (800 – 4000 grit) using a high-speed rotating machine. Figs. 1(c) and 1(d) show the plastic scintillator which the polishing operation is completed and which is wrapped in Teflon tape to protect the scintillator.

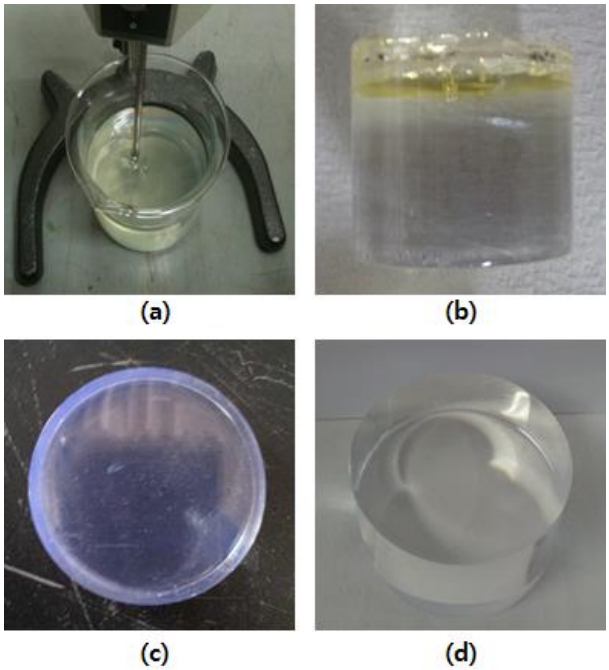

Fig. 1. Fabrication process of plastic scintillator and view of each step for the scintillator shape.

2.2 Emission Wavelength

An emission wavelength of the fabricated plastic scintillator was measured using the Varian`s spectrophotometer. Generally, the commercial plastic scintillator have a maximum emission wavelength of 425 nm. Fig. 2 shows the emission wavelength of the scintillator. In this study, the plastic scintillator fabricated by the high temperature polymerization reaction in this laboratory had the emission wavelength

of 426.05 ± 1.5 nm. As a result, it can know that the fabricated scintillator has same properties comparing to the commercial plastic scintillator since it has a similar emission wavelength spectrum.

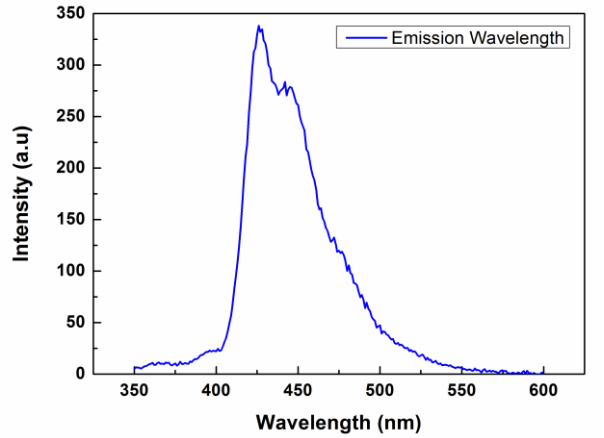

Fig. 2. Emission wavelength spectrum of fabricated plastic scintillator measured using the Varian`s spectrophotometer.

2.3 Decay Time

The schematic of the experimental setup is presented in Fig. 3. In order to avoid any potential distortion of investigated pulse shape, the scintillation pulses were sent directly from the anode output of the PMT to the oscilloscope input. The anode signals were recorded using a digital Tektronix oscilloscope DPO4054. Since it was decided to use anode signals only for recording of the scintillation decay, signals from the PMT dynode were used to calibrate the detector terms of energy deposition in the scintillator and to produce triggers to record in the oscilloscope the anode pulses corresponding to the selected energy depositions. The dynode signals were sent to an amplifier (Ortec`s 572A) and then, signals generated from the amplifier output was sent to a input channel of a multichannel analyzer (Ortec`s 919E) used for energy calibration of the scintillator and selection of the deposited energies.

The decay times of the plastic scintillator for the different energy depositions were measured by the foregoing setup under electron excitations which were induced by Cs-137, Co-60, Na-22, and Ba-133 source. The results obtained by measurement channel g(t) consist of the intrinsic time response of the whole measurement system f(t) which was recorded buy monitoring channel [2 - 4]:

$$g(t) = f(t) * e^{-\frac{t}{\tau}} = \int_0^t f(x) * e^{\frac{-(t-x)}{\tau}} dx \qquad (1)$$

where τ is the decay time of the scintillator. The trailing edge of the time response waveform recorded by monitoring channel displays a fast scintillation decay, so it can be considered that the trailing edge of the time response waveform recorded by measurement channel is attenuated in the same minus exponential rule approximately [5]. Therefore, the decay constant estimated from the trailing edge of the time response waveform recorded by measurement channel is equivalent to the decay time of the fabricated scintillator. Fig. 4 shows the time response waveform of the scintillator using the digital phosphor oscilloscope. Fittings the trailing edge of the waveforms in accordance with the function equation (1), the decay times were obtained. Fig. 5 shows the decay times of the scintillator using various gamma-ray source. Table I indicates decay times of the fabricated scintillator measured for different energy depositions. The decay time of the fabricated scintillator was evaluated to approximately 4.72 ns. The decay time of the fabricated scintillator was measured slightly higher than the commercial scintillator such as BC-408, EJ-200 (2 – 4 ns) [6, 7]. It can be thought of as a difference occurred in the production process such as mass ratio and polymerization time, etc.

Table I. Decay time of fabricated scintillator measured for different energy depositions

	Energy (MeV)	Decay time (ns)	Standard error
Cs-137	0.662	4.41	0.115
Co-60	Avg. 1.25	4.83	0.145
Na-22	0.511	4.67	0.123
Ba-133	0.386	4.99	0.136

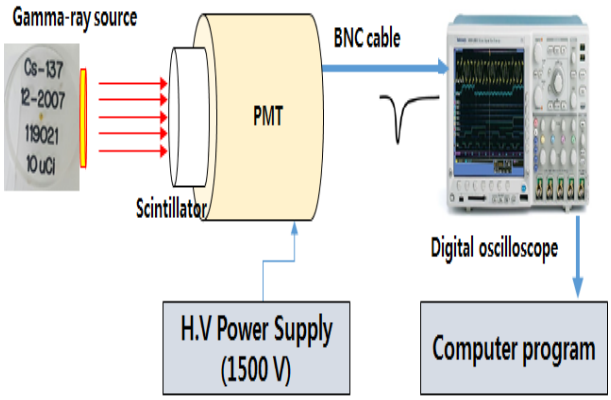

Fig. 3. Schematic view of the experimental setup.

3. Conclusions

A plastic scintillator was fabricated to measure decay time for different energy depositions using the high temperature polymerization. Emission wavelength was measured of 426.05 nm to confirm a scintillator property using the spectrophotometer. Four gamma-ray sources (Cs-137, Co-60, Na-22, and Ba-133) were used to evaluate effect for decay time of different energy depositions. The average decay time of the fabricated plastic scintillator was measured to approximately 4.72 ns slightly higher more than commercial plastic scintillator. In future, light output and linearity will be measured to evaluate other property compared with the commercial scintillator. Also, new fabrication methods will be researched to increase the scintillator properties.

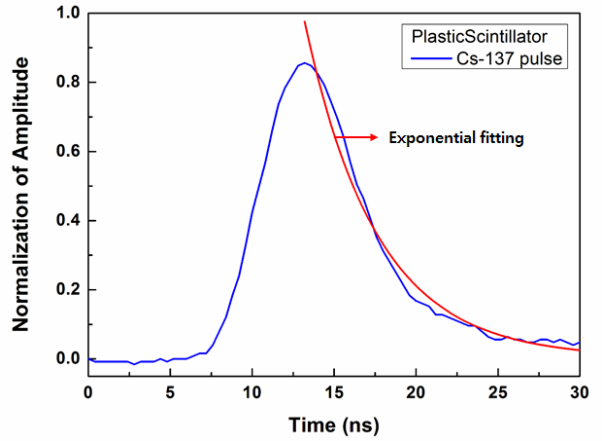

Fig. 4. Time response waveform of fabricated plastic scintillator. The waveform using the Cs-137 source was indicated on the figure.

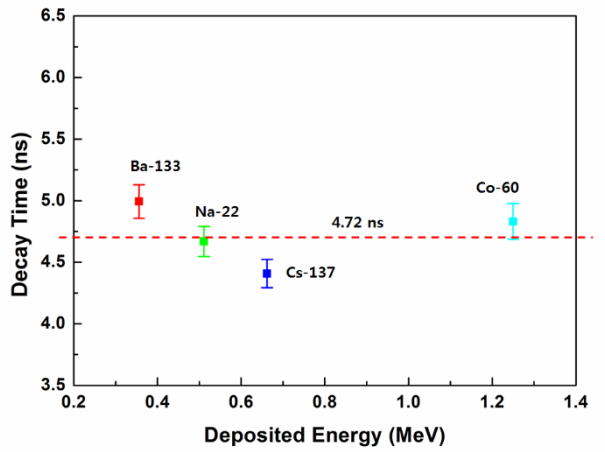

Fig. 5. Energy dependence of the decay time constants of fabricated plastic scintillator measured using various gamma-ray source such as Cs-137, Co-60, Na-22, and Ba-133.

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