Light Output of Plastic Scintillators Fabricated by UV Curing

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1. Introduction

Plastic scintillators are one of the materials used in radiation measurement and they have some advantages such as fast rise and decay time, high optical transmission, ease of manufacturing [1]. Unlike conventional methods of fabricating plastic scintillators by high temperature polymerization, recent studies have found that scintillators are fabricated by UV polymerization. UV curing has been shown to increase production speed, surface hardness and gloss, and productivity. Jun Zhu *et al.* reported the change in the performance of the scintillator fabricated using a UV curing machine [2]. We have also made some plastic scintillators by UV polymerization with known scintillator materials.

The curable resins we blend were composed of primary solvent, scintillating component, wavelength shifter and photoinitiator. These resins were cured using an UV curing machine. The light outputs of the fabricated scintillators were determined by gamma-ray measurement and compared with the commercial scintillator.

2. Methods and Results

2.1 Materials

As a primary solvent, styrene monomer (Duksan Pure Chemicals Co., LTD) was used. As a primary scintillating component, PPO (2,5-Diphenyloxazole), was used. POPOP (1,4-Bis(5-phenyl-2-oxazolyl)benzene) was used as a wavelength shifter which converts the wavelength of photon emitted from the PPO to longer wavelength. Photoinitiator 819 (Phenylbis(2,4,6-trimethylbenzoyl)phosphineoxide) and TPO (Phenylbis(2,4,6-trimethylbenzoyl)phosphineoxide) are used, respectively, to encourage a polymerization reaction under ultraviolet lights. All of the above four substances are from Aladdin Reagent Co., LTD.

2.2 Formulation and UV Curing

We formulated resins by changing the type and ratio of two photoinitiators. The formulation was composed of styrene monomer, PPO and POPOP, and they were stirred for 150 minutes with a little heat. To this formulation, photoinitiator was added with various concentrations and stirred for 30 minutes with a little heat. We prepared six resins using two kinds of photoinitiators, TPO and 819, and the compounding ratio was showed in Table I.

The resins we made were irradiated under the UV lights for 95 hours in UV curing machine. Since the photopolymerization speed of styrene was very slow and the power of the UV lamp was too low (6 Watts), it took a very long time to cure.

3.1 Experimental Setup

The experiment to determine the light yield of the fabricated scintillators was carried out. One side of the fabricated plastic scintillator was attached on the window of the PMT with optical grease, the other sides of the scintillator were covered with a few layers of Teflon tape, and finally a few layers of black tape were wrapped around to block the external light.

The energy spectrum was measured using the ^{137}Cs gamma source. The channel corresponds to the half value of Compton edge count was selected as the Compton edge position in the study. Fig. 1 shows schematic of the experimental setup and specification of the modules used in the measurement.

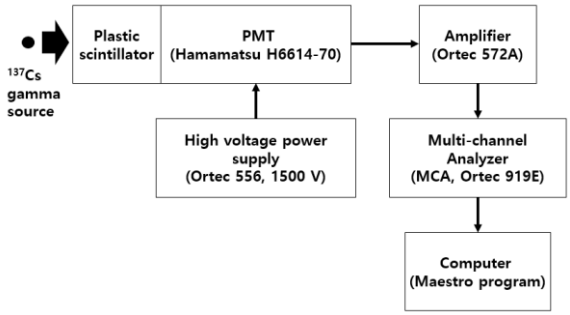

Fig. 1. Schematic of the experimental setup for the measurement of the Compton edge spectra.

3.1 Emission Spectrum

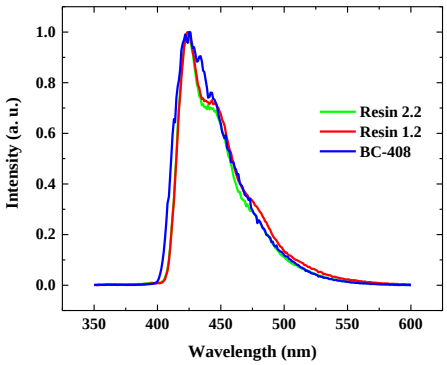

Fig. 2. Normalized emission wavelength spectrum of BC-408 and two scintillators fabricated using Resin 1.2 and 2.2.

Table I: Compounding ratio of each resin

	Resin 1.1	Resin 1.2	Resin 1.3	Resin 2.1	Resin 2.2	Resin 2.3
Styrene	98.85 %	98.65 %	98.45 %	98.85 %	98.65 %	98.45 %
PPO	1 %	1 %	1 %	1 %	1 %	1 %
POPOP	0.05 %	0.05 %	0.05 %	0.05 %	0.05 %	0.05 %
TPO	0.1 %	0.3 %	0.5 %	-	-	-
819	-	-	-	0.1 %	0.3 %	0.5 %

Table II: Properties of the fabricated scintillators

Scintillator	Wavelength of Maximum Emission [nm]	Light Yield (N_{phe}) [phe/MeV]	Average QE [%]	Light Output [ph/MeV]
BC-408	425	1363.29	22.20	6139.93
Resin 1.1	425	543.01	21.89	2480.98
Resin 1.2	423.93	584.96	21.53	2716.74
Resin 1.3	426.06	551.07	20.85	2643.63
Resin 2.1	426.06	907.82	21.99	4129.08
Resin 2.2	423.93	729.71	21.94	3326.18
Resin 2.3	425	729.91	21.85	3339.52

As the first step, we measured the emission wavelength to calculate the quantum efficiency required to calculate the light output using the fluorescence spectrophotometer (Varian Cary Eclipse). Fig. 2 shows the emission wavelength of two fabricated scintillators and BC-408.

The emission wavelength peaks of all fabricated plastic scintillators were in the range of 423 to 427 nm (see Table II). BC-408, commercial plastic scintillator has the maximum emission wavelength of 425 nm. This value corresponds to the wavelength of maximum response on photomultiplier tube (PMT). One can expect that the plastic scintillators fabricated by UV curing could have nearly same optical properties to that of commercial plastic scintillator because they have similar emission spectrum to that of commercial plastic scintillator.

3.2 Relative Light Output

Light yields of the fabricated scintillators were calculated by using Bertolaccini *et al*. method [3, 4]. Number of photoelectrons per energy unit was calculated by comparison between the peak position of the single photoelectron spectrum and the Compton edge position in the given energy spectrum. The number of photoelectrons per energy unit (N_{phe}) is given by the following equation:

$$N_{phe} = (PP_E / K_E)/(PP_{1phe}/K_{1phe})/0.477334 \text{ [phe/MeV]} \quad (1)$$

where PP_E is the Compton edge position of the ^{137}Cs gamma source, K_E is the gain of the spectroscopy amplifier in the experiment, PP_{1phe} is the peak position of the background and K_{1phe} is the gain of the spectroscopy amplifier in the experiment.

The quantum efficiency of the PMT should be considered when calculating the light output because there is a difference in the quantum efficiency depending on the wavelength. We obtained the average of quantum efficiency using spectral response characterization data of the PMT [5]. The average quantum efficiency (QE_{avg}) of the PMT is given by the following equation:

$$QE_{avg} = \sum_{x=a}^{b} \left[\frac{I(x)\times QE(x)}{I(x)}\right] \quad (2)$$

where x represents the emission wavelength (nm), $I(x)$ and $QE(x)$ stand for the intensity and the quantum efficiency of the PMT as a function of the wavelength, respectively. The QE_{avg} of all scintillators were given in the range of 20 to 23%. The light output was obtained by dividing the N_{phe} by the QE_{avg}. The light outputs of the fabricated scintillators are shown in Table II. The light outputs of the scintillators using the photoinitiator TPO and 819 were about 40 to 44% and 54 to 67% of that of BC-408. These show that photoinitiator 819 is better than TPO in terms of light output. There was no significant change in the light output with respect to the concentration of photoinitiator.

4. Conclusions

Six scintillators with different compounding ratios were fabricated by changing the type and concentration of two photoinitiators using a UV curing machine, and their light outputs were compared with a commercial scintillator BC-408. The light outputs of the scintillators with photoinitiator TPO and 819 were about 42% and 59% of BC-408 light output, respectively. The change of the light output according to the concentration of the photoinitiator was not clearly shown in the study.

The estimation of additional characteristics such as linearity and decay time is required for further identification of the performance of the scintillator fabricated by UV curing in the future.

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