Characteristics of 3D Printed Plastic Scintillator for Thermal Neutron Measurement with Pulse Shape Discrimination

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Introduction

Neutron detectors based on 3He have large increased in use demand for homeland security and basic research [1]. Therefore, alternative technologies to replace 3He such as have actively been studied. Plastic scintillator, which is capable of neutron detection, is considered one of the alternatives. Since neutron fields are typically present with γ-ray and plastic scintillators have relatively high γ-ray sensitivity, those require neutron and γ-ray separation techniques such as pulse shape discrimination (PSD) methods. PSD capability of general plastic scintillators based on polyvinyltoluene (PVT) is known to be possible at 20-30% of 2.5-diphenyloxazole (PPO) although to difficult at 1.5-8% [2]. Plastic scintillator is one of the organic scintillator types, and they can be manufactured by 3D printing techniques. The advantages of the technique are simple way, fast production, low cost and customizing easily. In previous study, PSD capability of 3D printed scintillators based on acrylic monomer according to PPO concentration had been confirmed; and it was also possible with 2%w PPO [3]. In this study, PSD was attempted using 3D printed plastic scintillators through nuclear reaction, and %Li had been doped for the reaction. The %Li has advantages such as reasonable neutron capture cross-section, relatively high energy released in the capture reaction, as well as the absence of γ-ray through secondary particles [4]. The fabricated scintillators were evaluated through relative light output (LO) and figure of merit (FOM). In the research of Zaitseva et al. [5], the FOM was analyzed as a useful PSD performance when is greater than 1.27.

Materials and Methods

1. Fabrication of 3D Printed Plastic Scintillator

3D printer (Asiga-PICO 2HD UV385) based on digital light processing (DLP) technique was used for fabrication of scintillators, and it is relatively fast with top-down stacking structure. Each 3D printed scintillator was fabricated to cylindrical and diameter of 25 mm and height of 10 mm. The resin for 3D printed scintillators were composed of 1.5%wt-PPO. Li concentration was 0wt% and 0.05wt%. Fig. 1 presents the configuration of 3D printer.

2. Energy Calibration

The plastic scintillators were connected to PMT (Hamamatsu-H6410) with -1400 V of high-voltage. The charge signals were delivered to Flash-ADC (Notice-NGT600). Data acquisition was sent to an online PC with the ROOT software framework through Ethernet. In this study, the scintillators were calibrated using three Compton edges of 137Cs (477.65 keV) and 2Na (340.67 keV and 1061.67 keV). The measurement system and results are shown in Fig. 2 below.

3. Relative Light Output

LO is calculated using the correlation between light yield, which consist of energy peak positions and gain of amplifier, and effective quantum efficiency (QEэфф). The equation is given by the following equation (1):

\[
\text{Light output} = \frac{P_{PE}}{K_E} \times \frac{P_{phe}}{K_{phe}} \times \frac{1}{E_{\text{compton edge}}} \times \frac{1}{1 - Q.E_{\text{eff}}} \times [\text{ph/MeV}]
\]

FWHM: Full width half at maximum

LY was defined by the number of photoelectrons per unit energy. This is generally derived from the single photoelectron peak position and specific of energy peak position with each gain of amplifier. It was calculated using the 137Cs energy spectrum measured through the equal voltage and gain. The effective quantum efficiency was derived through calculation between quantum efficiency of PMT and emission intensity of scintillators. Emission wavelength of each scintillators were measured using the fluorescence spectrophotometer (Cary Eclipse, Varian), respectively. The spectra of emission wavelength and quantum efficiency of H6410 are shown in Fig. 3.

4. Figure of Merit

FOM was evaluated in energy region of thermal neutron spectrum. The values used for calculation of FOM are shown in the Fig. 4. FOM was defined by following equation (2):

\[
\text{FOM} = \frac{\text{FWHM}_{\text{gamma}} + \text{FWHM}_{\text{thermal}}}{S}
\]

S: Distance between mean ΔQ/Q neutron and γ-ray
FWHM: Full width half at maximum

β-

For γ-ray through PSD (right).

Table I. Effective quantum efficiency and light output

<table>
<thead>
<tr>
<th>Scintillator</th>
<th>Q.E.эфф (%)</th>
<th>Light output [ph/MeV]</th>
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<tbody>
<tr>
<td>EL-254</td>
<td>23.29</td>
<td>7178.03</td>
</tr>
<tr>
<td>no-Li</td>
<td>17.75</td>
<td>9991.53</td>
</tr>
<tr>
<td>0.05wt% Li</td>
<td>18.01</td>
<td>9894.81</td>
</tr>
</tbody>
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5. PSD measurement of moderated 220Cf source using 3D printed scintillators (left) and energy spectra separating n-γ through PSD (right).

Table II. Figure of merit of Li loaded scintillators.

<table>
<thead>
<tr>
<th>Scintillator</th>
<th>Thermal neutron energy region [keV]&lt;sub&gt;n&lt;/sub&gt;</th>
<th>FOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>no-Li</td>
<td>320-413</td>
<td>1.18 ± 0.029</td>
</tr>
<tr>
<td>0.05wt% Li</td>
<td></td>
<td></td>
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</tbody>
</table>

Conclusion

3D printed scintillators were confirmed that could have PSD capability about thermal neutron and γ-ray through %Li doped. The scintillators were evaluated with LO and FOM. The scintillator doped with 0.5wt% Li was also attempted, but its performance was poor. The 0.5wt% Li scintillator was lower LO and FOM than 0.05wt% Li, as well having poor resolution. The resolution was confirmed through thermal neutron energy region. It was considered to be attenuation by %Li that the pulse shapes were not completely decomposed. FOM of 0.05wt% Li scintillator was 92.9% of useful FOM. It is expected that continuous research and optimization of compositions will make it possible to produce commercial-level thermal neutron detectable plastic scintillators by 3D printing technique.

Reference