Development of LiGaO₂ nanoparticle-loaded plastic scintillators for neutron detection

Haruhisa Tsukahara¹, Yutaka Fujimoto², Keisuke Asai², Masanori Koshimizu¹

¹Research Institute of Electronics, Shizuoka University, 3-5-1 Johoku, Naka-ku, Hamamatsu 432-8011, Japan
²Department of Applied Chemistry, Tohoku University, 6-6-07 Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan

Keywords: neutron, nanoparticle, scintillator

1 Introduction

For neutron detection, ³He and ¹⁰BF₃ proportional counters have been used for a long time. These detectors having long dead time are not suitable for measurements of high intensity neutrons in facilities such as J-Parc at a high counting rate. In addition, there are also issues such as high production costs because of ³He shortage of raw materials. Currently, there is a need to develop a low-cost neutron detector with a short dead time. Recent, plastic scintillators with fast scintillation decay and scalability have received particular attention for neutron detection applications.

Thermal neutron detection capability of plastic scintillators is negligible without loading. Therefore, organometallic compounds containing ⁶Li and ¹⁰B, which react with neutrons and emit charged particles, have been dissolved in plastic scintillators to add neutron detection capability. Recently, a method to add neutron detection capability has been proposed based on addition of nanoparticles containing ⁶Li or ¹⁰B to plastic scintillators as described in [1]. Adding nanoparticles has the advantage that they are less likely to inhibit scintillation. Thus, adding nanoparticles containing ⁶Li or ¹⁰B to plastic scintillators to add neutron detection capability is an effective method. So far, our group has successfully added LiAlO₂ nanoparticles to plastic scintillators to add neutron detection capability to plastic scintillators [2]. The scintillation light yield of 1600 photons/neutron was achieved, which is higher than that of a commercially available ¹⁰B-loaded plastic scintillator (800 photons/neutron). In this study, ⁶Li-enriched LiGaO₂, which has similar properties to LiAlO₂, is added as nanoparticles to plastic scintillators to add neutron detection capability.

2 Experimental methods

In the synthesis of LiGaO₂ nanoparticles, we referred to a previous paper [3]. ⁶Li-enriched Li₂CO₃ (⁶Li:95 atom%) and Ga(NO₃)₃·nH₂O (99.99%) were dissolved in deionized water. The solution was heated to 70°C and stirred for 1 h. Anhydrous citric acid and ethylenediaminetetraacetic acid (EDTA) were separately dissolved in an ammonium hydroxide solution, whose pH value was adjusted to around 9. These two solutions were dropped simultaneously to the metal containing aqueous solution. The molar ratio was 1:1:1:1.5 for Li₂CO₃:Ga(NO₃)₃·nH₂O:citric acid:EDTA. To the solution, ammonium hydroxide solution was added to adjust the pH value to around 8. The solution was heated to 90°C and stirred for 24 h. After the evaporation of the solvent, the powder was calcinated at 300°C for 6 h and 700°C for 10 h.

In the fabrication of plastic scintillators, polystyrene and DPO-POPOP (the molar ratio of 80:1) as organic phosphors were dissolved in tetrahydrofuran. LiGaO₂ nanoparticles were added to the solution, and subsequently the solvent was completely evaporated to obtain plastic scintillators loaded with LiGaO₂ nanoparticles. DPO was added to styrene monomer unit at 10 mol%, and LiGaO₂ was added at 5, 10, 15, 20, and 25 wt% to polystyrene.

3 Results and Discussion

Fig. 1 shows TEM image of LiGaO₂ nanoparticles. Particles of ~150 nm of elliptical, circle and polygonal in shape was observed.

Fig. 2 shows the pulse height spectra of LiGaO₂ nanoparticles-loaded plastic scintillators under neutron irradiation from ²⁵²Cf. Concentrations of nanoparticles were 5~25 wt%. Full energy peak was observed around 95-130 channels. The full energy peak channels depend on the nanoparticle concentration.

Table 1 shows the full energy peak channels and scintillation light yield of plastic scintillators with 5~25 wt% LiGaO₂. The light yield was estimated based on the channels of the full energy peak of the LiGaO₂-loaded plastic scintillators and that of NE-142 having a light yield of 5200 photons/MeV under γ-rays from ²⁵⁰Am. The light yields were 1800~2450 photons/neutron and higher than commercially available ¹⁰B-loaded PS (BC-454) having a light yield of 800 photons/neutron and LiAlO₂ nanoparticle-loaded plastic scintillator having a light yield of 1600 photons/neutron [2].

Fig. 3 shows XRL spectrum of LiGaO₂ nanoparticles. The peak was observed around 390 nm. The origin was attributed to oxygen vacancies.

Fig. 4 shows XRL spectra of LiGaO₂ nanoparticles-loaded plastic scintillators. The peak around 420 nm observed in all the samples is derived from POPOP, and negligible scintillation from LiGaO₂ nanoparticles was observed in the plastic scintillator.
Fig. 1. TEM image of LiGaO$_2$ nanoparticle.

Fig. 2. Pulse height spectra of LiGaO$_2$ nanoparticle-loaded plastic scintillators under neutron irradiation from $^{252}$Cf.

Table 1. Scintillation light yields for neutron.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Peak channel</th>
<th>Light yield [photons/neutron]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 wt%</td>
<td>95</td>
<td>1800</td>
</tr>
<tr>
<td>10 wt%</td>
<td>99</td>
<td>1880</td>
</tr>
<tr>
<td>15 wt%</td>
<td>129</td>
<td>2450</td>
</tr>
<tr>
<td>20 wt%</td>
<td>104</td>
<td>1970</td>
</tr>
<tr>
<td>25 wt%</td>
<td>112</td>
<td>2120</td>
</tr>
</tbody>
</table>

Fig. 3. XRL spectrum of LiGaO$_2$ nanoparticles.

Fig. 4. XRL spectra of LiGaO$_2$ nanoparticle-loaded plastic scintillators.

4 Conclusions

$^6$Li-enriched LiGaO$_2$ nanoparticles were added to plastic scintillators for neutron detection. 15 wt\% LiGaO$_2$-loaded plastic scintillator had the highest light yield of 2450 photons/neutron.

References