Performance study of GAGG: Ce crystal

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1, Introduction of GAGG: Ce crystal

Recently developed cerium-doped GAGG(GAGG: Ce) is a novel scintillator characterized by a high density(6.63g/cm3), high light yield(56,000 photon/MeV), fast scintillation decay time(~100 ns), very good radiation hardness, non-hygroscopicity and extremely low internal background.

GAGG:Ce crystal is a promising scintillation material for high energy physics calorimeter.
2, Scintillation properties of GAGG: Ce

S1 (5mm cube) and S2 (5mm cube) samples are single crystal GAGG: Ce, produced in China and Russia, fabricated by the conventional Czochralski method.

S3 (5mm cube) and S4 (5mm cube) samples are ceramic GAGG: Ce, produced in China and Japan, fabricated by the vacuum sintering method.
Photodetectors

PMT-XP2020

Hamamatsu MPPC
Area: 6mm × 6mm,
Pitch: 10, 25, 50, 75 um

NDL SiPM
Area: 3mm × 3mm,
Pitch: 10 um

Different types of photodetectors are coupled to GAGG:Ce scintillators to do performance study.
Primary emission spectra of these 4 samples appeared from 500 to 700 nm, but different with each other. Weak emission peaks clearly appeared at around 380 nm in crystal GAGG:Ce.
Decay times

A filter is used to test the decay times of the weak peaks in sample 1 and 2.
In general, ceramic GAGG:Ce have higher light yield than crystal GAGG:Ce

S1:S2:S3:S4 = 1:0.68:1.72:1.55
Linearity of GAGG:Ce light output

Light output of GAGG:Ce scintillator is linear in the range of 31 keV-1.27 MeV
Response curve of GAGG:Ce coupled with MPPC/SiPM

Response curve of GAGG:Ce scintillator coupled with Hamamatsu MPPCs

Response curve decided by the dynamic range of the MPPC/SiPM
Energy resolution

Energy resolution of GAGG:Ce scintillator measured with two different MPPC:25/75 um pitch

Pulse height spectrum measured with GAGG coupled to Hamamatsu MPPC:75um pitch

Cs-137 source, S3 GAGG:Ce $5 \times 5 \times 5$ mm$^3$ + Hamamatsu MPPC $6 \times 6$mm$^2$, 75 um pitch

FWHM = 3.5% @ 662 keV
3. Neutron detection with GAGG:Ce

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Energy $T_n$</th>
<th>Cross section (b)</th>
<th>Q-value (MeV)</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^1$H(n, n')</td>
<td>100 keV - 10 MeV</td>
<td>0.7-28</td>
<td>-</td>
<td>proton</td>
</tr>
<tr>
<td>$^3$He(n, p)</td>
<td>Thermal</td>
<td>5330</td>
<td>0.764</td>
<td>proton, triton</td>
</tr>
<tr>
<td>$^{10}$B(n, α)</td>
<td>Thermal</td>
<td>3840</td>
<td>2.792</td>
<td>alpha, lithium ion</td>
</tr>
<tr>
<td>$^6$Li(n, α)</td>
<td>Thermal</td>
<td>940</td>
<td>4.78</td>
<td>alpha, triton</td>
</tr>
<tr>
<td>$^{157}$Gd(n, γ)</td>
<td>Thermal</td>
<td>254000</td>
<td>7.937</td>
<td>photons, electrons</td>
</tr>
<tr>
<td>$^{155}$Gd(n, γ)</td>
<td>Thermal</td>
<td>60900</td>
<td>8.536</td>
<td>photons, electrons</td>
</tr>
<tr>
<td>$^{113}$Cd(n, γ)</td>
<td>Thermal</td>
<td>20600</td>
<td>9.04</td>
<td>photons, electrons</td>
</tr>
</tbody>
</table>

$^{157}$Gd + n -> $^{158}$Gd + gamma + X ray + conversion electron
$^{155}$Gd + n -> $^{156}$Gd + gamma + X ray + conversion electron

The detection of photopeaks in a thin slice due to conversion electrons and low-energy X-rays make GAGG:Ce scintillator possible to discriminate the high energy gamma background efficiently.

The low-energy gamma background incident on the crystal from outside can be easily stopped by using a thin lead sheet wrapped around the scintillator.
Neutron detector

GAGG:Ce slice 5 mm × 5 mm, thickness of 1.0 and 0.5 mm

Hamamatsu MPPC
Area: 6×6 mm², Pitch: 75 um

Neutron detector

Am-Be neutron source
HDPE with 5 cm thickness is used as moderator.
The detector is shielded using a 2 mm lead (Pb) and 2 mm stainless steel (SS) sheet.
A 3-mm cadmium sheet used to shield the detector for recording the background data.
Energy calibration

Pulse height spectrum of 1mm thick GAGG:Ce calibrated by Barium(Ba-133) 31 and 83 keV gamma
Thermal neutron detection

The photopeaks around 35 and 83 keV well discriminated from the background could be successfully observed by this neutron detector, providing a clear signature for thermal neutron detection.

The signal-to-background ratio of 83 keV is 5.6
Light output of GAGG:Ce slice

Light output of GAGG:Ce slice with different thickness, 5.0 mm: 1.0 mm: 0.5 mm: 0.2 mm = 1:1.09:1.26:1.34
Summary

1, Scintillation properties of GAGG:Ce scintillator as a calorimeter material studied detailed.

2, Slice of GAGG:Ce can clearly separate thermal neutron from gamma background.

Thanks!