Emission Spectra of LSO and LYSO Crystal Scintillators Excited by UV Light, X-ray and $\gamma$-ray

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**Introduction**

We reported at Puerto Rico (NSS05, N12-6) a comparison of light output of large size (2.5 x 2.5 x 20 cm) LSO and LYSO samples, and found that a CTI LSO has a higher light output with APD readout, but not with PMT readout. This anomaly disappeared after $\gamma$-ray irradiation to 1 Mrad.

<table>
<thead>
<tr>
<th>Crystal</th>
<th>PMT: R1306, HV=-1100V</th>
<th>Gate: 200 ns</th>
<th>E.R.:</th>
<th>ADC</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIC-BGO</td>
<td></td>
<td></td>
<td>15.4±0.2%</td>
<td></td>
<td>Na-22</td>
</tr>
<tr>
<td>CTI-LSO</td>
<td></td>
<td></td>
<td>11.3±0.2%</td>
<td></td>
<td>Na-22</td>
</tr>
<tr>
<td>CPI-LSO</td>
<td></td>
<td></td>
<td>22.4±0.3%</td>
<td></td>
<td>Na-22</td>
</tr>
<tr>
<td>SG-LSO</td>
<td></td>
<td></td>
<td>10.6±0.2%</td>
<td></td>
<td>Na-22</td>
</tr>
</tbody>
</table>

- **SIC-BGO-L**
  - 2 x Hamamatsu S8664-55
  - HV = 400 V, $\tau$ = 250 ns
  - No obvious signal can be detected

- **CTI-LSO-L**
  - pedestal = 118 ADC
  - peak = 652 ADC
  - $\sigma$ = 71 ADC
  - L.O. = 2490 p.e./Mev

- **CPI-LSO-L**
  - pedestal = 118 ADC
  - peak = 415 ADC
  - $\sigma$ = 78 ADC
  - L.O. = 1380 p.e./Mev

- **SG-LSO-L**
  - pedestal = 118 ADC
  - peak = 504 ADC
  - $\sigma$ = 74 ADC
  - L.O. = 1800 p.e./Mev
Quantum efficiency and Emission

Why?
The LSO sample had an emission peaked at longer wavelength under γ-ray excitation, and the emission was changed after γ-ray irradiations.

Can we prove it?
Six Large LSO and LYSO Samples

Three CTI LSO samples are provided by Chuck Melcher.

Three LYSO samples are purchased from Saint-Gobain.
UV, X-ray & $\gamma$-ray Excited Emission

Photo-luminescence measured with $\theta = 10^\circ$: No internal absorption

UV and X-ray excited emission

- X-ray tube
- UV lamp and monochromator
- Hitachi F4500
- Monochromator and PMT

$\gamma$-ray excited emission

- Co$^{60}$
- Monochromator (Oriel 77250) and PMT (R2059)
- Merlin system (Oriel 70103)
System Checks

UV (θ=0°), X-ray and γ-ray excited emission spectra are consistent. UV (θ=10°) excited emission has a blue shift because of no absorption.
UV (θ=0º) and γ-ray excited emission spectra are consistent. UV (θ=10º) excited emission has a strong blue shift (See N49-1). X-ray excited emission is slightly narrow. Why?
The narrow X-ray excited emission spectra of LYSO may be explained by a surface effect since X-ray does not penetrate.

<table>
<thead>
<tr>
<th>Excitation Type</th>
<th>Attenuation Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV excitation (3-6 eV)</td>
<td>100~700 μm</td>
</tr>
<tr>
<td>X-ray (8-30 keV)</td>
<td>~10 μm</td>
</tr>
<tr>
<td>γ-ray (Co$^{60}$) (~1.2 MeV)</td>
<td>1.14 cm</td>
</tr>
</tbody>
</table>

![Graph showing emission spectra and excitation types](image-url)
All emission spectra are similar to that of LYSO, except that $\gamma$-ray excited emission has a “red shift”, which disappeared after irradiations with $\gamma$-ray.
γ-Ray Irradiation on Sample’s ID End

Lead shield

Co$^{60}$

Gamma Ray

CTI-LSO-L3

SG-LYSO-L3

ID End received
~5000 rad
The emission peak of sample’s irradiated ID end has a \(~15\) nm “blue” shift.
LYSO: $\gamma$ -Ray Excited Emission Spectra

The emission peak of sample’s ID (irradiated) end has NO “blue” shift

Before irradiation

After irradiation

SG-LYSO-L 3
As received

$\gamma$-ray emission:
- ID end
- NID end

SG-LYSO-L 3
After 5x$10^3$ rad irradiation @ ID end.

$\gamma$-ray emission:
- ID end
- NID end
The irradiated end (ID) has no change in decay time. Its light output degradation is half of that of the NID end because of the emission “blue shift”.

### Irradiated Half

**ID end**

- **Before I.R.**
  - Light Output (p.e./MeV): 1140

- **After I.R.**
  - Light Output (p.e./MeV): 1080
  - Degradation: -5.3%

**Non-irradiated**

**NID end**

- **Before I.R.**
  - Light Output (p.e./MeV): 1150

- **After I.R.**
  - Light Output (p.e./MeV): 1010
  - Degradation: -12.2%
The emission “blue shift” of the irradiated end causes a relative larger LO for the PMT readout.

Before irradiation

CTI-LSO-L 3
As received
A (NID) end coupled to PMT

\[ \delta = (-0.1 \pm 1.0) \]
Average L.O. = 1100 p.e./MeV (300 ns)

CTI-LSO-L 3
As received
B (ID) end coupled to PMT

\[ \delta = (-0.8 \pm 1.1) \]
Average L.O. = 1110 p.e./MeV (300 ns)

After irradiation

CTI-LSO-L 3
5 X 10^3 rad irradiation @ ID end
A (NID) end coupled to PMT

\[ \delta = (2.3 \pm 1.0) \]
Average L.O. = 1020 p.e./MeV (300 ns)

CTI-LSO-L 3
5 X 10^3 rad irradiation @ ID end
B (ID) end coupled to PMT

\[ \delta = (-4.3 \pm 1.0) \]
Average L.O. = 1030 p.e./MeV (300 ns)
LYSO Uniformity with PMT Readout

No significant variations in the light output and light response uniformity for the PMT readout

Before irradiation

SG-LYSO-L 3  After 300°C annealing
A (NID) end coupled to PMT

$\delta = (-3.1 \pm 1.0)$
Average L.O. = 1300 p.e./MeV

SG-LYSO-L 3  After 300°C annealing
B (ID) end coupled to PMT

$\delta = (-1.8 \pm 1.0)$
Average L.O. = 1300 p.e./MeV

After irradiation

SG-LYSO-L 3  After $10^4$ rad irradiation
A (NID) end coupled to PMT

$\delta = (-4.0 \pm 1.0)$
Average L.O. = 1200 p.e./MeV

SG-LYSO-L 3  After $10^4$ rad irradiation
B (ID) end coupled to PMT

$\delta = (-2.2 \pm 1.0)$
Average L.O. = 1210 p.e./MeV
The $\gamma$-ray irradiated half shows less long wavelength emission when excited at 325 nm and 380 nm.
UV Excited Emission Spectra of Two Halves of the LYSO Sample

The $\gamma$ -ray irradiated half shows consistent emission as the non irradiated half when excited at 325 nm and 380 nm.
Ce\(^{3+}\) Luminescence Centers in LSO


Ce1: two regular Lu\(^{3+}\) crystallographic sites, ex: 360 nm, em: 430 nm
Ce2: irregular sites, proposed “interstitial site”, ex: 325 nm, em: 500 nm
Conclusions

- A strong blue shift of the photo luminescence (θ=10°) in LSO/LYSO is attributed to its self absorption.
- A narrow X-ray excited emission spectra in LSO/LYSO seems caused by a surface effect.
- A broader γ-ray excited emission spectrum with a “red shift” as compared to the X-ray and UV excited emission spectra is observed in large size LSO samples. This shift disappeared after γ-ray irradiations. This observation consists with the light output and uniformity data and with what reported in NSS05 at Puerto Rico.
- No such shift was observed in large size LYSO samples.
- We tentatively attribute this shift to the contribution of the “irregular” sites of Ce³⁺ (the component around 450 nm). The fact that it can be “cured” more or less by γ-ray irradiations supports that this site is a defect perturbed irregular site of Ce³⁺.