LYSO: A Radiation Hard Material for the SLHC

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October 29, 2009
Introduction

LSO/LYSO is a bright (200 times of PWO) and fast (40 ns) crystal scintillator. It has been widely used in medical industry for the PET application with mass production capability exits in the world. The Caltech crystal laboratory has been investigating this material for applications in HEP experiment since FY06. It was found that its radiation hardness is excellent against $\gamma$–ray and neutron irradiations. The light output loss after 1 Mrad $\gamma$–ray irradiation is about 10% for 20 cm long samples. This work is supported by the DOE Advanced Detector R&D program from FY06 to FY08, and also by the US CMS Upgrade R&D Program in FY09.

BGO, LSO & LYSO Samples

2.5 x 2.5 x 20 cm (18 X₀)

SIC BGO
CPI LYSO
Saint-Gobain LYSO
CTI LSO
LSO/LYSO with PMT Readout

11% FWHM resolution for $^{22}\text{Na}$ source (0.511 MeV)
40 ns, 1,200 p.e./MeV, 5/230 times of BGO/PWO
LSO/LYSO with APD Readout

L.O.: 1,500 p.e./MeV, 4/200 times of BGO/PWO
Readout Noise: < 40 keV

Pedestal
2 × Hamamatsu S8664-55
HV = 400 V, \( \tau = 250 \text{ ns} \)
pedestal = 46 ADC \( \sigma = 34 \text{ ADC} \)
oise = 57 electrons

Fe-55 Calibration
Fe-55: 1278 electrons
pedestal = 46 ADC
peak = 814 ADC
\( \sigma = 52 \text{ ADC} \)
1.664 electrons/ADC

SIC-BGO-L
2 × Hamamatsu S8664-55
HV = 400 V, \( \tau = 250 \text{ ns} \), \( M = 500 \)
ped = 43, peak = 173
L.O. = 420 p.e./MeV

CTI-LSO-L
ped = 44, peak = 530
L.O. = 1580 p.e./MeV

CPI-LYSO-L
ped = 44, peak = 446
L.O. = 1310 p.e./MeV

SG-LYSO-L
ped = 44, peak = 539
L.O. = 1610 p.e./MeV
Excellent Linearity: > 0.511 MeV

Observed with APD readout

ADC = 458.2 \ E_\gamma

- Na-22 (0.511 MeV)
- Cs-137 (0.662 MeV)
- Co-60 (1.173 MeV)
- Na-22 (1.275 MeV)
- Co-60 (1.333 MeV)
\(\gamma\)-Ray Induced Damage

No damage in photo-luminescence

Transmittance recovery slow

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**Figure:**

- **Graph 1:**
  - Title: Recovery after 8500 rad/h, 96 h irradiation
  - X-axis: Wavelength (nm)
  - Y-axis: Intensity (a.u.)
  - Data points for different samples:
    - CTI-LSO-L: \(T_0 = 76.1\), \(y = 68.46 \pm 0.0002 x\)
    - SG-LYSO-L: \(T_0 = 74.1\), \(y = 66.88 \pm 0.0000 x\)
    - CPI-LYSO-L: \(T_0 = 70.2\), \(y = 61.02 \pm 0.0008 x\)

- **Graph 2:**
  - Title: SG-LYSO-L
  - X-axis: Wavelength (nm)
  - Y-axis: Difference (%) normalized area 380 - 460 nm
  - Data points before and after irradiation

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γ-Ray Induced Transmittance Damage

300°C thermal annealing effective

LT damage: 8% @ 1 Mrad
About 10% L.O. Loss after 1 Mrad

All samples show consistent radiation resistance

10% - 15% loss by PMT

9% - 14% loss by APD

Normalized Average Light output

Irradiation Dose (rad)

CTI-LSO-L 1
CTI-LSO-L 1
CPI-LYSO-L 1
CPI-LYSO-L 1
SG-LSO-L 1
SG-LSO-L 1
SG-LSO-L 3
SG-LSO-L 3
SIPAT-LSO-L 1
SIPAT-LSO-L 1

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CMS ECAL SLHC Workshop at Fermilab, Ren-yuan Zhu, Caltech
LSO/LYSO ECAL Performance

- Less demanding to the environment because of -0.2%/°C T coefficient.
- This material is expected to survive better the SLHC radiation environment.
- A better energy resolution, $\sigma(E)/E$, at low energies than L3 BGO and CMS PWO may be achieved because of its high light output and low readout noise:

$$2.0 \%/\sqrt{E} \oplus 0.5 \% \oplus .001/E$$
Issues to be addressed

Φ60 ingot may be cut to two crystals, significantly increasing the usage of ingot. A key issue is the light response uniformity, which is crucial to achieve crystal resolution. The distribution of the cerium activator with 0.15 segregation, however, is not uniform along the crystal. Work is needed to achieve designed uniformity.
Light Response Uniformity

25 x 25 x 200 mm samples measured for their L.R.U. and fit to a linear function

\[ Y = Y_{mid} [1 + \delta (x / x_{mid} - 1)] \]
L.R.U. by PMT & LAAPD: SIPAT-LYSO-L5

Issue: Ce doping was optimized for the uniformities measured by PMT with two end-couplings, but a large difference observed between the PMT & APD readouts.
L.R.U. by PMT & LAAPD: SG-LYSO-L3

Consistent uniformities between PMT and APD
Some difference between two end-couplings
Radio-luminescence for LSO/LYSO

Crystal wrapped with Tyvek paper; \(\gamma\)-ray shooting at two ends (1 cm); PMT: XP2254B running @ -1800V.
Radio-luminescence

Found: SIPAT-LYSO-L5 has an extra green emission component at the tail end, which does not show in other samples. This may explain the large difference observed in uniformities measured by PMT and APD.
SIPAT-L6: Consistent Emission at two ends

Extra green component at the tail end eliminated

With grating & PMT QE corrected

Intensity (arbitrary unit)

Wavelength (nm)
SIPAT-LYSO-L6: Consistent slopes for PMT and APD readout. They may be compensated by the optical focusing effect.

- For Seed end coupled to PMT:
  - SIPAT-LYSO-L6
  - Average L.O. = 960 p.e./MeV (300 ns)
  - \( \delta = (-6.9 \pm 1.0) \)

- For Tail end coupled to PMT:
  - SIPAT-LYSO-L6
  - Average L.O. = 940 p.e./MeV (300 ns)
  - \( \delta = (-4.2 \pm 1.0) \)

- For Seed end coupled to LAAPD:
  - SIPAT-LYSO-L6
  - LAAPD covered with quartz
  - Average L.O. = 2140 p.e./MeV
  - \( \delta = (-3.5 \pm 1.5) \)

- For Tail end coupled to LAAPD:
  - LAAPD covered with quartz
  - Tail end coupled to LAAPD
  - Average L.O. = 2080 p.e./MeV
  - \( \delta = (-4.3 \pm 1.5) \)
Progress in 2009 (II)

The 1\textsuperscript{st} Φ61 x 310 mm LYSO ingot was successfully grown recently at SIPAT, which may be cut into two 28 cm (25 X\textsubscript{0}) crystals.

The Caltech crystal laboratory is looking forward to test the 1\textsuperscript{st} 2.5 x 2.5 x 28 cm sample.
After $10^{13}$ neutrons/cm$^2$ the induced absorption of LYSO is five times less than that of PWO. See talk by Guenther Dissertori in this workshop.
Summary

- LYSO crystals with blight, fast scintillation and excellent radiation hardness is a good candidate material for calorimeter at the SLHC.

- While the quality of LYSO crystals is adequate for low energy applications, such as KLOE-2 and SuperB, work is needed to further develop crystals for the SLHC. A upgrade R&D proposal for CMS is underway. Support from the US CMS upgrade program is crucial for this effort.