An LSO/LYSO Crystal Calorimeter for the ILC

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This paper reports an investigation on cerium doped lutetium oxyorthosilicate and lutetium-yttrium oxyorthosilicate crystals and discusses their potential application in the ILC.

1. INTRODUCTION

Because of its total absorption nature crystal calorimetry provides excellent energy and position resolutions for electrons and photons, good e/γ identification and reconstruction efficiencies and missing energy and jet energy resolutions [1]. A crystal calorimeter at the international linear collider (ILC) would enhance detector's physics discovery potential by isolating rare new physics from "Standard" backgrounds. In the last decade, cerium doped silicate based heavy crystal scintillators have been developed for the medical industry. As of today, mass production capabilities of lutetium oxyorthosilicate (LSO or Lu_2SiO_5) and lutetium-yttrium oxyorthosilicate (LYSO or $Lu_{2(1-x)}Y_{2x}SiO_5$, where x is 5–10%) crystals are established, and their potential application in future high energy physics experiments were explored [2]. Fig. 1 is a photo showing four long crystal samples with dimension of 2.5×2.5×20 cm. They are, from top to bottom: a BGO sample from Shanghai Institute of Ceramics (SIC), LYSO samples from Crystal Photonics, Inc. (CPI) and Saint-Gobain Ceramics & Plastics, Inc. (Saint-Gobain) and an LSO sample from CTI Molecular Imaging (CTI).

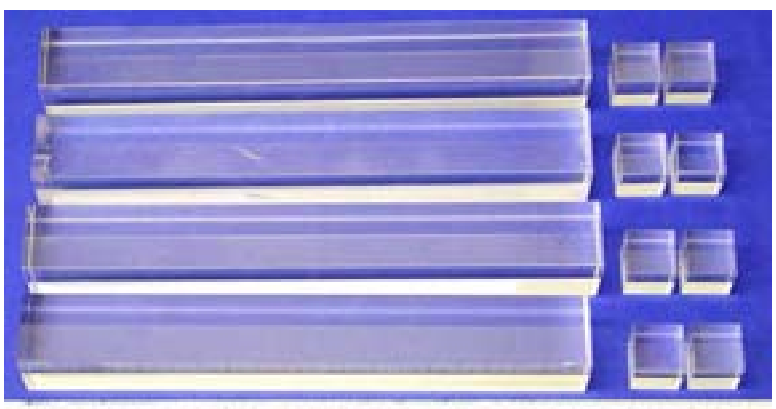

Figure 1: A photo showing four long (2.5×2.5×20 cm) crystal samples, from top to bottom: SIC BGO, CPI LYSO, SG LYSO and CTI LSO, together with two corresponding small cube samples (1.5 X_0 cubic) from each manufacture.

2. LSO/LYSO SCINTILLATION AND OPTICAL PROPERTIES

One intrinsic advantage of LSO/LYSO crystals is their high density, which makes a compact LSO/LYSO calorimeter possible. The second advantage is their fast and bright scintillation, which facilitates a precision crystal calorimeter with superb low energy reach at a high rate environment, such as the ILC. Fig. 2 shows a comparison of the transmittance, emission and excitation spectra as a function of wavelength for four long samples. No difference

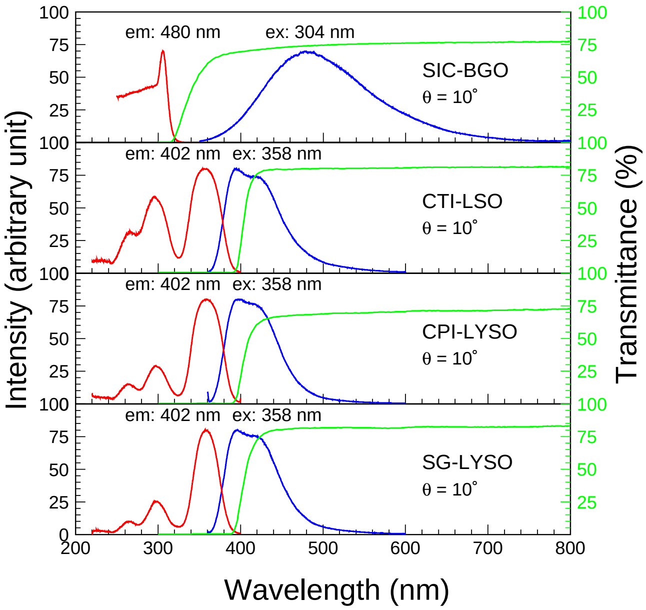

Figure 2: The excitation (blue) and emission (red) spectra (left scale) and the longitudinal transmittance (green) spectra (right scale) are shown for four long samples.

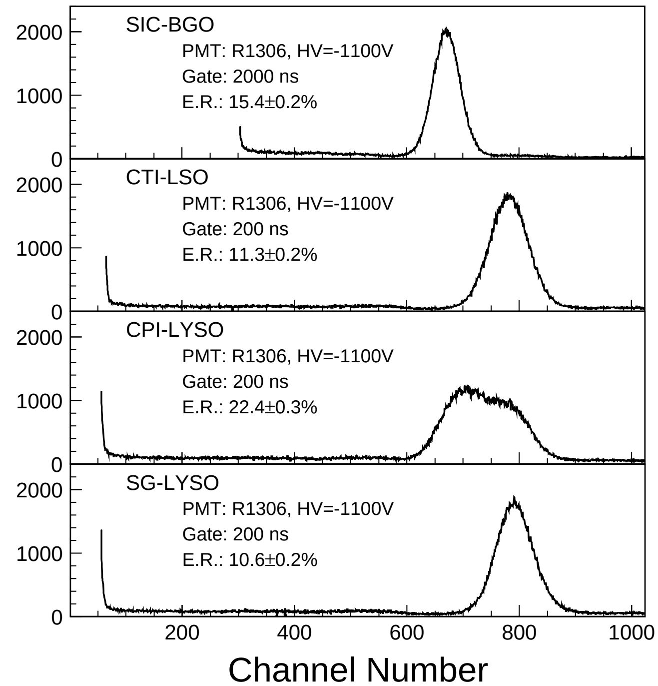

Figure 3: The spectra of 0.511 MeV γ-rays from a ^{22}Na source with coincidence by using a Hamamatsu R1306 PMT are shown for four long samples.

was observed between LSO and LYSO crystal samples. Fig. 3 shows γ-ray energy spectra measured by using a

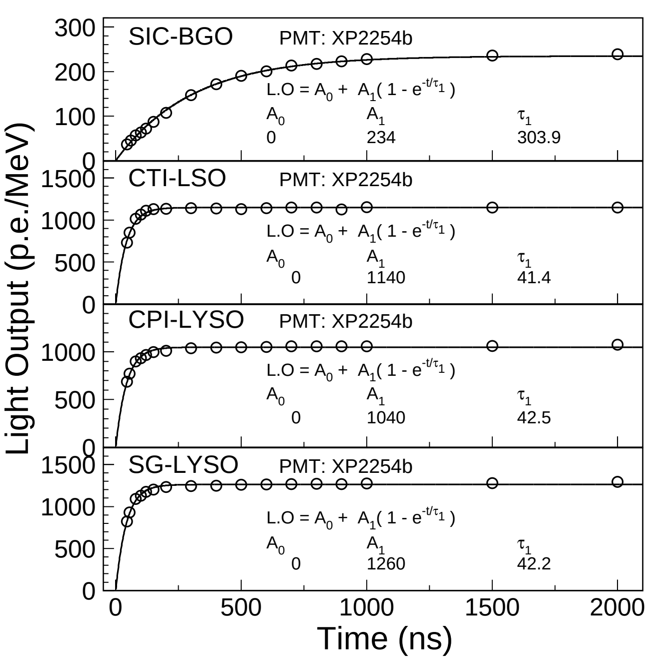

Figure 4: Light output measured using a Photonis XP2254b PMT is shown as a function of integration time for four long samples.

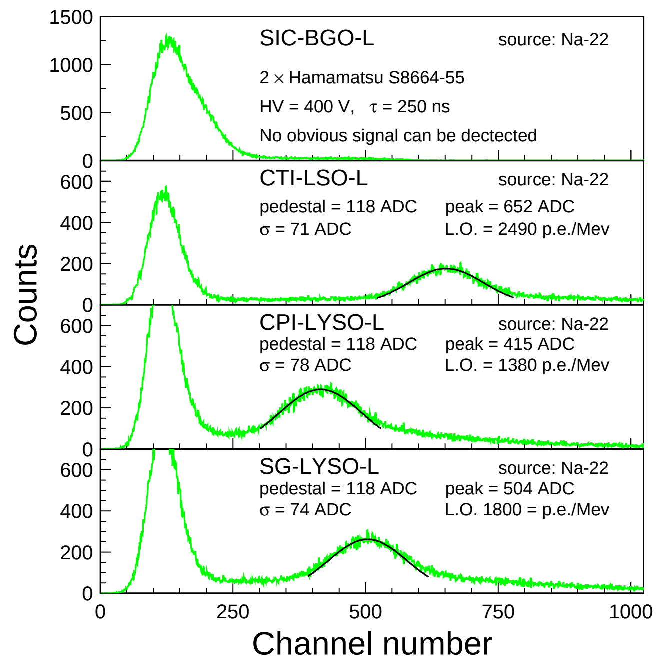

Figure 5: The spectra of 0.511 MeV γ-rays from a ^{22}Na source measured using two Hamamatsu S8664-55 APD with coincidence are shown for four long samples.

Hamamatsu R1306 PMT with bialkali photo cathode. The FWHM resolution for 0.511 MeV γ-rays from a ^{22}Na source measured with coincidence is about 10% to 11% for Saint-Gobain LYSO and CTI LSO long samples, and is 15% for SIC BGO. Fig. 4 shows light output and decay kinetics measured using a Photonis XP2254b PMT with multi-alkali photo cathode. The LSO and LYSO samples exhibit consistent decay times and photoelectron yields: the decay time is a factor of 7 faster than that of BGO and the photoelectron yield is a factor of 6 larger that that of BGO. Fig. 5 shows spectra of 0.511 MeV γ-rays from a ^{22}Na source measured using two Hamamatsu S8664-55 avalanche photodiodes (APD with a dimension of 5×5 mm) with coincidence. While there is no clear signal from BGO, the peak is clearly identified by both LSO and LYSO long samples. By using a calibration performed with a ^{55}Fe source the absolute light output and energy equivalent readout noise were determined to be about 2,000 p.e./MeV and 35 keV respectively. It is worth noting that with the two Hamamatsu S2744 photodiode (PD) readout employed by the *BABAR* and Belle CsI(Tl) calorimeters, it is not possible to separate radioactive source signals of this energy from noise. Table I summarized numerical values of the emission weighted average quantum efficiencies for these readout devices. Taking into account the PMT response, we conclude that the light yield of LSO and LYSO crystals is a factor of four of that of BGO.

Table I: Emission Weighted Quantum Efficiencies (%)

Emission	LSO/LYSO	BGO	CsI(Tl)
Hamamatsu R1306 PMT	12.9±0.6	8.0±0.4	5.0±0.3
Photonis XP2254b	7.2±0.4	4.7±0.2	3.5±0.2
Hamamatsu S2744 PD	59±4	75±4	80±4
Hamamatsu S8664 APD	75±4	82±4	84±4

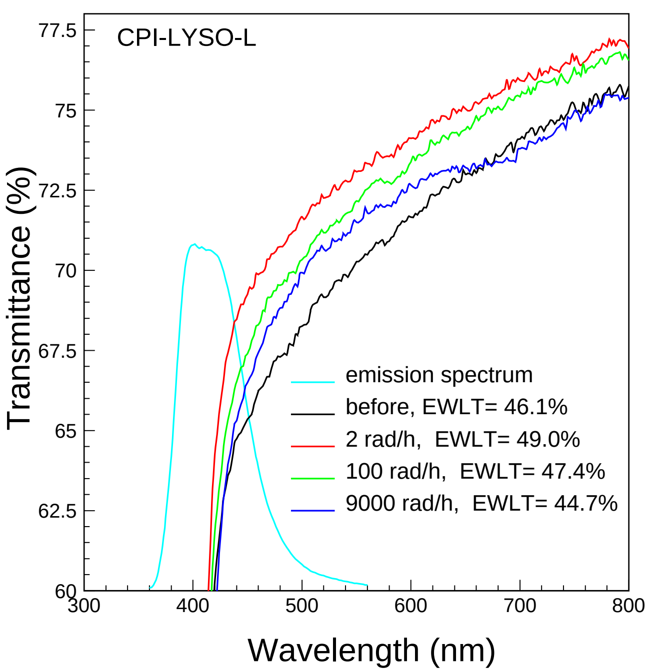

Figure 6: Longitudinal transmittance spectra and values of the emission weighted longitudinal transmittance (EWLT) measured before and after 2, 100 and 9,000 rad/h irradiations are shown for the CPI long LYSO sample.

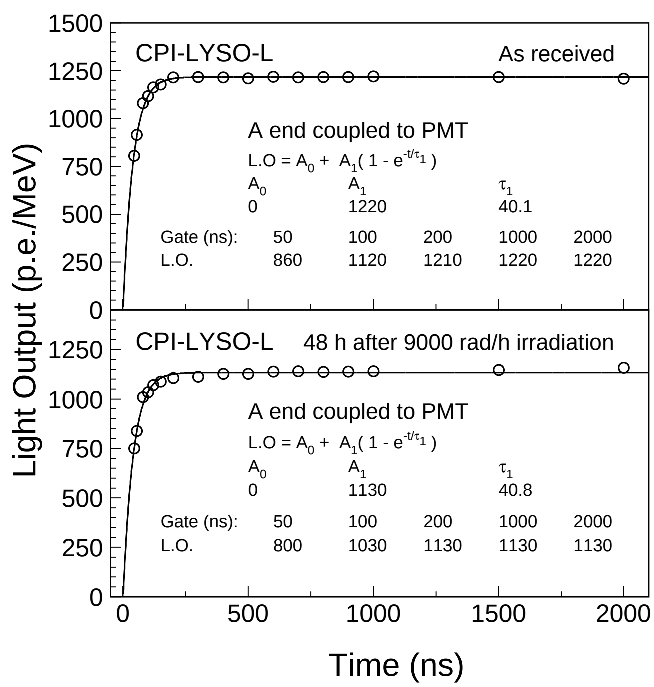

Figure 7: A comparison of the light output and the decay kinetics measured before irradiation and after the 9,000 rad/h irradiation is shown for the CPI long LYSO sample.

3. LYSO RADIATION DAMAGE

Crystal radiation damage may show up in radiation induced phosphorescence, color center formation and/or damage of the scintillation mechanism [3]. Two long LYSO samples were investigated with γ-ray irradiations in 24 hour steps at dose rates of 2, 100 and 9,000 rad/h [2]. No variation was observed in emission and excitation spectra, indicating no damage in the scintillation mechanism. Minor degradations were observed in the longitudinal transmittance and the light output, but the decay time remains stable, as shown in Fig. 6 and 7. One of the main consequences of radiation damage in LYSO crystals seems the radiation induced phosphorescence. A Hamamatsu R2059 PMT was used to measure the γ-ray induced anode current for two LYSO samples. Table II summarizes the result, where F is the γ-ray induced anode current per unit dose rate. Q_{15} and Q_{500} are the induced photoelectron numbers in 100 ns gate for these two samples under 15 and 500 rad/h respectively, which were calculated by using the F and the corresponding gain of the PMT. σ_{15} and σ_{500} are the corresponding energy equivalent readout noise, which were derived as the r.m.s. fluctuation of the photoelectron numbers and corresponding photoelectron yield. The radiation induced related readout noise thus is estimated to be about 0.2 and 1 MeV equivalent with 100 ns integration time for these two long LYSO samples under 15 and 500 rad/h respectively.

Table II: γ-ray Induced Readout Noise in Two Long LYSO Samples

Sample ID	F μA rad^{-1}h	Q_{15} p.e.	Q_{500} p.e.	σ_{15} MeV	σ_{500} MeV
CPI	41	6.98×10^4	2.33×10^6	0.18	1.03
Saint-Gobain	42	7.15×10^4	2.38×10^6	0.17	0.97

4. EXPECTED PERFORMANCE OF AN LSO/LYSO CALORIMETER AT THE ILC

Ce doped LSO and LYSO crystals have fast bright scintillation light, which has 40 ns decay time and an amplitude about four times of BGO. The light output of $2.5 \times 2.5 \times 20$ cm LSO/LYSO samples can be read out by using two Hamamatsu S8664-55 APD with electronic noise of about 30 keV equivalent. The radiation effect on transmittance and light output is small in LYSO samples as compared to other commonly used crystal scintillators. The γ-ray induced phosphorescence related readout noise for 100 ns integration time is about 0.2 and 1 MeV equivalent, estimated for $2.5 \times 2.5 \times 20$ cm LYSO samples in an radiation environment of 15 and 500 rad/h respectively. The combination of the above characteristics makes LSO and LYSO crystals a good candidate for a precision crystal calorimeter at the ILC. If built it would provide a superb low energy reach and an energy resolution of $\delta E/E = 2\%/\sqrt{E} \oplus 0.5\% \oplus 0.002/E$, where E is in GeV and $\oplus$ represents addition in quadrature.

Acknowledgments

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References

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[3] R.-Y. Zhu, *Radiation Damage in Scintillating Crystals*, *Nucl. Instr. and Meth.* **A413** (1998) 297–311.