Evaluation of Cerium Doped Lutetium Oxyorthosilicate (LSO) Scintillation Crystal for PET

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ABSTRACT

A new scintillation crystal, cerium-doped lutetium oxyorthosilicate (LSO) was recently discovered (1,2), with light intensity 75 % of NaI(Tl), scintillation decay time of 12 ns (30%) and 42 ns (70%), effective Z of 66, and density of 7.4 g/cc. The fast decay time and scintillation light output of LSO are superior to those of BGO for PET and the stopping power of LSO for 511 keV photons is only slightly lower than BGO.

In this study we directly compared the detection characteristics relevent to PET applications of small crystals of LSO (2 x 2 x 10 mm) with those of BGO. The energy resolution at 511 keV was 12% FWHM for LSO and 2 to 3 times wider for BGO. The coincidence timing of two opposing crystals, using a position sensitive PMT (Hamamatsu R2486), were 1.4 ns FWHM for LSO and more than 3 times higher for BGO. Using a fast PMT (Hamamatsu R3177) coincidence timing for LSO yielded 0.46 ns FWHM. These crystals are being used to simulate a small scale PET scanner and to investigate its imaging performance.

I. INTRODUCTION

A new scintillation crystal, cerium doped lutetium oxyorthosilicate (LSO) was recently discovered [1-5]. Some of the properties of LSO are compared with those of BGO and NaI(Tl) in Table 1. BGO is currently the most widely used scintillator in positron emission tomography (PET) because of its high atomic number and high density. NaI(Tl) is used in many applications because of its high light output and consequent superior energy resolution. In devices such as gamma cameras and some PET scanners which rely on the distribution of light among several photomultiplier tubes (PMT's) to determine the position of interactions, the high light output results in better spatial resolution. LSO has a light output which is about 75% that of NaI(Tl) and an attenuation for 511 keV photons which is only slightly less than that of BGO. Furthermore, the decay time is much shorter. LSO would therefore appear to be an excellent potential scintillator for PET applications.

In this study we directly compared the detection characterisitics relevant to PET applications of small crystals of LSO with those of BGO. Experimental simulations of PET imaging are currently underway to evaluate various image parameters (such as resolution, single-to-true ratio, scatter-to-true ratio, etc.) under various conditions

II. SCINTILLATION LIGHT OUTPUT

The spectra of Ge-68 with both LSO and BGO were acquired. The scintillators (2 x 2 x 10 mm) were optically connected to PMTs (Hamamatsu R647-04). The results of these experiments are shown in Figures 1 and 2. The light output of LSO was 4 to 5 times larger than that of the BGO (depending on the type of Teflon tape wrapping). The energy resolution (FWHM) of the 511 keV photon was 12% for LSO and 32% for BGO. In the BGO spectrum a number of counts above the channel 400

Table 1 Properties of LSO, BGO and NaI(Tl)

	LSO	BGO	NaI(Tl)
Relat. light intensity	75	15	100
Peak wavelenght	420 nm	480 nm	410 nm
Decay constant (ns)	12 (30%); 42 (70%)	300	230
Density (g/cc)	7.4	7.13	3.67
Effective atomic No.	66	75	51
Index of refraction	1.82	2.15	1.85
Hygroscopic?	no	no	yes
Rugged?	yes	yes	no

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are due to Compton interaction, if these counts are extrapolated and subtracted, the FWHM of BGO becomes approximately 28%.

Position sensitive PMT's (e.g. Hamamatsu 2487) are not sensitive on the areas close to the edges. In order to use position sensitive PMT's in a circular PET configuration and avoid gaps due to the insensitive edge areas of the PMT's, we plan to use light guides to transmit light from the scintillators to PMT's. To investigate the loss of light in the light guide a piece of LSO (2x2x10 mm) was optically connected to a position sensitive PMT via a 50 mm long, 2x2 mm in cross section, polished piece of Lucite. In order to increase the light transmission the light guide was wrapped in Teflon tape. The spectrum of Ge-68 was acquired showing approximately 50% light loss.

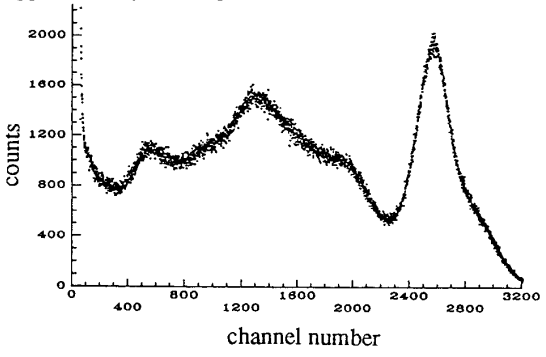

FIGURE 1. The spectrum of Ge-68 in a small piece of LSO crystal (2 x 2 x 10 mm). This crystal is coupled to a PMT (Hamamtsu R647-04) via its 2x2 mm side. The x-axis is the channel number.

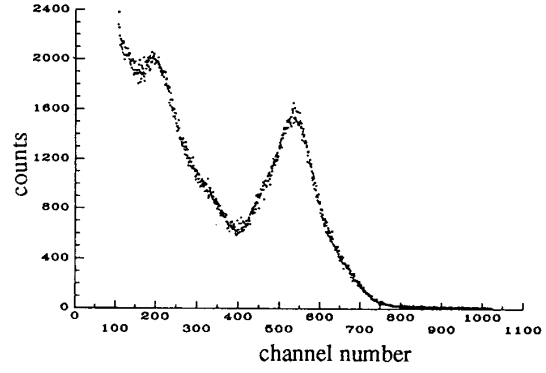

FIGURE 2. The spectrum of Ge-68 in a small piece of BGO crystal (2 x 2 x 10 mm). This crystal is coupled to a PMT (Hamamtsu R647-04) via its 2x2 mm side. The x-axis is the channel number.

III- PHOTOFRACTION

The photofraction is defined as the number of counts in the photopeak region divided by the total number of counts. The lower atomic number of LSO (effective Z = 66) lowers the probability of photoelectic interaction of 511 keV photons compared to BGO (effective Z = 75). But since the light output of LSO is higher, it is not clear how the photofraction as measured in small cuts of LSO compares with similar sizes of BGO. This quantity was measured from the acquired spectrum of Ge-68 in both LSO and BGO crystals. The crystals were isolated in air, i.e. no solid material was in the immediate vicinity other than the PMTs. (Note: electronic noise was extrapolated and subtracted).

The photofraction of LSO was measured to be 29% and that of a similar size BGO was 28% when the counts due to the Compton interactions are extrapolated and subtracted from the photopeak region. Without this subtraction photofraction of BGO was 35%.

IV- COINCIDENCE TIMING

Two pieces of LSO were coupled to two opposing PMTs . A Ge-68 rod source was placed in the middle and a fast coincidence system was used to acquire the coincidence time-spread function. A similar experiment was done with BGO.

The signals were amplified with a fast amplifier. Two constant fraction discriminators (Ortec 583) were used to discriminate signals above 1 or 2 photoelectrons. A delay generator was used on one of the branches and the time difference of the two signals were converted to pulse height using a TAC (Ortec 857) which was connected to an MCA.

The coincidence time spread function for LSO and BGO resulted in a FWHM of 0.95 ns for LSO and 2.2 ns for BGO using two Hamamatsu R647-04 PMTs. Since we intend to investigate the use of position sensitive PMTs for a small PET design, the experiment was repeated with one PMT being replaced with a position sensitive PMT (Hamamatsu R2486). The FWHM in this case was 1.4 ns for LSO (Fig. 3). Another experiment was conducted using two fast PMTs (Hamamatsu R3177) yielding a FWHM of 0.46 ns for LSO (Fig. 4).

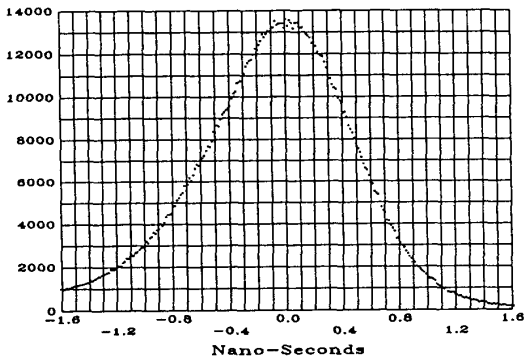

FIGURE 3. Coincidence time spread function of annihilation photons of positron decay in two small pieces of LSO (2x2x10 mm). One of these crystals was coupled to a position sensitive PMT (Hamamatsu R2486), and one is coupled to a head on PMT (Hamamatsu R647-04).

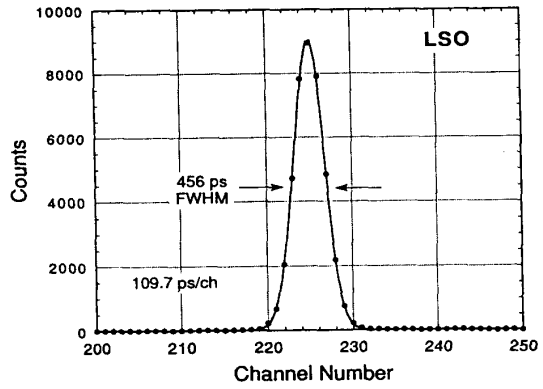

FIGURE 4. Coincidence time spread function of annihilation photons of positron decay in two small pieces of LSO (2x2x10 mm). These crystals were coupled to two fast PMTs (Hamamatsu R3177).

V- DISCUSSIONS AND CONCLUSIONS

1) For small crystals (2 x 2 x 10) the light output of LSO is 4 to 5 times higher than that of BGO, resulting in better energy resolution.

2) A simple light guide attenuates the scintillation light of LSO by a factor of 2 but still yields more light at the PMT than a directly coupled BGO crystal. This makes it feasible to pack crystals, each connected to a Lucite light guide, in continous ring PET designs utilizing position sensitive PMTs which have a sensitive area smaller than their physical area.

3) Despite the slightly lower atomic number of LSO, the photofraction for small crystals of LSO and BGO are equal due to the higher energy resolution of LSO.

4) The smaller FWHM of the time spread function of LSO permits a narrower timing window for PET and in turn a reduction in random to true coincident rate. The different values obtained with three different LSO-PMT combinations indicate the importance of the contribution of the PMT time jitter for the time window setup of a PET scanner with LSO.

ACKNOWLEDGMENT

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