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COMPARISON OF THE SCINTILLATION PROPERTIES OF LSO:Ce AND YSO:Ce AS THE DETECTORS FOR HIGH RESOLUTION PET* **

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We investigate the application of LSO and YSO scintillating crystals for Positron Emission Tomography (PET). Properties such as light output, energy resolution, detection efficiency for various energy threshold, and timing resolution are presented. These data allow us to evaluate the usage of finger-like LSO:Ce and YSO:Ce crystals coupled to photomultiplier tube, and to establish optimal operating conditions for high-resolution PET. Both crystals have advantages over BGO currently used in PET and LSO is considered as a possible replacement for BGO based systems.

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1. Introduction

Inorganic scintillators are critical elements for several medical imaging techniques, including X-ray imaging, single photon emission computer tomography (SPECT), and positron emission tomography (PET). With PET, a radioactive labeled compound (*e.g.* drug or gas) is administered to a patient. This compound then accumulates in the patient and the pattern of its subsequent radioactive emissions is used to estimate its distribution within the body. The radioisotopes used with PET are positron emitters, for which pairs of 511 keV annihilation photons are detected in timing coincidence and

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imaged. The high energy of photons, and the need to produce an accurate timing signal (below 10^{-9}sec) in order to identify coincident photons, set additional demands for the detection system of PET.

Bismuth germanate (BGO, $Bi_4Ge_3O_{12}$) is most often used due to its short attenuation length and high density resulting in high detection efficiency for annihilation radiation. LSO (lutetium orthosilicate, Lu_2SiO_5:Ce) which was invented by C.L. Melcher [1] shows potential for replacing BGO as the scintillator of choice for PET, due to its higher light output and improved timing properties [1,2]. LSO allows to achieve high spatial resolution without deterioration of any other detector property. The growing interest in the use of the LSO in commercial PET scanners stimulates research to establish optimal operating conditions in such applications. We present also results from measurements with YSO (Y_2SiO_5:Ce), which is known as the commercial phosphor [3], and has similar chemical composition to the LSO.

2. Experimental details

For comparison of scintillator properties crystals with dimensions of $3 \times 3 \times 20$ mm^3 have been cut from a boule of LSO and YSO respectively. These boules were delivered by CTI PET Systems Inc., Knoxville, TN, USA.

Natural lutetium contains ca. 2.59 % of radioactive ^{176}Lu which decays with the half-life of 3.78×10^{10} years by β^- of 597 keV maximum energy and 307 keV, 202 keV and 88 keV γ-rays. The yield is ca. 280 decays of ^{176}Lu per second per cm^3 of LSO. The main physical properties of LSO and YSO are presented in Table I.

TABLE I

Main physical crystal properties

Crystal	LSO:Ce	YSO:Ce
Manufacturer	CTI	CTI
Peak wavelength [nm]	420	420
Density [g/cm^3]	7.44	4.54
Atten. length for 511 keV [cm]	1.15	2.57
Background	280 c/s/cm^3	none

In all measurements, a calibrated XP2020Q photomultiplier with radiant sensitivity of 83 mA/W at 420 nm, corresponding to the integral quantum efficiency of 0.20 for both crystals, was used. The samples were coated with white PTFE (polytetrafluoroethylene) tape, an optical reflector of good quality [4], and were glued by one face to the PMT with silicone oil.

3. Results

3.1. Light output

In order to determine the light output of the investigated crystals, the number of photoelectrons per energy unit (phe/MeV) was measured by comparing the position of the 661.6 keV full-energy peak from ^{137}Cs source with that of the single photoelectron peak (see Fig. 1). First, the crystals were glued to the PMT with one 3×20 mm^2 face (horizontal geometry) in order to check the quality of the scintillator material. The measured number of photoelectrons equal to 5730$\pm$440 phe/MeV and 5200$\pm$240 phe/MeV for LSO and YSO respectively, confirmed the good quality of the scintillator material [5]. Furthermore, the number of photoelectrons were measured for the same crystals optically coupled with one of the 3×3 mm^2 face to the PMT (vertical geometry). In this case a lower number of photoelectrons of 3600$\pm$360 phe/MeV for LSO and 2900$\pm$300 phe/MeV for YSO respectively, was obtained. The reason for this observation is that in the latter case, the mean photon pathway inside the crystal is longer. This is manifested by the higher light absorbtion. We can conclude that LSO and YSO crystals show moderate light attenuation properties. This suggests, that they do not exhibit the same strong parasitic absorption as observed for BGO samples [4].

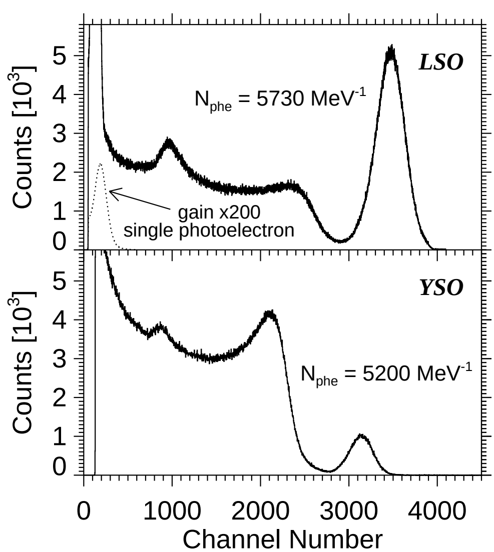

Fig. 1. Pulse height spectra of a ^{137}Cs source measured with LSO and YSO in horizontal geometry. For all measurements a single photoelectron spectrum comparable to that shown in the upper figure has been obtained.

3.2. Energy resolution

Fig. 1 shows the energy spectra of the fully polished crystals of LSO and YSO irradiated with γ-rays from ^{137}Cs source in horizontal geometry. The measured energy resolution was equal to 11.0±0.4 % and 8.9±0.3 % for LSO and YSO respectively. Further, the energy spectra of γ-rays from a ^{22}Na source were measured in vertical geometry with the same samples. Again, a very good energy resolution of 13.9±0.4 % (LSO) and 9.5±0.3 % (YSO) was observed for 511 keV γ-rays, which was much better than that reported previously for BGO crystal (26.6 %, see [4]).

3.3. Detection efficiency

The detection efficiency plays a very important role in human PET diagnostics. In particular, the detection efficiency for 511 keV positron annihilation photons should be considered as an essential factor.

Detection efficiency defined as a peak to total ratio was equal to 0.15 for YSO, and 0.58 for LSO, for energy threshold set to 250 keV. Note, four times lower detection efficiency for 511 keV γ-rays for YSO than that measured for LSO. This is due to the low atomic number of yttrium (Z=39) and moderate YSO density. A further limitation of the YSO crystal in PET application is the Compton scattering of γ-quanta, which are easily detectable in neighboring crystals of a multi-crystal block detector. This effect will deteriorate the spatial resolution of PET system. In order to reduce this effect, one has to use a rather high energy threshold *e.g.* 300 keV. This will, however, reduce the detection efficiency of the system even further. Summarizing, scintilation properties of YSO sugest rather limited application in PET.

3.4. Timing properties

The timing properties were tested for LSO crystals with dimensions of $3 \times 3 \times 20$ mm^3. To reasemble a typical configuration of PET detector, we measured coincidence time resolution for 511 keV annihilation quanta from a ^{22}Na source with two LSO crystals in vertical geometry. Anode signals of the XP2020Q photomultipliers were sent to constant fraction discriminator CFD 1512 [7]. Then, for one crystal the signal was sent to start input of TAC, while the signal of the second one served as a stop signal of TAC. This method allows the selection of an energy threshold in the CFD for both samples. Typical time spectra measured with two LSO crystals for the energy thresholds set at full energy peak are presented in Fig. 2. The timing resolution of LSO crystals for various energy thresholds is summarized in Table II.

TABLE II

Coincidence time resolution of LSO scintillator for 511 keV γ-rays as a function of the lower-energy threshold.

Energy threshold [keV]	100	250	400	450
FWHM [ps]	980±30	665±25	510±30	472±27

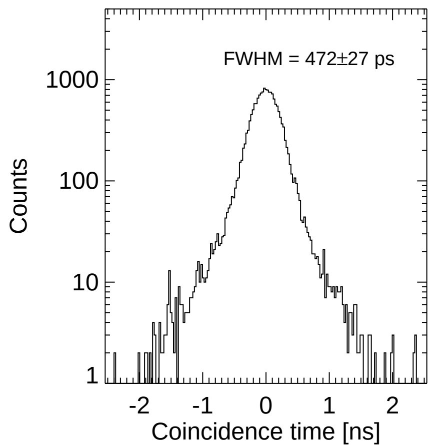

Fig. 2. Coincidence time spectrum measured with two LSO crystals in vertical geometry for 511 keV annihilation quanta from a ^{22}Na source.

The time resolution of 472 ps is comparable to that reported in [8] for the same size of the crystals but for slightly different energy threshold. The timing results confirm the conclusions of [6] and [8] that a time-of-flight PET may be designed using LSO crystals.

4. Conclusion

We presente the feasibility studies of LSO:Ce and YSO:Ce in the design of a new high-resolution PET scanners. We demonstrate, that detection systems which combine PMT and a new inorganic scintillator such as LSO:Ce can be successfully used in Positron Emission Tomographs. The high number of photoelectrons, a good energy resolution, and an excellent coincidence time resolution determined for LSO are the key factors in PET applications. Despite of the slightly lower than for BGO fraction of events which interact photoelectrically, and the natural background activity, properties such as good spatial resolution, high signal-to-noise-ratio, and excellent count rate capability, makes LSO scintillator superior to BGO for PET scanner.

YSO may be considered as an alternative, if the high light output of LSO is required (*e.g.* in order to enable higher spatial resolution), and in cases when natural background of LSO is limiting factor. This is particularly important for low count rate applications.

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