LaBr₃:Ce scintillation gamma camera prototype for X and gamma ray imaging


*INFN and Department of Experimental Medicine, University of Rome “La Sapienza”, Viale Regina Elena 324, 00161 Rome, Italy

INFN and Department of Physics, “La Sapienza” University, Rome, Italy

INFN and “Roma III” University, Rome, Italy

INFN and Department of Physics, University of Bologna, Italy

INFN and University of Padova, Italy

INFN and ENEA Casaccia Research Center, Rome, Italy

INFN and Department of Electronics Engineering, “Roma III” University, Rome, Italy

Available online 3 February 2007

Abstract

LaBr₃:Ce has been showing very promising characteristics as gamma ray imager and spectrometer. In particular its excellent energy resolution values (6% at 140 keV and ~3% FWHM at 662 keV), obtained when coupled to a PMT, make it the major competitor of semiconductor detectors working at room temperature. In order to improve its imaging performances, the LaBr₃:Ce can easily work as continuous detector allowing sub-millimeter spatial resolution values at 140 keV photon energy when coupled to a Position Sensitive PMT. Further interesting characteristics like a short scintillation decay time (16 ns), a very high light yield (63 000 photons/MeV) and a low afterglow are attracting the scientific community for the potential improvement of a wide range of applications in medicine like PET, SPECT and CT instrumentation. In this paper, we present some preliminary imaging results obtained by coupling H8500 Hamamatsu Flat Panel PMT to two LaBr₃:Ce crystals with 50 x 50 mm² area, 5 and 10 mm thickness respectively. With the aim to propose a single detector able to combine functional information, for example from Single Photon Emission technique, with the morphological ones from X-ray imaging the spatial resolution results obtained in the energy range between 30 and 302 keV are analyzed and discussed. We obtained very interesting spatial resolution results for gamma ray energy value greater than 60 keV (better than 1 mm, intrinsic value), while in the energy range proper to X-ray applications, like RX-Mammography (about 30 keV), the spatial resolution values resulted about 2 mm.

© 2007 Elsevier B.V. All rights reserved.

PACS: 87.58.Pm; 07.85.Fv; 07.85.Fv; 29.40.Gx

Keywords: Lanthanum bromide; Gamma ray imagers; Nuclear medicine

1. Introduction

Dual modality systems for Nuclear Medicine represent a powerful diagnostic tool in molecular imaging technique. In particular, Positron Emission Tomography (PET)/CT or Single Photon Emission Tomography (SPECT) systems combine the functional information of the nuclear medicine technique with the morphological information of X-ray computed tomography (CT) [1,2]. Industries mostly involved in this field, like Siemens or Philips, have developed and commercialized dual modality scanners daily utilized in hospitals [3,4]. The main characteristic of these scanners is the presence of two detectors, usually a rotating gamma camera and a CT. The development of one detector and electronic readout to be used simultaneously
in both CT and Nuclear Medicine modality, is highly desired with spatial resolution also useful to acquire morphological information. With this aim, we propose a preliminary study of imaging capabilities on two gamma camera prototypes obtained by coupling an H8500 Hamamatsu Flat Panel PMT with two LaBr$_3$:Ce crystals, 50 × 50 mm$^2$ detection area, with 5 and 10 mm thickness, respectively. LaBr$_3$:Ce scintillation crystal presents very promising characteristics for gamma ray imaging and spectrometric applications. In particular, its very high light emission (63 000 photon/MeV) and the flat response as a function of incident gamma energy, as it is shown in Fig. 1 in comparison with NaI(Tl) scintillator [5,6], are responsible for the intrinsic energy resolution of scintillator, and as a consequence for its excellent energy resolution value (6% at 140 keV and ~3% FWHM at 662 keV) [7,8]. These features satisfy the principal SPECT/PET requirements like high light output, high photo-fraction and excellent energy resolution. Furthermore, the short scintillation decay time (16 ns) makes it attractive also for PET. For CT applications, the requirements regard principally a high spatial resolution at energy involved in X-ray imaging and a low afterglow of the crystal. Different papers show a residual intensity emission, for LaBr$_3$:Ce crystal, less than 0.01% after 200 s from the irradiation time [5].

Finally, in order to evaluate the spatial resolution of the detectors at energy involved both in CT and SPECT applications, we propose an analysis of the intrinsic spatial resolution response of the integral assembly detector as a function of the impinging photons energy ranging from 32 to 302 keV.

2. Equipment and method

In this work, a couple of continuous LaBr$_3$:Ce crystals have been studied. The crystals are continuous because of fragility of material which introduced serious concerns in pixellated manufacturing. For both lanthanum trialuminate crystals, the entrance face were grinded with certain grit and covered with white diffusive reflector in order to obtain the best light output result; black light absorber was placed on edges to avoid position distortions due to the light reflections. The first crystal present 50 × 50 mm$^2$ active area and 10 mm thickness with 3 mm glass window, due to its higrosopicity. It was coupled to a Hamamatsu H8500 Flat Panel PMT, which has an external size of 52 mm × 52 mm × 14.4 mm, 49 × 49 mm$^2$ detection area, and 1.5 mm glass window. The photocathode is bialkali and 12 stage metal channel dynodes were used as electron multiplier. An 8 × 8 matrix anode is utilized for positioning with 6 mm pitch in both directions.

The second detector is also based on a LaBr$_3$:Ce crystal, with the same shape of the other but of 5 mm thickness and hermetically sealed with the H8500 Flat Panel PMT. This assembly allows, avoiding additional glass window, to enhance the spatial resolution performance by reducing the distance between the scintillation point and the photocathode. The detector efficiency at 140 keV is 80% and 95% for the integral assembled and the 10 mm thickness camera, respectively.

A multi-anode readout (READ system) has been utilized in which the charge on each anode is individually read out and digitized. Basic detector principle is the same of Anger camera with scaled dimensions. The READ system was developed at Southampton University and consists of HX2 multi-channel amplifiers with fixed gain [9].

The position linearity was studied by scanning the imagers with 1 mm $^{57}$Co point source at 1.5 mm step. Through this measurement, also spatial and energy resolution has been investigated. Finally, to evaluate the behavior of spatial resolution as a function of the incident gamma ray energy, we performed on the integral assembled detector five spots 5 mm step scanning with 1 mm collimated $^{133}$Ba source, 100 μCi activity. We analyzed each spot in three different energy windows (±10%) centered on the $^{133}$Ba source emissions at 30, 80 and 302 keV energy.

![Fig. 1. Relative Light yield vs. gamma ray energy for NaI(Tl) and LaBr$_3$:Ce crystals. (A) Prescott and Narayan [5] and (B) Bizarri et al. [6].](image)

![Fig. 2. Position linearity for both LaBr$_3$:Ce detectors in comparison with the response of other gamma cameras.](image)
3. Results

In Fig. 2 the position linearity response, as obtained by the scanning of both detectors, is shown. The results are compared with the same one obtained with other gamma imagers [10] with different continuous scintillator crystals (surfaces treatment, i.e. edges and entrance faces, similar to LaBr₃:Ce crystals). All the NaI(Tl) and CsI(Na) crystals were coupled to Hamamatsu R2486 PSPMT, which represents the early generation of PSPMT.

The results show an improvement of the detector linearity for the lanthanum cameras and, as a consequence, a consistent increase of effective FoV (up to 36 × 36 mm²).

By previous scanning measurements, we calculated the energy and the spatial resolution of the detectors as a function of the source position on the detection area; the results in comparison with the other imagers are shown in Figs. 3 and 4, respectively. The better performances of the lanthanum cameras, although for higher thickness value are highlighted. In particular, the energy resolution has a flat behavior of 8% and 12% mean value for 5 and 10 mm thick lanthanum crystal, respectively, and it showed a worsening on the crystal edge of about 25%.

The spatial resolution trend of the curve is very similar to the energy resolution one with a mean value of 1.16 and 1.80 mm for 5 and 10 mm thick lanthanum camera, respectively (in the active FoV). These results confirm the best performances of the lanthanum camera within an effective area of 36 mm size, which corresponds to a 73% of the overall area of the detector. However, also in terms of uniformity response, the LaBr₃:Ce detectors present better results with respect to the other cameras. Finally, in Fig. 5, we report the images and respective profiles of the

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Mean overall value (mm)</th>
<th>Mean intrinsic value (mm)</th>
<th>Best intrinsic value (mm)</th>
<th>Absorption efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>2.16</td>
<td>1.91</td>
<td>1.66</td>
<td>100</td>
</tr>
<tr>
<td>80</td>
<td>1.51</td>
<td>1.14</td>
<td>0.83</td>
<td>95</td>
</tr>
<tr>
<td>302</td>
<td>1.24</td>
<td>0.73</td>
<td>0.55</td>
<td>34</td>
</tr>
</tbody>
</table>
1 mm $^{133}$Ba spot source scanning, 5 mm step, for 32, 80 and 302 keV gamma ray energy.

In Table 1 we summarize the spatial resolution (SR) values in terms of overall, intrinsic and best result at different gamma ray energy. The results are very interesting: the intrinsic spatial resolution is better than 1 mm for photon energy higher than 60 keV and better than 2 mm for energy of about 30 keV.

4. Conclusions

Two continuous LaBr$_3$:Ce crystals, 5 and 10 mm thick, respectively, were coupled to a Hamamatsu H8500 Flat Panel in order to evaluate the imaging capabilities for applications in Nuclear Medicine. The very good performances in terms of energy and spatial resolution (7.5% and 0.9 mm at 122 keV for integral assembly camera) and the short decay time make it attractive also for dual modality applications. We have studied the intrinsic spatial resolution as a function of photon energy: the results at photon energy involved in CT technique (70 keV) are good in terms of spatial resolution, about 1 mm, and an adequate low afterglow. Furthermore, the results are extremely satisfying for SPECT applications (better than 1 mm). For X-ray application, like RX-Mammography (30–32 keV), the results in terms of spatial resolution seem to be not completely satisfying, but in any case better than 2 mm. Probably, it will be necessary to test LaBr$_3$:Ce crystals with smaller thickness and to integral assembly with the PSPMT, in order to obtain a trade off between efficiency in gamma application and spatial resolution in X-ray application.

These results suggest planning a hybrid SPECT/CT system of about 2–4 mm in SR for both modalities so to easily obtain co-registered images. For dedicated application, like breast imaging, a solution could be a SPEM/RX-Mammography combined system, with a dedicated high-resolution gamma camera and a RX-Mammography useful to have accurate morphological information.

References