Optimization of Crystal Surface Treatment for a Double Layer Depth of Interaction Detector*

TIAN Yi LIU Hua-Feng[1)]

(State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou 310027, China)

Abstract A depth of interaction (DOI) detector for γ-rays has been developed for a high-resolution positron emission tomography (PET) system dedicated to small animal studies. It is well known that different surface treatment on the crystals influences the total light output, and consequently affects the performance of the detectors. In order to optimize the performance of the new proposed DOI detector, we have focused on the comparison of the detectors consisting of narrow LSO crystals with different surface conditions. We observed a significant improvement in crystal identification, energy resolution, time resolution and detector response resolution for constructing detectors using polished crystals compared to those using roughened LSO crystals. The results of this study can provide useful information for LSO detectors to be used in practical PET systems.

Key words LSO crystal, detector, positron emission tomography

1 Introduction

It is challenging to design high efficiency gamma-ray detectors for use in small-diameter, high resolution positron emission tomography (PET) for small animal imaging. One of the major concerns in such PET design is spatial resolution. There is a trend to use narrower crystals, because its size is the largest contribution for improving the spatial resolution[1, 2]. However, the depth of interaction (DOI) of gamma rays in the narrower crystals has exaggerated the spatial resolution uniformity across the field of view (FOV) in the ring geometry of PET detectors. Up to now, many types of DOI detectors have been proposed to overcome the problem[3—5].

In order to achieve higher spatial resolution and good uniformity across the entire FOV, a DOI detector which consists of a double layered array of LSO crystals and a PS-PMT (R7600-00-C12) has been developed[6]. It is well known that different surface treatments on the crystals influences the total light output, and consequently affects the spatial resolution of the detector. In this study, we have focused on the comparison of light output, energy resolution and spatial resolution capability of narrow LSO crystals with different surface conditions.

The results of these studies will provide useful information for adopting the new DOI detector in a practical PET system.

2 Experimental results and discussion

2.1 Crystal identification

We constructed two double-layer scintillator blocks consisting of a 6×6 LSO array on a 7×7 LSO array, as shown in Fig. 1. The upper array was placed on the lower array with a shift of half the element pitch in both X and Y directions. The dimensions of each LSO element are 1.8mm×1.8mm in cross sec-

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1) E-mail: liuhf@zju.edu.cn

tion and 10mm in depth. All the surfaces of the crystal elements in one block are mirror-polished (While those in the other block are with coarsely-ground side faces), and each element is optically isolated from the adjacent elements with a 0.2mm thick PTFE film. The experimental setup for position map measurement is shown in Fig. 2. The cross-wired anodes of the PS-PMT are connected to two resistor chains in each X and Y direction, and the four output signals ($X+$, $X-$, $Y+$, $Y-$) from the resistor chains are amplified and integrated. Each output signal is then converted to 12 bit digital code and acquired into PC through GPIB interface in list mode. After the data acquisition, we calculate the position and energy for each event.

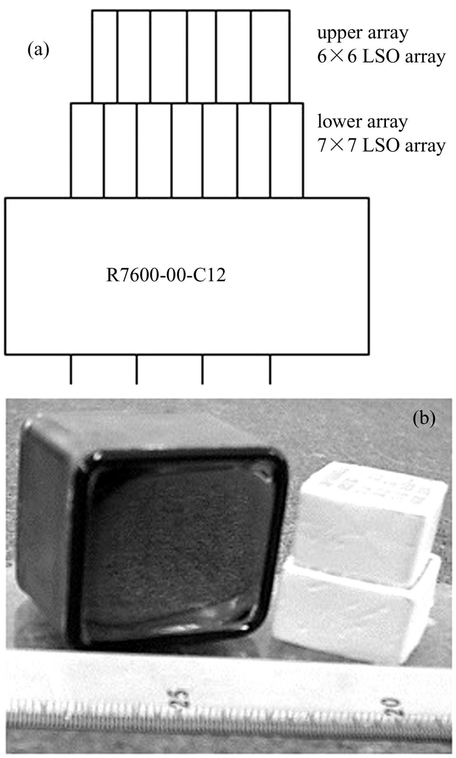

Fig. 1. Depth-encoding detector used in experiment (a) plan view; (b) photograph.

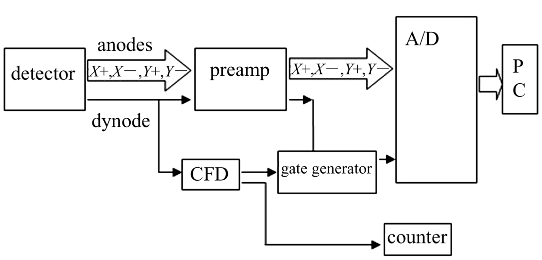

Fig. 2. Experimental set-up for position map measurement.

Fig. 3 shows position histograms measured with the DOI detectors using polished surface LSO segments (a) and roughened surface LSO segments (b), where the LSO blocks were uniformly irradiated by 511keV gamma rays from a ^{22}Na source. In each flood image, millions of events are accumulated. It is shown that the block detector using mirror-polished segments provides good crystal separation characteristics, while that using roughened surface segments shows blurred images, especially in the peripheral region.

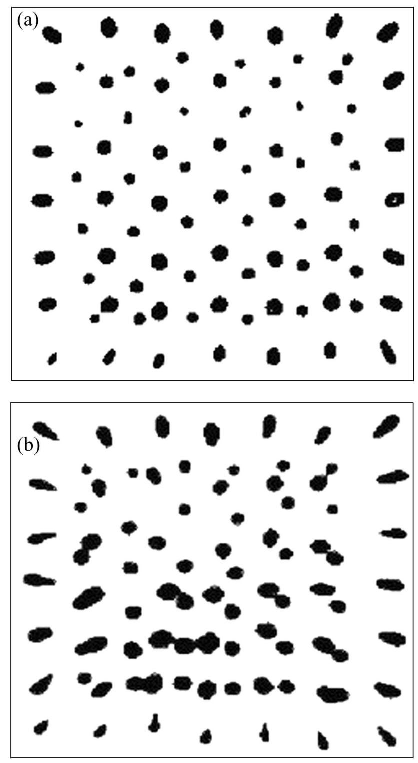

Fig. 3. 2D position map of the polished (a) and roughened (b) detector.

2.2 Energy resolution

After generating a position look-up-table (LUT), which defines regions corresponding to each crystal element on the 2D position histogram, the energy spectrum for each crystal was obtained by summing up four position signals in each region. For individual crystal's spectrum, the response peak maximum was assumed to be 511keV and the energy discrimination was set to be the desired fraction of the 511keV channel. The energy resolution values for 511keV gamma-ray differ from segment to segment. For the detector with polished surface, the energy resolution values for the lower elements vary from 15.2% to 23.5% (average: 19.6%). The upper elements vary from 21.4% to 27.3% (average: 23.7%). While for the detector with roughened surface, the energy resolution values for the lower elements vary from 18.1% to 28.7% (average: 24.6%). The upper elements vary from 24.2% to 32.3% (average: 27.1%).

2.3 Coincidence time resolution

The coincidence time resolution was measured between two detector modules using the fast-slow coincidence technique, as shown in Fig. 4. The BaF2 is a fast detector which provides a very good timing reference due to its fast decay time (0.8ns) compared to LSO (40ns). Thus the time resolution of the system is dominated by the LSO detector. The dynode signals from each detector was amplified and sent into the constant fraction discriminators (CFDs). The CFDs output signals were supplied to the start and stop inputs of the time-to-amplitude converter (TAC) device. The distribution of time intervals was recorded by the MCA. A highly collimated gamma-ray source was used in order to irradiate the upper and lower array, separately. Only these events satisfying the energy window 350—650keV were accepted in the timing spectrum.

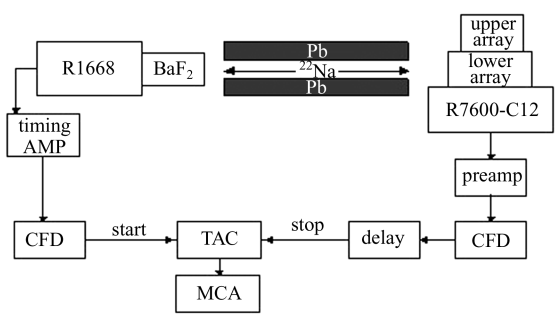

Fig. 4. Experimental setup for time resolution measurement.

The time resolution of the polished detector for the upper array is 0.97ns in FWHM and 1.93ns in FWTM, and 3.5ns in FWHM and 6.1ns in FWTM for the roughened one. For lower array the time resolution becomes 0.82ns in FWHM and 1.6ns in FWTM (polished), and 1.14ns in FWHM and 2.24ns in FWTM (roughened) respectively. These results are presented in Fig. 5. It is shown that the block detector using mirror-polished segments provides good time resolution, while that using roughened surface segments shows poorer time resolution, especially for the upper array.

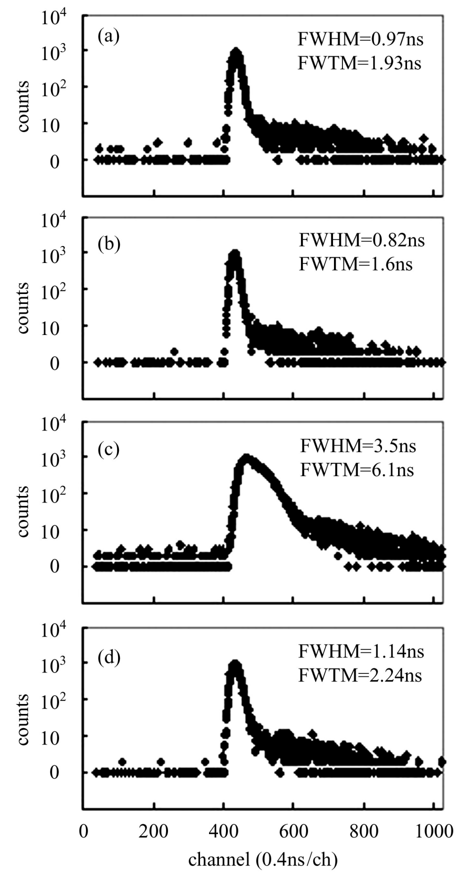

Fig. 5. Timing spectra for the upper array (a) and lower array (b) of polished LSO detector. Timing spectra for the upper (c) and lower (d) side measured from roughened LSO detector.

2.4 Spatial resolution

We measured the detector response function (DRF) to evaluate the spatial resolution of the detector. The experimental set-up is the same one as shown in Fig. 2, where the collimated gamma ray source through 0.5mm slit is scanned in steps of 0.5mm in front of each detector. The measured DRF profiles for the lower segments of the block are shown in Fig. 6. The FWHM values with the polished detector vary from 1.4mm to 1.9mm, and those with the roughened detector vary from 1.5mm to 2.1mm.

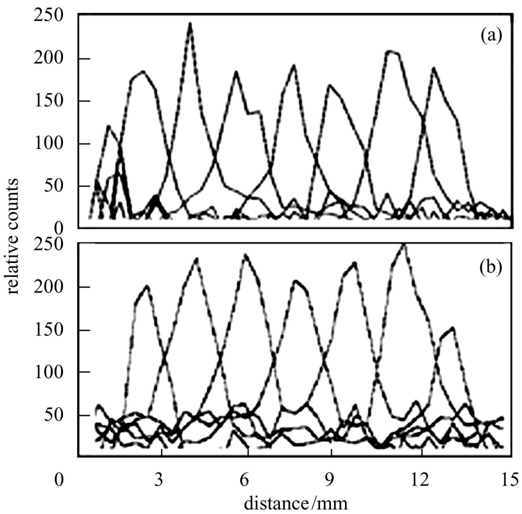

Fig. 6. DRF Profiles of the sixth row elements in lower array for the polished detector module (a) and the roughened detector module (b).

3 Conclusions

A compact DOI detector consisting of a double-layer LSO array and a compact PS-PMT are under development. The performance of the new DOI detector was evaluated by optimizing the crystal surface treatment. We observed a significant improvement in crystal identification, energy resolution, time resolution and detector response resolution for constructing detectors using polished crystals compared to those using roughened LSO crystals.

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双层深度编码探测器的晶体表面优化*

田毅　刘华锋[1)]

(浙江大学现代光学仪器国家重点实验室　杭州　310027)

摘要　设计了双层LSO晶体和位置灵敏型光电倍增管耦合构成的用于小动物PET成像的深度编码探测器. 众所周知, 晶体的不同的表面处理影响着光输出量, 进而影响着它们构建的PET探测器的性能. 为了优化设计的深度编码探测器的性能, 测试了两种不同表面处理的LSO闪烁晶体阵列探测器的晶体分辨能力及其能量、时间和空间分辨率, 结果表明, 光滑表面LSO晶体构建的深度编码探测器显示出良好的空间、能量及时间分辨特性.

关键词　LSO晶体　探测器　正电子发射断层成像系统

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1) E-mail: liuhf@zju.edu.cn