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Design of a γ-Ray Imaging System for Plant Studies*

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Abstract To take advantages of positron emission tomography (PET) in studies of physiological functions of plants, a γ-ray imaging system composed of two block detectors facing each other is under developing. The block detector consists of 10 × 10 lutetium oxyorthosilicate (LSO) crystals and a position sensitive photomultiplier tube (PSPMT), Hamamatsu R5900-C12, where the element size of the LSO is 1.8mm × 1.8mm × 10mm. The performance of LSO detector was evaluated in terms of applicability to PET. All the detector elements are clearly visualized in the position map. Energy resolution ranges from 14.5 % to 22 % *FWHM* at 511keV. Coincidence timing resolution is improved as the supply voltage of the PSPMT is increased. These measurements indicate that the LSO detector is applicable for high resolution dual block detector imaging system.

Key words lutetium oxyorthosilicate, position sensitive photomultiplier tube, imaging system

1 Introduction

Autoradiography is a useful tool for studying uptake and transportation of nutrients in plants. However this technique is limited by providing only static image of the result of tracer movement.

Positron Emission Tomography (PET) uses the idea of injecting chemical compounds labeled with positron-emitting isotopes into a body to measure their spatial and temporal distribution externally. PET has demonstrated its ability as a very promising tool for basic and clinical research in the last 30 years. Recently, the application of PET technique to study physiological functions of plants has increased. Researchers are especially interested in visualizing the dynamics of organic metabolites in plants[1—4].

Two planar gamma ray detectors operating in coincidence is a simple method to obtain functional PET imaging from plants. One approach has utilized two block detectors which composed of bismuth germanate (BGO) scintillator array coupled to a position sensitive photomultiplier tube (PSPMT; Hamamatsu R3941-2)[5]. However, the spatial resolution and timing resolution is limited by light output emitted from BGO and capability of the R3941-2. With the recent advent of commercially produced new scintillators and PSPMTs, it has become possible to construct simple detectors with a good resolution. Our dedicated system design consists of two planar lutetium-oxy-orthosilicate (LSO) detector arrays facing each other. The system is better than other dedicated designs in spatial and timing resolution. This paper reports on the evaluation of LSO block detector and concept design of a γ-ray imaging system for plant analysis applications.

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2 Experimental results and discussions

2.1 Detector design and performance

We constructed a detector block consisting of a 10 × 10 scintillator array, which is composed of LSO sample with aperture$(1.8 \times 1.8)mm^2$ and a length of 10mm. The arrangement of LSO detector is shown in Fig.1. Each element which all surfaces are polished, is optically isolated by a 0.2mm thick polytetra-fluoro-ethylene(PTFE) tape.

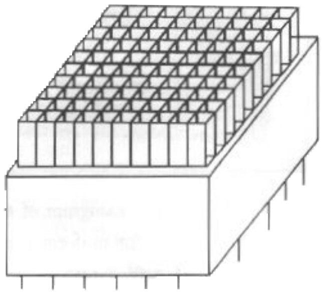

Fig.1. Arrangement of a LSO detector.

In our design, the Hamamatsu Tube PSPMT(R5900-C12) has been used, which has a 27.7mm squire X 20mm high and the effective area is $(22 \times 22)mm^2$. The emitted photoelectrons from the photocathode are multiplied by the channel dynodes while retaining the position information, and then the multiplied electrons are read out by crossed multi-plate anodes. The R5900-C12 has a Bi-alkali photocathode 10-stage of channel dynodes and 1-stage of reflecting plate dynode and $6X + 6Y$ crossed anode plates located between the 10th dynode and the reflecting plane dynode.

Four output signals are collected through two external resistive chains connecting X and Y wires respectively. The position originating the light photons is calculated by applying a center-of-gravity detection using cross wire anodes method. From the four signals $X_1 X_2 Y_1 Y_2$, the position ψ, ζ in the X and Y direction can be obtained as follows:

$$\psi = X_2/(X_1 + X_2), \quad \zeta = Y_2/(Y_1 + Y_2).$$

2.1.1 Flood source measurements

Fig.2 shows the measurement apparatus for the flood source measurements. The last dynodes and four X-Y position signals from PSPMT are respectively amplified through the preamplifier. Then four position signals are fed into a CAMAC analogue-to-digital converter(ADC). The output of the last dynode from the preamp is introduced to a constant fraction discriminator(CFD) with a threshold to select the photoelectric absorption events. The CFD unit offers an output signal as the gate of ADC modules. A personal computer(PC) acquires the digitized data from CAMAC ADC.

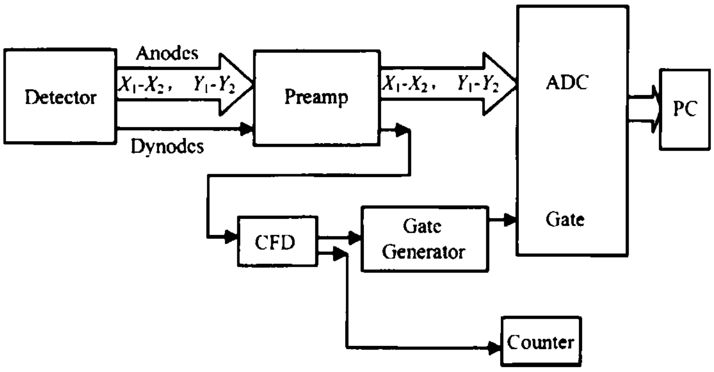

Fig.2. Experimental setup for flood source measurements.

The LSO detector was uniformly irradiated by 511keV gamma rays from a ^{22}Na source, and the data was collected in the computer until reaching millions of events. The γ-ray hit positions of ψ and ζ are calculated event by event. The position map of the detector is shown in the Fig. 3, which proves that the block detector provides good crystal separation characteristics.

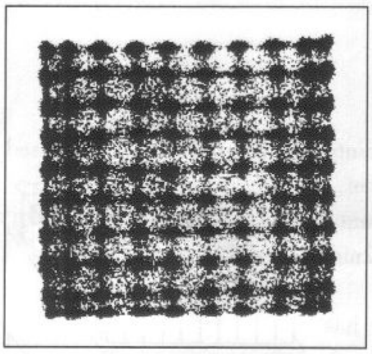

Fig. 3. 2D position histogram of the LSO detector measured for uniform irradiation 511 keV γ-rays.

2.1.2 Energy resolution

The ψ and ζ value of a position signal event are first computed, then a crystal identification method is to define the regions that correspond to each crystal on the two-dimensional flood field histogram. After generating the position look-up-table (LUT) map, the energy spectrum for each crystal is obtained.

The energy resolution values for 511keV γ-ray differ from the segment to segment: The best energy resolution was 14.5 % (Fig. 4. (a)), while the worst was 22 % (Fig. 4. (b)).

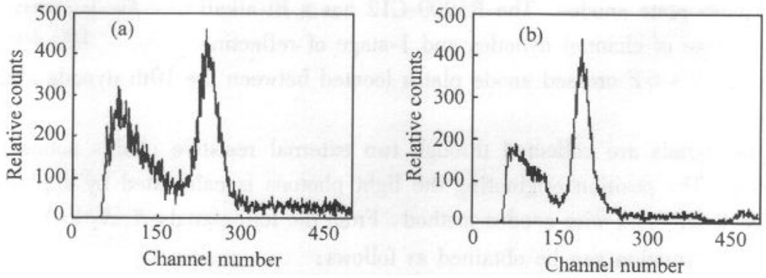

Fig. 4. Energy spectra for the LSO elements of the detector
(a) best energy spectrum; (b) worst energy spectrum.

2.1.3 Timing resolution

We coupled a single 1.8mm × 1.8mm × 10mm LSO crystal to the R5900-C12 PSPMT and measured the timing resolution, where a BaF_2 detector was used as a reference probe. A ^{22}Na point source encapsulated in a 25mm diameter, 3mm thick plastic disc with the activity in the central 1mm was placed in the center of two detectors. The measurements of timing resolution for using different high voltage bias to the R5900-C12 are presented in Table 1. The experimental results clearly show that the timing resolution of the LSO detector having smaller supply voltage decreases as expected.

Table 1. Timing resolution vs. supply voltage.

Supply Voltage/V	*FWHM*/ns	*FWTM*/ns	Supply Voltage/V	*FWHM*/ns	*FWTM*/ns
650	0.66	1.18	750	0.60	1.13
700	0.62	1.17	800	0.58	1.09

2.2 Concept design of a γ-ray imaging system

2.2.1 Description

We are proceeding to develop a γ-ray imaging system dedicated to plant studies, to which the LSO detector described above will be applied. The plant samples containing a positron emitter are placed at center between the two opposite detectors. Thus the pair of annihilation γ-rays flying off from plants can be detected using a coincidence technique, as shown in Fig. 5.

The detector will be mounted on a gantry, which is designed to provide positioning capabilities allowing flexibility and ease of use in subject positioning. Plants studies can be carried out while the detectors are rotated in a ring to collect the tomographic information.

2.2.2 Electronics and data acquisition

The whole system is shown schematically in Fig.6. The PSPMT outputs are digitized by 8-bit AD, which can therefore take values between 0 and 254. One of annihilation γ-rays interacts with a segment in the scintillator array of one side detector and thereby event localization can be determined by a process similar to Anger logic. Once the position values are known, the original position of annihilation can be extracted from the line connecting the center of the two detectors (sometimes referred to as a line-of-response (LOR)). Events which are recorded within the coincidence time window are the raw data from which the PET imaging are reconstructed.

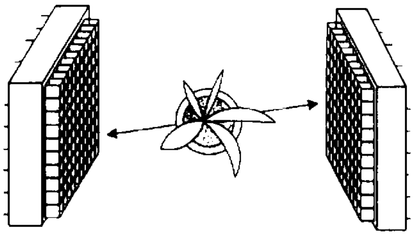

Fig.5. Block arrangement of the γ-ray imaging system for the plants studies.

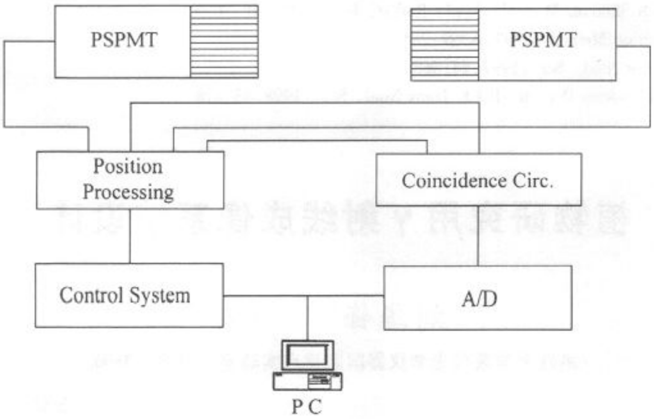

Fig.6. Block diagram of the whole system.

2.3 Discussion

We believe the imaging system will offer several advantages compared with existing dedicated PET system that use BGO.

The properties of BGO and LSO are summarized in Table 2[6–8]. The high density of the two materials will result in very high detection efficiency even for small crystals. They are not hygroscopic and, therefore do not need to be hermetically sealed as does NaI(Tl). It can be seen that the light output of LSO is three times higher than that of BGO. On the other hand, LSO appears very attractive due to its shorter decay time, while retaining high stopping power. Thus the LSO detector will provide better spatial, timing and energy resolution comparing to BGO detector in the same condition. Furthermore, the compact size of the system will mean that the tomograph will be relatively inexpensive and portable. The system also allows small animal studies to be performed, making additional use of expensive radiochemical syntheses.

Table 2. Comparison of BGO and LSO materials.

Physical properties	BGO	LSO	Physical properties	BGO	LSO
Density $\rho/(g/cm^3)$	7.13	7.35	Relative light yield	22	72
Index of refraction	2.15	1.82	Major decay constants/ns	60/300	40
Radiation length/cm	1.13	1.23	Peak wavelength of emission/nm	480	420

3 Conclusions

We are now constructing a dual block detector system, which is used to investigate the transport of positron emitting isotope introduced into a plant. Each detector block is a 10 × 10 array of LSO crystals which are 1.8mm × 1.8mm × 10mm in size and separated by 0.2mm. The intrinsic physical performance of the block with respect to crystal identification, energy resolution and timing resolution has been reported. This study demonstrates that the detectors employing LSO and R5900-C12 PSPMT can be used successfully in the new γ-ray imaging system.

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植物研究用γ射线成像系统设计*

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摘要 为了利用正电子发射断层成像技术在植物生理功能研究中的优势，正在开发由两个探测器相向放置构成的γ射线成像系统．系统中采用的探测器是由10×10的氧正硅酸镥(LSO)晶体阵列与滨松R5900-C12耦合组成．单个LSO尺寸为1.8mm×1.8mm×10mm．根据PET应用的特点，测试了该探测器的性能．所有闪烁晶体的图像在位置图谱中清楚可见；511keV全能峰处的能量分辨率位于14.5％—22％之间；符合时间分辨率随着位置灵敏光电倍增管的供给电压的增加而得到改善．这些实验结果表明，该LSO探测器适于构造高分辨率的双探测器成像系统．

关键词 氧正硅酸镥晶体 位置灵敏光电倍增管 成像系统

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