Studies of a 3D PET Detector with Wavelength Shifting Fibers

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***Abstract*– The depth of interaction (DOI) PET detector is one way to achieve high resolution image by determining the depth where most of gamma ray energy is deposited in a scintillator. Because a 2D or 3D profile is obtained for each element, the large amount of data makes the image reconstruction difficult. In this study, we propose a new type of DOI PET detector and estimate a photon yield of a channel and the cost of the materials for manufacturing. An element block of the detector consists of 16 slices of inorganic scintillators, one flat panel PMT, wave length shifting fibers and 256 ch position sensitive (PS) PMT per six element blocks. The main principals of this detector are the condition of total reflection and wave length shifter material. We can see the position where photoelectric effect occurred using the scintillation light not satisfying the condition of total reflection. The photons from the position are transmitted to a channel of PS PMT by wave length shifting fibers. With this detector it is expected to achieve ±1.3 mm resolution for x direction, ±1.5 mm resolution for y and z direction. Ideally we can get the information of the position out of a 50×50×24 mm^3 element from only 40 bits signal. Unfortunately we could not perform experimented evaluation owing to delay of delivery of the GSO slices from a company.**

I. Introduction

A positron emission tomography (PET) detector contains thick scintillators in radial direction to increase sensitivity. However, a parallax error makes a degradation of the spatial resolution. Therefore the depth of interaction (DOI) PET detector is one way to achieve high resolution by determining the depth where most of gamma ray energy is deposited in the scintillator.

The DOI PET, however, has some issues itself. The large amount of data makes the image reconstruction difficult because a 2D or 3D profile is obtained for each element. In the PET elements, a square bar-like or a small cubic scintillator is usually used in order to achieve good resolutions in position [1]. However making these shapes raises the cost for cutting and polishing of many pieces scintillator.

In this study we propose a new type of a DOI-PET detector with sliced GSO crystals and wave length shifting fibers aiming simple data and an easier image reconstruction with low cost.

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II. Materials and Construction of An Element

An element block of the detector consists of 16 pieces of inorganic scintillator, one flat panel PMT, wave length shifting fibers and 256 ch position sensitive (PS) PMT per six element blocks. A flat panel PMT is used as a detector to measure the deposit energy, wavelength shifting fibers as a light readout and PS-PMT as only multi-channel detector for much positional information.

1. Scintillator

Scintillator is the size of 2.6 mm (x) × 48 mm (y) × 24 mm (z) and made of Gd2SiO5:Ce (GSO, Hitachi Chemical) inorganic crystal has more sensitivity to gamma ray than an organic scintillator. The GSO crystal has 13.8 mm radiation length and 430 nm peak emission. On average 12500 photons emitted per 1 MeV by the scintillator [5].

2. Wave Length Shifting Fiber (WLSF)

A wavelength shifter (WLS) is a fluorescent material that absorbs shorter wavelength light and re-emits longer wavelength light. Being made as a shape of fiber, the wavelength shifting fiber (WLSF) absorbs photons from its side and transmits the photons to its both ends.

We choose Y-11, blue to green shifting fiber, KURARAY Co., while Y-11 has a good agreement in emission range of the wavelength from the GSO scintillator [2]. Moreover, the Y-11 has attenuation length over 3.5 m, long enough to connect to signal [3], and the multi-clad structure that can trap and deliver more photons (trapping eff. = 5.4 %). 0.2 mm ϕ fiber will be used to enlarge the scintillation volume as we will mention it later.

3. The construction of an element

The schematic of this new type DOI-PET is shown in Figure 1. As we stated it before, Scintillator has the size of 2.6 mm (x) × 48 mm (y) × 24 mm (z). 120 and 240 wave length shifting fibers (0.2 mm ϕ) are attached to each wide side of the scintillator (48 mm × 24 mm) and 13 fibers to the narrow side (2.6 mm × 48 mm). By putting 16 structures of scintillator slice with fibers side by side across the shielding sheet, we can get 48 mm × (x) 48 mm (y) effective area for the incident particle in the direction of the z axis. The structures are connected to a single anode flat panel PMT (50 mm × 50 mm). 15 fibers attached on wide side of a scintillator are bunched together with fibers attached on other scintillator plates and make 16 (240/15) and 8 (120/15) fiber bunches in direction of y and z, as shown with the purple line in Figure 1. Additionally, 13 fibers attached on narrow side are bunched together and make 6 bunches.

4. Signal collection

Scintillation lights whose angle is smaller than total reflection angle pass through the boundary while some of them are absorbed in the wave length shifting fiber. These scintillation lights pass into flat panel PMT and WLSFs. In order to measure the energy of an incident gamma ray and make a trigger, scintillators are connected to a single anode flat panel PMT. On the both wide sides of the scintillator slice the lights are absorbed fibers near and lights can be observed from only several tens of fiber ends [Figure 2]. Therefore, by connecting the PS-PMT with brunches (16+16+8), the position where gamma ray deposits its most energy can be measured.

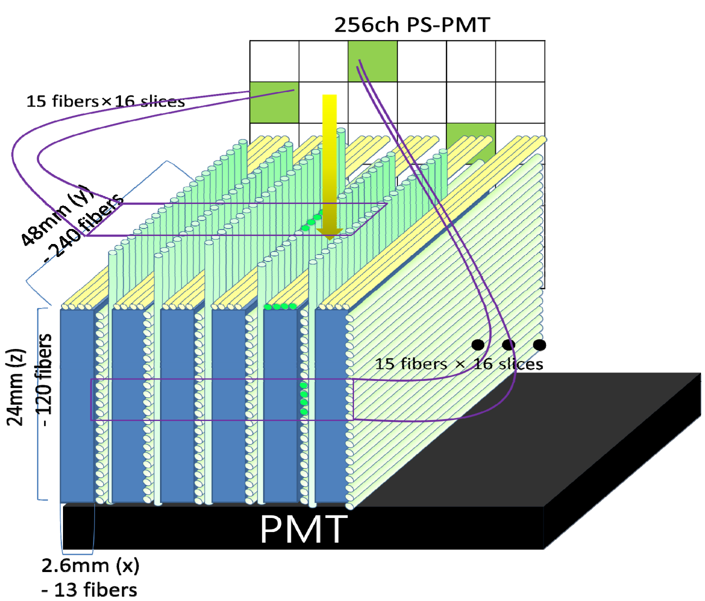

Figure 1. An element of the detector

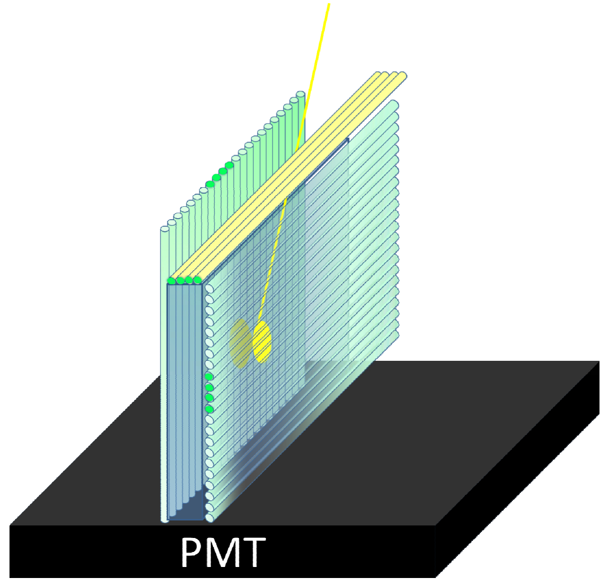

Figure 2. The region scintillation lights can go out

III. Estimations of the Photon Yield and the Cost

We made a rough estimate of some characteristics of this new type DOI PET. The photon yield is the first point we concerned about while using the WLSF. The cost for materials is the next point we focused on.

1. Estimation of Photon Yield

In case of PET, incident gamma ray has 0.511 MeV and it makes over 5000 photons when the gamma ray deposits most energy in a point of the scintillator slice (see photon yield per MeV in section II. 1).

Lights not satisfying the condition of total reflection between the scintillator and the air cannot pass out from scintillator surface, therefore, approximately 5/6 of photons are not available.

About a half of photons are absorbed and re-emitted in WLSF. Only 5 % of them satisfy the condition of total reflection and are transmitted to each end of a fiber.

The quantum efficiency of the PS PMT in the range of wavelength of emission light is about 1/5.

Now calculating above we expect to get 4 or more photons. From the yield of 4 photons, the detection efficiency of a bunch is 98 % (~ $1-e^{-4}$) and the detection efficiency of 3D position is 94% (~ $(1-e^{-4})^3$).

2. Cost Estimation

Another aim of this proposal is to reduce the cost for producing the detector. Now we estimate the cost of materials for the manufacture of this system.

Table 1 shows the price of each material and the price for an element block. It was derived from what we bought and used. A slice shape crystal is cheaper than a small cubic shape crystal (in the same volume) or a square bar-like crystal because it requires fewer tasks for cutting and polishing their sides. The reason why we chose 256ch PS-PMT is it needs least cost per channel. If there were less cost material such as 1 × 256 array PMT, we would choose that one.

From this table we can estimate the cost of materials for an element block to 1,000$ or for this DOI-PET to 100,000$ +α

Material	Price	Price for an element block
GSO slice	30$	500$
Flat Panel PMT	200$	200$
256ch PS-PMT	480$	80$
WLSF	300$/13km	100$
Other electrics	100$	100$

Table 1. Prices of each material.

IV. CONCLUSION

We proposed the concept of a new type DOI-PET detector. The position resolution of this detector will be ±1.3 mm (x) and ±1.5 mm (y and z). We estimated it is not important to get more resolution from an event. But if needed, it can be improved by bunching fewer fibers on a scintillator slice together (in this case more channel should be needed). Only 41(16+16+8+1) signals from an element block are read out for the energy information in order to set the trigger level and 40 are for the position information. Ideally the 40 position information can be read as binary information. Therefore, the position is easily calculated with the binary information without a complex data analysis. In this paper we proposed 16 × 16ch PS-PMT but there is no need of 16 × 16, only need of many channel per cost.

Owing to delay of delivery of the GSO slices from the company and not to equip scintillator polished 2 or more side, we could not perform experimented evaluation. There seems no commercial product of single anode flat panel PMT just right size therefore we are searching a company could make it for this project. The experiment and results will be reported in the next research.

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