Consideration on Various Conditions of Two-Dimensional Crystal Arrays for the Next Generation PET Detector

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ABSTRACT

As a part of the next generation PET project, we have developed a depth of interaction detector which is consist of three-dimensional arrays of GSO crystal elements sized 2.9mm x 2.9mm x 7.5mm. The basic structure of a detector block is 4-stages in depth, one stage is composed of 2 by 2 array of the crystal elements. The blocks are optically coupled to a position sensitive photomultiplier tube. Each crystal element can be in different conditions; rough or chemical etching for the crystal surface. The effect of the difference of crystal surface condition on the detector performance was analyzed in one-dimensional crystal array as a basic study for the three-dimensional detector by a simple model which is considered only probabilities of transmission, reflect and absorption of photons are in a crystal. As the next step, we investigated the effect of different crystal surface condition in a "U shaped detector" which is an array of stacked crystals bending at the center.

Keywords: Positron Emission Tomography (PET), depth of interaction, position sensitive detector, nuclear medicine.

1. INTRODUCTION

We have developed a depth of interaction (DOI) detector, which can provide the information of a detected point in depth. It may reduce the parallax error and achieve high sensitivity and high resolution[1]. To develop DOI detector consisting of scintillation crystal elements, it is important to know the behavior of photons in a crystal block. The output signals from the block actually are dependent on the conditions of each crystal element and materials between the elements. Therefore we have possibilities to control the behavior of photons in a crystal block. We had developed a simple model for the transition of photons between crystal elements before, which model was based on one-dimensional array of crystal elements[2]. In this time, we have improved the model and extended it to two-dimensional case. And we compared the model with experimental results of "U shaped detector".

2. MATERIALS AND METHODS

2.1 U Shaped Detector

Fig.1 shows the "U shaped detector" which is an array of stacked crystals bending at the center. GSO (Gd_2SiO_5: Ce: 0.5mol%) in dimensions of 2.9x2.9x7.5 mm^3 was used as a scintillation crystal element. The material between each stages and between PMT and crystals of first stage is silicone oil, whose refractive index is n=1.45. The material between crystals of fourth stage is air. Another faces of crystals are covered with reflectors. The reflector is a multilayer polymer mirror whose thickness is 0.065mm and reflective index is 98%. We consider rough and chemical etching for the crystal surface in this setup.

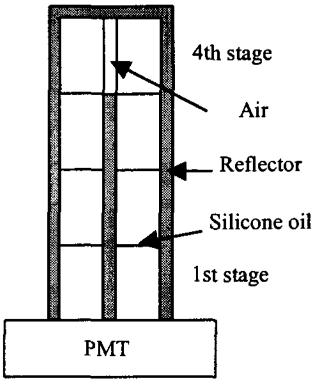


Fig.1 U shaped detector

2.2 The Simple Model on One-Dimensional Crystal Array

Suppose that side faces of a crystal are covered with reflectors so that photons can go out of only the top and bottom faces as shown in Fig.2. Here we consider two parameters: One is a transmittance 'a' and the other is an unabsorption rate 'b'. We can express two amounts of light which goes out of the top and bottom faces of the crystal as a x b and (1-a) x b, respectively, where the amount of incoming light is 1. These two parameters were decided by the following way. At first we define light output 'q1' in Fig.3 (a) when gamma rays are irradiated to the crystal, where the top face of the crystal is covered with a black tape and side faces are covered with reflectors. Here we assume that a black tape absorbs light completely.

Similarly, we define light output 'q2' and 'q3' (Fig.3 (b), (c)) when gamma rays are irradiated to lower and upper crystals, respectively. q1, q2 and q3 are expected to satisfy the following expressions,

$$q2 = q1 + q1 \cdot a \cdot b \cdot (1-a) \cdot b + q1 \cdot a \cdot b \cdot (1-a)^3 \cdot b^3 + \cdots = q1 + q1 \cdot a \cdot b \cdot \sum \left[(1-a) \cdot b\right]^{2i-1}$$

$$q3 = q1 \cdot a \cdot b \cdot (1-a)^2 \cdot b^2 + q1 \cdot a \cdot b \cdot (1-a)^4 \cdot b^4 + \cdots = q1 \cdot a \cdot b \cdot \sum \left[(1-a) \cdot b\right]^{2i}$$

Thus we can calculate the parameters 'a' and 'b'. In order to verify this model, we did the experiment of 8 stage linear array and measured light output when each crystal is irradiated. “U shaped detector” is a variant of this 8 stage linear array.

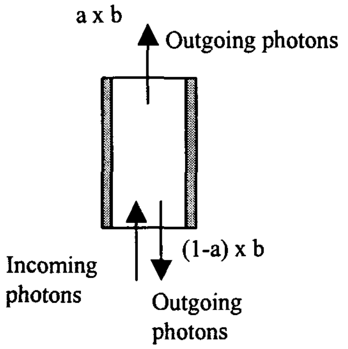
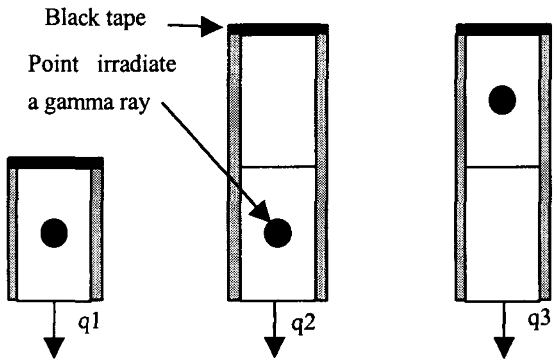


Fig.2 Model of light output from on crystal element.



(a) Case of a single crystal.

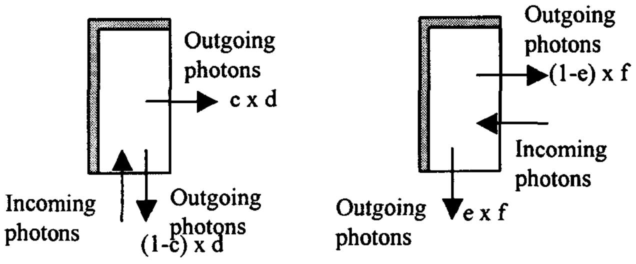
(b) Case of the botto crystal emits light.

(c) Case of the to crystal emits light.

Fig.3 Factors for the one-dimensional model

2.3 The Simple Model on Two-Dimensional Crystal Array

To extend the simple model to the “U shaped detector”, we need consideration to fourth stage as shown in Fig.4. The top face and three side faces of this crystal are covered with reflectors and one side face is open. Fig.4 (a) and (b) show the cases that photons are incoming from the bottom face and the open side face, respectively. We decide four parameters in both cases, 'c' and 'e' for transmittances and 'd' and 'f' for unabsorption rates, in similar way to the one-dimensional model.



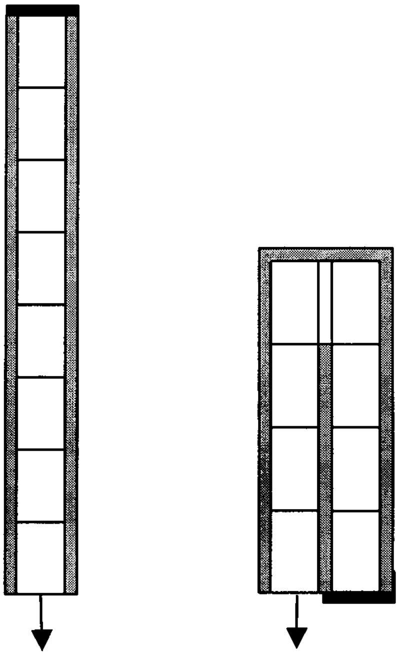
(a) Case that photons ar incoming from the bottom face.

(b) Case that photon are incoming from the one ope side face.

Fig.4 The model corresponding to fourth stage of “U shape detector”

3 EXPERIMENTS AND RESULTS

Irradiating a ^{137}Cs gamma ray collimated 1mm in diameter with a lead collimator to the middle of each crystal element, the pulse height spectra were recorded with Multi-Channel Analyzer. We measured full energy pulse height of the signals from one end of the array. The other end is covered with a black tape. Table.1 shows parameters that we calculated by applying the model to the experimental results in both cases of rough and chemical etching for the crystal surfaces. Fig.5 shows the setup of detectors and the crystal numbers mentioned in Fig.6 where the comparison of the model calculations with experimental results is shown.

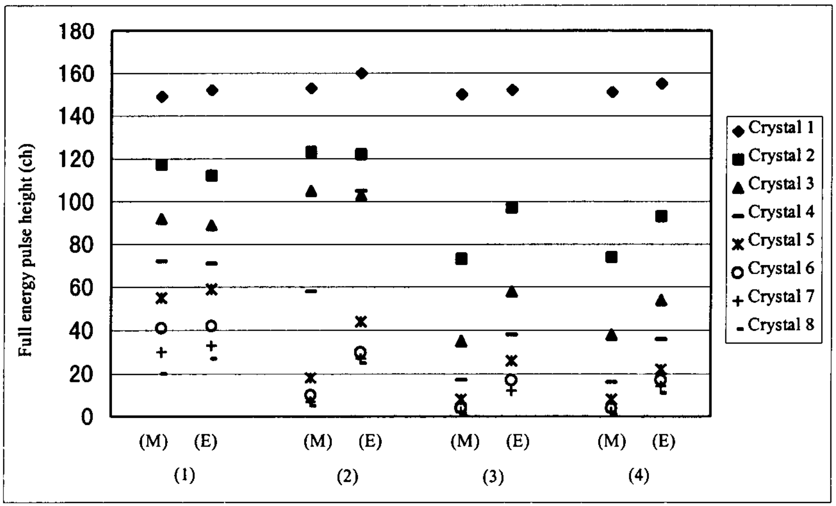


(a) 8 stage linear detector (b) U shaped detector

Fig.5 Crystal number

Table.1 Parameters of the transmittances and the unabsorption rates

	a	b	c	d	e	f
Rough	0.59	0.73	0.47	0.76	0.40	0.91
Chemical etching	0.81	0.91	0.39	0.94	0.51	0.66



(1) 8 stages linear detector, chemical etching
(2) U shaped detector, chemical etching
(M) Model calculations

(3) 8 stages linear detector, rough
(4) U shaped detector, rough
(E) Experimental results

Fig.6 Result of simple model and Full energy pulse height.

4 DISCUSSION AND CONCLUSION

As shown in table.1 the absorption rate for rough etching is lower than for chemical etching, and the transmittance for chemical etching is higher than for rough etching in the case of the model of one-dimensional crystal array. Fig.6 shows the comparison of the model with experiments. The vertical axis shows full energy pulse height. Each marker corresponds to a crystal number which crystal was irradiated. As shown in Fig.6 (1) we can see good agreement between the model and experiments. However in the case of "U shaped detector" (Fig.6 (2)), output signals of crystal 3 and 4 are equivalent, but the model did not agree. Additionally, predictions from the model for crystal 5 to 8 are lower than experimental results. We think these differences would be caused by a wrong setup of the black tape. For the cases of rough etching (Fig.6 (3), (4)), the model predicts lower signals than experimental results except for the case of crystal 1.

5 REFERENCES

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