Scintillator Array Sensor for Position Measurements of Radioactive Sources

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1. Introduction

As an increment of radioactive waste generation due to nuclear utilization in various industries, the importance of its management is getting higher in recent years [1]. In the radioactive waste management, the identification of radioactive nuclides and the measurement of radioactivity distributions should be carried out before the disposal process. Especially, finding hot spots is important because most of the radioactive sources are concentrated in these points [2]. At this procedure, the nondestructive assay based on a gamma detector is generally used. HPGe detector is mainly used as the gamma detector, but it is hard to use in various environments because of disadvantages such as high cost, large volume and cooling requirement.

The goal of this study is the development of a scintillation detector system for nondestructive assay. In this paper, we fabricated a scintillator array sensor and conducted the position measurements of the radioactive source as preliminary research.

2. Materials and Methods

GAGG:Ce	
Density (g/cm^3)	6.63
Light Yield (photon/MeV)	46,000
Decay Time (ns)	88
Peak Wavelength (nm)	520
Energy Resolution	4.9% @ 662 keV
Hygroscopicity	No
Self-Radiation	No

Table. 1. The properties of GAGG:Ce scintillator.

The properties of GAGG:Ce inorganic scintillator are listed in Table 1. We chose GAGG:Ce as the scintillator of the array sensor because of its high density, high light yield, short decay time, and the absence of hygroscopicity and intrinsic radioactivity [3]. Due to these features, it is expected that the scintillator can generate enough light for measurement with small dimension and be stable with low noise in various measurement environments. The dimension of a single GAGG:Ce crystal (Epic Crystal) is 4 x 4 x 20 mm^3.

Fig. 1 shows the schematic model of the scintillator array sensor. 20 GAGG:Ce crystals are arranged in parallel and covered with 1 mm thick $BaSO_4$ reflector to optimize scintillation light collection and prevent optical crosstalk between scintillators. Each crystal is directly connected with 1 mm diameter plastic optical fiber (GH-4001-P, Mitsubishi Rayon) to transmit scintillation light to the detector.

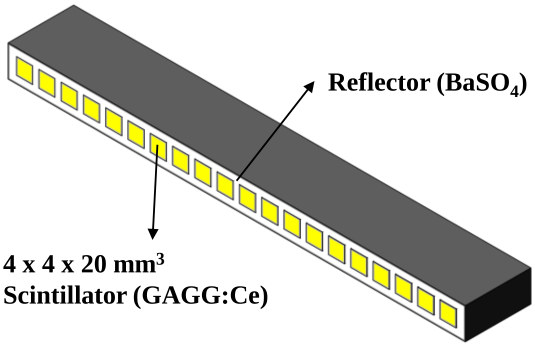

Fig. 1. The schematic model of the GAGG:Ce inorganic scintillator array sensor.

Fig. 2 shows the schematic diagram of the experimental setup for measuring the radioactive source position. Two scintillator array sensors are combined as an L-shape and affixed to the driving part of an electric linear actuator (LEFS25RA-300, SMC). The length of the scintillator array sensor is 100 mm and the length of the actuator driving part is 300 mm, so the dimension of measurement region is 100 x 100 x 300 mm^3.

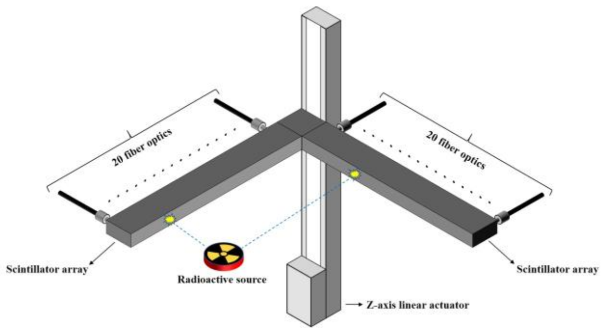

Fig. 2. The schematic diagram of the experimental setup.

The experiment was conducted by moving the sensors. The radioactive source was fixed at random position in the measurement region.

First, one of 40 channels which seem to be on the same line with the source was used. From 0 to 300 mm, the sensor was moved in a 1 mm step. Through this process, the height distribution according to Z-direction of the source was measured. Second, the sensor was placed at the same plane with the sensor array and the 2-dimensional source distribution was measured with a 40-channel scintillator array sensor. These data were processed to obtain the source position within the measurement area. As a light measuring device, a compact photon counting head (H11890-210, Hamamatsu) was employed to convert scintillation light signals to the number of generated photons. The radioactive source used in this experiment was ^{60}Co disc-type check source with 43.21 μCi.

3. Results and Discussion

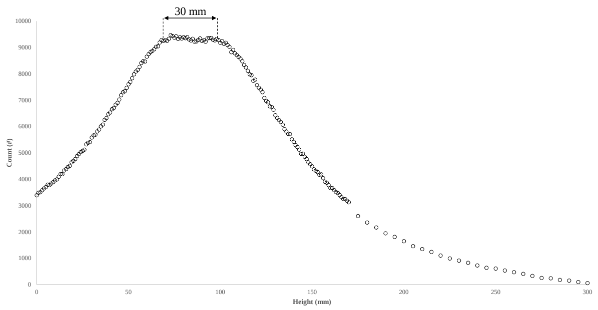

Fig. 3. The single channel light output variation according to the Z-direction of the source.

Fig. 3 shows the measurement of light output variation with a single channel in the array sensor according to the Z-direction of the source. The length of the plateau in Fig. 3 is about 30 mm which means the disc source is located at the height between 70 and 100 mm. Considering that the diameter of the source disc is 25.4 mm and the active element is enclosed in the middle of the disc, the hot spot of the source is estimated to be located between 82.7 and 87.3 mm.

When assuming that there is no information about the source dimension, the 30 mm gap seems too big for a small hot spot. However, the plot of Fig. 3 shows very symmetrical and exponential trend. Considering that, it is reasonable to say that the hot spot is in the middle (85 mm) of the plateau.

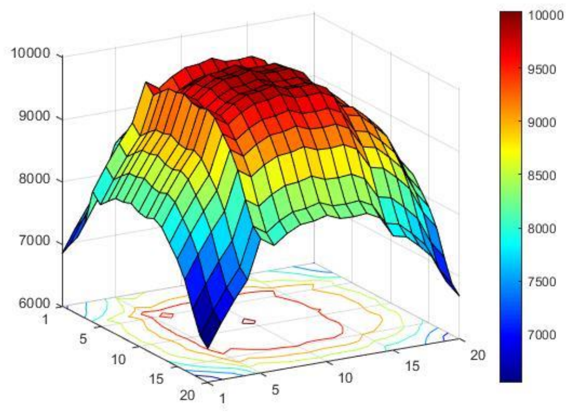

Fig. 4. The light output distribution over the measurement area.

Fig. 4 shows the light output distribution over the measurement area of 100 x 100 mm^2. The dark red area in the middle of the contour plot is the highest count area, where the source is estimated to be located [4, 5]. Considering each channel of the sensors as a 2-D coordinate, the source position in Fig. 4 could be expressed with a channel number as (10, 10).

To narrow the plateau length in Fig. 3, the single channel experiment was conducted using 2 mm thick lead plates with a 2 mm pinhole. The comparison of the plateau length in two experiments is shown in Fig. 5. The length decreased from 30 mm to 18 mm. Although the theoretical calculation was only 13% decrease at ^{60}Co energy range [6], it shows that even the simple lead collimator can improve the spatial resolution.

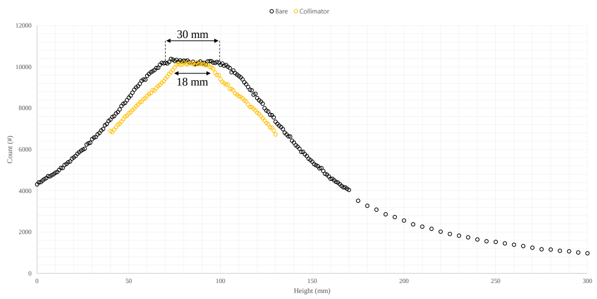

Fig. 5. The comparison of the plateau length in two experiements.

4. Conclusion

In this paper, we fabricated the scintillator array sensor and conducted the position measuring experiment of the radioactive source. GAGG:Ce was selected as the inorganic scintillator because of its fine properties.

With 43.21 μCi ^{60}Co source, the symmetrical and exponential plot was acquired in the Z-direction single channel measurements. In the 2-D measurements, the source position was acquired as channel number coordinate. Also, the spatial resolution improvement was shown when the lead collimator was used.

Further studies will be carried out to measure the 3-D position of the radioactive source and identify the nuclides with the scintillation detector system which has a multi-channel analyzer (MCA). Also, for improving the resolution, the optimization process will be conducted for the collimator in the scintillator array sensor.

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