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Measurement of Gamma-ray Energy Spectrum According to Temperature Variation Using a Fiber-Optic Radiation Sensor Based on YSO:Ce Crystal

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1. Introduction

Pyro-processing is the technique to recycle nuclear wastes and reuse them as a nuclear fuel. For the pyro-processing, a radionuclide analysis in high-temperature conditions up to 400℃ is very important. Thus, an appropriate monitoring system is required to control the nuclear wastes and endure in the high-temperature environments. However, the existing radiation detectors cannot endure and operate in the harsh environments.

As an alternative to conventional radiation detectors, various fiber-optic radiation sensors (FORSs) have been investigated for gamma-ray monitoring because of their various desirable advantages, such as their small sensing volume, substantial flexibility, remote operation, ability to make real-time measurement, and immunity to high electromagnetic interference [1]. In general, the basic principle of a radiation detection using scintillators is to measure the scintillating light signals generated from the interactions between the scintillators and the radiations. To measure gamma-ray, the inorganic scintillators used in the FORS should have some properties, such as high atomic material, high light yields, fast decay time, high density, and high stopping power. For these reasons, a cerium-doped lutetium yttrium orthosilicate (LYSO:Ce) crystal has been introduced as a promising scintillator in various radiation sensor applications. According to the recent studies, however, LYSO:Ce crystal is impossible to be applied in high-temperature conditions because it serves the fluctuations of its light yields with the temperature variation (*i.e.*, thermosluminescence) [2,3].

In this study, to obtain gamma-ray energy spectra by measuring scintillating light signals emitted from the scintillators in high-temperature conditions, we first fabricated an FORS system using various inorganic scintillator crystals and then evaluated the light yields of each inorganic scintillator. As a promising scintillator for use in high-temperature conditions, a cerium-doped yttrium orthosilicate (YSO:Ce) crystal was selected and evaluated its thermal property according to the elevated temperature up to 300℃.

2. Methods and Results

2.1 Fabrication of a Sensing Probe

In this study, four kinds of inorganic scintillators are employed in a sensing probe of the FORS and those scintillators have the same dimensions with a diameter of 3 mm and a length of 15 mm. The physical properties of four kinds of inorganic scintillators are listed in Table I. In order to collect scintillating light effectively, the outer surface of the inorganic scintillator were covered with a reflector tape based on Teflon (BC-642, Saint-Gobain Ceramic & Plastics).

Table I: The physical properties of inorganic scintillators

Inorganic scintillator	Light yields (Photons/MeV)	Peak emission wavelength (nm)
LYSO:Ce	25,000	420
BGO	> 8,000	420
YSO:Ce	10,000	480
YAP:Ce	15,000	370

For transmitting scintillating light signals to a light-measuring device, we fabricated an optical fiber bundle using twenty-one glass optical fibers (GOFs: SFS 600/660/710, Fiber-guide Industries) having a multi-mode and a step index profile. The GOF consists of a pure silica core with a refractive index of 1.457 and the fluorine-doped silica-based cladding with a refractive index of 1.439, thereby the numerical aperture (NA) is 0.22. Diameters are 600 ± 12 μm for the core only and 660 ± 13.2 μm including the cladding. The jacket with a diameter of 710 ± 15 μm is made of polyimide. The operating temperature range is from -190 to 350℃.

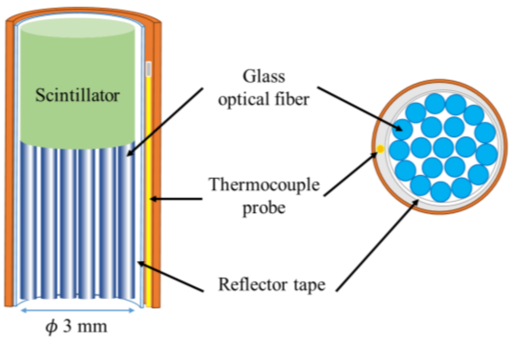

Fig. 1. The internal structure of the sensing probe.

Fig. 1 illustrates the internal structure of the sensing probe, which is composed a scintillator and a 30 cm long optical fiber bundle. To quickly and uniformly transmit the heat caused by a custom-built coil-heater system with a temperature controller (Taeyoung Electric Heater), the sensing probe was inserted in a brass pipe which has high thermal conductivity. Two K-type thermocouple probes (54II thermometer, Fluke) were also installed both inside and outside of the brass pipe to measure inner and outside temperature of the sensing probe because the temperature of the coil-heater itself and the inner temperature of the sensing probe are slightly different.

2.2 Experimental Setup

Fig. 2 shows the experimental setup to evaluate thermal properties of the inorganic scintillators in the FORS. The scintillating light signals generated from the sensing probe are transmitted to a PMT (H9305-03, Hamamatsu Photonics) through the optical fiber bundle under changing temperature. The PMT converts the scintillating light signals to the electrical signals. The output voltage signals generated from the PMT then are amplified by using a low-noise pre-amplifier (C7319, Hamamatsu Photonics) and shaping amplifier (ORTEC 572A, Advanced Measurement Technology) system. Finally, the inherent energy spectra of the gamma-rays emitted from the specific radioisotope are measured by using a multichannel analyzer (MCA: ORTEC 927 ASPEC MCA, Advanced Measurement Technology) in a bin system (ORTEC 4006 Minibin & Power Supply, Advanced Measurement Technology).

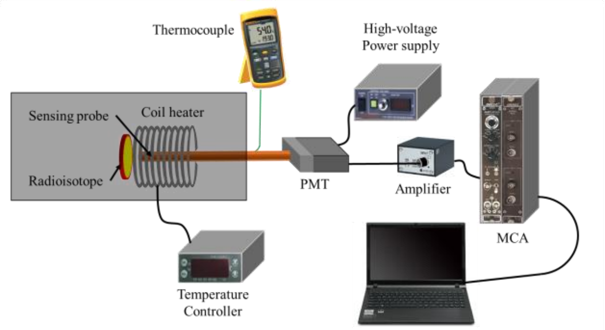

Fig. 2. Schematic diagram of the experimental setup.

In this study, a solid-disc type cobalt-60 (Co-60) radioactive isotope with an activity of 42 μCi was used as a gamma-ray emitter. Co-60 produces two distinct gammas, 1.173 and 1.332 MeV.

2.3 Results

Before the experimental study on thermal property of scintillator, we measured the gamma-ray energy spectra using the four kinds of inorganic scintillator crystals to select an adequate scintillator used in high-temperature condition. Fig. 3 shows the gamma-ray energy spectra for Co-60 at room temperature according to the species of the inorganic scintillators. Among four different scintillators, LYSO:Ce crystal has highest light intensity. In order of decreasing intensities, they are LYSO:Ce, YSO:Ce, BGO, and YAP:Ce. However, according to the recent study, it has been reported that LYSO:Ce crystal has easily affected by temperature variation. In the case of the YSO:Ce, it has also high light intensity not as much as that of LYSO:Ce and it can clearly appeared the two photopeaks of Co-60. Therefore, we selected YSO:Ce crystal to apply in high-temperature condition.

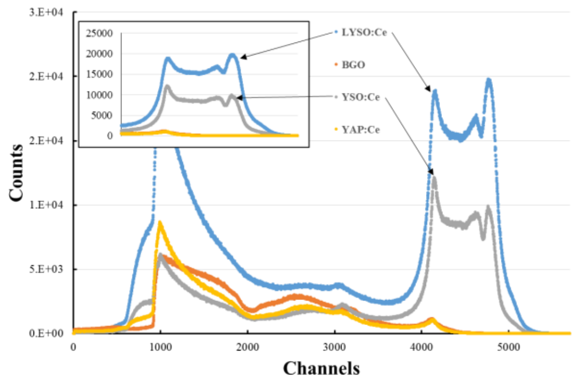

Fig. 3. The spectra of Co-60 measured by using four kinds of inorganic scintillators.

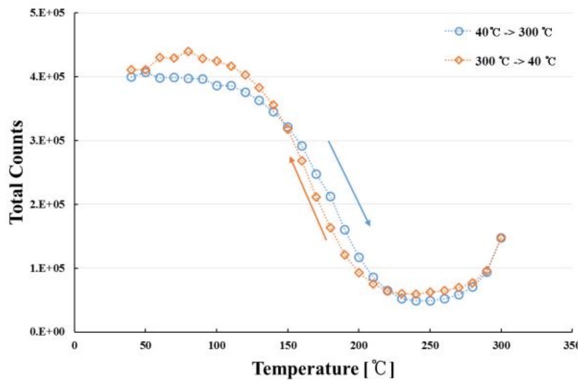

Fig. 4. The total counts of the scintillating light emitted from YSO:Ce according to the temperature variation.

Fig. 4 shows the total counts of the scintillating light generated in YSO:Ce according to the temperature variation from 40 to 300℃. As increase and decrease of the temperature, the total counts increase and decrease along a sigmoid curve. This result shows that YSO:Ce crystal can recover some of the light signal to its initial value again.

3. Conclusions

We fabricated an FORS using inorganic scintillator and an optical fiber bundle. To select an adequate scintillator to apply in high-temperature conditions, the gamma-ray energy spectra were obtained by using four kinds of inorganic scintillators. From the experimental results, we selected YSO:Ce crystal as an optimum scintillator. In contrast with LYSO:Ce, the YSO:Ce had a reproducibility even when temperature are changed from 40 to 300℃. Based on the results of this study, we anticipated that an FORS system can be developed to measure gamma-rays in high-temperature conditions.

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REFERENCES

[1] K.-T. Han, W. J. Yoo, J. K. Seo, S. H. Shin, D, Jeon, S. Hong, S. Cho, J. H. Moon, and B. Lee, Optical fiber-based gamma-ray spectroscopy with cerium-doped lutetium yttrium orthosilicate crystal, Optical Review, Vol. 20, No. 2, p. 205-208, 2013.

[2] D, Jeon, W. J. Yoo, S. H. Shin, S. Hong, H. I. Sim, S. G. Kim, K. W. Jang, B. Lee, B. G. Park, and J. H. Moon, Thermal properties of a fiber-optic radiation sensor for measuring gamma-ray in high temperature conditions, Journal of the Korean Physical Society, Vol. 66, Issue. 1, p. 46-50, 2015.

[3] L. A. Boatner, J. S. Neal, J. A. Kolopus, J. O. Ramey, and H. Akkurt, The characterization of scintillator performance at temperatures up to 400 degrees centigrade, Nuclear Instruments and Methods in Physics Research A, Vol. 709, p. 95-107, 2013.