Preliminary study of CdS/ZnS quantum dot-loaded plastic scintillator for detection of ^{137}Cs-contaminated soil

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1. Introduction

After the nuclear facilities are dismantled, the contamination of the site must be evaluated for site reuse. There are generally used sampling methods and in-situ measurement methods. Since the in-situ measurement method directly measures the radiation, it saves time and does not generate secondary radioactive waste. However, the accuracy of the results is lower than that of the sampling method. Semiconductor detectors or inorganic scintillators, which are mainly used in in-situ measurement systems, cannot be manufactured in a large size. But, plastic scintillators can be manufactured in a large size, and have a fast decay time, and low hygroscopicity. In addition, since the plastic scintillator is composed of low atomic numbers, it is difficult to analyze nuclides, and is mainly used for alpha and beta analysis [1-2].

Recently, research on the development of optical sensors using quantum dot materials has been actively conducted. Unlike bulk materials, quantum dots have a nanometer size and have unique photophysical properties due to their energy levels being quantized.

In this study, a preliminary study was carried out on whether it is possible to measure gamma ray by loading a CdS/ZnS quantum dot with a high atomic number into a plastic matrix. The performance of the plastic scintillator loaded with CdS/ZnS quantum dots was verified through a performance comparison with a commercial plastic scintillator.

2. Methods

This section includes a plastic manufacturing method using CdS/ZnS quantum dots and a measurement experiment using a sample of soil contaminated with Cs-137.

2.1 Fabrication of plastic scintillator

CdS/ZnS-based plastic scintillators were manufactured through thermal polymerization using monomeric styrene, PPO (2,5-Diphenyloxazole), POPOP ((2,2-p-phenylene-bis (5-phenyloxazole)), and CdS/ZnS. Styrene was used as the primary solvent, PPO as the primary fluorophore, and POPOP as the secondary fluorophore. The amount of materials added to styrene was PPO (0.4wt%), POPOP (0.01wt%), CdS/ZnS quantum dot (0.2wt%) [3], and was manufactured with a diameter of 50mm and a thickness of 30mm. All materials used in this study were purchased from Sigma Aldrich.

Micro-bubbles generated in the polymerization process may cause cracks due to internal stress, so a process of removing the bubbles is required. Fig. 1 shows the manufacturing process sequence of a plastic scintillator loaded with CdS/ZnS quantum dots.

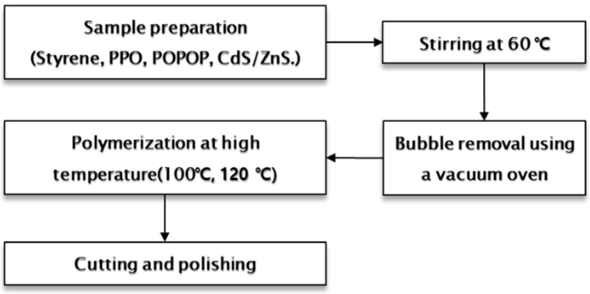

Fig. 1. CdS/ZnS-loaded plastic scintillator manufacturing process

2.2 Measurement system configuration

In this study, the performance of the CdS/ZnS-based plastic detector was verified using soil samples contaminated with Cs-137. A sample of contaminated soil plates was prepared by mixing an unsealed source, into commercial soil. The contaminated soil was made into a plate shape of 500 x 500 x 40mm. A 10Bq/g soil plate sample (500 x 500 x 10) was prepared by mixing soil, immobilizing agent, water and Cs-137 source on an acrylic plate. A total of 10 Bq/g soil plate samples were used by overlapping 4 plates. In addition, the manufactured plastic scintillator and the commercial plastic scintillator were connected to PMT (ET-9266KB, ET Enterprises Ltd), respectively, to establish a detection system, and measurement experiments were performed at distance of 20, 50, and 100 mm from the soil plate sample. Configuration of radiation detection system is shown in Fig. 2.

3. Results

3.1 Performance verification

To verify the performance of the plastic scintillator manufactured in this study, the performance of the commercial plastic scintillator (EJ-200, Eljen Technology) was compared and analyzed.

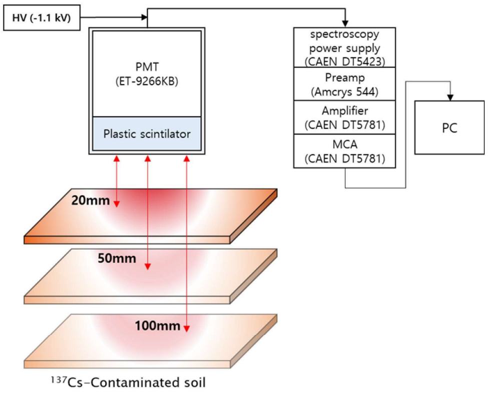

Fig. 2. Radiological measurement system for detection of ^{137}Cs-contaminated soil

The results are shown in Table I. Since the plastic scintillator is composed of a material with a low atomic number, the full-energy peak does not appear, so energy calibration was performed based on the Compton edge. As a result of calculating the relative efficiency compared to the commercial plastic scintillator by the gross counting method, it was improved by up to 15%.

After fabricating a plastic scintillator using a quantum dot material with a CdS/ZnS core-shell structure, the relative efficiency compared to commercial plastics was analyzed, and a count ratio was calculated to see the effect of the CdS/ZnS quantum dot material on each energy. The count ratio was calculated to investigate the effect of the CdS/ZnS quantum dot material for each channel. It was calculated through the following equation [4].

$$Relative\ count\ ratio(\%) = \frac{\text{Count rate per channel (CdS/ZnS plastic)}}{\text{Count rate per channel (Commercial plastic)}}$$

The calculation result is shown in Fig. 3. Fig. 3 is the average value of the data calculated by distance. In the Compton edge region, the CdS/ZnS quantum dot material showed the effect of improving the counting rate by more than about 20%. A ratio above '1' mean that the CdTe nanoparticle improved the light yield in the polymer corresponding to each channel. The effect that appears in the energy region larger than Compton edge is the signal scattered by the CdS/ZnS quantum dot.

Table I: Total count rate(cps) of commercial and CdS/ZnS quantum dot-loaded plastics according to measurement distance

	20mm	50mm	100mm
Commercial plastic	56,652 ± 422	47,524 ± 434	34,397 ± 262
CdS/ZnS plastic	67,045 ± 898	52,036 ± 184	36,444 ± 188

4. Conclusions

Currently, the detector mainly used for in-site measurement of the decommissioning site is a semiconductor detector or an inorganic scintillator. In this study, CdS/ZnS quantum dot-loaded plastic detector which has better processability, lower hygroscopicity, and can save time, was fabricated. Quantum dot materials can be adjusted by the quantum confinement effect, and the energy level is quantized so that the behavior of electrons and holes is different from that of bulk materials. Due to the unique photo-physical properties of such a quantum dot material, a lot of research has been carried out in various fields. As a result of this study, it was analyzed that the CdS/ZnS quantum dot-loaded plastic scintillator has better efficiency than commercial plastic scintillator. Based on the results of this study, CdS/ZnS-loaded plastic scintillators are expected to be used as an alternative to existing systems in waste management as well as decommissioning sites characterization.

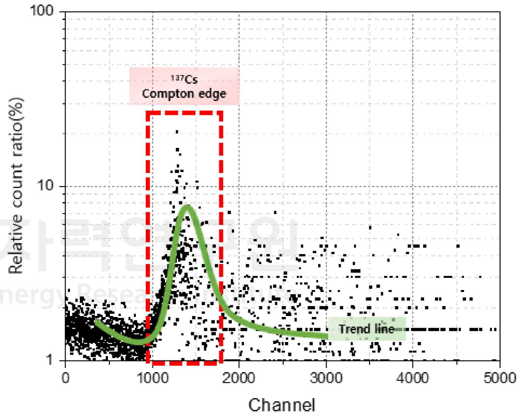

Fig. 3. Average of relative count ratio(%) calculated in Compton edge region by measurement distance

5. Acknowledgement

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