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Radiation Shielding Test of CdSe Nanoparticles-Polymer Composites

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1. Introduction

Nuclear technologies are widely utilized in various industrial fields, because of their remarkable efficiency and versatility. However, in nuclear facilities, it is essential to shield a radiation because the radiations make an ionization of molecules or highly reactive free radicals, leading to the disrupture of DNA and other components of the human body. Therefore, various high-performance radiation shielding materials are used to achieve this purpose, and these materials are made using heavy metals like lead and concrete. However, most of these materials are not made using nanomaterials. If radiation shielding materials are made using nanoparticles with 10's nm or less, the cross sectional area colliding between radiations and nanoparticles will increase significantly, leading to a drastic improvement in shielding efficiency. Moreover, high shielding efficiency will be helpful in reducing costs. Several studies have demonstrated the potential of utilizing nanoparticles as a radiation shielding material [1, 2].

CdSe is a quantum dot (QD) nanoparticle that exhibits various luminescent properties depending on its size. Additionally, it seems that CdSe can have a high multi-radiation shielding efficiency as it contains heavy metals and cadmium that are effective in gamma radiation shielding and neutron, respectively. However, CdSe has a hydrophobic surface after synthesis, this limits its use in aqueous solutions. To overcome this limitation, we modified the hydrophobic surface of CdSe by physically adsorbing amphiphilic molecules onto their surface. Then, the prepared CdSe was mixed with the agarose polymer, leading to a hydrogel of the CdSe-polymer complex. The CdSe-polymer complex was tested for the neutron and X-ray shielding on the small angle neutron scattering instrument in HANARO and the small angle X-ray scattering instrument in JBNU.

2. Experiment and Results

In this experiment, the CdSe QDs were synthesized by hot injection method at 240℃ [3] with controlling the reaction time, where the reaction time for the growth of CdSe QDs ranged from 20 seconds to a maximum of 140 seconds, with experiments conducted at 20 second intervals. The prepared CdSe QDs were characterized by UV-Vis and TEM analyses. The position of the absorption peak in the UV-vis shifted from 483 nm to 533 nm depending on the reaction time (Fig. 1. a). TEM image s of the CdSe QDs with reaction time of 20 seconds and 100 seconds revealed a spherical shape with diameters of 2.41 nm and 2.61 nm. UV-Vis and TEM analysis confirmed the uniform size and optical properties of CdSe QD. Additionally, under UV lamp illumination, it was observed that the QDs exhibited luminescence properties in the green to orange range as the particle size increased (Fig. 1. b). Therefore, as the particle size increased with reaction time, both absorption and emission energies decreased. The surface of the prepared CdSe QDs was modified using amphiphilic triblock copolymers consisting of a triblock structure (PEO-PPO-PEO) with hydrophilic blocks (PEO) and hydrophobic blocks (PPO), resulting in the functionalized CdSe QDs with a hydrophilic surface. Specifically, Pluronic P105, P85, P65 and L35 were used for this purpose.

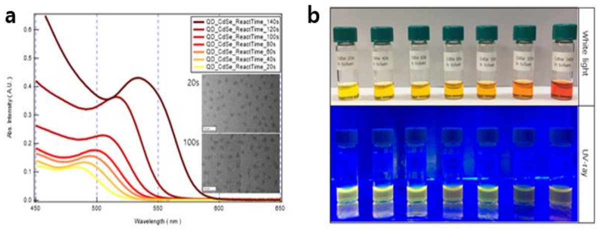

Fig. 1. a) UV-Vis absorbance measurement data and TEM image of CdSe QDs. b) Photos of CdSe QD samples dispersed in toluene solution under visible light and UV lamp.

After the modification of CdSe QDs with a diameter of 3.9 nm, they were stably dispersed in the water (Fig.

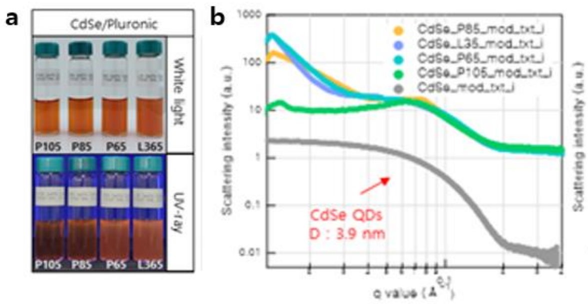

Fig. 2. a) Photos of CdSe/Triblock copolymer samples under visible light and UV lamp. b) SAXS data of CdSe/Triblock copolymer samples.

2. a). The microstructure of the modified CdSe QDs in aqueous solution was analyzed by the small-angle X-ray scattering (SAXS) and revealed a core-shell spherical structure with various shell thicknesses depending on the type of molecules (Fig. 2. b) [4].

To expand the moldability and processability of the CdSe QDs, the CdSe-Agarose (a hydrophilic natural polymer) complexes were fabricated. In addition, the CdSe-Agarose polymer complexes were prepared into the 2D film types with a different thickness to accurately measure its shielding performance against neutrons and photons.

Eight film type samples with different block copolymers and QD concentrations were prepared for the comparison of the radiation shielding performance (Fig. 3). Sample #1 was an Agarose film without any additives. Samples #2-#5 were prepared by mixing of different types of Pluronic (L35, P65, P85, and P105, respectively) and CdSe QD with a concentration of 6 wt%. Samples #6-#8 were prepared by mixing of P65 polymer and CdSe QDs with a different concentration (0, 11.3, and 20.3 wt%, respectively).

Fig. 3. Photos of CdSe/Pluronic Triblock copolymer complexes film (Sample #1 to #8 from the left).

To confirm the radiation shielding performance of the CdSe-Agarose complexes, the transmission experiments for the neutrons and photons were performed for all samples by using energies of 3.3 meV and 1.54 KeV, respectively.

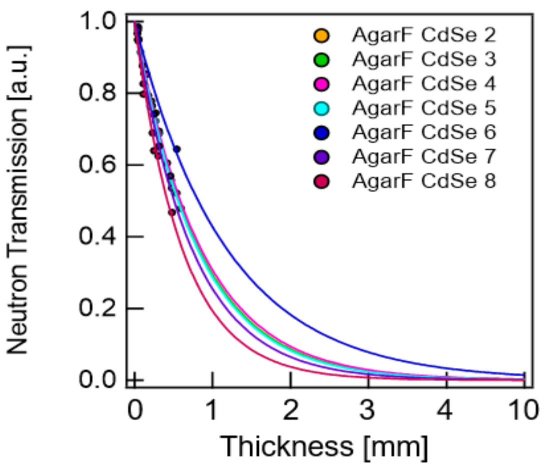

Fig. 4. Results of neutron transmission experiments.

Based on the findings of Samples #2-#5 in Fig. 4, the neutron shielding efficiency did not depend on the type of the triblock copolymer used for the dispersion of CdSe QD in aqueous solution (The calculated neutron attenuation coefficients of Samples #2-#5 were 6.1, 6.1, 5.9 and 6.2 mm^{-1}, respectively) . However, the data obtained from Samples #6-#8 indicated that the neutron shielding efficiency increases with the concentration of CdSe QDs (The calculated neutron attenuation coefficients of Samples #6-#8 were 4.5, 6.8 and 8.2 mm^{-1}, respectively).

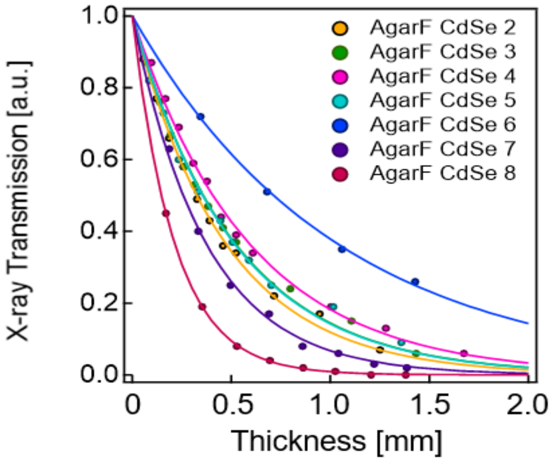

Fig. 5. Results of photon transmission experiments.

In the case of the photon shielding test, it is similar to the tendancy for the neutron shielding itself test but the CdSe-Agarose complexes are more efficient for the photon shielding (The calculated photon attenuation coefficients for Samples #2-#8 were 21.3, 19.4, 17, 19.5, 9.7 27 and 47.2 mm^{-1}, respectively) (Fig. 5). These results were consistent with the result of the calculated result from the simple estimation from the composition of the complexes.

3. Conclusion

In this study, we tested CdSe QD as a radiation shielding material. The properties of CdSe QD were characterized by UV-Vis and TEM analyses. The SAXS analysis was performed to reveal microstructures of the modified CdSe QDs in aqueous solution. Experiments were performed to confirm the radiation shielding performance of the CdSe-Agarose complexes against neutrons and photons.

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