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Preparation of CeF₃ nanoparticles loaded PPO/PVT composites for radiation detection

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Composite materials for radiation detection were developed from PVT, PPO, and CeF₃ nanoparticles. The effects of PPO and CeF₃ nanoparticles content were studied using their photoluminescent spectra and energy spectra from ⁵⁷Co and ¹³⁷Cs sources. Under an excitation wavelength of 300 nm, a sharp emission was detected at 366 nm with a possible CeF₃ energy transfer indication. Scintillation enhancement of CeF₃ nanoparticles loaded PPO/PVT composites was investigated with a photomultiplier setup. The response to gamma radiation and count increase was observed.

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Keywords: Scintillation, Photoluminescent, CeF₃, Energy transfers

1. Introduction

Nowadays, radioactive is applied in science and technology, industrial, agricultural, geological, and medical, resulting in easier exposure to radiation and the risk of illness when exposed to excessive radiation. Humans cannot detect radiation with the naked eye, so radiation measurement is essential to prevent hazards and control radiation. The use of radiation in medicine includes diagnostic radiation, which is the source of radiation outside the body, and nuclear medicine, where the source of radiation is inside the body. In nuclear medicine tests, radiation detectors are essential equipment that is important in radiation measurements. The material that is commonly used in radiation measurement applications is a scintillator. The scintillator is a material that exhibits scintillation, which is the property of luminescence when ionizing radiation is excited. The ideal scintillator should have the following characteristics: (1) high atomic number (Z) to increase gamma attenuation and photoelectron production; (2) high light yield (LY, low-energy photons produced per unit energy deposited, photons/MeV); (3) short emission decay lifetime; and (4) low cost and ease of large-scale fabrication [1]. Usually, scintillators are liquids, plastics, or crystals.

Plastic scintillators are widely used to detect charged particles and neutrons' spectroscopy. Although its light output is lower than that of most inorganic scintillators, it has many advantages, e.g., the short decay time of the light pulse, non-hygroscopic, ease to manufacture in any shape, and low cost [2]. However, plastic scintillators are limited in determining high-energy radiation due to the adequate atomic number and low density, causing the photopeak to be unclear [3]. The addition of highly effective atomic number substances to plastic scintillators is a way to make plastic scintillators more effective in radiation measurement. However, large particles' doping reduces the optical properties of plastic scintillators due to the particles' aggregation [1]. For this reason, researchers have made efforts to prepare composite materials consisting of nanomaterials with a high atomic number for scintillator application [4]. CeF₃ nanoparticles due to the permitted 5d–4f transition in Ce³⁺ ion have substantial fluorescence properties, high density, short decay time, fast response, and high resistance to radiation. Due to the 5d–4f transition of Ce³⁺ ions, Ce³⁺ ions are promising candidate materials for fast and efficient scintillators [5].

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In this research, CeF_3 nanoparticles loaded PPO/PVT composites were prepared. We also improved PVT radiation measurement's effectiveness by incorporating CeF_3 nanoparticles with a small amount of 2,5 diphenyloxazol (PPO) as a shifter wavelength. A fluorescent spectrophotometer determined fluorescent spectra of prepared plastic scintillators. Energy spectra of a gamma ray from ^{57}Co ^{137}Cs source were analyzed by photomultiplier set up.

2. Experiment

2.1. Preparation of CeF_3 nanoparticles loaded PPO/PVT composites

All the chemicals utilized in this work were analytic grade and employed without further purification. Firstly, 2 g of PVT and PPO were dissolved in 20 ml of toluene. The mixture was stirred for 15 min at room temperature. The different amounts of CeF_3 nanoparticles (2, 4, 6, 8, and 10 mg) were added into the above mixture and continuously stirred for 1 h at room temperature. The mixtures were transferred in a petri dish and annealed in an oven at 50°C for 5 days.

2.2. Testing

Photoluminescence emission (PL) was taken on the Hitachi F-7000 fluorescence spectrophotometer. Radiation response measurement was taken on a photomultiplier tube (Photonis XP5200B PMT) with optical grease, without additional polishing. The sample were exposed to the ^{57}Co and ^{137}Cs sources.

3. Results and discussion

PVT scintillator filled with PPO at a content of 10, 40, 60, 80, 100, 120, 140, and 160 mg are shown in Fig. 1. From the figure, the prepared samples are a transparent sheet. When exposed to UV light, a bluish emission was observed, which could be observed with the naked eye, as shown in Fig. 2.

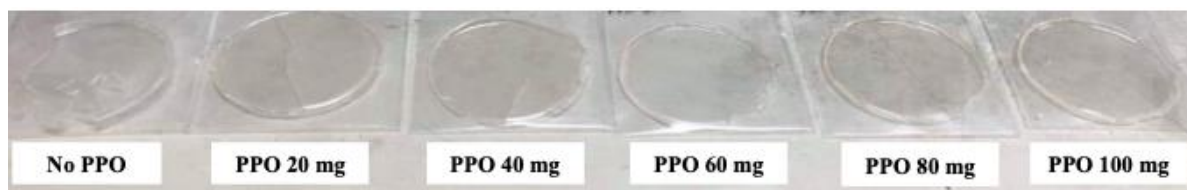


Fig. 1. Prepared PVT/PPO composites.

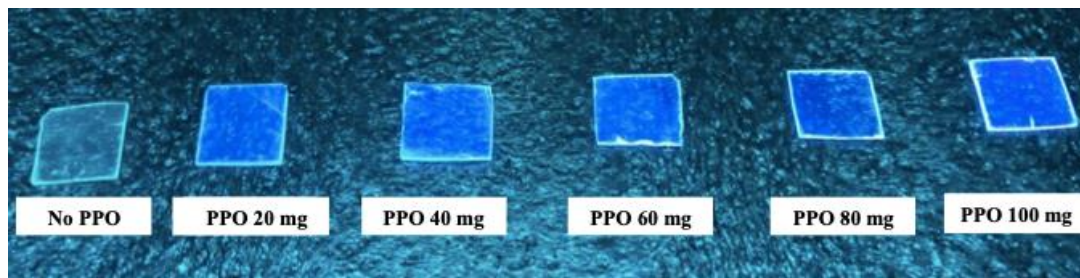


Fig. 2. The bluish light is emitting under the UV light of the plastic. PVT/PPO composites.

Fig. 3 shows the prepared sample spectrum as measured with a fluorescence spectrophotometer using an excitation wavelength of 300 nm. The figure shows that the sample without PPO was not luminous, and when the PPO was added, it emits light at a wavelength of 366 nm in all samples. PVT added with a PPO at a dosage of 10 mg had the highest emitting intensity.

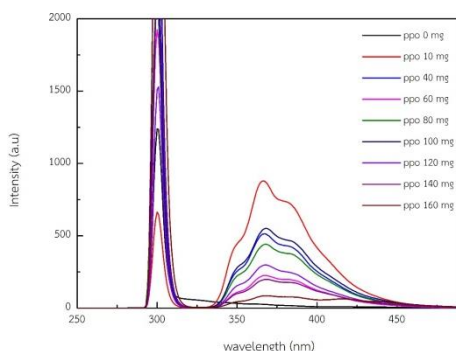


Fig. 3. Photoluminescent spectra of PVT/PPO composites with excited wavelength of 300 nm.

Various content of CeF_3 nanoparticles was loaded into the PVT matrix while the PPO concentration has been maintained at 10 mg. Compared to the unloaded sample, PPO/PVT composites loaded with CeF_3 nanoparticles exhibited brighter emissions under UV light, as shown in Fig. 4. CeF_3 nanoparticles greatly improved the photoluminescence of PPO/PVT composites. As expected, this increase in the emission intensity of nanocomposites loaded with CeF_3 nanoparticles is due to the transfer of energy from CeF_3 to PPO in the PVT matrix. Besides, when excited at 300 nm wavelengths, the CeF_3 nanoparticles loaded PPO/PVT composites' photoluminescence spectra do not reveal any emissions from CeF_3 nanoparticles. Since the CeF_3 emission perfectly overlaps with PPO absorption in PVT, nanoparticles excitation will transfer their energy to PPO in the PVT matrix [6].

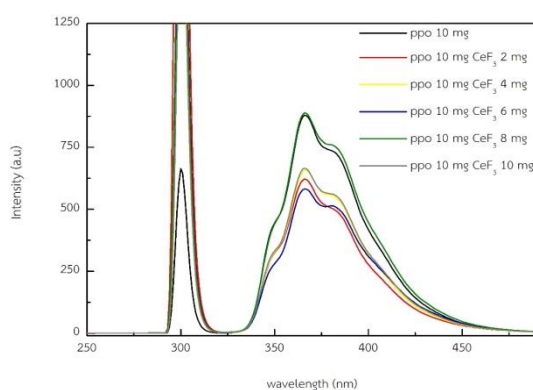


Fig. 4. Photoluminescent spectra of CeF_3 doped PVT/PPO composites with excited wavelength of 300 nm.

The mechanism of fluorescence resonance energy transfer (FRET) from CeF_3 to PPO is shown in Fig. 5. The energy transfer from CeF_3 nanoparticles to PPO in the PVT matrix has increased in the nanocomposite's emission intensity. Also, the disappearance of CeF_3 nanoparticles emissions in the spectra confirms the occurrence of the FRET phenomenon among CeF_3 nanoparticles and PPO/PVT composites [4-7].

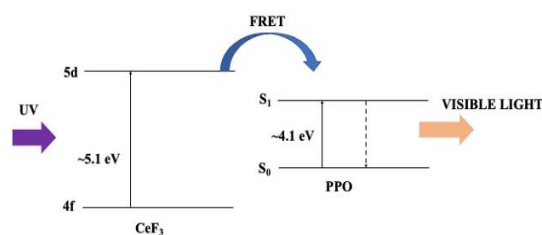


Fig. 5. Mechanism of fluorescence resonance energy transfer (FRET) from CeF₃ to PPO.

Fig. 6 and Fig. 7 show the gamma ray's energy spectra from the ⁵⁷Co and ¹³⁷Cs sources of CeF₃ nanoparticles loaded PPO/PVT composites with different CeF₃ nanoparticle loading content. The results show that the CeF₃ nanoparticles contribute to enhancing radiation detection capability. No CeF₃ emission is also seen under gamma ray excitation due to the high absorption of PPO/PVT composites in the CeF₃ emission region. However, when more nanoparticles were added, the radiation detecting ability was reduced compared to samples without nanoparticles added. This incident is necessary for further studies to explain the mechanisms involved in detecting high-energy radiation of this composite.

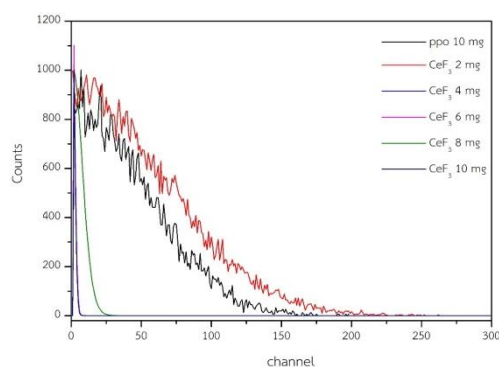


Fig. 6. The gamma ray's energy spectra from the ⁵⁷Co source of CeF₃ nanoparticles loaded PPO/PVT composites.

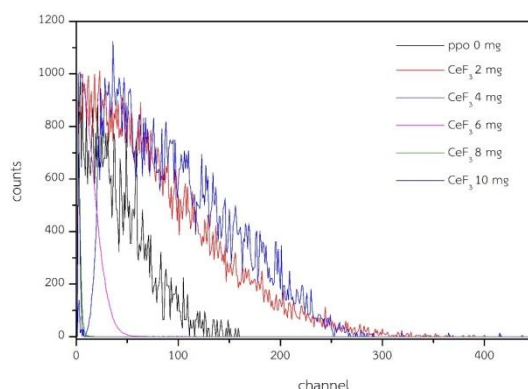


Fig. 7. The gamma ray's energy spectra from the ¹³⁷Cs source of CeF₃ nanoparticles loaded PPO/PVT composites.

4. Conclusion

In this research, the CeF₃ nanoparticles loaded PPO/PVT composite materials were developed. The effect of nanoparticles on the composite material's photoluminescent and scintillation properties was studied in which nanoparticles were found to increase the emission intensity when excited with UV and gamma ray. The decrease in emission intensity as the CeF₃ nanoparticles content increases is topic to study further.

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