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Scintillation properties of quantum-dot doped styrene based plastic scintillators

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ABSTRACT

We fabricated quantum-dot doped plastic scintillators in order to control the emission wavelength. We studied the characterization of the quantum-dots (CdSe/ZnS) and PPO (2, 5-diphenyloxazole) doped styrene based plastic scintillators. PPO is usually used as a dopant to enhance the scintillation properties of organic scintillators with a maximum emission wavelength of 380 nm. In order to study the scintillation properties of the quantum-dots doped plastic scintillators, the samples were irradiated with X-ray, photon, and 45 MeV proton beams. We observed that only PPO doped plastic scintillators shows a luminescence peak around 380 nm. However, both the quantum-dots and PPO doped plastic scintillators shows luminescence peaks around 380 nm and 520 nm. Addition of quantum-dots had shifted the luminescence spectrum from 380 nm (PPO) toward the region of 520 nm (Quantum-dots). Emissions with wavelength controllable plastic scintillators can be matched to various kinds of photosensors such as photomultiplier tubes, photo-diodes, avalanche photo-diodes, and CCDs, etc. Also quantum-dots doped plastic scintillator, which is irradiated 45 MeV proton beams, shows that the light yield of quantum-dots doped plastic scintillator is increases as quantum-dots doping concentration increases at 520 nm. And also the plastic scintillators were irradiated with Cs-137 γ-ray for measuring fluorescence decay time.

1. Introduction

Due to the low cost, easy fabrication and fast response time, plastic scintillator materials have been widely used as detectors in nuclear, particle physics, and homeland security applications. Plastic scintillators have a fast decay time of 2–3 ns and high light output [1–3]. Most of the plastic scintillators are composed with solvents and primary solutes like p-terphenyl (1, 4-Diphenylbenzene), PPO (2, 5-diphenyloxazole) and butyl PBD (2–4(biphenyl)-5-(4-tert-butyl-phenyl)-1, 3, 4-oxadiazole) [4,5]. In order to match the emission wavelength of plastic scintillators to the quantum efficiency of a photomultiplier tubes (PMTs), secondary solutes like POPOP (5-phenyl-2-[4-(5-phenyl-1, 3-oxazol-2-yl) phenyl]-1, 3-oxazole) are used as wavelength shifters. Thus, most of the secondary solutes have an emission wavelength around 400 nm [1,4,6].

Many photosensors like PMTs, photo-diodes, avalanche photo-diodes and CCDs detect scintillation light. Each sensor has different properties such as quantum efficiency, detection mechanism, etc. Most of the PMTs have maximum quantum efficiency around 400 nm but photo-diodes and CCDs have theirs around 600 nm. Due to the different quantum efficiencies of photosensors, it is important to match the emission wavelength of the scintillator with the photosensor.

Colloidal semiconductor nano-crystals, quantum-dots (QDs), have been used as light emitting diodes (LEDs) and sensors for bio-imaging. One of the properties of QDs is their size effect. It is known that an increase in the size of the QDs causes a red shift. Thus, as the size of the QDs increase, the color of the light emission changes from blue to red [7,8].

Plastic scintillators are easy to mix with other dopant materials. Thus it is possible to fabricate the QDs doped plastic scintillators. By using different size QDs, the emission wavelength of the plastic scintillator could be controlled to match with various photosensors.

At this paper, we present the scintillation properties of QDs doped styrene based plastic scintillators. In order to study the luminescence property, the samples were irradiated with Cs-137 γ-ray, X-ray, photon and 45 MeV proton beams.

2. Fabrication of quantum-dot doped plastic scintillators

2.1. Materials

We fabricated styrene based scintillators with PPO, POPOP and QDs as the dopants. The monomer styrene was obtained from the SAMCHUN Chemical. Primary solute PPO and secondary solute

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Table 1
Concentrations of styrene based plastic scintillators.

Num.	Styrene (wt%)	PPO (wt%)	POPOP (wt%)	QDs (wt%)
1	~99	0.4	0.01	–
2		0.4	–	–
3		0.4	–	0.4
4		0.4	–	0.1
5		0.4	–	0.05
6		–	–	0.1
7		–	–	0.05

POPOP were purchased from the Lancaster Company. Home-made QDs were fabricated using the trioctylphosphine (TOP) and the trioctylphosphine oxide (TOPO) synthesis methods [9]. The QDs consisted of a core (CdSe) and shell (ZnS).

2.2. Preparation of styrene based plastic scintillators

Plastic scintillators were grown by using the thermal polymerization method [10,11]. Initial temperature was in the range of 100 °C during the first 24 h, followed by 120 °C during the next 72 h for the polymerization and then 80 °C during the last 24 h for the annealing. Whole growth process was carried out in glass bottles about 2.5 cm in diameter and 5 cm in length. Plastic scintillators were fabricated with different concentrations of QDs. Both POPOP and QDs were used as a wavelength shifter. Detailed dopant concentrations are given in Table 1. Fig. 1 shows the fabricated samples of plastic scintillators which are cut and polished to dimension of 2.5 cm × 2.5 cm × 0.6 cm. Plastic scintillator #1 consisted of styrene, PPO (0.4 wt%) and POPOP (0.01 wt%). Plastic scintillator #2 consisted of styrene and PPO (0.4 wt%). Plastic scintillator #3, #4 and #5 consisted of styrene, PPO and different concentrations of QDs with 0.4 wt%, 0.1 wt% and 0.05 wt %, respectively. Plastic scintillator #6 and #7 consisted of styrene and 0.1 wt% and 0.05 wt%, respectively.

3. Measurement system

In order to study the scintillation properties, all plastic scintillators were irradiated with X-ray, photon and 45 MeV proton beams. All luminescence measurements were made at room temperature. X-ray induced emission spectra were measured using a tungsten target X-ray generator, QE65000 spectrometer (Ocean Optics Co.) and optical fiber. The X-rays with an intensity of 100 kV and a current of 1.5 mA were irradiated to all plastic scintillators [12].

Photo-induced excitation and emission spectra were measured using a xenon lamp (HORIBA Jobin Yvon Inc., Fluorlog-3 Model FL3-21). The excitation and emission signal was detected using a PMT (Jobin Yvon Inc., R928P). The xenon source was placed at a right angle to the detector. The plastic scintillators were located at 45° from the excitation xenon source.

The proton-induced emission spectra of the plastic scintillators were measured at the Korea Institute of Radiological and Medical Sciences (KIRAMS). When the proton beam passed through the beam pipe, the proton beam energy changed from 45 MeV to 38 MeV [13]. The proton-induced scintillation light passed through an optical fiber and was detected using a USB4000 spectrometer (Ocean Optics Co.).

In order to fluorescence decay time, we used 2-in. Bi-alkali PMTs and 400 MHz flash analog to digit converter (FADC). The plastic scintillator was wrapped in 0.1 mm thick Teflon tape and attached to PMTs. All plastic scintillators were irradiated Cs-137 (661 keV) γ-ray source to measure fluorescence decay time.

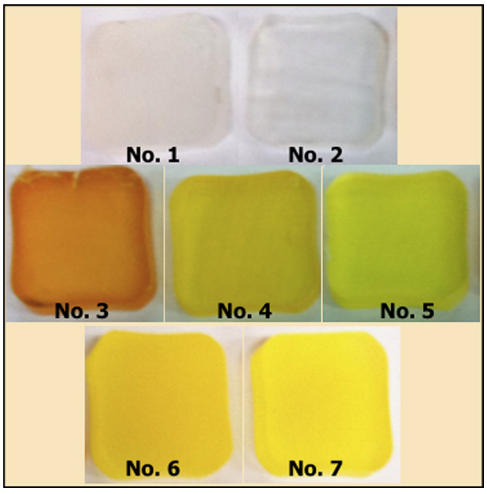

Fig. 1. Photograph of the styrene based plastic scintillators.

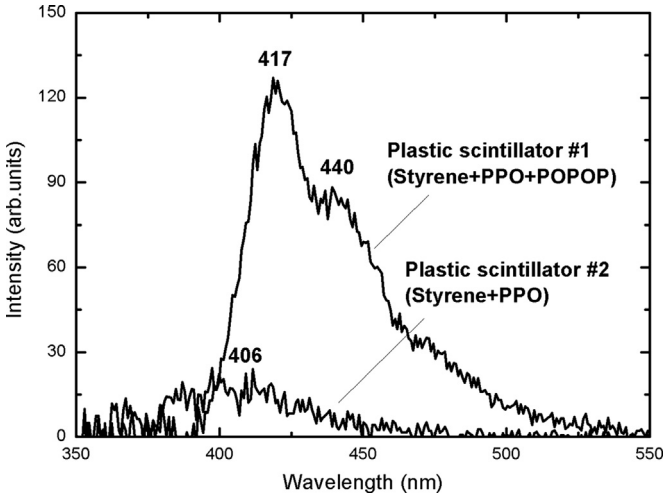

Fig. 2. The X-ray induced luminescence of plastic scintillators #1 (Styrene+PPO+POPOP) and #2 (Styrene+PPO).

The signals generated in the PMTs due to scintillation in the plastic scintillator were amplifier. The signal from the PMTs was fed to 400 MHz FADC. The data is analyzed with a C++ based data analysis program, ROOT package [14].

4. Results and discussion

We had two ideas about the luminescence mechanism of the QDs doped plastic scintillators. One idea was wavelength shift from the PPO to QDs. Thus, we fabricated plastic scintillators #3, #4 and #5. Another idea was the direct transfer of luminescence energy from the styrene to the QDs. Therefore we fabricated plastic scintillators #6 and #7. Among the QDs doped plastic scintillators, plastic scintillators #3, #6 and #7 did not show any significant X-ray emission spectrum. Thus, in this paper, we present only the results on the QDs doped plastic scintillators #4 and #5.

4.1. X-ray induced luminescence

Figs. 2 and 3 shows the X-ray induced emission spectra of the fabricated plastic scintillators. Fig. 2 shows the emission spectra of plastic scintillators #1 and #2. The emission peaks of plastic scintillator #1 are located at 417 nm and 440 nm, whereas