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Preparation and characterization of a novel UV-curable plastic scintillator

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ABSTRACT

A novel UV-curable plastic scintillator was first prepared by using the technology of photosensitivity rapid prototyping. It used the copolymer of 621A-80, TPGDA and styrene as the matrix doped with PPO and POPOP. Its fluorescence spectra displayed a maximum emission wavelength at 428 nm. The light yield of the plastic scintillator was approximately 7.1% of anthracene on the basis of a comparison with the commercially available scintillator (ST-401). The as-prepared plastic scintillator also displayed a fast scintillation decay. Its decay time is 2.6 ns approximately. Importantly, through the technology of photosensitivity rapid prototyping, the plastic scintillator could be prepared in a short period of time at low temperature. What's more, this preparation method provides the possibility of combining the plastic scintillator with 3D printing technology, and then the applications of the plastic scintillator may be expanded greatly.

1. Introduction

Protection of people against a variety of threats (such as nuclear, radiological, biological, and explosive) represents a true challenge along with the continuing development of science and technology. The scintillator is widely used in various devices, which serves for nuclear physics, photonics, quantum physics, high-energy physics, medical diagnostics and so on [1–4]. Used as materials to detect nuclear radiation, plastic scintillators display a lot of advantages. They are cheap, easy to handle, chemically stable (as the matrix is a polymer), can be processed into large volume and have a fast response to gamma rays [5–7]. Besides, the developed technology of preparing plastic scintillators makes much benefit for its application.

A polymer matrix embedding one or several fluorescent dyes (primary dye and wavelength-shifter) is defined as a plastic scintillator, which can emit light when interacting with a radioactive material [8]. For instance, a typical plastic scintillator was prepared by using the thermal polymerization of styrene containing p-Terphenyl and POPOP. Generally, polystyrene, polyvinyl toluene and polymethyl methacrylate were used as the traditional matrix of plastic scintillators. The earliest description of preparing plastic scintillator was reported in the late 1950s [9].

The matrix serves as an agency for energy transfer of fluorescent probes and interacts with neutron to produce scattering electrons [10]. The basic principle of the interaction between radiations and scintillators is as follows: when a new radiation interacts with the matrix, it will lose part of energy. The energy is deposited both in the matrix and the fluorescent dyes, then multiple interactions occur, and the matrix will realize the release of UV photons. Following other interactions among matrix and dyes, the newly formed photons will be transferred from UV to visible light which can be strengthened by photomultiplier [1,11–15]. The photon-to-electron conversion of photomultiplier allows physical access to the interaction between radiations and scintillators.

In order to achieve better performance, the plastic scintillator should have a good transparency and its matrix should own a good solubility for the fluorescent dyes. According to current reports, aromatic hydrocarbons with the benzene ring structure were suitable for using both as matrix and dyes [13,14]. The traditional plastic scintillator was manufactured by the thermal polymerization at a high temperature (above 100 °C) and the whole preparation process took more than one week generally [16]. To

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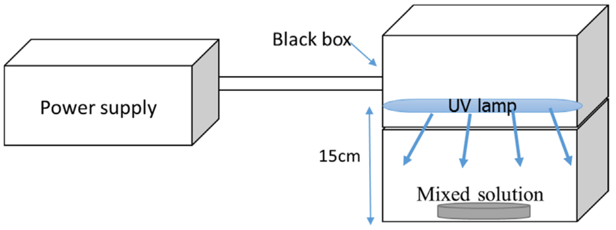

Fig. 1. Schematic view of UV curing machine. The scintillator was placed at a distance of 15 cm from the UV lamp. The power of the UV lamp is 2 kW.

prevent the crack and the generation of bubbles, a typical polystyrene plastic scintillator should have to be raised the temperature slowly before the polymerization and be cooled slowly after the polymerization [5].

In this study, a novel UV-curable plastic scintillator was first prepared under the irradiation of UV curing machine. Its matrix was the copolymer of oligomer 621A-80, diluent TPGDA and styrene. The polymerization of the matrix was initiated by the photoinitiator 184. PPO and POPOP were used as the fluorescent dyes of the scintillator. The light yield, fluorescence emission spectrum, decay time of the scintillator were measured and compared with the commercially available scintillator (ST-401). Importantly, the as-prepared plastic scintillator could be prepared in a very short time at a low temperature through the technology of UV-curing forming.

2. Experimental

2.1. Materials

POPOP (1,4-bis-[2-(5-Phenyl)oxazolyl]benzene) used in the experiment was purchased from TCI(Shanghai) Development Co., Ltd. PPO (2,5-Diphenyloxazole) was purchased from Sigma Aldrich China. Oligomer 621A-80 and reactive diluent TPGDA (tri(propylene glycol)diacrylate) were purchased from Eternal Materials Co., Ltd. Photoinitiator 184 (1-Hydroxycyclohexyl phenyl ketone) was purchased from J & K Technology Co., Ltd. Styrene was purchased from ChengDu Kelong Chemical Co., Ltd. and it was used after removing the inhibitor by vacuum distillation. Commercial plastic scintillator ST-401 (Φ40 mm*10 mm) was purchased from CNNC Beijing Nuclear Instrument Factory.

2.2. The preparation of the UV-curable plastic scintillator

The novel UV-curable plastic scintillator was synthesized at a low temperature in a short time by using the technology of photosensitivity rapid prototyping. It used the copolymer of oligomer 621A-80, TPGDA and styrene (the mass ratio is 7:3:3) as the matrix, containing the primary fluorescent dye PPO (2 wt%), the wavelength-shifter POPOP (0.02 wt%), and photoinitiator 184 (2 wt%). The polymerization of the matrix was initiated by the photoinitiator 184 under the irradiation of the UV curing machine.

The schematic view of UV curing machine is shown in Fig. 1. In order to investigate the impact of illumination time on the performance of the plastic scintillator, five Φ40 mm*1 mm plastic scintillator samples were prepared: they were irradiated under the UV light irradiation for 90, 100, 110, 120, 130 s respectively. The temperature in the whole preparation process of the UV-curable plastic scintillator was below 60 °C.

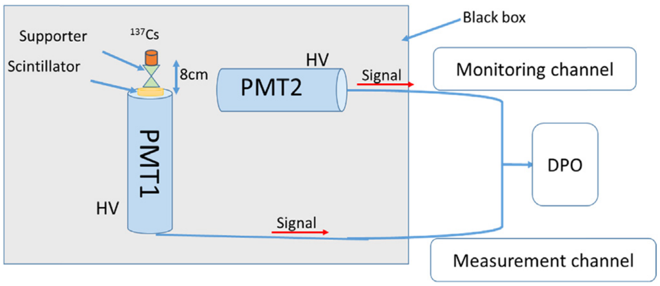

Fig. 2. Schematic diagram of the experimental setup for measuring the scintillation yield and decay time. HV: high voltage. DPO: digital phosphor oscilloscope.

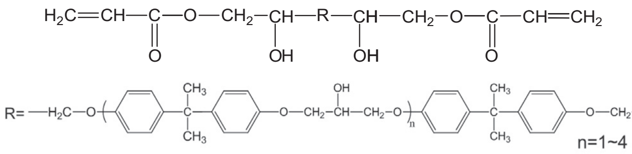

Fig. 3. The structure of oligomer 621A-80.

2.3. Characterization

The luminescence spectra of the plastic scintillator were recorded by an Edinburgh Instruments F900 fluorescence spectrophotometer. The absorption spectra of different additives were obtained by an ultraviolet spectrophotometer.

The measurement setup of the decay time is diagrammatically shown in Fig. 2. All the devices were covered with a black iron box and used in a darkroom. Two ET9814B photomultiplier tubes were used in this instrument. The upper surface and lateral of the plastic scintillator to be measured were coated with an enhanced specular reflector. The scintillator was placed directly on the first photomultiplier tube (PMT1) to detect all the occurring events. The radioactive source ^{137}Cs (emitting 662 keV gamma-ray) was placed on the top of the scintillator. In order to reduce the pulse accumulation for ensuring the accuracy of testing, an 8 cm high supporter was placed between the scintillator and the radioactive source. The monitoring channel composed of PMT2 records all response time produced by the combined function of radioactive source, photomultiplier tube and the system. The role of PMT2 was to record the impact of the whole system on the measurement results of the scintillation decay. If the whole system had a great influence on the measurement of the actual decay time, we could minimize the impact by adjusting the parameters of the instrument. This could minimize measurement errors of the decay time. Then the small impact of the whole system could be ignored in the process of data processing. All the signals from monitoring channel and measurement channel were recorded by the digital phosphor oscilloscope DPO4054.

Using the multi-channel analyzer and computer instead of PMT2 and DPO, the measurement setup of the light yield could be obtained. The pulse height spectrum of the plastic scintillator was recorded in the computer by the software GammaVision.

3. Results and discussion

3.1. New matrix and preparation method

The new matrix of the UV-curable plastic scintillator is the copolymer of oligomer 621A-80, diluent TPGDA and styrene. Because it has many advantages: high and low temperature resistance, excellent chemical stability and yellowing resistance,