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Comparative study of neutron and gamma-ray pulse shape discrimination of anthracene, stilbene, and p-terphenyl

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ABSTRACT

Solid state organic scintillators, such as anthracene, stilbene, and p-terphenyl were investigated on their basic scintillation properties and neutron–gamma discrimination capabilities. Scintillation wavelengths under X-ray irradiation of anthracene, stilbene, and p-terphenyl were 445–525, 400–500, and 350–450 nm, respectively. Scintillation light yields of anthracene, stilbene, and p-terphenyl under ¹³⁷Cs gamma-ray irradiation were 20100, 16000, and 19400 ph/MeV, respectively. Neutron and gamma-ray events discrimination capabilities were examined and anthracene exhibited the best figure of merit among three organic scintillators.

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1. Introduction

In ionizing radiation detection measurements, scintillators which convert ionizing radiations to visible photons have been widely used [1]. As a viewpoint of the market volume, inorganic crystalline materials possess a dominant position since they are main devices in medical and security applications. On the other hand, organic crystals are also one of the common scintillators and show a significant presence especially in particle detectors from mid-20th century. Organic scintillators are characterized by relatively large light yield compared with most of the inorganic scintillators and fast decay times with suitable emission wavelength to the most conventional photodetectors, PMTs. The most conventional organic scintillator is anthracene and this material is treated as a standard scintillator in a standard text book of ionizing radiation measurement [2]. Due to a recent technological progress, some new solid state organic scintillators are introduced. For example, new chemical composition like fluorocarbon materials [3] and new structural challenge like microsphere materials [4] have been introduced. In addition, ³He gas shortage [5] has motivated many research groups to develop organic scintillators for neutron detectors [6,7]. For the next stage of development of organic scintillators, comparison of some famous organic scintillators in neutron detection capability is important.

In this work, we compared neutron–gamma discrimination capability of famous organic scintillators such as anthracene

(treated as a standard organic scintillator in [2]), stilbene [8], and recently introduced p-terphenyl [9,10] based on the pulse shape discrimination (PSD) technique. Fig. 1 demonstrates photographs of three organic scintillators. Anthracene (Tamaroya, Japan) was packaged since it had a sublimability. Other two scintillators, stilbene and p-terphenyl were not packaged and were the products of Cryos-Beta Ltd., in Ukraine. Samples had sizes of 30 mm $\varnothing \times 10$ mmt (anthracene) and 10 mm $\varnothing \times 10$ mmt (other two crystals).

2. Experimental procedures

Basic scintillation properties of X-ray induced radioluminescence and scintillation decay time profiles were evaluated. In this evaluation, X-ray generator was used as an excitation source. Supplied bias voltage and tube current were 80 kV and 1 mA, respectively. Scintillation photons were detected by the monochromator (SR163, Andor) equipped CCD (DU420A-BU2, Andor) camera. The detailed description can be seen in past work [11]. Scintillation decay time profiles were evaluated by using pulse X-ray afterglow characterization system in the scintillation mode [12]. The timing resolution of the system in this mode was around 1 ns limited by the response of PMT (Hamamatsu R7400P) and emission wavelength was not resolved to simulate actual applications. The pulse X-ray had Bremsstrahlung spectral shape and the endpoint of the energy was 30 keV. Pulse height spectra to evaluate scintillation light yields were measured by using a common system. Sample crystals were optically coupled with PMT R7600-200 (Hamamatsu) and anode signal was fed into

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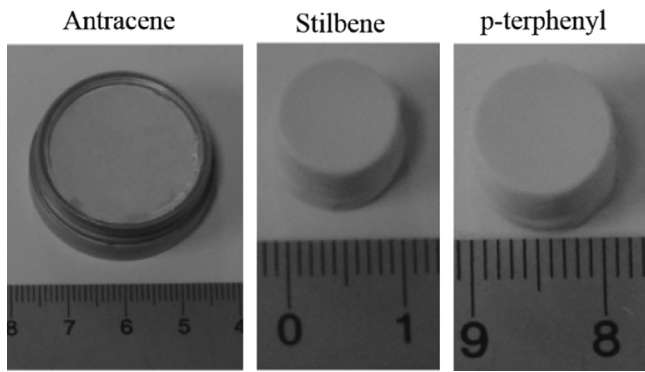


Fig. 1. Photographs of anthracene (left), stilbene (center), and p-terphenyl (right). The unit of the number in ruler was cm. Anthracene was encased and other two were wrapped by Teflon tape reflector.

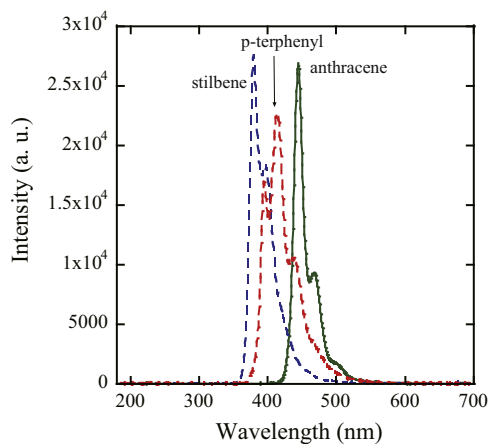


Fig. 2. X-ray induced radioluminescence spectra of three organic scintillators. Emission intensities were validly scaled to compare emission wavelengths.

preamplifier (ORTEC 113), shaping amplifier (ORTEC 572), and multichannel analyzer (Amptek Pocket MCA). The excitation source was ^{137}Cs . Because no photoabsorption peak can be seen due to their low atomic number chemical compositions, the light yields were determined through comparison of Compton edge between the measured and simulated spectra. The simulated spectra were derived using Monte Carlo code EGS 5 and convoluted with a proper energy resolution.

Then, the pulse shape discrimination technique was conducted to distinguish neutron and gamma-ray events. The basic concept of our system was published previously [13]. Neutron and gamma-ray sources were ^{252}Cf and ^{60}Co , respectively. The anode signal of PMT was fed into high-speed digitizer (Agilent U1071A). Digitized waveforms were digitally processed with PC in order to discriminate neutron and gamma-ray induced events. By using this system, neutron and gamma-ray induced scintillation decay time profiles were evaluated at the same time. Scintillation decay time profiles were deduced by two components exponential assumption. All experiments were done at room temperature.

3. Experimental results and discussion

Fig. 2 represents X-ray induced radioluminescence spectra of three organic scintillators. Emission wavelengths of anthracene, stilbene, and p-terphenyl were 445–525, 400–500, and 350–450 nm, respectively. These emission wavelengths were consistent with previous literatures [2,9] and emission wavelengths were same as those under UV excitation (photoluminescence). Fig. 3 shows X-ray induced

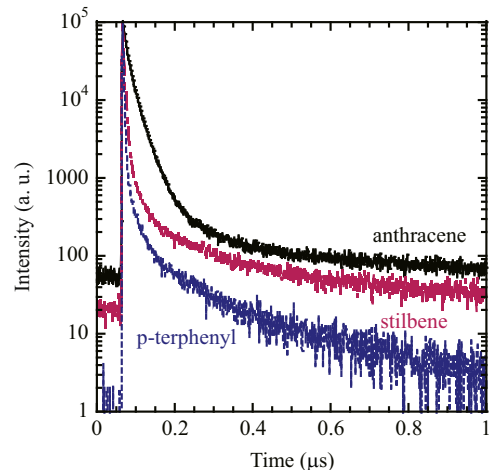


Fig. 3. X-ray induced scintillation decay time profiles of three organic scintillators.

scintillation decay time profiles of three organic scintillators. As shown in this figure, p-terphenyl exhibited the fastest response. Scintillation decay times of anthracene, stilbene, and p-terphenyl resulted to be $27.6 + 224.1$, $3.4 + 19.4$, and $1.9 + 14.1$ ns, respectively. Typical errors in these evaluations were 1 ns which was the timing resolution of the system. Though scintillation decay times determined from excitation sources, observed results of anthracene and stilbene were consistent with previous reports [2]. For example, primary decay times of anthracene and stilbene in the textbook [2] were 30 and 4.5 ns, respectively. Fig. 4 shows pulse height spectra of three organic scintillators under ^{137}Cs irradiation superposed with calculations by EGS5. The shaping time of the amplifier was $0.5 \mu\text{s}$ in all cases and sufficiently longer than the scintillation decay times. Compton edge was clearly observed in all organic scintillators and simulation data well reproduced experimental results around Compton edge. Although no photoabsorption peaks can be shown in these spectra due to their low atomic number chemical compositions, positions of the photo-peaks can be determined by fitting the EGS5 simulation data to the experiments. Based on the pulse heights of the photoabsorption peaks, scintillation light yields of anthracene, stilbene, and p-terphenyl irradiation resulted to be 20,100, 16,000, and 19,400 ph/MeV, respectively, by taking into account the quantum efficiency of R7600U-200 at each emission peak wavelength based on Fig. 2. It should be noted that the wavelength sensitivity of our PMT was high at ultraviolet wavelength and pulse height of anthracene looked inferior to others.

Fig. 5 (Top) demonstrates neutron and gamma-ray induced events as the two-dimensional histogram between the pulse height with fast integrated time window and the ratio of the pulse height under fast and slow integrated time windows. Definition of the fast and slow integrated time windows were tuned to each material and slightly differed. Fast/slow integrated time windows of anthracene, stilbene, and p-terphenyl were 20–40/40–150 ns, 20–40/40–150 ns, and 20–30/30–150 ns, respectively. In this plot, neutron and gamma-ray events were clearly separated. Although we tested the conventional two-dimensional plot on fast and slow integrated time windows plane [14,15], separation looked better in our plotting way. In Fig. 5 (bottom), scintillation decay time profiles under ^{252}Cf neutron and ^{60}Co gamma-ray selected by two-dimensional plots are exhibited. Fast scintillation component did not show difference at faster time range and a difference was observed in a time range around several hundreds ns. When irradiated by neutrons and normalized at fast emission peak-top, intensity of the slow component increased. As a result, decay times under neutron irradiation of anthracene, stilbene, and p-terphenyl were $32 + 370$, $5.3 + 50$, and $4 + 31$ ns, respectively. Typical uncertainty of this evaluation was around 1 ns. Compared with 30 keV

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