



An organosilicon-loaded plastic scintillator synthesized for neutron/gamma discrimination

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Abstract

In this study, we report the development of a scintillator used for neutron/gamma discrimination, which consists of a polyvinyltoluene matrix loaded with monomers of 2,4-diphenyl-1,3,2-dioxasilolane (DDS) and fluor dyes, namely 2,5-diphenyloxazole and 7-diethylamino-4-methylcoumarin, as the primary fluorophore and wavelength shifter, respectively. DDS is an organosilicon compound containing double benzene rings that facilitate fluorescence emission and radiation resistance. Several measurements were performed to explore the optical and detection properties of the scintillators, including ²³⁸Pu-Be neutron radiation tests and relative light yield measurements using a ¹³⁷Cs gamma-ray source. The results indicate that the synthesized plastic scintillators can effectively discriminate between neutrons and gamma rays. They exhibit a light output comparable to that of a commercial scintillator (EJ-200). The scintillators are inexpensive, productive, highly transparent, and somewhat soft but sufficiently hard for post-production processing (machine cutting and polishing). This design may contribute to a new strategy for highly efficient neutron/gamma discrimination in organic scintillators.

Keywords Neutron detection · Plastic scintillation · Pulse shape discrimination · Polyvinyltoluene · Organosilicon scintillator

1 Introduction

Organic scintillator-based neutron detection has been employed effectively for decades in nuclear and particle physics experiments, particularly in high-radiation environments [1–3]. However, it is always accompanied by gamma rays caused by the neutron activation of the surrounding

materials. Consequently, the ability to distinguish between neutrons and gamma rays, known as pulse shape discrimination (PSD) [4, 5], is essential for reliable neutron spectroscopy using organic scintillators, especially when detecting high-energy neutrons in the presence of gamma rays [6]. For many years, neutron detection has predominantly relied on ³He proportional counters owing to their excellent gamma rejection capability and high detection efficiency for thermal neutrons [7–9]. However, their extremely high cost prevents their widespread usage in neutron detection; consequently, an intensive search for relatively inexpensive raw materials has been stimulated. Among the PSD organic scintillators, plastic scintillators have recently emerged as promising candidates for large-scale scientific infrastructure, border security systems, and reactor monitoring applications [10]. Unlike single crystals, which are constrained by manufacturing costs, or liquid scintillators, which are limited by toxicity, flammability, and handling challenges for large-area detectors, plastic scintillators offer distinct advantages, such as low production cost, inherent safety, ease of fabrication, and the ability to be manufactured in customizable geometries [11, 12].

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The most widely used plastic scintillators are ternary systems composed of polystyrene (PS) or polyvinyltoluene (PVT) matrices doped with primary fluorophores and secondary wavelength shifters [13–15]. These aromatic hydrocarbon polymers contain benzene rings bonded to methyl (CH_3 -) and vinyl ($\text{CH}_2=\text{CH}$ -) groups. When irradiated by high-energy particles, molecular chains in such polymers undergo damage through scission and cross-linking [1], altering their chemical structure and generating free radicals that form color centers [16, 17]. These radiation-induced transformations correlate with bond dissociation energies in the polymer backbone: 3.59 eV for C-C bonds, 3.71 eV for C-O bonds, and 4.61 eV for Si-O bonds [17]. Polysiloxane, also known as an organosilicon base with a backbone of alternating Si-O-Si bonds and organic substituents, exhibits high bond energy and excellent radiation resistance. Studies have demonstrated that polysiloxane-based scintillators show no color yellowing at radiation doses of 100 kGy [18]. These scintillators are capable of discriminating neutrons in the presence of a gamma-ray background using the time-of-flight (TOF) method [19] or the PSD technique [20]. However, they are soft owing to their elastic nature. Although cross-linking strategies can improve fluorescence scintillation [21], they exhibit inherently inferior PSD performance compared to conventional PS/PVT-based systems.

In this study, we developed a novel PSD organic scintillator to combine the advantages of both pure PVT and polysiloxane matrices via copolymerization of 2,4-diphenyl-1,3,2-dioxasilolane (DDS) monomers with PVT resins and doping with 2,5-diphenyloxazole (PPO) and 7-diethylamino-4-methylcoumarin (MDAC) as the primary fluorophore and wavelength-shifting component, respectively. Through low-density self-polymerization, the DDS monomers can form linear polysiloxane segments that interpenetrate the PVT cross-linked network, resulting in bulk scintillators with some elasticity while retaining adequate rigidity for mechanical machining. The synthesized scintillators are highly transparent, cost-effective, and exhibit outstanding PSD performance. Such advantages make the scintillator a promising candidate for large-scale radiation detection applications.

2 Samples fabrication and characterization

Vinyltoluene monomers (C_9H_{10} >98%, m- and p- mixture, containing stabilizer TBC) were purchased from TCI Chemicals (Shanghai) Industrial Development Co., Ltd. DDS, MDAC, and the initiator 2,2'-Azobis(2-methylpropionitrile) (AIBN, >98%) were obtained from Shanghai Macklin Biochemical Co., Ltd. PPO was purchased from Shanghai YuanYe Biotechnology Co., Ltd., and divinylbenzene (DVB,

containing stabilizer) was obtained from Meryer (Shanghai) Chemical Technology Co., Ltd.

The synthesis procedure for the scintillator samples is similar to that described in our previous work [13]. Prior to sample preparation, vinyltoluene monomers and divinylbenzene were passed through an aluminum oxide column to remove the stabilizers and then mixed and stirred at room temperature for three minutes. The mixture was sonicated until a homogeneous and clear mixed solution was obtained. Subsequently, fluorophores (30 wt% PPO, 0.2 wt% MDAC, "wt%" weight percent), radical polymerization initiator (0.05 wt% AIBN), and cross-linking agent (2 wt% DVB) were added to the mixture, additionally stirred for 2–5 min, and transferred to glass vials with a flat bottom for ultrasonication until the dopants were completely dissolved. The mixed solution was poured into glass vials and treated repeatedly at least three times by the process of fast freezing with liquid nitrogen, vacuum degassing (3–5 min), and thawing at room temperature to completely remove dissolved oxygen. The vials were sealed in an oxygen-free atmosphere and heated in a thermostat to promote radical thermal polymerization. To prevent the occurrence of explosive polymerization, the temperature of the thermostat was maintained at 50.0 °C for two days. Then, it was slowly raised to 80.0 °C to 110.0 °C at the rate of 3 °C/h and maintained for 24 h. To prevent formation of cracks and bubbles at the annealing stage, the polymers were slowly cooled down to room temperature at the rate of 3 °C/h, then placed in a constant temperature environment at 50.0 °C to 60.0 °C for inner stress releasing. The plastic scintillators with different amounts of DDS (RK_1 to RK_5 corresponding to 20, 25, 30, 35, 40 wt% DDS contents, respectively), measuring approximately 20.0 mm in diameter and 10.0 mm in thickness, were obtained from the thermostat by carefully breaking out the vials after cooling to room temperature.

The scintillators were cut and polished to the same size as the control samples (EJ-200, EJ-276). The difference in thickness between the samples was found to be no more than 100 μm , as measured using a Mitutoyo micrometer (Mitutoyo Corp.). The Shore hardness of the samples was evaluated using a portable digital durometer (Shore A hardness meter, Taizhou AI Measurement Instrument Co., Ltd.). Five equidistant points on the flat side of each sample were measured and averaged to obtain the hardness value. Elastic recovery testing and excitation-emission spectra were performed using metallographic microscopy (BX53M, Olympus Corp.) and an FLS1000 fluorescence spectrometer (Edinburgh Instruments), respectively. The ultraviolet-visible transmission spectra were recorded using a UV-Vis spectrophotometer (PerkinElmer Lambda 750) with an emission wavelength range of 250–800 nm. Thermal decomposition behavior of the scintillators was studied in the temperature range of 30 °C to 800 °C using a thermogravimetric analyzer

(STA 449 F3 Jupiter, Netzsch GmbH, Germany), and the Fourier-transform infrared spectra (FTIR) based on a Fourier transform infrared spectrometer (Nicolet 6700, Thermo Fisher Scientific, USA) was analyzed to obtain structural and functional group information.

The scintillators were irradiated with a 20 Ci ^{238}Pu -Be neutron source installed at the University of South China to study their PSD performance using an 8-channel 14-bit 500 MS/s flash ADC waveform digitizer (CAEN DT5730). All samples were wrapped in three layers of polytetrafluoroethylene (PTFE) tape on every surface, except for the one coupled to a photomultiplier tube (PMT) Hamamatsu H1949-51 with optical dimethyl silicone (Dow Corning, PMX-200). The signals collected from the PMT anode were converted into digital waveforms and analyzed using the CAEN DPP-PSD firmware, which combines the functions of a digital QDC (charge integration) and discriminator of different shapes for particle identification. A ^{60}Co source (1.17 MeV, 1.33 MeV) in tandem with a ^{137}Cs (662 keV) source was used for electron equivalent energy calibration by Gaussian fitting to the position of the Compton edge of each source. The light output (LO) of the scintillators using the maximum position of the Compton edge in the ^{137}Cs pulse height spectra was compared with that of a commercially EJ-200 sample that had been stored for three years to determine the relative LO. To explore the stability of the samples in terms of relative LO and PSD performance, the above measurements were performed three times at intervals of 2 days, 96 days, and 172 days after preparation. The experimental setup was standardized by keeping the following parameters constant: the digitizer configuration, the PMT operated at -1600 V via a high-voltage power supply (ISEG GmbH), a 10 cm source-to-sample distance, and shielding with a lead-brick enclosure.

3 Results and discussion

3.1 Physical property

DDS is a cost-effective organosilicon compound bearing double benzene rings, and some organic dyes can be efficiently dissolved in it. Organosilicon has been demonstrated to have superior radiation resistance relative to conventional PVT- or PS-based scintillators [1, 22–25]. Therefore, it is expected that the PVT-DDS-based PSD organic scintillator will exhibit enhanced radiation stability relative to a pure PVT-based scintillator. The aromatic matrices (PVT and DDS) inherently exhibit specific optical properties: they emit fluorescence primarily in the ultraviolet region (250–380 nm) [26], and their absorption spectra show noticeable absorption starting around 380 nm, increasing sharply below 350 nm [12]. In particular, PVT exhibits

excitation and emission peaks at 266 and 310 nm, respectively, whereas DDS shows corresponding peaks at 302 and 353 nm (Fig. S1, Supplementary Materials). To minimize self-absorption by the matrix itself, primary fluorophore PPO is added to absorb the photons from the emission of the matrix and emit photons with a peak emission at 393 nm. To maintain scintillation in the blue-green region of the optical spectrum, which matches well most of the PMT spectrum sensitivity, a further fluorophore dye, namely wavelength-shifter MDAC, is chosen to shift the scintillators emission wavelength to 410–500 nm. As the primary fluorophore, PPO has high solubility in aromatic solvents, whereas MDAC, a secondary dye with high light output (LO), is used for the routine preparation of plastics. The PPO-MDAC dye pair can probably lead to excellent PSD capability of the PVT-DDS-based scintillators from the viewpoint of the basic principle of energy transfer [27]. With 20–40 wt% DDS, the synthesized scintillators are colorless and optically transparent without yellowing and surface dye precipitation to the naked eye, even after six months of preparation (Fig. 1(a)). However, when the DDS content exceeds 40 wt%, microcracks, cracking, and yellowing are observed in the scintillators (Fig. 1(b)-top).

In contrast to a pure PVT-based sample (0 wt% DDS), scintillators containing 0–30 wt% DDS and 50 wt% PPO were prepared. They remained optically transparent after 15 days of storage (Fig. 1(b)-bottom), revealing that fluorophore dissolution stability was significantly improved by DDS monomers. This may be explained by the molecular isolation within the network subdomains constructed by such functional monomers, where the spatial separation of fluorophores minimized the intermolecular interactions. Combined with our previous research [21], a conclusion may be drawn here that any small amount of functional monomers that are loaded into the host matrix of scintillator and participate in cross-linked network formation, will always help dye (solute) dispersion and then prevent the dye aggregation.

The mechanical hardness values of the scintillators (RK_1 – RK_5) were determined to be $45.5 \pm 0.8\text{ HA}$, $41.4 \pm 0.5\text{ HA}$, $39.7 \pm 0.3\text{ HA}$, $39.3 \pm 0.9\text{ HA}$, and $37.2 \pm 0.5\text{ HA}$, respectively, indicating a general decrease with increasing DDS content. As evidenced in Fig. 2, the 30 wt% DDS composite exhibited no significant spectral alterations in the FTIR spectra compared to the pure PVT matrix (0 wt% DDS), except for a distinct absorption band at 1065.59 cm^{-1} . This absorption line corresponds to the Si-O-Si vibration. The absence of both new characteristic peaks and peak shifts suggests that the incorporation of DDS does not chemically modify the polymer chain structure but rather establishes a physically compatible blended system. We speculated that during thermal polymerization, chains of low-molecular-weight siloxane derived from DDS monomers were incorporated into the PVT-based cross-linked network. This structural integration,

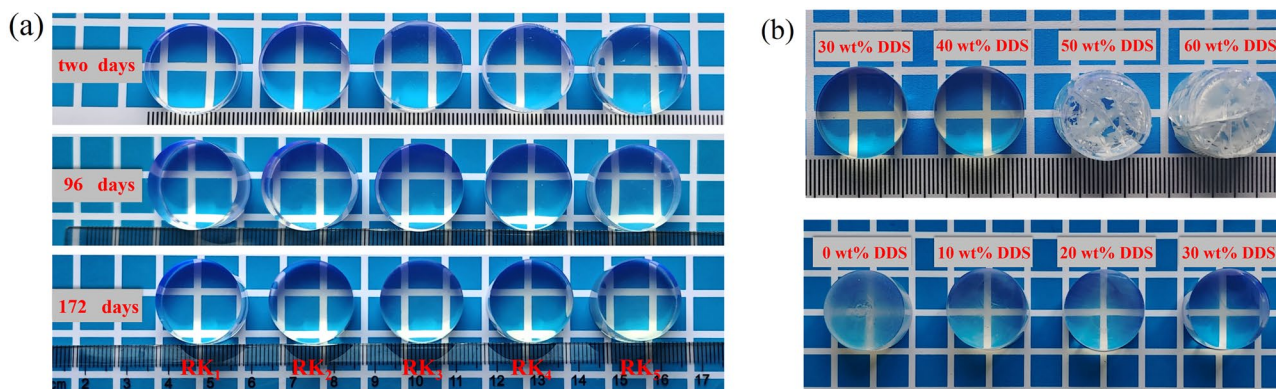


Fig. 1 (Color online) (a) Photographs of the synthesized scintillators (RK₁–RK₅) taken at the time after two, 96 and 172 days of preparation. The scintillators are stored at room temperature in an air atmosphere. (b) Top: The additional synthesized scintillators containing 30

wt% PPO and loaded 30 wt%, 40 wt%, 50 wt%, 60 wt% DDS monomers. Bottom: The additional synthesized scintillators with 50 wt% PPO and doping DDS content ranging from 0 wt% to 30 wt%

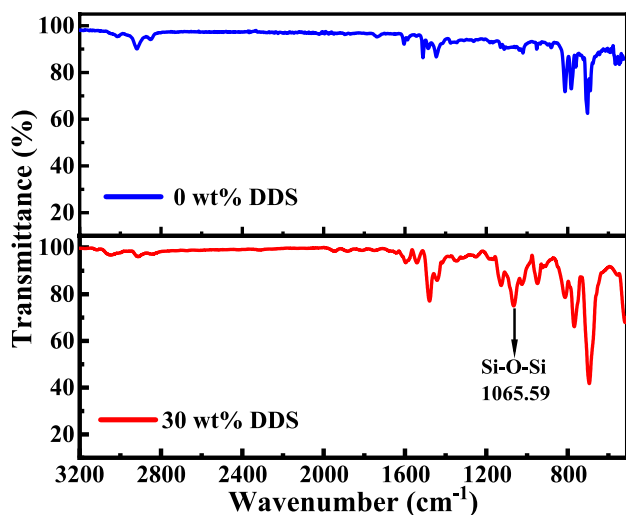


Fig. 2 (Color online) FTIR spectra of the scintillator with 0 wt% DDS and the scintillator with 30 wt% DDS (RK₃)

combined with the inherent elasticity of DDS siloxane components, likely contributes to the reduced mechanical hardness. Such a reduction is not necessarily unfavorable in terms of elastic recovery properties. To confirm this, a blunt needle with a diameter of 0.79 mm was used to press the scintillator sample (30 wt% DDS) for one minute. The time evolution of the surface morphology of a prepared scintillators (RK₃) is shown in Fig. 3 and Fig. S2 in the Supplementary Materials. The initial indentation produced by pressing exhibited a cylindrical geometry with a depth of 1.5 mm. Remarkably, within 30 s of post-compression, the indentation underwent near-complete recovery to a planar surface. After 60 s, residual deformation or surface extrusion traces were almost imperceptible, confirming that the introduction of DDS imparted elastic recovery properties

to the scintillator. This phenomenon may be attributed to the high mobility of siloxane main chains facilitated by the exceptionally low energy barriers for Si-O-Si bond bending and torsional motions [28].

Thermal stability was evaluated using thermal gravimetric analysis (TGA) under a protective nitrogen atmosphere. The temperature was increased at a heating rate of 10 °C/min from 30 °C to 800 °C. The results are shown in Fig. 4. No mass loss occurred below 120 °C. The synthesized scintillators exhibited similar thermogravimetric profiles during the first degradation stage (120–260 °C), where the samples underwent the evolution of inter- or intrachain reactions, generating low-molecular-weight products, including volatile compounds, linear oligomers, and fluorophores (PPO and MDAC). Compared with the 0 wt% DDS scintillator (decomposition temperature ~160 °C), the scintillators containing DDS started to decompose at a lower temperature, perhaps because of the presence of phase-separated domains created between the DDS and PVT constituents. Above 210 °C, the thermal degradation rate showed a slight dependence on DDS content in a complex manner requiring future study. In the second stage (260–380 °C), DDS-containing samples exhibited faster weight loss than pure PVT-based scintillators, indicating reduced thermal stability of DDS short-chain structures. During the third stage (380–800 °C), degradation continued, with 2–5% solid residue primarily consisting of SiOC carbonaceous substance from mineralization [29].

3.2 Optical performance

The synthesized scintillators utilized PVT and DDS as matrices. Critically, the emission spectra of both PVT and DDS matrices significantly overlap with the absorption spectrum of the fluorophore PPO, enabling efficient Fö

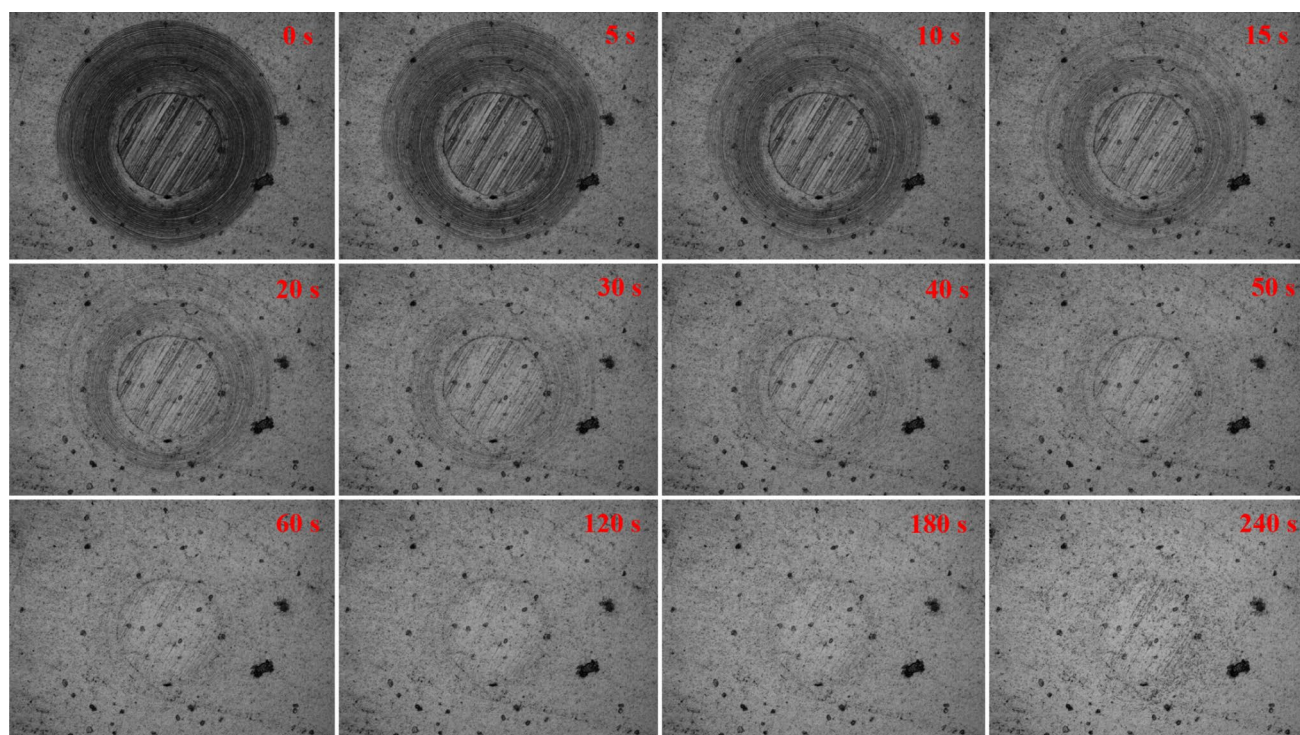


Fig. 3 (Color online) Microscope photograph of the RK₃ sample containing 30 wt% DDS, taken at the time points in the range of 0–240 s as indicated in the pictures

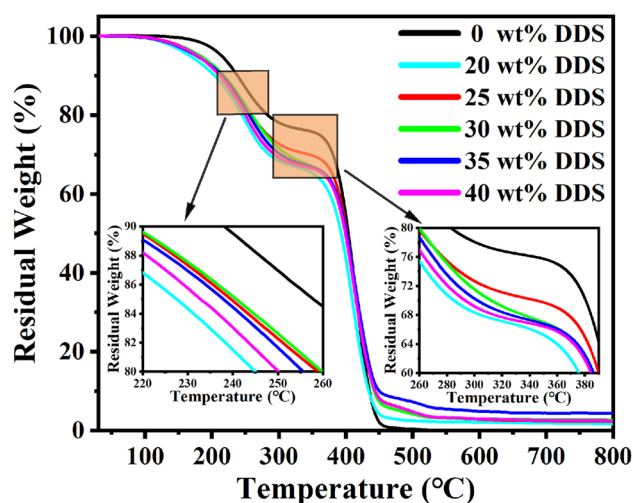


Fig. 4 (Color online) TGA curves obtained in nitrogen atmosphere for the synthesized scintillators RK₁ – RK₅ and the additional 0 wt% DDS scintillator

rather resonance energy transfer (FRET) from the matrices to PPO. To simultaneously excite the PVT and DDS matrices, a 270 nm UV source was selected. This wavelength lies well below the 310–330 nm absorption peaks of both the PPO and MDAC fluorophores, thereby minimizing direct fluorophore excitation and allowing us to

specifically investigate the resonance energy transfer originating from the excited matrices. Figure 5(a) presents the excitation-emission matrix of the RK₃ scintillator (30 wt% DDS). Under 270 nm excitation, its emission spectrum (scanned from 400–600 nm) shows a distinct 434 nm peak. The excitation spectrum over the range of 250–400 nm was monitored using a 434 nm wavelength. The prominent emission peak at 434 nm signifies the characteristic fluorescence of the MDAC dye. Notably, its presence under 270 nm excitation provides strong evidence for efficient energy transfer from the excited matrices to the MDAC dye.

Photoluminescence (PL) spectra excited at 270 nm are shown in Fig. 5(b) and Fig. S3 (Supplementary Materials). Increasing the DDS content promotes π - π stacking of the benzene moieties, enhancing exciplex formation, and resulting in broadened emission peaks with a 10–30 nm red shift. The PL intensity initially increases with DDS concentration but decreases above 30 wt% DDS. At such high concentrations, fluorescence emission is likely dominated by aggregation-caused quenching (ACQ), where dense π - π stacking creates compact molecular proximity. This facilitates electron energy level rearrangement in the matrix, primarily through splitting of ground-state and first excited-state levels. Consequently, the concentration-dependent PL intensity correlates with the scintillator's optical transparency, as both

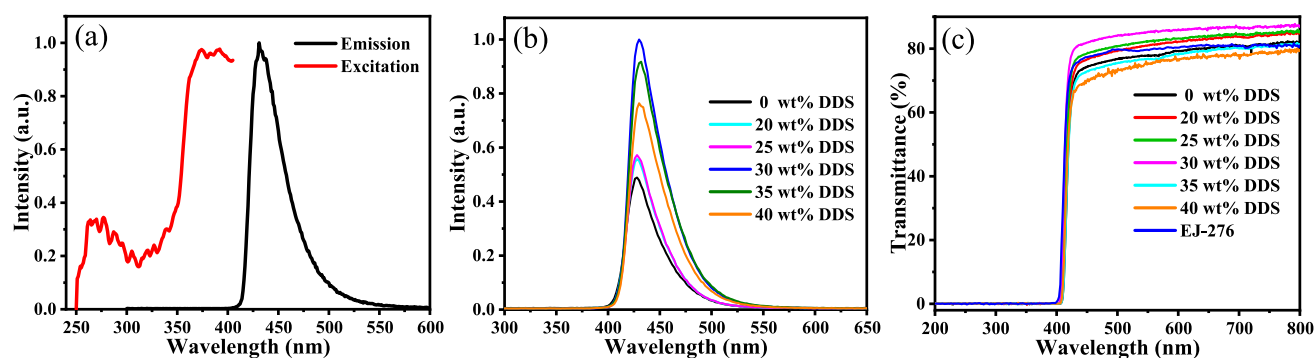


Fig. 5 (Color online) (a) Excitation-emission spectrum of the scintillator with 30 wt% DDS (RK₃). The excitation spectrum with excitation wavelengths of 250–400 nm was recorded at the 434 nm emission maximum, while the fluorescence emission spectra were induced

by a 270.0 nm-wavelength UV. (b) Emission spectra excited at 270 nm wavelength and (c) ultraviolet-visible transmittance spectra in the wavelength range of 250–800 nm for RK₁–RK₅ samples and the additional synthesized scintillator with 0 wt% DDS

phenomena originate from photon loss mechanisms in the aggregated system.

The optical transparency of the scintillators was very high (Fig. 5(c)). All samples exhibited transmittance values between 70% and 87%, which was comparable to that of the commercial scintillator EJ-276 (Fig. S4, Supplementary Materials). Within the visible spectrum, the transmittance initially increased with the DDS content up to 30 wt%. However, further increases in DDS content led to a decrease in transmittance. This non-monotonic behavior was attributed to two factors: self-absorption within the matrix material and aggregation of the dye molecules at higher DDS concentrations. Below 30 wt% DDS, monomers were sparsely dispersed. Most did not participate in thermal polymerization and acted as photon scattering centers, reducing transparency. As DDS approaches 30 wt%, dispersed monomers polymerized into linear-chain segments, enhancing transparency. However, above ~30 wt% DDS, the high density of benzene rings promoted strong π - π stacking interactions that induced fluorophore aggregation [30]. At these concentrations, numerous low-molecular-weight DDS chains embedded within the cross-linked PVT network, creating phase-separated domains with mismatched plastic deformation behaviors. This structural incompatibility generated interfacial shear stresses and micro-cracks at phase boundaries (Fig. 1(b)-top), causing the observed transparency reduction.

3.3 PSD and relative LO

The synthesized scintillators were irradiated with a ²³⁸Pu-Be source to study their PSD performance. The PSD method is based on the different proportions of the prompt and delayed components in scintillation pulses and is used to identify particles. When energetic particles pass through a scintillator, the π electrons of the scintillator molecules are ionized and recombine to produce both singlet and triplet

excited states, which promptly de-excite to the lowest singlet (S_1) and triplet states (T_1) [31]. Transition through S_1 to the ground state (S_0) with fluorescence emission on a timescale of 10^{-9} – 10^{-8} s yields the prompt component. Direct transition from T_1 to S_0 is spin-forbidden; instead, a bimolecular process of triplet-triplet interaction and annihilation ($T_1 + T_1 \rightarrow S_1 + S_0$), namely, the TTA process, occurs kinematically with subsequent de-excitation of the S_1 to S_0 ($S_1 \rightarrow S_0 + h\nu$) over a longer timescale (10^{-4} s), yielding the delayed component. The T_1 state density depends on the ionizing power of the incident particles. For a given incident energy, heavy charged particles produce more T_1 states per unit path length than light particles, resulting in a more pronounced slow scintillation component. This difference in the ratio of integrated charges between the prompt and delayed components forms the basis of the PSD method.

The PSD capability was evaluated using the charge integration method [32]. For each digital waveform, the integrations over a short-time gate (Q_{short} , fast component) and a long-time gate (Q_{total}) yield the PSD parameter: $PSD = 1 - Q_{\text{short}}/Q_{\text{total}}$, where Q_{short} is the charge integral over a short gate covering the prompt scintillation component, and Q_{total} is the integral over the full-waveform gate including the delayed component. The two-dimensional (2D) plots of PSD versus Q_{total} are shown in Fig. 6 and Fig. S5 (Supplementary Materials) for the prepared scintillators (RK₁–RK₅, and the 0 wt% DDS sample) two days after synthesis, alongside those for EJ-276. Excellent separation between neutron and gamma-ray signals was observed. The locus with higher PSD values corresponds to neutrons, whereas the locus with lower PSD values corresponds to gamma-rays. Notably, the neutron and gamma bands exhibit distinct curvature, potentially arising from PMT nonlinearity under high-voltage operation (Fig. S6, Supplementary Materials) [33, 34]. The capability of separating neutrons from gamma-rays is quantified by the figure of merit (FOM),

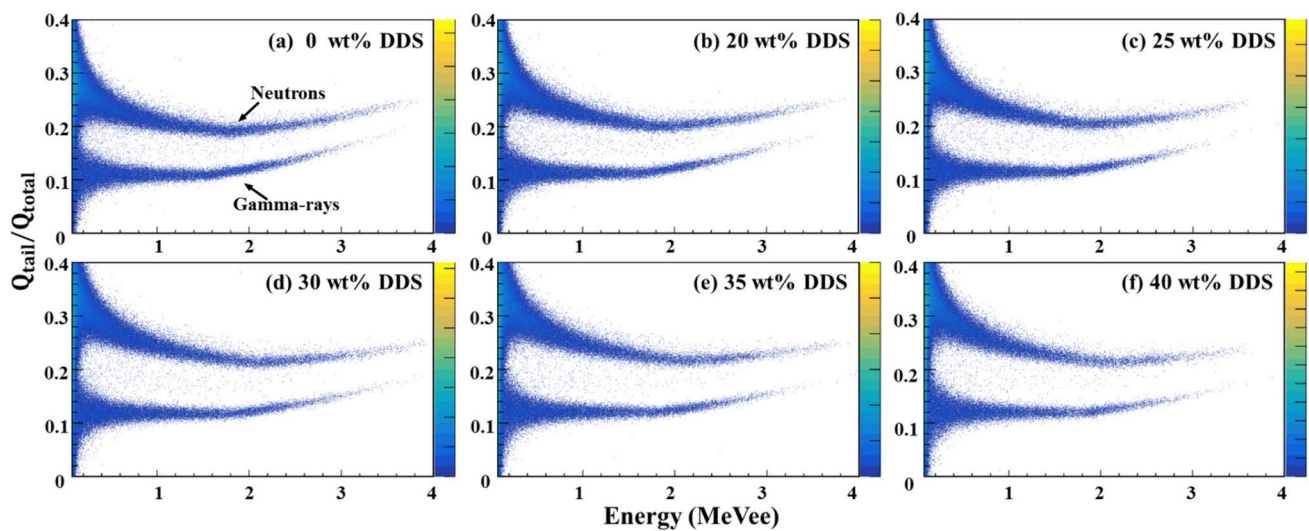


Fig. 6 (Color online) Two-dimensional PSD distributions of the synthesized RK_1 – RK_5 samples and the additional synthesized scintillator with 0 wt% DDS

defined as $FOM = S/(\sigma_\gamma + \sigma_n)$. Here, S represents the separation between the gamma and neutron distribution peaks, and σ_γ (σ_n) denotes the full width at half-maximum (FWHM) of the gamma (neutron) peaks in the one-dimensional PSD distribution. These parameters were obtained using Gaussian fitting. Consequently, the PSD FOM depends on two factors: the neutron/gamma peak separation (S) and their respective widths. Increasing the LO reduces the FWHM of both distributions, thereby enhancing the PSD FOM [27].

To quantitatively assess the dependence of the PSD capability on the DDS concentration, we extracted the PSD values within the Q_{total} range of 0.2–1.2 MeVee (MeVee is the MeV electron equivalent energy) from the 2D distributions. Figure 7(a) plots the calculated FOM values against the DDS concentration, whereas Fig. 7(b) shows the FOM values calculated within each interval of $Q_{total} - 0.1$ to $Q_{total} + 0.1$

bins (in units of MeVee) for the prepared scintillators (black dots). As clearly demonstrated in Fig. 7(b), each scintillator achieves superior neutron/gamma separation with an FOM of 1.27 at Q_{total} values down to 0.15 MeVee. The value 1.27 is typically recognized as the FOM threshold for efficient pulse shape discrimination (PSD) [11].

The LO of the prepared scintillators was studied using a ^{137}Cs source by comparing the Compton edge positions in their pulse height spectra with those of the EJ-200 standard (Fig. S7, Supplementary Materials). As shown in Fig. 7(c), the LO relative to EJ-200 exhibits an overall decreasing trend within the calculated uncertainties as the concentration of the DDS monomer increases. Conversely, the neutron/gamma PSD capability, quantified by the FOM, shows a slight concentration-dependent enhancement before reaching a plateau (Fig. 7(a)). This apparent inverse correlation

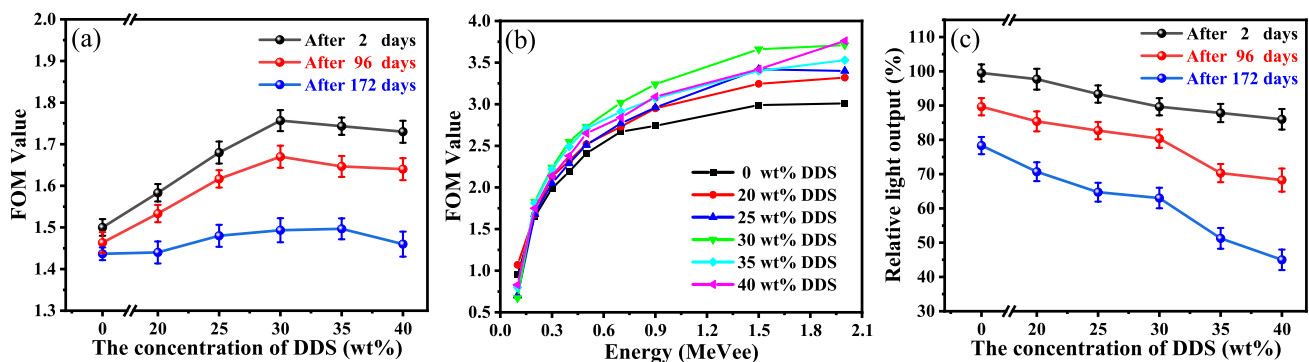


Fig. 7 (Color online) (a) The obtained FOM values evaluated over the energy range of 0.2 to 1.2 MeVee, (b) dependence of the FOM values calculated within the each interval of $Q_{total} - 0.1$ to $Q_{total} + 0.1$ bins (in unit of MeVee), where Q_{total} values are selected in the range

of 0.12 to 1.9 MeVee, and (c) relative LO as a function of the DDS concentrations for the prepared scintillators (RK_1 – RK_5) and the scintillator containing 0 wt% DDS

between PSD performance and LO is likely attributed to the formation of a more efficient triplet (T_1) state energy transfer network. This network arises from the gradual substitution of PVT with DDS, which increases the density of benzene rings that are required for triplet energy migration. Furthermore, the enhanced dissolution of fluorophores facilitated by DDS incorporation likely affects the local T_1 excitation density and the efficiency of the TTA process governing the neutron/gamma separation parameter S .

Long-term stability was evaluated through repeated measurements at 96 and 172 days after synthesis (Fig. 7a and c). After approximately six months of aging, the synthesized scintillators exhibited reductions of 9–16% in FOM and 27–41% in LO relative to their initial values. This degradation highlights a significant challenge. Although the incorporation of DDS offers potential advantages in terms of radiation resistance and PSD performance, the observed aging effects, likely stemming from factors such as fluorophore aggregation and potential matrix instability at higher DDS loadings (as suggested by Fig. 1(b)), or chemical degradation pathways, currently limits the practical long-term utility of these materials. Addressing this stability issue, potentially through optimized fluorophore selection, stabilization additives, or refined matrix compositions, is crucial for realizing the promising PSD performance of PVT-DDS-based scintillators for demanding applications.

4 Summary

Organic scintillators based on PS and PVT are widely used in many fields, from nuclear physics experiments to safeguard equipment. However, the main drawback of these materials is their poor radiation resistance. The breaking of the C-C and C-H bonds results in the generation of free radicals and hydrogen release from the polymer, which gives rise to yellowing and a reduction in light yield and transparency. One approach to circumvent this problem is to replace or partially replace the materials with polysiloxane polymers with higher radiation hardness. In this work, we successfully developed a new elastic scintillator by incorporating a 20–40 wt% siloxane compound, DDS, into the PVT matrix for neutron/gamma discrimination. The obtained organosilicon-loaded plastic scintillators are mixtures of PVT and siloxane-based matrices (DDS). They are transparent, mechanically hard enough for machining and polishing, and allow for excellent discrimination between neutrons and background gamma rays. Performance characterization has shown that the addition of DDS increases the elasticity of the scintillator and improves the solubility of dye molecules by preventing their aggregation. Although the PVT-DDS-based scintillators exhibit excellent PSD performance, they also show a decreased light yield (98–86%

LO with respect to EJ-200) as the DDS concentration (RK_1 – RK_5) increases, implying that the radioluminescence in such scintillators is not favorable compared to that in PVT-based scintillators. Measurements at different times after preparation indicate that the stability in terms of PSD and LO still needs to be improved. Our future work will focus on the investigation of cross-linked networks in scintillators synthesized through copolymerization and homopolymerization, aiming to understand the singlet and triplet exciton migration required for an efficient PSD capability of organosilicon-loaded scintillators. Nevertheless, the newly designed organosilicon-loaded plastic scintillator is promising for the fabrication of next-generation neutron detectors used under high-dose irradiation.

Supplementary file 1 (DOCX 19 kb)Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s41365-026-01973-8>.

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Author contributions All authors contributed to this study. The design and preparation of the scintillators were done by Wei-Rong Liu, Ying-Du Liu, and Jie Bao. The experimental measurements were performed by Wei-Rong Liu, Zhi-Yun Zhu and Si-Yu Zhang. Data analysis was performed by Wei-Rong Liu and Peng-Cheng Shi. Wei-Rong Liu and Peng-Cheng Shi wrote the first draft of the manuscript, and all authors commented on the previous versions of the manuscript. All authors have read and approved the final version of the manuscript.

Data availability The data that support the findings of this study are openly available in Science Data Bank at <https://cstr.cn/31253.11.sciencedb.j00186.00792> and <https://www.doi.org/10.57760/sciencedb.j00186.00792>.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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