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Polysulfone as a scintillation material without doped fluorescent molecules

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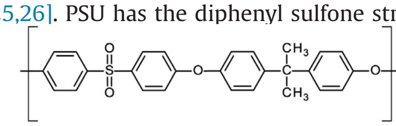
ABSTRACT

Scintillation materials made from un-doped aromatic ring polymers can be potentially used for radiation detection. Here we demonstrate that Polysulfone (PSU) works without doped fluorescent guest molecules, and thus broadens the choices available for radiation detection. The transparent PSU substrate (1.24 g/cm^3) significantly absorbs short-wavelength light below approximately 350 nm. Visible light absorption colours the substrate slightly yellow, and indigo blue fluorescence is emitted. The fluorescence maximum occurs at the intersection of the 340-nm excitation and 380-nm emission spectra; thus the emission is partially absorbed by the substrate. An effective refractive index of 1.70 is derived based on the wavelength dependence of the refractive indices and the emission spectrum. A peak caused by 976-keV internal-conversion electrons from a ^{207}Bi radioactive source appears in the light yield distribution. The light yield is equivalent to that of poly (phenyl sulfone), which has a similar structure. Overall, un-doped PSU could be a component substrate in polymer blends and be used as an educational tool in radiation detection.

1. Introduction

Scintillation materials based on aromatic ring polymers, such as polystyrene (PS) and poly (vinyltoluene) (PVT), have been used for over half a century [1–3]. The optical characteristics of their base substrates have been significantly improved by advanced refining techniques, and a previously unknown fluorescence mechanism in these scintillation materials was revealed [4–7]. In addition, aromatic ring polymers no longer need doped fluorescent guest molecules to detect radiation [8–13]. Useful aromatic ring polymers include poly (ethylene naphthalate), which has a 420-nm emission maximum and is used in radiation survey metres as an effective alternative for more common scintillation materials [14,15]. Others include polycarbonate and poly (ethylene terephthalate), which are common industrial plastics that can serve as educational materials for radiation detection [16–18].

Blends of aromatic ring polymers are also found in scintillation materials [19,20]. These include transparent polymers with diphenyl sulfone groups, such as poly (ether sulfone) (PES) or poly (phenyl sulfone) (PPSU) [21–24]. Polysulfone (PSU) exhibits heat and hydrolysis tolerance, chemical inertness, and toughness; thus it has been used in coffee machines, showers, and hot water plumbing [25,26]. PSU has the diphenyl sulfone structure:



Here, we examine PSU for radiation detection, and compare it with PPSU, which has a similar structure [24].

2. Material and methods

Extrusion-moulded PSU resin (P-1700 NT; Solvay Specialty Polymers Co., Ltd.) was shaped into a 31 × 31 × 5-mm^3 plate and polished. PSU absorption and fluorescence spectra were acquired with a UV–vis photometer (V-670; JASCO Co.) and a fluorescence spectrometer (F-2700; Hitachi High-Technologies Co.), respectively. Refractive indices for the 405-nm mercury h line, the 486-nm and 656-nm hydrogen F and C lines, and the 589-nm sodium D line were measured with a refractometer (PR-2; Carl Zeiss Jena).

The PSU light yield was generated by mono-energetic, 976-keV internal conversion electrons emitted from a ^{207}Bi radioactive

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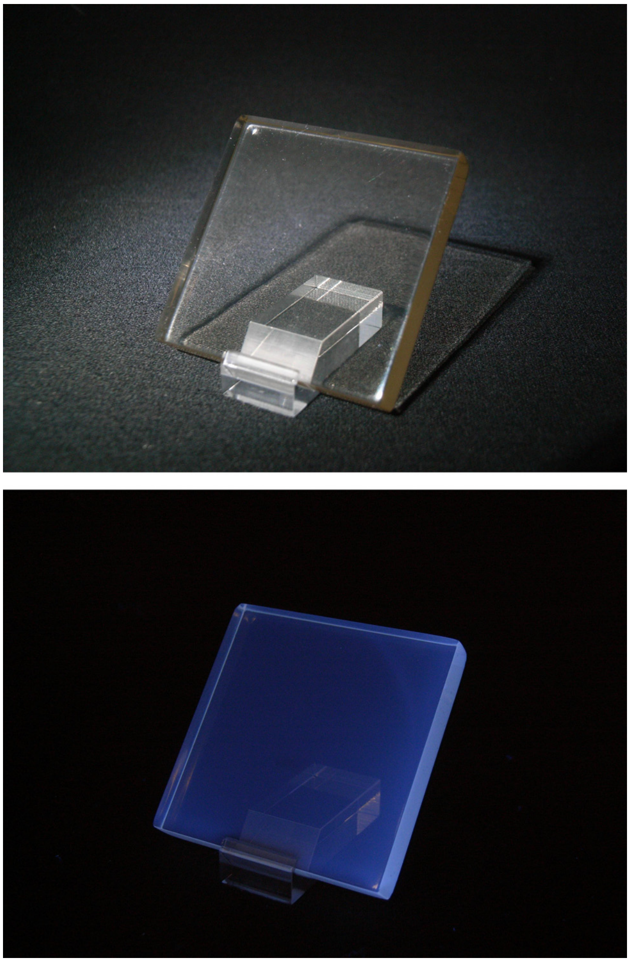

Fig. 1. A slightly yellow transparent PSU substrate (Top). Indigo fluorescence induced by ultra-violet light (Bottom). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

source (BIRB1083; High Technology Source Ltd.). The source was placed in the centre of one $31 \times 31\text{-mm}^2$ face, while the light emitted from the opposite face was detected with a photomultiplier tube (PMT; R878-SBA, Hamamatsu Photonics Co., Ltd.), mounted via optical grease (BC-630; Saint-Gobain Ceramics & Plastic Inc.). The PMT signals were fed directly into a charge-sensitive analogue-to-digital converter (RPC-022; REPIC Co.).

3. Results and discussion

The density of PSU substrate was determined to be 1.24 g/cm^3, which is slightly lower than that of PPSU (1.29 g/cm^3). Figure 1 shows a transparent PSU substrate emitting indigo blue fluorescence when exposed to ultra-violet light. Because of UV–vis photometer detection limits, the PSU absorbance was measured by using a 0.1-mm thick sheet. Figure 2 shows that PSU significantly absorbs short-wavelength light below approximately 350 nm. It can also be seen from the visible light absorption, that the substrate is slightly yellow.

For fixed excitation wavelengths, the PSU emission intensity was monitored as function of wavelength. Emission spectra acquired for excitations over the range 250 – 500 nm are displayed as a two-dimensional map in Fig. 3. High fluorescent intensity is plotted with light colours, and the diagonal line where the excitation wavelength coincides with the emission wavelength, is

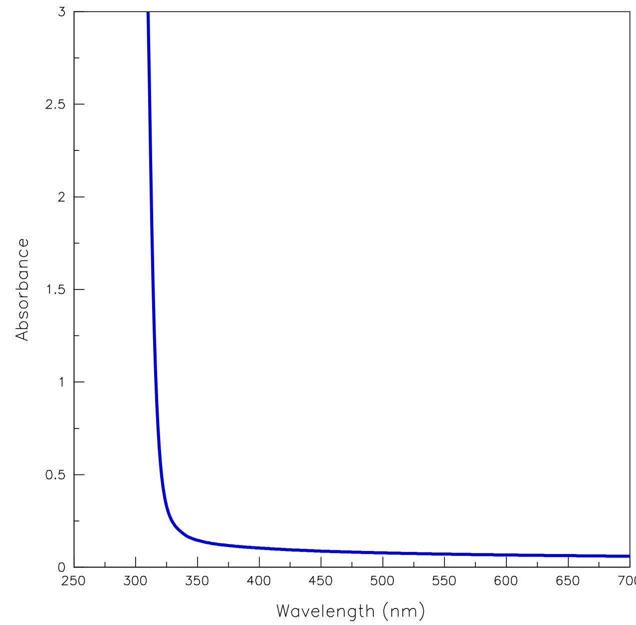

Fig. 2. UV–vis absorbance by a 0.1-mm-thick PSU sheet.

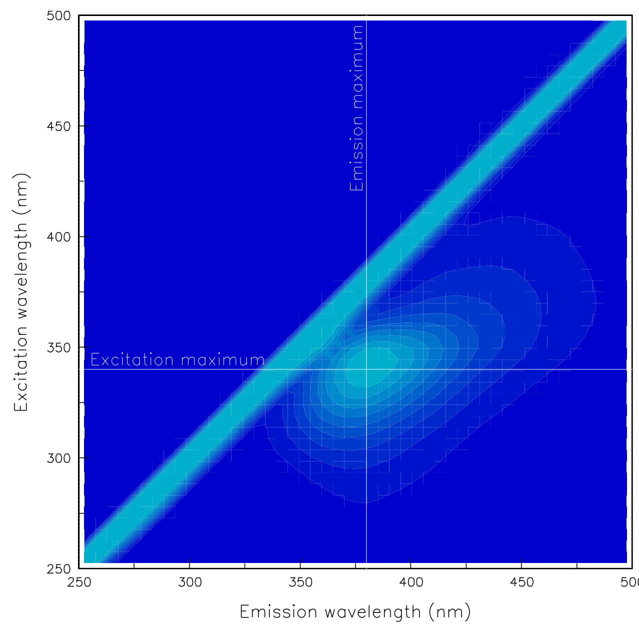

Fig. 3. PSU fluorescence. The intersection of the two white lines from each axis is the maximum fluorescence. Stray light in the fluorescence spectrometer appears as the diagonal line. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

caused by stray light in the fluorescence spectrometer. The PSU fluorescence has a peak at the intersection of the 340-nm excitation and 380-nm emission spectra. The 340-nm excitation maximum was the same as that of PPSU, whereas the 380-nm emission maximum was slightly shorter than that of PPSU (390 nm). The excitation and emission spectra for the PSU fluorescence maximum are extracted from the map in Fig. 3 and re-plotted in Fig. 4. The spectra are similar to those for PPSU, and it can be seen from Fig. 2 that PSU partially absorbs the fluorescence emission. The emission wavelengths fell within the standard PMT sensitivity range.

The PSU refractive indices for the four atomic lines are plotted in Fig. 5. Because of the wavelength dependence, the refractive