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Optical characteristics of pure poly (vinyltoluene) for scintillation applications

Hidehito Nakamura [a,b,*], Yoshiyuki Shirakawa [b], Nobuhiro Sato [a], Hisashi Kitamura [b], Osamu Shinji [c], Katashi Saito [c], Sentaro Takahashi [a]

[a] Kyoto University, 2, Asashiro-Nishi, Kumatori-cho, Sennan-gun, Osaka 590-0494, Japan
[b] National Institute of Radiological Sciences, 4-9-1, Anagawa, Inage-ku, Chiba 263-8555, Japan
[c] Kuraray Co., Ltd., 2-28, Kurashiki-cho, Tainai, Niigata 959-2691, Japan

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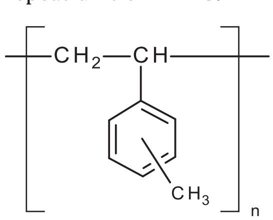
ABSTRACT

Advanced refining techniques have enabled the application of high-purity aromatic ring polymers with favourable scintillation characteristics for radiation detection, without requiring doped fluorescent guest molecules. Here, we show the optical characteristics of pure poly (vinyltoluene) (PVT). It has a 285-nm excitation maximum and a 315-nm emission maximum. The effective refractive index is 1.66, which was derived from its emission spectrum. Light yields were determined by irradiation with ^{137}Cs and ^{207}Bi radioactive sources. The light attenuation length is an unexpectedly high 40.5 ± 0.3 mm. These results indicate that thick samples of undoped PVT can be used as effective scintillation materials, and will stimulate future applications.

1. Introduction

When excited by radiation, organic scintillation materials with doped fluorescent guest molecules generate light at detectable wavelengths *via* base substrates composed of aromatic ring polymers [1,2]. Critical optical characteristics for radiation detection include the excitation and emission wavelengths, refractive indices, and light attenuation lengths [3–5]. State-of-the-art refining methods produce aromatic ring polymers with high purity [6]. These substrates have favourable characteristics for radiation detection that do not require fluorescent guest molecules, and thus they are becoming attractive scintillation materials [7–18]. Examples include common polymers such as poly (ethylene terephthalate) and polycarbonate [19–23].

Poly (vinyltoluene) (PVT) has been used for many years as a base substrate for doped scintillation materials. The structural repeat unit of PVT is:



* Corresponding author at: Kyoto University, 2, Asashiro-Nishi, Kumatori-cho, Sennan-gun, Osaka 590-0494, Japan. Tel./fax: +81 72 451 2463.
E-mail address: hidehito@rri.kyoto-u.ac.jp (H. Nakamura).

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The attenuation length for short-wavelength light emitted from PVT has been reported to be several millimetres [24]. This limits the quantities and types of fluorescent guest molecules that can be used. Here, we characterise the optical characteristics of undoped, high-purity PVT and demonstrate that it is a suitable scintillation material for radiation detection.

2. Materials and methods

A 60–40% mixture of *meta* and *para* vinyltoluene monomer (98% purity, Wako Pure Chemical Industries, Ltd.) was distilled to reduce the level of p-tert-butylcatechol inhibitor to <1 ppm. The monomer was then poured into a glass vessel through a 0.2-μm membrane filter and vacuum-encapsulated. Polymerisation was performed without initiators in an oil bath. In this way, coloration and impurities, caused by thermal degradation or oxygen contamination, were reduced in the PVT. Polymerisation was 98.0%, with an average molecular weight of 550,000 and a density of 1.02 g/cm^3.

A single PVT sample was cut into 62×62 mm^2 blocks with thicknesses of 5, 15, 25, and 35 mm. All surfaces for each block were polished. Fluorescence from the PVT was characterised with a fluorescence spectrophotometer (F-2700; Hitachi High-Technologies Co.). To characterise the refractive index of a scintillation material in detail, it is important to take into account its emission spectrum. Thus, the wavelength dependence for the PVT refractive index was acquired with a refractometer (PR-2; Carl Zeiss Jena) at the g line of a mercury lamp (436 nm), the F and C lines of a hydrogen lamp (486 and 656 nm), and the D line of a sodium lamp (589 nm).

Figure 1 is a schematic of the experimental arrangement for determining the PVT light yields. The samples are excited by ^{137}Cs (CS21; Japan Radioisotope Association) or ^{207}Bi (BIRB4391; High Technology Source Ltd.) radioactive sources that emit monoenergetic internal conversion electrons. The light was detected with a short-wavelength-sensitive photomultiplier tube (PMT; R878-SBA, Hamamatsu Photonics Co., Ltd.) [4]. The PMT window was interfaced to a 62 × 62 mm^2 block faces *via* a thin layer of optical grease (EJ-550; Eljen Technology), while the radioactive sources were positioned at the centre of the opposite face. A 12 bit charge-sensitive ADC (RPC022; REPIC Co.) was used to digitise output pulses from the PMT.

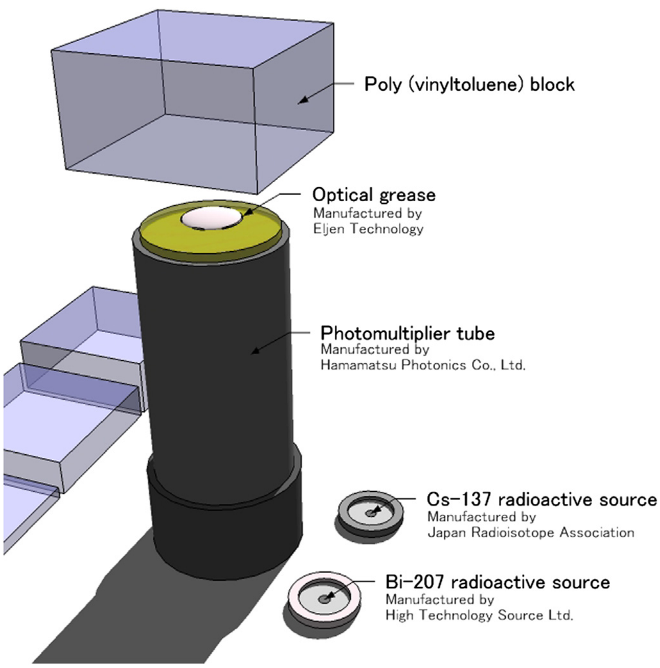

Fig. 1. Apparatus for acquiring light yields from PVT excited by a radioactive source. High-purity 62 × 62-mm^2 PVT blocks with thicknesses of 5, 15, 25, and 35 mm were used. ^{137}Cs- and ^{207}Bi-radioactive sources were positioned at the centre of the 62 × 62 mm^2 face.

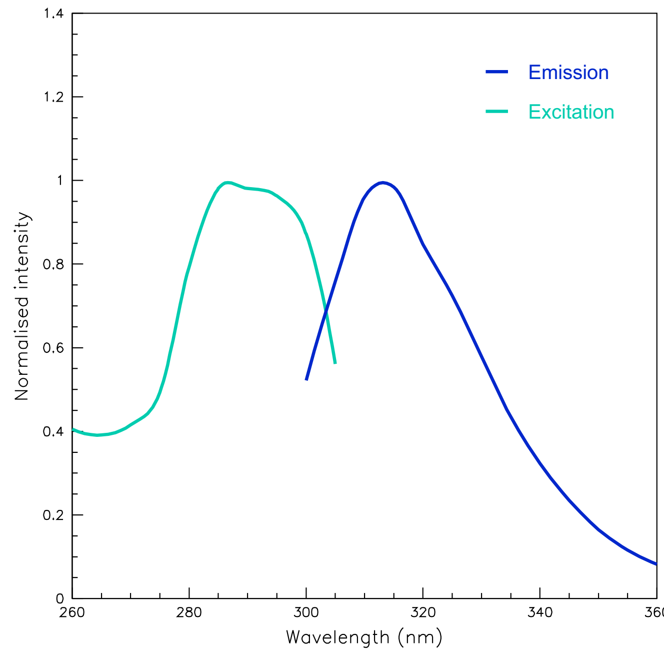

Fig. 3. PVT excitation and emission spectra. The excitation spectrum (green) was monitored at the 315-nm emission maximum, while the emission spectrum (blue) was acquired at the 285-nm excitation maximum. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

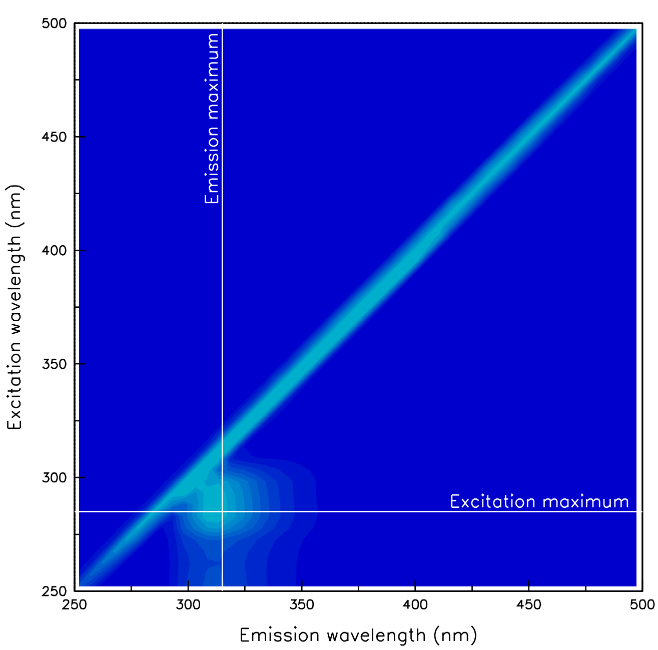

Fig. 2. Correlation between excitation and emission wavelengths for PVT fluorescence. The white lines are the 285-nm excitation and the 315-nm emission maxima. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

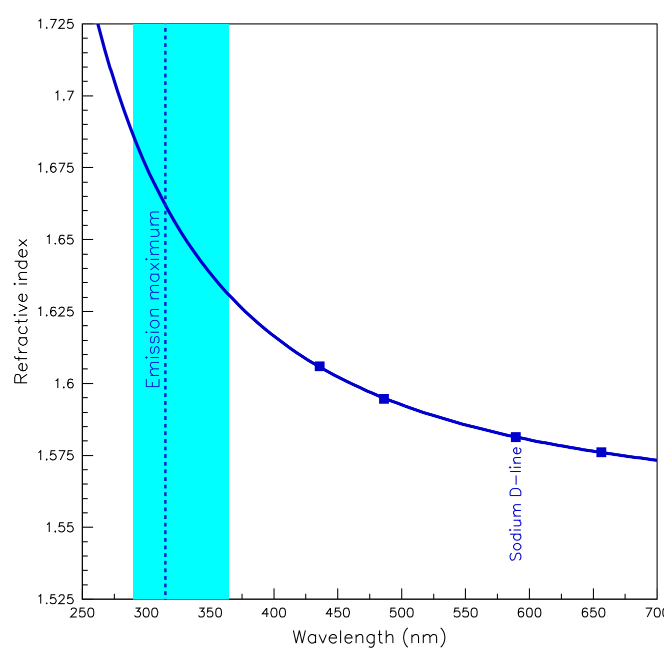

Fig. 4. PVT refractive indices at specific wavelengths. The dominant emission is highlighted in light blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)