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Technical note

Optimised mounting conditions for poly (ether sulfone) in radiation detection

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HIGHLIGHTS

- Mounting conditions for PES in radiation detection are optimised.
- Optical coupling, surface treatment, and background sources are discussed.
- Absorption by optical grease of short-wavelength light emitted from PES was negligible.
- Despite the high effective refractive index for PES, light yield was increased by surface roughness.
- Radiation background from the PES plate itself was not above the ambient level.

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ABSTRACT

Poly (ether sulfone) (PES) is a candidate for use as a scintillation material in radiation detection. Its characteristics, such as its emission spectrum and its effective refractive index (based on the emission spectrum), directly affect the propagation of light generated to external photodetectors. It is also important to examine the presence of background radiation sources in manufactured PES. Here, we optimise the optical coupling and surface treatment of the PES, and characterise its background. Optical grease was used to enhance the optical coupling between the PES and the photodetector; absorption by the grease of short-wavelength light emitted from PES was negligible. Diffuse reflection induced by surface roughening increased the light yield for PES, despite the high effective refractive index. Background radiation derived from the PES sample and its impurities was negligible above the ambient, natural level. Overall, these results serve to optimise the mounting conditions for PES in radiation detection.

1. Introduction

Advances in materials refining techniques and in ultraviolet photodetectors have resulted in the discovery of previously unknown characteristics of aromatic ring polymers (Nakamura et al., 2013a, 2013b). Examples include poly (ethylene terephthalate) (PET) and poly (ethylene naphthalate) (PEN), which are used in radiation detection (Nakamura et al., 2010, 2011). One of their advantages is that they do not need doped fluorescent guest molecules to function as scintillation materials. Now, worldwide efforts are being made to identify other potential polymers, and to characterise light propagation generated in them (Kumar et al., 2012; Nagata et al., 2013a, 2013b; Nakamura et al., 2012, 2013c, 2014a; Sen et al., 2012). In addition, there is also an effort to develop prototypes for radiation detectors that use aromatic ring polymers (Shirakawa et al., 2013a, 2013b).

There recently have been reports on the use of undoped poly (ether sulfone) (PES) as a scintillation material (Nakamura et al., 2014b). However, relative to PET and PEN, PES has short emission wavelengths, while its effective refractive index, based on its emission spectrum, is high (Nakamura et al., 2014c). These characteristics directly affect the propagation of light generated in PES to external photodetectors (Beringer et al., 2012; Leo, 1992; Knoll, 2010; Sellmeier, 1871). It is also important to examine the presence of background radiation sources in manufactured PES (Nakamura et al., 2013d). Here, we characterise the optical coupling, surface treatment, and background levels for PES.

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Overall, these results help to optimise the mounting conditions for PES in radiation detection.

2. Materials and methods

PES resin (4100G; Sumitomo Chemical Co., Ltd.) was formed into two $31 \times 31 \times 5$ mm^3 plates. Amber-coloured, transparent PES possesses sulfur in the repeat unit and its density is 1.37 g/cm^3. The emission maximum is 350 nm, and the effective refractive index of 1.74 was determined by taking into account its emission spectrum (Nakamura et al., 2014b). To boost the detectable light yield, all six faces of one plate were roughened by a milling machine (VHR-G; Shizuoka Machine Tool Co., Ltd.). The other plate was unmodified and was also examined for background sources.

To determine the light yield from the roughened PES plate, a radioactive source was positioned at the centre of a 31×31 mm^2 face to excite the plate. The sources were ^{137}Cs (CS21; Japan Radioisotope Association) and ^{207}Bi (BIRB4391; High Technology Source Ltd.). The light yield was detected with a photomultiplier tube (PMT, R878-SBA; Hamamatsu Photonics Co., Ltd.) mounted on the opposite 31×31 mm^2 face. A charge-sensitive analogue-to-digital converter (RPC022; REPIC Co.) was used to digitise the output signals from the PMT. Between the PES plate and the PMT window was a thin layer of optical grease (BC-630; Saint-Gobain Ceramics & Plastic Inc.). Light absorbance by the grease was determined by a UV–vis photometer (V-670; JASCO Co.) by placing it in a 2-mm thick optical cell formed by two quartz windows.

To assess background radiation emitted from the PES plate itself, alpha and beta particles were measured with a background counter (LBC4351; Hitachi Aloka Medical, Ltd.) equipped with ZnS (Ag) and plastic scintillators. Gamma-rays were measured with a shielded germanium detector (IGC3019SD; Toshiba Co.). The energy and detection efficiency of the germanium detector were calibrated with standard gamma-ray sources.

3. Results and discussion

The absorption spectrum for the 2-mm thick optical grease is shown in Fig. 1. It overlaps a section of the PES emission spectrum. However, the thickness of the grease used to couple the PES plate to the PMT window is less than 0.1 mm; thus absorption of light emitted from the PES should be negligible.

The light yield distribution excited by radiation from the ^{137}Cs radioactive source is plotted in Fig. 2. The small peak is from 624 keV internal conversion electrons. The counts in the low light yield region are predominately from beta particles with an endpoint-energy of 514 keV, with smaller contributions from Compton recoil electrons generated by gamma-rays. The light yield distribution excited by radiation from the ^{207}Bi radioactive source is plotted in Fig. 3. The large peak is from 976 keV internal conversion electrons. The counts in the low light yield region are primarily from Compton recoil electrons generated by gamma-rays; the light yield from 482 keV internal conversion electrons is included in the counts. It was determined that the light yields from the PES plate having all six faces roughened were 1.02 times than those from the unmodified plate. Thus, diffuse reflections provided by the surface treatment helped to efficiently propagate the light generated in PES to the external photodetector, despite the high effective refractive index.

Alpha and beta particle emission from the PES plate were below the detection limit of the background counter. The energy spectrum of the gamma-rays emission is plotted in Fig. 4.

There was no significant emission from the PES sample above the natural background (absence of plate). Activities for the

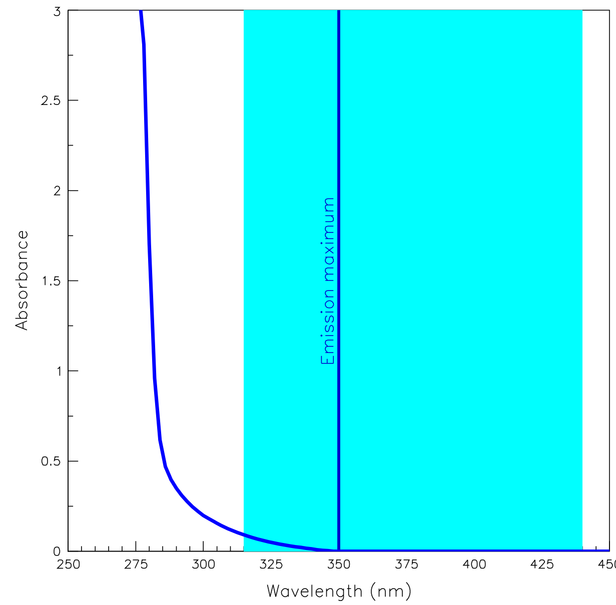

Fig. 1. Absorption spectrum of the optical grease used between the PES sample and the PMT window. The highlighted region (light blue) shows the emission spectrum of PES, where the maximum is 350 nm. The thickness of the grease used to couple the PES to the PMT is less than 0.1 mm; here it is 2 mm thick. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

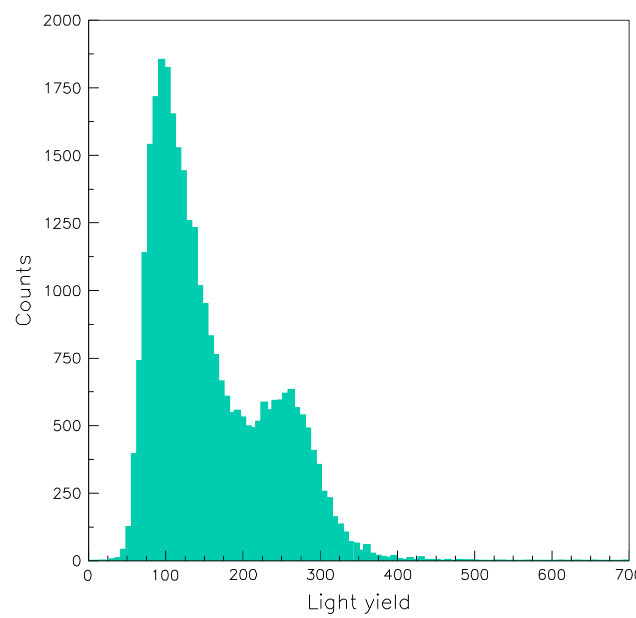

Fig. 2. Light-yield distribution from a PES plate that had all six faces roughened, when excited by radiation from a ^{137}Cs radioactive source. The small peak is from 624-keV internal conversion electrons. The counts for the low light-yield region are predominately from beta particles with an endpoint-energy of 514 keV, with smaller contributions from Compton recoil electrons generated by gamma-rays.

detected radioactive nuclides are listed in Table 1. In summary, the results indicate that radiation background derived from the PES and its impurities was not above the ambient level.

4. Conclusions

We have characterised the optical coupling, the surface treatment, and the background sources for PES. There was negligible