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Scintillation characteristics on anthracene-doped naphthalene crystal for ^{137}Cs-γ ray source

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Abstract

In this paper, we report scintillation characterizations on anthracene-doped naphthalene (NA) crystal. Crystals of this scintillator have been grown using the Bridgman-growth process. The peak of NA crystal emission is at 425 nm. The luminescence intensity of the NA crystal is 3 times that of pure naphthalene crystal. Naphthalene when doped with anthracene has high light output and fast principal decay constant (<30 ns). For 662 keV γ rays (^{137}Cs source), energy resolution of 18% (FWHM) has been recorded at room temperature for NA crystals coupled to a photomultiplier. The pulse height of NA is 10 times greater than the pure naphthalene crystal. The NA detector exhibited a good timing performance compared to *trans*-stilbene detector.

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Keywords: Bridgman technique; Aromatic organic materials; Scintillation detector; X-ray diffraction

1. Introduction

Scintillation spectrometers are widely used in detection and spectroscopy of X-rays and γ-rays [1]. Broser and Kallman [2] discovered that γ-rays could be detected with high efficiency using a naphthalene crystal and photomultiplier. Many organic and inorganic scintillators have become available since then and a complete discussion of the scintillation counter is given by Birks [3]. Common applications of scintillation spectrometers include medical imaging, nuclear and particle physics, non-destructive evaluation, nuclear non-proliferation, environmental monitoring, and X-ray diffraction. There are a variety of radiation detector applications that desire scintillators with high light output, good attenuation power, and a low level of afterglow, but absolutely require a fast scintillation decay time. This is particularly true for positron emission tomography and γ-ray/α particle discrimination via time-of-flight techniques. The scintillators in some security inspection systems must have decay constants less than 50 ns [4].

Naphthalene is the first organic scintillator [2] and then anthracene was introduced as an efficient scintillation material, which is 5 times better than naphthalene [5]. However, anthracene is not easily purified and the production of perfect crystals is quite difficult. The naphthalene crystals containing small amounts of anthracene as an impurity are as easy to grow as pure naphthalene, but give a greater scintillation response [6]. Energy resolution of anthracene is better than stilbene and plastic scintillator NE213 [7]. Many reports [8–19] are available for anthracene-doped naphthalene (NA) crystals with various characterization analyses like the scintillation response for various charged particles, decay time spectra, emission spectra, energy transfer analysis, etc. The reports concluded that NA crystals show better scintillation performance than pure naphthalene crystals.

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To the best of our knowledge, no one has so far actually recorded the energy spectrum and time response spectrum for naphthalene crystals for γ-rays. In this communication, we report the overall scintillation characterizations including the energy and time-resolved spectral studies for naphthalene crystals using the ^{137}Cs γ-ray source.

2. Preparation of naphthalene:anthracene (NA) crystals

Naphthalene and anthracene purchased from Aldrich were purified by recrystallization from ethanol and by zone refining. NA has been grown using Selective Self Seeding Bridgman method which is proposed by Arulchakkaravarthi et al. [20]. Multiple twinning, multi-nucleations, and impurity effects on nucleation were all sorted out by the above method. In the most careful preparation, different procedures may lead to pulse height variations of 20% in scintillators [6].

Borosilicate glass ampoule was used as a crucible and zone-refined naphthalene and anthracene (10^{-2} mole) powders (99.99%, Aldrich) were loaded in such an ampoule, which was then sealed. These ampoules were then dropped through a two-zone furnace. The upper zone of the furnace was kept at a temperature of 85 °C, which is above the melting point of naphthalene (80 °C). This allowed the constituents to mix well and the anthracene dissolved in the molten phase. The lower zone of the furnace was kept at 40 °C. As a result, NA crystals were formed as the ampoule entered the lower zone. The NA crystals have been grown by the Bridgman's method using a precise crystal puller. The inner tube was borosilicate glass of 15 mm diameter and 150 mm height. In this way, crystals of 15 mm diameter and 50 mm length have been obtained. A portion of the grown crystal with 15 mm diameter and 20 mm length is shown in Fig. 1.

3. Scintillation properties

Scintillation properties of NA crystals have been characterized. This included measurements of emission spectrum, energy spectrum, time resolution and decay time constants of NA.

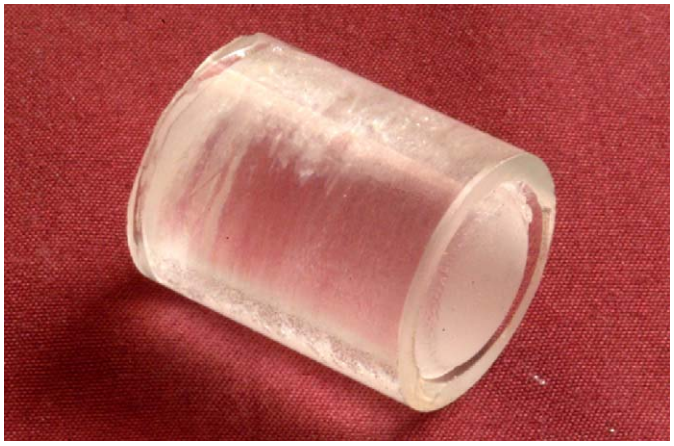

Fig. 1. NA crystal for characterization studies.

4. Emission spectrum

The NA crystal was excited with radiation from a FlouroMax-2 equipped with the modified Czerny–Turner spectrometer with continuous ozone-free xenon lamp of 150 W in the excitation wavelength of 270 nm. Fig. 2 represents the emission spectrum of naphthalene containing 10^{-2} mole of anthracene per mole of naphthalene. The spectrum of pure naphthalene recorded under similar conditions is also shown in Fig. 2. From the figure, it is revealed that the fluorescence of naphthalene is completely quenched by anthracene impurity and a new emission spectrum peaks at 425 nm. This value is well matched with the reported value [21]. It has been observed that very small addition of anthracene completely quenches weak violet fluorescence of naphthalene and an intense blue fluorescence appears from NA. This shift indicates a coupling and charge transfer between the naphthalene and the anthracene molecules. Fig. 3 illustrates the energy transfer process from the host–guest system. From the host–guest system it is understood that the incident radiation is entirely absorbed by naphthalene molecule, and that naphthalene is transparent to the fluorescence emission of anthracene.

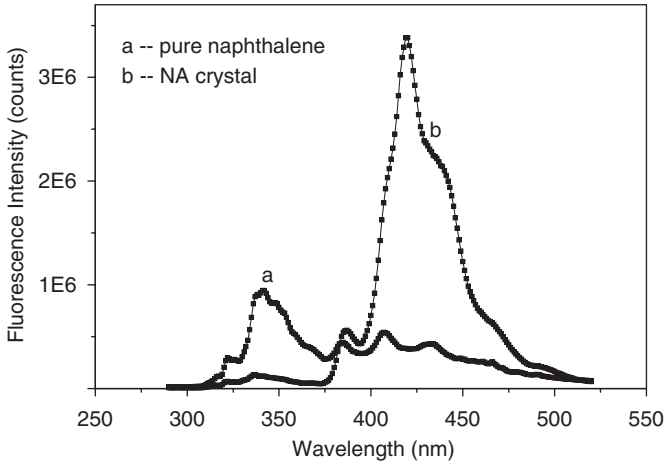

Fig. 2. Emission spectrum of NA crystal excited via naphthalene (270 nm).

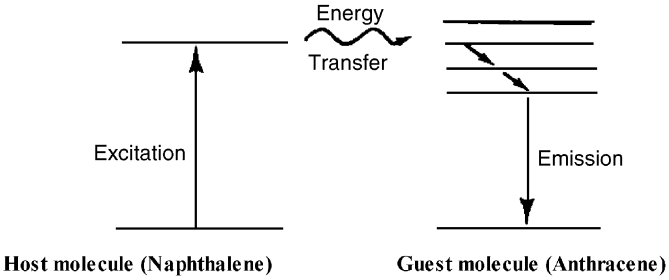

Fig. 3. Schematic of host-guest single energy transfer mechanisms in crystalline complexes.