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Self-absorption in SrI_2:2%Eu^{2+} between 78 K and 600 K

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ABSTRACT

Self-absorption of the Eu^{2+} emission is an important aspect in SrI_2:Eu that affects its scintillation performance. To calculate the probability of self-absorption, we measured the light yield and the decay time of 1–15 mm thick SrI_2:2%Eu samples at temperatures between 78 K and 600 K. The obtained properties of SrI_2:2%Eu crystals were then compared to those of SrI_2:5%Eu. The decay times of SrI_2:5%Eu crystals were the same or somewhat longer compared to those of twice as thick SrI_2:2%Eu crystals. Accordingly, doubling the thickness has the same effect on the probability of self-absorption as doubling the Eu concentration.

1. Introduction

Due to its very high light yield and excellent energy resolution, SrI_2:Eu has recently attracted large scientific interest [1–9]. In SrI_2:Eu, a photon emitted by one Eu ion can be re-absorbed by another Eu ion, a process known as self-absorption. The absorbed photon can be re-emitted again, and finally the majority of the photons escape from the crystal. Due to numerous re-absorptions and re-emissions the decay time τ of the scintillation pulse substantially increases [3]. In [5], we introduced and applied a simple mathematical model to calculate the probability of self-absorption a, which was defined as the probability that a photon emitted by an Eu^{2+} ion is reabsorbed by another Eu^{2+} ion before leaving the crystal. Both, τ and a strongly depend on three parameters, the sample temperature, the Eu concentration, and the sample size. In this work, we will address the last two parameters and check how an increase of one parameter can be compensated by another one in order to keep τ and a constant.

2. Experimental methods

SrI_2:2%Eu crystals were grown from commercially available SrI_2 and EuI_2 starting materials with a conventional crystal growth method from the melt. The reported Eu concentrations are the ratios of EuI_2 to SrI_2 in the starting material. For sample size-dependence studies, nine irregularly tablet-shaped crystals with various thicknesses were cleaved from the originally grown one. The cross-section of each crystal was approximately 2–4 times larger than its thickness h. Out of these nine samples, three were selected for further temperature dependent studies. The values of h, and approximate sample volumes V are compiled in Table 1.

The experimental setups are schematically shown in Fig. 1. Detailed descriptions can be found in [5]. The setup for room temperature photoelectron yield measurements is shown in Fig. 1a. The yield was determined from ^{137}Cs pulse-height spectra. The bare crystals were mounted on the window of a Hamamatsu R1791 (quartz version of R878) photomultiplier tube (PMT) and covered with several layers of Teflon tape. The measurements were performed inside an M-Braun UNILAB dry box with moisture content less than 1 ppm. The setup for photoelectron yield measurements as a function of temperature is shown in Fig. 1b. The crystal was fixed at the bottom of a parabolic-shaped stainless steel reflector, which was mounted on a cold finger of a Janis VPF-800 Cryostat. The reflector faced a Hamamatsu R6231-100 PMT, which was placed outside the cryostat and kept at room temperature during all experiments. The setup shown in Fig. 1c was used for temperature-dependent scintillation decay time measurements, which were performed with a conventional delayed coincidence single photon counting method. The stop photons were recorded via a small hole in the sample holder. For all the experiments, the crystals were positioned in such a way that the axis of the crystal, along which h was measured, was in the direction to the PMT(s). This direction is designated as z-axis in Fig. 1.

3. Results and discussions

3.1. Photoelectron yield studies

The photoelectron yields derived from 662 keV pulse height spectra recorded with a shaping time of 10 μs at room temperature with a sample mounted as in Fig. 1a are shown in Fig. 2.

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The yield of SrI_2:2%Eu decreases approximately 20% with increasing sample thickness from 1 mm to 15 mm. This drop is not as large as in SrI_2:5%Eu, where the 15 mm thick sample produces 40% less photoelectron yield than the 1 mm thick sample. The decrease of the yield with increasing sample size is ascribed either to self-absorption by Eu with the re-emission probability smaller than 100% or to absorption losses due to imperfect optical quality of the crystal.

The 2 mm, 6 mm, and 15 mm thick samples of SrI_2:2%Eu crystals were selected for temperature dependent studies. The relative photoelectron yield as a function of temperature was derived from pulse-height spectra recorded with a shaping time of 10 μs under ^{137}Cs 662 keV γ-ray excitation as shown in Fig. 1b. The relative photoelectron yield curves were pinned to an absolute photoelectron yield in Fig. 3 using the room temperature values from Fig. 2.

The photoelectron yield as function of temperature for SrI_2:2%Eu behaves similarly as observed for SrI_2:5%Eu [5]. Starting at 80 K, first the photoelectron yield increases rapidly; then, it gradually decreases with increasing temperature. The photoelectron yield at 600 K is 50–55% of that at 120 K. The decrease in the yield with increasing temperature is attributed either to self-absorption losses or to a poorer transfer efficiency of the excitation energy from the host to Eu. Using the model of self-absorption [5], we calculated the quantum efficiency of the Eu^{2+} emission and found 0.95 ± 0.05 for all sample sizes at all temperatures, which is the same as in SrI_2:5%Eu.

3.2. Decay time studies

Temperature-dependent scintillation decay measurements were performed with the same 2 mm, 6 mm, and 15 mm thick SrI_2:2%Eu samples as used in Section 3.1. Scintillation decay profiles were recorded under ^{137}Cs 662 keV γ-ray excitation with the setup of Fig. 1c. The results are shown in Fig. 4.

Table 1
Sample thicknesses *h* and volumes *V* of the studied crystals.

Crystal	*h*, mm	*V*, cm^3
SrI2:2%Eu	15	5 ± 0.5
	6	0.45 ± 0.1
	2	0.08 ± 0.02
SrI2:5%Eu [5]	7.3	1.6 ± 0.2
	3.3	0.15 ± 0.03
	1	0.01 ± 0.003

More than 90% of the total emission in 2%Eu doped samples consists of Eu^{2+} emission [5] whose decay time constants are plotted in Fig. 5. As in SrI_2:5%Eu, the decay time constant increases with temperature and sample size as a result of self-absorption.

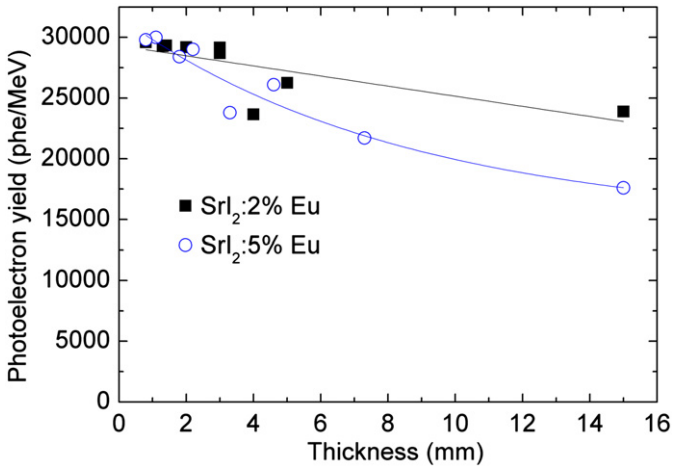

Fig. 2. Photoelectron yield of SrI_2:Eu versus sample thickness at room temperature. Squares—the results for SrI_2:2%Eu, and circles—for SrI_2:5%Eu, taken from [5]. The solid lines are drawn to guide the eye.

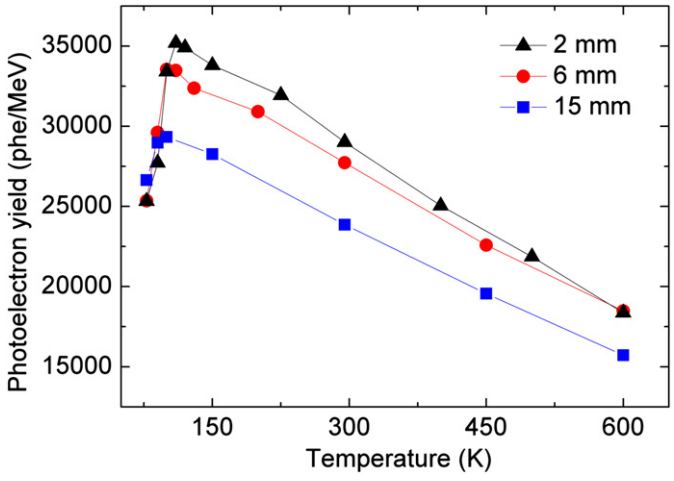

Fig. 3. The absolute photoelectron yield of SrI_2:2%Eu versus temperature. The yield is corrected for the ballistic deficit.

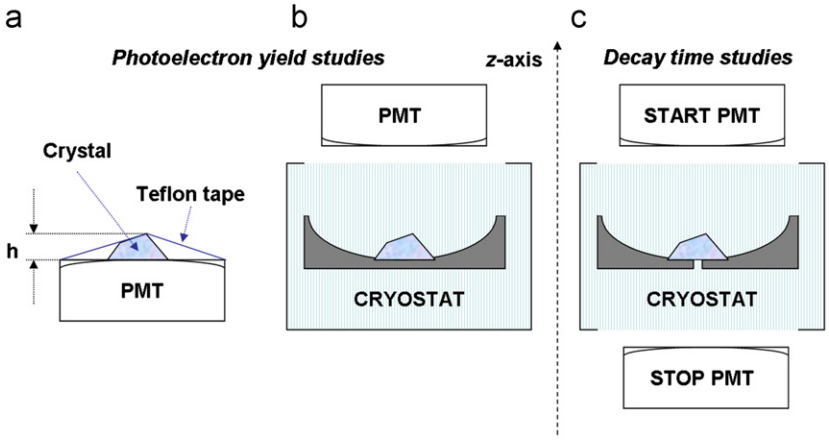

Fig. 1. Schematics of the experimental setups for: (a) Photoelectron yield measurements as a function of sample size at room temperature; (b) photoelectron yield as a function of temperature; and (c) decay time as a function of temperature.