Nuclear Instruments and Methods in Physics Research A 706 (2013) 65–68

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Transition radiation detector based on the usage of thin scintillators

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ARTICLE INFO

Available online 29 May 2012

Keywords:
Transition radiation
TRD
Thin scintillators
SiPM

ABSTRACT

Transition Radiation Detector based on the usage of thin scintillators (Sci-TRD) is proposed for particle identification. Such type of TRD may be especially interesting for space apparatus because of no gas. The proposed detector is based on the thin transparent films with incorporated micro-granules of Lu_2SiO_5:Ce scintillator. Scintillation signal produced by absorbed TR photons is registered by SiPM connected to WLS fibers. Results of measurements with samples of such films are presented. The clear signals from ^{55}Fe ($\sim$ 5 keV) and ^{241}Am ($\sim$ 16 keV) gamma sources were observed. The detailed Monte Carlo simulations of such kind of TRD are also presented.

1. Introduction

Registration of transition radiation (TR) photons in traditional TRDs is realized by detectors filled with high-Z gas mixtures—usually based on Xe or Ar. But in many cases the usage of gas is rather difficult, e.g. in space apparatus—because of gas system complexity, limitation in acceptable gas amount reserve, ageing problems, *etc.* So, the idea to use in TRD some solid state detectors, e.g. scintillators [1,2] or silicons [3] seems very attractive.

In practical cases for better separation between TR-producing and TR-sterile identified particles the optimal thickness of one detector layer in gaseous TRD should be $\sim$1 cm. Taking into account the density of gas and solid state, one can expect the optimal thickness of scintillator layer for Sci-TRD to be $\sim$10 μm. Two global problems are arose in this connection: (1) how to produce such a thin scintillators and (2) how to collect the light? This paper describes a possible approach.

2. Proposed Sci-TRD layout

The proposed layout of TRD based on thin scintillators is presented in Fig. 1. Several TRD sections consist of radiator for TR generation and detecting layer of thin scintillator. Scintillation light produced both by ionization of primary particle and by absorbed TR photons is captured in WLS fibers adjoined to scintillator layer. The light collected by WLS is registered using small silicon photomultipliers (SiPMs).

Besides of simplicity due to the absence of bulky gas system, the proposed detector has some additional advantages: no HV, compactness, not great material budget on the path of incident particle. The usage of WLS also gives a coordinate measurement possibility. But the key question—whether is effective light collection possible for such TRD?

The number of photoelectrons (more precisely, the number of fired cells) detected by SiPM, can be written as

$$N_{phe} = E \times k \quad (1)$$

where E (keV) is an energy loss – dE/dx or TR photon – in scintillator media, and k (photoelectrons/keV) is a product of scintillator yield, light transfer efficiency from scintillator to SiPM and photodetector efficiency itself. Here k will be named the light collection coefficient.

It is obvious to use scintillators with large Z and high light yield. Scintillators based on Lutetium seem to be a good candidates. For example, LSO (Lu_2SiO_5) has effective $Z \approx 66$, light yield $\sim$30 photons/keV, fast response $\sim$40 ns and emission spectrum with $\lambda_{max} \sim 440$ nm suitable for detection by SiPMs. Taking into account mentioned light transfer and SiPM efficiencies, our preliminary estimation was $k=0.2$ photoelectrons/keV. Typical dE/dx loss in 10 μm of LSO is $\sim$10 keV, mean energy of absorbed TR photons $\sim$15 keV, so we can expect $\sim$2 photoelectrons for dE/dx and $\sim$3 photoelectrons for TR in one TRD section. Statistical fluctuations of such small number of detected photoelectrons are very large and will significantly smear the original distributions of dE/dx and (dE/dx+TR) energy losses for hadrons and electrons, making the rejection power worse.

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http://dx.doi.org/10.1016/j.nima.2012.05.020

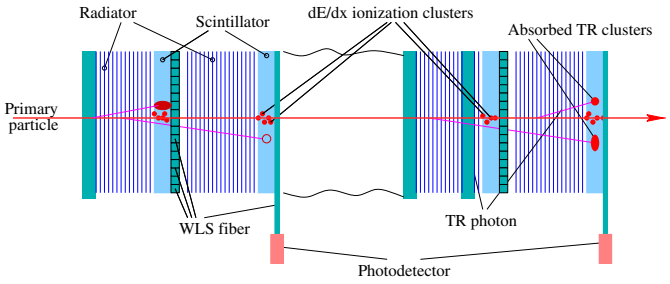


Fig. 1. Layout of proposed Sci-TRD.

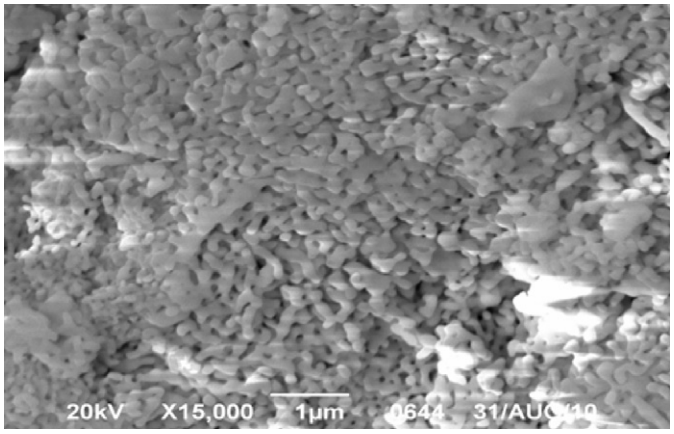


Fig. 2. Microscopic view of Lu_2SiO_5:Ce powder.

3. Scintillator films production

The technology of thin scintillator films production was developed at Central Research and Development Institute of Chemistry and Mechanics (CRDICM) [4]. Films are produced as a suspension of sub-micron powder of scintillator crystals in optically transparent (but not scintillating) media with total thickness of 100−300 μm. $LuBO_3$:Ce and Lu_2SiO_5:Ce with different concentrations of Ce were used as scintillating crystals.

The production of films consists of two main stage. During the first one, using sol–gel method in water media with subsequent air-drying at $T=150$–$160\,^{\circ}C$ and ~ 4 h crystallization at $T=950\,^{\circ}C$, the powder of $LuBO_3$:Ce (or Lu_2SiO_5:Ce at $T=1100\,^{\circ}C$) was obtained. The microscopic photo of Lu_2SiO_5 powder is shown in Fig. 2.

The second stage consists of the powder mixing with optical epoxy compound, spreading of the mixture on thin Al base, and subsequent 24 h hardening. Examples of obtained scintillator films are presented in Fig. 3.

4. Experimental measurements

Many experimental studies with different film samples were made both with vacuum PMTs and (WLS fibers+SiPM) configurations. First measurements were done using experimental setup presented in Fig. 4. Investigated film samples via optical contact were directly pressed to input window of vacuum PMT. Spectra from ^{55}Fe (~ 5 keV) and ^{241}Am (~ 16 keV) gamma sources were obtained. After proper calibration, we got the light collection coefficient (formula (1)) $k=1.1$ photoelectron/keV.

Experimental setup with light registration using WLS shifters and SiPM is shown in Fig. 5. Here the films via optical contact were pressed to raw of nine adjacent fibers 1×1 mm^2 in cross-section. All nine fibers were connected to one 3×3 mm^2 SiPM

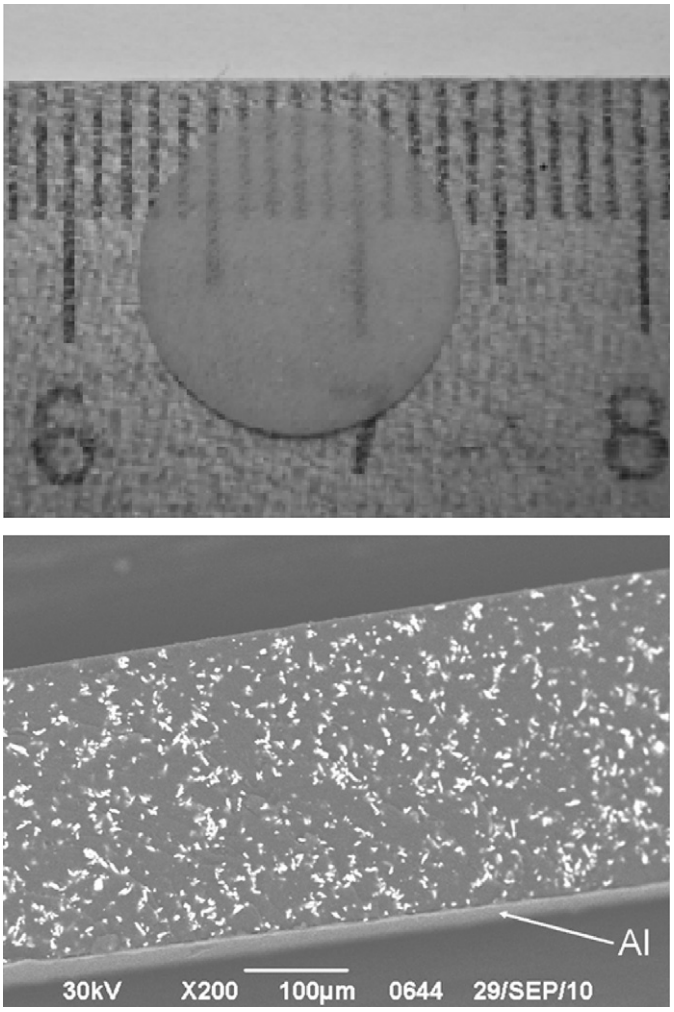
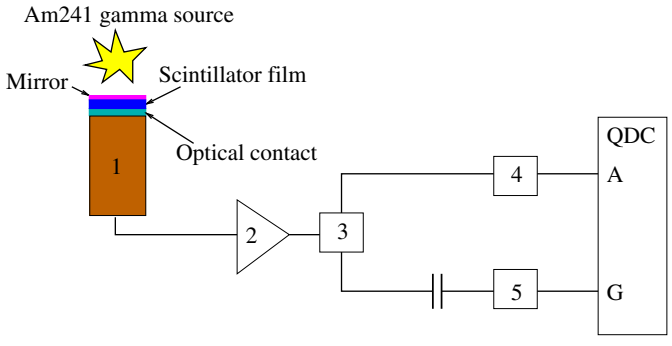


Fig. 3. Top: a sample of scintillator film on the top of ruler. Bottom: microscopic cross-section of scintillator film with visible Lu_2SiO_5 granules inside.



1 – Vacuum PMT
2 – Amplifier
3 – Linear Fan in/Fan out
4 – Delay
5 – Discriminator

Fig. 4. Experimental setup for calibration and light yield measurements using vacuum PMT.

Hamamatsu S10362-33-05C. As most of the optical photons from scintillator were not caught by WLS, they were registered by vacuum PMT situated under fibers and used for trigger production.

Spectra measured by SiPM are shown in Fig. 6. Assuming Poisson distribution for number of registered photoelectrons in