Characterization of Pr:LuAG scintillating crystals for X-ray spectroscopy


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Abstract

The main features of the Pr doped Lu₃Al₅O₁₂ (Pr:LuAG) scintillating crystals for X-ray spectroscopy applications have been studied using different radioactive sources and photo-detectors. Pr:LuAG is cheaper, compared to a Germanium detector, but with remarkable properties which make it useful for many applications, from fundamental physics measurements to the PET imaging for medical purposes: high density, elevate light yield, fast response, high energy resolution, no hygroscopicity. A sample of Pr:LuAG crystals with 14 mm x 14 mm surface area and 13 mm thickness and a NaI crystal of the same surface and 26 mm thickness used as a reference have been characterized with several radioactive sources, emitting photons in the range 100–1000 keV. Different light detectors were adopted for the Pr:LuAG studies, sensitive to its UV emission (peak at 310 nm): a 3 in. PMT (Hamamatsu R11065) and new arrays of Hamamatsu SiPM S13361, with siliconic resin as a window. Preliminary results are presented on the performance of the Pr:LuAG crystals, to be mounted in a 2 x 2 array to be tested in the 2015 run of the FAMU experiment at RIKEN-RAL muon facility. The goal is the detection of the X-rays (around 130 keV) emitted during the de-excitation processes of the muonic hydrogen after the excitation with an IR laser with wavelength set at the resonance of the hyperfine splitting, to measure the muonic atom proton radius with unprecedented precision.

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1. Introduction

Rare earth activated wide band gap oxide crystals can be very useful as detectors of ionizing radiation in nuclear and high energy physics, nuclear medicine and industry. With a density of 6.7 g/cm³ and a scintillation decay time of 20 ns and an energy resolution of few percent, Lu₃Al₅O₁₂:Pr (Pr:LuAG) is regarded as an attractive material for a number of applications [1]. However, the presence of the 176Lu isotope makes the Pr:LuAG a β⁻ emitter with a specific activity of 37 Bq/g. We focus on a preliminary characterization of few Pr:LuAG crystal samples provided by Furukawa Co. Ltd, Japan, for their possible use in the FAMU experiment to be set at RIKEN-RAL muon facility.

The FAMU goal is the detection of the characteristic X-rays (around 130 keV) emitted during the de-excitation processes of the muonic hydrogen after the excitation with an IR laser with wavelength set at the resonance of the hyperfine splitting, to measure the muonic atom proton radius with unprecedented precision. FAMU could explain the 7σ disagreement between the experimental values of the proton RMS charge radius extracted from e⁻–p scattering and muonic hydrogen spectroscopy. This discrepancy has not been explained yet (“proton radius puzzle”).

2. Measurements with high QE PMT

Single Pr:LuAG crystals, cut in rectangular shape (14 mm x 14 mm surface area and 13 mm thickness) and mechanically polished were tested. Measurements were carried out by optically coupling a Pr:LuAG crystal, whose peak emission is around 310 nm, to the 3” window of a Hamamatsu R11065 PMT with ~33% Quantum Efficiency (QE) at 310 nm. The PMT window area is suitable to house an array of 2 x 2 Pr:LuAG crystals, which will be then set-up for a FAMU test run to be held at RIKEN-RAL at the end of 2015. Crystals were optically coupled to the PMT window using silicone grease (Bicron BC-630) and covered with a layer of aluminum foil to improve the reflectivity. Crystals were encapsulated inside a custom housing realized with a 3D printer to prevent ambient light to hit the PMT window, see Fig. 1.

Signal from the PMT anode was passed to a Canberra 2005 pre-amplifier and then sent to an ORTEC 672 spectroscopy amplifier.
Measurements were carried out with 3 $\mu$s shaping time constant in the amplifier. An ORTEC Multi Channel Analyzer (MCA) was used to record energy spectra by using Maestro software. Pr:LuAG energy resolution was measured with a 137Cs $\gamma$ ray source (0.25 $\mu$Ci, $E_{\gamma} = 662$ keV), also encapsulated in the custom housing.

Preliminary spectra of 137Cs were taken for two Pr:LuAG crystals, see Fig. 2. 137Cs peak is well evident, and the energy resolutions at 662 keV have been found to be 12.3% and 14.1%, respectively. These values result to be larger than the expected energy resolution as provided by Furukawa ($\Delta E/E = 4.2\%$ at 662 keV) with a 10 x 10 x 10 mm$^3$ crystal.

As a comparison, a NaI crystal of the same surface and 26 mm thickness was exposed to the 137Cs source with the same setup, see Fig. 3. In this case the energy resolution at 662 keV has been found to be 5.8%. Possible effects, limiting the light collection from Pr:LuAG emission are now under investigation, namely:

- the Pr:LuAG light auto-absorption and photon scattering: this effect may be relevant due to the crystal thickness, see [1];
- the non-optimization of the reflector material (a deposition of BaSO$_4$ on the Pr:LuAG faces should improve the reflectivity as suggested in [2]).

### 3. Measurements with SiPM arrays

The same type of crystals has been tested with a new 4 x 4 MPPC Hamamatsu readout, based on UV extended S13361-
3050HS-04(X) SiPM arrays with a Silicon resin window (Vop 53.8 V, TSV technology). The layout of the test is shown in Fig. 4 (Left). Analog output of the 16 independent 3 \times 3 mm\(^2\) SiPMs composing the MPPC array is summed via a custom made basette and sent to an Ortec Spectroscopy amplifier 672 or a fast Ortec amplifier 579. Its output is then sent to a NIM CAEN N957 8 K MCA and then analyzed via a ROOT program. Fig. 4 right is taken with a 10 kBq 137Cs source, after background subtraction, and shows a preliminary FWHM resolution of \(\sim 10\%\). Optical coupling of the crystal with the SiPM array is given by an optical grease and the crystal is coated only with Bicron Teflon tape. Again, improvements are expected with the coating with a proper UV reflector, such as BaSO\(_4\).

4. Conclusion

Preliminary tests were carried out on a sample of Pr:LuAG crystals, which will be adopted for detecting X-rays emitted during the de-excitation processes of the muonic hydrogen, with the purpose of solving the proton radius puzzle with the FAMU experiment at RIKEN-RAL muon facility. These tests, carried out with a 137Cs source, showed that the typical 662 keV peak is well resolved, despite the energy resolution of such crystals is still not comparable with the one found with NaI. However, a number of improvements that should enhance the light collection and thus the energy resolution of Pr:LuAG crystals will be soon implemented in our setup.

References