PROCEEDINGS OF SCIENCE

Characterization of new crystals for X rays detection

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The use of PrLuAg and Ce:CAAG crystals developed for PET scanners have been proposed for a new experiment (FAMU) at RiKEN-RAL studying the proton radius puzzle. They are not-hygroscopic and have high photon yields, good energy resolution and fast decay time. To have compact detectors, a SiPMT array readout was studied. Preliminary laboratory results are reported.

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1. Introduction

PrLuAg and Ce:CAAG crystals have been introduced for radiation imaging in medical physics [1], with a PMT or single SiPMT readout (up to 3×3 mm^2). An R&D was pursued to realize compact large area detectors (up to some cm^2) with a SiPMT array readout, aiming at good energy resolution for low-energy X-rays and fast time response. A natural application was found inside the FAMU project at RAL.

The FAMU project aims at the precise determination of the Zemach radius of the proton, by using the high intensity pulsed Riken-RAL muon beam [2], [3], [4]. A large discrepancy (at $\sim 9\sigma$ level) is apparent between the proton rms charge radius measurements extracted from the experimental determination of the Lamb shift value in muonic hydrogen and previous ones from hydrogen spectroscopy and electron scattering [5], [6]. For the FAMU experiment it is essential to detect low-energy X-rays in the range 100-700 KeV escaping the target filled with a suitable mixture of Hydrogen and an heavier gas (Oxygen, Argon, ...). For their detection high-precision HPGe detectors and LaBr$_3$ detectors, with PMT readout, were foreseen. In parallel to this main option, compact X-ray detectors with SiPMT arrays readout may be of interest to equip regions otherwise difficult to be instrumented, due to lack of space, as for example, under the target vessel.

1.1 Properties of PrLuAG and CeCAAG crystals

The two crystals under study feature high photon yields, high density and fast decay time. Their main properties are shown in table 1, together with the ones of the more commonly used Ce:LaBr$_3$ and LYSO:Ce crystals.

Table 1: Main characteristics of used crystals.Ce:LaBr$_3$ and LYSO:Ce are reported for reference.

Scintillators	PrLuAG	Ce:GAGG	Ce:LaBr$_3$	LYSO:Ce
Density (g/cm^3)	6.73	6.63	5.08	7.1
Light yield (photons/MeV)	22,000	57,000	75,000	32,000
Decay time (ns)	20	88 (91 %) 258 (9 %)	30	41
Peak emission (nm)	310	520	375	420
(Bq/g)				
Hygroscopicity	no	no	yes	no
Cleavage	no	no	no	no
Melting point ($^\circ C$)	2043	1850	783	2100

Single crystals of $14 \times 14 \times 13 mm^3$ dimensions were grown by the Czochralski method by Furukawa Co. Ltd., Japan [7]. As naturally occurring lutetium consists of two isotopes, of which one (Lu^{176}) is unstable [1] an intrinsic activity for PrLuAg crystals is expected. The intrinsic activity for both crystals under test was measured with an HpGe detector, read through a standard spectroscopy chain made of a pre-amp, an Ortec 672 spectroscopy amplifier (with a $3\mu s$ shaping time)

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[1] $\tau_{1/2} = 3.78 \cdot 10^{10}$ years, 2.59 % abundance

and a Ortec Aspec-927 MCA. The complex nature of the intrinsic activity spectrum is shown in figure 1. While the intrinsic activity of PrLuAg crystals is not negligible (~ 36 Bq/g), the intrinsic activity of CeCAAG crystals is minimal ($\leq 1.5 \times 10^{-3}$ Bq/g).

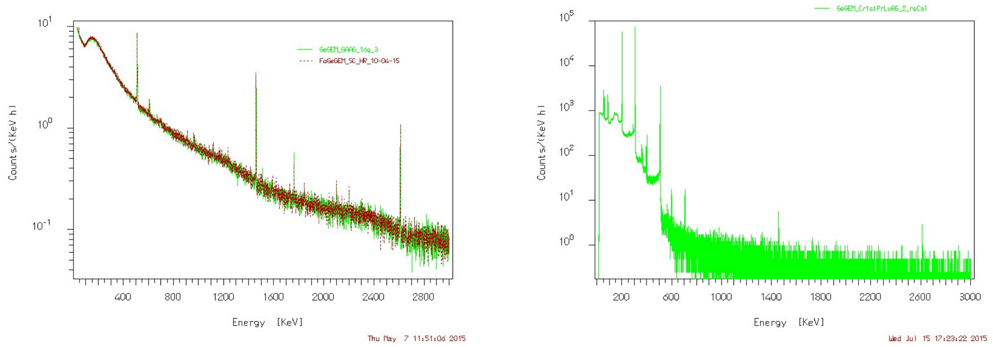

Figure 1: Left (right) panel: intrinsic activity of CeCAAG (PrLuAg) crystals, as measured with a HpGE detector.

2. Experimental setup

The crystals under test are read by SiPMT arrays. The used SiPMT arrays are 4×4 arrays made of 3×3 mm^2 SiPMT from SenSL, Advansid and Hamamatsu and their main characteristics are shown in table 2.

Table 2: Main characteristics of used SiPMT arrays.Photon detection efficiency (PDE) are at typical overvoltage values, at λ_{max} .

	$V_{brk}(V)$	Bias range (over V_{brk})	$\lambda_{max}(nm)$	PDE (at λ_{max})	response range (nm)
SenSLArray SB-4-3035-CER	24.5 ± 0.5	1-5	420	$\sim 30\%$	300 to 800
Advansid ASD-SiPM3S-4x4T	27 ± 2	2-4	550	$\sim 32.5\%$	350 to 900
Hamamatsu S13361 TSV	65 ± 10	1-4 (?)	450	$\sim 35\%$	320 to 900

The new Hamamatsu S13361 arrays use a TSV ("through silicon via") technology to eliminate the need of a wire bonding pad, that creates dead space problems. The anode of each channel is traced to the backside panel by TSV.

Most of the results were obtained with Hamamatsu S13361 arrays. For CeCAAG crystals an epoxy window was used, while for PrLuAg (with emission in the near UV) arrays with a Silicone window was used instead, to increase response.

The output from each pixel of the SiPMT array is summed up on a home-made "basette", shown in the left panel of figure 2.

The right panel of figure 2 shows the crystal holder, put in front of the SiPMT array, the plastic cap holding the test radioactive sources and the lead collimator used in some of the tests.

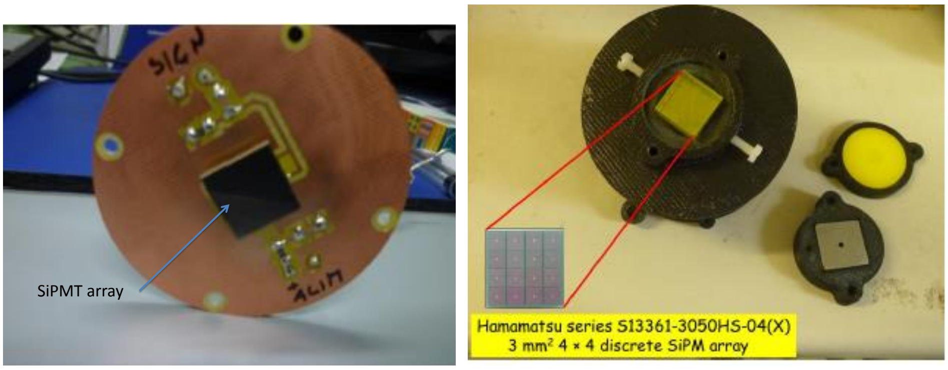

Figure 2: Left panel: image of a “basette”.Right panel: crystal mounting, realized with a 3D printing technology

3. Experimental results

Studies of the response of the crystal detectors have been done at room temperature ($\sim 22^\circ C$ with $\pm 1^\circ C$ excursions). The crystals are mounted inside a light-tight housing printed with a 3D printer that contains also the SiPMT array and the “basette”, (see figure 2 for some details). The optical coupling between the crystal under test and the SiPMT array was obtained with a Bicron BC630 optical grease [2]. The crystal was covered on five out of six faces with an optical reflector. As the PrLuAg emits around 310 nm it was difficult to find a proper optical diffuser or reflector. Many types were used, including aluminized mylar, teflon tape, Bicron BC642 PTFE reflector tape and Avian-B optical paint. The best solution, for both crystals, was to use the water based Avian-B optical coating (mainly based on $BaSO_4$) that has a $\geq 97\%$ reflectance in the range 350-850 nm and greater than 92% in the range 250-1300 nm. Temperature excursions in the test setup were monitored with a precision thermometer [3]. The SiPMT array were powered by a Keithley 2600 sourcemeter and signals were amplified and then acquired with a CAEN N957 MCA. Data written as ASCII files were then analyzed with a program based on ROOT. In most of the tests an Ortec 672 spectroscopy amplifier, with a 3μs shaping time, was used. In some tests Phillips Scientific PLS 774 , Ortec 579 fast amplifiers or a CAEN A1423 wideband amplifiers [4] were used. The best results were obtained with the Ortec 672 Spectroscopy amplifier. In the other cases energy resolutions were a 20-30 % worse. Figure 3 shows the MCA spectrum obtained from a CeCAAG (PrLuAg) crystal read by a S13361 Hamamatsu SiPMT array, using a Cs^{137} source (with a characteristic X-rays line a 662 KeV) with an Ortec 672 shaping amplifier.

While with the CeCAAG crystal a 4% resolution is obtained, with the PrLuAg crystal the best resolution obtained is around 7%. This last result is worse as compared with what obtained with a PMT readout in reference [8], but is better with what obtained with a SiPMT array readout in reference [9]. Probably this is due to the lower dark noise of the new TSV S13361 Hamamatsu SiPMT arrays used.

Figures 4 and 5 show the linearity and energy resolution obtained for such X-rays detectors,

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[2] with a nearly flat transmission (95%) between 280 and 700 nm

[3] Hanna Checktemp 1 with 0.1^0C resolution and $\pm 0.30^C accuracy$

[4] with a $\sim$ 1.5 GHz bandwith and a +18 to 54 dB gain range

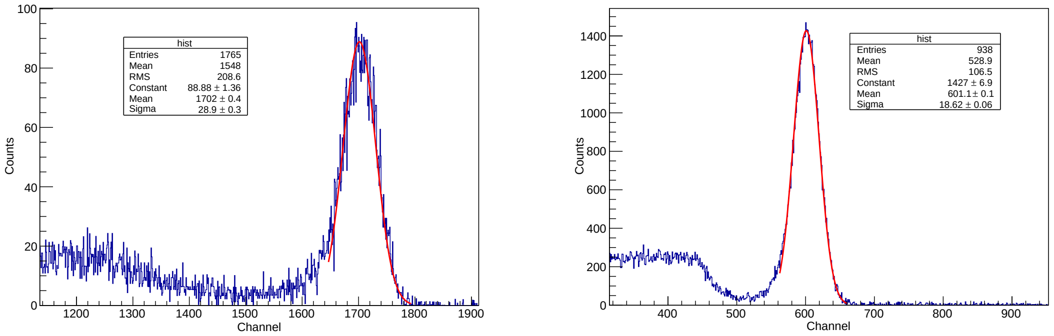

Figure 3: Left (right) panel: energy spectrum of the 662 keV gamma rays, as measured with the $14 \times 14 \times 13$ mm^3 CeCAAG (PrLuAg) crystals coupled to the MPPC array (Hamamatsu S13361 with epoxy or Silicone window).

using Na^{22}, Cs^{137}, Ba^{133}, Co^{57} and Eu^{152} exempt sources from Spectrum Techniques..

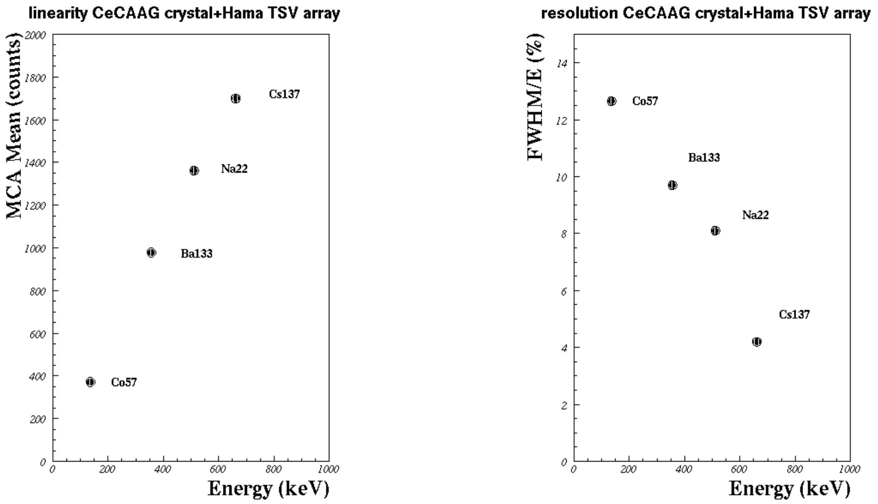

Figure 4: Left panel: linearity of the CeCAAG crystal with Hamamatsu TSV 13361 SiPMT array readout. Right panel: energy resolution for the same crystal.

In the plotted resolution many effects are folded in, such as crystal intrinsic resolution and dimensions, effects of thermal excursions on the SiPMT arrays, electronic noise (as signals from individual SiPMT cells are simply summed up), optical coupling, .:..

Studies are under way to reduce electronic noise and optimize performances, especially in the case of PrLuAg crystals.

4. Conclusions

Preliminary results with a SiPMT array readout for CeCAAG or PrLuAg crystals show that they are promising for what regards energy resolution, even if performances for PrLuAg are not yet optimal. Their possible use with low-energy X rays needs further optimization.

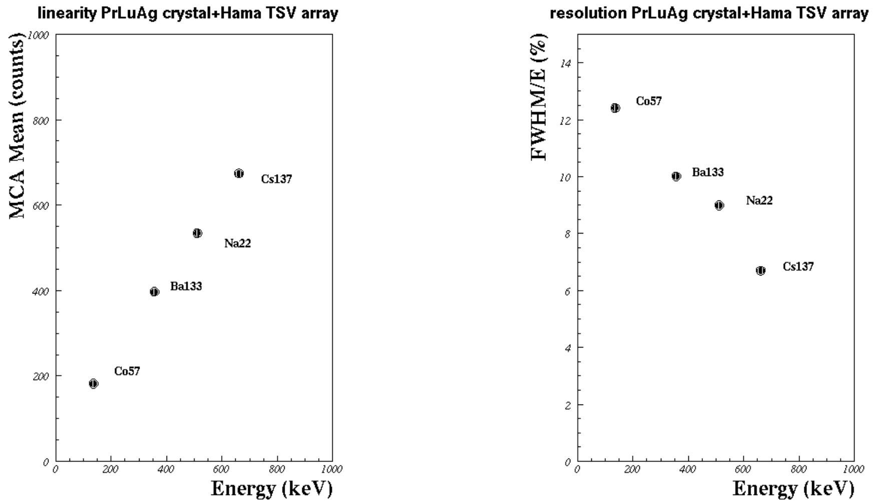

Figure 5: Left panel: linearity of the PrLuAg crystal with Hamamatsu TSV 13361 SiPMT array readout. Right panel: energy resolution for the same crystal.

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