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YAG:Ce SCINTILLATOR DETECTOR FOR GAMMA RADIATION

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Abstract. *A new detector with Cerium-doped yttrium garnet (YAG:Ce) scintillator crystal plate is reported. The crystal of YAG:Ce, made in China at Hangzhou Yong Hee Photonics Co. Ltd has 0.2% Cerium activator and was grown by Bridgeman method. Since the maximum of the peak emission of YAG:Ce is situated at 550nm, the readout can be made with a PIN photodiode. The dimensions of the crystal plate are 18x18x10mm^3. The photodiode used in this experiment was of type S3204-08, made in Japan by Hamamatsu, with an active area of 18x18mm^2, which is not affected by magnetic field. The signal from this detector was fed into a charge sensitive amplifier. Two positron sources of 48V (with energies of 511 keV, 983.5 keV, 1312.1 keV) and 22Na (511keV, 1274 keV) were used to measure the energy resolution obtained. We find a value 12%, bigger than the energy resolution obtained for CsI(Tl)(6.7%) with the same PIN photodiode readout and the same charge sensitive preamplifier. Also, the YAG:Ce crystal was polished on all faces and then was wrapped with black paper on lateral faces. The YAG:Ce crystal is non-hygroscopic in comparison with NaI(Tl) and CsI(Tl) crystals, and so it can be used in high temperature and ultra-high vacuum conditions for a long time. The decay time of 70ns for YAG:Ce is smaller than the decay time for CsI(Tl), which makes it a fast detector. Indeed, the YAG:Ce crystal is very good for replacing the old crystals used in gamma radiation detectors from a positron emission tomography (PET) scanner and from other types of end detectors used for high energy experiments.*

Keywords: *activator, detector, gamma radiation, positron, scintillator, YAG:Ce*

1. Introduction

YAG:Ce- is cesium activated yttrium aluminium garnet $Y_3Al_5O_{12}$, and is considered one of the newest, nonhigroscopic inorganic scintillators doped with a rare earth Cerium, although it was discovered in 1980. Together with YAP:Ce, it was used in nuclear medicine [1] and laser applications, and can be activated with Neodimium into YAG:Nd [2]. YAG:Ce is good for high energy physics, too, because of its response for a wide range of energies [3] and because of the transition 5d-4f of the Ce^{+3} ions [4].

1.1. Crystal scintillator properties

The crystal YAG:Ce used in our experiment is a crystal from Hangzhou Yong Hee Photonics Co. Ltd. The concentration of Cerium is 0.2% and the crystal is grown by Bridgeman method. The properties of YAG:Ce are given in Table 1.

Table 1. YAG:Ce (from Hangzhou Yong Hee Photonics, China) characteristics

YAG:Ce	Value
Density (g/cm3)	4.55
Melting Point (°C)	1970
Decay time (ns) Peak emission (nm) Light yield (Photons/MeV) Light output (to NaI(Tl) Higroscopicity	70 550 15000 20% None

Since the element Cerium is inside the crystal composition, the color of the YAG:Ce is yellow, as in Figure 1:

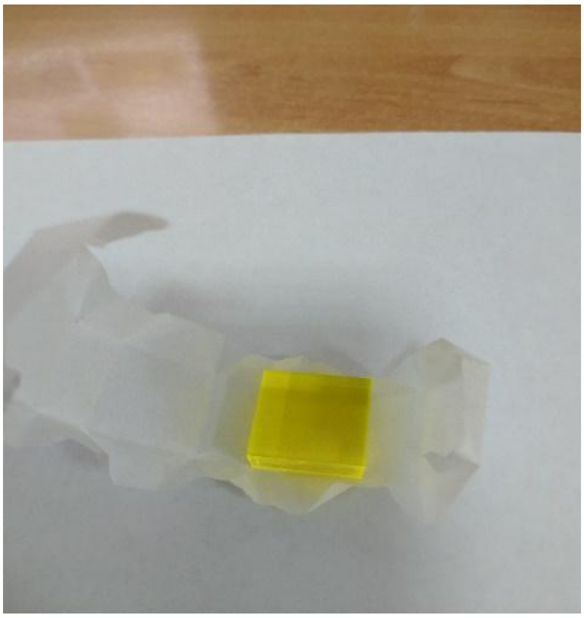

Figure 1. YAG:Ce crystal with dimensions 18x18x10mm^3

The dimensions of the YAG:Ce crystal are 18x18x10mm^3. Since the maximum of the spectral emission of the YAG:Ce is situated at 550nm, which

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means 1/3 from the maximum of the spectral response of the PIN photodiode, the crystal should be connected with a PIN photodiode, with the same area 18x18mm^2 of its lateral face. The photodiode quantum efficiency is higher than the photomultiplier quantum efficiency. In addition, when a photomultiplier is used with the crystal YAG:Ce, the volume of the system detector becomes larger. This is not good for large arrays and other types of detectors. The type of the photodiode used for this experiment is S3204-08, from Hamamatsu, Japan, with an active area of 18x18mm^2. In contrast with CsI(Tl) and NaI(Tl) crystals, YAG:Ce is not hygroscopic and need not vacuum incapsulation. A black paper is used to wrap the lateral faces of the crystal.

2. Detector assembly

By using this crystal of YAG:Ce, a detector system was assembled. A charge sensitive amplifier was connected to the PIN silicon photodiode type S3204-08 and to the YAG:Ce crystal. The detector system works at room temperature 25 ˚C and the signal is amplified by a spectroscopy amplifier N968 from CAEN Italy. Figure 2 shows the detector assembly in a lead shield made from bricks with 2 cm thickness.

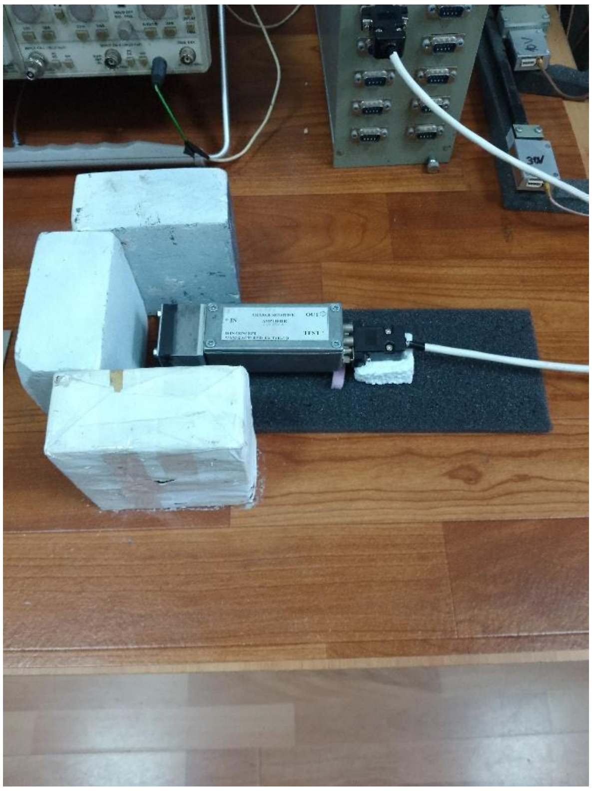

Figure 2. Detector assembly with a lead shield of bricks of 2 cm thickness. In the back side is the power supply.

2.1. Gamma spectroscopy with YAG:Ce

For medical imagistic or PET (Positron Emission Tomography) which contain such detectors positron radioactive sources are necessary. To this end two positron sources of Na^{22} and V^{48} were chosen. Both sources have the 511keV peak energy. Two spectra were obtained with Interwinner 6.0 software from an MCA (multichannel analyzer) type N957 from CAEN Italy. Figure 3 shows the Na22 gamma spectrum with energy resolution, full width at half maximum (FWHM) of 12% at the 511keV energy:

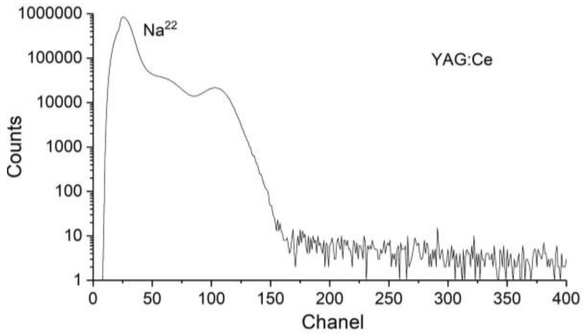

Figure 3. Gamma spectrum for Na^{22}, with two peaks of 511keV and 1274keV

The energy resolution obtained by this detector is good. With detectors of CsI(Tl) and the same charge sensitive preamplifiers, the energy resolution is 6.7% for 1000 ppm Tl concentration [5]. With a different photodiode [5] the energy resolution has a different value.

For a wide range of energies Vanadium 48 radionuclide was used, which has many gamma energies: 511 keV, 983.5 keV and 1312.1keV. The same energy resolution of 12% was obtained for V^{48}. Figure 4 shows the gamma spectrum for the vanadium 48 with 12% energy resolution at the 511 keV energy.

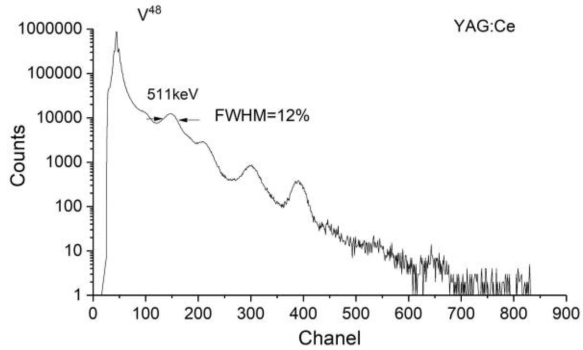

Figure 4. Gamma spectrum for V^{48} with FWHM=12% at 511keV

In Figure 3 and Figure 4, the gamma spectra show the spectrometric properties of the YAG:Ce with 2000ppm of the activator Cerium.

3. Timing with YAG:Ce

The decay time for the YAG:Ce is only 70ns. This means that YAG:Ce is a fast scintillator in comparison with CsI(Tl) which has 1000ns decay time and NaI(Tl) with 250 ns decay time. Timing studies can be done with this detector. In particle physics, Pulse Shape Analysis (PSA) and ΔE-E identification can be used [7].

4. Comparison of YAG:Ce with CsI(Tl)

A study of YAG:Ce was made in order to substitute the traditional crystals of CsI(Tl) from the old experimental arrangements. Although the CsI(Tl) light output is high, 59000Photons/MeV, it is a slow crystal (1000 ns), and it is slightly hygroscopic. In experiments like Crystal Barrel [8], Cleo [9], Belle [10] and BaBar [11], CsI(Tl) can work in strong magnetic fields, because the PIN photodiodes are insensitive to magnetic field.

5. Conclusion

The YAG:Ce detector with photodiode readout can be introduced in PET devices in order to obtain a good imagistic results. The YAG:Ce crystal is able to replace the CsI(Tl) crystal in other detector arrays for high energy physics or other types of detectors (telescopes, ΔE-E detectors).

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References

1. M. Khoshakhlagh, J. P. Islamian, S. M. Abedi, B. Mahmoudian, "Development of scintillators in nuclear medicine," *World J. Nucl. Med.*, vol. 14, no. 3, pp. 156 – 159, Sep.-Dec. 2015.
   DOI: 10.4103/1450-1147.163241
   PMid: 26420984
   PMCid: PMC4564916
2. M. C. Rao, "Applications of Nd:YAG Lasers in material processing: Fundamental approach," *IJAPBC*, vol. 2, no. 3, pp. 518 – 522, Jul.-Sep. 2013.
   Retrieved from:
   https://www.ijapbc.com/files/17-2316.pdf
   Retrieved on: Feb. 22, 2024
3. C. W. E van Eijk, "Development of inorganic scintillators," *Nucl. Instr. Meth. Phys. Res. A*, vol. 392, no. 1 – 3, pp. 285 – 290, Jun. 1997.
   DOI: 10.1016/S0168-9002(97)00239-8
4. J. Andriessen, P. Dorenbos, C. W. E. van Eijk, "Calculation of energy levels of cerium in inorganic scintillator crystals," *Mater. Res. Soc. Symp. Proc.*, vol. 348, pp. 355 – 365, Jun. 1994.
   DOI: 10.1557/PROC-348-355
5. M. Cruceru, I. Cruceru, O. G. Duliu, "On the spectroscopic properties of highly doped CsI(Tl) scintillators," *Rom. Rep. Phys.*, vol. 63, no. 3, pp. 693 – 699, 2011.
   Retrieved from:
   https://rrp.nipne.ro/2011_63_3/art07Cruceru.pdf
   Retrieved on: Feb. 22, 2024
6. M. Moscynski, T. Ludziejewski, D. Wolski, W. Klamra, L. O. Norlin, "Properties of the YAG:Ce scintillator," *Nucl. Instr. Meth. Phys. Res. A*, vol. 345, no. 3, pp. 461 – 467, Jul. 1994.
   DOI: 10.1016/0168-9002(94)90500-2
7. R. Bougault et al., "The FAZIA project in Europe: R&D phase," *Eur. Phys. J. A*, vol. 50, 47, Feb. 2014.
   DOI 10.1140/epja/i2014-14047-4
8. E. Aker et al., "The Crystal Barrel Spectrometer at LEAR," *Nucl. Instr. Meth. Phys. Res. A*, vol. 321, no. 1 – 2, 69 – 108, Sep. 1992.
   DOI: 10.1016/0168-9002(92)90379-I
9. C. Bebek, "A Cesium Iodide Calorimeter with Photodiode Readout for {CLEO}-{II}," *Nucl. Instr. Meth. Phys. Res. A*, vol. 265, no. 1 – 2, pp. 258 – 265, Mar. 1988.
   DOI: 10.1016/0168-9002(88)91079-0
10. Y. Ohshima et al., "Beam test of the CsI(Tl) calorimeter for the BELLE detector at the KEK B factory," *Nucl. Instr. Meth. Phys. Res. A*, vol. 380, no. 3, pp. 517 – 523, Oct. 1996.
    DOI: 10.1016/0168-9002(96)00706-1
11. A. Stahl, "The BaBaR Electromagnetic calorimeter," *Nucl. Instr. Meth. Phys. Res. A*, vol. 409, no. 1 – 3, pp. 615 – 617, May 1998.
    DOI: 10.1016/S0168-9002(97)01335-1