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Development of LuAG:Ce Ceramic Fibers for the RADiCAL Detector Concept

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***Abstract*– HEP experiments at future hadron colliders require fast and radiation hard calorimetry. An ultra-compact RADiCAL electromagnetic calorimeter concept with radiation hard LYSO:Ce crystals as active material and LuAG:Ce ceramic fibers as wavelength shifter is under development. In this paper we report characterization of LuAG:Ce ceramic fibers of various diameter. Their photoluminescence spectra and longitudinal uniformity were measured and compared to quartz capillary wavelength shifters. Their application in a RADiCAL cell will also be discussed.**

I. Introduction

An LYSO/W/quartz capillary ultra-compact, radiation hard and fast-timing shashlik calorimeter concept (RADiCAL) is proposed for the high luminosity large hadron collider (HL-LHC) and the proposed FCC-*hh*, where an absorbed dose up to 100 Mrad, a 1 MeV equivalent neutron fluence up to 3×10^{16} n_{eq}/cm^2 are expected in the endcap region. Fig. 1 shows a RADiCAL module where cerium doped lutetium-aluminum garnet ($Lu_3Al_5O_{12}$:Ce, or LuAG:Ce) ceramic fibers are used as wavelength shifter (WLS) for LYSO:Ce crystal plates. LuAG:Ce fibers were inserted into the RADiCAL module at different locations, providing longitudinal segmentation and precision timing for electron and photon showers [1].

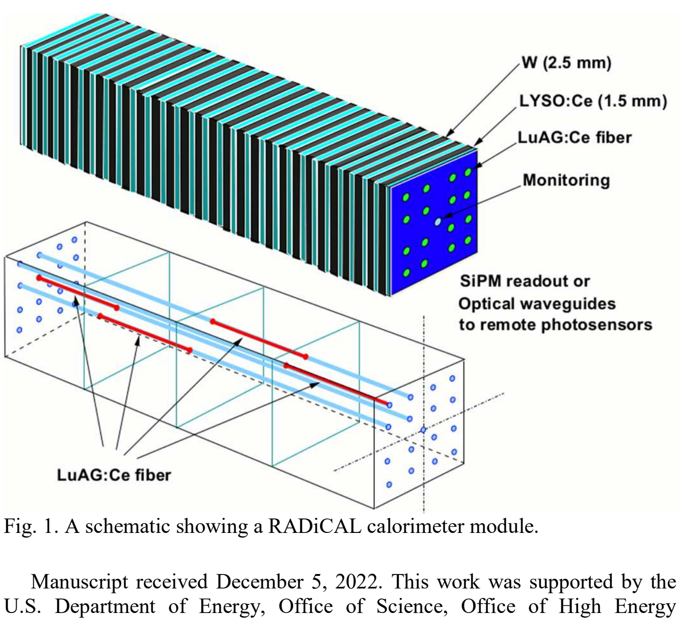

Fig. 1. A schematic showing a RADiCAL calorimeter module.

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LuAG:Ce ceramic fibers are used as WLS because of 1) its photo excitation spectrum matches the LYSO:Ce emission spectrum and 2) LuAG:Ce ceramics show a factor of two better radiation hardness than LYSO:Ce crystals against protons, and neutrons [2]. In this paper, we report LuAG:Ce ceramic fibers of various diameter produced at Shanghai Institute of Ceramics (SIC).

II. Samples and Experimental Setup

Fig. 2 shows LuAG:Ce ceramic fibers of Φ0.6 and 0.7 mm of 40, 60 and 120 mm long produced by using the laser heated pedestal growth (LHPG) technology. While the 12 cm long fibers are used for energy measurement, short fibers are used to measure precision timing for electromagnetic showers at the shower maximum, and provide longitudinal segmentation. In addition, Φ 1 mm LuAG:Ce fibers of different length are also produced for the RADiCAL concept.

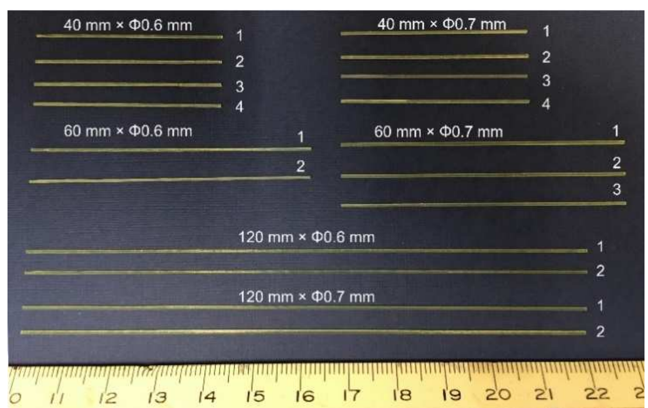

Fig. 2. A photo showing LuAG:Ce ceramic fibers of 0.6 and 0.7 mm in diameter of up to 120 mm long.

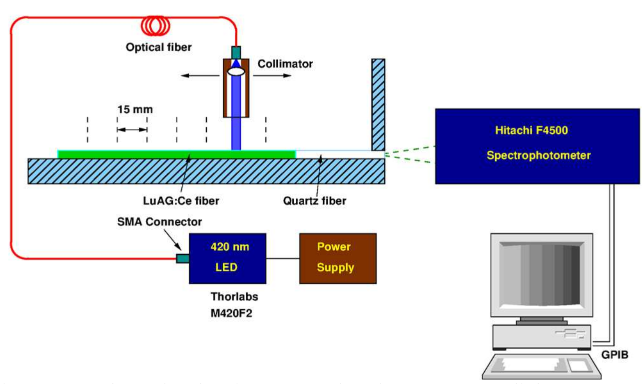

Fig. 3. A schematic showing a test bench to measure light output and longitudinal response uniformity for 120 mm long LuAG Ce fibers.

Fig. 3 shows a test bench used to measure light output (LO) and longitudinal response uniformity (LRU). LuAG:Ce fibers were excited by a 420 nm LED at different longitudinal locations and coupling to a quartz fiber with an air-gap, mimicking its practical application in a RADiCAL module. Each fiber was measured twice with two alternative ends (A or B) couped to the quartz fiber.

III. Results and Discussion

Fig. 4 shows the photoluminescence spectra of a Φ0.6 × 120 mm^3 LuAG:Ce fiber 120-0.6-2 with the B end coupling measured with the LED excitation at 7 longitudinal positions. Also listed in the figure are the photon numbers integrated over the emission spectrum, representing its LO. Fig. 5 shows the LO as a function of the distance of the LED excitation light from the coupling end for two alternative coupling ends. The slightly different average LO values with different coupling ends are due to the absorption and scattering centers in the fiber. The relative rms (%) values of the seven LO values represent the LRU of the fiber.

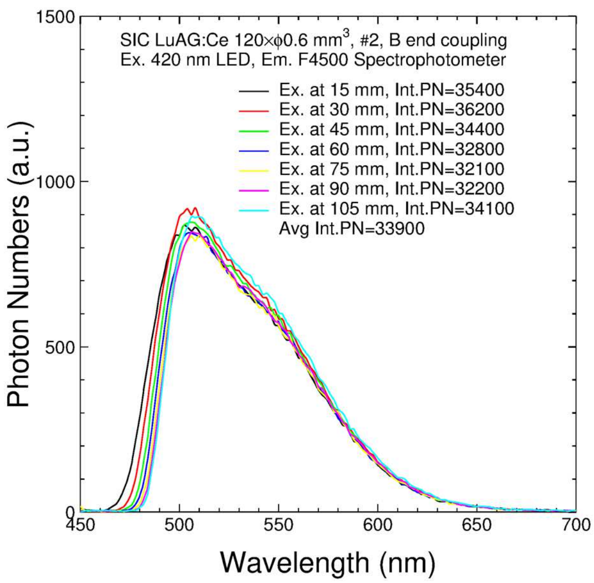

Fig. 4. The photoluminescence spectra of a Φ0.6 ×120 mm LuAG:Ce fiber 120-0.6-2 excited by 420 nm LED at 7 longitudinal positions along the fiber.

Table 1 summarizes the numerical values of LO and LRU for a total of six 120 mm long LuAG:Ce fibers of Φ0.6, 0.7 and 1.0 mm for two alternative coupling ends, and a 16 cm long quartz capillary s136, which uses a liquid form of organic WLS DSB. The average LO of LuAG:Ce fibers is found proportional to the fiber diameter since fibers of larger diameter would absorb more excitation photons from the excitation LED light with a fixed FWHM of about 5 mm. The average LO of LuAG:Ce fibers is also found less than the quartz capillary s136, indicating that LuAG:Ce is less effective than organic DSB as WLS for LYSO:Ce crystals. The best LRU of 4.6% is found for the Φ0.6 × 120 mm^3 LuAG:Ce fiber 120-0.6-2 with the B end coupling. It is also not as good as 3.2% from the quartz capillary s136.

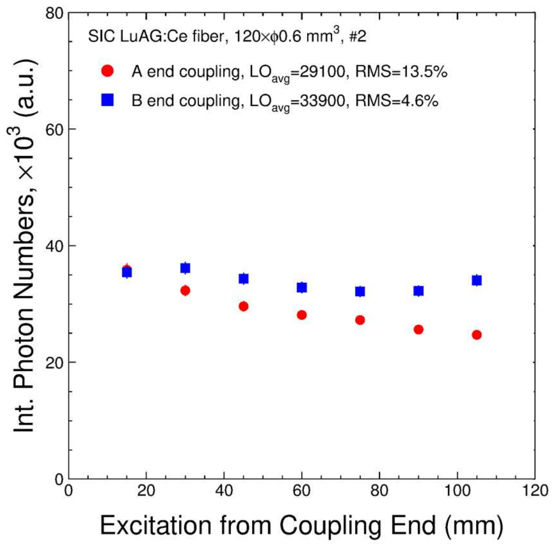

Fig. 5. The LO and LRU (RMS) of a Φ0.6 × 120 mm^3 LuAG:Ce fiber are shown as the distance from the coupling end for two alternative couplings.

Table 1: Summary of LO and LRU of 120 mm long LuAG:Ce fibers

ID	Φ (mm)	A end LO (a.u)	A end rms (%)	B end LO (a.u)	B end rms (%)
120-0.6-1	0.6	28900	11.0	37800	19.4
120-0.6-2	0.6	29100	13.5	33900	4.6
120-0.7-1	0.7	24300	41.8	27100	38.5
120-0.7-2	0.7	36500	18.8	38800	16.0
120-1.0-1	1.0	44700	5.0	50400	10.6
120-1.0-2	1.0	36300	22.8	43700	20.5
Capillary s136	1.0	58200	3.2		

IV. Summary

Future HEP experiments require fast and radiation hard calorimetry. The RADiCAL concept proposes an ultra-compact, radiation hard and fast-timing electromagnetic calorimeter concept for the HL-LHC and the proposed FCC-*hh*, where bright, fast and radiation hard LYSO:Ce crystals and LuAG:Ce ceramic WLS are used. LuAG:Ce ceramic fibers of Φ0.6, 0.7 and 1 mm of up to 120 mm long were fabricated by using the Laser Heated Pedestal Growth technique. Beam tests are planned for a LYSO/W/LuAG RADiCAL prototype to measure its energy and timing resolution, and for individual modules to measure their radiation hardness. R&D will continue to improve quantum yield and LRU for LuAG Ce ceramic fibers, and to investigate their radiation hardness

References

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