LFS-3 - new radiation hard scintillator for electromagnetic calorimeters.

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Abstract

Radiation damage of new heavy $LFS-3$ scintillating crystals has been studied using powerful ^{60}Co source at the dose rate of 4 Krad/min. No deterioration in optical transmission of $LFS-3$ crystals was observed after irradiation with the dose of 23 Mrad.

1 Introduction

In the last years extensive effort has been directed to develop new scintillating materials for Positron Emission Tomography (PET). These materials must be characterized by high light yield, a fast scintillation decay time, a good energy resolution and small absorption length for gamma radiation.

Fast and dense scintillating crystals $Lu_2SiO_5(LSO)$ were discovered and investigated by C.L. Melcher and J.S.Schweitzer in 1992 as promising material for gamma-ray detection [1, 2]. Later lutetium-yttrium oxyorthosilicate ($LYSO$) crystals were discovered and tested [3].

Stoichiometric lutetium oxyorthosilicate ($Ce_xLu_{1-x}SiO_5$, LSO) and yttrium substituted $LYSO$ ($Ce_x(Lu,Y)_{1-x}SiO_5$) crystals are currently commercially grown for the fabrication of scintillation detectors. The large-size $LSO/LYSO$ crystals were proposed for application in future high-energy physics experiments as attractive materials for homogeneous high resolution electromagnetic (EM) calorimeters [4, 5]. Recently first prototype of EM calorimeter based on 3×3 large volume $LYSO$ crystals was successfully tested at MAMI accelerator with photons up to 490 MeV energy [6] .

The one drawback of LSO is the relatively large spread of its scintillation parameters within the boule (top and bottom) and between different boules. The advertised $LYSO$ crystals show slightly better light yield efficiency and decay time as compared to LSO. They, however, exhibit similar non-uniformity of scintillation parameters across the boule, with an additional intrinsic tendency to cracking.

2 Results and discussion

Table 1: The basic properties of the scintillating crystals.

Material	$NaI(Tl)$	LFS-3
Density, ρ (g/cm^3)	3.67	7.35
Melting point, (^0C)	651	2000
Radiation length, X_0 (cm)	2.59	1.15
Moliere radius, R_m (cm)	4.3	2.09
Light output (%)	100	85
Decay time, (ns)	230	35
Peak emission, (nm)	410	425
Refractive index, n in maximum of emission	1.85	1.81
Hardness, (Moh)	2	5
Hygroscopic	Yes	No

Proprietary, bright scintillators $LFS-3$ (Lutetium Fine Silicate) developed by Zecotek Imaging Systems Pte Ltd provide much improved scintillating parameters and reproducibility [7]. LFS is a brand name of the set of Ce-doped scintillation crystals of the solid solutions on the basis of the silicate crystal, comprising lutetium and crystallizing in the monoclinic system, spatial group $C2/c$, $Z = 4$. The patented $LFS-3$ compositions is $Ce_xLu_{2+2y-x-z}A_zSi_{1-y}O_{5+y}$, where A is at least one element selected from the group consisting of Ca, Gd, Sc, Y, La, Eu and Tb.

The raw materials were 99.999% pure Lu_2O_3, SiO_2 and the scintillating CeO_2 dopant. The LFS crystals demonstrated stable scintillation parameters for top and bottom of large boules in comparison with LSO. The most important parameters of LFS scintillating crystals are presented in Table 1 in comparison with characteristics of common inorganic scintillator $NaI(Tl)$. The main properties of LFS crystal make it highly suitable as a scintillating material for electromagnetic calorimeters in high energy particle physics experiments.

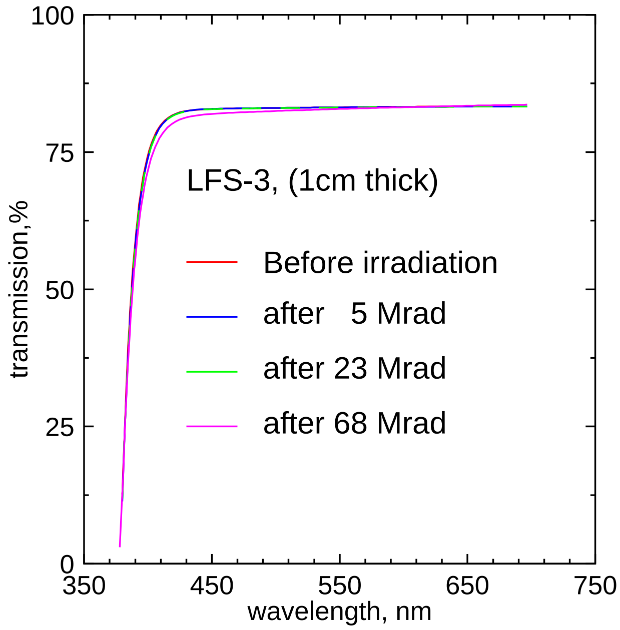

Figure 1: Transmission spectra of $LFS-3$ crystal before and after irradiation(sample thickness 10 mm)

Currently there is a strong demand for ultra radiation resistant crystals for electromagnetic calorimeters located near beam-pipe, in the endcap region, and capable of working under heavy radiation conditions during an extended length of time.

In this work we study radiation hardness of small $LFS-3$ samples at accumulated doses from low-energy gamma-ray irradiation up to 68 Mrad.

The $LFS-3$ crystals were grown by Zecotek Imaging Systems Pte Ltd, Division of Zecotek Photonics Inc., Vancouver, Canada with the Czochralski technique. The $10 \times 10 \times 10\ cm^3$ samples (from top, middle, bottom) were cut from $LFS-3$ boule of 10 cm diameter and 20 cm length then polished to an optical grade. Optical transmission spectra across a 10 mm thickness were measured with a spectrophotometer (Kruess Optronic VIS 6500).

Radiation hardness of $LFS-3$ samples was studied by comparing transmission spectra of the samples before and after irradiation. The irradiation was carried out using ^{60}Co source (maximum power is about 4 Krad/min). All $LFS-3$ crystals (top, middle, bottom of boule) were sequentially irradiated with three doses: 5 Mrad, 23 Mrad and 68 Mrad. Optical transmission spectra measurements were performed just after irradiation. The result for one $LFS-3$ crystal is plotted in Fig. 1.

From the analysis of the spectra it can be seen that with an increase of the irradiation dose the transmission drops down for the 68 Mrad dose only. There was no reduction in transmission spectra for $LFS-3$ after irradiation with the dose 23 Mrad, for samples produced from top, middle and bottom of a large LFS boule.

3 Conclusions

Earlier radiation hardness of LSO and $LYSO$ crystals has been already investigated [8–10]. For example, the $Ce : LSO$ degradation in optical transmission after irradiation with ^{60}Co gamma-rays is about $\sim 2.5\%$ per cm at 10 Mrad [8]. $LFS-3$ is a faster scintillator with better radiation hardness, making it a very suitable scintillation material for electromagnetic calorimeter used in high-energy particle physics experiments.

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