Studies on radiation hard scintillating crystals for nuclear and high energy physics experiments

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Introduction

In the last two decades new types of scintillators namely lutetium oxyortho silicate Lu_2SiO_5 (LSO) and lutetium-yttrium oxyorthosilicate [$Lu_{(2-X)}Y_XSiO_5$] (LYSO) have been developed for medical industries. Because of their high stopping power, high light yield, fast decay time (40 ns) and superior radiation hardness these crystals have also attracted a broad interest in the physics community. R & D is being carried out for these to be used as calorimeters for high energy physics experiments.

At the Large Hadron Collider (LHC) [1] at CERN, many detectors use scintillators for the calorimetry. The LHC upgrade is already underway and it is expected to lead to a peak luminosity of 10^{34} $cm^{-2}s^{-1}$ by 2013. The luminosity will be upgraded to 2-4 times by the year 2016 and 10 times by year 2020. It means a higher radiation level for detectors such as Compact Muon Solenoid (CMS) [2] and which must be upgraded to cope with the very high pile-up rates and large radiation levels to take advantage of the increasing LHC luminosity.

LYSO Crystals

As of today, mass production capabilities of lutetium oxyortho silicate and lutetium – yttrium oxyortho silicate are established [3]. The main obstacles of using these crystals in the experimental physics are two-fold: the availability of high-quality crystals in sufficiently large size and quantity and high cost of lutetium oxide (rare availability) and their growth (high melting point 2100ºC). Recent emergence of large size LSO and LYSO crystals, however, inspired this investigation on possible applications of this new generation scintillators in the physics experiments.

The Ce doped LYSO crystals have been obtained from M/s Saint-Gobain. It has high density 7.1 gm/cm^3, short decay time 40 ns, emission peak at 420 nm, light yield 32000 photons/MeV gamma ray. Its photo-yield is about 75 % that of NaI(Tl) for gamma rays.

Experimental method

The LYSO crystal has been exposed to two levels of gamma radiation dose from ^{60}Co of energies 1.173 and 1.333 MeV. The transmission spectra have been recorded before and after each level of the radiation dose. The first dose was 150 Gy/h for 68 h amounting to a total integrated dose of about 10^4 Gy. Second time the crystal was exposed to 3800 Gy/h for 46 h amounting to a total integrated dose of about 2×10^5 Gy. The typical radiation levels in the CMS will be 0.25 Gy/h in barrel and 15 Gy/h in the endcap after the luminosity upgrade of 2013.

The emission and excitation spectra of these crystal are recorded in the range of 200-800 nm using a Fluorescence spectrometer (Model: Edinburgh FLP 920) having xenon lamp as the excitation source. The transmission and absorption are measured in the range of 200-1100 nm using a spectrophotometer (Model: Chemito 2500) having deuterium and tungsten lamps as light sources [4].

Results and discussions

Figure 1 shows the excitation and emission spectra along with the transmission spectrum in the 200-700 nm range. The excitation spectrum show two prominent peaks around 300 and 340 nm corresponding to emission at 400 nm. The emission is characteristic of the 5d $\rightarrow$ 4f electronic transition of the Ce^{3+} ions. The emission peak shows that it may consist of more than one component due to spin-orbit coupling and crystal field splitting.

Figure 2 shows the transmission spectrum of the crystal before exposing to radiation and also after exposing with two levels of doses (10^4 and 10^5 Gy). We observe that an integrated dose of about 10^4 Gy does not change the transmission properties of the crystal. While a dose of the order of 10^5 Gy reduces the transmission of the crystal by about 5% which indicates a good radiation hardness of the crystal. Figure 3 shows the induced absorption (due to irradiation) calculated using the formula;

$$\mu = (1/d) \ln(I_0/I)$$

where, d is sample thickness in cm, I_0 and I are transmission in percentage before and after the exposure. From this figure it is clear that the maximum induced absorption is near the peak emission wave length which could be a drawback for the scintillation application.

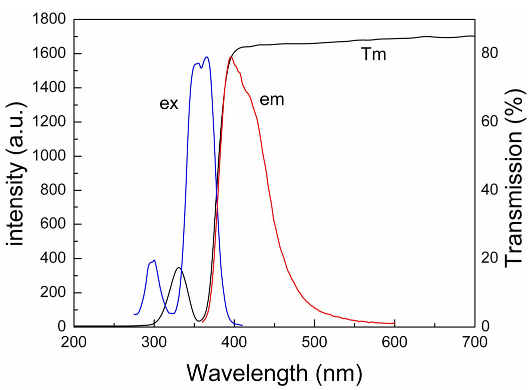

Fig. 1 Excitation, emission and transmission spectra of LYSO crystal.

To summarize, we have studied the emission and transmission properties of the Ce activated LYSO crystal supplied by M/s Saint-Gobain. With a dose level of 2×10^5 Gy, the transmission is reduced by 5 %. The maximum radiation level in the CMS is 15 Gy/h. Thus these crystals will be damaged less than 5 % over a period of 3 years (assuming a 50 % duty cycle). More studies on radiation hardness with gamma and also with neutrons are being carried out with the silicate crystals.

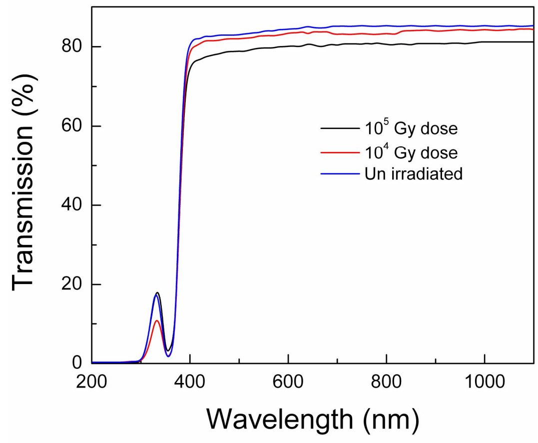

Fig. 2 Transmission spectrum of LYSO crystal without radiation and after radiation to two different doses.

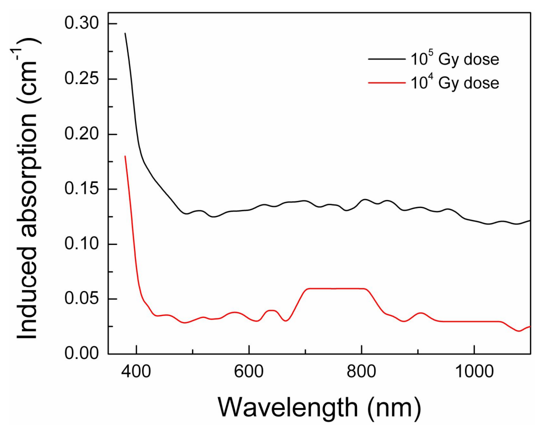

Fig. 3 Absorption induced in the LYSO crystal after two different irradiation doses.

References

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