Proton induced damage in LFS-3 and LFS-8 scintillating crystals.

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Abstract

Scintillating \textit{LFS} – 3 and \textit{LFS} – 8 crystals were exposed to a 155 MeV/c proton fluence $\Phi_p = (4.4 \pm 0.4) \cdot 10^{12} cm^{-2}$. There was negligible reduction in transmission spectrum of \textit{LFS} – 3 crystal measured in 30 days after irradiation.

1 Introduction

Construction of the electromagnetic calorimeters for the experimental setups at LHC and ILC colliders require use of new radiation hard fast materials such as heavy scintillators and Cherenkov radiators, because of the planned high luminosities for these accelerators. At present scintillating lead tungstate crystals $PbWO_4$ are successfully used in ALICE and CMS experiments at LHC. It is well known, that dominant radiation damage of scintillating crystals is a hadron induced one because of the large flux and interaction cross section. During last decade radiation damages of $PbWO_4$ crystals were extensively studied by CMS collaboration using pion and proton beams.\cite{1,2,3,4} It was found, that high-energy pions and protons cause hadron-specific cumulative damage of $PbWO_4$ crystals. Studies of CMS collaboration showed, that an important limitation for the
existing lead tungstate crystals at HLLHC (and possible even at LHC) appears to come from “star” formation under irradiation by high energy hadrons through nuclear fission. Therefore, search of heavy, fast and radiation resistant against hadron irradiation scintillating crystals is very important now. Recently CMS collaboration has published their results on proton induced damage in scintillating \( \text{CeF}_3 \) crystals, a potential candidate for electromagnetic calorimetry at HLLHC. [5]

Below we present the first results on measurements of radiation damage of \( LFS \) crystals caused by 155 MeV/c proton beam.

## 2 Results and discussion

| Material | \( \text{NaI(Tl)} \) | LFS-3 | LFS-8 |
|----------|----------------------|-------|-------|
| Density, \( \rho \) (g/cm\(^3\)) | 3.67 | 7.35 | 7.4 |
| Melting point, (\(^{0}\)C) | 651 | 2000 | 2000 |
| Radiation length, \( X_0 \) (cm) | 2.59 | 1.15 | 1.14 |
| Moliere radius, \( R_m \) (cm) | 4.3 | 2.09 | 2.07 |
| Light output (%) | 100 | 85 | 82 |
| Decay time, (ns) | 230 | 35 | 19 |
| Peak emission, (nm) | 410 | 425 | 422 |
| Refractive index, \( n \) in maximum of emission | 1.85 | 1.81 | 1.81 |
| Hardness, (Moh) | 2 | 5 | 5 |
| Hygroscopic | Yes | No | No |

Proprietary, bright scintillators \( LFS \) (Lutetium Fine Silicate) developed by Zecotek Imaging Systems Pte Ltd provide much improved scintillating parameters and reproducibility [6]. \( LFS \) 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 $LFS$ compositions is $Ce_xLu_{2+2y-x-z}A_{z}Si_{1-y}O_{5+y}$, 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 ends of large boules in comparison with $LSO$. The most important parameters of two types of $LFS$ scintillating crystals in comparison with characteristics of common inorganic scintillator $NaI(Tl)$ are presented in Table[1]. The main properties of $LFS$ crystal make it highly suitable as a scintillating material for electromagnetic calorimeters in high energy particle physics experiments. Earlier radiation damage of new heavy $LFS - 3$ crystal has been studied using powerful $^{60}Co$ source at the dose rate of 4 Krad/min. No deterioration in optical transmission of $LFS - 3$ crystal was observed after irradiation with the dose 23 Mrad. [7]

The large $LFS - 3$ and $LFS - 8$ crystals were grown by Zecotek Imaging Systems Pte Ltd, Division of Zecotek Photonics Inc., Vancouver, Canada with the Czochralski technique. The initial crystal boules have been cut up to the samples with the dimensions of $11 \times 11$ mm$^2$ and 20 mm long. All crystals samples have been polished to an optical grade. The crystals were packed to $3 \times 2$ matrix for simultaneous irradiation with proton beam from ITEP proton synchrotron. The proton beam with diameter $\sim 50$ mm was parallel to long size of $3 \times 2$ crystal matrix. The beam uniformity was about $\leq 5\%$ over the whole beam spot. All crystals have been irradiated to a 155 MeV/c protons up to fluence of $4.4 \cdot 10^{12}$ p/cm$^2$. Optical transmission spectra across a 20 mm thickness were measured with a spectrophotometer (Shimadzu UV-3101PC) before and at various intervals after proton irradiation.

Due to induced radioactivity of $LFS$ crystals first measurements of optical transmission of crystals were made in 30 days after proton irradiation. The transmission spectra for $LFS - 8$ and $LFS - 3$ crystals are presented in Fig. 1 and Fig. 2. Spontaneous recovery at room temperature was observed for $LFS - 8$ crystal during ten months after irradiation. It is evident, that irradiated $LFS - 3$ crystal has negligible reduction in transmission spectrum measured in 30 days after irradiation.

3 Conclusions

The results of studies on radiation damage of different $LFS$ crystals by using 155 MeV/c proton beam from ITEP proton synchrotron are presented. A significant progress has been made in the development of $LFS$ crystals which could be used as the active medium of a fast performance electromagnetic calorimeter for a wide range of particle physics application. The obtained results indicate, that $LFS - 3$ seems to be the best in terms
Figure 1: Transmission spectra of LFS – 8 crystal before and at various intervals after irradiation(sample thickness 20 mm).

Figure 2: Transmission spectra of LFS – 3 crystal before and at various intervals after proton irradiation(sample thickness 20 mm).

of radiation resistance against hadron irradiation among all other crystals used in high-energy physics experiments.

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