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Proton induced radiation damage in fast crystal scintillators

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ABSTRACT

This paper reports proton induced radiation damage in fast crystal scintillators. A 20 cm long LYSO crystal, a 15 cm long CeF_3 crystal and four liquid scintillator based sealed quartz capillaries were irradiated by 800 MeV protons at Los Alamos up to 3.3×10^{14} p/cm^2. Four 1.5 mm thick LYSO plates were irradiated by 24 GeV protons at CERN up to 6.9×10^{15} p/cm^2. The results show an excellent radiation hardness of LYSO crystals against charged hadrons.

1. Introduction

Because of their superb energy resolution and detection efficiency, crystal scintillators are widely used in HEP experiments. A lead tungstate ($PbWO_4$ or PWO) crystal calorimeter, for example, has played an important role for the discovery of the Higgs boson by the CMS experiment [1]. One crucial issue is crystal's radiation damage in severe radiation environment. Cerium doped lutetium yttrium oxyorthosilicate ($Lu_{2(1-x)}Y_{2x}SiO_5$:Ce or LYSO) crystals were chosen by the SuperB, Mu2e and COMET experiment to construct total absorption crystal calorimeters. They were also proposed as the active medium for a LYSO/W Shashlik calorimeter which was one of the two options proposed for the CMS forward calorimeter upgrade [2,3] for the HL-LHC. In this paper, we report an investigation on proton induced radiation damage in fast crystal scintillators.

2. Samples and experiment

Table 1 lists six samples loaded on a remote controlled linear stage with a travel distance of 1 m at the Weapons Neutron Research facility of Los Alamos Neutron Science Center (LANSCE). They are a LYSO/W Shashlik cell, a box containing four liquid scintillator based quartz capillaries and four large size crystals: LFS, LYSO, BGO and CeF_3. The 800 MeV proton beam has a Gaussian shape with a FWHM of about 2.5 cm at Los Alamos. Because of the 20 cm spacing between the samples multiple scattering effect to neighboring crystal is negligible.

Fig. 1 shows an optical fiber and lock-in amplifier based spectrophotometer used to measure longitudinal transmittance in situ for long crystal samples during and after the irradiation. Because of a power outage, only four quartz capillaries, the 20 cm LYSO crystal and the 15 cm CeF_3 crystal grown 20 years ago were irradiated to 2.7, 3.3 and 1.4×10^{14} p/cm^2 respectively, as shown in Table 1. To avoid multiple Coulomb scattering and shower leakage in 20 cm long crystals, four LYSO plates of $14 \times 14 \times 1.5$ mm^3 were irradiated by 24 GeV protons at CERN from 7.4×10^{13} to 6.9×10^{15} p/cm^2. All samples were measured at Caltech before and about 80 days after the irradiation.

3. Results and discussions

No visible damage was observed in quartz capillaries after 2.7×10^{14} p/cm^2. The LYSO sample (SG-LYSO) was irradiated in two steps. Fig. 2 shows the radiation induced absorption coefficient (RIAC) spectra measured after 1.6 and 3.3×10^{14} p/cm^2. The emission weighted radiation induced absorption coefficient (EWRIAC) is about 1 m^{-1} after 3.3×10^{14} p/cm^2. Fig. 3 shows the RIAC values at 430 nm as a function of the proton fluence for this 20 cm long LYSO crystal and four $14 \times 14 \times 1.5$ mm^3 LYSO plates irradiated by 24 GeV protons at CERN from 7.4×10^{13} to 6.9×10^{15} p/cm^2. Both data groups can be described well by linear fits. The factor of three difference between these two sets of data is caused by the multiple Coulomb scattering and hadronic shower

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Table 1
Samples loaded on the linear stage and the proton fluence.

Sample	Dimension (cm^3)	Fluence (p/cm^2)
Shashlik cell	$1.4 \times 1.4 \times 15$	–
Capillaries	$\varnothing\ 0.1 \times 6$	2.7×10^{14}
OET-LFS	$2.5 \times 2.5 \times 18$	–
SG-LYSO	$2.5 \times 2.5 \times 20$	3.3×10^{14}
SIC-BGO	$2.5 \times 2.5 \times 20$	–
SIC-CeF_3	$2.2^2 \times 2.6^2 \times 15$	1.4×10^{14}

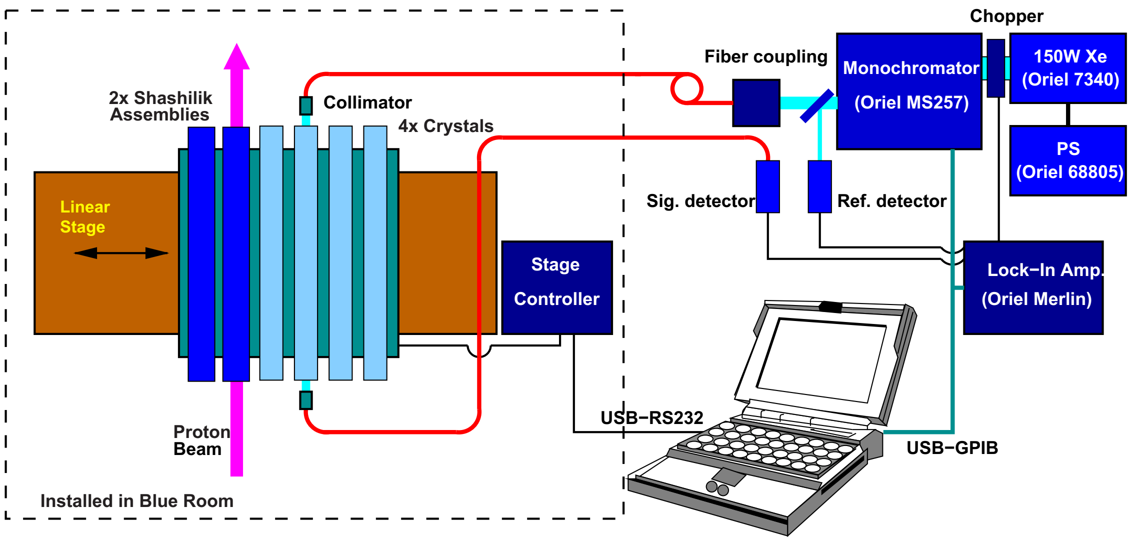

Fig. 1. A schematic showing the experimental setup used to measure crystal's longitudinal transmittance in situ.

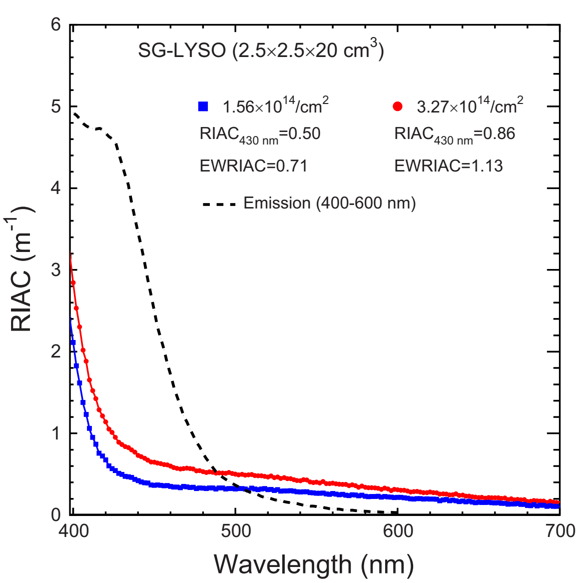

Fig. 2. The RIAC spectra measured after each irradiation steps are shown for SG-LYSO.

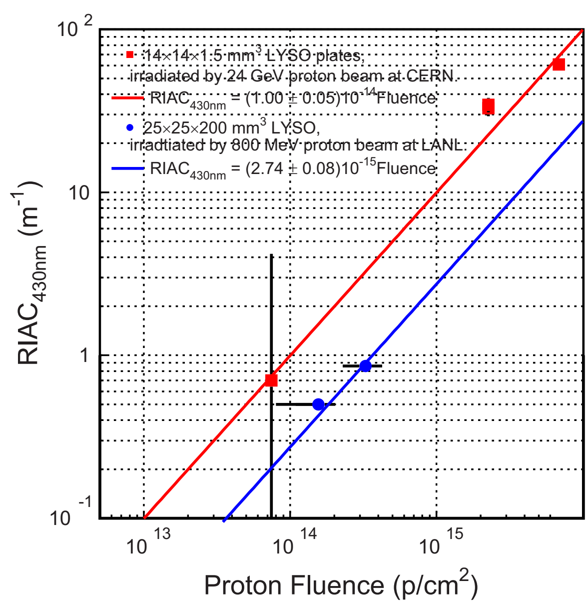

Fig. 3. The RIAC at 430 nm are shown as a function of the proton fluence for LYSO bar/plates after 800 MeV/24 GeV irradiation.

leakage of 800 MeV protons in the first nuclear interaction length of 20 cm in LYSO.

The 15 cm long CeF_3 sample (SIC-CeF_3) was irradiated to 1.4×10^{14} p/cm^2. Fig. 4 shows the RIAC spectra measured after irradiation and during recovery of about 2 h. EWRIAC values of larger than 10 m^{-1} and a significant recovery from 16.5 to 11.6 m^{-1} were observed. Quality improvement is needed for this material to be used at the HL-LHC.

4. Summary

Three samples, a box containing four 6 cm long sealed quarts capillaries, a 20 cm long LYSO crystal sample and a 15 cm long CeF_3 crystal sample, were irradiated by 800 MeV protons at Los Alamos up to 3.3×10^{14} p/cm^2 with crystal's longitudinal transmittance measured in situ. Four 1.5 mm thick LYSO plates were

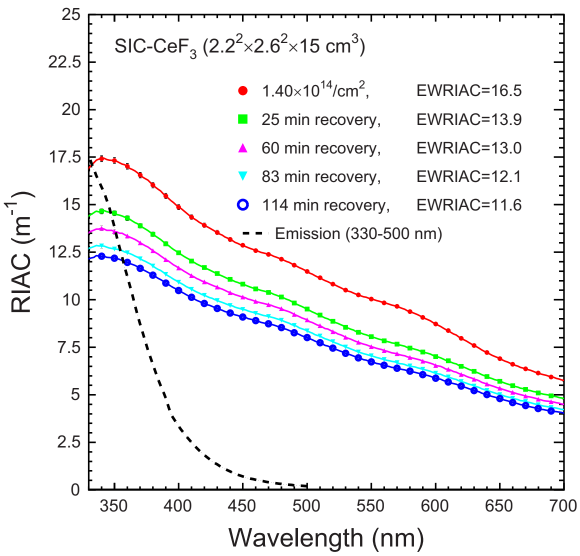

Fig. 4. The RIAC spectra measured after irradiation are shown for SIC-CeF_3.

irradiated by 24 GeV protons at CERN up to 6.9×10^{15} p/cm². No visible damage was observed in quartz capillaries. The emission weighted radiation induced absorption in the 20 cm long LYSO crystal is about 1 m^{-1} after 3.3×10^{14} p/cm², which is an order of magnitude smaller than that in the 15 cm long CeF_3 sample. The results of these experiments provide important information for understanding proton induced radiation damage in fast crystal scintillators and their use in future HEP experiments at the energy and intensity frontiers.

Acknowledgments

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