Proton-Induced Radiation Damage in Twenty cm Long LYSO:Ce and BaF_2:Y Crystals

Christina Wang[a], Liyuan Zhang[a], Chen Hu[a], Ren-yuan Zhu[a],
Kranti Gunthoti[b], Michael Mocko[b], Steve Wender[b] and Zhehui Wang[b]

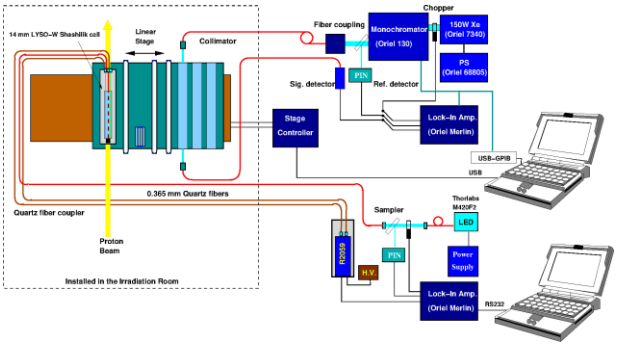
[a] *California Institute of Technology,1200 E California Blvd, Pasadena, CA 91125, USA*

[b] *Los Alamos National Laboratory, Los Alamos, NM 87545, USA*

Abstract

Inorganic scintillators are widely used in high-energy physics (HEP) experiments. Bright and fast cerium doped lutetium yttrium oxyorthosilicate ($Lu_{2(1-x)}Y_{2x}SiO_5$:Ce or LYSO:Ce) crystals have been chosen to construct the CMS barrel timing layer (BTL) detector at the high luminosity large hadron collider (HL-LHC), where up to 2.5 Mrad ionization dose, 1.7×10^{13} charged hadrons/cm^2 and 2×10^{14} n_{eq}/cm^2 are expected. With an ultrafast scintillation of less than 0.6 ns decay time and a suppressed slow component yttrium doped BaF_2 (BaF_2:Y) crystal is a promising ultrafast inorganic scintillator for future HEP time of flight and calorimeter applications at the energy and intensity frontiers. Twenty cm long LYSO:Ce and BaF_2:Y crystals were irradiated by 800 MeV proton beam at the blue room of Los Alamos Neutron Science Center (LANSCE) up to 7.5×10^{15} p/cm^2. We report degradation of their optical and scintillation properties.

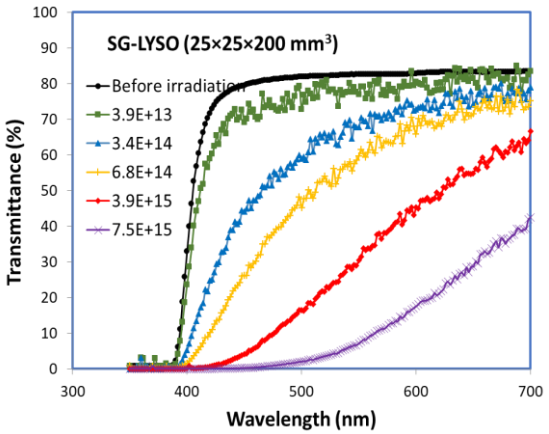
Following previous experiments 6501, 6990, 7324 and 8051, the proton irradiation experiment 9168 was conducted in October 2022 at the blue room of the Los Alamos Neutron Science Center (LANSCE) by using 800 MeV proton beam. Fig. (a) shows the setup used in the experiment 9168, where longitudinal transmittance (LT) was measured for three 20 cm long crystals *in situ*. Fig. (b) is a photo showing a total of eight samples mounted on the linear stage. They are one LYSO-W shashlik cell with different wavelength shifter readout, three groups of small LYSO:Ce crystal and LuAG:Ce ceramic samples, one group of LYSO:Ce crystal bars from various vendors for the CMS barrel timing layer (BTL) detector, a 20 cm long LYSO:Ce crystal from Saint-Gobain, and two 20 cm long BaF_2:Y crystals from SIC and BGRI.



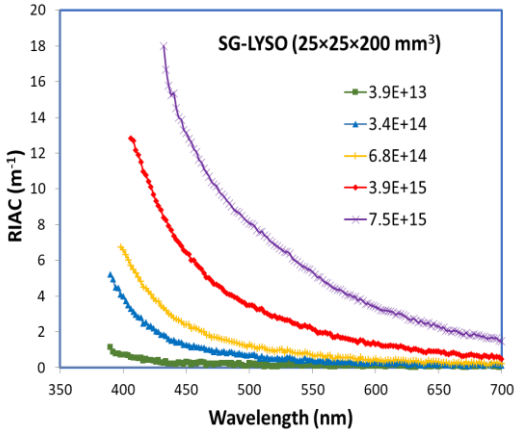
(a)

(b)

Fig. (c) and (d) show the LT transmittance and radiation induced absorption coefficient (RIAC) spectra measured *in-situ* before and after irradiation in five steps for the 20 cm long SG LYSO:Ce sample. The result is consistent with other 20 cm long LYSO:Ce crystals from SIC, SIPAT and Tianle irradiated in previous experiments. The RIAC values are found to be less than 1 m^{-1} at 420 nm after 3.9×10^{13} p/cm^2 which meets the CMS BTL radiation hardness specification.

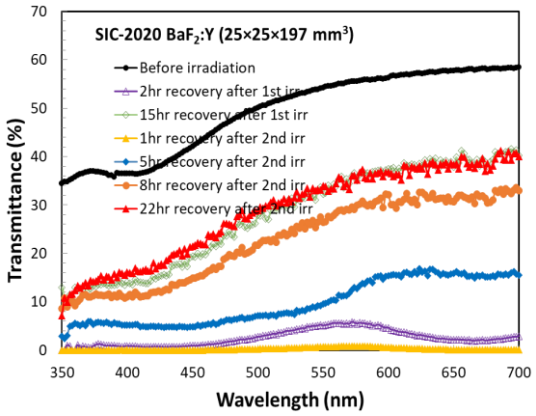


(c)

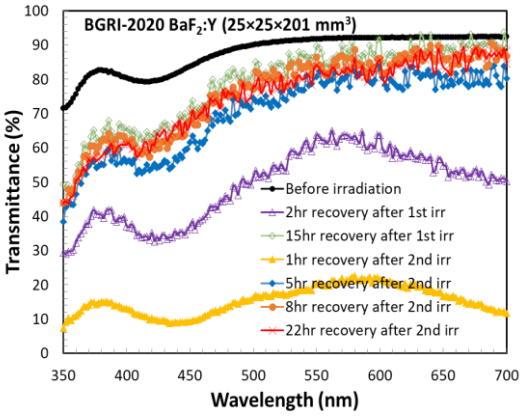


(d)

Figs. (c) and (d) show transmittance spectra measured for two 20 cm long BaF_2:Y crystals after the 1st irradiation of about 1×10^{13} p/cm^2 followed by two recovery steps of 2 and 15 hours, as well as after the 2nd irradiation of about 2×10^{13} p/cm^2 followed by four recovery steps of 1, 5, 8 and 22 hours.



(e)



(f)

The observed recovery indicates that the proton-induced damage in BaF_2:Y crystals is proton flux dependent. Data analysis is under way to investigate the kinetics of color center density and their corresponding equilibrium levels under different proton fluxes. The result of this investigation would help understanding proton-induced damage mechanism and exploring further improvement. At this writing, all irradiated samples are in a cooling down process at LANCE and are expected to be shipped back to Caltech in June 2023. We plan to measure their optical and scintillation properties at the Caltech HEP crystal lab, and present result in the coming NSS-MIC conferences.