Photo-luminescence and Decay Time of LYSO:Ce Crystals at 22, -35 and -60 °C

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1. Introduction

The CMS barrel timing layer (BTL) project uses bright and fast LYSO crystals with SiPM readout for the HL-LHC. One technical difficulty is the high dark current or dark counting rate expected in the radiation environment at the HL-LHC. Fig. 1 shows thermal electric coolers (TEC) mounted on SiPMs to make them operating at -35 °C (238 K) to reduce the SiPM dark counting rate at the HL-LHC. We measured photo-luminescence (PL) for four LYSO bars of BTL size from different vendors at 213, 238, and 295 K. A slight increase of the PL intensity at low temperature was observed for some vendors at the low temperature. Good correlation was also observed between the decay time measured for PL and radio-luminescence. These results demonstrate that BTL LYSO bars work well at low temperature down to -60 °C.

Fig. 1 SiPM arrays mockup for TECs testing.

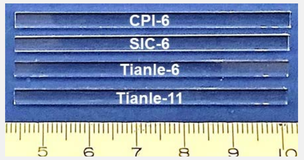

Fig. 2 Four LYSO crystal bars used in this study.

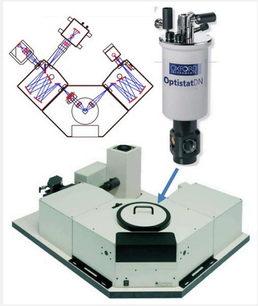

Fig. 3 Setup for the PL measurement at low temperature.

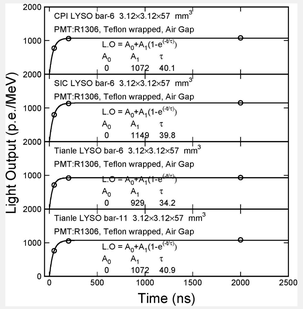

Fig. 4 Light output as a function of integration time for 4 LYSO bars at 22 °C.

Fig. 2 shows four LYSO crystal bars of 3.12×3.12×57 mm³ used in this study procured from CPI, SIC, and Tianle. Fig. 3 shows an Edinburgh Instrument FLS920 spectrometer with an Oxford OptistatDN cryostat used for PL measurement. Samples were oriented with an angle of 10° between its surface normal and the excitation light to eliminate internal absorption. Fig. 4 shows the light output (LO) as a function of integration time for four LYSO bars at room temperature. All samples show consistent light output of more than 1,000 p.e./MeV and 40 ns decay time, except Tianle-6, which shows a short decay time of 34 ns and a smaller light output.

2. PL excitation and emission at 22, -35 and -60°C

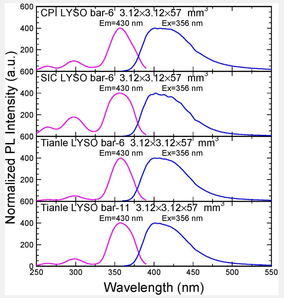

Fig. 5 Excitation (magenta) & emission (blue) spectra for four bars at 295 K.

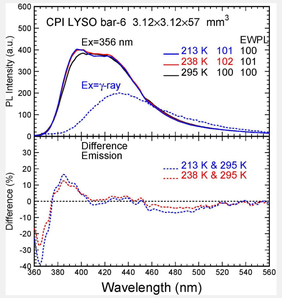

Fig. 6 PL intensities measured at 213, 238, and 295 K for CPI-6.

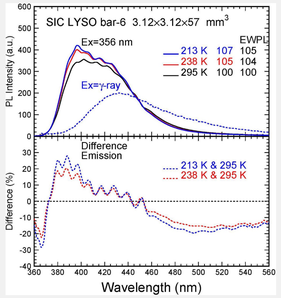

Fig. 7 PL intensities measured at 213, 238, and 295 K for SIC-6.

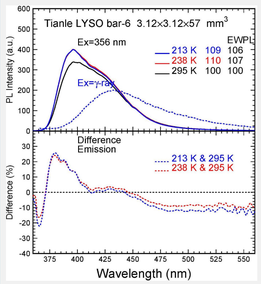

Fig. 8 PL intensities measured at 213, 238, and 295 K for Tianle-6.

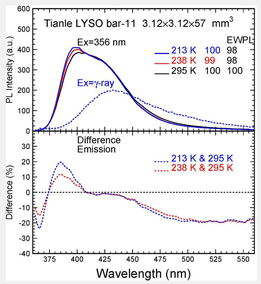

Fig. 9 PL intensities measured at 213, 238, and 295 K for Tianle-11.

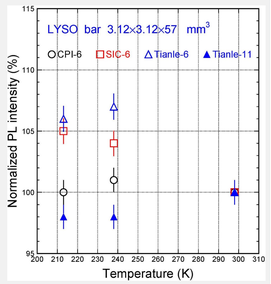

Fig. 10 The PL intensity values normalized to 295 K are shown as a function of temperature.

Fig. 5 shows photo-luminescence excitation and emission spectra for four LYSO bars measured at room temperature. The γ-ray excited emission peak of 430 nm was used as the emission wavelength for the excitation measurement. All the four crystal bars show an excitation band peaked at 356 nm and an emission band peaked at ~400 nm. Figs. 6-9 show the PL intensities measured at 213, 238, and 295 K for CPI-6, SIC-6, Tianle-6, and Tianle-11, respectively. Also shown in the figure are the γ-ray excited emission spectra and the numerical values of the emission weight PL intensity (EWPL). Fig. 10 shows the PL intensity values normalized to 295 K as a function of temperature. SIC-6 and Tianle-6 show a slight increase of the PL intensity at 213 and 238 K, which is suspected due to variation of the [Ce1]/[Ce2] ratio to be investigated in follow on research.

3. PL decay time at 22, -35 and -60 °C

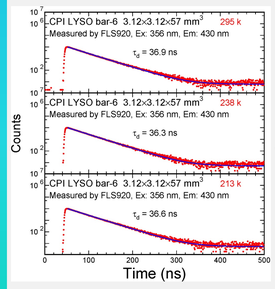

Fig. 11 PL decay time measured at 213, 238, and 295 K for CPI-6 crystal.

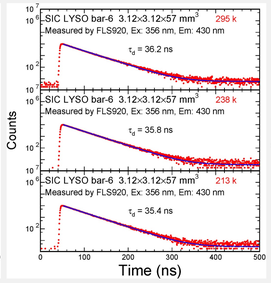

Fig. 12 PL decay time measured at 213, 238, and 295 K for SIC-6 crystal.

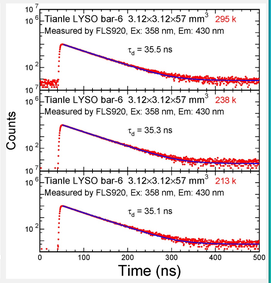

Fig. 13 PL decay time measured at 213, 238, and 295 K for Tianle-6 crystal.

Figs. 11-14 show the PL decay profile measured at 213, 238, and 295 K for CPI-6, SIC-6, Tianle-6, and Tianle-11, respectively. The PL decay time does not change at low temperature, indicating that the typical 5d-4f emission from normal Ce site is stable from 213 to 295 K.

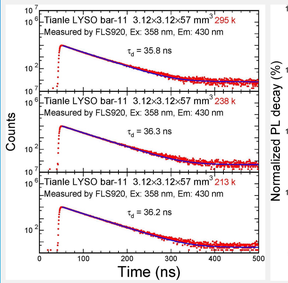

Fig. 14 PL decay time measured at 213, 238, and 295 K for Tianle-11 crystal.

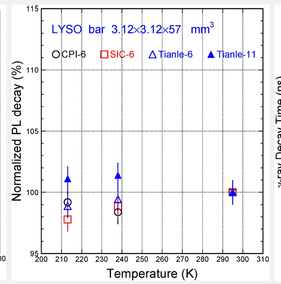

Fig. 15 Decay time normalized to 295k is shown as a function of temperature for 4 LYSO bars.

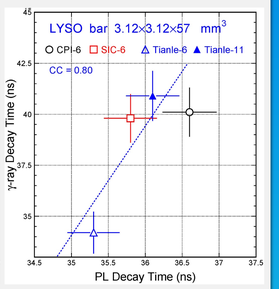

Fig. 16 Correlation between the PL decay time and the radio-luminescence for 4 LYSO bars.

Fig. 15 shows the PL decay time normalized to 295 K as a function of temperature for four LYSO bars, showing consistent decay time down to 213 K. Fig. 16 shows a good correlation between the decay time values measured for the PL and the radio-luminescence shown in Fig. 4, indicating that LYSO bars work well down to -60 °C. The longer radio-luminescence decay time as compared to PL is caused by an additional energy transfer process in radio-luminescence. Future works include radiation damage investigation for the LYSO bars under γ-rays, neutrons, and protons expected at the HL-LHC.

4. Summary

- Excitation, emission and decay of PL were measured with Edinburgh FLS920 fluorescence spectrometer for four LYSO samples from CPI, SIC, and Tianle at 22, -35 and -60 °C.
- No significant PL/EWPL intensity variation observed at low temperature. SIC-6 and Tianle-6 show a slight increase of PL/EWPL intensity at low temperature, which is suspected due to variation of the [Ce1]/[Ce2] ratio to be investigated.
- PL decay time does not change at low temperature. A good correlation is observed between the PL decay time and the radio-luminescence.
- Conclusion: BTL LYSO crystals work well at -35 and -60 °C.

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