A Comparison of Photoluminescence and Decay Time for LYSO:Ce Crystals at 22, -35 and -60 °C

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***Abstract*–Bright and fast LYSO:Ce crystals with SiPM readout are used for the barrel timing layer of the CMS MIP timing detector project at the HL-LHC. A thermal electric cooler is mounted on SiPMs to mitigate the expected high dark counting rate. The SiPM temperature will be controlled at -35 ºC (238 K) during beam on to reduce the dark counting rate, and at a high temperature, such as 25 ºC (298 K) during beam off to facilitate thermal annealing. We report photo-luminescence spectra measured at 213, 238, and 295 K for four LYSO bars from different vendors. No significant variation in both intensity and decay time was observed. The results demonstrate that LYSO:Ce crystals work well down to -60 ºC.**

I. Introduction

The CMS Barrel Timing Layer (BTL) of the MIP Timing Detector (MTD) project uses bright and fast cerium doped lutetium-yttrium oxyorthosilicate ($Lu_{2(1-x)}Y_{2x}SiO_5$:Ce, LYSO or LYSO:Ce) crystals readout by silicon photomultipliers (SiPM) to be operated at the high luminosity large hadron collider (HL-LHC). One technical difficulty is the high dark current or dark counting rate expected in the radiation environment. A mini thermal electric cooler (TEC) will be mounted on SiPM to control its operation temperature down to -35 ºC (238 K) during beam on to reduce the SiPM dark counting rate, and to a high temperature, such as 25 ºC (298 K) during beam off to facilitate thermal annealing.

We report photoluminescence (PL) spectra measured at 213, 238, and 295K for four LYSO bars of BTL size from different vendors. Their PL emission spectra, intensity and decay time were measured at low temperature and compared to that measured at room temperature.

II. Experimental Details

Fig. 1(a) shows TECs mounted on SiPMs. Fig. 1(b) shows four LYSO crystal bars of 3.12×3.12×57 mm^3 used in this study. They were procured from CPI, SIC, and Tianle. The detailed optical and scintillation performance for these four crystals can be found elsewhere [1]. 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 shorter decay time of 34 ns and a lower light output of 929 p.e./MeV.

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Fig.1 (c) shows an Edinburgh FLS920 spectrometer with an Oxford OptistatDN cryostat for PL spectrum measurement. Samples were glued to a homemade sample holder with a low temperature adhesive. They were oriented with an angle of 10º between its surface normal and the excitation light to eliminate internal absorption. All samples were measured following a sequence of 295 K, 238 K, and 213 K. At each temperature, a waiting time of 30 min was applied to a reach thermal equilibrium for the entire sample compartment.

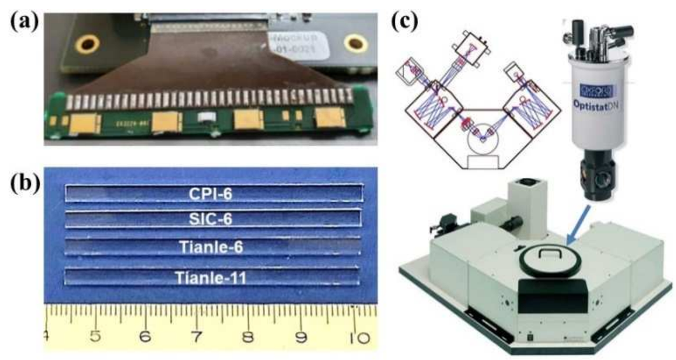

Fig. 1 (a) SiPM arrays mockup with TECs. (b) Four LYSO crystal bars used in this investigation. (c) The setup used for the PL measurement at low temperature.

III. Results and Discussion

Fig. 2 (top) shows the PL emission spectra measured at 213 (blue), 238 (red), and 295 (black) K for CPI-6. Fig. 2 (bottom) shows the difference between the PL spectra measured at low and room temperature. While an increase of emission between 375 and 405 nm was observed at low temperature, a decrease was observed between 455 to 520 nm. Also shown in the top plot is the γ-ray excited radioluminescence spectra (RL, blue dashed lines) and the numerical value of the RL emission weight PL intensity (EWPL) calculated according to Eq. 1:

$$EWPL = \frac{\int PL_{em}(\lambda) RL_{em}(\lambda) d\lambda}{\int RL_{em}(\lambda) d\lambda} \qquad (1)$$

where $PL_{em}(\lambda)$ and $RL_{em}(\lambda)$ are the PL and RL emission spectra. The EWPL value provides a numerical representation of the PL intensity over the entire RL emission spectrum, which is directly related to crystal's light output.

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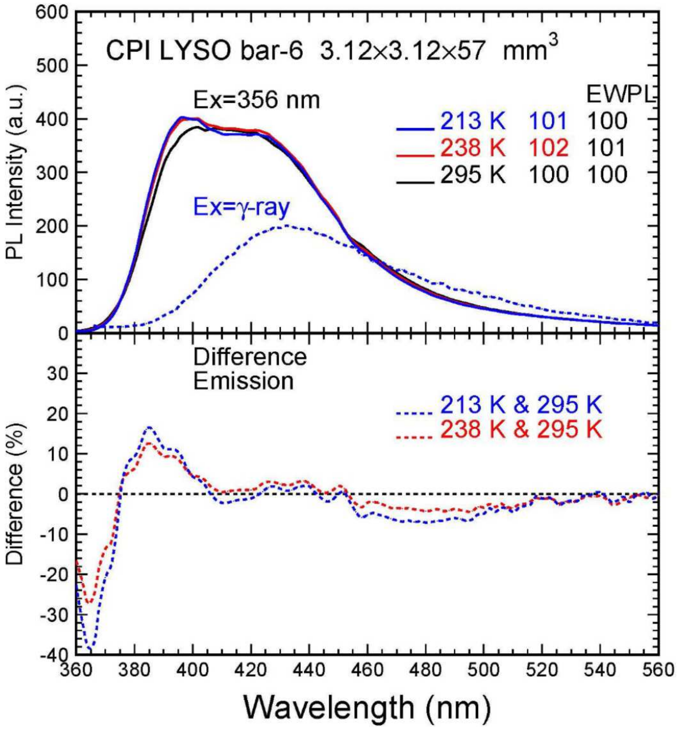

Fig. 2 Top: PL spectra measured at 213 (blue), 238 (red), and 295 (black) K for CPI-6. Bottom: Difference between the PL spectra at low and room temperature.

Fig. 3 compares the PL spectra measured at 213 (blue), 238 (red), and 295 (black) K for CPI-6, SIC-6, Tianle-6, and Tianle-11 respectively from top to bottom. We notice that the average EWPL values for four samples at 213 and 238 K are about 2% higher than 295 K, which are consistent with the measurement uncertainty, indicating no significant variation in LYSO PL intensity from 22 to -60 ºC.

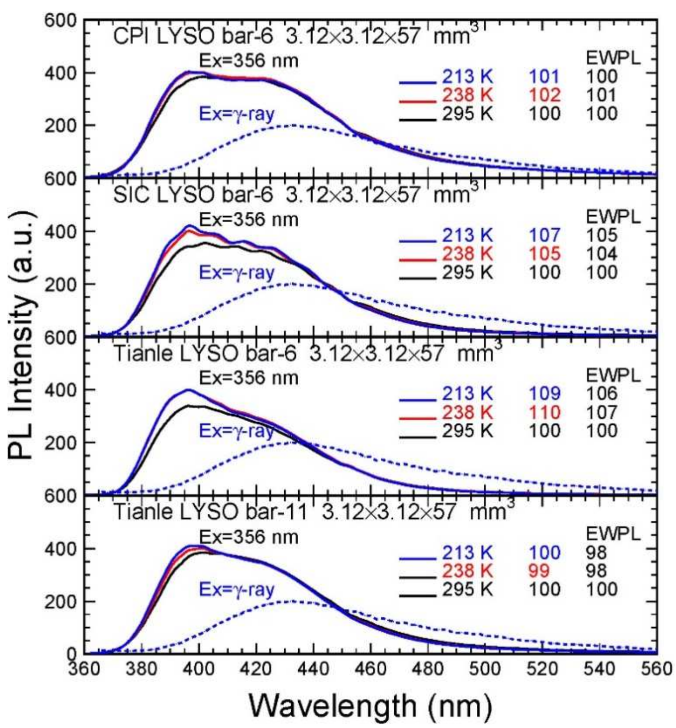

Fig. 3 PL emission spectra measured at 213, 238, and 295 K for CPI-6, SIC-6, Tianle-6, and Tianle-11 samples, respectively from top to bottom.

Figs. 4 and 5 show the PL decay profile measured at 295 and 213 K for CPI-6, SIC-6, Tianle-6, and Tianle-11 respectively from top to bottom. A single exponential fits the data well for all four samples with consistent average decay time of 36 ns, indicating no variation in decay time from 22 to -60 ºC. We also observed a good correlation between the decay time values measured for PL and RL.

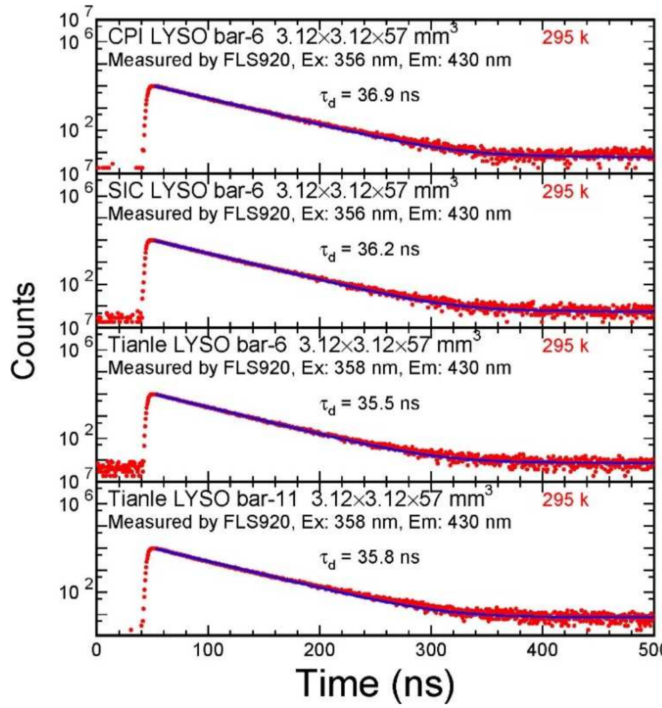

Fig. 4 PL decay time measured at 295 K for CPI-6, SIC-6, Tianle-6, and Tianle-11 respectively from top to bottom.

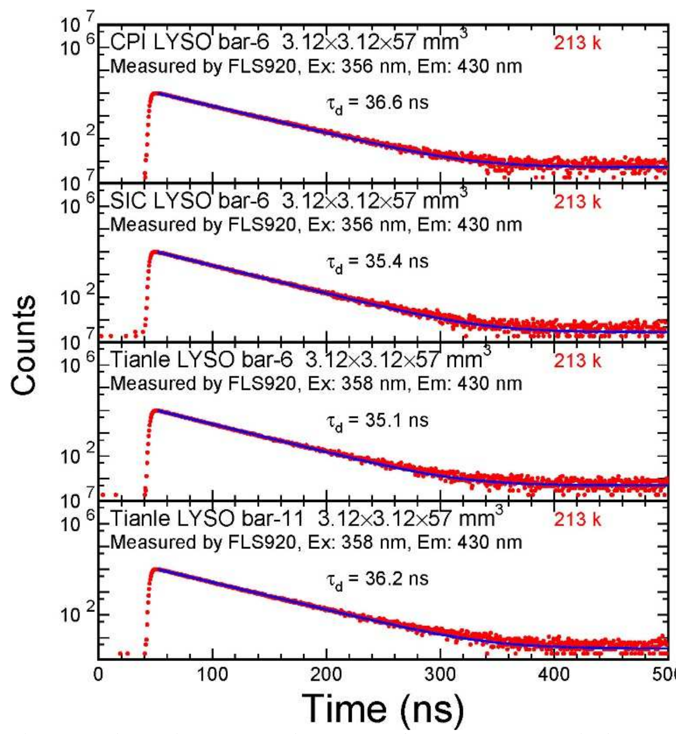

Fig. 5 PL decay time measured at 213 K for CPI-6, SIC-6, Tianle-6, and Tianle-11, respectively from top to bottom.

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IV. SUMMARY

PL emission spectra and decay profile were measured with Edinburgh FLS920 fluorescence spectrometer with an Oxford OptistatDN cryostat for four LYSO samples from CPI, SIC, and Tianle at 22, -35 and -60 ºC. No significant variation in PL intensity and decay time was observed at low temperature. Our conclusion is that the BTL LYSO:Ce crystals work well between 22 and -60 ºC.

REFERENCES

[1] http://www.hep.caltech.edu/~zhu/talks/4CMS_191015_60_LYSO.pdf.

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