Next Generation LYSO:Ce,Ca Single Crystals

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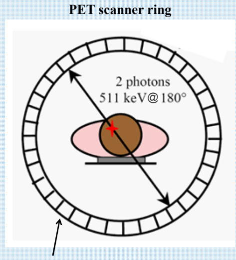
Context

PET scanner ring



Crystals + Photomultiplier Tubes

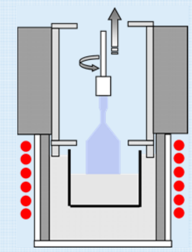
LYSO:Ce for Positron Emission Tomography (PET)

	Density	1/µ (511 keV)	$\lambda_{emission}$ (nm)	Light Yield (ph/MeV)	Energy Resolution	Decay time
BGO	7.1	10.5 mm	480	8200	15%	300 ns
LuAP:Ce	8.3	10.6 mm	365	11000	9%	60 + 600 ns
LSO:Ce	7.4	11.5 mm	420	30000	9%	40 ns + afterglow
LYSO:Ce (10%Y)	7.1	12.2 mm	420	32000	8%	40 ns + afterglow

LYSO:Ce combines interesting features:
- High density
- Suitable $\lambda_{emission}$ for PMTs,
- Good scintillation performance

Grown by Czochralski technique

Possible improvements:
- Faster Decay Time
- Lower Afterglow



Czochralski growth

Consequences of co-doping

Crystal Composition	Pulse Height (^{137}Cs – 662 keV) Light Yield (photons / MeV)	Energy Resolution	XRL Rel. intensity
LYSO:Ce	28,000	8.9%	1
LYSO:Ce,Mg	33,000	8.4%	1.12
LYSO:Ce,Ca	34,000	8.5%	1.19

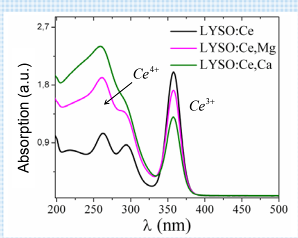
Performance improvement:
- Higher Light Output
- Reduced Afterglow

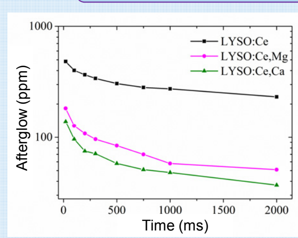
Ce⁴⁺ stabilization:
- Proved with XANES [1]
- Ce⁴⁺ has to be considered

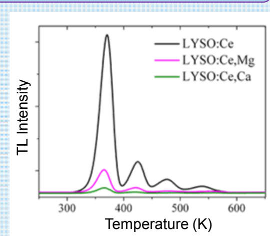
(WO 2012/066425)

Proposed explanation:
- Less efficient trapping due to Oxygen vacancies stabilization
- Charge compensation mechanism with Ce⁴⁺

$Ca^{2+}_{RE} \leftrightarrow V_O^{\bullet\bullet}$, Ce^{3+}



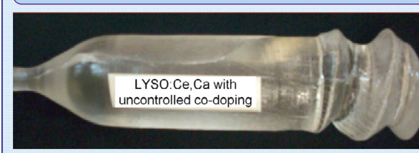




Limits of standard co-doping

Uncontrolled co-doping content:
- Bad crystal growth leading to spiral shape
- Cracks more likely to occur

Possible explanation:
- Reduced surface tension due to too many impurities (Ca, Mg…)



LSO:Ce,Ca

Spurrier *et al.* J. Crystal Growth (**2008**) 2110 [2]

Performance enhancement by increasing co-doping content is limited.
→ A compromise is required

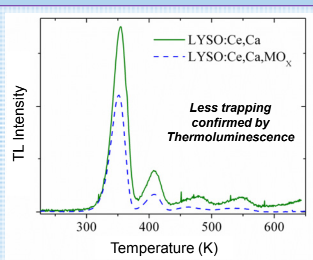
Solutions and Improvements (3rd Generation LYSO)

Optimized composition

Optimized doping and co-doping contents

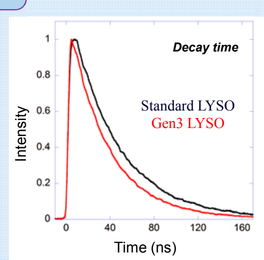
Oxidizing agent (*e.g.* MO_X) can be used during the growth:
- Decomposition in the melted bath
- Source of oxygen

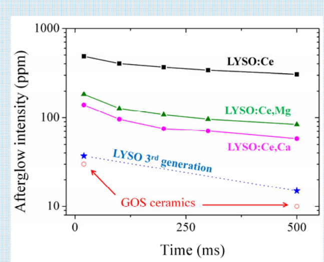
Consequences on the growth:
- Increased surface tension
- Better quality crystals



Performance improvement

Composition	Standard LYSO	LYSO:Ce,Ca	Gen3 LYSO
Light Yield (Photons/MeV)	28,000	34,000	38 – 42,000
Decay time	43 – 45 ns	42 ns	34 – 37 ns
Energy Resolution	8.9%	8.5%	7 – 8%
Afterglow	High	Medium	~ GOS ceramics





Controlled Growth

Progressive optimization of the composition:
- Improved crystal growth
- High quality material with enhanced performance

Conclusions & Perspectives

Improvements and Limitations with standard co-doping:
- Improved Light Yield, Decay Time and Afterglow
- Stabilization of Ce⁴⁺ for charge compensation
- Uncontrolled co-doping leads to bad crystal growth
- ❖ **A Growth/Performance compromise is required**

The oxidizing agent technique
- Solution to growth issues with high co-doping
- Source of oxygen during the growth
- No significant pollution to impact scintillation
- ❖ **NEW possibilities for scintillator preparation**

3rd GENERATION LYSO
- Light Yield better than 40000 Ph/ MeV (γ 662 keV) ;
- Decay Time down to 34 ns (γ 662 keV) ;
- Afterglow similar to the commercial GOS ceramics
- ❖ **A NEW option for the market (PET or CT systems)**

References

[1] S. Blahuta, A. Bessière, B. Viana, P. Dorenbos and V. Ouspenski, IEEE Transactions On Nuclear Science **60**, 3134-3141 (2013).
[2] M. Spurrier, P. Szupryczynski, H. Rothfuss, K. Yang, A. A. Carey and C. L. Melcher, J. Crystal Growth **310**, 2110-2114 (2008).

Acknowledgments

S. Leforestier, Saint-Gobain Crystals, Gières, France