Performance Engineering of LYSO Single Crystals

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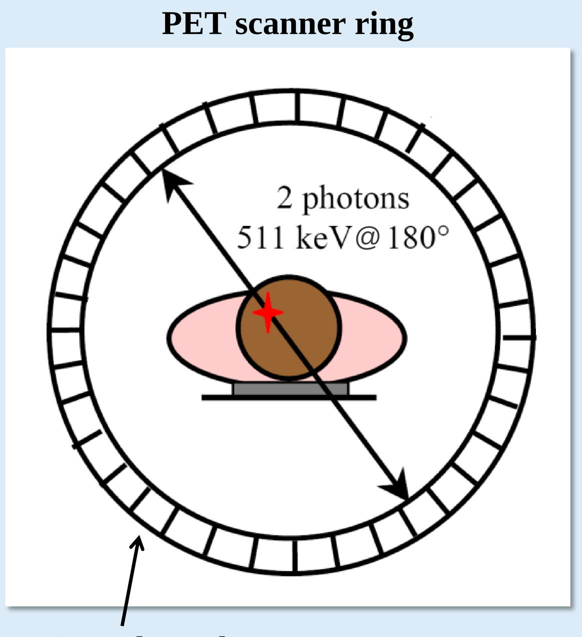
Context

PET scanner ring



Crystals + Photo-sensors

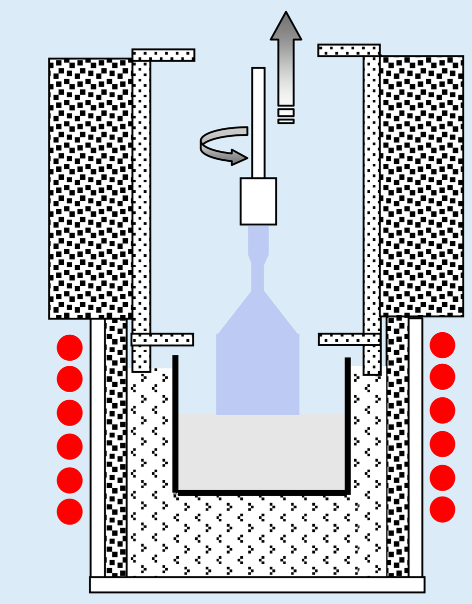
LYSO:Ce for Positron Emission Tomography (PET)

	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

LYSO Performance Enhancement by 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

Ce^{4+} stabilization:
- Proved with XANES [1]
- Ce^{4+} has to be considered

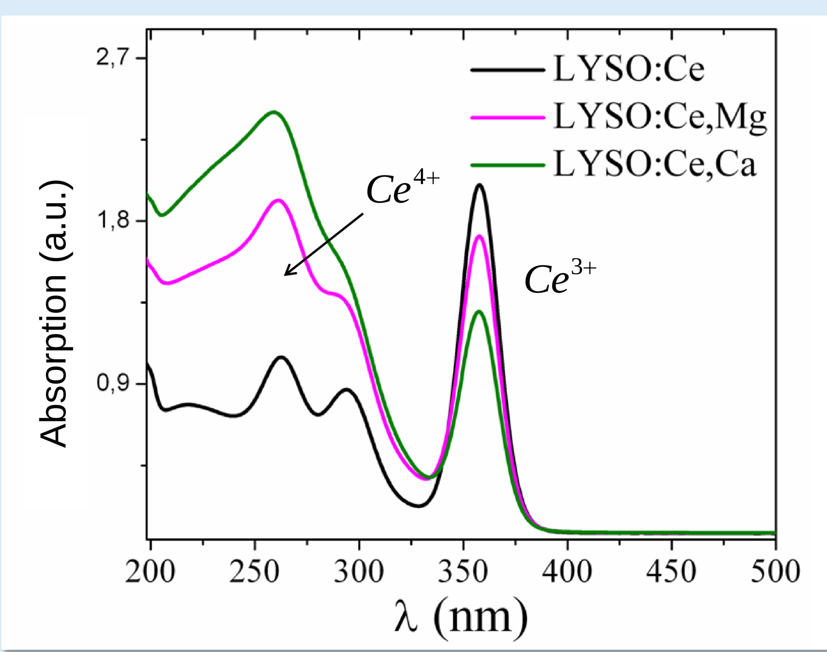
(WO 2012/066425)

Proposed explanation[1]:
- Less efficient trapping due to Oxygen vacancies stabilization
- Charge compensation mechanism with Ce^{4+}

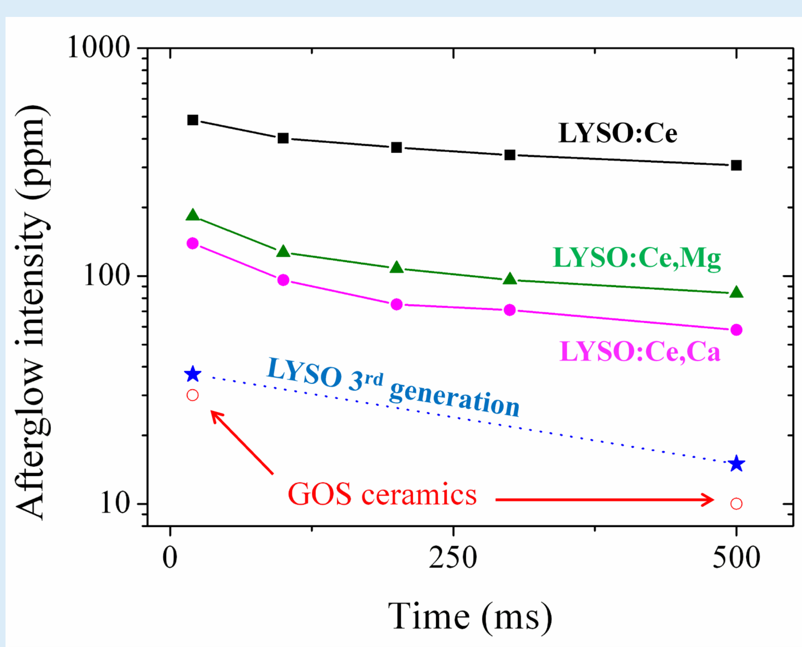
$Ca^{2+}_{RE} \leftrightarrow V_O^{\bullet\bullet}$, Ce^{3+}

Uncontrolled co-doping content:
- Unstable crystal growth leading to spiral shape
- Cracks more likely to occur
- Low production yield

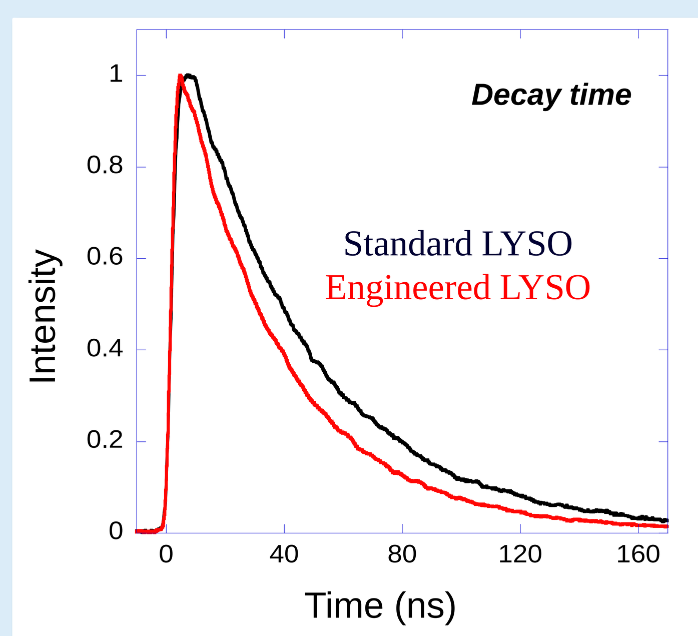
Possible explanation:
- Reduced surface tension due to high impurities/ doping [2]



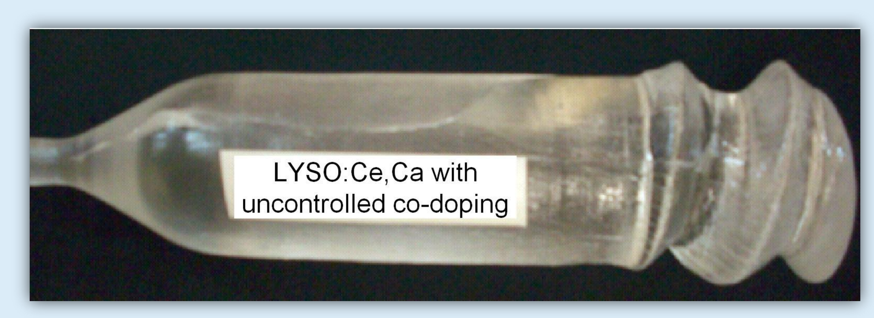
Stabilization of Ce^{4+} centers



Significantly suppressed afterglow



Reduced decay time



Standard co-doping is not suitable for industrial production.

- Low co-doping content leads to poor performance;
- High co-doping content leads to unstable crystal growth.

Engineered LYSO for Large Scale Industrial Production

Synthesis Optimization

Progressive optimization of the composition:
- Modify crystal growth characteristics by precise control of the concentrations of both activator-dopant and co-dopants

Oxidizing agent (*e.g.* MO_X) can be used during the growth:
- Decomposition in the melted bath
- Source of oxygen
- Reduce the amount oxygen-related defects without introducing undesired contamination

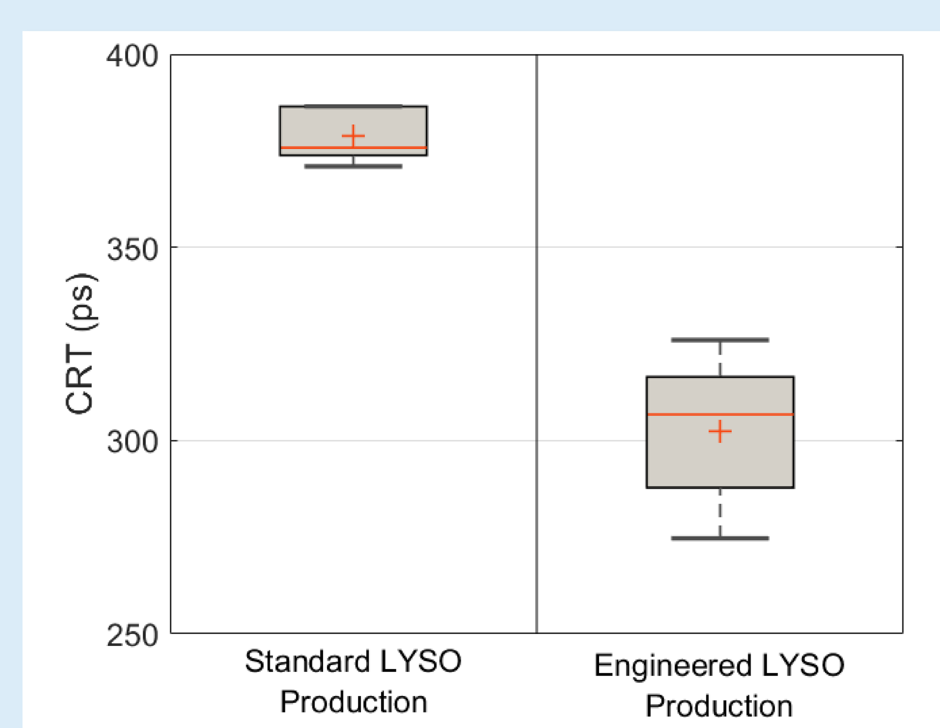
Consequences on the growth:
- Increased surface tension
- Stabilized crystal growth even at large diameters
- Eliminate cracking
- Better quality crystals

Large Diameter Controlled Growth

Performance of Engineered LYSO

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

Consistently Improved Timing Resolution



Timing Resolution of Engineered LYSO*

*Measured with 4x4x20mm LYSO pixels, ends-on coupling
Two Photonis XP20Y0 PMT's @ -900V, 100 μCi ^{22}Na source

Conclusions & Perspectives

Improvements and limitations with standard co-doping:
- Improved Light Yield, Decay Time and Afterglow
- Stabilization of Ce^{4+} for charge compensation
- Uncontrolled co-doping leads to unstable crystal growth
- ❖ **Cannot be directly applied to industrial production**

Engineering of LYSO for industrial production
- Control of doping concentrations
- Oxidizing agent technique
- No pollution to impact scintillation
- ❖ **NEW possibilities for scintillator preparation**

Engineered LYSO is available in full production sizes
- Light Yield better than 40000 Ph/ MeV (γ 662 keV) ;
- Decay Time down to 34 ns ;
- 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

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Patent pending (US 2016/0252631)

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