# Performance Improvement of Large $Sr^{2+}$ and $Ba^{2+}$ co-doped $LaBr_3:Ce^{3+}$ Scintillation Crystals

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## $LaBr_3$: 5% Ce ( *BriLanCe® 380* )

Cerium doped lanthanum bromide ($LaBr_3$:Ce) scintillation crystal possesses a unique combination of favorable scintillation characteristics [1], including high scintillation light output, excellent energy resolution, fast scintillation decay time, good density, and excellent energy proportionality. These makes $LaBr_3$:Ce attractive in a variety of applications including geophysical radiation detection, medical imaging, homeland security and radiation detection in space.


Fig. 1 Photo of ϕ 60 mm x 80 mm $LaBr_3$:Ce scintillation detectors

$LaBr_3$:5% Ce has been successfully commercialized by Saint-Gobain Crystals and marketed under the trade name "**BriLanCe® 380**". Saint-Gobain Crystals has developed a reliable growth process which produces **large diameter crack-free** $LaBr_3$ crystals [2].

Recently, Saint-Gobain Crystals has developed a new family of $LaBr_3$ scintillator by means of ionic co-doping. In this work, we present the exciting performance improvement achieved by $Sr^{2+}$ and $Ba^{2+}$ co-doping.

All measurements were performed on three **ϕ 60 mm x 80 mm** large size $LaBr_3$:Ce detectors. The three samples were Ce only, 0.5 at% Sr and 0.17 at% Ba co-doped ( in the melt, with respect to La) .

[1] E.V.D. van Loef, P. Dorenbos, C.W.E. van Eijk, K. Krämer, and H.U. Güdel, Appl. Phys. Lett., vol. 79, pp. 1573-1575, 2001.
[2] P. R. Menge, G. Gautier, A. Iltis, C. Rozsa, and V. Solovyev, Nucl. Instrum. Meth. A, vol. 579, pp. 6-10, 2007.

## Emission Characteristics

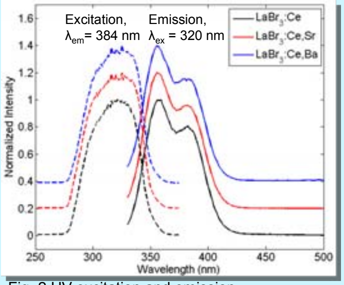


Fig. 2 UV excitation and emission

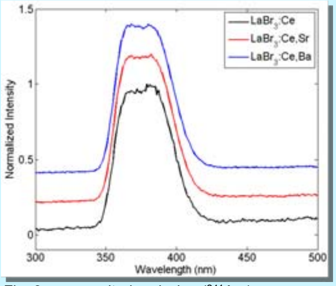


Fig. 3 γ-ray excited emission ($^{241}$Am)

UV excitation and emission spectra were measured with a Varian Eclipse Spectrophotometer equipped with a Xenon lamp. A 10 mCi $^{241}$Am source (59.5 keV γ-rays) was used to excite the crystal for radio-luminescence measurements.

**Ce only, Sr co-doped and Ba co-doped $LaBr_3$:Ce crystals exhibit almost identical emission characteristics.** No peak shift was observed on any sample. The relative intensity of the Ce emission peak at 383 nm is slightly reduced in Sr and Ba co-doped $LaBr_3$:Ce (Fig. 2). Similar trend is also observed in radio-luminescence spectra (Fig. 3).

## Scintillation Time Profile

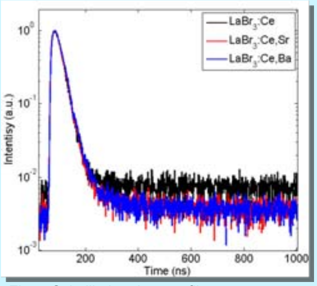


Fig. 4 Scintillation time profiles

Delayed coincidence method, originated by Bollinger and Thomas, was used to determine the scintillation time profiles [3]. Two Photonis XP20Y0 PMTs were used in the measurements.

Table 1 Decay time from Bollinger-Thomas

| | Decay (ns) |
|---|---|
| Ce only | 22.3 |
| **Sr co-doped** | **24.8** |
| **Ba co-doped** | **25.6** |

These large crystals add dispersion to the scintillation pulse due to significant variation in photon path length through the crystal. Figure 5 shows the impulse response function as simulated by the Monte Carlo program DETECT [4].

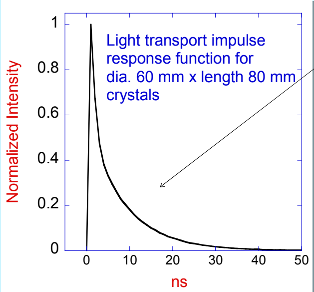


Fig. 5 Impulse response function for ϕ = 60 mm, ℓ = 80 mm crystals

The above time profiles can be deconvolved with this function to get the "true" decay time of the scintillation pulses

Table 2 Deconvolved decay time

| | Decay (ns) |
|---|---|
| Ce only | 17.2 |
| **Sr co-doped** | **18.2** |
| **Ba co-doped** | **19.1** |

**No significant change in timing characteristics with co-doping was observed.** The scintillation decay remains single exponential.

[3] L. M. Bollinger, G. E. Thomas, Review of Scientific Instruments, vol.32, no.9, pp.1044-1050, 1961
[4] GF. Knoll, TF. Knoll and T.M Henderson, IEEE Trans. Nucl. Sci., 35, p.872 (1988)

## Light Output and Energy Resolution

Table 3. Absolute light output for Ce only, Sr and Ba co-doped $LaBr_3$ crystals

| | Absolute light output (photon/MeV) | Light Output Improvement |
|---|---|---|
| Ce only | 70,000 | / |
| **Sr co-doped** | **88,000** | **+ 25%** |
| **Ba co-doped** | **89,000** | **+ 26%** |

Table 4. Energy resolution at representative energies measured for ϕ 60 mm x 80 mm crystals

| | 122 keV | 662 keV | 2.615 MeV |
|---|---|---|---|
| Ce only | 9.0% | 3.7% | 2.0% |
| **Sr** | **7.7%** | **3.2%** | **1.7%** |
| **Ba** | **7.7%** | **3.3%** | **1.9%** |

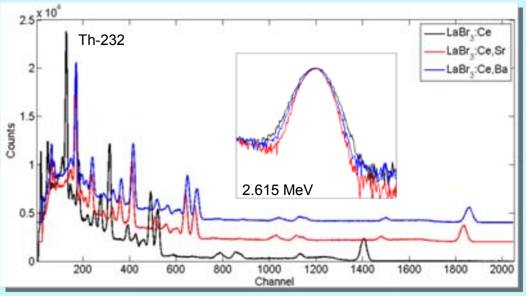


Fig. 6 Th-232 energy spectra measured by Ce only, Sr and Ba co-doped $LaBr_3$:Ce; The insert compared the normalized 2.615 MeV energy peak measured by three crystals.

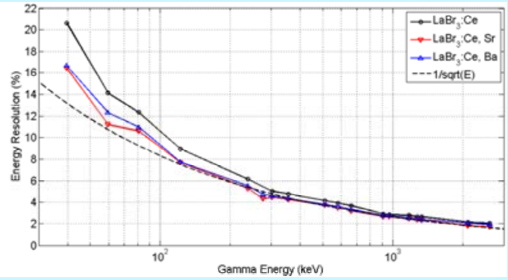


Fig. 7 Energy resolution at various gamma energies

Absolute light output was determined at 661.6 keV by using a Hamamatsu R1307 PMT for its distinct single photo-electron peak. Pulse height spectra measurements at various energies were carried out by a ET Enterprises 9305 PMT for its excellent gain linearity.

As is shown in Table 4 and Fig 7, **both Sr and Ba co-doping improved the energy resolution of $LaBr_3$ over a wide energy range**. This is due to improved light output combined with improved energy proportionality.

## Light Output Proportionality

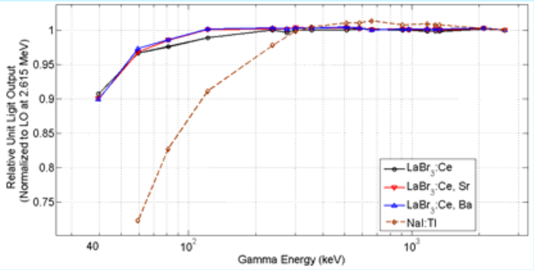


Fig. 8 The relative light output (with respect to 2.615 MeV) as a function of γ-ray energy

**Light output proportionality in the low energy range is also improved** by both Sr and Ba co-doping. Sr and Ba shows very similar proportionality performance.

Table 5. Relative light output at some representative energies

| | Ce only | Sr | Ba |
|---|---|---|---|
| 60 keV | 96.7% | **96.8%** | **97.3%** |
| 81 keV | 97.6% | **98.5%** | **98.6%** |
| 122 keV | 98.8% | **100.1%** | **100.1%** |
| 662 keV | 100.1% | **100.1%** | **100.1%** |
| 2.615 MeV | 100% | 100% | 100% |

## Summary


- The scintillation light output of $LaBr_3$:Ce is significantly improved (~25%) by Sr and Ba co-doping.
- Sr and Ba co-doping improved the energy resolution over a wide energy range.
- Light output proportionality is also improved by Sr and Ba co-doping.
- Sr and Ba slightly lengthen the scintillation decay times of $LaBr_3$:Ce.
- The emission characteristics of $LaBr_3$:Ce remain unchanged with Sr and Ba co-doping.


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