# LGSO Scintillation Crystals Coupled to New Large Area APDs Compared to LSO and BGO [1]

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## *Abstract*

Recent developments of large area avalanche photodiodes (APDs) and fast scintillators with high light yield offer unique advantages for imaging applications. To test possible scintillator-APD combinations, 3.7x3.7x12.0 $mm^3$ LGSO, BGO and LSO crystals were coupled to large area, low capacitance, round and rectangular APDs (5 mm diameter, 3x3 $mm^2$ and 5x5 $mm^2$, Hamamatsu, Japan). Light output, energy resolution and time resolution were compared.

The light output of BGO was about 86% worse and of LGSO about 30% worse compared to LSO (100%). The energy resolution at 511 keV was 13.8±0.5% for LSO and 15.1±0.5% for LGSO (FWHM). For BGO, 16.9±0.5% (FWHM) was measured at 662 keV. The coincident time resolution of two opposing single detectors was 2.7±0.2 ns for LSO and 3.9±0.2 ns for LGSO (FWHM).

Chemical treatment of crystals showed an improved energy resolution compared to mechanical polishing of more than 1%, providing reduced cost and less processing time. An energy resolution of 10.7±0.5% for LSO could be reached after chemical etching.

With the new large area APDs, results similar to PMT readout could be achieved. The scintillation characteristic of LGSO makes this material a promising candidate for APD readout, although the performance was inferior to LSO.

## I. INTRODUCTION

Combined with high light yield scintillators, new avalanche photodiodes (APDs) show many advantages over photomultiplier tubes (PMTs) and PIN photodiodes, such as their compactness, low noise and potential mass production [1, 2, 3]. In our study, we investigated the readout of the new cerium doped lutetium gadolinium oxyorthosilicate (LGSO) in comparison to bismuth germanate (BGO) and cerium doped lutetium oxyorthosilicate (LSO) [4] using new large area APDs. The light yield, energy resolution and time resolution were determined.

In many applications, such as calorimeters or nuclear medical applications, a large number of crystals are needed. Therefore, it is very important to treat the surface of the scintillator efficiently to save time and money. Light yield and therefore energy resolution can significantly be improved by applying a mechanical polish to the surface of the crystals [5, 6]. Employing a chemical etching process instead of a mechanical polish would help to drastically reduce manufacturing costs. We further investigated the the influence of chemical etching on the energy resolution of LSO and LGSO scintillaton crystals with APD readout in comparison to mechanical polishing. Particularly, we investigated the effect of etching time on the scintillator light yield and energy resolution.

## II. MATERIALS AND METHODS

### A. *Crystal Samples*

Measurements were performed using LGSO crystals (10% gadolinium, 90% lutetium) from Hitachi, Japan. The 3.7x3.7x12.0 $mm^3$ crystals were chemically etched by the producer. For comparison, mechanically polished BGO crystals and LSO crystals (CTI Inc., Knoxville, TN) of the same size were used.

In addition, a chemically etched 2.0x2.0x7.0 $mm^3$ LSO crystal (CTI Inc., Knoxville, TN) was used for measuring the dependence of energy resolution and scintillation light output on the capacitance of the diode.

To test the influence of chemical etching on the light output, six 2.0x2.0x7.0 $mm^3$ LSO crystals, untreated, as-sliced, (CTI Inc., Knoxville, TN), three mechanically polished 3.7x3.7x12.0 $mm^3$ LSO crystals and 3 pre-etched 3.7x3.7x12.0 $mm^3$ LGSO crystals (Hitachi, Japan) with different light output and energy resolution were used.

For better light collection, the crystals were wrapped in four layers of 180 $\mu m$ teflon tape. All crystals were heated in the dark at $150^0$ C for 60 minutes and then kept in a light-tight box to avoid changes in light yield caused by crystal afterglow [7].

### B. *Avalanche Photodiodes*

Table 1 shows the specifications of the APDs (Hamamatsu Photonics, Japan).

The active surfaces of the APDs were protected by a thin epoxy layer. The crystals were optically coupled to the APDs by 1 mm silicone rubber discs. To avoid gain shifts of the APDs induced by temperature variations, the crystal-APD detector was kept at 300 K during all measurements.

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Table 1
Specification of Avalanche Photodiodes

| APD type | active surface | break-down voltage | voltage at gain=100 | dark current | C (pF) |
|---|---|---|---|---|---|
| 1246 | 3x3 $mm^2$ | 440 V | 433.9 V | 2.5 nA | 37 |
| 1247 | 5x5 $mm^2$ | 441 V | 433.8 V | 7.3 nA | 111 |
| 0576 | 5 mm ∅ | 443 V | 436.4 V | 7.1 nA | 87 |

## C. Etching Process

LSO and LGSO crystals were etched with phosphoric acid at 170° C for time intervals from 20 seconds up to 40 minutes to investigate the effect of etching time on light yield. The etched crystals were rinsed with water immediately after the etching process.

## D. Measurements

The APD charge was converted to a voltage signal by a fast, low noise preamplifier (r.m.s. noise 560 $e^-$ + 17 $e^-$/pF at 50 ns shaping time, rise time 20 ns) and then fed into a 50 ns integration shaper with a resulting gain of 2.00 $\mu$V/$e^-$ (both preamplifier and shaper by Max-Planck-Institut für Physik, München). The signal was digitized by a multichannel analyzer (qVt 3001, LeCroy) and displayed via qVt-Interface (No 3157, LeCroy) on a monitor.

Measurements were performed with positron emitting sources ($^{22}$Na and $^{18}$F) for comparing LSO and LGSO. The peak position of the 511 keV photopeak and energy resolution were monitored, using the APD 1247 for LGSO and LSO. The parameters of BGO and LSO were measured with APD 0576 and a 662 keV $^{137}$Cs gamma-source.

APDs 1246 and 1247 were used to determine the influence of APD capacitance (size of active surface area) on the energy resolution.

Two detectors (APD 1247) with 64 mm distance were used to measure the coincident time resolution of LSO and LGSO. A $^{22}$Na point source was placed in between the detectors. The time spectrum was displayed on a monitor by the LeCroy qvt (t-mode). The energy threshold of the constant fraction discriminator (CFD, EG&G #634) was set at 350 keV.

# III. RESULTS

Figure 1 shows the gain (511 keV peak position, figure left) and the energy resolution (FWHM for 511 keV gamma rays, figure right) of LSO and LGSO crystals coupled to a 5x5 $mm^2$ APD (APD gain=50 at U=426 V). The energy resolution of LGSO was 1-2% worse and the light output was about 32% worse compared to LSO.

The light yield of BGO was 86% lower compared to LSO. To get an energy resolution of 16.9% (for 662 keV gamma rays) with BGO crystals, the APD had to be operated at a gain >100. For an APD gain of 50 (APD diameter 5 mm), the energy

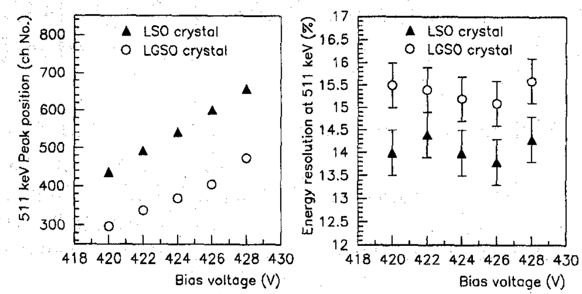


Figure 1: Gain (left figure) and energy resolution (right figure) of LSO and LGSO crystals versus bias voltage (APD gain).

resolution was 21.8% for BGO and 12.1% (FWHM, 662 keV) for LSO.

The position of the 511 keV photopeak, measured with a LSO crystal coupled to high capacitance APDs (5x5 $mm^2$) was not significantly different from the one measured with smaller APDs (3x3 $mm^2$), as documented in figure 2. At low gains, high capacitance diodes (upper curve in figure 2, right) yielded a poor energy resolution (15.6% at 420 V). Increasing the bias voltage improved the energy resolution of high capacitance APDs. At an APD gain of 80 (428 V) the influence of detector capacitance on the energy resolution became less dominant (13.7% for high capacitance APDs, 12.6% for low capacitance APDs).

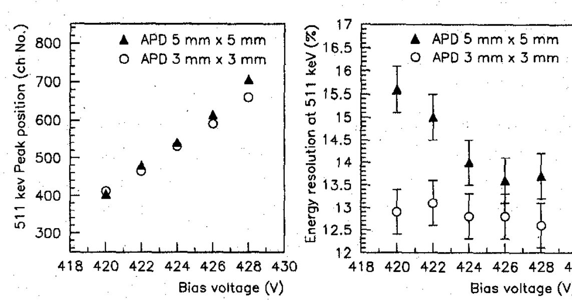


Figure 2: Gain (left figure) and energy resolution (right figure) of different APDs (active surface area), coupled to a LSO crystal versus bias voltage (APD gain).

The time resolution of two detectors was 2.7±0.2 ns for LSO and 3.9±0.2 ns for LGSO.

The energy resolution, light output (peak position) and size of the crystals before and after chemical etching are given in table 2. The results show, for pre-treated crystals, that an etching time of more than 5 minutes does not improve the results. The optimal etching time for raw crystals was 20 minutes (see figure 3).

Table 2
Energy resolution, photo-peak position and size before and after chemical etching of the crystal

| Crystal ($mm^3$) | Etching time | $\frac{\Delta E}{E}$ before (FWHM) | $\frac{\Delta E}{E}$ after (FWHM) | peak position before (ch No.) | peak position after (ch No.) | size before ($mm^3$) | size after ($mm^3$) |
|---|---|---|---|---|---|---|---|
| LSO 3.7x3.7x12.0 | 20 sec | 12.8% | 12.1% | 726 | 854 | 3.68x3.71x11.91 | 3.68x3.71x11.90 |
| | 5 min | 15.3% | 11.4% | 525 | 856 | 3.64x3.67x12.14 | 3.64x3.65x12.12 |
| | 40 min | 12.4% | 11.2% | 703 | 828 | 3.69x3.70x11.87 | 3.64x3.65x11.82 |
| LSO 2.0x2.0x7.0 | 20 sec | 30.6% | 15.9% | 634 | 1238 | 1.95x2.23x7.36 | 1.94x2.20x7.34 |
| | 1 min | 30.2% | 18.9% | 752 | 1104 | 2.01x2.00x7.35 | 1.99x1.98x7.34 |
| | 5 min | 33.2% | 13.5% | 707 | 1118 | 1.97x2.01x7.34 | 1.94x1.98x7.32 |
| | 10 min | 36.5% | 11.9% | 668 | 1118 | 2.02x2.07x7.34 | 1.96x2.01x7.31 |
| | 20 min | 21.9% | 10.7% | 780 | 1198 | 2.20x1.98x7.32 | 2.15x1.94x7.30 |
| | 40 min | 27.6% | 10.7% | 482 | 1454 | 2.07x1.97x7.37 | 2.02x1.92x7.30 |
| LGSO 3.7x3.7x12.0 | 20 sec | 17.7% | 15.0% | 469 | 540 | 3.71x3.72x12.00 | 3.70x3.72x12.00 |
| | 5 min | 15.3% | 14.3% | 517 | 563 | 3.71x3.70x12.00 | 3.71x3.70x12.00 |
| | 40 min | 26.1% | 22.4% | 416 | 489 | 3.70x3.72x12.01 | 3.68x3.71x11.97 |

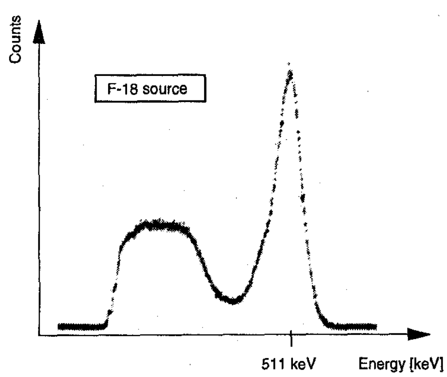


Figure 3: Energy spectrum of a 2x2x7 $mm^2$ LSO crystal after etching. Energy resolution: 10.7% (FWHM) at 511 keV

## IV. Conclusion

With the new, large area APDs, despite their high capacitance and therefore higher electronic noise, results similar to those obtained with PMTs [8] and small area APDs can be achieved at high gains.

LGSO is a good candidate for APD readout, although the performance in terms of energy resolution, time resolution and light yield was inferior compared to LSO, but much better than BGO. The good time resolution of LGSO, which is close to the time resolution of LSO, makes this crystal a promising candidate for fast timing applications in gamma ray measurements.

The chemical surface treatment showed significant advantages over mechanical polishing. Improved light collection in the crystal can be reached at reduced time and cost. Especially if thousands of individual crystals are needed, the chemical etching process may be advantageous.

## V. Acknowledgments

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## VI. References

[1] I. Holl, E. Lorenz, S. Natkaniez et al.: "Some Studies of Avalanche Photodiode Readout of Fast Scintillators" *IEEE Trans. Nucl. Sci., NS-42, 1995* pp. 351-356

[2] M. Moszynski, M. Kapusta, D. Wolski et al.: "Blue enhanced large area avalanche photodiodes in scintillation detection with LSO, YAP and LuAP crystals" *IEEE Trans. Nucl. Sci., NS-44, 1997* pp. 436-442

[3] E. Lorenz, S. Natkaniec, D. Renker et al.: "Fast readout of plastic and crystal scintillators by avalanche photodiodes" *Nucl. Instr. Meth., A 344, 1994* pp. 64-72

[4] C.L. Melcher, J.S. Schweitzer: "Cerium-doped Lutetium Oxyorthosilicate: A Fast, Efficient New Scintillator" *IEEE Trans. Nucl. Sci., NS-39, 1992* pp. 502-505

[5] J.S. Huber, W.W. Moses, M.S. Andreaco et al.: "Geometry and Surface Treatment Dependence of the Light Collection from LSO Crystals" *submitted to IEEE Trans. Nucl. Sci.*

[6] K. Kurashige, Y. Kurata, H. Ishibashi et al.: "Surface Polishing of GSO Scintillator Using Chemical Process" *IEEE Trans. Nucl. Sci., NS-45, No. 3, June 1998* pp. 522-524

[7] C.L. Melcher: private communication. 1997

[8] C.L. Melcher and J.S. Schweitzer: "A promising new scintillator: cerium-doped lutetium oxyorthosilicate" *Nucl. Instr. and Meth., A314, 1992* pp. 212-214