Lanthanum Chloride Scintillator for X-ray Detection

T. Martin and C. Allier and F. Bernard

ESRF, Cyberstar and Saint Gobain

Abstract. In this presentation we describe the testing of a new cerium doped Lanthanum Chloride crystal (LaCl$_3$:Ce), which makes an excellent scintillation material for X-ray counting applications. Detailed measurements were taken to determine the properties of the scintillator over an energy range of 5 to 60KeV; the results demonstrate that, when used with an appropriate PMT, the crystal sustains high count rates, minimal dead time and good energy resolution. For example an energy resolution of 35% (FWHM) was achieved at 22KeV and count rates of up to 1MHz are possible without dead-time correction. A comparison of LaCl$_3$:Ce with two conventional scintillation materials, YAP:Ce and NaI(Tl) is also presented, which shows that that LaCl$_3$:Ce offers a good balance of performance parameters for X-ray experiments.

Keywords: Scintillator, LaCl$_3$:Ce, x-ray, detector

PACS: 07.85.-m X and gamma ray instruments, 07.85.Qe Synchrotron Radiation Instrumentation

INTRODUCTION

NaI(Tl) and YAP:Ce counting detectors are readily available and used for a variety of experiments on Synchrotron beamlines. NaI(Tl) based systems demonstrate excellent energy resolution but are limited to count rates of up to 500Kcps, whereas YAP:Ce scintillators can count up to 5Mcps (with counting loss correction). Although YAP:Ce scintillators have high count rate, at energies below 20keV they have poor resolution and so separation of the signal from underlying noise can not be achieved.

Lanthanum Chloride is a new commercial material that seems to offer good energy resolution and fast emission. This manuscript provides an overview of some of the testing carried out on the material over a 5keV to 60keV energy, including measurement of energy resolution and dead time.

Experimental Set-up

These tests were performed using a scintillation counter and processing electronics module available from Oxford Danfysik, produced by Cyberstar.

The scintillation detector head consists of a scintillation crystal from Saint Gobain, a Hamamatsu 10-stage photomultiplier tube (PMT) and a preamplifier. The PMT has a rise time of 2.5ns, a transit time spread of 2.2ns and a sufficiently high anode current limit. The system is operated between 800V and 1000V and the quantum efficiency of the PMT is well matched with YAP:Ce and LaCl$_3$:Ce scintillators; 26% at 370nm.

The processing electronics (X2000 – CBY-2202) is widely used on synchrotron beamlines all over the world. It has a fast preamplifier and fast shaping constants (50ns to 1μs peaking time). The faster shaping times are used for YAP:Ce and LaCl$_3$:Ce scintillation crystals and the slower shaping times for NaI(Tl) scintillators.

Energy Resolution Measurement

In order to measure the detector heads energy resolution it was irradiated with an iron source ($^{55}$Fe – 5.9 KeV) and a cadmium source ($^{109}$Cd – 22KeV). The PMT signal was then processed with the X2000 unit detailed above; the spectrum, shown in Fig.1, was recorded with peaking time of 100ns.
Energy resolution for the 22keV peak was measured at about 35% (FWHM) at room temperature. The peak to valley ratio is excellent at 5.9keV; approximately 20, compared to the ratio of about 5 for YAP. Table 1 shows results for both YAP an LaCl₃ scintillators.

**TABLE 1.** LaCl₃: Gain 100, ⁵⁵Fe source (5.9keV)

<table>
<thead>
<tr>
<th>High Voltage (V)</th>
<th>⁵⁵Fe source (5.9keV)</th>
<th>¹⁰⁹Cd source (22keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ΔE/E (peaking time=100ns)</td>
<td>ΔE/E (peaking time=300ns)</td>
</tr>
<tr>
<td>850</td>
<td>80%</td>
<td>130%</td>
</tr>
<tr>
<td>900</td>
<td>75%</td>
<td>84%</td>
</tr>
<tr>
<td>950</td>
<td>69%</td>
<td>77%</td>
</tr>
<tr>
<td>1000</td>
<td>70%</td>
<td>73%</td>
</tr>
</tbody>
</table>

**Count Rate Measurement**

When the distance between the radioactive source and the scintillator is reduced the data input is increased, subsequently modifying the pulse height of the preamplifier. Fig. 2 shows the pulse height of the preamplifier output when excited with a ¹⁰⁹Cd source, versus count rate. It is shown that the pulse height is stable until ~900000cps for both YAP and LaCl₃ scintillators; the amplitude begins to decrease above count rates of around 1 MHz. This limitation is due to the passive divider network of the PMT, which doesn’t allow constant PMT gain at high count rate – this means that for count rates higher than 1Mcps the lower threshold must be very accurately set.

**FIGURE 1.** Spectrum recorded with LaCl₃:Ce scintillator

**FIGURE 2.** Pulse height of the preamplifier output vs. the count rate for YAP (left) and LaCl₃ (right)
Dead Time Measurement

Dead time was determined by measuring the intensity of X-rays (from a 60KeV americium source) after passing through a fixed absorber; the true count rate being assumed proportional to the incident count rate and the transmission of the absorber. In this test a single Fe foil was utilised as the absorber.

Data was fitted to both paralyzable and nonparalyzable models, shown in Fig. 3 and Fig. 4 below (LaCl3: Gain=30, peaking time=50ns, HV=1000v and YAP: Gain=30, peaking time=50ns, HV=900v). Table 2 shows a summary of measured dead time for YAP and LaCl3.

<table>
<thead>
<tr>
<th>Model type</th>
<th>$\tau_{\text{YAP:Ce}}$</th>
<th>$\tau_{\text{LaCl3:Ce}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non paralyzable</td>
<td>97ns</td>
<td>208ns</td>
</tr>
<tr>
<td>Paralyzable</td>
<td>87ns</td>
<td>151ns</td>
</tr>
<tr>
<td>100% absorption YAP</td>
<td>87ns</td>
<td>151ns</td>
</tr>
</tbody>
</table>

Figure 5 shows measured energies, from obtained peak position, versus the known X-ray energy from a radioactive source, for LaCl3.

The response indicates that LaCl3 is a very linear scintillator over the 5.9keV to 60keV energy range. The highest non-proportionality is about 11% at 8.9keV.
**CONCLUSIONS**

LaCl₃:Ce crystal is a promising crystal for X-ray counting applications; demonstrating a compromise between energy resolution and high counting rate. The scintillator can be used up to 1MHz without dead time correction and the theoretical maximum count rate, using the paralysable model, is 2.5 Mcps. These results were obtained using a radioactive source; future experimentation, to confirm the crystal's potential, should be carried out on a Synchrotron beamline.

High quality LaCl₃ scintillation detectors, with integrated state-of-the-art pre-amplifiers and ancillary electronics are now available from Oxford Danfysik (shown in Fig. 6 below).

**REFERENCES**

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**FIGURE 5.** Graph demonstrating the energy linearity of LaCl₃ (HV = 960v, Gain = 40, peaking time =100ns)

**FIGURE 6.** Scintillation detector heads and count processing modules available from Oxford Danfysik.
LaCl₃ Scintillator for X-ray detection

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In this presentation we describe the testing of a new Cerium doped Lanthanum Chloride crystal (LaCl₃:Ce), which makes an excellent scintillation material for X-ray counting applications.

Count Rate Measurement

This was measured by reducing the distance between a ¹⁰⁰Cd radioactive source and the scintillator; this increases data input and subsequently modifies the pulse height of the preamplifier. Figure 2 shows the pulse height of the preamplifier output versus count rate. It is shown that the pulse height is stable to around 900,000 cps for both YAP and LaCl₃:Ce scintillations; the amplitude begins to decrease above count rates of around 1 MHz. This limitation is due to the passive divider network of the PMT, which doesn’t allow constant PMT gain at high count rate – this means that for count rates higher than 1Mops the lower threshold must be very accurately set.

Energy resolution

Energy resolution was determined using both a ⁵⁵Fe source (5.9 keV) and a ¹⁰⁰Cd source (22 keV). Energy resolution for the 22 keV peak was measured to be about 35% (FWHM) at room temperature. The peak to valley ratio is excellent at 5.9 keV, approximately 20, compared to the ratio of about 5 for YAP.

Dead Time Measurement

Dead time was determined by measuring the intensity of X-rays, from an Am source, after passing through a fixed absorber; the true count rate being assumed proportional to the incident count rate and the transmission of the absorber. In this test a single Fe foil was utilised as the absorber. Data was fitted to both paralyzable and nonparalyzable models, shown below. LaCl₃:Ce, Gain=30, peaking time=50 ns, HV=1000 v and YAP: Gain=30, peaking time=50 ns, HV=900 v. Table 2 shows a summary of measured dead time for YAP and LaCl₃:Ce.

LaCl₃ production and detector manufacture

These tests were performed using a scintillation counter and processing electronics module available from Oxford Danfysik. Oxford Danfysik provides a full range of scintillation detector heads with various dimensions, crystal types, and thicknesses; allowing you to match a product to your efficiency, resolution, speed, and integration requirements.

The processing modules are designed to obtain maximum performance from the entire scintillation detection range. The scintillation detector head consists of a scintillation crystal, a Hamamatsu 10-stage photomultiplier tube (PMT) and a preamplifier. The processing electronics (X2000 – CBY-2202) is widely used on synchrotron beamlines all over the world.

Energy Linearity Measurement

Figure 5 shows measured energies, from obtained peak position, versus the known X-ray energy from a radioactive source. The response indicates that LaCl₃:Ce is a very linear scintillator over the 5.9 keV to 60 keV energy range. The highest non-proportionality is about 11% at 8.9 keV.

Conclusion

LaCl₃:Ce crystal is a promising crystal for X-ray counting applications; demonstrating a compromise between energy resolution and high counting rate. The scintillator can be used up to 1 MHz without dead time correction and the theoretical maximum count rate, using the paralyzable model, is 2.5 Mcps.

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