# A phoswich composed of CsI:Na and LaBr$_3$:Ce To improve the low energy response of LaBr$_3$:Ce

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A phoswich composed of single crystals CsI:Na and LaBr$_3$:Ce was designed and constructed to improve the low energy response of LaBr$_3$:Ce. The Monte-Carlo program MCNP5 was used to simulate the radiation energy deposition in the two scintillators of phoswich to determine the size. It is found that a phoswich composed of Φ20×2 mm CsI:Na and Φ20×20 mm LaBr$_3$:Ce can optimize the energy resolution of 22.1 keV X-rays, 9% superior compared with LaBr$_3$:Ce, while the energy resolution of 662 keV γ-ray slighly deteriorates compared with LaBr$_3$:Ce.

## 1. Introduction

The phoswich is a combination of two layers of scintillators with widely different decay times and optically coupled to a single Photomultiplier (PMT), which has established itself as a very useful detection system for over three decades [1]. The basic purpose of the phoswich has been an efficient detection of low-energy and low-intensity X-ray, γ-ray, α and β particles in the presence of a high energy background since developed. The wide application of phoswich detectors range from particle identification, X- and γ-ray astronomy to medical imaging recently. The measurements of X-ray and low energy γ-ray require the primary detector to be thin but thick enough for total absorption of the radiation. The higher energy radiation depositing partial energies in both the scintillators can be rejected by using the detector in anti-coincidence mode using rise time discrimination.

The LaBr$_3$:Ce single crystal has excellent scintillation properties compared with traditional scintillaors such as NaI:Tl and CsI:Na [2-3]. But the performance advantage doesn't occur in all the energy region. In fact, in low energy region, below 50 keV, for example, the traditional ones exhibit superior properties, which reminds us to design a structure to utilize the advantage of different scintillators in different energy region. The phoswich is a potential structure to achieve the vision.

## 2. Design and construction of phoswich

The scintillation properties of CsI:Na are even better in the low energy region than NaI:Tl[2], so a phoswich composed of CsI:Na and LaBr$_3$:Ce was designed to utilize the low energy advantage of the former and high energy advantage of the latter. The Monte-carlo program MCNP5 was used to simulate the radiation energy deposition in phoswich (Fig. 1).
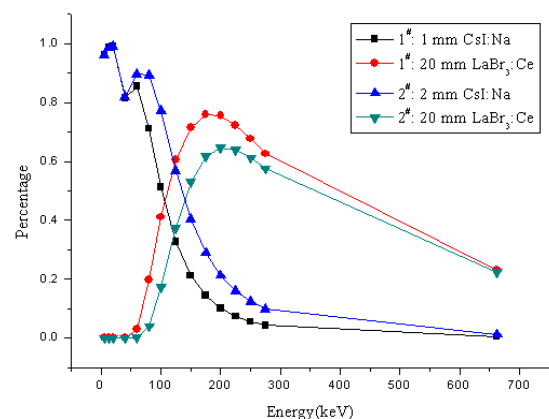


*Fig. 1. The percentage of energy deposited in phoswich (1[#]: 1 mm thick CsI:Na+20 mm thick LaBr$_3$:Ce; 2[#]: 2 mm thick CsI:Na + 20 mm thick LaBr$_3$:Ce), simulated by MCNP5.*

From Fig. 1, it's found that phoswich composed of 2-mm-thick CsI:Na and 20-mm-thick LaBr$_3$:Ce can stop most of the rays below 50 keV, while seldom of 662 keV rays deposite in CsI:Na. So we decide to use 2-mm-thick CsI:Na and 20-mm- thick LaBr$_3$:Ce to construct the phoswich.

Fig. 2 is the schematic diagram of the phoswich we designed. The phoswich was packaged by Al shell and quartz glass. CsI:Na and LaBr$_3$:Ce were coupled by grease, and covered by Teflon reflector at side and end face except for the plane coupled to photomultiplier (PMT). A 1-mm-thick Carbon fiber was used as a cover to replace Al shell to reduce the countercheck of low energy rays. Fig. 3 is the physical map of phoswich after construction, composed of Φ20×2 mm CsI:Na and Φ20×20 mm LaBr$_3$:Ce.

response of the phoswich.
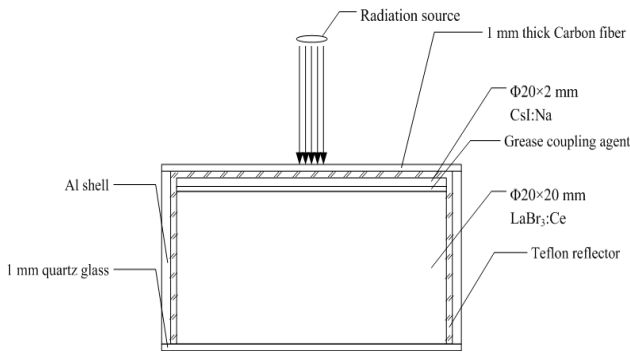


*Fig. 2. The schematic diagram of phoswich composed of Φ20×2 mm CsI:Na and Φ20×20 mm LaBr$_3$:Ce.*



(a)



(b)

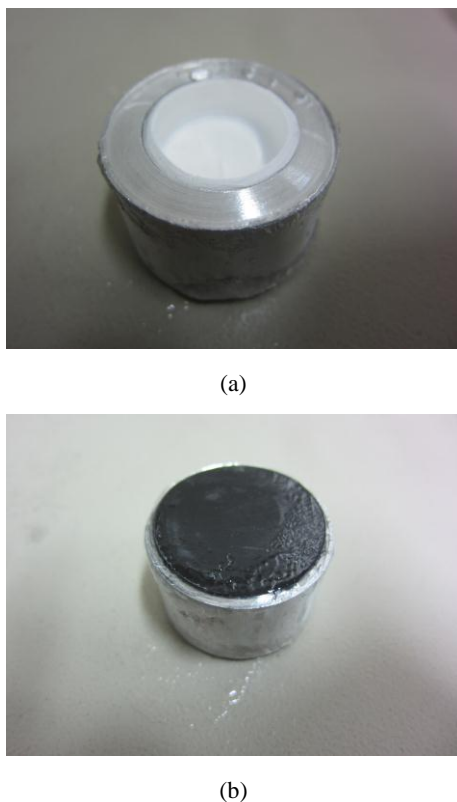*Fig. 3. The physical map of phoswich composed of Φ20×2 mm CsI:Na and Φ 20 ×20 mm LaBr$_3$:Ce. (a) The side facing PMT; (b) The side facing rays.*

## 3. Results and discussion

The $^{241}$Am, $^{57}$Co, $^{137}$Cs were used to test the scintillation properties of the phoswich we designed and constructed. In order to get the energy of rays low enough, we used a sheet of Ag metal to reflex the 59.5 keV rays of $^{241}$Am, which could yield the 22.1 keV K$_α$ X-ray of Ag.

The phoswich was coupled to a Hamamatsu R6233-100 PMT while the scintillation properties were measured.

Fig. 4 and 5 is the phoswich scintillation pulse height spectrum measured by 662 keV and 22.1 keV rays, respectively, which represents the high and low energy
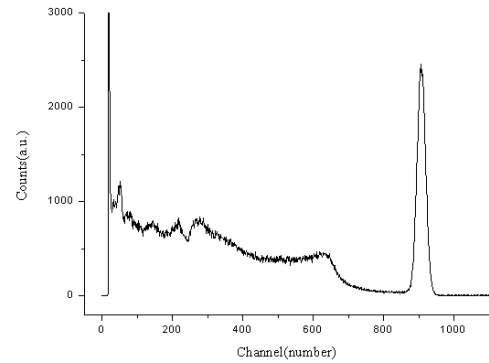


*Fig. 4. $^{137}$Cs 662 keV scintillation pulse height spectrum measured with phoswich composed of Φ20×2 mm CsI:Na and Φ 20 × 20 mm LaBr$_3$:Ce, under the shaping time of 0.5 μs.*



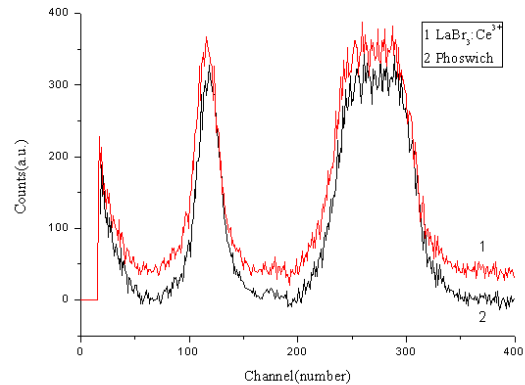*Fig. 5. 22.1 keV scintillation pulse height spectrum measured with LaBr$_3$:Ce single crystal and phoswich composed of Φ20×2 mm CsI:Na and Φ20×20 mm LaBr$_3$:Ce, under the shaping time of 0.5 μs and 12 μs, respectively.*

From Fig. 4, there is only one Photoelectric peak caused by LaBr$_3$:Ce in phoswich. The energy resolution of 662 keV in phoswich is 2.90%, just slightly poorer than the rays in single crystal LaBr$_3$:Ce (2.60%), and the relative light output is 0.96. The slight deterioration may be due to the escape of photons from the interface of CsI:Na and LaBr$_3$:Ce.

The energy resolution of 22.1 keV in phoswich is 21% (Fig. 5), 9% superior compared with which in LaBr$_3$:Ce (23.1%), and the relative light output is 0.97 and 0.96, respectively, relative to the light output in CsI:Na. Photons yielded in CsI:Na may be absorbed in LaBr$_3$:Ce before reaching the interface of phoswich and quartz glass, which may deteriorate the light output and energy resolution.

Fig. 6 and 7 are the phoswich scintillation pulse height spectra measured by 59.5 keV and 122 keV, respectively, which represents the middle energy response. As the shaping time increases, the spectrum induced by CsI:Na moves to the right continuously, but the position of Photoelectric peak doesn't exceed the peak induced by LaBr$_3$:Ce, merged at most, for 59.5 keV radiation.
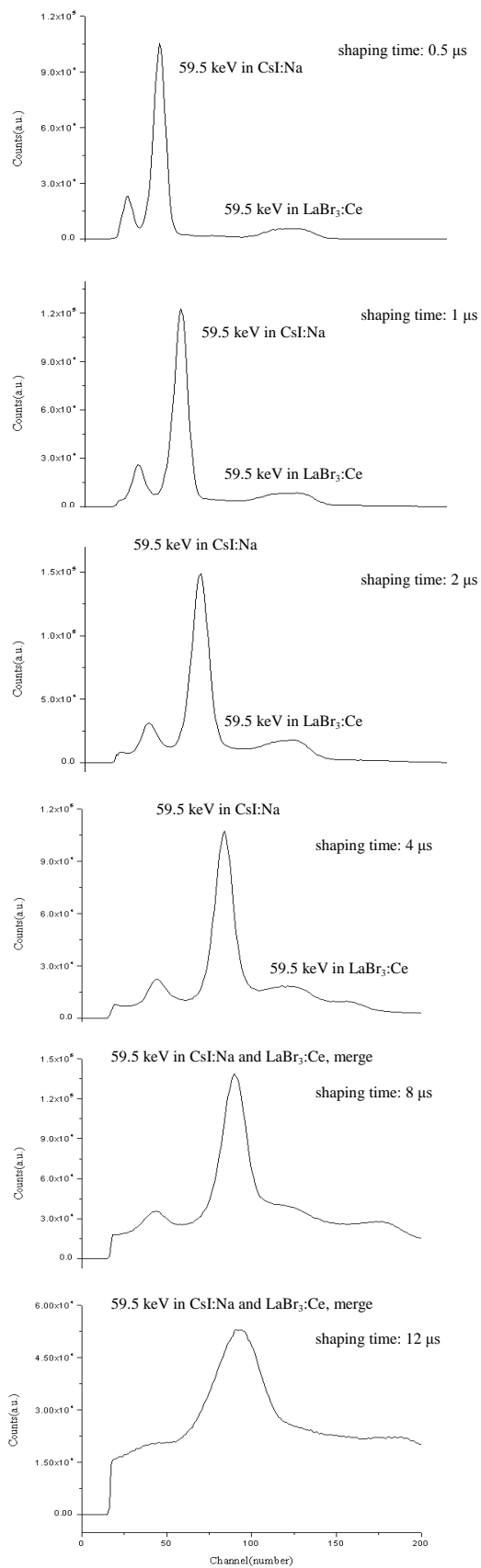
*Fig. 6. $^{241}$Am scintillation pulse height spectra measured with the phoswich composed of $\Phi20\times2$ mm CsI:Na and $\Phi20\times20$ mm LaBr$_3$:Ce under different shaping times: 0.5, 1, 2, 4, 8 and 12 µs.*
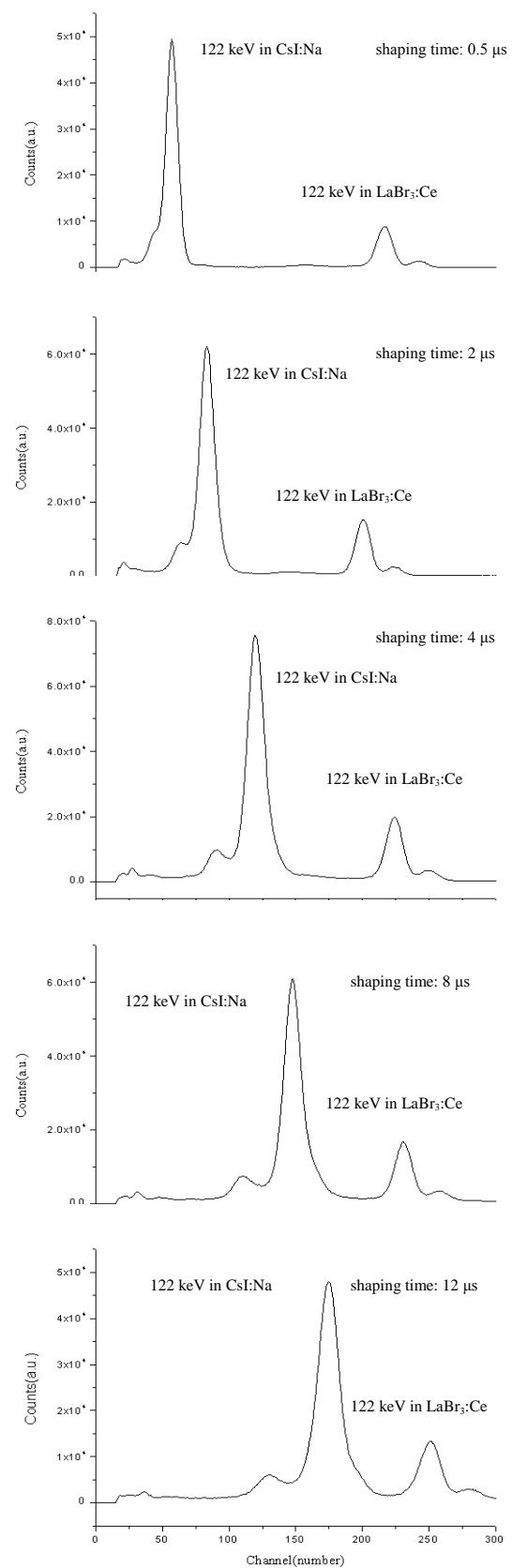


*Fig. 7. $^{57}$Co scintillation pulse height spectra measured with the phoswich composed of $\Phi20\times2$ mm CsI:Na and $\Phi20\times20$ mm LaBr$_3$:Ce under different shaping times: 0.5, 2, 4, 8 and 12 µs.*

Table. 1 lists the information of scintillation properties of phoswich composed of Φ20×2 mm CsI:Na and Φ20×20 mm LaBr$_3$:Ce extracted from Fig. 4 to 7, and single crystals Φ20×2 mm CsI:Na and Φ20×20 mm LaBr$_3$:Ce, as comparisons.

*Table. 1. The scintillation properties of phoswich and single crystal scintillators.*

| Scintillator | Size (mm) | Radiation Sourse | Shaping Time (μs) | Relative Light Output | Energy Resolution |
|---|---|---|---|---|---|
| CsI:Na | Φ2×20 | $^{241}$Am+Ag (22.1 keV) | 12 | 1[a] | 16.7% |
| | | $^{241}$Am (59.5 keV) | 12 | 0.708[b] | 14.5% |
| | | $^{57}$Co (122 keV) | 12 | 0.846[c] | 8.52% |
| | | $^{137}$Cs (662 keV) | 12 | 0.870[d] | 4.90% |
| LaBr$_3$:Ce | Φ20×20 | $^{241}$Am+Ag (22.1 keV) | 0.5 | 0.96[a] | 23.1% |
| | | $^{241}$Am (59.5 keV) | 0.5 | 1[b] | 11.1% |
| | | $^{57}$Co (122 keV) | 0.5 | 1[c] | 7.33% |
| | | $^{137}$Cs (662 keV) | 0.5 | 1[d] | 2.60% |
| Phoswich (CsI:Na + LaBr$_3$:Ce) | Φ2×20+Φ20×20 | $^{241}$Am+Ag (22.1 keV) | 12 | 0.97[a] | 21.0% |
| | | $^{241}$Am (59.5 keV) | 0.5 | 0.350 (CsI:Na)[b] | 17.1% (CsI:Na) |
| | | | 1 | 0.450 (CsI:Na)[b] | 15.9% (CsI:Na) |
| | | | 2 | 0.543 (CsI:Na)[b] | 15.5% (CsI:Na) |
| | | | 4 | 0.715 (CsI:Na)[b] | 13.0% (CsI:Na) |
| | | | 8 | 0.769 (CsI:Na)[b] | 14.3% (CsI:Na) |
| | | | 12 | 0.791 (CsI:Na)[b] | 25.7% (CsI:Na) |
| | | $^{57}$Co (122 keV) | 0.5 | 0.225 (CsI:Na)[c] 0.855(LaBr$_3$:Ce)[c] | 17.3% (CsI:Na) 5.73% (LaBr$_3$:Ce) |
| | | | 2 | 0.329 (CsI:Na)[c] 0.792(LaBr$_3$:Ce)[c] | 13.7% (CsI:Na) 5.84% (LaBr$_3$:Ce) |
| | | | 4 | 0.473 (CsI:Na)[c] 0.885(LaBr$_3$:Ce)[c] | 11.4% (CsI:Na) 5.74% (LaBr$_3$:Ce) |
| | | | 8 | 0.582 (CsI:Na)[c] 0.911(LaBr$_3$:Ce)[c] | 8.48% (CsI:Na) 5.94% (LaBr$_3$:Ce) |
| | | | 12 | 0.689 (CsI:Na)[c] 0.990(LaBr$_3$:Ce)[c] | 8.63% (CsI:Na) 6.21% (LaBr$_3$:Ce) |
| | | $^{137}$Cs (662 keV) | 0.5 | 0.960 (LaBr$_3$:Ce)[d] | 2.90% (LaBr$_3$:Ce) |

a: The light output was relative to 22.1 keV rays in 2 mm thick CsI:Na.
b: The light output was relative to 59.5 keV rays in 20 mm thick LaBr$_3$:Ce.
c: The light output was relative to 122 keV rays in 20 mm thick LaBr$_3$:Ce.
d: The light output was relative to 662 keV rays in 20 mm thick LaBr$_3$:Ce.

## 4. Conclusions

The phoswich composed of Φ20×2 mm CsI:Na and Φ20×20 mm LaBr$_3$:Ce was designed and constructed. The phoswich utilized the advantages of CsI:Na for low energy (22.1 keV) and LaBr$_3$:Ce for high energy (662 keV). In the middle energy region, 59.5 keV and 122 keV radiation were used to test the phoswich, and the energy resolution and relative light output information of scintillators in the phoswich was acquired.

## References

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