SCIONIX

Application Note

YAP:Ce Detectors for fast X-ray spectroscopy

YAP:Ce main advantages

- Ten times faster than NaI(Tl)
- Inert
- High density

Fast X-Ray spectroscopy with scintillation detectors

For the detection of low energy X-rays and γ-rays, traditional **thin NaI(Tl) crystals** are used in combination with photomultiplier tubes (PMT's). Because of the high light output of NaI(Tl) (typically 40 photons/keV), these detectors combine a good detection efficiency with a reasonable energy resolution.

Typically, 1-3 mm thick crystals are used for applications in for example, X-ray diffraction instruments, or gauging tools. Coupled to PMT's having a typical quantum efficiency of about 25% at 400 nm, these detectors produce approximately 10 photoelectrons per keV of absorbed X-ray energy.

Often, **high count rates** are required for the above applications (> 100 kHz). The count rate capability is often limited by the decay time of NaI(Tl) which amounts to roughly 0.25 µs. To avoid pile-up of signals, short electronic shaping times must be used. Practically, the count rate of NaI(Tl) scintillation detectors is limited to several hundreds of kHz because of the above reasons.

A **disadvantage of NaI(Tl)** scintillation crystals is the fact that the crystals are hygroscopic. Therefore, NaI(Tl) scintillation detectors need to be hermetically sealed.

For an optimum transmission of low energy X-rays, Beryllium entrance windows (0.2 – 0.3 mm thick) are normally used. In practice the possibility of leakage at the window / housing seals remains.

In short: NaI(Tl) crystals are not ideal scintillators for low energy X-ray detection but have set the standard due to their unequaled high light output.

The alternative: YAP:Ce

Cerium-doped oxide crystals can be **very efficient fast scintillators.** An example is YAP:Ce ($YAlO_3$:Ce) also called Yttrium Aluminium Perovskite. This material emits scintillation light caused by 5d-4f transitions of the Ce^{3+} ion. Since these transitions are allowed dipole transitions, the scintillation is fast with a typical decay time of 25 - 30 ns. The crystals are absolutely non-hygroscopic and the typical photoelectron yield when coupled to a PMT, amounts to 35-40% of NaI(Tl). This is equivalent to 3.5-4 photoelectrons per keV. The crystal density is 5.5 g/cm^3.

YAP:Ce scintillation crystals are optically polished and do not have any "dead layers" such as NaI(Tl). This allows for an efficient detection of soft x-rays. Because of the fast decay time, electronic shaping times of less than 100 ns can be used without any loss of signal. This means that scintillation detectors using these crystals can be operated at count rates of **several MHz!**

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Because of the low Z-value of the material (Z_{avg}=36), Yap:Ce crystals are not suited for the detection of γ-rays with an energy larger than 100 keV. Table 1 summarize some properties of YAP:Ce compared to NaI(Tl).

Table 1
Physical Properties of YAP:Ce compared to NaI(Tl)

	YAP:Ce	NaI(Tl)
Density (g/cm^3)	5,55	3,67
Effective atomic number	36	50
Rel. photo electron yield	35-40	100
Refractive index	1.94	1.85
Emission maximum (nm)	350	410
Decay time (ns)	27	230
Hardness (Mho)	8.5	2
Hygroscopic	no	yes
Maximum diameter (mm)	50	500

Because of the lower light output of YAP:Ce compared to NaI(Tl), the energy resolution of scintillation detectors equipped with YAP:Ce crystals is worse. In the low energy region (below 100 keV), the energy resolution is dominated by photon statistics. Table 2 shows the optimal measured energy resolution for some X-ray energies measured with 1 mm diameter thick YAP:Ce crystals. The lowest energy that can be detected above the PMT noise amounts to approx. 1 keV. Because of the non-hygroscopic nature of YAP:Ce, thin Mylar entrance windows can be used.

Table 2
Energy resolution for YAP:Ce scintillation detectors

Source	Energy	Energy resolution (FWHM)
Am-241	59.5 keV	20%
I-129	30.0 keV	32%
Co-57	14.4 keV	45%
Fe-55	5.9 keV	69%

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