A Fast Analysis Technique to Evaluate Scintillation Response

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Demands for national security, medical physics, and high-energy nuclear physics applications have prompted research efforts for both improved performance of materials for radiation detection and accelerated materials discover (van Eijk 2003). Existing detector materials do not meet the increasing requirements of nuclear nonproliferation and homeland security applications. Next-generation radiation detector materials with excellent energy resolution at room temperature are needed. Both accelerated materials discovery and efficient techniques that can investigate material properties relevant to detector performance are required.

For gamma ray (γ-ray) detection, a relatively large high-quality crystal is needed for complete absorption of γ-ray energies of interests. New materials discovery has been limited due to the difficulties inherent to large crystal growth; whereas high-quality thin films of candidate materials can be readily produced by various modern deposition techniques. Charged particles, such as He^+, can easily deposit all their energy within a few tens of micrometers, and the corresponding scintillation response can be used to characterize material properties relevant to detector performance. In the current study, a fast screen technique, applicable to thin films or small crystals, is demonstrated to provide the scintillation response of the materials, where energetic ions are used instead of gamma rays. Benchmark materials of bismuth germanate (BGO, $Bi_4Ge_3O_{12}$) and europium-doped calcium fluoride (CaF_2:Eu) crystals are chosen to demonstrate the ion approach.

Experimental Procedures

The scintillation response of materials to He^+ was measured using a time-of-flight (TOF) setup. He^+ ions with energy of 3.5 MeV were produced using a forward scatter method, as shown in Figure 1. Monogenic particles of helium were produced by an NEC tandem accelerator and forward scattered at 45 degrees to the primary beam direction into the TOF telescope by a bulk gold target. Using the forward scatter method, energetic He^+ particles were produced over a continuous range of energies from a few tens of keV to a few MeV, so the scintillation response could be investigated over a continuous energy range.

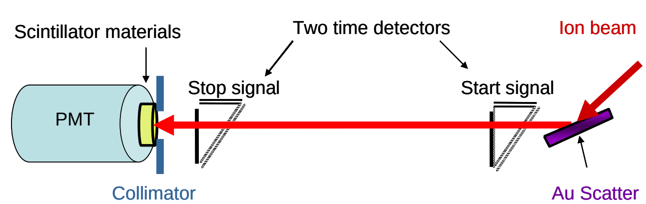

Figure 1. *Schematic drawing of the TOF-scintillator-PMT setup for the scintillation measurement, where BGO or CaF_2:Eu is mounted between the second time detector and the PMT.*

Results and Discussion

Energy Resolution

To demonstrate that the current approach that can be used as a fast screening technique, the scintillation response of both BGO and CaF_2:Eu was examined, and the results are shown in Figure. 2. With superior energy resolution and fast response of the TOF telescope, the energy of individual particles before impinging on the scintillating crystal were determined with a high counting rate. In about 30 minutes, more than 1 million particles were detected by both the CaF_2:Eu crystal and the TOF telescope in a coincident mode, which allows quantitative analysis of material performance over a continuous energy range in a relatively short time.

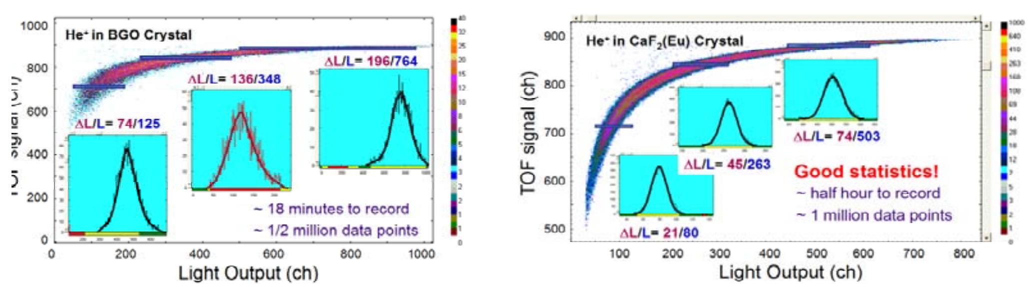

***Figure 2**. TOF versus light output of BGO (left) and CaF_2:Eu (right) to He^+ particles. The insets are the light output profile of the particle at TOF=715, 840 and 885, respectively. The light intensity is governed by the peak position L and the energy resolution can be determined by ΔL/L as shown by the three insets.*

The measured energy resolution in the current study is defined as the full width at half maximum (FWHM) of the peak normalized to its energy (ΔL/L). Fast determination of energy resolution of scintillation response can be obtained by online analysis, as shown by the three examples with corresponding ΔL/L values in Table 1 and Figure 2. Compared with the BGO crystal, the CaF_2:Eu crystal indicates a much better energy resolution, as demonstrated by the examples at three energies (different TOF).

TABLE I

FAST ESTIMATION OF ENERGY RESOLUTION (ΔL/L) OF SCINTILLATION RESPONSE

TOF (ch)	BGO	CaF_2:Eu
715	59%	26%
840	39%	17%
885	26%	15%

Light Yield

Absolute light yield is one of the critical properties when evaluating a scintillation material. The scintillator light yield in this study is given by the pulse height (related to the number of photons) measured due to the total energy deposition of the impinging particles. The scintillation response of the two crystals was measured over the energy range from about 100 keV to approximately 3400 keV using the current technique. As shown in Figure 3, much higher light yield is observed for CaF_2:Eu, as compared with BGO. The relative ratio is in good agreements with the literature value from gamma ray measurements, where the absolute light yield is 8,200 and 24,000 photons/MeV for BGO and CaF_2:Eu, respectively (Knoll 2000; Holl et al. 1988).

Conclusion

For fast screening purposes, the candidates of radiation detector materials can be simply investigated using readily available energetic ions, such as hydrogen or helium ions. The measured light yield and energy resolution observed in the candidate scintillation materials can be compared with the results from benchmarked detector materials. This approach can be applied as a fast analysis technique to assist current efforts on the discovery of new radiation detection materials. The primary assumption is that thin-film materials or small crystals, whose energy resolution to alphas is poor, are unlikely candidates for gamma detectors, while materials that demonstrate good detector response are candidate materials for further investigation, including large crystal growth.

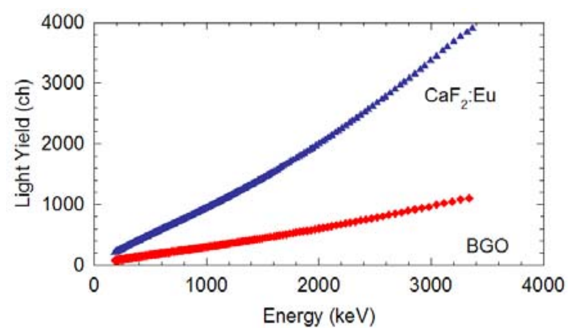

Figure 3. *Light yield (L) as a function of particle energy (E) for CaF_2:Eu and BGO from a similar experimental setup.*

Furthermore, the use of charged particles to deposit energy provides additional control and separation of mechanisms related to photon response and transport properties. This work demonstrates a possible pathway to achieve fundamental understanding of charged particle response and energy resolution, which may provide insight into the different mechanisms that govern the scintillation processes and the origins of light yield nonlinearity in different materials.

Citations

Holl I, E Lorenz, and G Mageras. 1988. “A Measurement of the Light Yield of Common Inorganic Scintillators.” *IEEE Transactions on Nuclear Science* 35(1):105-109.

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