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IMPROVEMENTS IN THE ENERGY RESOLUTION AND
HIGH-COUNT-RATE PERFORMANCE OF BISMUTH GERMANATE

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Abstract: Several methods for improving the energy resolution of bismuth germanate (BGO) have been investigated. It is shown that some of these methods resulted in a substantial improvement in the energy resolution. In addition, a method to improve the performance of BGO at high counting rates has been systematically studied. The results of this study are presented and discussed.

1. Introduction Scintillators made of bismuth germanate (BGO) offer an attractive alternative to sodium iodide (NaI) in many applications in nuclear physics and related fields for several reasons. For example, for a given absolute efficiency for detecting gamma-rays, BGO scintillators are smaller in size and less sensitive to neutrons [1]. In addition, BGO is much more rugged than NaI, BGO is not hygroscopic and suffers from less afterglow than NaI. However, a problem with BGO is its relatively poor energy resolution. It has been demonstrated that the poor energy resolution of BGO is largely the result of its low light output [2-7].

Several methods have been demonstrated or suggested for increasing the light output of BGO. These include cooling the scintillator [8,9], using various surface preparations [10-12], and the use of specially designed shapes [7,10,11]. A limitation of previous cooling studies is that they either do not address the effect of the increase in light output on energy resolution, or were performed with scintillators too small to be useful in most experiments which detect medium- to high-energy gamma-rays. Also, many of the other previous studies involving surface preparations and different crystal geometries have been limited to Monte Carlo computer simulations. In the present work, the three methods for improving the light output of BGO mentioned above were studied for their effect on the energy resolution of BGO. Furthermore, most of the measurements were performed using large (7.6 cm in height and diameter) BGO crystals in an arrangement which is directly applicable in actual experiments. The results of these studies are presented in section 2 below.

A second problem with BGO is its relatively long fluorescence decay time. This property can lead to unacceptable amounts of pulse pileup distortion under conditions of moderate to high counting rates. Furthermore, the combination of low light output and long decay time renders pileup rejection circuits for BGO much less efficient than is possible with other scintillators. Gating the output of BGO to a short time can lessen count rate effects by reducing the time over which the system is sensitive to pileup. Unfortunately, this also worsens the energy resolution. In the present work, the degradation in energy resolution was measured as a function of gate time at several temperatures. The results

are discussed in section 3 below.

2. Improving the energy resolution of BGO

2.1. Cooling BGO

The change in the light output and the decay time of BGO with temperature is well known from previous studies [8,9,13]. In general, both the light output and the decay time increase as the temperature of the scintillator is lowered. However, the change in energy resolution with temperature has been studied very little, and only for very small scintillators. In the present work, the fluorescence decay constant, light output and energy resolution of several cylindrical BGO scintillators (7.6 cm in height and diameter) have been measured as a function of temperature between +24 C and -20 C. The three gamma-rays resulting from ^{22}Na and ^{54}Mn sources (0.511, 0.834 and 1.274 MeV) were used for the measurements. In this work only the BGO crystal was cooled directly. Except for the contact between the cooled BGO and the PMT, the PMT remained at room temperature. This was done in an effort to keep gain and resolution changes due to the PMT to a minimum. As a further aid in ascertaining the effects of changes due to the PMT, light from a light-emitting diode (LED) was input to the PMT as well as into a PIN photodiode. The photodiode output is stable with time and temperature. In this way, the measured light output and energy resolution could be corrected for changes due to the PMT. In anticipation of using the system for high-count-rate situations, the fast (anode) output of the PMT was used in all the tests to be described below.

In general, the variations in the light output and decay constant with temperature measured in the present work are in good agreement with the previous measurements of ref. [9] but substantially different than those reported in refs. [8,13]. Melcher et al [9] attribute these differences to variations in crystal quality.

The results for the energy resolution are displayed in figure 1. The full-width-at-half-maximum (FWHM) resolutions were determined by fitting the data to the sum of a Gaussian plus exponential background. Referred to the highest-temperature point, the energy resolution improved by $0.5\%/^{\circ}\text{C}$ in a fairly linear fashion over the range studied. Overall, the energy resolution improved by approximately twenty percent.

It has been shown in several previous studies [2-7] that the energy resolution of BGO is inversely proportional to the square root of the gamma-ray energy (or the light output). In figure 2, the energy resolution measured for the 0.834 MeV gamma-ray at several temperatures is plotted versus the reciprocal of the square root of the light output. The solid line in figure 2 shows the expected rate of improvement in the energy resolution with temperature based upon the resolution and light output at room temperature. It can be seen that the measured rate of improvement in the energy resolution is less than the expected value. This is probably an indication that thermal gradients exist in the BGO crystal at the lower temperatures causing a worsening of the energy resolution.

2.2. Effects of the surface properties of the scintillator on the energy resolution

It has been shown previously [12] that the light output from BGO can be improved by either polishing or roughening the sides of the scintillator. The choice of surface treatment depends on the geometry of the crystal. For scintillators having widths equal to their lengths, it has been shown [12] that the light output is greater if the scintillator sides which are not coupled to the PMT are finished rough rather than being polished. This result was verified for several scintillators tested in the present work. In addition, it was discovered that the light output also increases, and the energy resolution improves, when the face of the BGO crystal coupled to the PMT is roughened instead of being polished. This increase in light output occurs regardless of whether the other sides of the scintillator are polished or rough. Furthermore, the amount of increase in light output is dependent on the degree of roughness. Of the three different sizes of abrasives (5 μm , 25 μm and 34 μm) that were used to roughen the face of the scintillator coupled to the PMT, the 25 μm size gave the best result. The improvement in the energy resolution for each scintillator was between six and ten percent.

2.3. The use of different scintillator shapes

On the basis of Monte Carlo simulations many authors have suggested that the light output of BGO might be increased by using scintillator shapes other than the usual cylindrical or rectangular geometries [7,10,11]. To the authors' knowledge, none of these suggested alternative

geometries have been tested experimentally in terms of their effect on the energy resolution of BGO. In a previous paper, Wender [7] suggested that the light output from BGO could be almost doubled by forming the coupling face of the BGO into a spherical lens with a radius of curvature equal to one half the length of the scintillator. This idea was tested experimentally in the present work.

A spherical lens having a radius of curvature of 1.27 cm was cut into one face of each of two different BGO crystals which were originally right circular cylinders (2.54 cm in height and diameter). One was formed concave, the other convex. The lens side of each scintillator was coupled to a PMT via a plastic light guide. The energy resolution for the 661 keV gamma-ray from ^{137}Cs was measured before and after the lenses were cut into the BGO crystals. Unfortunately, an equipment failure made it impossible to compare the light output before and after the lenses were cut into the crystals. In both cases the energy resolution worsened from about 13.7% before the lenses were cut to about 16.2% after. The energy resolution was also measured with the lens face opposite the PMT. In this configuration, the energy resolution was about 17.9% for the convex BGO and 15.5% for the concave BGO. Also, for the convex BGO, there was a prominent, long tail on the high-energy side of the peak indicating that with the lens shape the response of the scintillator was not uniform throughout its volume. Hence, even though this technique may have led to an increase in light output, the energy resolution was degraded. It would be interesting to learn how the energy resolution is affected by the other geometries which have been predicted to increase the light output of BGO.

3. Improving the performance of BGO at high counting rates

Gating the output from BGO to a short time can lessen count-rate effects by reducing the time over which the measurement system is sensitive to pileup. Unfortunately, this also worsens the energy resolution. To ascertain the trade offs between the need for good resolution and the effects of pileup distortion, the degradation in resolution as a function of gate time was studied at several temperatures. The results are shown in figures 3 and 4.

Assuming that the light output due to the long decay constant of BGO is the only important contribution, the light output can be written as $L = \int_0^t I_0 e^{-t'/\tau} dt' = \tau I_0 (1 - e^{-t/\tau})$. Here, t is the gate time, τ the decay constant and I_0 the light intensity at $t=0$. Also, from arguments based on photoelectron statistics, it is expected that the energy resolution should be inversely proportional to the square root of the light output. Hence, it is expected that the energy resolution should be proportional to $1 - e^{-t/\tau}$. In figure 3, it can be seen that this expectation is verified by the measurements made in the present work.

In figure 4, the average of the energy resolution for the two gamma-rays from ^{60}Co is plotted versus the gate time at several temperatures. While the resolution is best for the coolest temperature at the longer gate times, the curves for the different temperatures do not converge as expected at short gate times, but actually intersect. This is because the resolution did not improve as quickly with temperature as

expected from a measurement of the light output alone as discussed in section 2.1. Thus, even though the resolution as a function of gate time behaves as expected for a given gamma-ray energy and temperature, the resolution versus gate time data for the lower temperatures are greater than expected from a measurement of the light output alone. Hence, at some short gate time the curves for the different temperatures actually cross one another instead of converging. It is believed that temperature gradients in the cooled BGO, which is in contact with the room-temperature PMT cause the resolution to be worse than expected at the lower temperatures. A new apparatus in which both the BGO and PMT are cooled is currently being designed to overcome these problems.

4. Conclusions

Several methods for improving the energy resolution of BGO have been investigated. It has been shown that some of these methods resulted in a substantial improvement in the energy resolution. Alternatively, one method which was predicted to increase the light output of BGO actually resulted in poorer energy resolution. Also, a method to improve the performance of BGO at high counting rates has been systematically studied. The results of this study were presented and discussed.

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References

- 1) O. Hausser, M.A. Lone, T.X. Alexander, S.A. Kushneriuk and J. Gascon, Nucl. Instr. and Meth. 213 (1983) 301.
- 2) O.H. Nestor and C.Y. Huang, IEEE Trans. Nucl. Sci., NS-22 (1975) 68.
- 3) A.E. Evans, Jr., IEEE Trans. Nucl. Sci., NS-27 (1980) 172.
- 4) D.M. Drake, L.R. Nilsson and J. Faucet, Nucl. Instr. and Meth., 188 (1981) 313.
- 5) S.A. Wender and G.F. Auchampaugh, Nucl. Instr. and Meth., 197 (1982) 591.
- 6) F. Buskirk, M. Caualli-Sforza, D. Coyne, I. Kirkbride and C. Newman, IEEE Trans. Nucl. Sci., NS-29 (1982) 346.
- 7) S.A. Wender, IEEE Trans. Nucl. Sci., NS-30 (1983) 1539.
- 8) H.V. Piltingsrud, J. Nucl. Med., 20 (1979) 1279.
- 9) C.L. Melcher, J.S. Schweitzer, A. Liberman and J. Simonetti, IEEE 1984 Nuclear Science Symposium, Orlando Florida, Oct. 31 - Nov. 2, 1984.
- 10) S. Anderson and M. Salomon, International Workshop on Bismuth Germanate, Princeton University, Nov. 10-13, 1982, p. 158.
- 11) S.F. D'orenzo and J.K. Riles, IEEE Trans. Nucl. Sci., NS-29 (1982) 191.
- 12) H. Ishibashi, S. Akiyama and M. Ishii, International Workshop on Bismuth Germanate, Princeton University, Nov. 10-13, 1982, p. 158.
- 13) M. S. Weber and R.R. Monchamp, J. Appl. Phys., 44 (1973) 5495.

Figure Captions

- 1) The dependence of the energy resolution of BGO on the temperature of the scintillator.
- 2) The variation in the energy resolution of BGO as a function of the reciprocal of the square root of the light output. The solid line shows the expected behavior from simple arguments based on photoelectron statistics.
- 3) The variation in the energy resolution of BGO as a function of the reciprocal of the square root of the light output collected within a given gate time. The measurements shown are for three gamma-ray energies at room temperature.
- 4) The dependence of the energy resolution of BGO on the gate time during which the light output was accepted. The average of the energy resolution for the two gamma-rays from ^{60}Co (1.173 and 1.332 MeV) is shown at three different temperatures. The lines between the data points have been drawn to guide the eye.

Figure 1

Figure 2

Figure 3

Figure 4