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BY DIRECT OBSERVATION OF ELECTRON LOSS IN
A COAXIAL Ge(Li) DETECTOR

By M. G. Strauss, I. S. Sherman and R. W. Bannon

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Abstract

A propeller-shaped region of reduced full-energy-peak efficiency was observed on the face of a true coaxial Ge(Li) detector. A similar pattern on the etch-pit photograph suggests that the propeller blades correspond to the 111 symmetry axes of the crystal. Spectra obtained when a 122 keV γ -ray beam was directed at this degraded region, show a low energy tail which is not present when the beam is directed at normal regions. Current pulses corresponding to γ -rays that interact in the propeller region have shapes that show deficiencies in the electron component. Thus, degraded crystal regions that are revealed by etch-pit distributions can be correlated to local detector performance by direct observation of trapping rather than only by inference from the presence of tails in the energy spectra.

I. Introduction

A γ -ray camera using a coaxial Ge detector is being developed for isotopic organ imaging.¹ Uniform efficiency over the face of the detector is important for such devices. Nonuniformity can deform the shape of the image and distort its shade gradations. Therefore, a measurement was made of the variations of the full-energy-peak efficiency as a function of location on the face of a true coaxial Ge(Li) detector. A propeller-shaped region of reduced efficiency was observed and compared to the etch-pit pattern of the crystal. The nature of the nonuniformity was studied by making spectral measurements inside and outside the propeller region. This was followed by making observations of the current pulse shapes due to γ rays interacting in and out of this region. The observed spectral degradation was then correlated to the pulse shape deformation.

II. Experimental Techniques

The study discussed in this report was done with a true coaxial detector purchased from ORTEC. It has an outer diameter of 50 mm, a core diameter of 6 mm, and a length of 20 mm. While it can operate with a bias in excess of 5000 V, 4000 V was used in these studies. The leakage current is only 100 pA and is

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essentially bias independent. The detector capacitance is only 10 pF.

The detector was scanned with a 1 mm² beam of γ rays from ⁵⁷Co (122 keV). The beam was produced by placing a ⁵⁷Co source behind a lead shield with a 1 mm² x 100 mm long collimating hole. The source-shield combination was mounted on a table which was moved with micrometer screws in the X, Y, and Z directions. A point marker attached to the table indicated the beam position relative to the detector.

Since the components due to electrons and holes are more easily distinguishable² in the current waveform than in the voltage waveform, the pulse shape studies were made by recovering the current pulse**. The circuit used to do this is shown in Fig. 1. Integrated pulses from a broadband, charge-sensitive preamplifier are first amplified by the operational amplifier consisting of Q1 and Q2 and then differentiated with a 20 nsec clip line, thereby recovering the current pulse. This pulse was then delayed 250 nsec while the oscilloscope (Tektronix type 581A) was triggered by the undifferentiated pulse. The trigger pulse was further amplified (x5) and slightly slowed down to minimize trigger jitter. Depending on the shape of the pulse, the optimum scope trace was obtained by triggering with 10 to 50% of the total charge. The 8 nsec time constant in the second operational amplifier and the 10 nsec filter at the output, minimize noise superimposed on the waveform without significantly distorting the pulse shape. The output pulses applied to the scope are negative, but for convenience are shown in Fig. 1 as being positive. All scope pictures were normalized by gating the shutter for 10,000 counts in the 122 keV peak.

III. Results

The results of the detector scan were plotted as counting rate in the 122 keV peak vs. beam position as shown in Fig. 2. The vertical scan along diameter AB is shown on the top left and the horizontal scan CD on the bottom left. On the right, two diagonal scans are shown, EF on the top and GH on the bottom. Note that the uniformity of peak efficiency varies. For example, on the bottom of the right side, the relative counting rate is highly uniform between H and the core, but between G and the core it gradually falls off and

**See Note.

risetime — a characteristic which is opposite to previous observations in which detrapping produced slow rising pulses.

Direct pulse observations similar to those in Fig. 6 showed no evidence of detrapping for at least 1 μ sec. Furthermore, the lower spectrum in Fig. 5 shows that during the integration time of 3-4 μ sec (corresponding to the two 2 μ sec integrating time constants in the amplifier) the lost charge has not been collected, as indicated by the reduced peaks and the existence of the trapping plateau. Thus it appears that in this detector once the electrons are trapped they are not released for at least 3-4 μ sec.

Trapping effects have generally been regarded as the prime factors responsible for spectral degradation when Ge(Li) detectors are uniformly irradiated with γ rays. Armantrout and Thompson⁵ indicated that heavier trapping would occur where etch-pits are more dense. However, the authors are not aware that a direct correlation was ever demonstrated between etch-pit density and local detector performance. This study suggests that a correlation exists between crystal structure defects at specific locations as revealed by etch-pit distributions, and degradation of spectra that are observed at these locations. From published reports^{3, 14-16} it is difficult to determine why previous studies have not revealed this correlation. It may be that the trapping process we have observed here is different from those commonly encountered because this detector is truly outstanding. Yet it may also be that very sensitive techniques are required to establish such correlation. Uniform irradiation would definitely not have revealed it. We have used a low energy beam of 122 keV to assure that most interactions are by photoelectric absorption and are therefore highly localized. The detector was meticulously scanned with a statistical accuracy of 0.5% so as to obtain an efficiency map that shows variations as small as a few percent. The measured spectra were carefully analyzed quantitatively as well as qualitatively. We seriously doubt if without these techniques we would have been able to link crystal defects with local detector performance.

Having studied only one detector, we are not in a position to state general conclusions regarding the observed correlation. We found this correlation interesting and are therefore reporting it. We hope that it will stimulate further studies which will lead to insight into the trapping processes and in turn to detectors with spatially more uniform full-energy efficiency characteristics.

The presence of trapping has generally been established by postulating a detector model from which the pulse-height distribution with trapping is calculated.³⁻⁷ Such a spectrum is usually characterized by a low energy shoulder and/or an extended low energy tail. If an experimentally observed spectrum exhibits similar characteristics it is then attributed to trapping. We have shown that by examining the shape of current pulses, the partial or complete absence of electrons or holes can actually be seen on an oscilloscope. Thus trapping can be observed directly and not entirely deduced from tails in the energy spectra. Moreover, this technique has the advantage of being very simple. When a detector is to be surveyed with a spot beam being directed at many points, the pulse shape technique is far less time consuming than taking a number of spectra. Finally, it was shown that the pulse shape technique is sufficiently sensitive to detect even small trapping effects which would otherwise require long counting times to give statistically mean-

ingful evidence in a spectrum. It should be noted that pulse shape analysis is not a new technique for studying properties of insulators and semiconductors.^{17, 18} However, it has not been widely used in studying detector characteristics.

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**Note: Recovery of the current pulse from the voltage signal results in a signal-to-noise ratio which is much better than that obtained by observing the current pulse directly on a low value resistor across the detector.

† Note: After completing this report, another coaxial detector (made at Brookhaven National Laboratory) was scanned with a 1 mm γ -ray beam. The results obtained show characteristics similar to those discussed in this paper including efficiency nonuniformity across the face of the detector (Figs. 2 & 3), trapping plateau in the energy spectrum (Fig. 5), and electron deficiency in the current waveform (Fig. 6). Thus, these crystal defects may be more prevalent than we had originally expected.

Captions

- Fig. 1 Shaping amplifier for pulse-shape observation. Current pulses are recovered by differentiating integrated preamplifier pulses with clip line. Optimum scope traces were obtained when differentiated pulses were filtered with two ~ 10 nsec integrators and oscilloscope (Tektronix type 581A) was triggered by amplified undifferentiated pulses.
- Fig. 2 Full-energy efficiency profile of coaxial Ge(Li) detector. Counting rate in 122 keV (^{57}Co) γ -ray peak vs. position of 1 mm beam for vertical scan AB, horizontal scan CD, and diagonal scans GH and EF are shown. Note variations of uniformity of peak efficiency — along radius H counting rate is highly uniform while along G it gradually falls off to 75% of maximum.
- Fig. 3 Isocount map of coaxial Ge(Li) detector. Top shows two isocount lines. Propeller-shaped region with relative counting rate in 122 keV peak less than 90% and p-core region with rate less than 50%. Propeller resembles etch-pit pattern in upper photo of Fig. 4. Bottom shows count profile through propeller-shaped region along dashed circle. Each dip corresponds to one propeller blade. Note that while the maximum dip in efficiency is 25%, average is only 10%.
- Fig. 4 Etch-pit distribution of crystal. Top photo (tail end) shows three spokes separated by 120° similar to propeller in Fig. 3.
- Fig. 5 Spectra of γ rays from ^{57}Co . Upper spectrum was obtained with 1 mm beam outside propeller (point 1, Fig. 3). Lower spectrum was obtained with 1 mm beam inside propeller (point 2, Fig. 3). Note reduced peaks and increased low-energy tail in lower spectrum, suggesting trapping in propeller region.
- Fig. 6 Calculated and observed current waveforms due to 122 keV γ -ray beam at 6 mm from center of true coaxial detector. Calculated waveform (left) shows current components due to electrons (i_e) and holes (i_h). Center waveform obtained when beam was outside propeller (point 1, Fig. 3), appears similar to calculated shape. Right waveform was obtained when beam was inside propeller (point 2, Fig. 3). Note that photo on right shows many pulses without characteristic shoulder on trailing edge due to electron component, thus indicating electron trapping. (Horizontal scale on all photos = $0.1 \mu\text{sec/cm}$.)

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

CURRENT WAVEFORMS

Fig. 6