

Temperature Dependence of the Crystal Properties of 18-fold Segmented HPGe Detector



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Abstract

High-purity germanium detectors are used in neutrinoless double-beta decay experiments like GERDA because they have very good energy resolutions and act as detectors and sources simultaneously. They are operated close to liquid nitrogen temperature. The mobility of the charge carriers is temperature dependent, and thus so is the rise time of the pulse induced by their drift. Therefore, pulse shape analysis must take into account possible temperature variations.

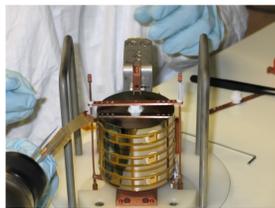
Measurements of the temperature dependence of the pulses were made using a high-purity *n*-type segmented germanium detector. The detector was installed in a vacuum cryostat and cooled through a copper cooling finger submerged in liquid nitrogen. A collimated ^{152}Eu source located at two different positions along the crystal axes $\langle 100 \rangle$ and $\langle 110 \rangle$ was used. The temperature was monitored using a PT100 resistor installed at the closest possible point to the detector. The pulse properties in the temperature range from 93 to 99 K are presented.

It is shown that a segmented HPGe detector can be reliably operated even if one segment is broken.

Introduction

Germanium detectors are generally used to detect radiation. The detectors operate close to liquid nitrogen temperature to reduce the number of electrons in the conduction band due to thermal excitation. When a particle interacts inside the crystal, it creates a cloud of charge carriers (electrons and holes). The charge carriers drift towards the electrodes. Their mobility determines the length of the resulting pulse, the rise time. The dependence of the rise time on crystal orientation and temperature is important for pulse shape analyses [1], that can play crucial roles for ultra-low-background experiments like GERDA because they distinguish between signal and background events.

Measurements were made using a detector with a segment drawing high leakage current (nA) due to surface damage. Analysis determined that, though the damaged segment could not be used for measurements, the remaining 17 segments could be used.



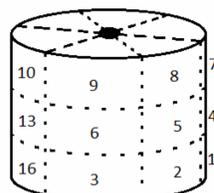
Experimental setup

The measurements were taken using the segmented 18-fold ($3z \times 6\phi$) germanium detector. The detector was installed inside the vacuum cryostat and cooled through a copper finger submerged in liquid nitrogen. The bias voltage of 2000V was applied. A collimated ^{152}Eu source was installed outside the cryostat. Measurements were taken with the source at two different azimuth angles, ϕ , and at the same height. The source always pointed to the center of the crystal, i.e. $z=0$. The two azimuth angles were chosen to correspond to the crystal axes: 145° corresponds to the axis $\langle 100 \rangle$; 195° to the axis $\langle 110 \rangle$.

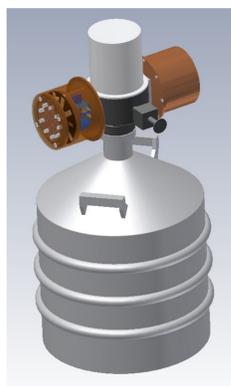
A DGF Pixie-4 [2] data acquisition system (DAQ) manufactured by XIA was used. The DAQ has a 14-bit analog-to-digital converter at 75 MHz.

Leakage current measurements were carried out using a FLUKE-289 multimeter [3] several hours after the cryostat refilling.

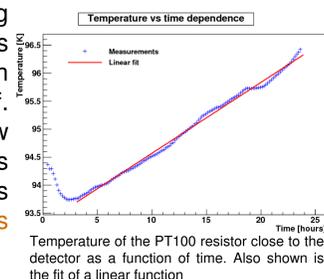
The temperature close to the detector, T , was measured at the top of the cooling finger using a PT100 thermal resistor. This resistor was located inside the vacuum can as close as possible to the crystal itself. After refilling the cryostat, it takes a few hours for the temperature to reach its minimum, after which time measurements are made. The temperature ranges between 85 and 112 K.



Segmented detector Siegfried II



Vacuum cryostat with electronics installed in "ears"



Temperature of the PT100 resistor close to the detector as a function of time. Also shown is the fit of a linear function

Investigation of Temperature Dependence of the Rise Time

Method

To reduce the effect of noise, a simulated standard pulse was used as reference (Fig.1, left). This pulse is taken as a template and is fitted to every measured pulse (Fig.1, right), yielding the amplitude and time scale, t_r , factors. The t_r parameter is then used to obtain the rise time (Fig 2).

Results

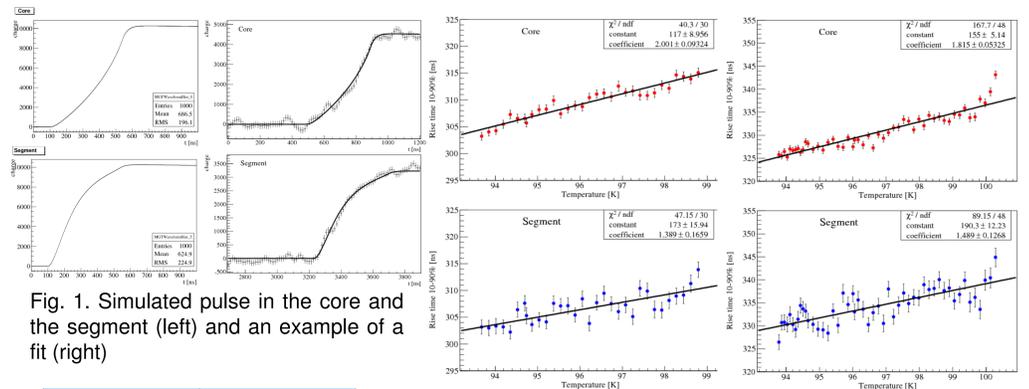


Fig. 1. Simulated pulse in the core and the segment (left) and an example of a fit (right)

145°(<100> axis)	190°(<110> axis)
6.5±0.2 %/K	5.5±0.1 %/K
4.5±0.4 %/K	4.4±0.3 %/K

Percentage value of the rise time per degree Kelvin for the core and the segment for different crystal axes

Fig. 2. Measured rise time versus temperature together with linear fits: left: $\phi=145^\circ$ (<100> axis), right: $\phi=190^\circ$ (<110> axis).

Investigation of eligibility for gamma spectroscopy operation of a damaged segmented detector

The stability of the detector is important, if it is supposed to operate for a long time. Especially, the amplitude and the shape of electronic pulses should not vary in time. However, the performance depends on the temperature, which is often difficult to measure. When the leakage current dependence is known, it is much easier to trace leakage current changes to monitor the temperature.

According to [4], if the leakage current observed in semiconductors, which is proportional to the charge carrier concentration, were volume generated, its temperature dependence would be

$$I \propto T^{3/2} e^{-E_g/2kT}$$

where $E_g \sim 0.73\text{eV}$ – the band gap at 95 K.

The measured leakage current is displayed in Fig 3. It is three orders of magnitude higher than expected. The leakage current is the combination of the volume current with the presence of additional energy levels in the forbidden zone and the current caused by surface effects. The behaviour is similar but with an effective band gap that is

- $E_g \sim 0.16\text{eV}$.

To operate this detector, it is necessary to be sure that the energy resolutions of the other 17 segments is as expected for a fully working germanium detector. The full widths at half maximum for the ^{152}Eu peak at 122 keV for 6 undamaged segments are listed in the table. The measured values show that it is possible to extract useful information even if one segment is broken.

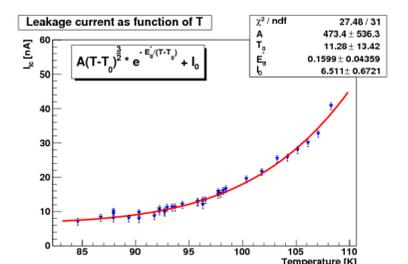


Fig. 3. The leakage current of the segmented detector as a function of the temperature. Also shown is the fit of the expected function

Segment no.	4	5	6	13	14	15
FWHM, keV	1.11	1.21	1.34	1.35	1.01	1.14

Full width at half maximum for 122 keV line of the ^{152}Eu source for the operating segments

Conclusions

The presented studies indicate a strong temperature dependence of crystal properties. The rise time of the pulses has a temperature coefficient of 4.5-6.5 %/K for the temperature range from 94 to 99 K. The observed leakage current of the crystal is three orders of magnitude larger than expected in germanium because one segment of the crystal is damaged. However, the damage of one segment out of 18 does not make this detector ineligible for gamma spectroscopy and pulse shape analysis.

References

1. Iris Abt *et al.* *Eur. Phys. J. C* 52, 19-27 (2007).
2. http://www.xia.com/DGF_Pixie-4_Download.html.
3. <http://us.fluke.com/usen/Products/Fluke+289.htm>.
4. M.S.Tyagi, *Introduction to semiconductors materials and devices* (1991) ch. 3.5.