Multi-Line Gamma-Ray Spectrometer Performance of a Si(Li) Detector Stack

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Abstract

Experimental data is presented which for the first time displays multi-line spectrometer performance of a Si(Li) detector stack at elevated temperature. The stack consists of four elements, each with a 2 cm diameter active area. ^{133}Ba and ^{110m}Ag spectra are obtained using various techniques to enhance the peak-to-background ratio. Spectral data are shown as a function of temperature (94 K $\leq$ T $\leq$ 230 K) using optimized peak shaping.

I. INTRODUCTION

We have previously reported laboratory experimental data and Monte Carlo analysis for a Si(Li) gamma-ray detector stack [1,2,3]. As described there, this detector configuration has been developed primarily for space science applications (e.g., orbiting platforms and Mars surface operations). That work established that 662 keV gamma-rays (^{137}Cs) could be detected with good resolution (full-width at half-maximum (FHWM) $\leq$ 10 keV) at temperatures up to 230 K, and that Compton scattered background could be suppressed for a single photopeak in a 2 cm stack using a "split-stack" anti-coincidence technique. (In the split-stack configuration, the detector(s) nearest the source are used in an anti-coincidence mode to reject Compton scattered background.) The current work addresses the multi-line spectroscopic performance of a Si(Li) stack at elevated temperature.

^{133}Ba spectra from 300 keV to 450 keV, (line spacing ~20–30 keV) and ^{110m}Ag peaks up to 1 MeV are obtained using a variety of techniques to enhance the peak-to-background ratio. Spectral data is shown as a function of temperature (94 K $\leq$ T $\leq$ 230 K) using optimized peak shaping to obtain FWHM resolution of 4–10 keV. Such a detector provides an attractive alternative to the poorer resolution of scintillators (~60 keV at 1.3 Mev) and the cryogenic cooling requirements of high purity germanium (HPGe), T $\leq$ 100 K.

II. EXPERIMENTAL PROCEDURE

A. Device Testing

Four devices were tested in a variable temperature cryostat constructed for this work. We employed two devices 3.3 mm thick and two devices 1 cm thick; all detectors having a 3 cm^2 active area. These devices were fabricated using standard lithium drifting techniques employed at the Lawrence Berkeley Laboratory (LBL) silicon detector laboratory, with no special attention to elevated temperature operation.

All devices feature a standard grooved structure, with their exterior annulus reduced in height to accommodate electrical connections to the center active area more easily. We followed the convention of applying positive bias to the Li n$^+$–contact, and obtaining the detector signal from the Au Schottky barrier side. The devices were always arranged in pairs such that the signal sides were common for each pair (see Fig. 1). Experimental work had demonstrated that other arrangements resulted in significant crosstalk and noise. Previous Monte Carlo analysis indicated that optimum split-stack peak-to-background performance for the energy range under consideration was obtained when the ratio of the front part of the stack to the back was approximately 1:3 [1]. This analysis dictated the selection of a pair of 3.3 mm devices (total ~7 mm) and a pair of 1 cm devices (2 cm total).

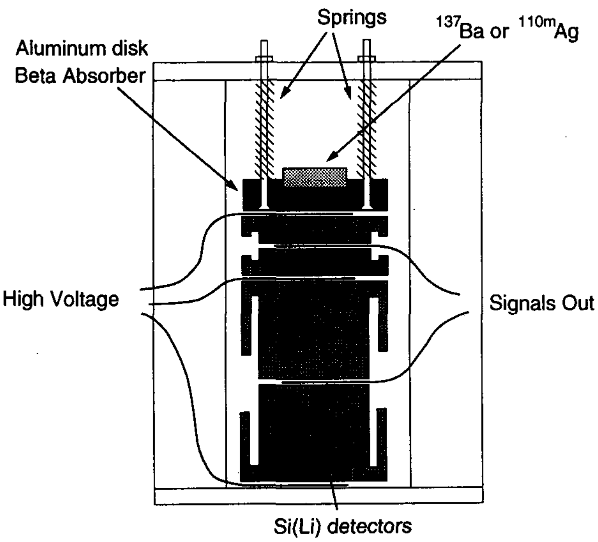

Figure 1. Physical Configuration of Detector Stack

Data collection conditions were standardized except as noted elsewhere. Both individual detectors and detector stacks were biased to 600 volts and data collection times were varied from approximately eight minutes to eight hours depending on the intensity of the photopeaks being detected.

As described below, amplifier shaping time was varied to yield optimum peak shape. ^{133}Ba and ^{110m}Ag were used throughout as the γ-ray sources. These isotopes were selected for two reasons: Together, the sources cover the range of interest (100 keV ≤ E ≤ 1 MeV) where Compton scattering is a dominant mechanism of energy deposition in Si and therefore represent a rigorous test of the full energy photopeak detection. Second, the isotopes produce closely spaced peaks (ΔE < 30 keV) where the peak intensity ratio for some peak pairs is relatively large (> 5:1), which again represents a rigorous test of device performance.

B. Signal Processing

Measurements in this current work were conducted using a variety of output modes. Data was taken from: a) a single pair in the stack, b) the entire stack employed in the split-stack anti-coincidence mode, or c) the summed mode. As displayed in Figure 2, the signal output from the two stack pairs is sent through separate vacuum feedthroughs to the preamplifiers. The spectroscopy amplifiers, high voltage power supplies and associated NIM modules and multichannel analyzer (MCA) used are standard commercially available units. Anti-coincidence signal processing was obtained via a set of delays and triggering events as shown. For that mode, the discriminators in the single channel analyzers were set to require that a pulse of > 100 keV be obtained in both device pairs before accepting the event in the MCA. An alternative scheme was to use only the events collected by the bottom (2 cm) pair or all four devices together (summed mode).

Selection and optimization of the preamplifiers (provided by LBL) was driven by the need to compensate for competing noise sources across the broad temperature range of interest. In the range of 150 K ≤ T ≤ 200 K (and higher) Si(Li) leakage currents become unacceptable for most DC-coupled preamps. AC-coupled preamps, which are far more tolerant of high leakage currents, are customarily designed for high capacitance surface barrier devices used for charged particle spectroscopy and therefore not optimized for a Si(Li) stack capacitance of ~10 pF. Our choice for the current experiments was an AC-coupled preamp with input circuit and FET selected for the lower capacitance and leakage current varying from a few pA to > 50 nA. Further optimization of the electronic noise appears possible and will be pursued in the future.

III. RESULTS AND DISCUSSION

Figure 3 shows the multi-line ^{133}Ba resolution of the Si(Li) stack at 172K compared to the performance of a 10% efficient HPGe and a 1" NaI scintillator detector. As can be seen, the Si(Li) stack clearly distinguishes the principal ^{133}Ba photopeaks. FWHM resolution at 355 keV is 4.86 keV, only about a factor of two worse than HPGe, and an order of magnitude better than NaI. Peak symmetry is excellent with a FWHM to tenth maximum ratio of 1:1.87. The adjacent peak at 383 keV is a factor of about seven less intense yet also clearly resolved with good peak shape. During the data collection, several different modes of stack operation were evaluated. It was found that at energies on the order of 300 keV, most of the full energy photopeaks were collected in the thicker (2 cm) bottom pair. Using the split stack technique was found to be unnecessary for this energy range and thus not employed.*

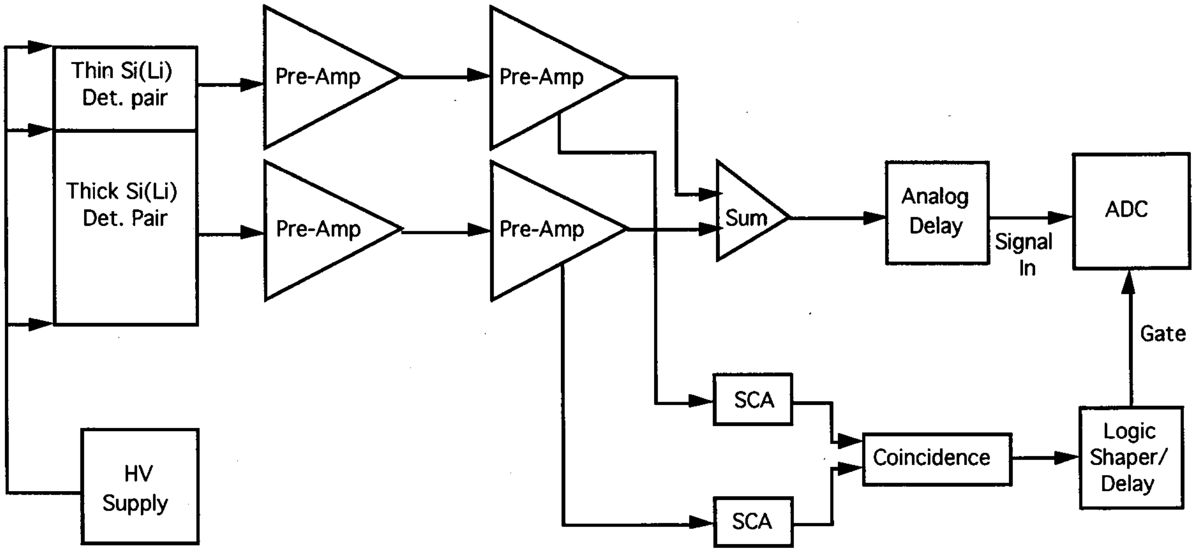

Figure 2. Schematic of Pulse Processing Electronics

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* As noted in a previous paper, the data collection procedure of choice will vary depending on the principal charge production mechanism and thus on the energy range of interest [2]. The split stack technique demands that the full-energy photopeaks occur as a result of interactions in both stack pairs and thereby discards many events including some full energy peaks which happen to occur in a single pair. A judicious choice must be made for the most effective procedure.

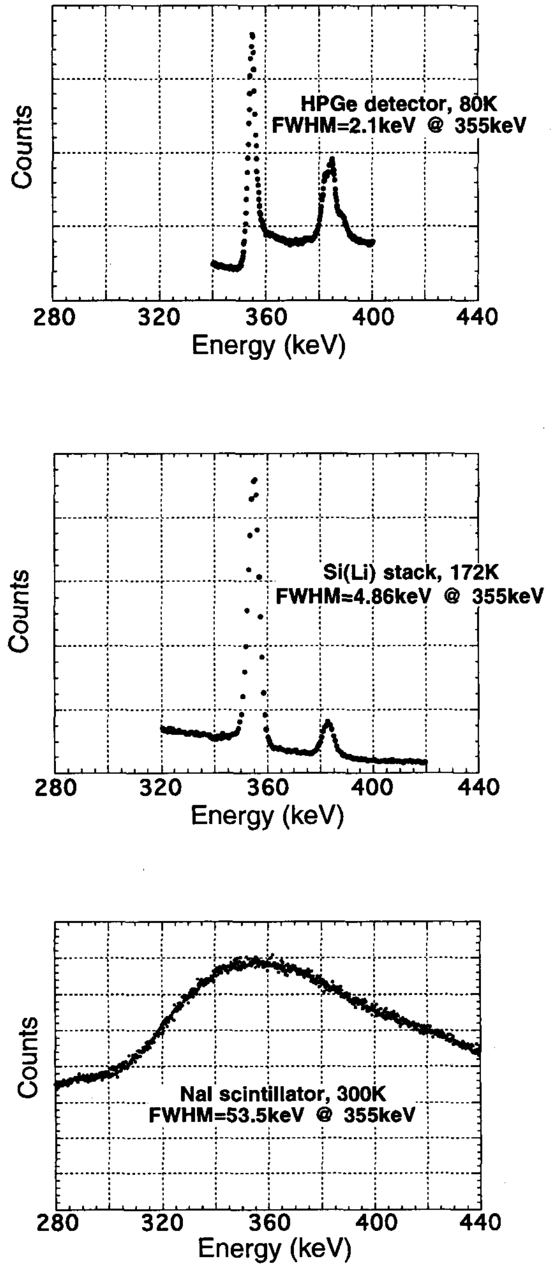

Figure 3. Resolution comparison of Si(Li) stack, HPGe and NaI scintillator.

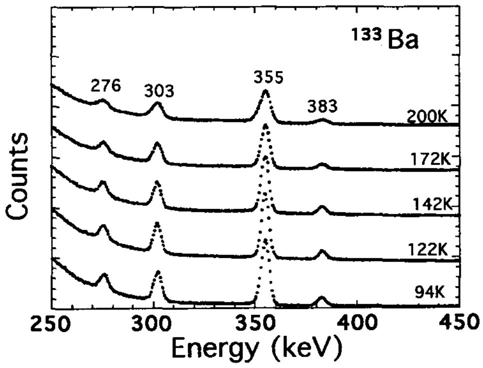

Figure 4. Detector resolution as a function of temperature, τ_S = 1-3 μS. Principal peaks are separated by 28 keV.

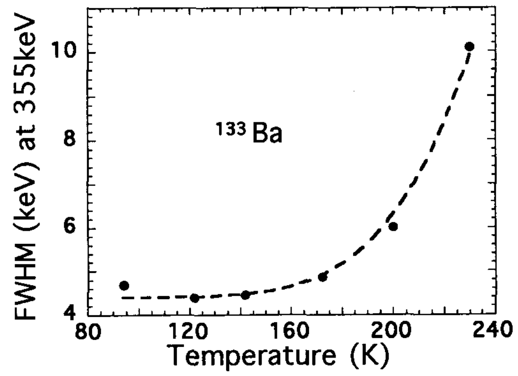

Figure 5. Fitted FWHM for 355 keV ^{133}Ba Gamma-Ray Energy, vs. Temperature.

Si(Li) data were collected initially at about 90 K to establish the baseline performance at minimum electronic noise conditions and then obtained at temperatures to > 200 K. Figure 4 displays the resolution of the Si(Li) stack as a function of temperature, for shaping times of 1 to 3 μS, adjusted for optimum peak shape. Previous work has demonstrated that at higher temperatures, a low energy tail may appear on the peaks, probably as the result of inhomogeneous charge collection. Peaks can be restored to gaussian symmetry by proper selection of the shaping time [3]. The principal peaks are clearly separated in all cases, and it should be noted that the resolution does not degrade significantly until T > 200 K. Figure 5 summarizes the FWHM resolution of the 355 keV peak as a function of temperature.

In order to evaluate the effectiveness of the split-stack technique in a multi-line environment, we collected data using a ^{110m}Ag source. This isotope produces a series of lines from about 650 keV to > 1 MeV. In this energy range, Compton scattering is by far the dominant charge production mechanism. As can be seen in Figure 6, the summed stack data yields almost no full energy photopeaks. The higher energy photons (~1 MeV) produce sufficient Compton scattering to mask the principal photopeak at 657 keV, resulting in a spectrum which is dominated by the Compton edges, with little other structure. Using the split-stack anti-coincidence technique, the principal full-energy photopeaks are clearly resolved, both cold (94 K) and at elevated temperature (186 K). FWHM resolution of the 657 keV peak is 10.1 keV at 186 K, meeting the basic performance requirement of resolution ~10 keV in the region of interest. In addition, the principal photopeaks at 885 keV and 937 keV are also clearly observed, with resolution (FWHM) ~9 keV.

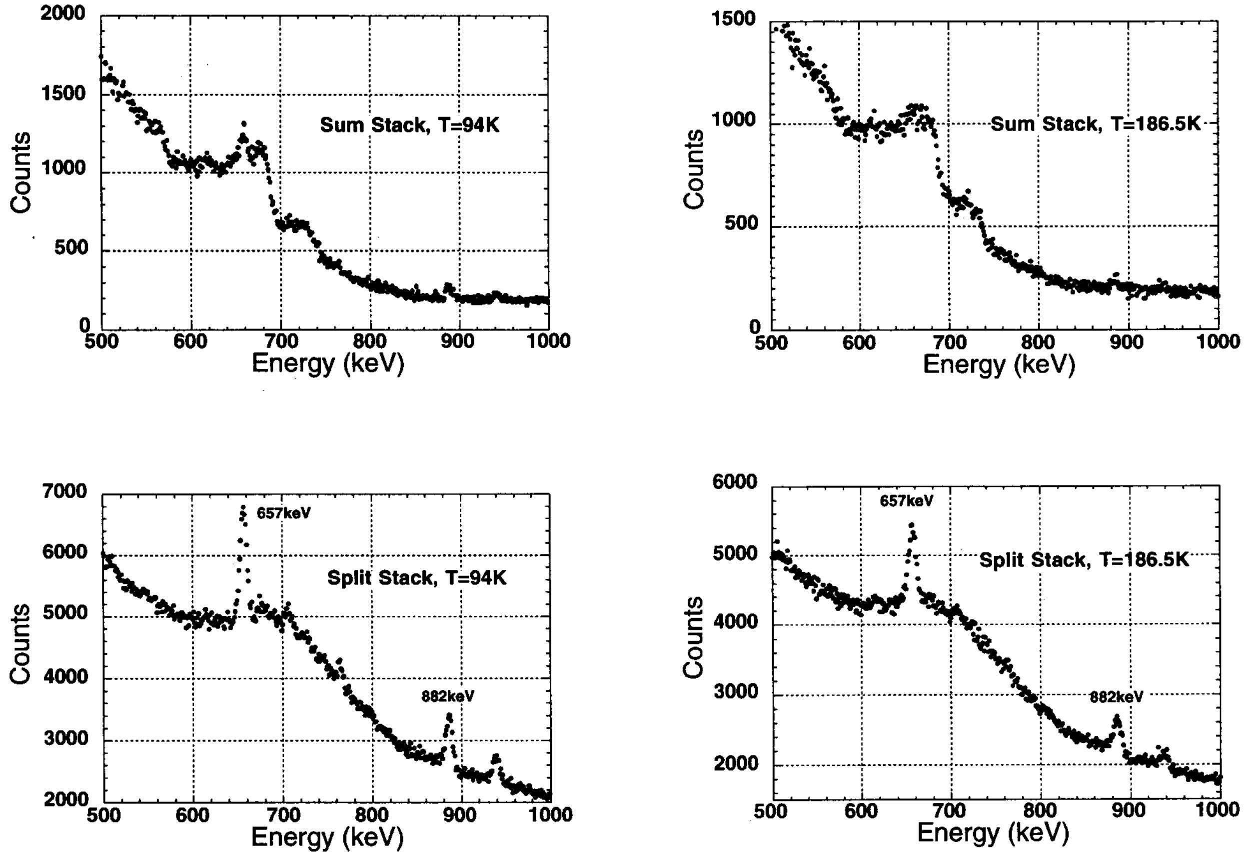

Figure 6. ^{110m}Ag Spectra from Sum and Split Detector Stack at 94K and 186.5 K.

IV. SUMMARY AND CONCLUSIONS

In summary, the Si(Li) stack exhibits the desired spectrometer performance over the temperature range of interest. For closely spaced ^{133}Ba peaks at 355 and 383 keV we have observed a FWHM of ≤ 6 keV for $T \leq 200$ K and ≤ 10 keV for $T \leq 230$ K. An optimized peak shape was obtained using longer τ_s as device temperature increased. Further measurements using a ^{110m}Ag source have shown that the ~2.7 cm Si(Li) stack can effectively resolve peaks up to 1 MeV in the presence of a significant Compton scattered background. This is an important result considering that to fully absorb 1 MeV photons requires on the order of 7 cm of Si. It should be noted that all of the earlier work we have reported employed a ^{137}Cs source which emits a single gamma-ray at 662 keV. Using this isotope enabled us to test resolution and charge collection at an energy where Compton charge production clearly dominates, but avoided the problems which result from scattered background in the range of interest. This paper presents the first results which clearly show that the Si(Li) stack approach can be used in a more realistic spectroscopic setting, where closely spaced peaks and/or peaks which exist in a significant background can be properly resolved at elevated temperature.

Further improvements are possible in detector noise performance and will be pursued in future work. We now have qualitative experience which suggests that excess noise, particularly at elevated temperatures, can be attributed to the degradation of passivation materials applied to the groove of the device. A number of alternate passivation techniques are being investigated. In conclusion, we believe that this Si(Li) gamma-ray detector stack represents a method for achieving good resolution spectrometer performance across a wide range of temperature and thus is a technique which can be serious considered for a number of applications, especially resource limited space missions.

V. REFERENCES

(1) G. Scott Hubbard, *et al, IEEE Trans. Nuclear Science*, **Vol. 39**, pp. 981–986 (1992).

(2) Robert E. McMurray, Jr., *et al, IEEE Trans. Nuclear Science*, **Vol. 40**, pp. 882–889 (1993).

(3) G. Scott Hubbard, *et al, IEEE Trans. Nuclear Science*, **Vol. 41**, pp.1338–1342 (1994).