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Author
Madden, Norman W.

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A HIGH-RESOLUTION Si(Li) SPECTROMETER
WITH THERMOELECTRIC COOLING*

Norman W. Madden, Joseph M. Jaklevic, John T. Walton
and Clyde E. Wiegand

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Abstract

A Si(Li) spectrometer cooled by a thermoelectric refrigerator
exhibited a peak width of 258 eV FWHM for x rays of 5.9 keV. The
measured electronic noise was equivalent to 224 eV FWHM.

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mental Research and the Division of High Energy and Nuclear Physics of the
The low noise and consequent high resolution capabilities of lithium-drifted silicon (Si(Li)) x-ray spectrometers have heretofore been achieved by operating the semiconductor detector and associated junction field effect transistor (JFET) at a temperature near that of liquid nitrogen (LN). Operation at low temperatures reduces the noise associated with thermally generated charge carriers in the semiconductor detector and in the JFET preamplifier. Using a selected JFET and a detector a few mm² in area, it is possible to achieve an electronic noise line width approaching $60 \text{ eV FWHM}$ when the system is operated at its optimum temperature. For Mn Kα x rays (5.9 keV) the corresponding line width would be $140 \text{ eV FWHM}$.

The performance of Si(Li) spectrometers at temperatures above LN has previously been explored and attempts to construct practical systems have been made. In one early effort the detector was operated at temperatures in the range of -40°C to -50°C and a resolution of 1.6 keV FWHM for 14.4 keV x rays was attained.

A major disadvantage of cooling by LN is the necessity for a reservoir to be an integral part of the spectrometer. If, as is common, the cryogenic temperature is maintained continuously, a convenient supply of LN is required. We describe a spectrometer that used a thermoelectric refrigerator to cool the Si(Li) detector and preamplifier input stage. The cooler was a commercially available device that worked on the Peltier effect. Although the resolution was not as good as that achieved with LN cooling, the performance was adequate for many applications including some uses of energy-dispersive x-ray fluorescence analysis.

Figure 1 illustrates the arrangement of the detector, JFET, and three stage thermoelectric refrigerator. The detector was made in our laboratory. It incorporated a guard ring and had a sensitive region 0.7 cm in diameter and 0.3 cm thick. When operated in the grounded guard ring configuration, the effect of surface leakage on the system noise was drastically reduced and leakage in the central region became the dominant noise source. At -68°C and a bias of -250 V, the total leakage current (central region plus guard ring) was $900 \times 10^{-12} \text{ A}$, while the leakage current for the central region alone was $1.5 \times 10^{-12} \text{ A}$.
The spectrometer utilized a pulsed-light feedback preamplifier\(^6\). Use of pulsed-light feedback is essential to avoid the noise associated with a high-valued feedback resistor.

At an input of 15 W to the thermoelectric module the temperature of the detector was maintained at -68°C. The base of the module was kept near room temperature by contact with an aluminum block that was cooled by a stream of air from a small fan. An essential part of the system was a copper heat shield held at -14°C by contact with the first cold stage of the thermoelectric module. The shield considerably reduced the amount of heat radiated by the warm walls to the low temperature detector assembly.

Figure 2 is a spectrum obtained with the new instrument. It indicates an electronic energy resolution (FWHM) of 224 eV as shown by the pulse generator curve. K\(\alpha\) x rays of Mn (5.9 keV) show a resolution of 258 eV FWHM. These data were acquired at a rate of about 4000 counts per second. The amplifier used a Gaussian pulse shape with a peaking time of 17 microseconds.

Comparison of the performance of the thermoelectrically cooled detector to that of LN cooled devices indicates that improvements can be expected at temperatures below -68°C. However, the x-ray energy resolution obtained by the new system is adequate for many practical applications. Consider that for adjacent elements in the periodic table, the separation of characteristic K\(\alpha\) x-ray lines is greater than 380 eV for elements heavier than potassium. As an example, for K and Ca the line width will be 243 and 245 eV respectively. These peak widths indicate that energy-dispersive fluorescence analysis for these elements and those of higher Z can be performed by the thermoelectrically cooled spectrometer in its present state of development. Elimination of the LN reservior will facilitate the design of portable x-ray fluorescence for field use.
References


4) Cambridge Thermionic Corp., Cambridge, MA 02138.


Figure Captions
Fig. 1. Diagram showing the arrangement of the detector, JFET, and thermoelectric cooler. A radiation heat shield made of copper is attached to the first stage of the cooler.

Fig. 2. Spectrum of Mn x rays from a source of $^{55}$Fe and a pulse generator peak.
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