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

Author
Madden, Norman W.

Publication Date
1978-07-01

Submitted to NUCLEAR INSTRUMENTS AND METHODS

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

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

July 1978

Prepared for the U. S. Department of Energy
under Contract W-7405-ENG-48

DISCLAIMER

LBL-7550

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.

*This work was supported in part by the Division of Biomedical and Environmental Research and the Division of High Energy and Nuclear Physics of the Department of Energy under Contract No. W-7405-ENG-48.

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 mm^2 in area, it is possible to achieve an electronic noise line width approaching 60 eV full width at half maximum (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 eV FWHM[1]).

The performance of Si(Li) spectrometers at temperatures above LN has previously been explored[2]) 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[3]).

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[4]) 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[5]). At -68°C and a bias of -250 V, the total leakage current (central region plus guard ring) was 900 x 10^{-12} A, while the leakage current for the central region alone was 1.5 x 10^{-12} 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. Kα 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 seperation of characteristic Kα 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

[1] Review article: F. S. Goulding and R. H. Pehl, Nuclear Spectroscopy and Reactions Part A (Academic Press, New York, San Francisco, London, 1974) 289.

[2] M. Martini and T. A. McMath, Nucl. Inst. and Meth. 76 (1969) 1.

[3] E. Belcarz et al., Nukleonika 19 (1974) 1043. Translation: Nukl. 19 (1974) 13.

[4] Cambridge Thermionic Corp., Cambridge, MA 02138.

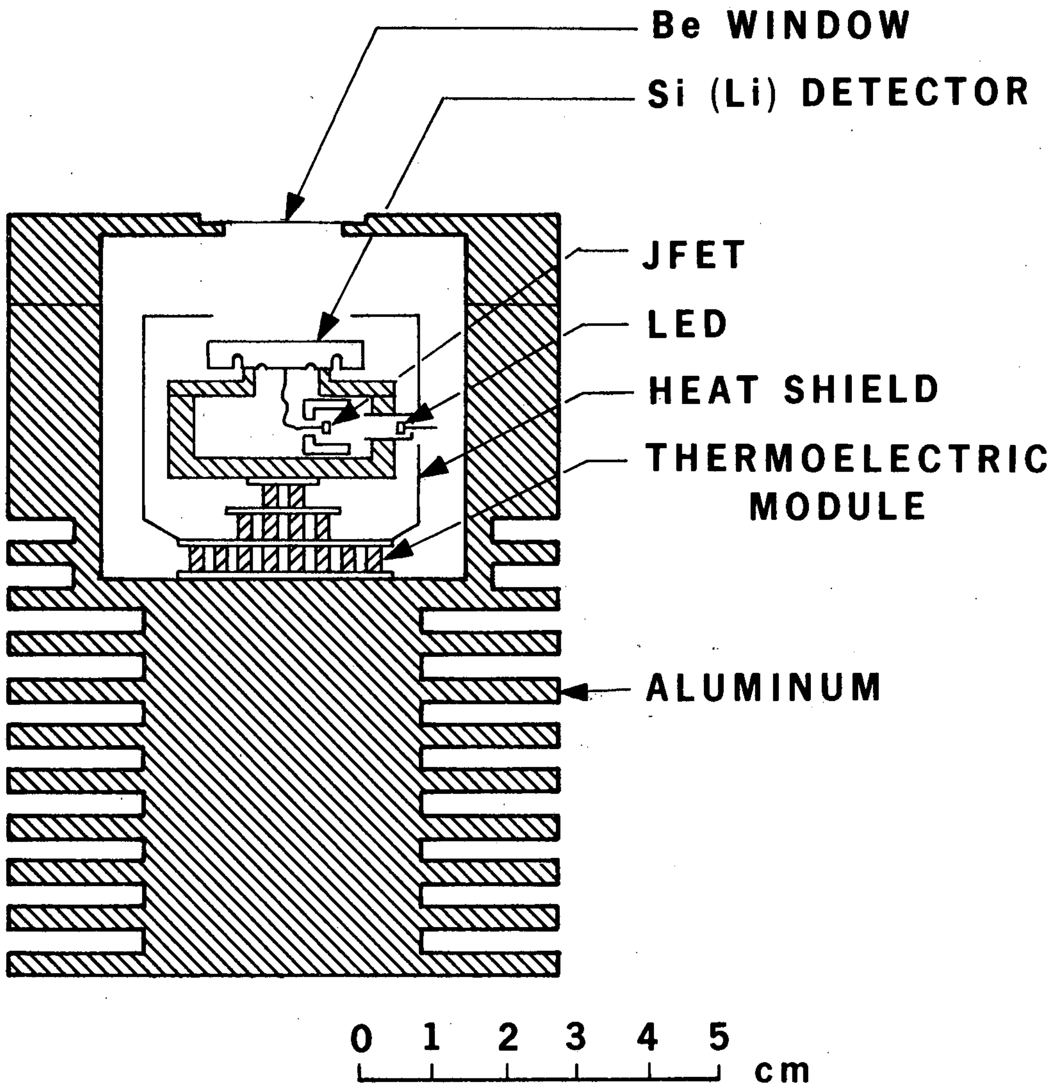
[5] F. S. Goulding and W. L. Hansen, Nucl. Inst. and Meth. 12 (1961) 249.

[6] D. A. Landis, F. S. Goulding, R. H. Pehl and J. T. Walton, IEEE Trans. Nucl. Sci. NS-18, no. 1 (1971) 115.

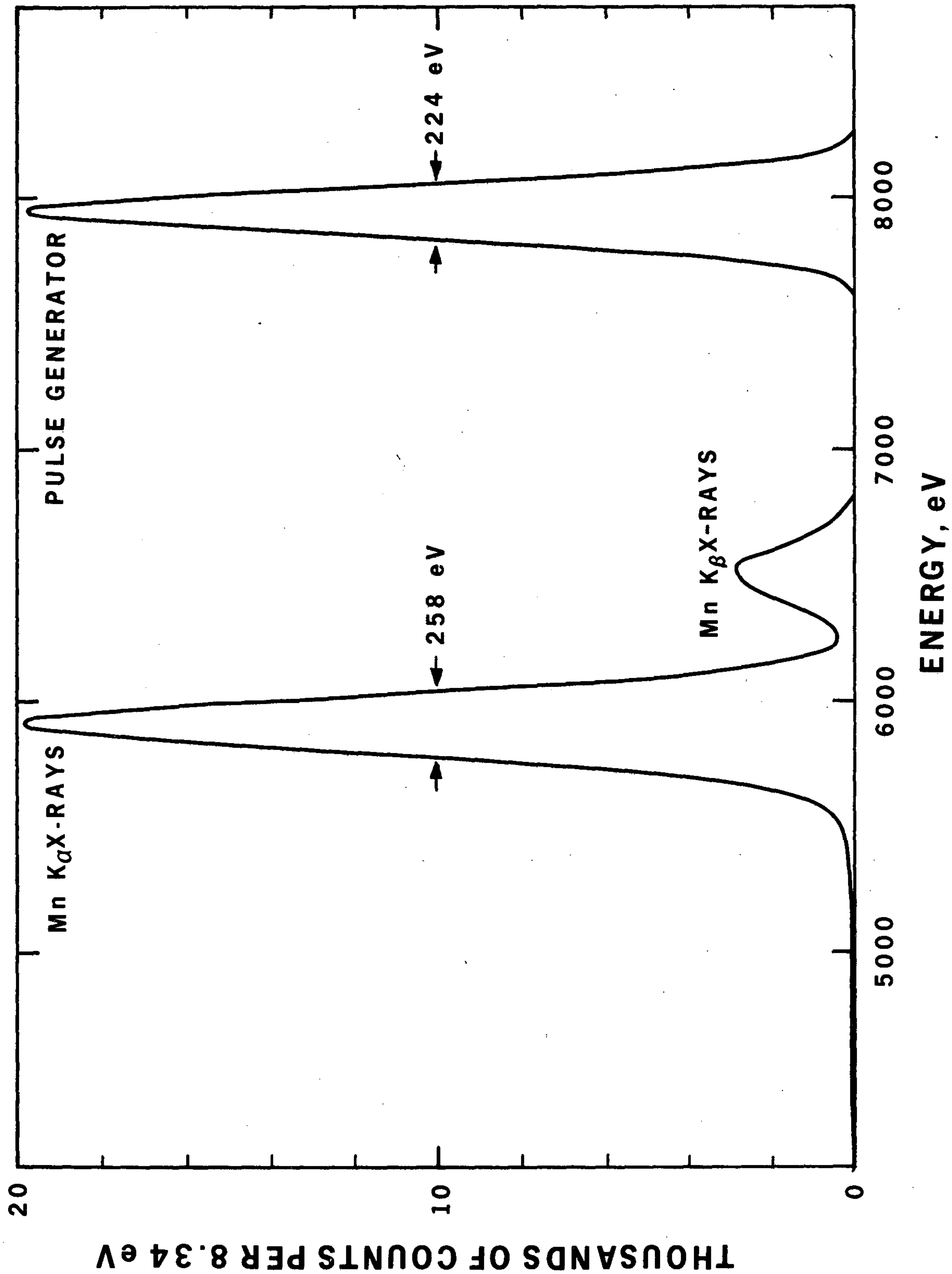
Figure Captions

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.


Be WINDOW
Si (Li) DETECTOR
JFET
LED
HEAT SHIELD
THERMOELECTRIC MODULE
ALUMINUM
0 1 2 3 4 5
cm

XBL 783-7783


PULSE GENERATOR
224 eV
258 eV
Mn KαX-RAYS
Mn KβX-RAYS
5000
6000
7000
8000
ENERGY, eV
0
10
20
THOUSANDS OF COUNTS PER 8.34 eV

XBL 783-7784

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720