Title
THIN WINDOW Si (Li) DETECTORS FOR THE ISEE-C TELESCOPE

Author
Walton, J.T.

Publication Date
1977-10-01

To be published in the Proceedings of the
IEEE Nuclear Science Symposium,
San Francisco, CA, October 19 - 21, 1977

LBL-6434
c.1

THIN WINDOW Si(Li) DETECTORS FOR THE ISEE-C TELESCOPE

J. T. Walton, H. A. Sommer,
D. E. Greiner, and F. S. Bieser

October 1977

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

LBL-6434

THIN WINDOW Si(Li) DETECTORS FOR THE ISEE-C TELESCOPE*

J. T. Walton, H. A. Sommer, D. E. Greiner, and F. S. Bieser
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Abstract

Special detectors have been developed for the NASA ISEE-C Cosmic Ray Telescope. These are Li-drifted silicon detectors 5 mm thick and 1500 mm^2 area with the criteria that thickness variations on the whole area be less than ±10 μm and that the Li-diffused contact dead-layer not exceed 15 μm. Techniques used to fabricate and test these detectors are presented.

Introduction

An experiment on the NASA ISEE-C Heliocentric satellite is designed to determine the isotopic composition of cosmic rays. A multi-detector telescope of lithium-drifted silicon (Si(Li)) detectors is to be used for this purpose. To provide the necessary identification, the telescope must contain ten detectors[1,2] of large area (1500 mm^2), 5 mm thick with thickness variations of less than ±0.2% (±10 μm). Furthermore to minimize the dead-layer effects between the detectors in the telescope, the Li-diffused contact must be less than 15 μm. Finally, the detectors were required to have less than 10 μA leakage and less than 300 keV noise at an RC shaping time constant of 5 μs.

These requirements represent a substantial step beyond existing techniques for the fabrication of Si(Li) detectors, necessitating the new procedures to be described. In addition the testing of the devices to assure that the specifications were met and to meet the testing requirements for a space flight have required the development of special test procedures which will also be discussed.

Fabrication

Figure 1 shows the cross-section of a typical Si(Li) detector using the "grooved" geometry. The device has a Li-diffused contact on one face and a Au-evaporated contact on the opposite face. The recessed or "well" region of the Au-contact serves a practical purpose in protecting the sensitive Au-contact from mechanical damage during processing and actual use. The "well" is normally etched in with a fast chemical etch and "ripples" and non-uniformities introduced by this etching process are a major source of any variation in the thickness of the final detector. To avoid these problems, the planar etching technique of Madden[3] was successfully adapted to the etching of this "well" to provide the necessary surface flatness.

Achieving a thin Li-diffused contact presents difficulties as this contact must provide the source of lithium for the drifting process. Furthermore since lithium diffuses from the original layer during the drift, thicknesses of 120-150μm, as shown in Fig. 1, are typical for this layer on the completion of the drifting process. To achieve the thin contact desired, the

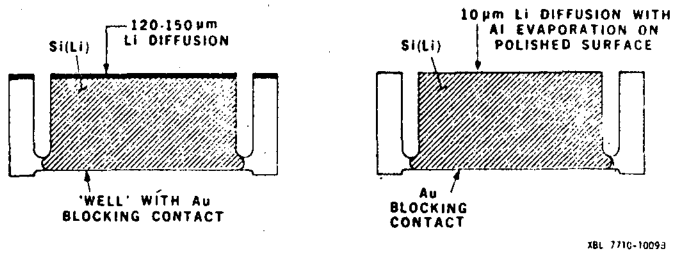

Fig. 1 Normal and modified Si(Li) detectors. Shown are the cross-sections of the devices with the Si(Li) compensated regions, the Li-contact and the Au-blocking contact.

thick contact was removed at the completion of the drifting process and the thin contact was produced by evaporating lithium onto the surface and carrying out a low temperature diffusion (180°C for 30 minutes). This diffusion cycle produces a 10 μm Li-diffused N^+ contact. Measurements on the depletion characteristics of the devices before and after the thin contact processing indicate that there is a negligible disturbance of the bulk-lithium compensation by this process. The final processing of the Li-contact involves polishing the surface using "Syton"[4] with a precision polishing machine and then evaporating aluminum onto the polished surface.

The stability requirements for a space mission can only be met if the surfaces (i.e., the grooves) of the detectors are adequately protected. Several types of protection were examined for their ability to protect the detector surfaces. The protection coating selected is under additional examination with a long-term evaluation of detector performance in ultra-high vacuum being conducted.

Tests

Electronics

An initial selection of detectors was performed by recording the leakage current and noise at a long shaping time (5 μs RC). By using such a long measurement time, incipient surface breakdown problems are usually revealed. Those detectors meeting the criteria at 600 volts bias of having less than 10 μA leakage and less than 300 keV equivalent rms noise were accepted for further testing.

Reliability

The selected devices were placed in a ultra-high vacuum (2 x 10^{-9} Torr.) and subjected to an automated test cycle for a period of 14 days. The test schedule involved 4 days at 25°C and 10 days at 35°C with continuous sampling measurements of leakage current

*This work was done with support from the United States Department of Energy.

and rms noise. Noise impulses or bursts were also counted and recorded. A block diagram of the test system is shown in Fig. 2. Testing of this type[5] has previously been employed in qualifying detectors for space flights and is intended to assess the stability and reliability of the devices.

A typical result of thermally cycling a detector in high vacuum is shown in Fig. 3. Three features were sought in detectors during this test:

a) absence of bursts of impulse noise,

b) constant or near constant leakage and noise following the temperature increase and a return close to the initial values at the end of the test, and

c) less than 20 μA leakage at 35°C.

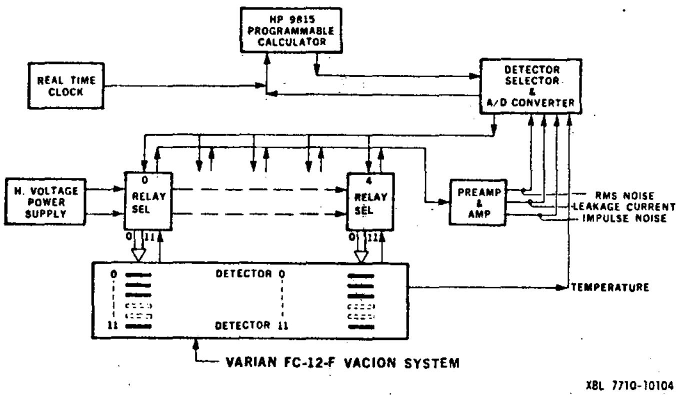

Fig. 2 Block diagram of the thermal-vacuum test system. The HP 9815 Calculator interfaces with the detectors through the detector selector module and relay selector module. Sixty detectors can be tested in each run.

Detectors passing this test were then subjected to tests for determining the thickness of the Li-diffused contact and for assessing the uniformity of the entire detector.

Contact Thicknesses

Am^{241} alpha particles were used to measure the thickness of the Li-diffused and Au-barrier contacts. As expected the results showed that the Au-contact thickness was negligible in comparison to the Li-diffused contact thickness. The thickness and uniformity of the Li-diffused contact was determined by scanning across the contact in 4 mm steps. Figure 4 shows the results of one scan. The contact thickness was determined from the observed shift in the position of the alpha-particle peak as compared with its position as measured through the Au-contact. As seen in Fig. 4, the Li-diffused contact in this case was 13 μm in the center with a 2 μm radial taper which is believed to be caused by the polishing of this surface on the precision polisher.

References to a company or product name does not imply approval or recommendation of the product by the University of California or the United States Department of Energy to the exclusion of others that may be suitable.

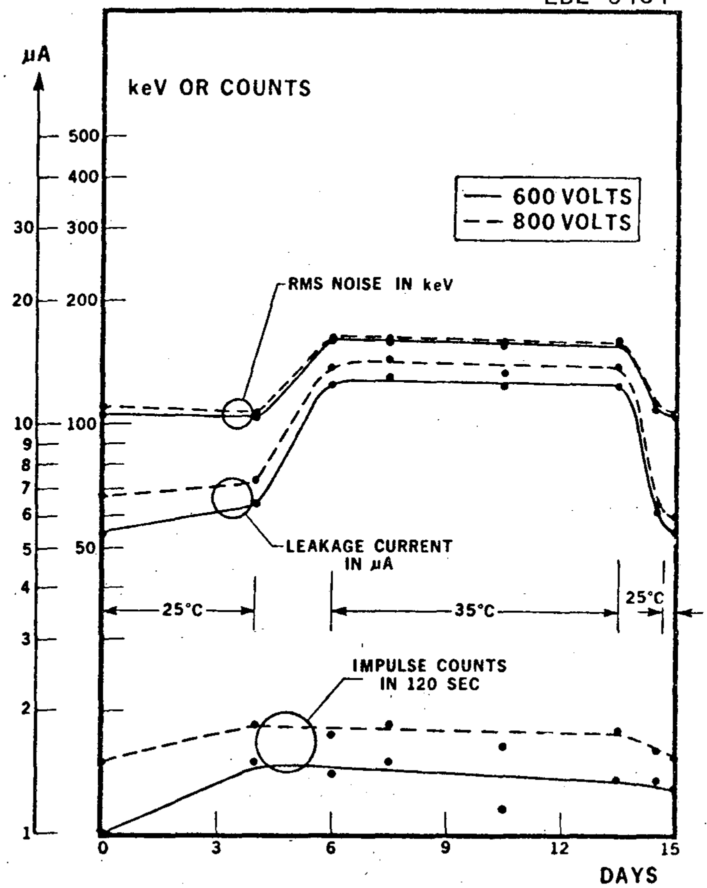

Fig. 3 Thermal-vacuum test results. Leakage current, rms noise, and number of impulse bursts in two minutes are plotted versus time in days. The time at which the device was at 25°C and 35°C is indicated.

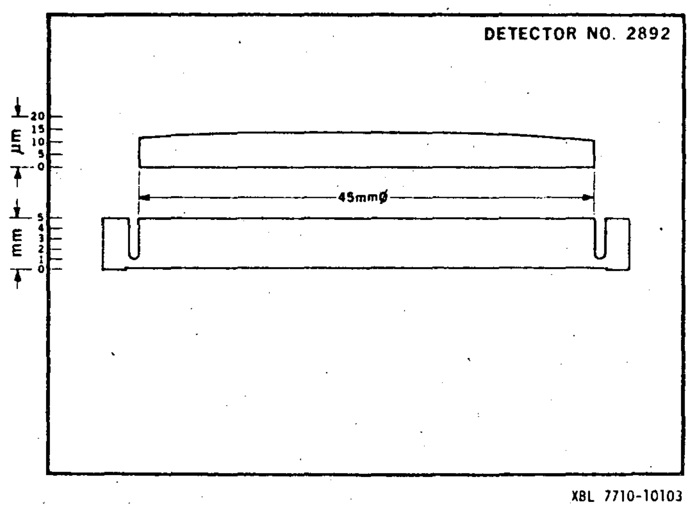

Fig. 4 Alpha scan results across the Li contact. The dead layer is shown in μm of silicon. The shape of the dead layer is shown against the cross-section of the detector.

Detector Thickness Uniformity

Two types of measurements were used to determine the detector thickness uniformity. As a final test, the detectors were subjected to high energy ^{40}Ar ions and the pattern of signals across the detector area was obtained and examined. Since this process is very expensive and time consuming, an optical measurement was used to screen for dimensionally non-uniform detectors before the Ar ion test. Of course, factors other than thickness variation may affect the signal amplitudes produced by the Ar ions. For example, charge loss due to trapping is one such factor. Therefore, while the optical measurement will measure dimensional uniformity, the Ar ion measurement will measure both dimensional and charge collection uniformity. Agreement between the two would indicate that charge loss mechanisms in the detector are not important.

Optical Measurements. The primary source of thickness variations in the detector, as indicated earlier, is the "well" on the Au-barrier side of the detector. Since the Au-barrier is sensitive to mechanical damage, an optical method provides the means for examining this surface. Fortunately, an optical scanner developed for nuclear emulsion track studies was available and its characteristics were quite adequate to measure variation of less than 10 μm on the gold surface. Scans were also performed on the Li-contact side of the detector. The data was reduced to produce uniformity profiles, as shown in Fig. 5, for each detector.

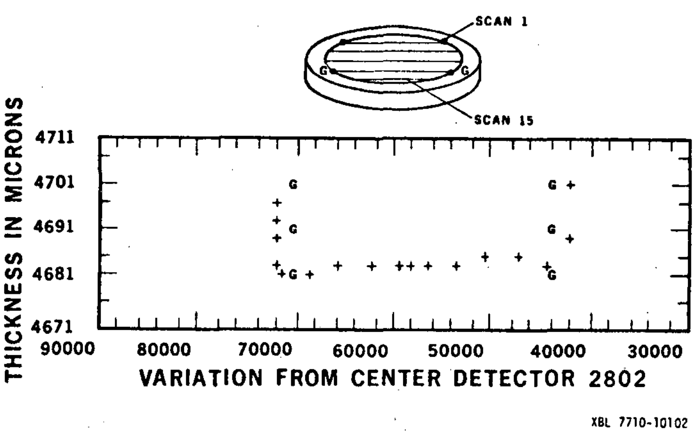

Fig. 5 Uniformity scan across the "well" side of the detector. Shown is the results of scan number 14 of the fifteen scans made across this surface. The crosses indicate the measured profile points. The symbol "G" shown both on the profile and on the inset depicting the detector denotes the device active region within which the detector uniformity was required.

Ar Ion Beam Measurement. Figure 6 shows the experimental arrangement used for these tests. A broad ^{40}Ar BEVALAC beam (482 MeV/Amu) at the Lawrence Berkeley Laboratory Bevatron was directed through the two, three-plane multi-wire chambers to the detector stack. The multi-wire chambers define the beam trajectories to within 1 mm through the stack. Only ^{40}Ar ions which passed completely through the silicon detectors and were detected in the plastic scintillator were recorded. The detector stack consisted of 4 planes each containing a square array of 4 detectors, thereby, allowing 16 detectors to be tested simultaneously.

Data obtained from the experiment was analyzed for each detector in terms of 90 equal area segments. The average signal amplitude from each segment and the average signal for the entire detector was calculated. The percentage deviation of each segment signal average from the entire detector average was calculated. The number of segments and their percentage deviation from the total detector average energy signal is shown for two detectors in Fig. 7.

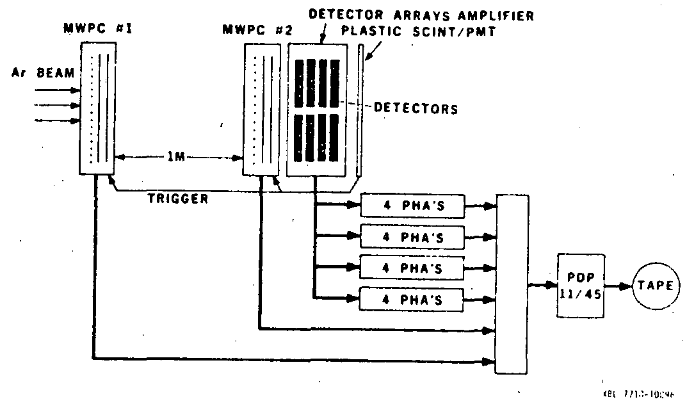

Fig. 6 Experimental arrangement at the Bevatron used to measure detector uniformity. The three layer Multi-wire Proportional Chamber (MWPC) define the beam location to within 1 mm.

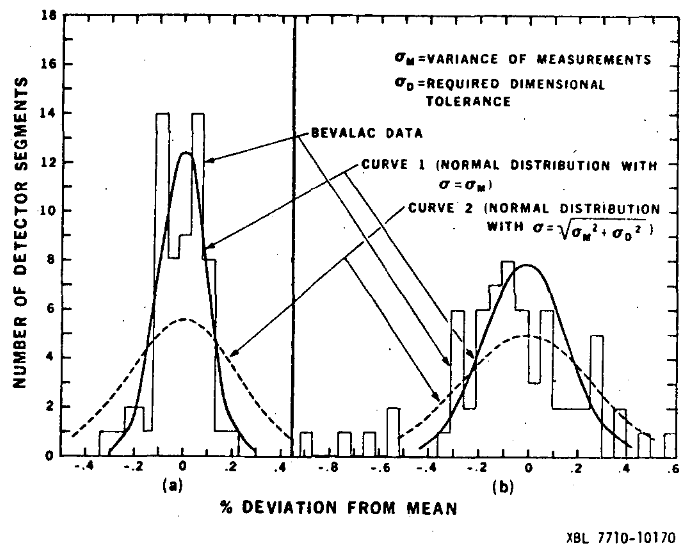

Fig. 7 BEVALAC uniformity measurement results. Ordinate gives the number of detector segments within a band of 0.05% with the percentage deviation from the mean average energy given on the abscissa. Detectors that meet the specifications are typified by (a) while those that exceed the specifications are typified by (b). Normal distribution function fits to the data are given by curves 1 and 2.

The number of events in each segment was used to determine the accuracy of the average energy determination of the segment. Many of the segments had insufficient counts for the averages to be determined at the level of precision required. For all the detectors measured, there were segments whose accuracy was so poor due to insufficient counts that the results in those segments had to be discarded. Unfortunately, the BEVALAC beam intensity was very low during these measurements and the availability of accelerator time has not permitted repetition of the experiment.

Consequently in assessing the BEVALAC data, the accuracy of the measurements was a big factor in selecting detectors for the flight telescope. In Fig. 7, a normal distribution curve whose variance is equal to the calculated variance (i.e., accuracy) in the experimental data is plotted as curve 1, while a second normal distribution curve 2 indicates the expected results if the accuracy of the measurements is folded in with the allowed dimensional variation of ±0.2% (±10 μm).

Figure 7(a) presents data where the measurements were considered sufficiently good for the detector to be selected as a flight detector since it is clear that the BEVALAC histogram falls well within the calculated expectations. For this detector, the thickness spread must be smaller than the ±0.2% requirement.

Figure 7(b) presents similar data on a detector not selected as a flight detector since the BEVALAC histogram falls outside the calculated expectations.

Conclusions

This work has demonstrated the feasibility of fabricating large area Si(Li) detectors meeting stringent requirements on the thickness uniformity and on the Li-diffused contact thickness.

While the BEVALAC measurements have been complicated by the low intensity of the BEVALAC beams during the experiments, the data obtained has been adequate to select 10 detectors that meet the uniformity and other specifications required for the ISEE-C Telescope.

Finally, the BEVALAC data would indicate that no good evidence exists to suggest that signal amplitude variations are caused by any factor other than thickness variations. Where the BEVALAC measurement has shown thickness variations substantially greater than the expected inaccuracy of the measurement, these variations have been confirmed by the optical measurements.

Acknowledgments

The authors gratefully acknowledge the support of F. S. Goulding who not only lent encouragement, but did the basic design work and all the programming for the thermal-vacuum tester; to D. A. Landis and R. A. Adachi who did the detailed design work on the tester, and to S. D. Wright, R. C. Davis, and R. C. Zink who assisted in the assembly.

The work in optical scanning and plotting of results from the thermal-vacuum tests by M. Banks and H. Yee is appreciated. Finally, the assistance of E. E. Haller in interpreting the BEVALAC data is also gratefully acknowledged.

References

1. D. E. Greiner, Nucl. Inst. and Meth., 103, 291-308 (1972).

2. D. E. Greiner, Proc. 15th International Cosmic Ray Conference, Plovdiv, Bulgaria (1977).

3. T. C. Madden and W. M. Gibson, 9th Scintallation and Semiconductor Counter Symposium, Washington, D. C., February 1964.

4. Obtainable from the Remet Chemical Corp., P. O. Box 278, Chadwick, NY 13319.

5. Alan Cummings, Bill Althaus, J.P.L., Cal. Tech., Pasadena, CA, private communication.

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