Lawrence Berkeley National Laboratory

Recent Work

Title

COMPUTER CONTROLLED DRIFTING OF SI(LI) DETECTORS

Permalink

<https://escholarship.org/uc/item/2433h80k>

Authors

Landis, D.A.

Wong, Y.K.

Walton, J.T.

Publication Date

1988-11-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Engineering Division

Presented at the IEEE 1988 Nuclear Science Symposium,
Orlando, FL, November 9-11, 1988, and to be published
in the Proceedings

RECEIVED
LAWRENCE
BERKELEY LABORATORY

MAR 17 1989

LIBRARY AND
DOCUMENTS SECTION

Computer Controlled Drifting of Si(Li) Detectors

D.A. Landis, Y.K. Wong, J.T. Walton, and F.S. Goulding

November 1988

For Reference

Not to be taken from this room

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Computer Controlled Drifting of Si(Li) Detectors

D.A. Landis, Y.K. Wong, J.T. Walton, and F.S. Goulding

**Engineering Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, California 94720
USA**

November 1988

COMPUTER CONTROLLED DRIFTING OF SI(LI) DETECTORS

D.A. Landis, Y.K. Wong, J.T. Walton and F.S. Goulding
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720 U.S.A.

ABSTRACT

A relatively inexpensive computer-controlled system for performing the drift process used in fabricating Si(Li) detectors is described. The system employs a small computer to monitor the leakage current, applied voltage and temperature on eight individual drift stations. The associated computer program initializes the drift process, monitors the drift progress and then terminates the drift when an operator set drift time has elapsed. The improved control of the drift with this system has been well demonstrated over the past three years in the fabrication of a variety of Si(Li) detectors. A few representative system responses to detector behavior during the drift process are described.

INTRODUCTION

Silicon radiation detectors made by the lithium-ion compensation process have long been employed in particle and photon detection. The fabrication of these silicon lithium drifted, Si(Li), detectors involves the compensation of boron impurities (acceptors) in the silicon crystal lattice with lithium ions (donors) to produce a large volume practically free of charge centers.¹ This compensation process is accomplished by applying a bias voltage and heat to an n⁺p junction which has been initially formed by diffusing lithium into a p-type substrate. Under a reverse bias of several hundred volts and a temperature above 100° C the lithium ions drift with time into the p-bulk material compensating the nascent acceptors. The lithium-drift process is the only satisfactory way at present of fabricating thick silicon radiation detectors, and such detectors up to 1 cm thick and up to 10 cm in diameter have been fabricated by this method.²

This silicon detector fabrication process requires control of the applied voltage and temperature, and monitoring of the leakage current. Since the total drift time can be hours to weeks depending on the thickness of the detector and the quality of the silicon crystal, manual control of the process can consume a considerable amount of effort. These problems have become very serious as we have started to make very large diameter detectors. Availability of low cost desktop computers, analog to digital (ADC) and digital to analog (DAC) converters makes it possible to build an inexpensive system to automatically control the drift process. An additional advantage of a good automatic control and monitoring system is the ability to document and reproduce conditions during drift. These considerations led to the design of the controller described here.

The requirements for the automatic drift system are as follows:

- ... Initialize the drift sequence in a prescribed manner.
- ... Monitor the bias voltage, temperature and current during the drift process.
- ... Adjust either the voltage or temperature or both to prevent catastrophic failure of the detector during the drift.

- ... Provide a visual display of the drift parameters.
- ... Calculate the expected compensation depth.
- ... Plot the detector leakage current as a function of time.
- ... Terminate the drift in a controlled manner.

CBB 881-71A

Fig. 1 The eight station drift system with a Si(Li) detector in place in one of the stations.

SYSTEM DESIGN

Fig. 2 A block diagram of the computer controlled drift system showing only one drift station.

The automatic lithium-drift system consists of eight independent drift stations with separate control and monitoring systems. Figure 1 shows a photograph of the system with two sets of four drift stations, the computer, and an 8-output high-voltage supply.

Figure 2 is a block diagram showing one drift station, interface card and computer. The drift station is a light tight chamber in which the detector is located during the drift process. Digital signals from the computer are fed to 16 DACs (eight for high voltage and eight for temperature) located on the interface card. The output of each voltage DAC is the demand value for one channel of the high voltage supply, and similarly for each temperature DAC. Voltages corresponding to the measured temperature, voltage and current of the detector are connected to three ADC units on the interface card and then onto the computer. The ADCs are multiplexed 8-input, 8-bit, and the DACs are dual 8-bit units. Eight bits provides for 4 volts per step for the high voltage and for 0.5° C per step for the temperature. Eight bits is not adequate for the expected range of currents; consequently a current

- NOTES: 1) UNMARKED DIODES ARE 1N4447 OR EQUIV.
2) UNMARKED CAP. ARE 6.8uF 35V TANT.
3) RESISTORS MARKED # ARE 1/8W 1% TO M.F.
4) OTHER RESISTORS ARE 1/4 5% CARBON UNLESS NOTED

Fig. 3 A schematic of the drift station and associated temperature control circuit.

shunt switched by the computer allows for 1 mA (4 μ A per step) and 10 mA (40 μ A per step) ranges.

PROGRAM DESIGN

The computer program developed for this system has five parts:

- 1) Initialization of drift conditions and variables.
- 2) Ramp-up of the drift conditions.
- 3) Control of the drift parameters during the extended lithium ion compensation process.
- 4) Ramp-down of the drift.
- 5) The generation of the display, printer and disk drive output including calculation of the current drift depth during the process.

Figure 3 is the schematic of a drift station showing how the voltage, temperature and current are measured, and how the temperature is controlled. The temperature of the heater plate is sensed by measuring the forward voltage drop of two series connected diodes attached to it. This diode voltage feeds the input of an operational amplifier (OP1). The zero and calibration adjustments are set to make 0 to +5 volts output correspond to 25 to 150° C. This output from OP1 feeds the temperature ADC and a second operational amplifier (OP2) which compares the sensing diodes' voltage with the demand voltage from the temperature DAC. The difference between these two voltages is then used to control the zero-cross Triac driver through a photo-isolator. The photo-isolator is required because the heater operates from 120 VAC power. A small current derived from a three second period saw tooth generator (common to all eight control circuits) is mixed at the input of the OP2 in order to provide proportional control and thereby to prevent the temperature from overshooting the control value. A micro-switch turns off the high voltage when the cover is removed and neon lamps indicate when the heater is on and when the HV is on (over 150 V).

These circuits maintain the temperature at the demand value within < 1° C. This close control of temperature is essential to produce a predictable drift; however, we note that our control is of the heater plate temperature and the actual detector temperature can be somewhat higher.

Any desktop computer could be used with this system but at present a Commodore 64 equipped with a Commodore 1520 printer, a Commodore 1541 disk drive and a monitor is employed. The printer is used to provide a permanent record of the drift conditions. The disk drive contains the computer program and it records drift conditions for further analysis. The monitor gives an up to date summary of the temperature, voltage and leakage current for each detector along with a calculated value of the present compensated depth and other parameters to indicate the status of the drift.

Fig. 4 The leakage current versus time for a "well behaved" detector during the drift process. The initial ramp-up proceeds smoothly to the set drift conditions of 110° C, 1000 V. The leakage current after the detector reaches the set drift conditions gradually decreases with time. There is a scale change in the time after the first day from three minutes between readings to six minutes between readings.

- 1) An initializing menu is presented to the operator with questions and default values for setting all the drift and readout conditions. The default values can also be changed.
- 2) Careful control of the ramp-up of the drift conditions is required to prevent damage to the n⁺p junction. A representative ramp-up sequence is shown in Fig. 4. Here the temperature is increased in 10° C steps until 110° C is reached; then the voltage is increased in 100 V steps until 1000 V is reached. After each step the current is monitored and when the current has passed its peak value a further delay of typically one hour occurs before the next step.
- 3) Upon reaching the target drift conditions, which are operator selected when initializing the program, the computer monitors the leakage current for any excursion above the preset current limit (typically 6 mA). If an excursion is detected, the voltage is reduced to 70% of its value and the temperature demand is reduced by 5° C to bring the leakage current below the preset level. If the current still exceeds the limit, the voltage is again reduced by 70% (this process is repeated as required). After about 10 minutes the detector temperature is down to the demand temperature; the computer then attempts to restore full voltage. If the current limit is exceeded again the demand temperature is reduced by another 5° C. This process is repeated if required until the temperature is at 80° C. Here the temperature is too low for significant drifting so the display is flagged to indicate that the detector requires operator attention.
- 4) When the calculation of the drift depth described in 5) below predicts that the detector is fully drifted or the drift time reaches a preset value, the program slowly ramps down the drift conditions, automatically performing a clean up drift.³ This ramp-down is also shown in Fig. 4.
- 5) The program also calculates continuously the current thickness of the compensated region based on the accepted value for lithium ion mobility in "good" silicon. It is known that silicon containing traces of oxygen or other defects will exhibit slower drift rates and agreement between our calculated and final measured drift depths provides an index of the quality of the silicon, particularly in large area devices where surface effects can be neglected.

The lithium ion mobility is given¹ by:

$$\mu = \frac{26.6}{T} \exp \left(\frac{-7.5 \times 10^3}{T} \right) \text{ cm}^2/\text{V} \cdot \text{sec} \quad (1)$$

where T is the absolute temperature.

Following an initial short drift period (where diffusion also occurs) the drift process can be represented by the relationship:

$$\frac{dW}{dt} = \frac{\mu V}{W} \quad (2)$$

where W is the thickness of the compensated region and V is the applied voltage.

Generally speaking, the whole drift will not be carried out at constant temperature or voltage. Considering an interval i during which the conditions are constant, and using Eq. 2 and integrating over the interval we have:

$$W_i^2 - W_{i-1}^2 = 2\mu_i V_i \Delta t_i \quad (3)$$

where W_i and W_{i-1} are the thicknesses of the compensated region at the end and start of the interval i , and μ_i , V_i and Δt_i are the mobility, voltage and duration for the interval.

If a series of n intervals are summed we have:

$$\begin{aligned} W_1^2 - W_0^2 &= 2\mu_1 V_1 \Delta t_1 \\ W_2^2 - W_1^2 &= 2\mu_2 V_2 \Delta t_2 \\ &\vdots \\ W_i^2 - W_{i-1}^2 &= 2\mu_i V_i \Delta t_i \\ &\vdots \\ W_n^2 - W_{n-1}^2 &= 2\mu_n V_n \Delta t_n \end{aligned}$$

Summing these equations we have:

$$W_n^2 - W_0^2 = \sum_{i=1}^n 2\mu_i V_i \Delta t_i$$

or, since $W_0 \ll W_n$:

$$W_n^2 = \sum_{i=1}^n 2\mu_i V_i \Delta t_i$$

Substitution for μ_i from Eq. 1 and expressing W_n in mm, Δt in hours, V_i in kV and T_i in $^{\circ}\text{K}$, we have:

$$W_n = 2 \times 10^{10} \sum_{i=1}^n \frac{V_i \Delta t_i}{T_i} \exp\left(\frac{-7.5 \times 10^3}{T_i}\right)^{1/2} \quad (4)$$

SYSTEM PERFORMANCE

In designing this computer-controlled drift system the initial objective was to build a controller to maintain the leakage current, voltage and temperature during the lithium ion drifting in Si(Li) detector fabrication. The ability of the system has been illustrated earlier in the discussion on Fig. 4, and is further illustrated in Fig. 5. As shown in this figure and discussed in the figure caption, the system made

two adjustments to the drift conditions (labeled A and B) in order to allow the preset drift time or drift thickness to be achieved by the detector.

The detector drift leakage currents in Figs. 4 and 5 are also illustrative of a second aspect of the system's capabilities. These detectors were part of an evaluation of various "gettering" procedures, and it was expected that some of these procedures would produce deleterious results, which in fact occurred with the device used to produce the results shown in Fig. 5. However, even with this relatively unstable device, the system controlled the drift conditions to allow the compensation of the device and therefore a more quantitative evaluation of the gettering processes. In fact both the devices used in Figs. 4 and 5 became usable detectors, and the effects of the gettering techniques which caused the instability of the device used in Fig. 5 are still being studied.

A third feature of this system is the accurate recording of the drift data and the potential for additional analysis. Figures 4 and 5 are plots of the detector drift leakage current versus time, but additional plots of leakage current versus drift depth and leakage current versus drift temperature would be helpful in characterizing the floating zone silicon used in Si(Li) detector fabrication. While the present system employing the Commodore 64 has performed well in controlling the drift process, another desktop computer with a larger memory and an analysis program is being debugged at present to perform the data analysis.

XBL 8810-3598

Fig. 5 The leakage current versus time for a somewhat unstable detector during drift. In contrast to Fig. 4, the initial ramp-up takes a long time and the leakage current constantly increases with time during the drift. The computer had to make two adjustments, (A) and (B), to the drift conditions before ramping down the drift. At (A) the drift conditions are changed from 110°C , 1000 V to 105°C , 700 V, while at (B) the conditions are changed from 105°C , 1000 V to 100°C , 700 V. At both (A) and (B) the voltage is restored to 1000 V after the heater plate reached the demand temperature. As in Fig. 4, the readings during the first day are every three minutes, while thereafter they are every six minutes. The number at the right of the time axis indicates the starting time of the ramp-down.

Computer-controlled drift stations of different degrees of complexity using the Commodore 64 have been in use in our laboratory for about three years with good reliability (one computer power supply failure). In comparison with our earlier manual systems, these computer-controlled systems have greatly reduced both the time spent "watching" detectors on drift, and the propensity to immediately remove detectors from drift for additional chemical processing when instabilities in the leakage currents are observed.

DISCUSSION

The drifting of Si(Li) detectors is somewhat of an art with a variety of procedures before, during and after the drift being used by various detector makers. The computer-controlled drift station described makes the actual drifting of these devices a well controlled and documented processing procedure.

The initial objectives for a computer-controlled drift system have been met with the described system and program. With the planned additions for improved data processing, this system will not only greatly aid in the fabrication of conventional Si(Li) detectors but will also be invaluable in the development of novel Si(Li) detectors and processing procedures.

Finally, this system is yet another example of the utility of small inexpensive desktop computers as controllers in research and manufacturing applications.

ACKNOWLEDGMENTS

We thank Billy Loo, Heinrich Sommer, Norman Madden, Martin Pollard and Christopher Cork for contributions during discussions on the system design. This work was supported by the Director's Office of Energy Research, Office of Health and Environmental Research, U.S. Department of Energy under Contract No. DE-AC03-76SF00098. Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

REFERENCES

1. E.M. Pell, Phys. Rev., 119, 1014 (1960).
2. T. Miyachi, S. Ohkawa, T. Masuda, I. Nakamoto, O. Nitoh, Y. Yosuda, Y. Ikeda, T. Koboyashi, H. Matsuzawa, I. Ogawa and H. Onabe, INS-655, University of Tokyo (1987).
3. A. Lauber, Nucl. Inst. and Meth., 75, 297 (1969).
4. U.M. Gosele, Annual Rev. of Mat. Sci., 18 (1988).

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