Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Physics Division

CHARGED PARTICLE DETECTORS MADE FROM
THIN LAYERS OF AMORPHOUS SILICON

J.R. Morel
(M.S. Thesis)

May 1986

Received by OSTI

SEP 30 1986

LEGAL NOTICE

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or 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 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. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

LBL--21728

DE86 016157

**CHARGED PARTICLE DETECTORS
MADE FROM
THIN LAYERS
OF
AMORPHOUS SILICON**

James Roy Morel

**Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720**

May 1986

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or 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 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. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *jsu*

CHARGED PARTICLE DETECTORS MADE FROM
THIN LAYERS OF AMORPHOUS SILICON

James Roy Morel

ABSTRACT

A series of experiments was conducted to determine the feasibility of using hydrogenated amorphous silicon ($a\text{-Si:H}$) as solid state thin film charged particle detectors. ^{241}Am alphas were successfully detected with $a\text{-Si:H}$ devices. The measurements and results of these experiments are presented in this paper. The problems encountered and changes in the fabrication of the detectors that may improve the performance are discussed.

Professor Selig Kaplan
Thesis Committee Chairman

ACKNOWLEDGEMENTS

First of all I would like to thank Taheren (Molly) Razazan for her help with all the initial work and for finding out about Dr. Street.

I would like to thank Dr. Robert Street of the Xerox Palo Alto Research Center for all his help in understanding the nature of the amorphous silicon samples he sent us and for being so generous with his time.

I would like to thank Dr. Terry Mulera for his help and patience in answering the many questions I have asked over the course of these experiments. I would also like to thank Gerald Schnurmaker for all his help building the chamber.

I would like to thank Professor Perez-Mendez and Professor Kaplan for giving me the opportunity to work on this project.

I would like to thank Professor Selig Kaplan, Professor Perez-Mendez and Professor Morse for their help and advice in preparing this thesis.

I would like to thank my family for all of their support and patience in dealing with me while I indulged myself in this endeavor.

I would like to thank Marla McGinnis for her patience and support.

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under contract #DE-AC03-76SF00098.

DEDICATION

This is dedicated to my family

and to my wife

Marla McGinnis.

TABLE OF CONTENTS

Chapter 1	Introduction	1
1.1	Motivation	1
1.2	Goal of the Experiment	2
Chapter 2	Properties of Amorphous Silicon	4
Chapter 3	Experimental Setup	8
3.1	Fabrication of The α -Si:H Device	8
3.2	Detector Configuration	8
3.3	Electronic Circuit	10
3.4	Alpha Attenuation	13
3.5	Temperature Control	17
Chapter 4	Experimental Procedure	19
4.1	Device Preparation And Mounting	19
4.2	The Measurement of Alpha Particles Energy	20
Chapter 5	Data Analysis	24
5.1	Data Forms	24
5.2	Calibration of PHA	24
5.3	Noise Analysis	25
5.4	Uncertainties In The Measurements	25
5.5	Data Analysis	25

5.5	Measured Alpha Energy Data Analysis	26
Chapter 6	Results	27
6.1	Results From The First Group of Samples	27
6.2	Discussion of Results From The First Group	28
6.3	Results From The Second Group of Samples	31
6.4	Discussion of Results From The Second Group	31
6.5	Results From The Third Group of Samples	38
6.6	Discussion of Results From The Third Group	38
6.7	Results From Temperature Reduction	41
6.8	Discussion of Temperature Results	41
6.9	Results From Alpha Attenuation	44
6.10	Discussion of Attenuated Results	44
Chapter 7	Analysis Of Results	48
7.1	Curve Fitting	48
7.2	Field Model Comparison With Results	52
Chapter 8. Conclusions		57
8.1	Accomplishments Of The Experiment	57
8.2	Problems Encountered	58
8.3	Conclusions	59
Appendix A	Theoretical Analysis and Programs	60
A.1	Calculation of Energy Deposited	60
A.3	The De/Dx Program	62

A.4	Field Analysis And Signal Size Determination	67
Appendix B	The Equations	75
B.1	Equations	75
B.2	Uncertainty Equations	77
Appendix C.	Tables of Sample Characteristics	89
References		91

CHAPTER 1

INTRODUCTION

1.1. Motivation

The motivation for this work was the development of a wide area position sensitive charged particle detector that was both economical and easy to build. The cost and difficulty of using crystalline silicon for wide area detector applications makes it necessary that new materials to be used in constructing large area devices should be tested. The recent development, in the solid state industry, of using amorphous materials, to make individual components and arrays of components indicates that a new technology is growing, and, if the field of radiation detection is to keep up with advancing technology, the use of amorphous materials in radiation detection needs to be investigated. In light of these considerations these experiments were started to determine the feasibility of using α -Si:H as a detector material which eventually could be applied to the use as wide area position sensitive detectors.

The disadvantage of single crystal silicon in wide area applications is the size limit of the largest grown single crystals. To use single crystal detectors in wide area applications would require several devices, and their associated electronics, arranged in an array to cover the large area. The cost of growing large single crystals of silicon and the cost of redundant first stage amplification makes the use of single crystal silicon detectors for wide area applications undesirable.

The potential advantage of α -Si:H is that the fabrication of a device would be relatively easy and inexpensive; and there are no apparent limitations on the area or geometry of the devices. Fabrication consist simply of alternating vapor depositions of metal contacts and layers of α -Si:H. The area of the α -Si:H detector would only be limited by the size of the deposition chamber. These fabrication techniques are not as expensive nor as difficult as large single silicon crystal fabrication. Another possible advantage, in the future development of these devices as charged particle detectors, is that transistors and other electronic devices, needed for amplifier circuits, can be made using α -Si:H. This means that the preamplifier circuits could be constructed along with the detector in the same deposition process and within microns of the detector. It may soon be possible to construct α -Si:H memory circuitry, which, when used in large area arrays, could store information about an event and upon interrogation, deliver the position and energy information, with no ambiguity as to where the event occurred.

1.2. Goal Of The Experiment

The goal was to demonstrate the ability of thin film hydrogenated amorphous silicon to detect charged particles and to characterize its response. This was achieved by building a test chamber and subjecting the α -Si:H devices to some charged particle and measuring the response. After demonstrating that the α -Si:H devices do detect charged particles, the next objective was to measure the response of these devices to variations in conditions such as bias voltage, temperature, and charged particle energy. The response of the device was compared with the theoretically expected results and, based on any discrepancies, improvements in the construc-

tion of the devices would be developed that would take advantage of what was learned, so that more efficient detectors could be made.

CHAPTER 2

PROPERTIES OF AMORPHOUS SILICON

Hydrogenated amorphous silicon is fabricated by a method in which the silicon and the hydrogen atoms precipitate out of a plasma state onto a substrate that is, relatively speaking, extremely cold. This is a very rapid process of creating a solid, and insufficient time passes for the silicon to form any extended crystalline structures. As a result of this process an amorphous material is created that has many dangling silicon bonds that can act as traps for carriers. Though initially it was believed that any impurities were detrimental to charge collection, it was discovered that the hydrogen was actually beneficial to reducing the defect density and improving the characteristics of α -Si:H as an electronic device material. The assumption is that the improvement is due to the hydrogen occupying the dangling bonds and effectively reducing the number of possible traps for the carriers.[1]

The properties of α -Si:H that are of interest are the properties that affect the signal development and limit the fabrication of these devices. The samples of α -Si:H used were fabricated at Xerox Palo Alto Research Center by Dr. Robert Street and his colleagues.[2]

The gap state density of states for a typical crystalline silicon and for α -Si:H are shown in Figure 1. The typical crystalline silicon band gap has sharp band edges and no states in between. In reference to Figure 1.2, R. Nemanich and M. J. Thompson state that the gap states are characterized by a sharp conduction band edge and a wider valence band edge. The extension of states from the valence band

Figure 1.1. The Gap States Density Of States For Crystalline Silicon.

Figure 1.2. The Gap States Density Of States For α -Si:H.

is a band of states associated with the dangling silicon bond defects in α -Si:H. The important features of the picture presented are that the holes are rapidly trapped in the band tail states and the electrons can be thermally excited out of the much shallower conduction band tails.[3] There is a band gap of about 1.8 eV but because the band edges are not well defined this is an approximation.[4] The Fermi energy (E_F) is about 0.7 eV below the conduction band, and Street has measured a defect band 0.25-0.35 eV wide just below E_F [5].

The conductivity of these samples is about $10^{-9} (\Omega \text{ cm})^{-1}$. [4] The electrons have a mobility of from 0.5 to 2 cm^2/Vsec and a lifetime of about 6.4×10^{-8} seconds. The holes have a much smaller mobility of about $1.5 \times 10^{-8} \text{ cm}^2/\text{Vsec}$ and a longer lifetime of $\approx 10^{-7}$ seconds.[5] The defect density of the α -Si:H that was used was about $10^{16} (\text{cm}^{-3} \text{ eV}^{-1})$. [4]

Johnson et.al. speak of properties of α -Si:H such as dielectric strength being $> 10^8 \text{ V/cm}$ and a dielectric constant of 11.8.[6] These authors also refer to a possible mechanism whereby there is a saturation of carrier mobility and thickness dependences on the performance of α -Si:H devices.

The nature of the electric field in an α -Si:H device is important because when a DC bias is applied to an α -Si:H device the field across it does not remain uniform. The applied DC bias ionizes the material by sweeping out the loosely bound carriers and a space charge develops which creates a field that opposes the applied field. The result is that an essentially exponential field develops across the device.[5] This property is discussed in more detail in the "Analysis of Results" section where the results and rationalizations used to develop a model of the electric field are

presented.

There are also material properties of α -Si:H that will affect the fabrication of α -Si:H devices. One of the material properties described in the literature is that as the α -Si:H is deposited, columnar and pebble like morphologies appear. These regions have higher concentrations of hydrogen than the bulk material. These structures demonstrate the accumulation of strain energies from long range interaction and may lead to subsequent relief mechanisms.[7] If these structures become large enough they may lead to flaws. Street has indicated that there appears to be a limit on how thick these devices may be. If they are thicker than about 25 μm there is a tendency for the film to crack and peel off the substrate.[4] As a result there will be a limit on how thick these devices can be ($< 20 \mu\text{m}$). This presents a limit on the amount of energy that can be deposited in an α -Si:H detector because of the small amount of material for the charged particle to interact with. The most common uses of α -Si:H are in the fields of solar cells, bipolar devices and FET devices, and in these applications thin films (0.5 to 5 μm thick) are suitable. As a result there is not a great incentive to solve the problems associated with thicker depositions of α -Si:H.

CHAPTER 3

EXPERIMENTAL SETUP

3.1. Fabrication Of The α -Si:H Device

The α -Si:H devices, that were received from Street, consisted of a thin layer of α -Si:H that was deposited between metal contacts (see Figure 2). The method of deposition was plasma decomposition of silane (SiH_4) gas. The glass substrate initially has a pattern of metal chromium contacts deposited on it. The α -Si:H was then deposited at a rate of 0.5 microns per hour. If doping of the α -Si:H was desired then doping gases of B_2H_6 for p material or PH_3 for n material were introduced into the deposition chamber for the amount of time necessary to create a doped region of the desired thickness (usually about 400 Å thick).[2] After the α -Si:H had been deposited the top metal contacts were deposited on the α -Si:H.

The α -Si:H depositions have a particularly low defect density, $10^{16} \text{ (cm}^{-3} \text{ eV}^{-1})$. This low defect density was necessary to allow the radiation induced electron-hole pairs to be swept out of the device without being lost due to some defect trapping them.

3.2. Detector Configuration

These detectors were built to use two basic solid state device configurations. The first configuration was undoped Schottky barrier devices.

Figure 2.1. The Single Layer Cross-Hatched Samples.

Figure 2.2. The Two Stacked Cross-Hatched Samples.

The top and the bottom metal contacts formed Schottky barriers with the α -Si:H due to the difference between the metal's work function and the work function of the α -Si:H. This essentially creates two back-to-back diodes, and, when a bias voltage is applied to one side of the detector, one of the two Schottky barriers is reverse biased. When the bottom contact was reverse biased it was found that it could not sustain a very large voltage. This observation was consistent with Street's reported results[2] and, following his practice and recommendation, the top barrier was used to create the sensitive depletion zone. The second configuration used was that of a doped p-i-n device. These devices performed extremely well as detectors. They were able to sustain much higher bias voltages, up to 100 volts across a $2\text{ }\mu\text{m}$ p-i-n device as compared to less than 30 volts across a $5\text{ }\mu\text{m}$ Schottky device. Eventually a third detector configuration was tested, which consisted of two of the second configuration stacked back to back. The latter two configurations (i.e. the p-i-n and the stacked n-i-p on top of the p-i-n) are shown in Figures 2.1 and 2.2.

3.3. Electronic Circuit

Over the course of this experiment two electronic arrangements were used. In the first arrangement the preamplifier was mounted inside the vacuum chamber right next to the detector. The other arrangement consisted of using a preamplifier and linear amplifier that were outside of the vacuum chamber. Both arrangements used the same basic circuit which is described below.

A schematic drawing of the electronic circuit used in this experiment is shown in Figure 3. There are essentially two parts to the electronics used in the experiment. The front end of the electronics was concerned with the detector, the bias

voltage, the test input and the charge sensitive preamplifier. The back end of the electronics was concerned with the signal amplification, discrimination and pulse height analysis.

The schematic diagram shows that the front end circuitry consist of a charge sensitive preamplifier ac coupled through a capacitor to the detector. The charge sensitive preamplifier was initially an Amptek A225 ultra low noise device. During subsequent parts of the experiment when the preamplifier was outside the vacuum

Figure 3. The Overall Circuit Diagram.

test chamber a standard Lawrence Berkeley Laboratory (LBL) preamplifier and its associated linear amplifier were used. The circuit was essentially the same except that only the detector was inside the vacuum chamber. The detector was supplied bias voltage through a filter circuit and a loading resistor. The other side of the detector was grounded. There was a test input into the preamplifier, where measured voltages were supplied to a test capacitor to simulate specific quantities of charge. The test signals provided the calibration points used to calibrate the alpha signals.

The output end of the electronics consisted of standard components used to analyze signals. The output of the preamplifier was fed into a TranLamp amplifier, where the pulse was amplified to increase the size of the preamplifier's signal so it would work in the pulse height analyzer(PHA). The zero crossing output of the TranLamp was used to feed a discriminator, which was adjusted to remove the small noise signals that are picked up by the electronics. The discriminator controlled a square wave gate generator, which, after being adjusted to be wide enough to encompass the width of the signal pulse, was used as a coincidence gate for the PHA. The TranLamp signal output and the discriminated gate pulse were fed into the input and the gate connectors on a Davidson 1056B Pulse Height Analyzer. The PHA was operated in the coincidence mode, with the time control function selected to stop accumulating data after a specific amount of time had passed. After the data had been accumulated it was printed out on a line printer. Included in Figures 2.1 and 2.2 are schematics of the ways the detector configurations were connected electronically.

3.4. Alpha Attenuation

A schematic drawing of the vacuum test chamber is shown in Figure 4. Figures 5 and 6 are photographs of the test chamber. In order to see the response of the α -Si:H detectors to alpha particles of more than one energy a method was devised of inserting and removing an alpha attenuator without disturbing the system. The ^{241}Am source was mounted in a source holder that fit inside the (cylindrical) cap of the vacuum chamber (see Figure 4). As the alpha attenuator a small circular disc with four holes in it was built. One hole was left open and the other three were

Figure 4. Vacuum Chamber Schematic Drawing.

covered with 1, 2 and 3 layers of aluminized mylar respectively. Aluminized mylar was used because it is very thin, and just 4 layers of it would stop the ^{241}Am alphas. The aluminized mylar consisted mostly of mylar (i.e. 500 Å of aluminium and the rest, about 0.3 MILS, of mylar). The different layers of aluminized mylar served as the variable attenuators. The attenuator disc was mounted on top of the ^{241}Am source holder, inside the vacuum chamber cap, just over a hole through which the alpha's exited the holder. A small hemispherical piece of iron was fastened by way of a sliding rod to the attenuator disc to create a magnetic actuator (see Figure 4). The purpose of the magnetic actuator was to provide a method to rotate the attenuator disc by way of a small magnet held outside of the vacuum chamber cap. By moving the exterior magnet the attenuator disc could be aligned in front of the source to give an unattenuated source, one of three attenuation thicknesses or completely block the alpha source from the detector, without having to open the vacuum chamber.

CBB 853-2525

Figure 5. Photograph of the Outside of the Test Chamber.

CBB 853-2521

Figure 6. Photograph of the Inside of the Vacuum Test Chamber.

3.5. Temperature Control

The reduction of thermal noise by cooling the α -Si:H devices was one of the initial concerns with these thin samples. To cool the α -Si:H devices a vacuum chamber that had a cold finger already incorporated in it was used. An aluminium mounting block was built that fit over the cold finger, and onto which could be mounted the detectors and the preamplifier. The Amptek A225 preamplifier had an operational low temperature limit of -55°C . There also appeared to be a limit on how cold the detector could be cooled. Crandall states that the mobility of the carriers would be reduced with decreasing temperature and that "below 200K the shallow states...behave like deep traps and the process is limited by emission rather than transit." [7] If the mobility is severely reduced by cooling, part of the signal will be lost because it will take longer to sweep out the carriers. The cooling experiment was conducted to see if the noise characteristics could be improved and to characterize the detectors change in efficiency as a result of cooling.

To monitor the temperature inside the vacuum chamber an IN 4447 switching diode was used as the thermometer. The forward-biased diode was calibrated by measuring the voltage drop across it (Figure 3) as it was cooled to various known temperatures. Using these measurements a calibration equation relating voltage and temperature was found. The thermometer was placed inside the aluminium mounting block just beneath the α -Si:H detector.

Two coolants were used in the cold finger. The first was a slurry of dry ice (CO_2) and acetone which reaches a temperature of -78.5°C (194.6 K). [8] With this coolant the heat generated by the preamplifier, when it was mounted inside the

chamber, kept the aluminium mounting block and the detector above our -55°C limit. When the detector was to be cooled down below -55°C , a measured amount of liquid nitrogen, which reaches a temperature of -196°C (77 K), was poured into the cold finger tube. This allowed the detector to be cooled as low as -180°C . However, when the $\alpha\text{-Si:H}$ and the preamplifier were cooled much below -55°C the signal size and signal to noise ratio clearly deteriorated (Figure 18).

CHAPTER 4

EXPERIMENTAL PROCEDURE

4.1. Device Preparation And Mounting

The α -Si:H device samples were mounted on thin P.C. boards that had previously been etched to leave a desired pattern of copper lines. The copper lines were connected to the bottom metal contact on the α -Si:H sample with silver conducting epoxy, and the rest of the circuitry could be connected to the copper lines.

The device was then placed on the aluminium mounting block and was held in place with clamps. The bottom contact was usually grounded and the top contact was connected electrically to the bias voltage and the coupling capacitor by means of a small gold plated finger contact. The finger contact was spring mounted so that it would maintain positive contact with the top contact of the detector.

Once the device was mounted and electronically checked for the continuity of the connections, the system was sealed and pumped down. Initially a mechanical pump that had a liquid nitrogen trap to prevent oil from contaminating the vacuum chamber was used. Later a cryogenic vacuum pump was used. Both pumps were able to evacuate the system to a vacuum of about 2-20 mtorr in a short time interval.

A typical sample test run consisted of setting the bias voltage, adjusting the alpha attenuator disc to the desired position, then doing several trial runs to set the calibration-pulse voltage and the discriminator, and finally accumulating the data on

the PHA for some set amount of time. The temperature, bias voltage and the system pressure were recorded.

If the test run was to involve reducing the temperature it was necessary to insure a continuous supply of the cooling medium was available and data taking took place after thermal equilibrium was achieved.

4.2. The Measurement of Alpha Particles Energy

At the beginning of the experiment the noise was expected to be a serious problem so there was an attempt to reduce or remove any possible sources of noise. An ultra low noise Amptek A225 preamplifier was mounted within about one inch of the detector inside the vacuum chamber to minimize the the lead pickup of noise. When the first evidence of alpha detection was seen the signal size was so small that it was barely seen above the noise. The noise was further reduced by rearranging the components and further reducing lead lengths until the signal size was clearly above the noise. With a stable and relatively noise free system all of the samples were tested to see if they would function as detectors. Low temperature tests were done and then an attempt was made to measure the detectors sensitivity to variations in incident alpha energy. First a measurement of the actual energy of the charged particles was necessary. A conventional solid state crystalline silicon detector was acquired and put into the system. The conventional crystalline detector used was a standard Lawrence Berkeley Laboratory (LBL) 150 μm thick crystalline silicon solid state charged particle detector. The range of a 5.48 Mev alpha in silicon is about 25 μm [9], so the total energy of the alpha was absorbed by the detector. The energy required for the creation of an electron-hole pair, in silicon, is 3.62 ev.[10] This may

or may not be the energy required for electron-hole pair production in α -Si:H, but in the absence of other information it is assumed to be correct. The energy of the alpha particle was measured using the Amptek A225 as the preamplifier and the indicated energy of the alphas was $3.43 \pm .03$ Mev, which was 37% below the expected 5.48 Mev for ^{241}Am alphas (see the ^{241}Am spectra in Figure 7.).[11] A LBL preamplifier and its associated linear amplifier were used to measure the alpha peak energy and the results were $4.66 \pm .06$ Mev. This was still lower than expected, so the source was taken to the LBL detector lab, that routinely measures alpha particle energies. They also found that the source was emitting alpha particles with only 80 to 85 % of the expected energy. This appears to be due to a coating on the surface

Figure 7. The Spectra Of ^{241}Am

of the source. Since the lab's measurements agreed with the LBL circuitry results it was concluded that the LBL circuitry was working correctly.

The unattenuated and the attenuated alpha particle energies were measured using the Amptek A225 preamplifier and using the LBL circuitry with the conventional crystalline silicon detector. The results are shown in Table 1. This comparison shows that the Amptek A225 gave consistently lower results (26.3% lower for unattenuated alphas) than the LBL results when using the crystalline silicon detector. The LBL measured results of the alpha's unattenuated and attenuated energies were used as input energies in the dX/dE analysis program.

A comparison of α -Si:H detector signals measured using the Amptek A225 preamplifier and the LBL preamplifier are shown in Table 2. For the 2, 5 and the 10 μm detectors compared there did not seem to be a significant difference between Amptek A225 and the LBL preamplifier results. The differences are within our experimental uncertainty.

When the 150 μm crystalline silicon detector was used a significant difference between the LBL and the Amptek A225 preamplifier results was observed. A possible explanation could be that the large thickness of the detector leads to a longer signal rise time than the Amptek A225 preamplifier was designed for. So the Amptek

Table 1. Comparison of Amptek A225 And LBL Measurements		
# Of Mylar Layers In Attenuator	Measured Alpha Energy With Crystalline Detector	
	LBL Preamplifier (MeV)	A225 Preamplifier (MeV)
0 Layers	4.659	3.435
1 Layer	3.840	2.597
2 Layers	3.040	1.899
3 Layers	1.470	0.788

**Table 2. Comparison of Amptek A225 And LBL Measurements
Alpha Charge Equivalent Measured Using Amorphous Silicon Detectors**

Detector Size	Bias Voltage (Volts)	Type of Preamplifier Used	
		LBL (e^{-1})	Amptek (e^{-1})
2 μm	40	10166	9315
	50	14170	9984
	60	17403	11494
	70	19061	13518
	80	20718	15247
	90	22718	18180
	100	24558	21018
	110	26132	24144
5 μm	30	9668	12620
	40	11768	13520
	50	12762	15150
	60	14171	16090
	70	15912	18510
	80	17099	20360
10 μm	20	6022	9880
	30	9503	12650
	40	10773	13480
	50	12293	14960
	60	14309	15880
	70	15994	17320
	80	17099	18810

measured a smaller signal than the LBL preamplifier did. With the $\alpha\text{-Si:H}$ detectors the size of the detector was so small and the signal rise time was so short that both the preamplifiers gave relatively similar results. In each of the plots of the results in this paper it will be indicated which preamplifier was used.

CHAPTER 5

DATA ANALYSIS

5.1. Data Forms

The data for this experiment came from the pressure monitoring device, the thermometer we made, the settings on the bias voltage power supply, the measured test voltage for the calibration peaks and the output spectrum of the PHA.

5.3. Calibration of PHA

The PHA had to be calibrated so the charge equivalence of the alpha peak could be determined. The method of calibrating the PHA was to inject two different specific amounts of charge into a charge sensitive preamplifier by putting a measured step voltage across a measured capacitor. The two calibrated pulses of charge were injected at the same spot as the coupling capacitor from the detector input its charge signal into the preamplifier. That way the measured test charge signals would experience the same amplification and distortion, as the alpha's signal. It was assumed that the amplification of these signals was linear and that a linear interpolation from the two calibration signals would give the charge equivalence of the alpha signal.

The source of the test voltage was a pulser and a variable attenuator box. The attenuators were adjusted to give two calibration peaks that were close enough to the alpha peak, to minimize the uncertainty in the alpha peak's charge equivalence, and separated from each other enough to reduce the sensitivity to small variations in

the system amplification.

5.3. Noise Analysis

The size of the voltage signal varies due to thermal noise, leakage noise, circuit noise; and due to fluctuations in the charge collected per interaction with the detector. The result was that the signals for many events come out in the form of a distribution of voltages. The PHA records this distribution of counts. The distribution was nearly gaussian and could be analysed to find the centroid, and the full width at half maximum (FWHM). The deposited charge from the alpha was calculated from the position of the centroid, and the noise from the FWHM.

5.4. Uncertainties In The Measurements

The errors associated with the bias voltage setting were $\pm 1/2$ a division or 0.5 volts. The uncertainty in the temperature reading was the uncertainty in reading the voltage across the thermometer which was ± 1 mvolt. The uncertainty of the calibration voltages was $\pm .05$ mvolts for the α -Si:H runs and ± 1 mvolt for the crystalline silicon detector runs. The uncertainty in the pressure measurement were not relevant since the pressure was kept low enough (2-20 mtorr) so that energy loss of the alphas in the residual gas was negligible.

5.5. Data Analysis

The analysis of the data from the PHA consisted of finding the centroid and the variance of the alpha peak and the calibration peaks. Then using the two calibration peaks centroid channel numbers to generate an equation that correlated channel number to charge equivalent. With this equation the charge equivalence of the alpha

peak and the variance of the calibration peaks was determined. The variance was used to determine the FWHM.

The analysis of the data was done by a program that would determine all the necessary quantities to calibrate the PHA spectrum. The program would determine the alpha particle peak's charge equivalence, the equivalent energy and the noise of the system. The development of the equations used in the analysis program, a copy of the analysis program, a sample PHA spectrum and the program's analysis of the spectrum are presented in appendix B.

5.3. Measured Alpha Energy Data Analysis

The determination of the amount of energy deposited in a medium by these low energy alpha particles was done using a computer program that incorporated the Bethe stopping power equation in the form:

$$-\frac{dE}{dX} = \frac{C_1}{T_e} \ln(C_2 T_e) \quad (1)$$

Where C_1 and C_2 are material constants of the absorbing medium, assuming alpha particles are always used as the charged particle, and T_e is the kinetic energy of the alpha particle. The derivation of this form of the Bethe equation is presented in Appendix A. The program used the conventionally measured alpha energies, as incident energies and would first determine the energy lost in 400 Å of chromium, which was the thickness of the metal electrical contact, then it would determine the energy deposited by the particle in the α-Si:H detectors. The program gave the amount of charge and energy deposited at various depths into the α-Si:H material. The details and the results are given in Appendix A.

CHAPTER 6

RESULTS

The samples tested for this series of experiments came in three groups. What follows is a short discussion about the results from each group and the inferences made based on those results. The plots of the results are shown in several figures at the end of each section.

6.1. Results From The First Group of Samples

The samples initially received were mostly Schottky barrier devices and they came in various thicknesses and dopings. The top metal contacts were 400Å thick small chromium circles and the bottom contact was just a 1/2 by 1/2 inch layer of chromium deposited on a substrate. Table C.1 in Appendix C lists the first group of samples and some of their characteristics.

All of these samples were tested and the ones that did give positive results were the 5, 7.5, 8.2 and the 15 μm samples. The 5 μm sample could not sustain a very large bias voltage and the signal was not very much above the baseline noise. The 8.2 μm sample was made on an aluminium substrate, which was supposed to make the signal develop faster, but it was not able to sustain a bias of greater than 9 volts before it had so much leakage current that it was not possible to discern any alpha peak. Neither the 1 μm undoped sample nor the 6 μm n^+ sample could hold any amount of bias voltage.

The 7.5 and the 15 μm devices functioned most reliably. The 7.5 and the 15 μm detector outputs increased with increasing bias voltage as shown in Figure 8. The 15 μm sample worked at higher bias voltages than the other samples and larger signals were measured. Figure 9 shows the signal vs bias voltage plot for the 5 and the 8.2 μm detectors.

6.2. Discussion of The Results Of The First Group Of Samples

These first samples yielded a few successful detectors and some things were learned from the successes and the failures.

The signal output was much smaller than expected. For example, the 15 μm detector produced a signal that was only 1.45% of what was expected (assuming a uniform field across the detector), and the 7.5 μm detector produced a signal that was only 2.8% of what was expected (see Appendix A Table A.2). Our signal to noise ratio (S/N) was 6 for the 15 μm detector and was about 2 for the 7.5 μm detector. Clearly larger signals or less noise was needed to improve the detector's S/N.

It appeared that the method to get larger signals was to use thicker detectors because thicker detectors would increase the amount of $\alpha\text{-Si:H}$ material that the alpha particle could interact with, then more charge would be generated in the detector and a larger signal would result. The other indication that thick detectors were the solution to getting a larger signal was that the thicker detectors were able to hold greater bias voltages than the thinner detectors and the only parameter that could be adjusted to get bigger signals was the bias voltage. There didn't appear to be any evidence that the thicker detectors generated more noise than the thinner detectors, so with a larger signal and no increase in the noise it should be possible to

improve the S/N of these detectors.

Street observed that his best success with making good diodes was when he made p-i-n devices.[4] Since heavily reverse biased diodes was what was needed, a 5 μm p-i-n sample was fabricated so that a comparison could be made between its results and the 5 μm undoped sample's results. The other new type of device to be fabricated would be some 10 μm thick samples, even though thicker (≈ 20 to 25 μm) samples were desired. The 10 μm limit was due the tendency of thicker samples to crack or peel.[4]

The testing of some basic aspects of a position sensing device was started. A deposition mask that would be used to deposit a pattern of three stripes of metal one millimeter wide and about 2 millimeters apart was built. If the top and the bottom stripes were deposited perpendicular to each other this would generate a cross-hatched pattern, which could function as a crude position sensitive device (see Figure 2.1). It also gave 9 different detectors at each of the overlap points (which were called dots).

Figure 8. Signal vs Bias Voltage For 7.5 μm and 15 μm α -Si:H Detectors (Amptek A225 Preamplifier).

Figure 9. Signal vs Bias Voltage For 5 μm and 8.2 μm α -Si:H Detectors (Amptek A225 Preamplifier).

6.3. The Results From The Second Group of Samples

The second group of samples consisted of some 10 μm undoped Schottky barrier samples and a 5 μm p-i-n sample. The 5 μm p-i-n and the undoped 10 μm samples worked very well and Figure 10 shows a typical signal vs bias-voltage result for each thickness. These samples had the cross-hatched contact pattern as shown in Figure 2.1. In order to keep the different overlap points straight, each point was numbered as dot 1 through 9. Each dot was a separate detector and was made functional by biasing the appropriate pair of stripes. All the 10 μm samples were tested and all the different dots or detectors on each sample were tested. In Figures 11, 12, 13 and 14 are presented the results of these measurements for a comparison of the uniformity of the samples characteristics. The characteristics of the second group of samples are listed in Table C.2 in Appendix C.

6.4. Discussion of The Results From The Second Group of Samples

The obvious result was that the 5 μm p-i-n detector was able to sustain very high bias voltages. The 5 μm p⁺ Schottky barrier detector (Figure 9), could only hold about 30 volts bias and the 5 μm p-i-n could hold up to 100 volts bias without heavy leakage currents. Another result was that the 10 μm sample did not give larger signals than the 5 μm p⁺ or the 5 μm p-i-n sample. This was unexpected and led to a reexamination of the results.

On the 10 μm samples the measurements on the same detector were repeated at several different times. Figure 11 shows a comparison of the results taken on one dot at three different times. The 3 sets of measurements track well at the lower voltages but seem to diverge at the higher voltages. This may be due the experimental

procedure because at higher voltages the two calibration peaks tend to be closer together than for the lower voltage measurements.

Measurements were made on different detectors (dots) of the same sample. Figure 12 shows the measurements from 3 different detectors on the same 10 μm sample. The consistency of the response over the range of bias voltages indicates the uniformity of the performance characteristics across the sample.

The results from 2 different 10 μm samples were compared. The measured signal vs voltage of the same detector on two different samples is shown in Figure 13. This shows that these devices performance is uniform even from sample to sample.

Eventually these devices are to be used as position sensitive detectors so the effect of applying bias voltage across three detectors on one sample at once was tested. Prior to this ground had been applied to only one of the bottom contacts and bias voltage to only one of the top contacts. This would put the full bias voltage across only one of the overlap points. There had been some evidence that there were smaller signals being produced by the two overlap points on the biased metal stripe that did not have the ground attached to their bottom contacts. These small signals were eliminated using a collimator. Figure 14 shows the results from 2 measurement when 3 detectors on the same sample were biased at the same time in parallel. The noise did increase slightly to about 2200 electrons as compared to about 2000 electron for a single detector. The most significant difference in the performance was that the 3 parallel detectors could not sustain a very large bias voltage. The same 10 μm sample could sustain 80 volts of bias when only one detector was biased. Again the similarity of the two measurements is good evidence for the uni-

formity of material used in these samples.

The comparisons show very good agreement from sample to sample, from different detectors on one sample and for the same detector over a period of time. The error bars contain the variations in signal size from one detector test run to the next run. This indicates the error analysis is nearly correct. The error bars are around $\pm 30\%$ but as seen in the comparison figures that large uncertainty is justified.

All of the results accumulated up to that time were put together on a single plot in Figure 15 and it was observed that most of the detectors were giving very similar results, even though there were differences in the thicknesses of the samples tested. The only really offset result was that of the $15\ \mu\text{m}$ sample, which had an aluminium substrate, and instead of being much larger than the $5\ \mu\text{m}$ samples (i.e. 3 times) it gave alpha signals just about the same range as the $5\ \mu\text{m}$ sample but at much higher bias voltages. This led to the conclusion that there seems to be no advantage, as far as signal size, to having thicker samples. It was apparent that even though more charge was generated in the thicker detectors it was not being moved by the applied field and consequently not contributing to the output signal. All these detectors performed as if only a small portion of the sample was actually sensitive.

A mechanism that explains these results is the polarization of the electric field inside the device.[4] When a DC bias is applied to the $\alpha\text{-Si:H}$, the large difference in the mobilities of the electrons and the holes allows an electric field of opposite polarity to the applied field to develop and thereby reduces the net field through the dev-

ice. The field across the device is no longer uniform, but becomes exponential and drops off rapidly as it enters the device. With an exponential field, only a narrow portion of the detector, where the field is strong enough to sweep the generated charge out, is functioning as a sensitive region. It was concluded that thick devices are actually not desirable and may in fact be detrimental to signal development. In addition the 15 μm detectors results suggested that very thick devices required much larger bias voltages to give signal that were the same size as those acquired from thinner detectors at lower bias voltages - that is, that thicker devices were less efficient.

It was decided that thinner p-i-n devices would be more efficient, because they would; 1) sustain high reverse biases, 2) give higher fields across the detector and 3) present fewer opportunities to loose part of the signal due to trapping. Considering the results that indicated that only a thin region near the biased contact was acting as a sensitive region it was suggested that stacking two devices back-to-back (i.e. an n-i-p deposited on top of a p-i-n), as shown in Figure 2.2, would allow both sides of the negatively biased center electrode to function as sensitive depletion regions and effectively double the size of the detector. There was concern that since the area of the detector was increasing, the capacitive noise would increase also, and there would be no gain in the signal to noise. It was considered worth the try and stacked devices, consisting of two back-to-back 5 μm devices arranged with an n-i-p device deposited on top of a p-i-n, were made along with several thinner 2 μm p-i-n devices.

Figure 10. Signal vs Bias Voltage For 5 μm p-i-n and 10 μm a-Si:H Detectors (Amptek A225 Preamplifier).

Figure 11. Signal vs Bias Voltage For Comparison of The Same 10 μm a-Si:H Detector Tested at Three Different Times (Amptek A225 Preamplifier).

Figure 12. Signal vs Bias Voltage For A Comparison of Three Different Detectors On The Same $10\mu\text{m}$ $\alpha\text{-Si:H}$ Sample (Amptek A225 Preamplifier).

Figure 13. Signal vs Bias Voltage For A Comparison Of The Same Detector On Two Different $10\mu\text{m}$ $\alpha\text{-Si:H}$ Samples (Amptek A225 Preamplifier).

Figure 14. Signal vs Bias Voltage For A Comparison Of Two Different Sets Of Three Detectors Connected In Parallel On The Same $10\mu\text{m}$ $\alpha\text{-Si:H}$ Sample (Amptek A225 Preamplifier).

Figure 15. Overall Results For Group 1 and 2 Samples Signal vs Bias Voltage (Amptek A225 Preamplifier).

6.5. The Results From The Third Group of Samples

The results from the $2\text{ }\mu\text{m}$ p-i-n detector are shown in Figure 16 along with the results from a $5\text{ }\mu\text{m}$ p-i-n sample and a $10\text{ }\mu\text{m}$ undoped Schottky barrier sample from the second group of samples. The results from the stacked diodes with a $5\text{ }\mu\text{m}$ n-i-p diode on top of a $5\text{ }\mu\text{m}$ p-i-n diode are shown in Figure 17 along with the the results from a single layer $5\text{ }\mu\text{m}$ detector for comparison. The characteristics of the third group of samples are given in Table C.3 in Appendix C

6.6. Discussion of The Results From The Third Group of Sample

The ability of the thin $2\text{ }\mu\text{m}$ p-i-n to hold 100 volts and not break down shows that good quality thin devices can be built and the slight increase in the signals size out of the $2\text{ }\mu\text{m}$ over the $5\text{ }\mu\text{m}$ p-i-n and the $10\text{ }\mu\text{m}$ devices outputs indicates that the thinner devices may be operating more efficiently than the thick devices. This may be insignificant in light of the uncertainties in the measurements. However the overall similarity of the signal size for the 2, 5 and the $10\text{ }\mu\text{m}$ detectors indicates that most of the detector does not function as a sensing region, and only a thin region of the detector is sensitive.

The results from the stacked diode test gave clear evidence that there is a method available to increase the signal size and not increase the noise by the same amount. It was expected that the signal size would increase as N , the number of stacked devices, and that the noise, since it was not coherent, should only increase with $\sqrt{N}$. If this rate of increase of signal and noise is assumed then a S/N of 10 could be accomplished with 100 layers of $2\text{ }\mu\text{m}$ stacked diodes or a S/N of 5 could be achieved with only 25 stacked diodes. For the stacked 2 layers of $5\text{ }\mu\text{m}$ diode the

signal increased an average of 1.86 and the noise did not increase appreciably. At this point it looks as if the next step should be to stack three and four layer of diodes to determine whether or not a detector can be built that has an adequate S/N ratio.

Figure 16. Signal vs Bias Voltage For 2 μm p-i-n, 5 μm p-i-n and 10 μm $\alpha\text{-Si:H}$ Detectors (LBL Preamplifier).

Figure 17. Signal vs Bias Voltage For Stacked 5 μ m Diode and Single 5 μ m Diode α -Si:H Detector (LBL Preamplifier).

6.7. Results From Temperature Reduction

The results of the temperature reduction runs are shown in Figure 18. The noise and the signal were both reduced by about 46% by the cooling process, so there was no gain in the S/N ratio. During one of the cooling test runs an attempt was made to isolate the source of the noise. Figure 19 shows the results from this test.

6.8. Discussion of Results From The Temperature Reduction Runs

The reduction in the signal size is explained by the reduction in the mobility of the charge carriers. As stated in Chapter 2, the reduction of the temperature of α -Si:H will result in a reduction in the mobility of the carriers. A longer integrating time constant on the preamplifier would allow the slower moving carriers to be sensed but this would mean the detector would not be very useful for high event rate applications. Since the S/N ratio was not improved there is no advantage to operating these detector at lower temperatures.

Throughout the experiment noise was a continuous problem. Part of the reduced temperature tests was a series of tests to isolate the source of the noise. Measurements of noise with the detector biased at -30 volts with alpha particles were done. Measurements of the noise with the detector biased at -30 volts but without the alpha particles were done. Then measurements of the noise with no bias applied to the detector were done, and finally measurements of the noise with the detector removed were done. These measurements were all performed at several temperatures to see if one of these variable's contribution to the noise would decrease considerably with reduced temperatures. The results in Figure 19 show that the alphas and the

bias voltage did not affect the noise at any temperature. With the detector disconnected, the system noise remained essentially constant for all temperatures at about 1000 electrons. The biggest source of noise was the detector which went from about 1900 electrons at room temperature to about 900 electrons at around -55 °C. If the total noise is given by:

$$N_T^2 = N_D^2 + N_S^2 \quad (2)$$

Where:

N_T = Total Noise
 N_D = Detector Noise
 N_S = System Noise

Then detector noise is given by:

$$N_D = \sqrt{N_T^2 - N_S^2} \quad (3)$$

Figure 18. Signal and Noise vs Temperature For $5\mu\text{m}$ p-i-n $\alpha\text{-Si:H}$ Detector With -30 Volts Bias (Amptek A225 Preamplifier).

Figure 19. Noise Isolation At Reduced Temperatures (Amptek A225 Preamplifier).

6.9. Results From Alpha Attenuation

As stated earlier the energies of the attenuated and the unattenuated alpha particles were measured using a conventional crystalline silicon detector. The results of those measurements and subsequent calculations of the expected energy deposition of the various attenuated alpha particles are presented in Table 1 and Appendix A Table A.2 and Table A.3.

The results of the measurements of the attenuated alphas on a 10 μm detector at several bias voltage are shown in Figure 20. Another point of view of this data is presented in Figure 21. Shown in Figure 22 are the results when the attenuated alphas were measured using a 2 μm p-i-n detector at -90 volts bias, a 5 μm p-i-n detector at -30 volts bias, a 10 μm undoped detector at -80 volts bias and a 15 μm undoped detector at -100 volts bias.

6.10. Discussion Of The Results From The Attenuated Alpha Runs

The results from the measurements of the alpha particles energy and the calculation of the expected charge deposited indicated that the signal size should be expected to increase considerably for the attenuated lower-energy alphas. The most obvious result in Figure 20 is that the signal size did not change significantly and instead of increasing as expected it dropped off. The lack of sensitivity to changing energies is also apparent in Figure 21. The other thing that is apparent in Figure 20 is that the pattern was the same regardless of the applied bias voltage.

Since from Figures 20 and 21 it appears as if the lack of response of a particular detector to variations in alpha energy is not affected by its bias voltage, a comparison of the responses of several different thickness detectors to the attenuated

alphas is possible even though they are not all measured at the same bias voltage. Figure 22 shows a comparison of the response of 2, 5, 10 and 15 μm thick detectors to the attenuated alphas along with a solid line to indicate the type of response that our calculations show should have been expected. The thicker detectors responses are relatively flat and tend to be decreasing when they should be increasing. The response of the 2 μm sample is also flat but does indicate a slight rise which is at least in the right direction. This response to variations of alpha energy indicates that there is some mechanism operating that has not yet been explained or adequately tested. The apparent nature of the mechanism is that, in these devices, increased deposition of charge throughout the volume of the material creates the effect of reducing the sensed charge or integrating current. This resembles a saturation mechanism and a method of seeing whether or not the effect is real would be to use higher energy alpha particle which would have a smaller dE/dX and deposit less energy.

Figure 20. Signal vs Deposited Energy For $10\mu\text{m}$ Undoped $\alpha\text{-Si:H}$ Detector At Various Bias Voltages (Amptek A225 Preamplifier).

Figure 21. Signal vs Bias Voltage For $10\mu\text{m}$ Undoped $\alpha\text{-Si:H}$ Detector With Various Incident Alpha Energies (Amptek A225 Preamplifier).

Figure 22, Signal vs Deposited Energy For 2 μm p-i-n at -90 Volts Bias, 5 μm p-i-n at -30 Volts Bias, 10 μm undoped at -80 Volts Bias and 15 μm undoped at -100 Volts Bias (Amptek A225 Preamplifier).

CHAPTER 7

ANALYSIS OF RESULTS

7.1. Curve Fitting

The results were analysed to see if there was any curve that fit the data the best. Linear fits to the voltage, linear fits to the square root of the voltage as well as power fits were tried. The curve that fit the best for most of the results was a linear fit to the square root of the voltage. This was interesting because for conventional devices the depletion thickness is proportional to the square root of the voltage.

$$w \approx \left[\frac{2 \epsilon \epsilon_0 V}{e N} \right]^{1/2} = 1.14 \mu\text{m} \sqrt{V} \quad (4)$$

Equation (4) clearly does not apply because it predicts depletion widths of 3.6 μm for 10 volts and 11.4 μm for 100 volts, which are too wide for these detectors. The only parameter that could be varied in equation (4) is the density of states. A comparison of the measured signal size and the expected signal size in Appendix A indicates that these devices may have a depletion width of from 0.3 to 1.0 μm wide. With -90 volts of bias applied, and using equation (4), the density of states required to have a width of this size would be from 1.3×10^{18} to $2.4 \times 10^{17} (\text{cm}^{-3})$.

Using weighted least square fitting equations a best fit equation with the square root of the bias voltage was found for the composite of all the original samples, excluding the 15 μm results:

$$EI = 2062 \sqrt{V_D} + 660.0 \quad (5)$$

This curve is shown superimposed on the data with the experimental error bars in Figure 23. For 2, 5 and 10 μm the best fit equation was:

$$EI = 3455 \sqrt{V_D} - 10965 \quad (6)$$

This curve is shown superimposed on the data with the experimental error bars in Figure 24.

To show how well these best fit curves agree with the data the uncertainties associated with the best fit curves were calculated. The error bars in Figures 25 and 26 were calculated using the error propagation in the least square fit equations and the error propagation in the best fit equation. These error bars encompass the data fairly well in Figures 25 and 26.

Figure 23. Signal vs Bias Voltage For Composite of The First α -Si:H Samples With Fitted Curve And Data Error Bars (Amptek A225 Preamplifier).

Figure 24. Signal vs Bias Voltage For 2, 5 and 10 μm α -Si:H Samples With Fitted Curve And Data Error Bars (LBL Preamplifier).

Figure 25. Signal vs Bias Voltage For Composite of The First α -Si:H Samples With Fitted Curve And Fitted Curve Error Bars (Amptek A225 Preamplifier).

Figure 26. Signal vs Bias Voltage For 2, 5 and 10 μm α -Si:H Samples With Fitted Curve And Fitted Curve Error Bars (LBL Preamplifier).

7.2. Field Model Comparison With Results

As the experiment progressed and the results measured were not what would have been expected for a uniform field across the device (see Appendix A), it became apparent that a different model for the electric field, other than uniform, was needed. The field will change from a uniform field, when bias voltage is initially applied, to a non-uniform field sometime after the bias has been applied.[4] The non-uniform field develops, as previously stated, because loosely bound carriers are ionized out of traps or defects and will be moved by the bias field. A space charge builds up that will polarize the device creating a field which opposes the applied field. The ionization of the defects takes a certain relaxation time given by the equation:

$$t = 10^{-12} e^{\frac{E_b}{kT}} \quad (7)$$

Where E_b is the barrier height, k is the Boltzman constant and T is the temperature.[13] When $E_b = 0.4$ eV and $T = 300$ K the time to ionize all the states above 0.4 eV in the band gap would be about 10 μ secs. If it were possible to see the signal at 10 μ secs after the bias had been applied there would be very few of defects states ionized (see Figure 1.2) and the electric field would be essentially uniform across the device. The signal measured should be much larger if a window could be arranged that would look around 10 to 50 μ secs after the bias was initially applied. A system that will allow this is being constructed but in the mean time the system that was being used, in the experiment, operated under DC conditions and a model of the electric field that applied during the polarized condition was needed.

The simplest case to consider when trying to understand the effects of biasing is one of a doped (n-type) crystalline semiconductor with a discrete donor level to

which a small reverse bias voltage (i.e. 5 volts) has been applied. The energy bands are shown in Figure 27. In the depletion layer, charge density would be equal to ne (where n is the donor density), and all of the donors sites are unoccupied.[4] Poisson's equation,

$$\frac{d^2V}{dz^2} = -\frac{\rho}{\epsilon\epsilon_0} = -\frac{ne}{\epsilon\epsilon_0} \quad (8)$$

has the solution:

$$E = E_0 - \frac{ne}{\epsilon\epsilon_0} z \quad (9)$$

$$V = V_0 - \frac{ne}{2\epsilon\epsilon_0} z^2 \quad (10)$$

This gives a field that is linear in z , and a voltage that is parabolic in z . However for α -Si:H a better approximation is that the states in the gap are uniformly

Figure 27. Energy Bands In n-Doped Reverse Biased Device.

distributed in energy. The charge density is not constant ($\rho = ne$), but rather is dependent on voltage ($\rho = neV$).[4] This means that both the voltage and the field decrease exponentially:

$$V = V_0 \exp\left[-\left(\frac{ne}{\epsilon \epsilon_0}\right)^{1/2} z\right] \quad (11)$$

$$E = E_0 \exp\left[-\left(\frac{ne}{\epsilon \epsilon_0}\right)^{1/2} z\right] \quad (12)$$

This exponential field is not a completely correct model either, because it assumes there is no leakage current. If there is leakage current there must be a voltage drop across the bulk of the sample, V_B , such that the leakage current is matched by a bulk current $I_B = V_B/R_B$, where R_B is the bulk resistance.[4] As was found during these experiments there was some leakage current and that would mean that a very small field existed over most of the sample.

Another complication is that when the bias voltage is increased so high that the Fermi energy crosses into the valence band, it requires very little energy to excite carriers and they are immediately swept out during the initial application of the bias voltage. This situation is referred to as deep depletion and the Fermi energy is held near the center of the gap by the competition between excitation of electrons and holes. The energy bands for the condition when a large bias voltage is used are shown in Figure 28 and the space charge is now given by the shaded region.[4]

The charge density is constant in the region of deep depletion (I), where the first solution to Poisson's equation is applicable, but it is not constant beyond the deep depletion region because in the adjacent depletion region (II) it is proportional to the applied voltage. Since high values of bias voltage were used, any field model

Figure 28. Energy Bands With Large Reverse Bias Voltages Applied.

developed must incorporate a region where the space charge will be constant up to some critical point and then, beyond the deep depletion region, there must be a region of regular depletion where the space charge should be proportional to the applied voltage. The space charge should be approximately equal to the dangling bond density ($10^{16} \text{ cm}^{-3} \text{ eV}^{-1}$). [4]

The properties just described were incorporated along with the observation made as a result of this experiment when the field model was developed. The shape of the field model is calculated in Appendix A and is shown in Figure A.3. Figure 29 shows the calculated signals using this model for 2 and 5 μm detectors. The calculated curves are essentially the same for 2 and 5 μm detectors. The model's curves don't track well at the low and the high voltages but they fit well in middle. Vari-

ous parameters are being checked to see if a better match of the slope can be found.

Figure 29. Signal vs Bias Voltage For 2 μm and 5 μm a-Si:H Samples With Field Model Calculations (Amptek A225 Preamplifier).

CHAPTER 8

CONCLUSION

8.1. Accomplishments of the Experiment

The experiment has demonstrated that α -Si:H devices will detect the passage of alpha particles. It was observed that the signal did increase as the bias voltage was increased. The signal to noise ratio was about 2 to 10 for a single detector. The signals were much smaller than expected for the silicon thickness involved. Polarization of the device, when a DC bias was applied, transforms the internal field from an initially uniform field into a non-uniform field. The internal field deteriorates to the point where the field was large enough to move carriers only for a narrow region of the detector. It was estimated that this region was from 0.3 to 0.7 μms wide and it was the same width regardless of the overall thickness of the detector. Consequently the signal size measured for different thickness detectors was essentially the same. The p-i-n doped detectors functioned better than the Schottky barrier devices because they could hold a larger reverse bias. The stacked diode detector showed good signal increase over the single diode with no associated large increase in the noise. The stacking of the diode detectors may be one solution to improving the signal to noise ratio to an acceptable level. The reduction of the temperature of these detectors did not improve the signal to noise ratio because the signal was reduced as much as the noise. The noise of a 5 μm detector varied from 1900 electrons at room temperature down to 900 electrons at about -55°C . The consistency of the perfor-

mance of several detectors over time and from sample to sample indicated the material was fabricated with uniformity and performance has not deteriorated over the period of this experiment.

The detectors were subjected to variations in alpha particle energy and very little sensitivity to energy changes was measured. This may be a result of some saturation mechanism or it may be due to insufficient signal development time. This results needs to be investigated further by experiments which will subject the detector to higher energy particles, which will deposit less energy in the detector, or by experiments that increase the integrating time constant of the preamplifier to allow more of the slower moving carriers to be sensed.

8.2. Problems Encountered

The problems encountered with these detectors was their low efficiency and their lack of energy sensitivity. These problem may be dealt with in several ways. Several papers have referred to thickness dependences of the performance of α -Si:H devices.[3] [14] [15] These papers suggest that thinner devices perform better, so a solution may be to build thinner detectors which should improve the efficiency. Another method of dealing with the poor efficiency will be to pulse the bias voltage. Street has shown that pulsing the bias voltage gives better signal collection for a short time (≈ 10 to $50 \mu\text{sec}$) after the pulsing.[5] During this time, with a near uniform field across the detector, more of the carriers will be subjected to a larger field and be swept out.

The sensitivity of the detectors may be improved by stacking devices. Whether or not to connect them in series or in parallel is not certain. Both methods are being

tested.[16] In this experiment tests were conducted with them connected in parallel and good results were observed. The lack of sensitivity may be due to a thickness dependent saturation of the carrier mobility. This was suggested by Johnson et. al. to explain why they got greater quantum efficiency as they reduced the thickness of the devices they tested. Using thinner stacked detectors may solve the sensitivity problem.

3.3. Conclusion

The α -Si:H detectors that were tested did demonstrate the ability to detect alpha particles. Several improvements in the performance of these detectors must be accomplished before they will be useful for position sensitive applications. But as more is learned about these detectors methods are being found to overcome the shortcomings encountered.

Assuming this endeavor will be successful, a new family of solid state detectors could be developed. The flexibility and ease of fabrication of α -Si:H should allow many new and interesting application to be considered.

APPENDIX A

THEORETICAL ANALYSIS AND PROGRAMS

This Appendix describes the specifics of how the theoretically expected results were determined.

1. The Calculation of The Energy Deposited

The formula used to determine the energy deposited is the Bethe stopping power equation[17]:

$$-\frac{dE}{dX} = \frac{4\pi z^2 e^4 N Z}{mv^2} \left[\ln\left(\frac{2mv^2}{I}\right) - \ln(1-\beta^2) - \beta^2 \right] \quad (A1)$$

Since these alpha particles have a kinetic energy (5.48 Mev) which is small compared to the rest mass of the an alpha particle (3726.3 Mev), the stopping power equation reduces to:

$$-\frac{dE}{dX} = \frac{4\pi z^2 e^4 N Z}{mv^2} \ln\left(\frac{2mv^2}{I}\right) \quad (A2)$$

Which can become:

$$-\frac{dE}{dX} = \frac{C_1}{T_e} \ln(C_2 T_e) \quad (A3)$$

Where C_1 and C_2 are material constants of the absorbing medium, assuming only alphas are used as the charged particle. The equation for C_1 and C_2 are given by:

$$C_1 = \frac{Z_m N_A z^2 2\pi r_e^2 M_e M_e}{A_m} \quad (A4)$$

$$C_2 = \left[\frac{4 M_e}{M_\alpha I} \right] \quad (A5)$$

Where:

Z_m = the number of protons of the absorbing medium

A_m = the atomic mass of the absorbing medium

N_A = Avogadro's number

z_α = the number of protons in an alpha particle (2)

$r_e = \left(\frac{e^2}{m_e c^2} \right)$ = Bohr radius (2.8178×10^{-13} cm)

M_α = rest mass of an alpha particle (3726.292 Mev)

M_e = rest mass of an electron (0.511006 Mev)

T_α = the kinetic energy of the alpha particle

I = the average excitation and ionization potential of the absorbing medium

$$I = 9.1 Z_m (1 + 1.9 Z_m^{-\frac{2}{3}}) eV [18]$$

For the media used C_1 and C_2 have the values shown in Table A.1.

Table A.1. Absorbing Medium Material Constants		
Absorbing Medium	C_1 $\frac{(\text{Mevcm})^2}{\text{gm}}$	C_2 Mev^{-1}
Silicon	1139.58	3.26461
Chromium	1055.23	2.01598
Mylar	1189.65	8.12798

2. The De/Dx Program

A program that used the dE/dX equation to determine the energy deposited and the number of electron-hole pairs generated by the passing of our 4.66 ± 0.06 Mev alpha particles was created. It calculated that the $400\text{\AA}$ of chromium, which made up the top electrical contact, attenuated the alpha's energy by about 14.78 KeV to about 4.64 Mev. The attenuated energy of 4.64 ± 0.06 MeV was used as the incident energy into the $\alpha\text{-Si:H}$ layer of the detector. The energy deposited (in Kev) and the number of electron-hole (in $10^3 e^-$) and the dE/dX (in KeV/ μm) for various thicknesses are presented in Table A.2. The De/Dx program also used the measured attenuated alpha energies to determine, after adjusting for the $400\text{\AA}$ of chromium, the energy deposited and the electron-hole pairs generated at various thicknesses of $\alpha\text{-Si:H}$ material. The results of the attenuated energy calculations are shown in Table A.3. A copy of the De/Dx program is attached after Table A.3.

Table A.2. Energy deposited and electrons generated.
 Energy in = 4.64 Mev Medium = Silicon

Thickness of Silicon (μm)	Energy Deposited (Kev)	Electron Generated (10^3 e^-)	dE/dX (Kev/ μm)
0.10	15.7	4.3	-152.6
0.20	31.0	8.6	-152.6
0.30	46.7	12.9	-152.6
0.40	62.4	17.2	-152.6
0.50	78.0	21.6	-152.6
0.60	93.8	25.9	-152.6
0.70	109.5	30.3	-162.1
0.80	125.3	34.6	-162.1
0.90	141.1	39.0	-162.1
1.00	157.0	43.4	-162.1
1.10	172.9	47.8	-162.1
1.20	188.8	52.2	-162.1
1.30	204.8	56.6	-162.1
1.40	220.7	61.0	-162.1
1.50	236.8	65.4	-162.1
1.60	252.8	69.8	-162.1
1.70	269.0	74.3	-162.1
1.80	285.1 ^A	78.8	-162.1
1.90	301.3	83.2	-162.1
2.00	317.5	87.7	-162.1
3.0	481.8	133.1	-162.1
4.0	650.2	179.6	-171.7
5.0	823.0	227.4	-176.4
6.0	1000.7	276.4	-181.2
7.0	1183.7	327.0	-186.0
8.0	1372.6	379.2	-190.7
9.0	1568.0	433.1	-200.3
10.0	1770.6	489.1	-205.0
15.0	2934.9	810.7	-267.0

Table A.3. Energy Deposited and Electrons Generated With Attenuators

Thickness(μm)=T, Energy deposited(KeV)=Edep, Electrons generated (10^3 e^-)=Eldep						
	1 Layer of Mylar Energy In 3.83MeV		2 Layers of Mylar Energy In 3.00MeV		3 Layers of Mylar Energy In 1.45MeV	
T	Edep	Eldep	Edep	Eldep	Edep	Eldep
0.10	17.6	4.9	20.3	5.6	28.5	7.9
0.20	35.1	9.7	40.5	11.2	57.2	15.8
0.30	52.7	14.6	60.8	16.8	86.2	23.8
0.40	70.4	19.5	81.3	22.4	115.3	31.8
0.50	88.2	24.4	101.8	28.1	144.6	40.0
0.60	105.9	29.3	122.4	33.8	174.2	48.1
0.70	123.8	34.2	143.0	39.5	203.9	56.3
0.80	141.7	39.1	163.8	45.2	233.9	64.6
0.90	159.6	44.1	184.6	51.0	264.0	72.9
1.00	177.6	49.1	205.5	56.8	294.4	81.3
1.10	195.6	54.0	226.6	62.6	324.9	89.8
1.20	213.7	59.0	247.7	68.4	355.7	98.3
1.30	231.9	64.1	268.8	74.3	386.6	106.8
1.40	250.1	69.2	290.1	80.1	417.7	115.4
1.50	268.3	74.1	311.5	86.0	449.0	124.0
1.60	286.6	79.2	332.9	92.0	480.4	132.7
1.70	305.0	84.3	354.5	97.9	512.0	141.4
1.80	323.4	89.3	376.1	103.9	543.7	150.2
1.90	341.9	94.5	397.9	109.9	575.5	159.0
2.00	360.5	99.6	419.7	115.9	607.3	167.8
3.0	549.2	151.7	643.7	177.8	880.5	243.2
4.0	744.4	205.6	879.2	242.9	1073.5	296.6
5.0	946.9	261.6	1127.9	311.6	1209.8	334.2
6.0	1157.6	319.8	1382.3	384.6	1306.0	360.8
7.0	1377.7	380.6	1675.1	462.7	1374.0	379.5
8.0	1608.5	444.3	1978.0	546.4	1421.9	392.8
9.0	1851.8	511.6	2287.5	631.9	1455.8	402.1
10.0	2109.9	582.8	2523.1	697.0	1479.6	408.7
15.0	3453.4	954.0	2989.4	825.8	1526.9	421.8

De/Dx Program

```

c      This program will determine the amount of
c      energy deposited in 400 angstroms of chromium
c      the amount of energy deposited in silicon
c      after having passed through the chromium.
      T=400
      E1=4.659
      E2=3.842
      E3=3.023
      E4=1.476
      DTC=.0000000719
      EZ=1.41935
      A=479.16298
      C1=1055.23486
      C2=2.0159757
c      this is where the effect of the Cr is calculated
      CALL EOT(E1,ECOUT1,ECDEP1,ECLDP1,T,DTC,EZ,A,C1,C2)
      CALL EOT(E2,ECOUT2,ECDEP2,ECLDP2,T,DTC,EZ,A,C1,C2)
      CALL EOT(E3,ECOUT3,ECDEP3,ECLDP3,T,DTC,EZ,A,C1,C2)
      CALL EOT(E4,ECOUT4,ECDEP4,ECLDP4,T,DTC,EZ,A,C1,C2)
      PRINT *, '*****'
      PRINT *, ' FOR 400 ANGSTOMS OF CHROMIUM AND UNATTENUATED ALPHAS'
      PRINT 150, E1, ECOUT1, ECDEP1, ECLDP1
150    FORMAT(3X, 'Ein=', f6.4, ' Eout=', F6.4, ' Edep=', f6.2, ' Eldep=',
1      f6.2)
      PRINT *, '*****'
      PRINT *, ' FOR SILICON AFTER PASSING THROUGH 400 A OF CHROMIUM'
      PRINT *, ' Ein(MeV) Edep(Kev) Eldep(1000 ELECTORNS)'
      PRINT *, '-----'
1    PRINT *, ' | T | NO LAYERS | 1 LAYER | 2 LAYERS'
1    | 3 LAYERS |
      PRINT 160, ECOUT1, ECOUT2, ECOUT3, ECOUT4
160    FORMAT(2X, '|', 4X, 4(' | Ein=', f5.3, 2X), '|')
      print *, ' | um | Edep | Eldep | Edep | Eldep |'
1    Edep | Eldep |
      PRINT *, '-----'
1    '-----'
      T=.05
      DTC=0.0002328
      EZ=.83255
      A=1494.659
      C1=1139.58
      C2=3.26461
      DO 200 J=1, 17
      CALL SIL(ECOUT1, ECOUT2, ECOUT3, ECOUT4, T, DTC, EZ, A, C1, C2)
      T=T+.05
200    CONTINUE
      DO 300 M=1, 11
      CALL SIL(ECOUT1, ECOUT2, ECOUT3, ECOUT4, T, DTC, EZ, A, C1, C2)
      T=T+.1
300    CONTINUE
      DO 400 N=1, 9
      CALL SIL(ECOUT1, ECOUT2, ECOUT3, ECOUT4, T, DTC, EZ, A, C1, C2)
      T=T+1
400    CONTINUE
      T=15
      CALL SIL(ECOUT1, ECOUT2, ECOUT3, ECOUT4, T, DTC, EZ, A, C1, C2)
      STOP
      END
      SUBROUTINE SIL(E1, E2, E3, E4, T, DTC, EZ, A, C1, C2)

```

De/Dx Program Continued

```

450  CALL EOT(E1,ESOUT1,ESDEP1,ESLDP1,T,DTC,EZ,A,C1,C2)
      CALL EOT(E2,ESOUT2,ESDEP2,ESLDP2,T,DTC,EZ,A,C1,C2)
      CALL EOT(E3,ESOUT3,ESDEP3,ESLDP3,T,DTC,EZ,A,C1,C2)
      CALL EOT(E4,ESOUT4,ESDEP4,ESLDP4,T,DTC,EZ,A,C1,C2)
      PRINT 500,T,ESDEP1,ESLDP1,ESDEP2,ESLDP2,ESDEP3,ESLDP3,
1    ESDEP4,ESLDP4
500  FORMAT(2X,F5.2,4(1X,F6.1,1X,F6.1))
      RETURN
      END
      SUBROUTINE EOT(Ein,Eout,Edep,Eldep,T,DTC,EZ,A,C1,C2)
        Eout=Ein
        Dt=(T/1000)*DTC
        DO 100 i=1,1000
          IF(Eout.LT.EZ) GO TO 90
          GO TO 95
C      THIS IS THE LINEAR PART OF DE/DX
90    DE=-A*(Eout+(EZ/10))
          GO TO 96
C      THIS THE REGULAR PART OF DE/DX IN Mev
95    DE=-(C1/Eout)*ALOG(C2*Eout)
96    Eout= Eout+DE*DT
100   CONTINUE
C      ENERGY DEPOSITED IN Kev
        Edep=(Ein-Eout)*1000
        Eldep=Edep/3.62
        dedx=de*dt*1000
        det=de*t
        print *,t,dedx,det
        print 98,eldep,edep,ein,eout,de
98    format(1x,' el=' ,f7.2,' en=' ,f6.1,' ein=' ,f7.5,
1    ' eo=' ,f7.5,' de=' ,f9.1)

      RETURN
      END

```

3. Field Analysis and Signal Size Determination

The most difficult part of the theoretical analysis is the prediction of the signal size. The difficulty arises from the large uncertainty of field shape inside the detector and the uncertainty in our understanding of the mechanisms affecting the motion of the charge carriers in the environment of dangling bonds and deep traps that exist in α -Si:H. Street has measured the field across some of his samples with bias voltages that are small when compared to ours, and he finds the field to be exponential at these voltages (5-10 volts).[2] The determination of the expected signal size due to the field across the detector consisted of first calculating the distribution, $N(z)$, of the charge created in the detector, by the charged particle. This could have been assumed to be constant but the calculated distribution from the De/Dx program was used. The equation used to find the number of charge carriers, N_{out} , that were sensed by a detector with an applied bias voltage, V_B , was:

$$N_{out} = \int_{z=0}^{z=d} \frac{V(z)}{V_B} N(z) dz \quad (A6)$$

Equation (A.6) gives the the signal sensed because the the portion of the deposited charge, at a specific z in the device, that is eventually sensed is equal the ratio of the voltage, at that point z , to the applied voltage, and to get the total signal sensed you must add up all the contributions from each z .

Next the ratio, ϵ , of the charge carriers that were moved by the field, N_{out} , and contributed to the signal size, to the charge carriers that were generated, N_{dep} , by the charged particle was calculated.

$$\epsilon = \frac{N_{out}}{N_{dep}} \quad (A7)$$

Where

$$N_{dep} = \sum_{z=0}^{z=d} N(z) \quad (A8)$$

Several fields were tried and the results are presented in the following sections.

3.1. Uniform Field

The fundamental field expected was a uniform field which assumes a uniform voltage gradient across the detector. The equation for the voltage is:

$$V = V_D(1 - \frac{z}{d}) \quad (A9)$$

With the boundary conditions:

$$v = V_D \text{ at } z = 0$$

$$v = 0 \text{ at } z = d \text{ (d = detector thickness)}$$

The uniform field gave values of ϵ of about 1/2 as shown in Table A.4. The amount of charge measured was not nearly as large as those predicted by the uniform field. The measured results range from 10,000 to 30,000 electrons as compared to these values of from 40,000 to 500,000 electrons. So clearly these detectors don't have a uniform field.

Table A.4. Uniform Field Signal Size and ϵ			
Thickness (μm)	Electrons* Deposited	Electrons** Sensed	ϵ
2.0	87700	41300	0.471
5.0	227400	109100	0.480
10.0	486200	230600	0.471

* Calculated in Table A.2

** Calculated from equation (A6)

3.2. Thin Depletion Region Field

This group of fields was based on a model that assumed a uniform field for a thin portion of the distance across the detector and the rest of the detector had essentially no field. The motivation for this model was that the results indicated such small signals from the detectors and the signal size was essentially the same regardless of the detector thickness. A thin depletion region across which the entire field was developed seemed to explain both of the observed results so a very simple thin field was analysed. Figure A.1 shows the basic configuration of the field.

The variable Z_1 was changed to create different fields. Several values of Z_1 from 0.05 to 0.7 μm were tried and the results are shown in Table A.5.

Figure A.1. Thin Depletion Regions Field

Table A.5. Thin Depletion Width Field's Signal Size And ϵ

Z_1 (μm)	$2\mu\text{m}$		$5\mu\text{m}$		$10\mu\text{m}$	
	ϵ	Electrons	ϵ	Electrons	ϵ	Electrons
0.05	0.0049	410	0.0049	1100	0.0047	2320
0.10	0.053	4640	0.023	5330	0.0134	6550
0.20	0.106	8890	0.042	9580	0.0221	10800
0.30	0.15	13200	0.061	13900	0.031	15100
0.40	0.199	17500	0.0798	18100	0.0396	19400
0.50	0.248	21700	0.0986	22400	0.0483	23600
0.60	0.297	26000	0.117	26700	0.057	27900
0.70	0.346	30300	0.136	31000	0.066	32300

These fields show that whatever the actual shape of the field may have been, the width of the sensitive region that would give signal sizes of the order of 10,000 to 30,000 electrons was from 0.3 to 0.7 μms wide. This indicates that the depletion region was only about $0.5\mu\text{m}$ wide and the rest of the $\alpha\text{-S:H}$ material was not serving any useful function. Whatever the mechanism was that causes the sensitive region to be so small it may or may not be affected by the overall thickness of the sample.

Comment

The last model was not adequate because it does not produce fields that give different signal sizes when different bias voltages are applied. The relationship between $V(z)$ and V_B remains the same for all bias voltages so ϵ was the same regardless of the applied bias voltage. This does not agree with our observation that the signal size increases with increasing bias voltage. In spite of these shortcomings this model does give an idea of what size a thin depletion region should be to get results that are of a magnitude similar to the results measured.

3.3. Field Model Based On Experimental Results

As explained in the "Analysis of Results" section a more accurate model of the electric field under DC condition was needed. There were two observed results to base our model on. First that the signal size did not change for different thickness detectors and second it appeared as if only a small portion of the detector was sensitive. A model of the electric field was developed that would reflect these experimental observations, the characteristics associated with the shape of the field, as previously discussed and would also generate signal sizes equivalent to the measured results over the range of applied bias voltages used.

First several assumptions were made. The model assumed a dE/dX of $-150\text{KeV}/\mu\text{m}$. Also it was assumed that all the electrons, and none of the holes, are swept out by the field. The model also assumes that there are two regions to the field. The first region was where the charge density was constant ($\rho = -ne$) and the second region was where the charge density was proportional to the applied voltage ($\rho = n_v e V$). The point where the transition between the two regions occurred was called the critical distance, t_c , and the voltage at that point was called the critical voltage, V_c . The analysis began with these equations and boundary conditions:

$$\frac{d^2V}{dz^2} = -\frac{ne}{\epsilon\epsilon_0} \quad \begin{array}{l} 0 \leq z < t_c \\ V_B \geq V > V_c \end{array} \quad (\text{A10})$$

$$\frac{d^2V}{dz^2} = -\frac{n_v e V}{\epsilon\epsilon_0} \quad \begin{array}{l} t_c \leq z \leq d \\ V_c > V \geq 0 \end{array} \quad (\text{A11})$$

Where:

d —detector total thickness

V_b —bias voltage

$V = V_b$ at $z=0$

$V=0$ at $z=d$

and solutions were found for the voltage which are given by these equations:

$$V = V_c \left[\frac{\sinh[f(d-z)]}{\sinh[f(d-t_c)]} \right] \quad z > t_c \quad (A12)$$

$$V = V_c \left[\frac{f^2 (t_c - z)^2}{2} + f(t_c - z) \coth[f(d - t_c)] + 1 \right] \quad z < t_c \quad (A13)$$

Where

$$f(\text{in } \mu\text{m}^{-1}) = 1.228 \sqrt{N(E)} \quad (A14)$$

and $N(E)$ is the energy density of shallow traps measured in units of $10^{16} \text{cm}^{-3} \text{eV}^{-1}$.

The expected signal size would then be:

$$En (\text{KeV}) = 150 \int_{z=0}^{z=d} \frac{V(z)}{V_b} dz \quad (A15)$$

In the actual calculation, a value was assigned to V_c . The corresponding value of t_c was then calculated from equation (A13), using the boundary condition $V = V_b$ at $z=0$. For the specific values of V_c and $N(E)$ listed, Figure A.2 shows the field and voltage across any size detector (it remains essentially the same for 2.5 or 10 μm detectors). In the "Analysis of Results" chapter, Figure 29, there is a comparison shown between the calculated results using this model, of the voltage across the detector with values of V_c and $N(E)$ listed in Figure A.3, and the measured signal for a 2 and a 5 μm detector. The calculated results in Figure 29 agree fairly well with the measured results. Improvements of this model are being attempted and it will be used to create a model of how the signal develops in time.

Figure A.3. Field Based On Experimental Results

APPENDIX B

Equations Used In Data Analysis

1. Equations

The equations that were used to analyse the data and their development are shown in the next pages.

The Equation Used To Determine The Centroid Of a Peak

$$I_n = \frac{\sum_{i=lc}^{i=hc} i N_i}{\sum_{i=lc}^{i=hc} N_i} \quad (B1)$$

The Equation For The Variance of a Peak

$$Var = \frac{\sum_{i=lc}^{i=hc} (i - I_n)^2 N_i}{\sum_{i=lc}^{i=hc} N_i} \quad (B2)$$

The Equation For FWHM Using The Variance

$$FWHM = \sqrt{8 \ln 2 \text{ Var}} \quad (B3)$$

Using these definitions:

I_n = channel number of the centroid of the peak n
 ($n = \alpha(\text{alpha}), n = 1(\text{high}), n = 2(\text{low})$)

i = channel number

N_i = count in channel i

lc = lowest channel in the peak

hc = highest channel in the peak

Development of The Equation For The Alpha Peak Analysis

The equation that related a channel number to an electron equivalence was the equation of the line ($y = ax + b$) generated by the two calibration peaks.

The electron equivalent of a peak is given by:

$$El_n = \frac{V_{T_n} C_T}{ex 1000} \quad (B4)$$

The slope is given by:

$$a = \frac{El_1 - El_2}{I_1 - I_2} \quad (B5)$$

The y intercept is given by:

$$b = \frac{El_2 I_1 - El_1 I_2}{I_1 - I_2} \quad (B6)$$

The alpha's peak electron equivalence is:

$$El_\alpha = a I_\alpha + b \quad (B7)$$

This leads to the alpha energy using:

$$E_\alpha (\text{KeV}) = 3.62 El_\alpha \quad (B8)$$

Using these definitions:

V_{T_n} = measured test voltage of peak n

C_T = test capacitor capacitance

e = the charge of an electron

El_n = calibration peak's electron equivalent

I_n = a peak's centroid channel number

ϵ = for Silicon is 3.62 eV/electron-hole pair

2. Uncertainty Equations

Development Of The Uncertainty Equation For A Peak's Centroid Channel

Beginning with equation (B1):

$$I_s = \frac{\sum_{i=lc}^{i=hc} i N_i}{\sum_{i=lc}^{i=hc} N_i} \quad (B1)$$

Take the derivative to get:

$$\Delta I_s = \frac{\left(\sum_{i=lc}^{i=hc} i \Delta N_i \right) \sum_{i=lc}^{i=hc} N_i - \left(\sum_{i=lc}^{i=hc} i N_i \right) \sum_{i=lc}^{i=hc} \Delta N_i}{\left(\sum_{i=lc}^{i=hc} N_i \right)^2} \quad (B9)$$

Squaring and time averaging leads to:

$$\overline{\Delta I_s^2} = \left[\frac{\sum_{i=lc}^{i=hc} i^2 N_i \left(\sum_{i=lc}^{i=hc} N_i \right)^2}{\left(\sum_{i=lc}^{i=hc} N_i \right)^4} \right] - \left[\frac{\left(\sum_{i=lc}^{i=hc} i N_i \right)^2 \sum_{i=lc}^{i=hc} N_i}{\left(\sum_{i=lc}^{i=hc} N_i \right)^4} \right] \quad (B10)$$

Substitution from equation (B1) this can become:

$$\overline{\Delta I_s^2} = \frac{\sum_{i=lc}^{i=hc} (i^2 - I_s^2) N_i}{\left(\sum_{i=lc}^{i=hc} N_i \right)^2} = \sigma_{I_s}^2 \quad (B11)$$

The uncertainty in a centroid's channel number.

Development of The Uncertainty For Calibration Peaks Electron Equivalence

There was a systematic uncertainty associated with the capacitance of the test capacitor which was neglected in the calculations because it effected all the measurements the same way. The absolute uncertainty of the alpha's equivalent energy was not determined, only a relative uncertainty. The value of the test capacitors capacitance (C_T) used with the Amptek was measured to be 2.5 ± 0.2 pf. The value used when using the LBL general purpose preamplifier was calculated to be 4.425 pf. This was mentioned here because the test capacitor's value is associated with the uncertainty of the electron equivalence as follows. Begin with equation (B4):

$$Ei = \frac{C_T V_T}{e} = K V_T \quad (B4)$$

If we let

$$K = \frac{C_T}{e} \quad (B12)$$

And the uncertainty for the electron equivalence becomes:

$$\sigma_{Ei}^2 = K^2 \sigma_{V_T}^2 \quad (B13)$$

Where σ_{V_T} was the uncertainty in the measured test voltage in units of mvolts.

When using the Amptek A225 preamplifier the value of K was 15.6 and when using the LBL general purpose preamplifier it was 27.62. These value resulted from the conversions from capacitance in picofarads, voltage in millivolts, e and wanting to end up with the electron equivalence in units of 1000 electrons.

Development of The Uncertainty In The Alpha Peak's Electron Equivalence

The equation used was equation (B7) expanded:

$$El_{\alpha} = \left(\frac{El_1 - El_2}{I_1 - I_2} \right) I_{\alpha} + \frac{El_2 I_1 - El_1 I_2}{I_1 - I_2} \quad (B14)$$

Which becomes:

$$= El_1 \left(\frac{I_{\alpha} - I_2}{I_1 - I_2} \right) + El_2 \left(\frac{I_1 - I_{\alpha}}{I_1 - I_2} \right) \quad (B15)$$

So

$$El_{\alpha} = El_{\alpha}(El_1, El_2, I_{\alpha}, I_1, I_2) \quad (B16)$$

The uncertainty of El_{α} would be:

$$\begin{aligned} \sigma_{El_{\alpha}}^2 = & \left(\frac{\partial El_{\alpha}}{\partial El_1} \right)^2 \sigma_{El_1}^2 + \left(\frac{\partial El_{\alpha}}{\partial El_2} \right)^2 \sigma_{El_2}^2 + \left(\frac{\partial El_{\alpha}}{\partial I_{\alpha}} \right)^2 \sigma_{I_{\alpha}}^2 \\ & + \left(\frac{\partial El_{\alpha}}{\partial I_1} \right)^2 \sigma_{I_1}^2 + \left(\frac{\partial El_{\alpha}}{\partial I_2} \right)^2 \sigma_{I_2}^2 \end{aligned} \quad (B17)$$

The equations for the partials are:

$$\left(\frac{\partial El_{\alpha}}{\partial El_1} \right)^2 = \left(\frac{I_{\alpha} - I_2}{I_1 - I_2} \right)^2 \quad (B18)$$

$$\left(\frac{\partial El_{\alpha}}{\partial El_2} \right)^2 = \left(\frac{I_1 - I_{\alpha}}{I_1 - I_2} \right)^2 \quad (B19)$$

$$\left(\frac{\partial El_{\alpha}}{\partial I_{\alpha}} \right)^2 = \left(\frac{El_1 - El_2}{I_1 - I_2} \right)^2 = (\text{slope})^2 = s^2 \quad (B20)$$

$$\left(\frac{\partial El_{\alpha}}{\partial I_1} \right)^2 = \left(\frac{El_1 - El_2}{I_1 - I_2} \right)^2 \left(\frac{I_{\alpha} - I_2}{I_1 - I_2} \right)^2 = s^2 \left(\frac{I_{\alpha} - I_2}{I_1 - I_2} \right)^2 \quad (B21)$$

$$\left(\frac{\partial EI_{\alpha}}{\partial I_2} \right)^2 = \left(\frac{EI_1 - EI_2}{I_1 - I_2} \right)^2 \left(\frac{I_1 - I_{\alpha}}{I_1 - I_2} \right)^2 = \sigma^2 \left(\frac{I_1 - I_{\alpha}}{I_1 - I_2} \right)^2 \quad (\text{B22})$$

Using these definitions:

$\sigma_{E_1}^2$ = the uncertainty in the high calibration peak electron equivalence

$\sigma_{E_2}^2$ = the uncertainty in the low calibration peak electron equivalence

$\sigma_{I_{\alpha}}^2$ = the uncertainty in the alpha peak centroid's location

$\sigma_{I_1}^2$ = the uncertainty in the high peak centroid's location

$\sigma_{I_2}^2$ = the uncertainty in the low peak centroid's location

Development of The Uncertainty In The FWHM Equation

Assuming that there is no uncertainty in the centroids location, which is a good assumption because the centroid location uncertainty was very small. Begin with equation (B3):

$$FWHM = \sqrt{8\ln 2} \sqrt{V_{sr}} = \sqrt{8\ln 2} \left[\frac{\sum_{i=lc}^{i=hc} (i - I_s)^2 N_i}{\sum_{i=lc}^{i=hc} N_i} \right]^{1/2} \quad (B3)$$

Taking the derivative leads to:

$$\Delta FWHM = \sqrt{8\ln 2} \frac{1}{2} \left[\frac{\sum_{i=lc}^{i=hc} N_i}{\sum_{i=lc}^{i=hc} (i - I_s)^2 N_i} \right]^{1/2} \times \left[\frac{\left(\sum_{i=lc}^{i=hc} N_i \right) \left(\sum_{i=lc}^{i=hc} (i - I_s)^2 \Delta N_i \right) - \left(\sum_{i=lc}^{i=hc} (i - I_s)^2 N_i \right) \left(\sum_{i=lc}^{i=hc} \Delta N_i \right)}{\left(\sum_{i=lc}^{i=hc} N_i \right)^2} \right] \quad (B23)$$

After squaring and averaging what is left is:

$$\overline{\Delta FWHM^2} = \frac{8\ln 2}{4} \left[\frac{\sum_{i=lc}^{i=hc} N_i}{\sum_{i=lc}^{i=hc} (i - I)^2 N_i} \right] \times \left[\frac{\left(\sum_{i=lc}^{i=hc} N_i \right)^2 \left(\sum_{i=lc}^{i=hc} (i - I)^4 N_i \right) - \sum_{i=lc}^{i=hc} N_i \left(\sum_{i=lc}^{i=hc} (i - I)^2 N_i \right)^2}{\left(\sum_{i=lc}^{i=hc} N_i \right)^4} \right] \quad (B24)$$

Which becomes:

$$\sigma_{FWHM}^2 = \overline{(\Delta FWHM)^2} = \frac{8 \ln 2}{4 \sum_{i=lc}^{i=hc} N_i} \left[\frac{\sum_{i=lc}^{i=hc} (i - I)^4 N_i}{\sum_{i=lc}^{i=hc} (i - I)^2 N_i} - \frac{\sum_{i=lc}^{i=hc} (i - I)^2 N_i}{\sum_{i=lc}^{i=hc} N_i} \right] \quad (B25)$$

Using equation (B2) this reduces to:

$$\sigma_{FWHM}^2 = \frac{2 \ln 2}{\sum_{i=lc}^{i=hc} N_i} \left[\frac{\sum_{i=lc}^{i=hc} (i - I)^4 N_i}{\sum_{i=lc}^{i=hc} (i - I)^2 N_i} - Var \right] \quad (B26)$$

Which is the uncertainty in the FWHM.

Analysis Program

```

dimension icount(127)
do 100 i=1,127
  accept 50,icount(i)
  continue
c 100 do 150 j=1,127
c print 140,j,icount(j)
c 140 format(' ','channel=',17,'counts=',17)
c 150 continue
c This is the Alpha peak analysis.lo,hi ch in alpa peak.
  accept 50,ialc
  accept 50,iahc
  afwhm=0.
  asw=0.
  asc=0.
  apc=0.
  avar=0.
  call stat(icount,ialc,iahc,na,apc,asc,asw,avar,afwhm,apa)
c This is the low peak analysis.lo ch,hi ch in lo peak
  accept 50,ilic,ilhic
  bpc=0.
  bsc=0.
  bsw=0.
  bfwhm=0.
  bvar=0.
  call stat(icount,ilic,ilhic,nl,bpc,bsc,bsw,bvar,bfwhm,bpa)
c What is the electron equiv.,halfmax of the low peak?
  accept 52,e1e,u1e1e
  call eleq(e1e,u1e1e,c1e1e,cu1e1e)
c This is the high peak anaysis.What is lo,hi ch in hi peak
  accept 50,ihlc,ihhc
  hpc=0.
  hsc=0.
  hsw=0.
  hfwhm=0.
  hvar=0.
  call stat(icount,ihlc,ihhc,nh,hpc,hsc,hsw,hvar,hfwhm,hpa)
c print *, 'What is the electron equiv.,hafmax of the high peak?'
  accept 52,ehe,u1e1e
  accept 51,sample,dot
  call eleq(ehe,u1e1e,c1e1e,cu1e1e)
  accept 54,thick
  accept 51,book,page
  accept 53,date
  accept 51,volt,alayer
  accept 55,temp
  accept 53,press
  ctemp=-437.86*temp+251.805
  sktemp=ctemp+273.15
50 format(17)
51 format(f6.0)
52 format(f7.3)
53 format(f6.0)
54 format(f6.1)
55 format(f5.3)
c This is the place where the energy is figured.
  vsln=ehe-e1e
  sln=c1e1e-c1e1e
  sld=hpc-bpc
  vs1=vsln/sld
  sl=sln/sld

```

Analysis Program Continued

```

vyint=(hpc*ele-bpc*ehc)/sld
yint=(hpc*cele-bpc*che)/sld
vae=apc*vs1+vyint
ael=apc*s1+yint
aen=ael*3.62
ba=(bpc-apc)/sld
ah=(apc-hpc)/sld
sel=s1*sqrt(asc**2+(ba*hsc)**2+(ah*bsc)**2)
sen=sel*3.62
tsel=sqrt(sel**2+(ba*cuehc)**2+(ah*cuele)**2)
tsen=tsel*3.62
call elen(afwhm,s1,afwel,afwen)
stn=aen/afwen
call elen(asw,s1,aswel,aswen)
ustn=(aen/afwen)*sqrt((tsen/aen)**2+(aswen/afwen)**2)
call elen(avar,s1,avarel,avaren)
avfwhm=(bfwhm+hfwhm)/2
call elen(avfwhm,s1,avfwel,avfn)
avsw=(bsw+hsw)/2
call elen(avsw,s1,avswel,avsn)
avvar=(bvar+hvar)/2
call elen(avvar,s1,avvrel,avvren)
call elen(hfwhm,s1,hfwel,hfwen)
call elen(hsw,s1,hswel,hswen)
call elen(hvar,s1,hvarel,hvaren)
call elen(bfwhm,s1,bfwel,bfwen)
call elen(bsw,s1,bswel,bswen)
call elen(bvar,s1,bvarel,bvaren)
avv=ael*.0001602
avfwep=avfwel+avswel
avfwn=avfwel-avswel
avfwp=avfn+avsn
avfwm=avfn-avsn
This is the out put part.
print *, '*****'
print 171,sample,dot,thick
print 172,volt,alayer
print 173,date,book,page
print 174,ctemp,aktemp,press
print *, '*****'
print *, 'ALPHA PEAK'
print *, 'channel=',apc
print 170,ael,tsel,aen,tsen
print *, 'el+',ael+tsel,'-',ael-tsel,'en+',aen+tsen,'-',aen-tsen
print *, 'alpha volts equiv=',vae,'mvolts charge=',avv,'pC'
print *, 'signal to noise=',stn,'uncert stn=',ustn
print *, '*****'
print *, 'NOISE'
print *, '*****'
print *, 'ALPHA'
print *, 'fwhm=',afwhm,'fwel=',afwel,'fwen=',afwen
print *, 'sigma=',asw,'sigel=',aswel,'sigen=',aswen
print *, 'var=',avar,'varel=',avarel,'varen=',avaren
print *, '*****'
print *, 'AVERAGE CALIBRATION PEAK'
print *, 'avfwhm=',avfwhm,'avfwel=',avfwel,'avfwn=',avfn
print *, 'sigma=',avsw,'sigel=',avswel,'sigen=',avsn
print *, 'var=',avvar,'varel=',avvrel,'varen=',avvren
print *, 'el+',avfwep,'-',avfwn,'en+',avfwp,'-',avfwm
print *, '*****'

```

Analysis Program Continued

```

print *, 'HIGH CALIBRATION PEAK'
print *, 'channel=', hpc, 'el eq=', cehe, 'uncert. el eq=', cuehe
print *, 'fwhm=', hfwhm, 'fwel =', hfwel, 'fwen=', hfwen
print *, 'sigma=', hsw, 'sigel=', hswel, 'sigen=', hswen
print *, 'var=', hvar, 'varel=', hvarel, 'varen=', hvaren
hsqv=sqrt(hvar)
print *, 'sqv=', hsqv, 'sqv1=', sl*hsqv, 'sqvn=', 3.62*sl*hsqv
print *, '
print *, 'LOW CALIBRATION PEAK'
print *, 'channel=', bpc, 'el eq=', cele, 'uncert el eq=', cuele
print *, 'fwhm=', bfwhm, 'fwel =', bfwel, 'fwen=', bfwen
print *, 'sigma=', bsw, 'sigel=', bswel, 'sigen=', bswen
print *, 'var=', bvar, 'varel=', bvarel, 'varen=', bvaren
bsqv=sqrt(bvar)
print *, 'sqv=', bsqv, 'sqv1=', sl*bsqv, 'sqvn=', 3.62*sl*bsqv
print *, '*****
print 176, sl, yint
print 177, apa, (hpa+bpa)/2, hpa, bpa
177 format(' * peak area a=', f7.0, ' av=', f7.1, ' hi=', f7.0, ' lo=', f7.0)
print 702, ialc, iahc, ilhc, ilhc, ele, ihlc, ihhc, ehe
702 format(' * LO+HI', 4(i4), f6.2, 2(i4), f6.2)
170 format(' * ael=', f9.4, ' sigel=', f9.6, ' aen=', f9.4, ' sigen=', f9.6)
171 format(' * sample=', f3.0, ' dot=', f5.0, ' thick=', f6.1, ' microns')
172 format(' * voltage= ', f5.0, ' #cf layers=', f3.0)
173 format(' * date=', f7.0, ' book=', f3.0, ' page=', f4.0)
174 format(' * temp=', f7.2, ' C (K ', f7.2, ') press=', f6.0, ' mtorr')
176 format(' * slope=', f7.3, ' yint=', f10.3)
print *, '
do 701 n=1, 128, 8
print 700, n, icount(n), icount(n+1), icount(n+2),
1 icount(n+3), icount(n+4), icount(n+5), icount(n+6)
2 , icount(n+7)
700 format(' ch=', i4, ' |-', 8(i6), ' -|')
701 continue
c write(20, 161)
c 161 format(' page volt # thick aen uen afwen awsen
c ave n avns stn ustn ')
c write(20, 160) page, volt, alayer, thick, aen, tsen, afwen, aswen
c , avn, avsn, stn, ustn
c 160 format(' ', f4.0, 1x, f4.0, 1x, f4.0, 1x, f5.1, f7.2, f6.2, 6(1x, f6.2))
stop
end
c This is the stat subroutine.
subroutine stat(icount, ilc, ihc, n, pc, sc, sw, var, fwhm, scd)
dimension icount(128)
scn=0.
scd=0.
do 210 is=ilc, ihc
scn=scn+icount(is)*is
scd=scd+icount(is)
210 continue
pc=scn/scd
wd=0
cd=0
do 220 js=ilc, ihc
wd=wd+((js-pc)**2)*icount(js)
cd=cd+((js**2-pc**2)*icount(js)
fortmo=fortmo+((js-pc)**4)*icount(js)
220 continue
var=wd/scd

```

Analysis Program Continued

```

sw=sqrt((1.386294361/scd)*((fortmo/wd)-var))
sc=sqrt(cd)/scd
fwhm=2.35482*sqrt(var)
return
end
c  this is electron and energy subroutine
  subroutine elen(st,s1,el,en)
    el=s1*st
    en=el*3.62
    return
  end
c  This is where I calculate el. equivalent and uncertainty.
  subroutine eleq(ev,uv,el,ucl)
    e1=15.605493*ev
    ucl=15.605493*uv
    return
  end

```

PHA Spectrum

Analysis Printout

```

*****
* sample=13. dot= 5. thick= 2.0microns
* voltage= - 90. #of layers= 0.
* date= 12485. book= 2. page=187.
* temp= 22.37C (K 295.52) press= 2.mtorr
*****
* ALPHA PEAK
* channel= 65.58868
* ael= 18.3185 sigel= 0.552685 aen= 66.3129 sigen= 2.000721
* el+ 18.87116 - 17.76579 en+ 68.31361 - 64.31216
* alpha volts equiv.= 1.173848 mvolts charge= 2.9346198E-03pC
* signal to noise= 5.894708 uncert stn= 0.1869696
*****
* NOISE
*
*
* ALPHA
* fwhm= 11.05005 fwl= 3.107614 fwen= 11.24956
* sigma= 0.1081327 sigel= 3.0410228E-02 sigen= 0.1100850
* var= 22.01978 varel= 6.192639 varen= 22.41735
*
* AVERAGE CALIBRATION PEAK
* avfwhm= 10.05568 avfwl= 2.827965 avfwen= 10.23723
* sigma= 0.1630018 sigel= 4.5841105E-02 sigen= 0.1659448
* var= 18.27076 varel= 5.138299 varen= 18.60064
* el+ 2.873806 - 2.782124 en+ 0.1659448 - -0.1659448
*
* HIGH CALIBRATION PEAK
* channel= 100.3338 el eq= 28.08989 uncert. el eq= 0.7802746
* fwhm= 9.610706 fwl= 2.702826 fwen= 9.784230
* sigma= 0.1854274 sigel= 5.2147899E-02 sigen= 0.1887754
* var= 16.65694 varel= 4.684443 varen= 16.95768
* sqv= 4.081291 sqvl= 1.147785 sqvn= 4.154980
*
* LOW CALIBRATION PEAK
* channel= 33.74586 el eq= 9.363296 uncert. el eq= 0.7802746
* fwhm= 10.50064 fwl= 2.953104 fwen= 10.69024
* sigma= 0.1405761 sigel= 3.9534315E-02 sigen= 0.1431142
* var= 19.88458 varel= 5.592156 varen= 20.74360
* sqv= 4.459213 sqvl= 1.254068 sqvn= 4.539726
*****
* slope= 0.281 yint= -0.127
* peak area a= 4911. av= 6410.0 hi= 6485. lo= 6335.
* LO-HI 53 79 22 46 0.60 88 113 1.80

```

ch#	1	0	0	0	0	0	0	0
ch#	9	0	0	0	0	0	0	0
ch#	17	0	19	137	57	27	20	33
ch#	25	76	121	164	258	337	439	497
ch#	33	551	568	543	416	412	320	204
ch#	41	177	106	81	64	31	21	13
ch#	49	15	16	21	17	17	28	40
ch#	57	87	106	158	188	238	281	358
ch#	65	452	395	424	396	303	252	223
ch#	73	128	84	46	42	22	17	10
ch#	81	4	1	2	0	3	0	4
ch#	89	17	35	44	75	129	167	290
ch#	97	460	536	575	627	620	617	484
ch#	105	318	235	156	93	79	44	20
ch#	113	7	5	2	0	0	0	0
ch#	121	0	0	0	0	0	0	0

APPENDIX C

Tables of Sample Characteristics

Table C.1. First Group of Samples						
Sample Number	Thickness (microns)	Substrate Material	Contact Pattern	Doping Sequence	Voltage Applied	Detected Alpha's
1	7.5	Glass	2(3mm) Circles	None	0-40	Yes
2	1	Glass	2(3mm) Circles	None	0-20	No
3	15	Aluminium	2(3mm) & 3(1.5mm) Circles	None	40-160	Yes
4	6	Glass	2(3mm) Circles	n ⁺	0-30	No
5	8.2	Aluminium	4(3mm) & 2(1.5mm) Circles	None	0-30	Yes
6	5	Glass	2(3mm) Circle	p ⁺	0-30	Yes
7	5	Glass	2(3mm) Circles	p ⁺	0-20	No

Table C.2. Second Group of Samples						
Sample Number	Thickness (microns)	Substrate Material	Contact Pattern	Doping Sequence	Voltage Applied	Detected Alpha's
8	5	Glass	6(3mm) Circles	p-i-n	5-35	Yes
9	10	Glass	Lines 1mm Wide	None	10-80	Yes
10	10	Glass	Lines 1mm Wide	None	10-80	Yes
11	10	Glass	Lines 1mm Wide	None	10-80	Yes

Table C.3. Third Group of Samples

Sample Number	Thickness (microns)	Substrate Material	Contact Pattern	Doping Sequence	Voltage Applied	Detected Alpha's
12	2	Glass	Lines 1mm Wide	p-i-n	10-100	Yes
13	2	Glass	Lines 1mm Wide	p-i-n	10-100	Yes
14	2	Glass	Lines 1mm Wide	p-i-n	10-100	Yes
15	2	Glass	Lines 1mm Wide	p-i-n	10-100	Yes
16	5	Glass	Lines 1mm Wide	p-i-n	10-100	Yes
17	5	Glass	Lines 1mm Wide	p-i-n	10-100	Yes
18	5	Glass	Lines 1mm Wide	p-i-n	10-100	Yes
19	5	Glass	Lines 1mm Wide	p-i-n	10-100	Yes
21	5-5	Glass	Lines 1mm Wide	p-i-n on n-i-p	10-100	Yes
22	5-5	Glass	Lines 1mm Wide	p-i-n on n-i-p	10-100	Yes

REFERENCES

- [1] R. A. Street, "Luminescence and Recombination in Hydrogenated Amorphous Silicon", *Advances in Physics*, **30.5** (1981) p.593.
- [2] R. A. Street, J. C. Knight and D. K. Biegelsen, *Phys. Rev. B* **18**, 1880 (1978).
- [3] R. J. Nemanich, M. J. Thompson, to be published in "Metal Semiconductor Schottky Barrier Junctions", Ed. B. L. Sharma, Plenum Press, New York, Chapter 8.
- [4] R. A. Street, Xerox Palo Alto Research Center, Private communication.
- [5] R.A. Street, *Phys. Rev. B*, **27**, 4924 (1983).
- [6] A.M.Johnson, A.M.Glass,et. al., *Appl Phys Lett.* **44** (4) 450 (1984).
- [7] H. Fritzsche, "Fundamental Physics of Amorphous Semiconductors", Ed. F. Yonezawa, Springer-Verlag Berlin Herdelberg (1981) p.4.
- [8] Crandall, R.S., *J. De Phys.*, **C4-10** 42, 412 (1981).
- [9] Ray E. Boltz, George L. Tuve, "CRC Handbook of tables for Applied Engineering Science", 2nd Ed., CRC Press Inc., Boca Raton, Florida (1976) p.1012.
- [10] Glenn F. Knoll, "Radiation Detection and Measurement", John Wiley & Sons Inc., New York (1979) p.47.
- [11] G. Bertolini and A. Coche.Eds. "Semiconductor Detectors",Elsevier-North Holland, Amsterdam (1968).
- [12] R. N. Chandra and R. A. Deal, "Catalogue of Semi-Conductor Alpha-Particle Spectra", IN-1261 (1970).
- [13] D. Adler, "Semiconductor and Semi Metals", vol. 21, Academic Press, Inc., New York (1984) p.314.

- [14] W. Rehm, R. Fisher and J. Beichler, Appl. Phy. Lett. 35 (5), 445 (1980).
- [15] D. G. Ast, M. H. Brodsky, Phil. Mag. B 41 3, 273 (1980).
- [16] Y. Hawakawa, H. Okamoto and Y. Nitta, Appl. Phy. Lett., 35 187 (1979).
- [17] G. Friedlander, et al., "Nuclear and Radiochemistry", 3rd Ed., John Wiley and Sons, New York (1981).
- [18] P. Marmier, E. Sheldon, "Physics of Nuclei and Particles, Vol 1", Academic Press, Inc., New York (1969) p.159.

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.

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.