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Testing of the Silicon Modules for the Run IIb Silicon Detector

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Abstract

A standardized procedure for testing the silicon modules is outlined. This will allocate the collection and comparison of data between the differing research groups working on these sensors and modules. A documentation of the results obtained by the Fermilab group will be included also.

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1. Introduction

With the influx of sensors from Hamamatsu Photonics for D∅ Run IIB, it has become ever increasingly important to outline a procedure for testing the sensors and modules to assist in creating an environment that encourages uniformity of data. These sensors are an integral part in the attempt to upgrade the D∅ detector to a higher luminosity, which cannot be accomplished without quality sensors. For more information about the D∅ Run IIb upgrade, the Technical Design Report should be consulted. By having a standard procedure, the comparison of data between the differing research groups will be easier as all involved will have a common base from which to work. Also, it will become easier to confirm the introduction of defects at various stages in the assembly process. This will make the revision of the building procedure easier and more affective. An outline of the testing station, module, and sensor layout will be developed, and a procedure for testing for defects, depletion voltage, chip integrity and for visual inspection and proper care of the modules and sensors will be discussed. At the end of the note, a documentation of the results obtained by the Fermilab group will be included as well.

2. Testing Station

The test station should consist of a few basic but essential items. The probe station should contain a clean, level stage on which to place the modules, a metal stave containing the mounted sensors and hybrid chips. This stage should be located next to the purple card [1], the intermediary between the module and SASeq (stand alone sequencer). A digital jumper cable is used to connect the module to the purple card, and a 50-conductor cable to connect the purple card to the SASeq. All this should be contained within a dark box that can be opened and closed manually. The cart should contain many important pieces of equipment, one of which being the 5V power supply for the hybrid and purple card. An infrared laser should also be included. The laser should have a 1060 nm beam in order to obtain the correct attenuation depth of 600±100 μm at 298°K [2] within the silicon sensor for optimization of results. This attenuation value corresponds to a silicon light absorption relationship seen in Figure 2.1[3] The HV (high voltage) supply and SASeq can be placed on the VME crate. A Bit 3 card is then used to read out the VME crate. A Windows 2000 or NT computer with an Excel spreadsheet in Visual Basic can be used to communicate with the Bit3 card. It is necessary to provide proper grounding for the module. This can be achieved by grounding the hybrid to the metal box, and the metal box to the stage or purple card in order to minimize the common mode noise. A microscope will also be necessary for the visual inspection. See figures 2.2 – 2.5 for an example of a proper test station setup.

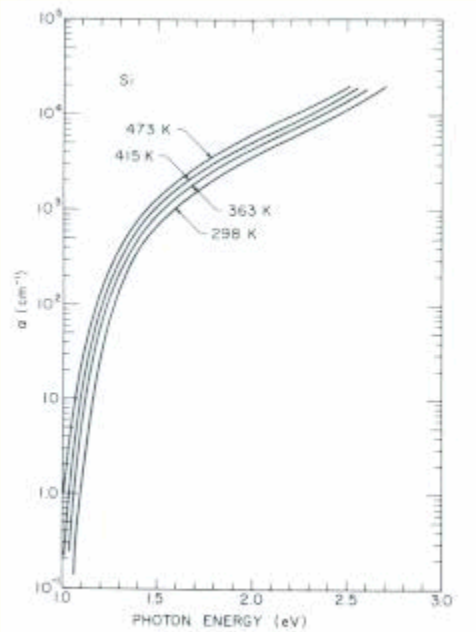

Fig. 2.1. Attenuation depth of silicon at varying temperatures and energies [3]

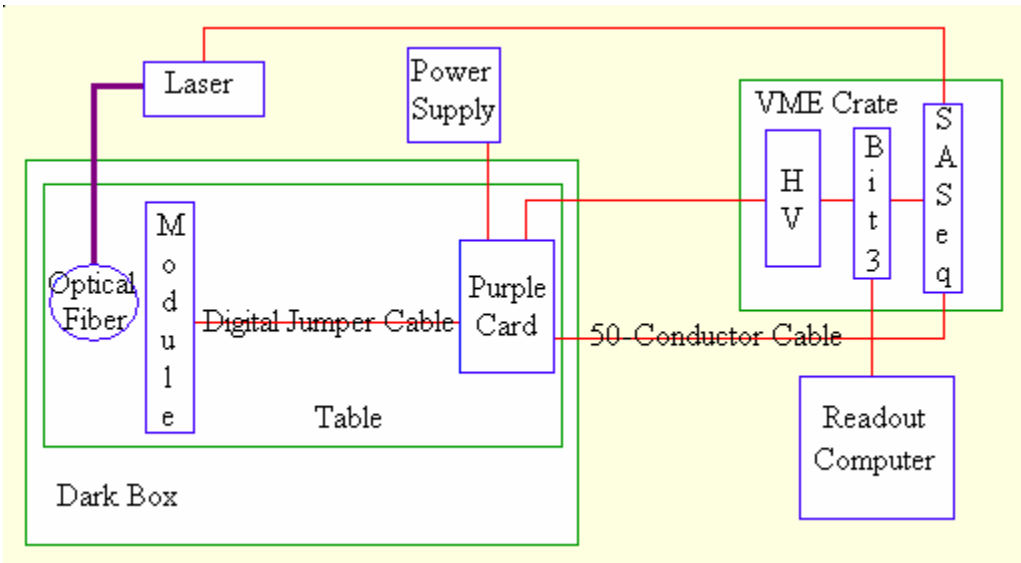

Fig. 2.2. General test stand schematic

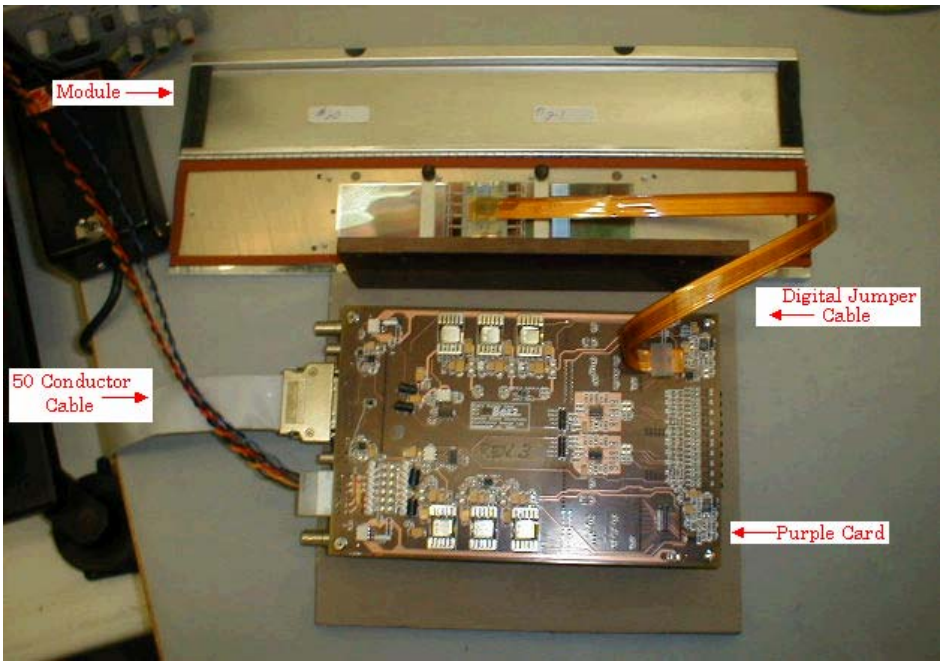

Fig. 2.3. Module to Purple Card setup

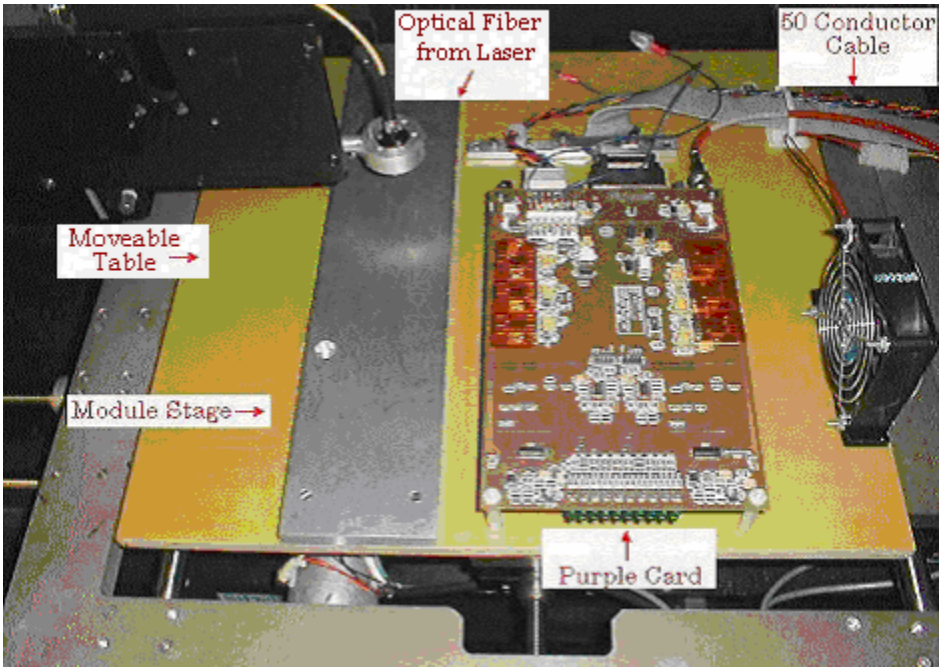

Fig. 2.4. Inside the dark box

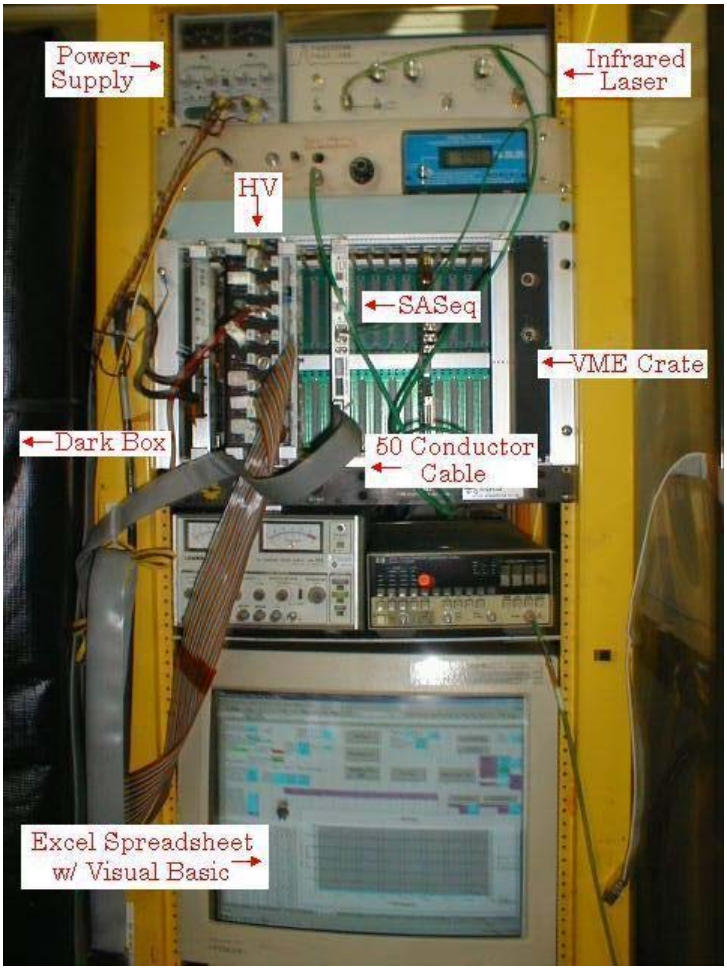

Fig. 2.5. The crate

3. Sensor and Module Layout

A full knowledge of the sensor and module layout will be necessary, especially when it comes time to do the visual inspection. There are four types of module layouts to be used in layers 2-5, a 20x20 axial, 20x20 stereo, 10x10 axial, and a 10x10 stereo. The diagrams below show the correct numbering scheme for chips and channels on each of these modules. When documenting the results of tests, a consistent numbering system will facilitate the sharing and analyzing of results. When referring to chips, the correct numbering scheme is the same as pictured in figures 3.1 – 3.4. The numbering of each channel on the chips is also shown in these figures. Sensors should be referred to by the serial numbers found on the front end of the sensor along the side closest to channel number 0. See figures 3.1 and 3.4 for clarification. The placement of the serial number on the sensors is the same for both the axial and stereo versions of each module. It is necessary to convert the serial number etched into the sensor from a hexadecimal format to that of the universal base ten. When referring to channels, two different systems of numbering can be used, the number of the channel on each chip or on the sensor. When using the chip system of numbering, it is necessary not only to state the channel number, but the chip number and hybrid

number as well. This will aid in the avoidance of any confusion. An example of this numbering system would be: Hybrid #108, chip 3, channel 62. When using the sensor system of numbering, it is necessary to list both the channel and sensor number. An example of this numbering system would be: Sensor #58, channel 31. Within a single document or list, one system or the other should be used consistently as to avoid any confusion. Familiarization with the module and sensor layout as well as the naming system is an important part in the effort to facilitate data sharing between research groups.

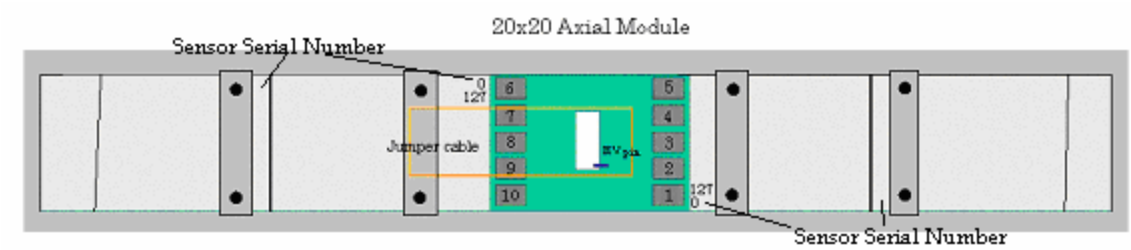

Fig. 3.1. 20x20 Axial Module

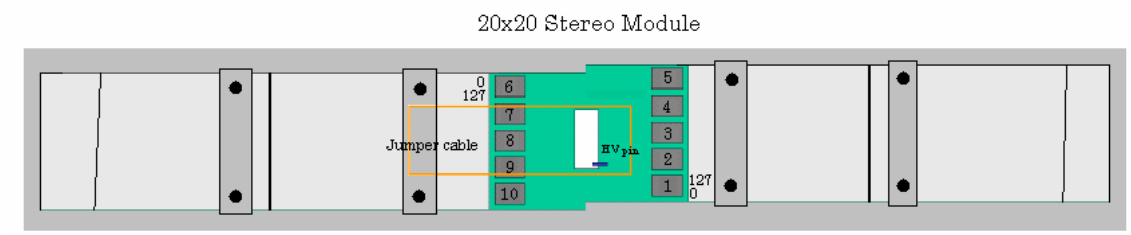

Fig. 3.2. 20x20 Stereo Module

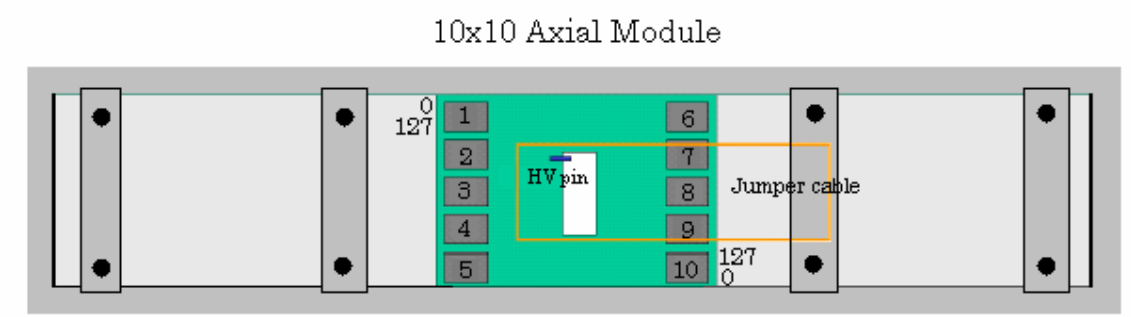

Fig. 3.3. 10x10 Axial Module

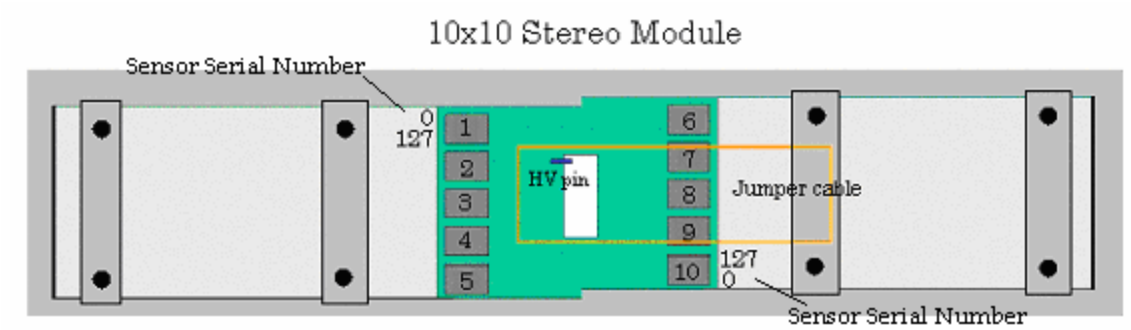

Fig. 3.4. 10x10 Stereo Module

4. Identifying Pinholes and Other Defects

Throughout the building process it is important to test each module for pinholes and other defects. By understanding when the defects are being introduced, the production procedure can be optimally modified and defects minimized.

It is first necessary to understand the different types of defects and their manifestations in the data results. A pinhole can be categorized as a metal-implantation short circuit [4]. When looking for pinholes using the recommended Excel based program, SVX4_MS_2.xx.xls, a pinhole will be manifested in a region of abnormal noise, as the current leaks out into the surrounding SVX4 channels from the pinhole and affects the neighboring channels. When the channel in the affected region containing the pinhole is masked, the preamplifier of that channel is continuously reset, causing the ADC count to read out at the pedestal level whatever the input charge may be. The noise of the disabled channel is also small for the same reason [6]. This should allow the other channels to return to a normal level of noise, as there would be no excess signal to leak into the surrounding SVX4 channels. Other common defects include connected channels or severed bonds. Connected channels happen when two channels are electrically connected, usually by a piece of metal lying across neighboring strips. It was found that connected channels usually exhibit one channel with higher than normal noise and one channel with lower noise. When a break occurs in a bond, the channel can display a lower level of noise, as there is no additional capacitance at the input of the preamplifier. Other defects may be responsible for abnormalities observed in the signal; however, these are the most common. See figure 4.1. A thorough investigation is necessary to isolate the cause of any problem within the module, and assumptions should not be made [5].

In order to do the pinhole test correctly, one must have a laboratory setup as mentioned in section two. The module should be moved from the dry box to the probe station with care, making sure to hold the module horizontally flat. It is not necessary to open the stave for this particular test and thusly the dark box can remain open. The digital jumper cable is then plugged into the purple card. The Excel program works exceedingly well for this test. It is necessary to set the program to "calinject" mode. The program should also be set to mask mode. For a basic tutorial on the program, see the Appendix. A more in depth overview of the program can be found in "Basic Instructions for SVX4 MS 2.4.dma.xls" by Gustavo Otero y Garzon located on "projects on D∅server6" in the "Spreadsheets" folder under the file name "Instructions for SVX4_MS_2.7." This file may be updated from time to time, so the file name is subject to change, though probably very slight [7]. A bias voltage of 70V is preferable for this test. A survey of several bias voltage steps; such as 0, 5, 10, 30, 50, and 70; may be of interest. The data should then be collected using the "M_S_ave" page. A data plot for all chips should appear. It is advisable to save this plot as well as the data points, in a separate Excel sheet, for future reference. Areas with bad channels should be given a closer look. This can be done by plotting the chip containing the bad channel or changing the range of the x-axis. Channels with pinholes can then be isolated by masking one channel at a time in a problem area until

the bad channel is determined. It is advisable to start with the middle channel in an area and work outward. The numbers of the bad channels should be recorded and plots of the areas before and after masking should be saved. The bad channels should then be located on the sensor by a visual inspection. If possible, a picture should be taken. An example of a typical result is given in figure 4.2. See figure 4.3.a and 4.3.b for an example of a pinhole found during testing before and after masking, respectively.

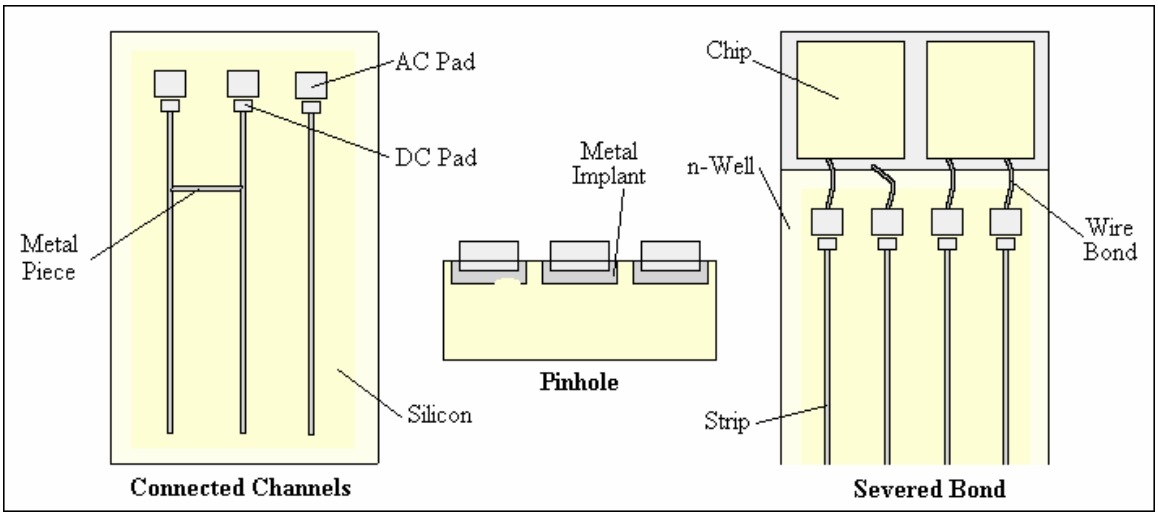

Fig. 4.1. Examples of the three major defects

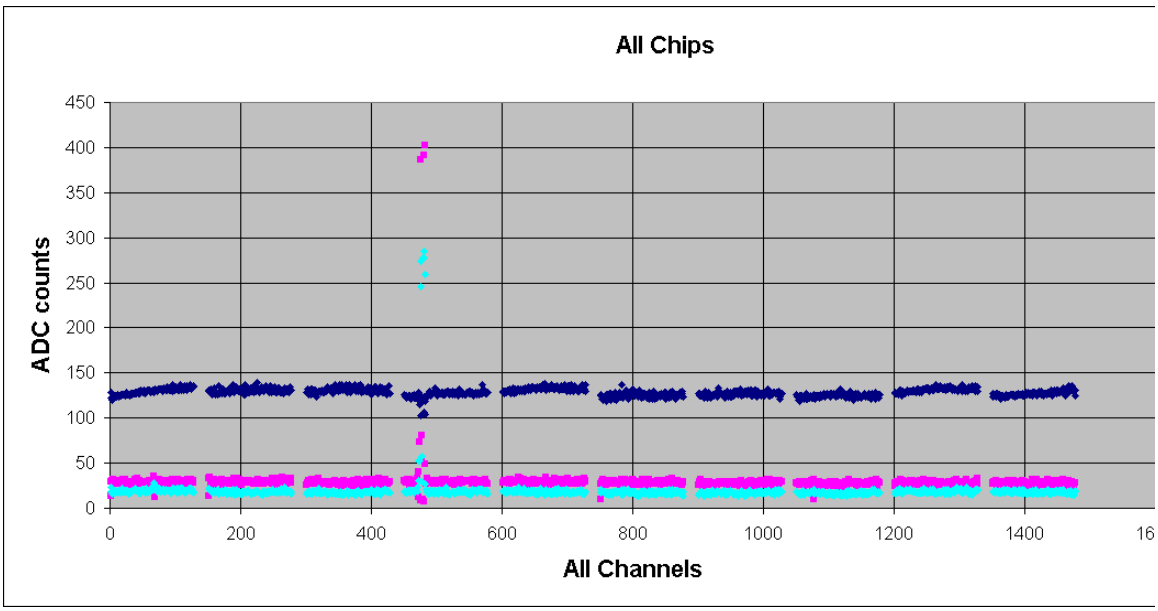

Fig. 4.2. A typical Pinhole test result

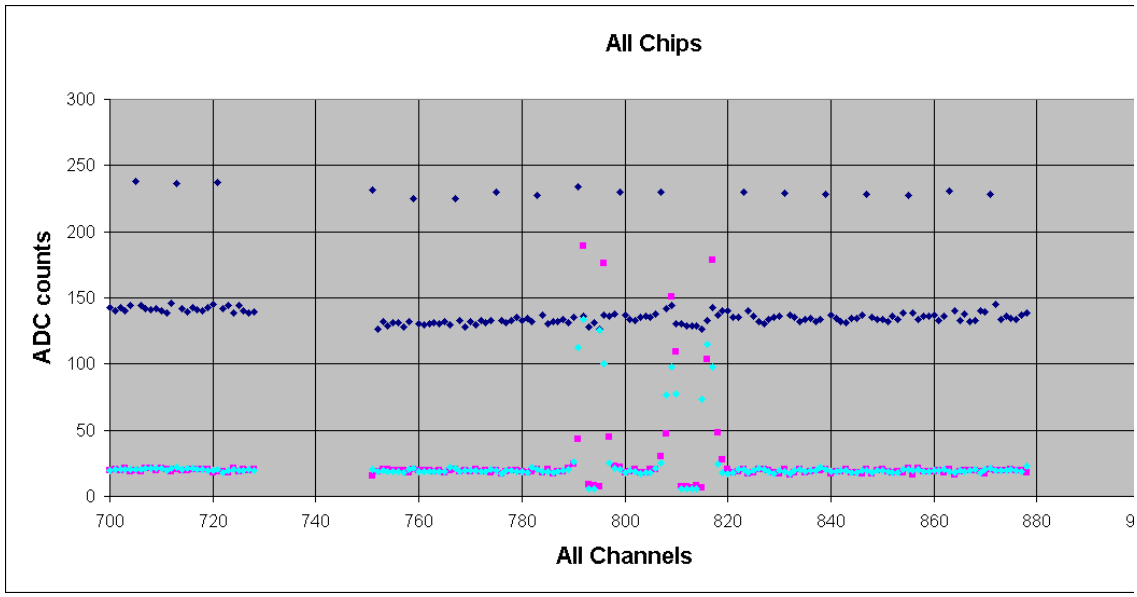

Fig. 4.3.a. Two pinholes before masking

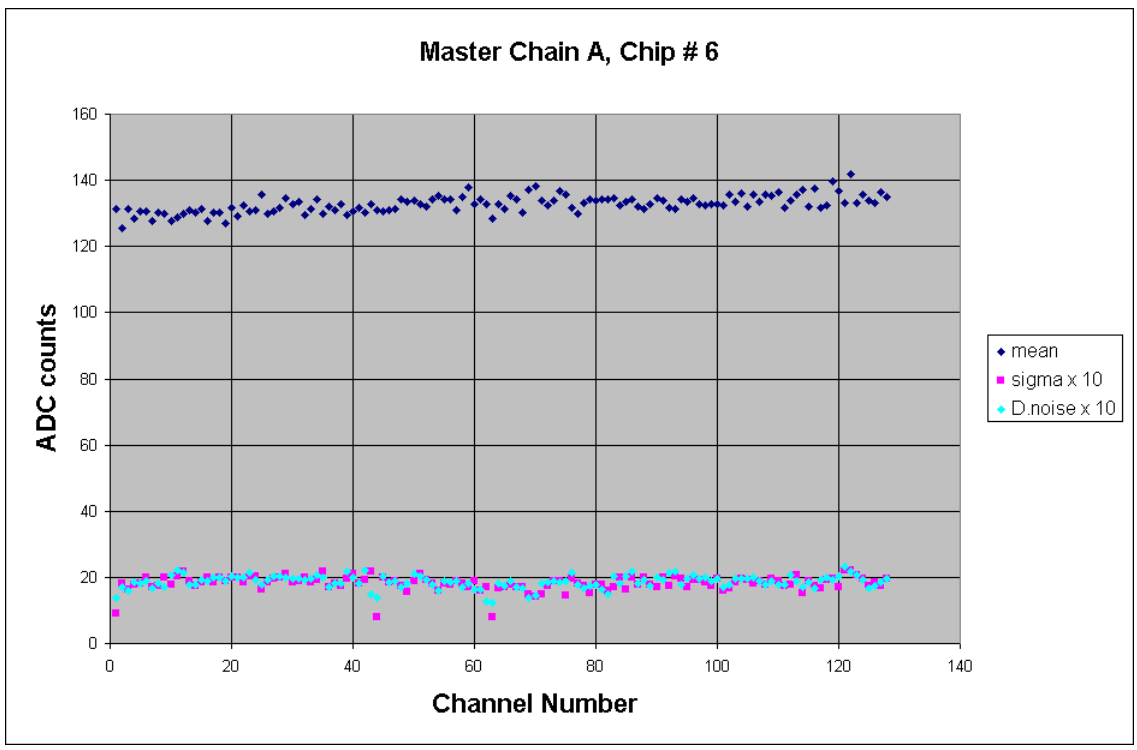

Fig. 4.3.b. The same two pinholes as in fig. 4.2.a. after masking

5. Depletion Voltage

When running the sensors in the detector, it is important for each sensor to operate at full depletion voltage. By running the depletion voltage test, the optimal value of the depletion voltage for the silicon sensor can be determined. A low value is preferable. The depletion voltage is highly dependent upon the leakage current, so a good ground

is necessary when running this test. In order to perform the depletion voltage test, the stave must be placed onto the probe station with its lid open. The laser should then be positioned over the sensor. Once the laser is positioned, the dark chamber must be closed in order to keep outside noise from affecting the data collection. The chamber should not be closed until this point, however, as it is possible to harm the module or table with large, unwatched movements of the laser. If some fine tuning is required or small movements are taken, it is acceptable to do so while the dark chamber is closed as long as the position and the subsequent direction of the laser is known with confidence. This requires a certain familiarity with the apparatus and should not be attempted by those with little experience. A bias voltage of 50V is recommended for this test as this is usually above the depletion voltage level and makes the laser curve easier to observe; however, the high voltage should not be run until the dark chamber is closed. Some areas of interest to check for depletion voltage might be sections with bad channels or several areas over the sensor in order to see how natural incongruities in the thickness and bowing of the sensor affect the depletion voltage. When doing a survey of several areas over the sensor for comparison, the data points themselves should be saved in a separate Excel file in order to allocate the comparison of data by graphs or other means. If just the plot of the data points is saved, the data points cannot be accessed later, making a comparison of several areas more difficult.

Once the stave and the laser are in position, data collection can begin. A few modifications to the program settings may be necessary in order to run this test correctly. It is necessary to set the program to "Data Mode" on the "M_S_ave" page. Also, the "Calpipe" and "Pipeline" on the "SASeq_Master" and "Init_SVX4_Master" page respectively should be set to the optimal value for the specific SASeq firmware version and associated laser readout delay. Currently, the pipeline and Calpipe value of 4 is being used. The Excel spreadsheet will not record a laser curve for any "Calpipe" and "Pipeline" value other than the optimal setting for the specific readout conditions. The "Init_SVX4_Master" page is used to turn the "RTPS" on, which is necessary for this test. The value for the "RTPS" should read zero. A picture of the laser curve on the "M_S_ave" page should be saved before the depletion voltage test is run. The laser curve should be optimized before a picture is saved. The laser curve should be narrow, with a range between 10 – 30 strips and a peak between 200 – 230 ADC counts for the maximum applied bias voltage and contain little elevated noise within the curve. The commands for the depletion voltage test can be found on the "hvSlot7" page. Before the test is run, the parameters should be checked and set. The "Step" should be set to five and the "Vend" range to 100. "Vstart" should be set to zero, and the "iLoop" should read a value of 500. In the "Begin" and "End" box, the range of the laser curve should be entered. The desired value of the channel corresponds to the channel number on the sensor. In order to convert the channel number of the channel on the chip to that of the sensor, the following formula should be used:

$$128 \times (\#\text{ of chip} - 1) + \text{channel number}$$

If, for example, the depletion voltage curve were being taken for the laser with the range of channels 12 – 32 on chip 8, it would correspond to channels 908 – 928. The range of the laser should be small and fined tuned until the range and the peak of the curve has been completely minimized. Once the parameters are set and the dark

chamber is closed, data can be collected. Follow the prompts during the test to turn off and on the laser. Make sure to follow all the directions as once the test has begun, it cannot be stopped and must run its course. The data plot must be saved before running another test. It is necessary to ramp the bias voltage again, if required, after the test is over. To thoroughly execute a study of how pinholes affect the depletion voltage, measurements before and after masking should be taken. To examine how the natural variation of the silicon affects the depletion voltage, it would be advisable to take a depletion voltage reading of each of the corners and the center (if not the cable side) of the sensor. An average for the sensor should be taken in order to determine the overall depletion voltage. An example of a depletion voltage curve for several areas of one chip can be seen in figure 5.1.

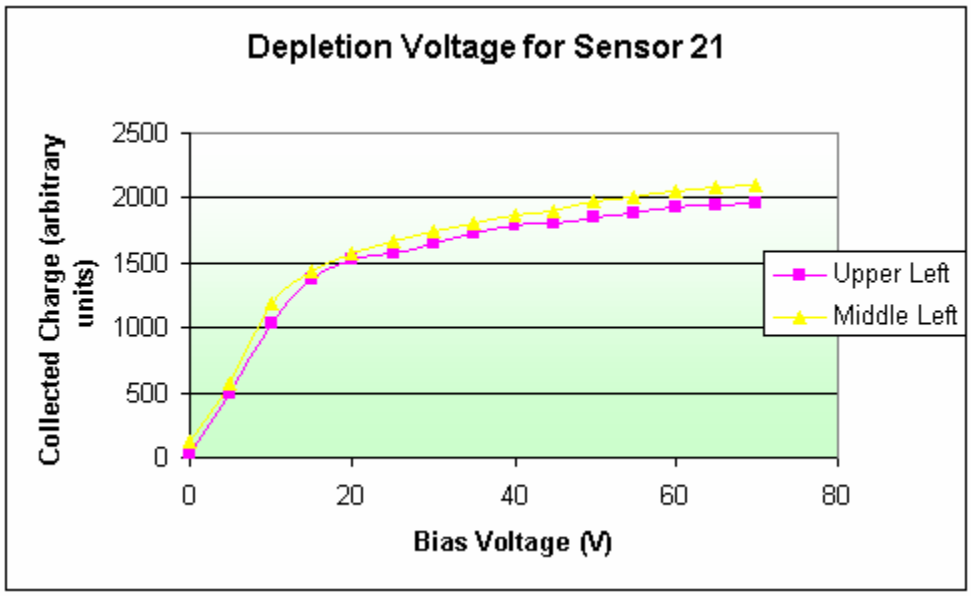

Fig. 5.1. A typical Depletion Voltage curve

6. *Chip Integrity*

To test for a chip malfunction, the pinhole test can be utilized. If an area of bad channels cannot be masked, it may be an indication of a chip malfunction. A plot of this region should be saved, and other modules of the same type should be tested for similar malfunctions. It may be of interest to see how the chip performs at the differing bias voltages mentioned in the pinhole test and to perform a cal injection. In order to do a cal injection, the program should be set to a value of zero in the "Cal Mask" line on the "Init_SVX4_Master" page. All data plots should be recorded. The problem should then be isolated [8]. After the data has been collected, a visual survey of the chip as well as the wire bonds and channels of the attached sensor is needed.

7. *Visual Inspection*

Various tests can give a good indication of the amount and kind of damage to a chip or sensor; however, a visual inspection leads to direct and conclusive evidence of a problem area located on a module. Once problem channels have been isolated, a visual inspection of the affected area and sensor is recommended. In order to do a thorough inspection, the bad channel, its neighboring channels, the wire bonds, and that area of the chip should be investigated. An overview can be done using a lower magnification in order to reduce the area of inspection, but a complete survey of the area should be done at a significantly higher magnification. The wire bond on the chip and the sensor side should be checked first. Then a survey the length of the channel should be executed. It is necessary to move along the channel slowly in order to ensure that nothing is missed and that the correct channel is not lost. If nothing is found, then the neighboring channels should be surveyed along their length as well. The chip to which the channel is bonded should be surveyed for defects as well. The most common defects are pinholes, a short in the metal-implantation; connected channels, most commonly a metal strip lying across two channels; or a broken bond. If a pinhole is the cause of the bad chip, a region of affected channels should have been detected in earlier testing. Connected channels are usually associated with low level of noise in one channel and a high level of noise in another, and if the wire bond is completely severed, no noise should have been detected at all.

8. Proper Care and Storage

Each module contains highly sensitive electronics and parts, so proper care and storage is essential to ensure minimal damage to the module. After the digital jumper cable has been connected to the hybrid, the stave that contains the module should not be opened. If it is necessary to open the stave, as such is the case for the depletion voltage test, it should be done in a clean room environment. Damage can be irreversible and cause a reduction in the productivity of the module. Water or other liquid damage may not cause any immediate effect; however, corrosion will begin to act upon the outer, protective coating of the sensor. Once the corrosion reaches the actual silicon detector, it will upset the specific doping ratios and lattice structure of the silicon. See figure 8.1. The modules should be stored in a dry box when not in use to reduce the exposure to potentially harmful humidity. Care should be taken in the handling of these modules. The sensors and hybrids should never be touched. Proper attention should be given whenever a cable is being plugged in or taken out, and the modules should be held horizontally flat whenever moved from one place to another. Before laying a module on a countertop or in the probe station, the contact surface should be determined to be clean. If common sense and care are used when handling the module, most accidents can be avoided. See figure 8.2 for an example of a proper storage area.

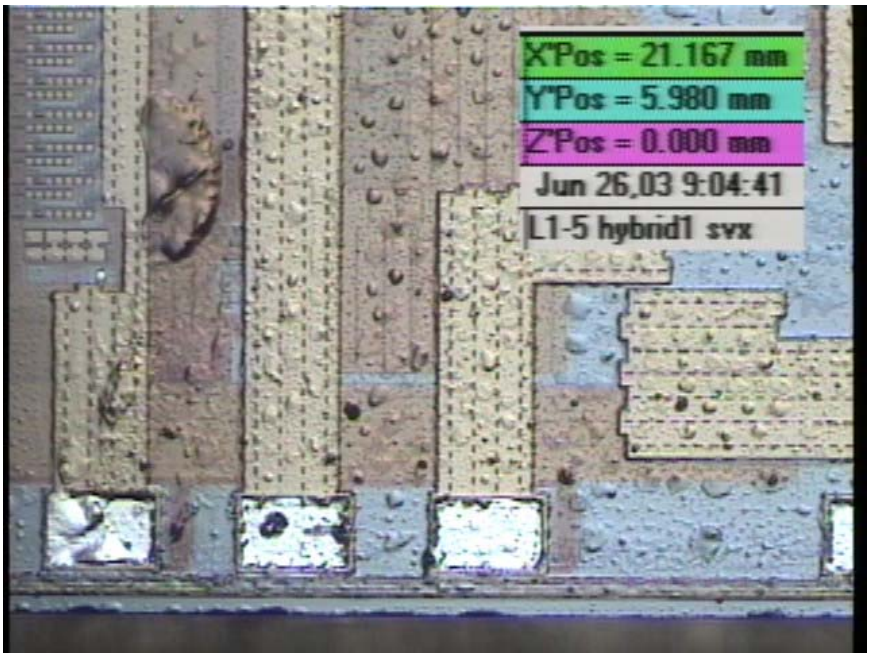

Fig. 8.1. Water damage on a SVX chip

Fig. 8.2. A proper storage area for modules and sensors

Appendix

Excel Spreadsheet with Visual Basic Tutorial

In order to run tests on the silicon sensors to check for defects, a basic understanding of how the Excel spreadsheet with Visual Basic is necessary. In order to activate the program, a module must first be connected to the purple card with a digital jumper cable. All power supplies and the crate should then be turned on. To start the program, open the "M_S_ave" page and enter the correct value for the chain that is being used in the "IGNORE Master=" parameter. Chain A is "21" and Chain B is "12." Both chains correspond to a value of "3," and when turning the program off, the value should read "0." "Init Bit 3," "Init Sequencers," and "Download SVX Chips" should then be pressed in that order. It may be necessary to press "Download SVX Chips" more then once if an error message is read in "Chip download=." When the chips are downloaded correctly, it should read "Init OK." To turn the program off, enter "0" in the "IGNORE Master=" parameter and hit "Init Bit 3" and "Init Sequencers." The program can be set to "cal inject" mode on the "M_S_ave" screen. To activate "cal inject" mode, the "callnject=" parameter should equal "True." To run the program in "data" mode, the "callnject=" parameter should read "False." The program can also be set to mask the channels. This can be achieved by typing a value of one in the "Cal Mask" line on the "Init_SVX4_Master" page. To apply a bias voltage, turn on the high voltage from the "hvSlot7" page. Each command must be executed in order, first "Init Bit3," then "Update Status," next "Reset," then "Set I_trip Start Chan," then a trip setting of 2000 μA should be entered, and finally hit "On." This initiates the high voltage board, and a bias voltage can then be applied by entering the desired voltage in the "volts" parameter and pressing "V Ramp Start Chan." Make sure that the correct channel on the high voltage has been selected for the "start chan=" and "end chan=" parameters. To change the bias voltage, type in the new value in the "volts" parameter and press "V Ramp Start Chan." Data can be collected using the "M_S_ave" page by pressing "Get Data." A data plot for all chips should appear. To save the plot, press "Export Active Plot." To save the data points, the desired points must be selected and then copied into another spreadsheet. A problem area can be zoomed in on in two ways. The chip containing the bad channel can be plotted by setting the "Chip=" parameter on the "M_S_ave" screen to the desired chip and pressing "Plot Favorite Chip" or the range of the x-axis by right clicking on the x-axis and then resetting the values. To change the "pipeline" value, first go to the "Init_SVX4_Master" page and then type in the desired value in the "Pipeline (6)" parameter. To change the "Calpipe" value, type in the new value in the teal portion of the "CALPIPE" parameter found on the "SASeq_Master" page. In order to activate the "real time pedestal subtraction" mode, the 1 value should be change to 0 for the "0=RTPS_on(1)" parameter on the "Init_SVX4_Master" page. In order for any change in the program to be effective, "Init Sequencers" and then "Download SVX Chips" must be pressed, in that order, on the "M_S_ave" page. This covers most of the basic operations needed to effectively utilize the spreadsheet. For further instructions, see "Basic Instructions for SVX4 MS 2.4.dma.xls" by Gustavo Otero y Garzon.

References

[1] D∅ Note 4089, *D0 Run IIb Test Card, also known as "Purple Card,"* T. Sobering and R. Sidwell

[2] F. Lehner, Institut fuer Physik Universitaet Zuerich, private communication

[3] *Temperature Dependence of the Optical Properties of Silicon*, H.A. Weakliem and D. Redfield, Journal of Applied Physics 50, 1979, p.p. 1491 - 1493

[4] CMS Tracker Technical Design Report, Chapter 3.4: The Silicon Detectors, p.99

[5] Pending D∅ Note, *HDI Troubleshooting Guide*, Linda Bagby

[6] K. Hanagaki, Fermilab National Accelerator Laboratory, private communication

[7] Pending D∅ Note, *Basic Instructions for SVX4 MS 2.4.dma.xls*, Gustavo Otero y Garzon

[8] Pending D∅ Note, *SVX Troubleshooting Hints*, Linda Bagby

[9] Pending D∅ Note, *Characteristics of the Outer Layer Silicon Sensors fro Run IIb Silicon Detector*, M. Demarteau *et al.*