Silicon Strip Detector Parameter Analysis

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Introduction

Most of my time at SCIPP was spent working on a project in which I analyzed the parameters of silicon strip detectors (SSD). The main parameters I looked at were I-V (current vs. voltage) curves, and C-V (capacitance vs. voltage) curves, which I will explain in depth later. I was given two SSD's, the IRST Smart2 W066 MCz, Sensors #10 and #3. The plan for this project was to get these curves and then irradiate them with the Cobalt-60 source in the basement. The source emits about 10 kilorads of radiation per hour, so we would leave the SSD's in for ten hours to get 100 kilorads of radiation. Unfortunately the interlock system on the Cobalt-60 source has broken and there is no way to access it. So in this report I just have the data from the analysis, some detector background, and the method of parameter analysis.

Silicon Detector Basics

Introduction: Silicon detectors are a relatively new type of particle detector that use doped semiconductors to detect photons and subatomic particles. SSD's are much more precise than other detectors such and scintillators, in that they can measure the position of a particle to within a few tens of microns. They are used in most particle accelerators today because layers of them can track particles' paths.

Design: The main body of a silicon strip detector is either P- or N-type doped silicon. The detectors I was working with were P-type. The main body of my detector therefore has positive "holes" that could be filled by electrons. This body is on average about 300 microns thick. On top of the main body of the detector there are strips deposited of the opposite doping as the body, i.e. my P-type body detector has N-type doped strips. The strips themselves are about 30 microns wide and the distance between strips varies from one detector to another. For my detectors, the distance from the center of one strip to another, for Sensor #10, is 100 microns, and for Sensor #3, is 50 microns. On top of the doped strips a layer of aluminum is deposited and then the entire top of the detector is covered with glass (SiO_2).

Doping: The silicon covalent network that makes up the bulk of the chip is basically one enormous molecule with each silicon atom bonded to four of its neighboring silicon atoms. This network forms because the silicon atom has four valence electrons and wants eight so it shares one electron with its four nearest neighbors. But the network changes drastically once doping atoms are introduced into in. The P-type network has boron, aluminum, or gallium atoms doped into it, all of which only have three valence electrons. When this P-type atom is introduced into the network it bonds to three of it's neighbors just a silicon atom would but it doesn't bond with the fourth one because it is out of valence electrons, so that fourth silicon atom has a "positive hole" that it wants filled by an electron. Similarly, N-type material is covalent network of silicon atoms that has had either phosphorus, arsenic, or antimony atoms doped into it. But with N-type doping the added atoms have five valence electron, so the atom bonds to four neighboring atoms just like a normal silicon atom, but then there is an extra “free” electron the is not bonded to any atom.

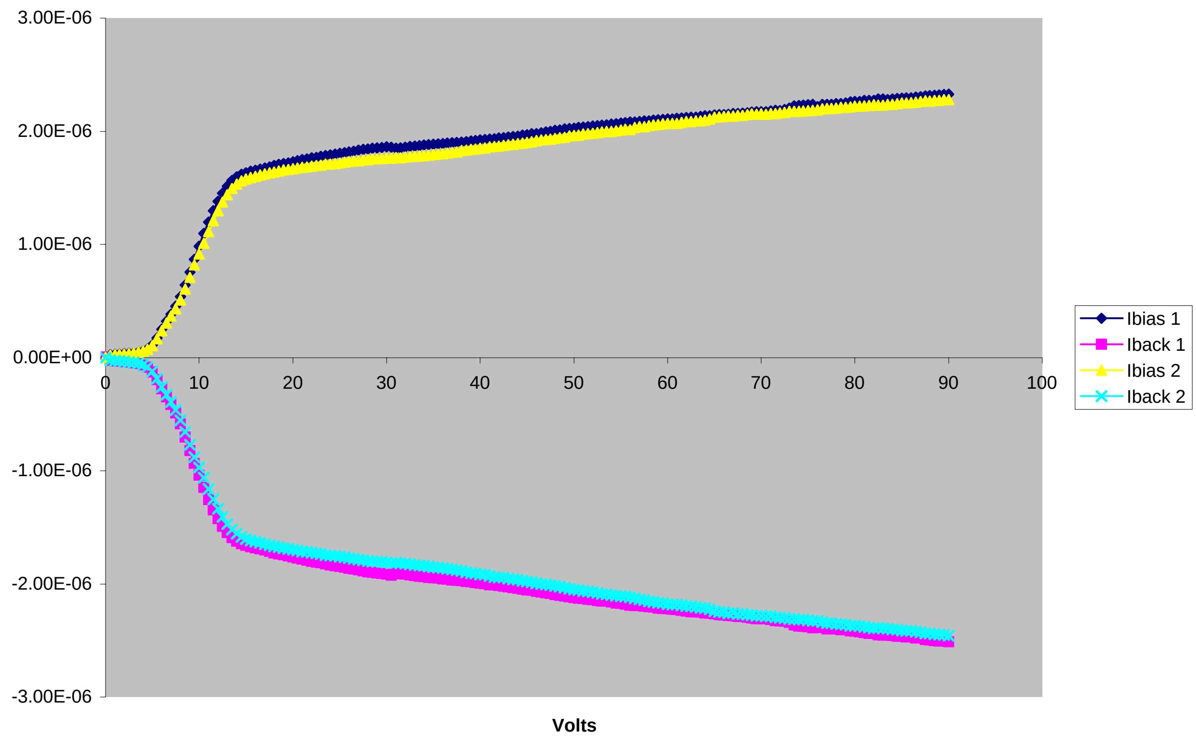
Depletion: At the point where an N-type material touches the P-type material there is a depleted region where some of the “free” electrons from the N-type material get attracted to the “holes” on the P-type side. In this region there are no holes or free electrons. In a silicon detector without any outside electric force, there is a small, depleted region between every N-type strip and the P-type body. Now, if we apply a bias voltage to the detector with a positive voltage to the strips and negative voltage to the body (we don’t apply the voltage directly to the body, but to the back plane, which is a conducting metal plate the silicon detector is adhered to using conducting glue), the negative voltage on the back plane “pulls” the P-type “holes” down towards the bottom and the positive voltage on the top attracts the “free” electrons (a side note on all the terms in quotes, they are quoted because there are not really physical holes that can be pulled to the bottom by the negative voltage but that is the easiest way to think of it). We can apply voltage until the entire body of the detector has been depleted. The voltage at which this occurs is called the depletion voltage.

Detection: Now that the detector is completely depleted it is ready to start detecting particles. When a particle or high-energy electromagnetic wave passes through the detector, it will pass through the depleted body of the detector. Along the particle or light’s path it will create electron/hole pairs. The holes are “drawn” towards the negative back plane and the electrons flow to the strips causing a current to flow in the strip. A computer detects this current, and the computer notes the time and which strip was hit. It is important to note that the current doesn’t flow through the N-type material but through the aluminum deposited on top. The N-type strips’ only purpose is to create the depleted region. Some detectors are double sided with strips running horizontally on one side, and vertically on another so the computer will get a hit on a vertical strip and a hit on a horizontal strip and from that you can get an (x,y) coordinate for the particle’s position to within a few tens of microns.

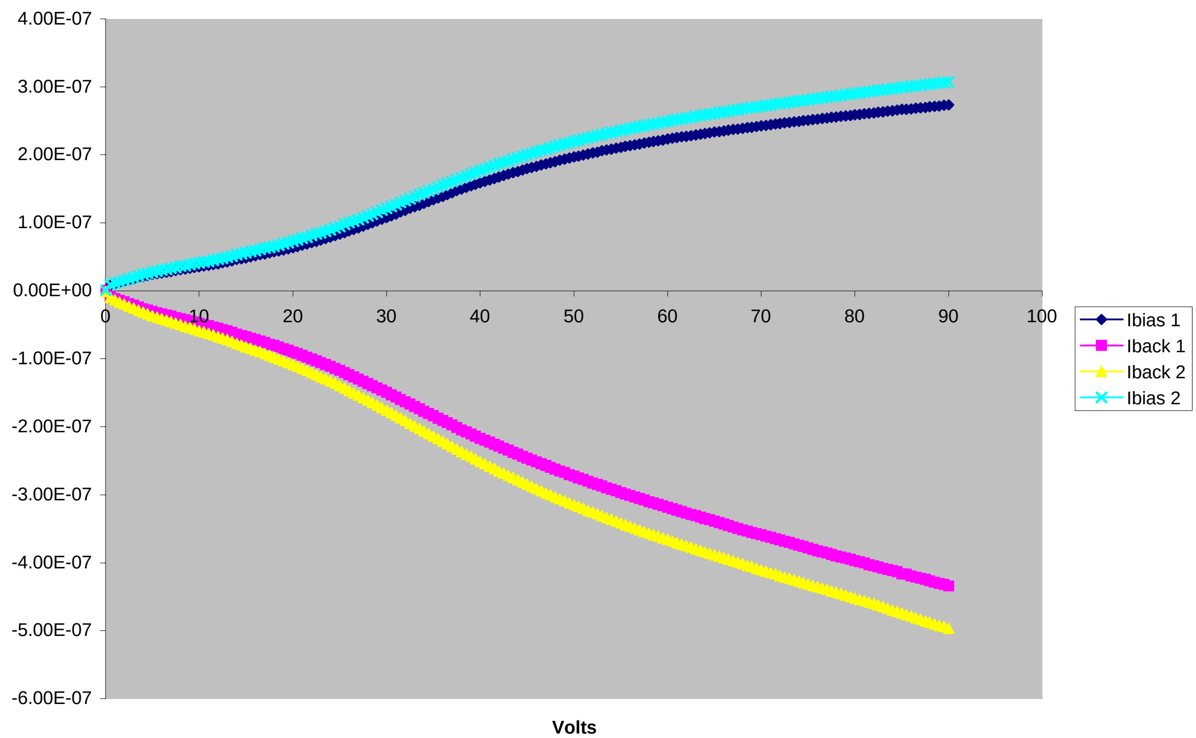
Parameter Analysis

I-V Curve: The first measurement I made was a current versus voltage, or I-V, curve. To make this measurement I used one of the probe stations in the GLAST lab. The probe station is a desk with a big wooden box on top. The side of the box facing outward is open and inside is a microscope. In order to make measurements on the detectors you have to make contact with some part of the detector, and since some of the parts you need to make contact with are only 30 or so microns wide we use things called probes. Probes are incredibly fine tungsten needles attached to a mechanism that adjusts the probe’s position. Probe tips are attached to BNC cables so we can apply voltage and measure using them. For I-V curves we set one probe down on the back plane and on the bias ring. The bias ring is an implanted strip that wraps all the way around the outside of the other detector strips. We the apply zero volts to the bias ring and sweep the back plane voltage from zero to negative ninety (negative because the body of the detector is P-type) and measure the current at each step. We expect that current is proportional to the square root of the voltage, and here are the curves for detectors #3 and #10.

Current Vs Voltage

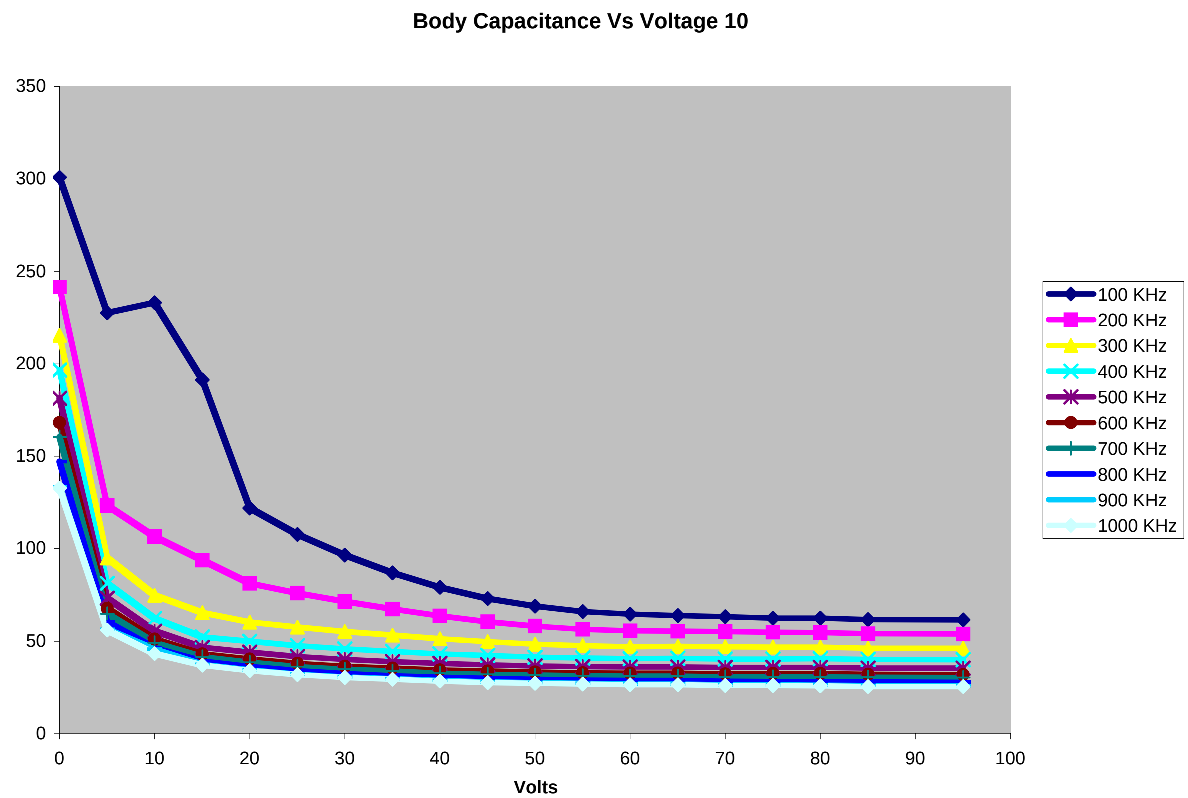


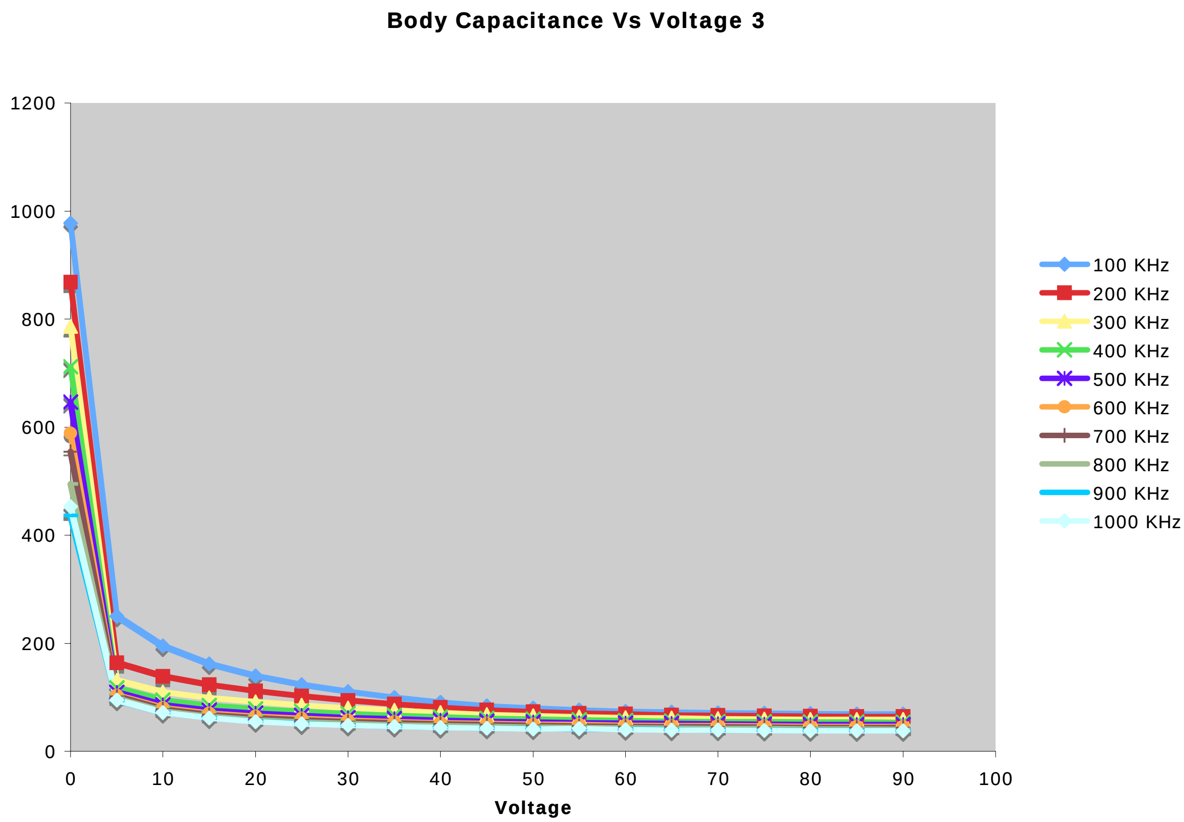
Current Vs Voltage 3



There are two tests shown on each graph, represented by the 1 and two. The Iback and Ibias should be equal but on opposite sides of the graph because one has the current flowing into it so its positive, and one has current flowing away from it so its negative (one important note; the volts here should be negative but it is easier to view the graphs with the volts increasing instead of decreasing. As you can see in both graphs they are fairly symmetric about the x-axis and the values are pretty similar between tests. As the voltage is increased well beyond the negative ninety volts shown there is a point where the chip breaks down and the current shoots straight up. For detector #10 that occurred at about -390 volts and for detector #3 it occurred at -470.

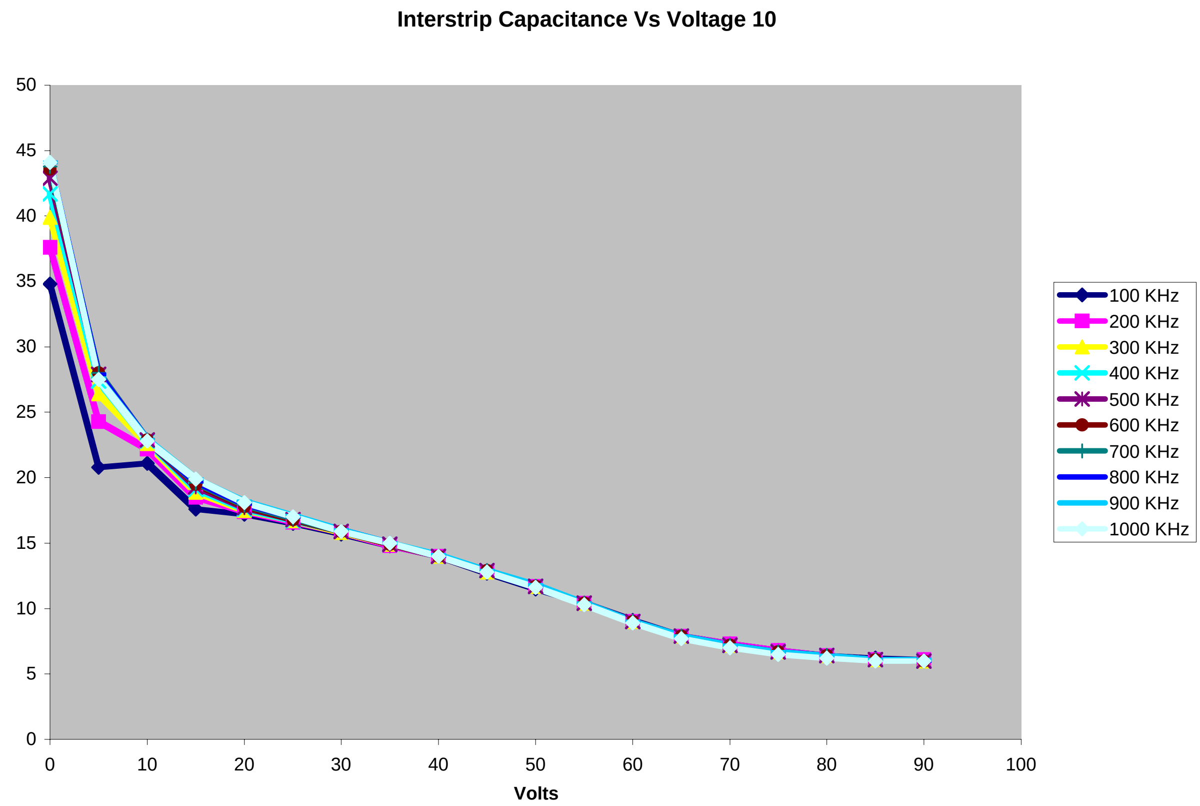
C-V Body: The next measurement I made was capacitance between the bias ring and the back plane versus voltage. To do this I again put one probe down on the back plane and one on the bias ring. But for this test the capacitance of the wires we were using was much greater than the body capacitance of the detector so I had to make a measurement before hand to correct for that. I measured the capacitance versus voltage from zero to negative ninety volts, and I did this for ten different frequencies, as shown in the following graphs.





There are a few remaining questions regarding these graphs, most important of which is the difference between the curves for the different frequencies. There shouldn't be nearly as large of a difference between them.

Interstrip C-V: This is the second type of C-V measurement I made. In this one we measured the capacitance between one strip and its three nearest neighbors on each side. For this measurement we needed to have all six of the neighbors (three on each side) bonded together, so all we would have to do, would be to touch a probe down on one strip and we could measure the capacitance on all of them. This measurement required four probes, one to be put down onto the main test strip, one to touch down to its neighbors, one to touch the back plane, and the last to touch the bias ring. The bias ring and back plane ones were just used to apply voltage while the other two actually made the capacitance measurement. The machine that made the measurement would make the measurement for all ten of the frequencies at one voltage and then I would have to manually change the voltage for every step. Again, we had to correct for the capacitance of the wires before making this measurement. This measurement was really difficult for me and the correct I made would always be too great and I would end up with negative capacitances. This measurement gave me such a hard time I was only able to get an I-V curve for detector ten.



As you can see from this graph there is much less of a difference between the frequencies on the measurement than on the body capacitance measurements.

Conclusion

The next step in this project would be to complete the interstrip capacitance for detector 3 and then do an interstrip resistance measurement for both. After that, the plan is to irradiate the detectors with around 100,000 rads of radiation, and then make the measurements again and compare them to these results.