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Capacitance of the GLAST Prototype Detectors

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About 40 single-sided silicon microstrip detectors of 500 μm thickness were procured from Hamamatsu Photonics. The detectors have a strip pitch of 236 μm and a strip width of 57 μm. The strip implant length is 5.8 cm. We have made use of one of the factory seconds as a test detector for measurements of capacitance and leakage current.

The expected capacitance of a strip to the backplane can be obtained from an analytic calculation.[†] The formula is

$$c = K \cdot \varepsilon_0 \cdot \frac{p}{d + p \cdot f(w/p)}$$

where p=236 μm is the pitch, d=500 μm is the thickness, w=57 μm is the strip width, K=11.9 is the dielectric constant of silicon, and $\varepsilon_0 = 0.0885\ \mathrm{pF/cm}$. The function f accounts for the gaps between strips and is given by

$$f(x) = \frac{-0.00111}{x^2} + \frac{0.0586}{x} + 0.240 - 0.651 \cdot x + 0.355 \cdot x^2$$

For the GLAST geometry we obtain $f(w/p) = 0.327$ and c= 0.431 pF/cm, which is 87% of the capacitance of an idealized parallel plate capacitor of the same size.

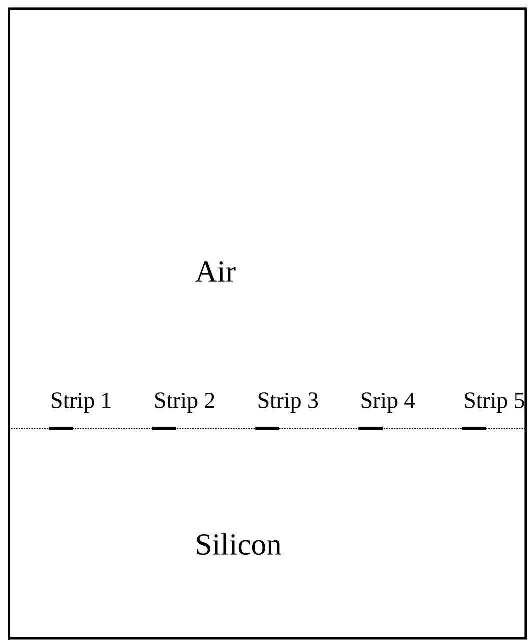

Figure 1. Detector model used for the capacitance calculations.

[†] E. Barberis *et al.*, “Capacitances in Silicon Microstrip Detectors, SCIPP 93/16, presented at the International Symposium on Development and Application of Semiconductor Tracking Detectors, at Hiroshima, Japan, May 22-24, 1993.

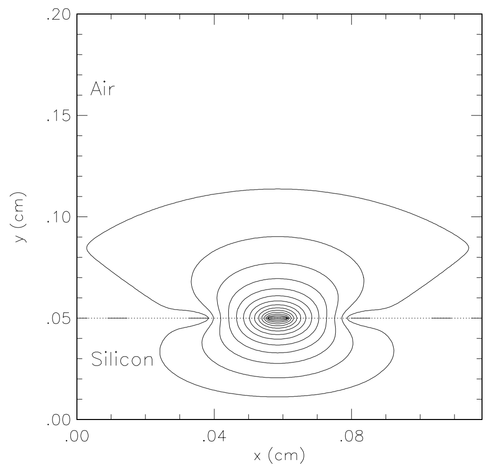

Figure 2. Equipotential lines from the numerical calculation of the total strip capacitance.

We made a numerical calculation of the capacitance using the simple two-dimensional model of the detector illustrated in Figure 1. The boundary condition used on the sides was periodic (or equivalently, the perpendicular component of the field along the sides was required to be zero). The top and bottom of the overall region were fixed to zero potential, and dielectric constants of 1 and 11.9 were used for the air and silicon, respectively. To obtain the total strip capacitance, the center strip was set to a potential of 1 V and the other strips to zero. A relaxation method was used to solve Poisson's equation on a grid, and the charge on the center strip was then calculated in order to derive the capacitance. The grid spacing and number of strips were varied and the calculations repeated in order to check the numerical precision. The size of the space above the strips was also varied in order to check that systematic error. There is, of course, some undetermined systematic error due to neglect of the complexities of the strip ends, not only due to fringing effects but also due to the complex pad structures in that region.

The value obtained for the strip capacitance was 1.08 pF/cm. Figure 2 shows a plot of a set of 14 equally spaced equipotentials from the capacitance calculation. The strip-to-body capacitance was calculated from the same model by fixing the potential of the other strips to 1 V. The result was 0.43 pF/cm, in excellent agreement with the analytic calculation. Subtracting this from the total capacitance gives 0.65 pF/cm for the interstrip capacitance.

The actual detectors were studied on a probe station, using a Keithley 237 High Voltage Source Measure Unit to bias the detector and an HP 4284 LCR meter for the impedance measurements. An HP 4145B Semiconductor Parameter Analyzer was also used for some current measurements. Lab-View, running on a Mac, was used to control the instruments to generate IV and CV curves. The detectors have pads connected to both the implants and the aluminum strips, greatly facilitating measurements of leakage current and capacitance. The bias ring has openings through the overglass at frequent intervals, facilitating bonding between strips and guard ring when necessary.

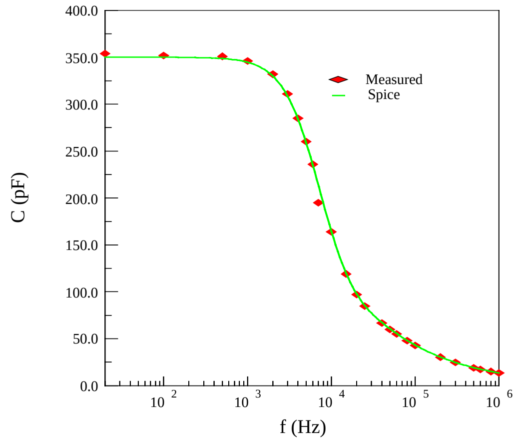

Figure 3. The measured capacitance between implant and strip, compared with a Spice simulation of a detector model based on discrete resistors and capacitors.

The AC coupling capacitance, between a strip implant and the aluminum strip, was most easily measured, because of its large value relative to the other capacitances in the detector. The measurement, shown in Figure 3, exhibits a large frequency dependence, due to the relatively large impedance of the implant. At high frequency the capacitance far from the pads does not contribute. The system can be well modeled by discrete capacitors and resistors, as is shown in Figure 3, where the data are compared with a Spice simulation. The Spice netlist was built by dividing the length of the strip into 64 segments of resistors and capacitors. The implant resistance was varied to find the value, $12.8\ \mathrm{k\Omega / cm}$, that best matched the data. For good detector performance, the AC coupling capacitance per unit length should be much greater than the corresponding strip capacitance. Comparing the measurement of 350 pF for 5.8 cm with the calculated strip capacitance of 1.08 pF/cm, we find a ratio greater than 50, which is more than adequate.

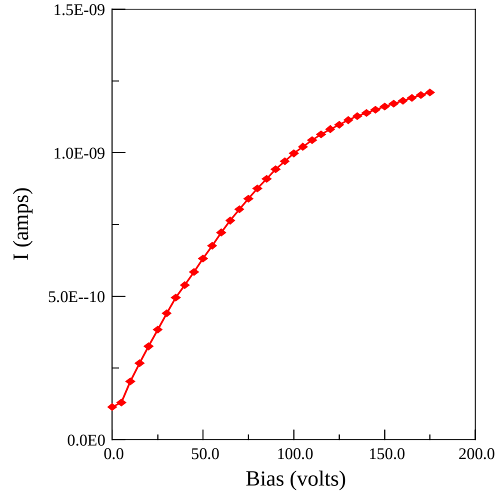

Figure 4. Leakage current on a single strip versus the detector bias voltage.

The AC coupling capacitance does not varying significantly with the detector bias. To compare measurements of interstrip and strip-to-backplane capacitance with the calculations, however, the measurements must be done on a fully biased detector. Figure 4 shows the leakage current measured on a single typical strip as a function of detector bias voltage. For this measurement the strip potential was held equal to that of the bias ring. During normal operation the strips are biased via punch-through structures and sit at a potential several volts above that of the bias ring. Figure 6 shows a measurement of the strip current versus the potential difference between strip and implant and clearly exhibits the punch-through at about 9 volts. The leakage current is acceptably low even at 175 V, but Figure 4 does not give any clear indication of the point of full depletion.

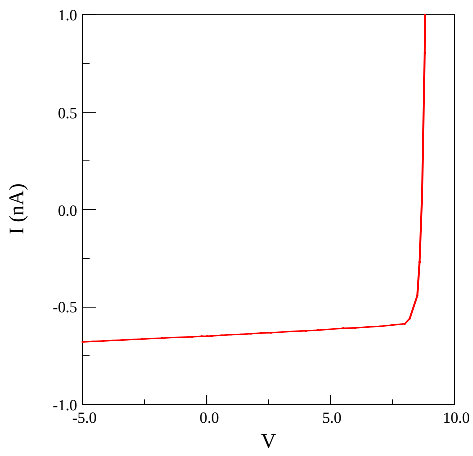

Figure 6. The strip current versus the potential between strip and bias ring, showing the punch-through at a potential difference of about 9 volts. The detector bias potential is 140 V.

The depletion voltage can be seen by measuring the capacitance between the strip and the detector body as a function of the bias voltage. To make that measurement, a strip was chosen and both pads of each neighboring strip were bonded to the bias ring. The bias ring was then connected to the shield of the LCR meter in order to cancel all interstrip capacitance from the measurement. Figure 5 shows the results, with $1/C^2$ plotted as a function of the bias voltage in order to display clearly where the plateau begins. Clearly the detector is not fully depleted until a potential difference of about 140 V is reached. Since the measurement was made on the pad connected to the implant, the implant resistance causes a reduction in the measured capacitance at high frequency. The results, however, show that for a wide range of lower frequencies the capacitance is stable at full depletion with a value of about 3.2 pF, corresponding to 0.55 pF/cm. This is 20% higher than the calculated value.

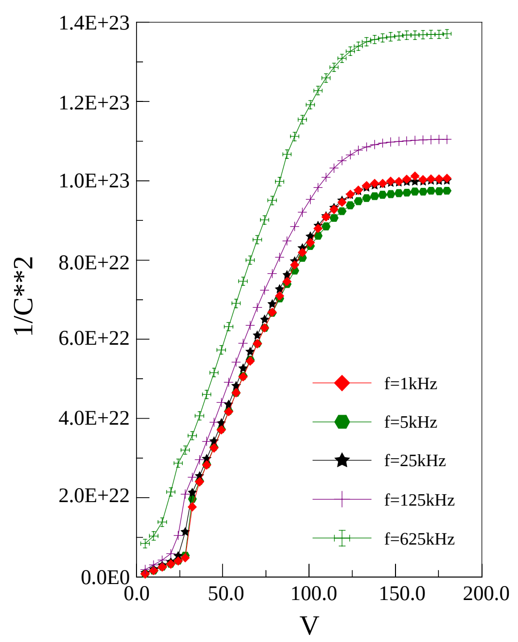

Figure 5. The capacitance between strip and body as a function of the bias voltage. The vertical scale is the inverse of the capacitance squared, with capacitance measured in Farads. The measurements were made on the pad connected to the strip implant.

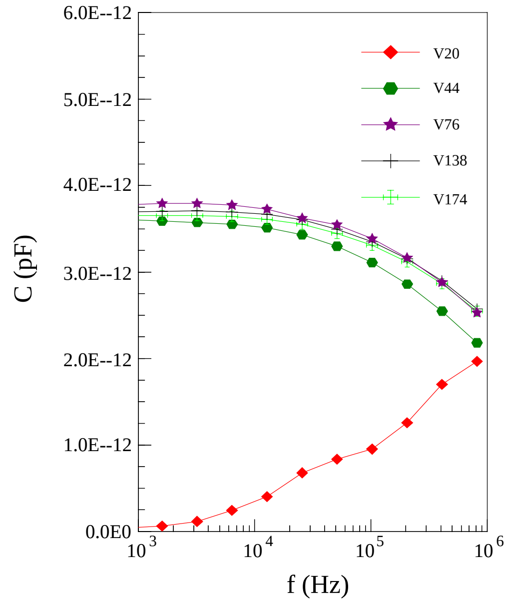

Figure 7. The interstrip capacitance, measured between pads connected to the implants, versus the measurement frequency. Measurements are shown for a range of bias voltages.

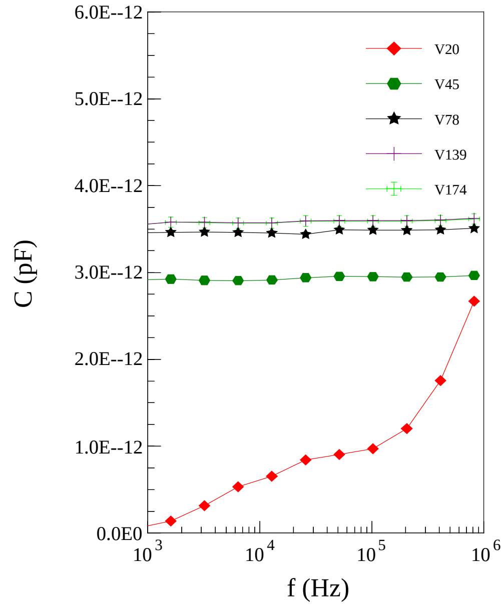

Figure 8. The interstrip capacitance, as measured on the AC coupled pads, versus frequency. The results are shown for several bias voltages.

The interstrip capacitance was measured by bonding together the pads of the four nearest neighbors surrounding a selected strip. The pads of the two strips bordering that region were bonded to the bias ring, which was connected to the shields. The Keithley 237 was used to bias the detector while the LCR meter was connected between the center pad and the four neighbors. The measurement was done on both the pads connected to the implants and those connected to the aluminum strips. The results from the former, shown in Figure 7, exhibit the usual falloff at high frequency, due to the implant resistance, but at low frequency there is good agreement between the two measurements. The measurements were repeated over a range of bias voltages. Very low voltages give complex results, but once the detector is fully depleted, above 140 V, the measurements are stable. From Figure 8, the interstrip capacitance at full depletion is 3.6 pF, or 0.62 pF/cm.

Adding together the interstrip capacitance with the body capacitance gives a total of 1.17 pF/cm, which agrees fairly well with the calculation. The main discrepancy is that the division between interstrip capacitance and body capacitance is off by about 20%.

In conclusion, we can expect a total capacitance of the 24 cm long GLAST strips of about 27 pF. Spice simulations of preamp designs and measurements of test CMOS transistors indicate that equivalent noise charges of less than 1000 electrons rms can be readily achieved for detectors of this capacitance with less than 200 μW of power per channel expended.

If 300 μm thick detectors are used for GLAST, instead of 500 μm, the capacitance will be higher, but only by 6%, according to the numerical calculation. The body capacitance increases roughly like $1/d$, but at the same time the interstrip capacitance goes down, so the increase is not nearly as large as the 5/3 that one might at first expect.