Measurement of Interstrip and Coupling Capacitances of Silicon Microstrip Detectors[1]

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Abstract

We present a set of measurements of the capacitances on silicon microstrip detectors which are important for the operation of the detectors. Various strip widths on both the junction and ohmic side and widths of blocking p+ implant on the ohmic side have been implemented on test detectors. The interstrip, body and coupling capacitances of the strips were measured. The measured capacitances exhibit a strong frequency dependence. We have simulated with SPICE the resistive and capacitive network represented by the detectors and find good agreement between measurement and simulation. We have irradiated the detectors with ionizing radiation to test the radiation hardness of the design.

We have measured the noise increase induced in a fast low-noise amplifier due to the capacitive load of different strip geometries. The results agree with those obtained using discrete external capacitors.

I. INTRODUCTION

In typical silicon microstrip detectors with a pitch of 50 μm and thickness of 300 μm the interstrip capacitance is the largest contribution to the parasitic capacitance while the body (strip to backplane) capacitance contributes less than about 20%. The total strip capacitance plays an important role since it contributes to the noise of the front-end amplifier.

The geometry of the strips has several consequences. We have pointed out before[1], that the interstrip capacitance can be minimized with narrow strip implants.

For the ohmic side where oxide charges tend to increase the interstrip capacitance, it is possible to decrease the interstrip capacitance with wide p-blocking strips[2]. In AC-coupled detectors, for fixed thickness of oxide and metal, the width of the strip implant determines the value of the coupling capacitance between the implant and the metal strip and therefore it has to be made large such that the signal collection in the amplifier is efficient. The width of the metal strip determines its resistance. This resistance is in series to the amplifier and has to be minimized in order to reduce the noise and the dispersion of the signal[3].

In this paper we describe the measurements of capacitances on AC-coupled test detectors of various geometries and simulations of the frequency dependence of the measurements. We also show the effect of ionizing radiation on the capacitance. Finally we verify our understanding of the capacitance of various strip width by measuring their effect on the noise of a fast amplifier-comparator chip.

II. EXPERIMENTAL SET-UP

We have measured both the interstrip and the body capacitance as a function of strip and p-blocking implant width. Test detectors were manufactured by Hamamatsu Photonics[4] to determine the optimal geometrical layout of double-sided silicon detectors for the SSC. They are single-sided sample detectors of 50 μm pitch with either junction or ohmic side processing. Each strip is AC-coupled to the implant for part of its length and DC-coupled for the remaining length. Each sample detector is divided into 4 areas in order to offer different strip geometries, a more complete description is given in Ref. [5]. The measurements have been performed on both the AC and DC pads with a HP4284A LCR meter. The terminals of the LCR meter were each connected through coaxial probes to one or several neighboring strips. Strips not directly used in the measurement but located close to the strips under test were grounded to avoid field distortions. The probe shields were connected among each other and to the system ground. We have measured the different contribution to the total interstrip capacitance due to the 2 first and the 2 second neighbors. We have also measured the coupling capacitance by connecting the two probes to the AC pad and the DC pad of the strip, respectively. During the measurements the detectors were biased at normal operating conditions (the p(n) implants were held at ground while the backplane was at 100 (-100) Volts).

III. FREQUENCY DEPENDENCE AND SPICE SIMULATION

The experimental results show that the measured capacitance has a strong frequency dependence; this is

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especially true for the coupling capacitance. This result should not be surprising if we consider the detector as an extended network of resistors and capacitors.

In order to extract the frequency independent capacitance per unit length, we have simulated our set-up and the LCR meter with the network simulator "SPICE"[6].

We have divided the detector in unit cells , each consisting of two resistors for the top layer of aluminum and two resistors for the p+ implant. The resistance of the implant is about $4*10^3$ times larger than that of the metal. A coupling capacitor bridges the four resistors. The simulated model contains five strips: one central and four neighbors. Each strip is capacitively coupled to the top layer of aluminum, the conductive backplane, its two closest neighbors and its two second neighbors. The LCR meter was simulated by introducing a voltage source at the point corresponding to the location of the high probe and monitoring the current with an amperemeter placed at the position of the low probe.

IV. RESULTS

A. Coupling capacitance

We have measured the coupling capacitance between the AC pad and the DC pad of the strip and we have obtained that the results are independent on the biasing conditions of the detector. The experimental and simulated results for the coupling capacitance are plotted in Fig. 3. The resistivity of the top aluminum layer has been measured directly but the design of the detector prohibits direct measurement of the p+ implant resistance, so SPICE was used to determine this value. The extracted coupling capacitance agrees with the low frequency limit of the measurement. At high frequencies (> 1KHz) only a small length of the p-implant contributes to the capacitance and thus the observed capacitance is reduced.

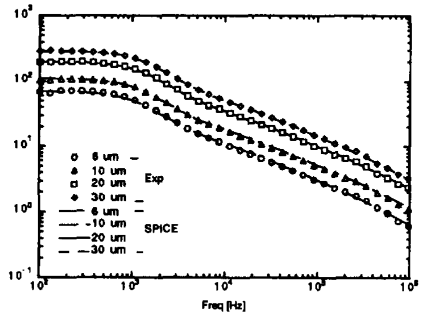

Fig. 3 Coupling capacitance (measurement and SPICE simulation) for different strip widths.

B. Interstrip capacitance

We have measured the interstrip capacitance using both the DC and AC pads of the detectors[5]. Fig. 4 shows the experimental and simulated results for the DC and AC interstrip capacitance. For the DC interstrip capacitance the agreement between data and simulation is good for low frequency values.On the AC side low frequencies are shunted to ground through the polysilicon resistors resulting in a high pass filter: the values for the AC interstrip capacitance extracted from SPICE are therefore close to the high frequency values.

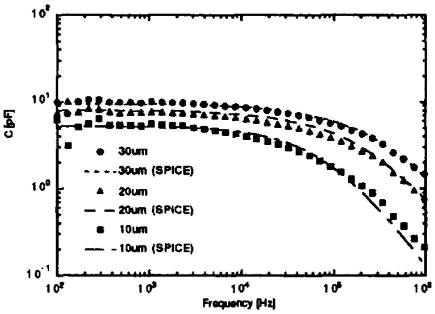

Fig 4: DC interstrip capacitance (measurement and SPICE simulation) for different strip width.

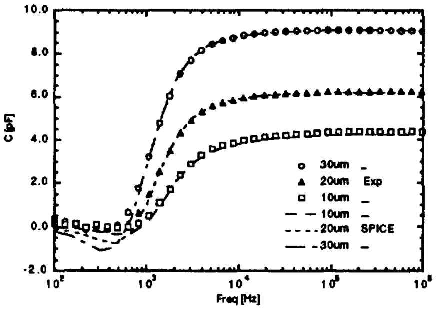

Fig. 5: AC interstrip capacitance (measurement and SPICE simulation) for different strip width.

C. Total capacitance

We have determined the total interstrip capacitance as the sum of the measured AC interstrip capacitance to the first 2 pairs of neighbors plus a small correction, 0.1pF/cm, due to the presence of all the remaining strips. This correction has been measured to be small since the coupling between strips decreases as their distance increases. The total capacitance is then the sum of the total interstrip capacitance and the body capacitance. The body capacitance is 0.16pF/cm for 50 µm pitch, independent of the implant width.

The total capacitance for p-side silicon detectors with different strip width but constant strip pitch (50 µm) is shown in Fig.6 as function of the ratio strip width over pitch. The results are compared with the theoretical prediction obtained solving numerically for the electric field inside the detector[1].

The measurement confirms our theoretical prediction that a reduced strip width lowers the total capacitance.

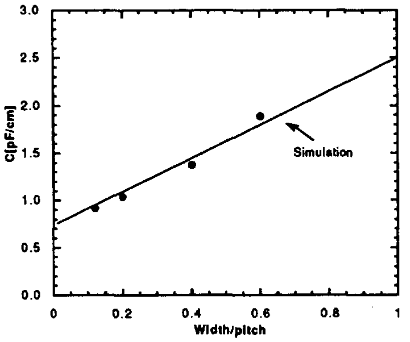

Fig. 6: Total capacitance for a 50 μm pitch p-side detector as a function of the ratio width/pitch.

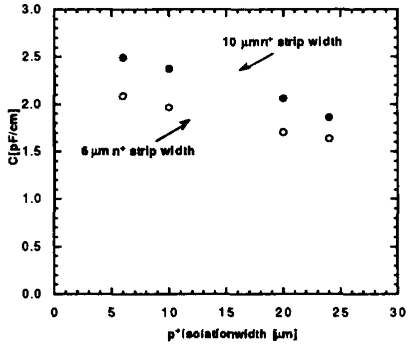

Fig. 7: Total capacitance for 50 μm pitch n-side silicon detectors for two strip widths as a function of p+ isolation width.

Fig. 7 shows the total capacitance for n-side detectors with 6 and 10 μm strip width as function of the width of the p+ blocking strip.For n-side detectors, wider p+isolation implants and narrower n-implants reduce the capacitance.

V. RADIATION DAMAGE

We have irradiated the sample detectors with gamma rays from a ^{60}Co source [7] with total doses of up to 5 Mrad.

During irradiation the backplane and the metal strip were held at ground while the p (n) implants were biased at -80 (+80) Volts. We determined the AC interstrip capacitance for both the junction and ohmic side as a function of the total dose, choosing the high frequency limit at 1 MHz (cf Fig. 5). The results show [5] that detector geometries which give small capacitance, i.e. narrow strip implants and wide p+isolation, are also radiation hard. Larger strip width and narrower p+isolation show marked capacitance increases with irradiation. We have found before that the body capacitance does not change during irradiation[8].

VI. NOISE

The total strip capacitance plays an important role since it contributes to the noise of the front-end amplifier. This means that from a noise measurement we can deduce the input capacitance.One can ask the question if a complicated network like a detector behaves as a simple capacitative load. In order to answer this questions we have measured the noise of a low noise amplifier-comparator chip with 20ns rise time [9,10] with either discrete capacitors or silicon strip detectors of different width as load. The two noise curves are nearly identical [5,10]. The finite resistance of the metal strip plays only a minor role because it is small enough.

VII. CONCLUSION

We have measured the parasitic and coupling capacitance of AC coupled silicon strip detectors. The frequency dependence of the measurement can be simulated with SPICE and is understood in terms of a network of distributed capacitors and resistors. We found that the parasitic capacitances are minimized with narrow implant widths and wide p+ isolation strips. These geometries are measured to be radiation hard.

We have measured the noise of a fast low-noise amplifier as function of strip width and we have found that the results agree with those obtained with discrete components.

VIII. REFERENCES

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