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Wedge silicon detectors for the inner trackering system of CMS

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One "wedge" Double Sided Silicon Detector prototype for the CMS forward inner tracker has been tested both in laboratory and on a high energy particle beam.The results obtained indicate the most reliable solutions for the strips geometry of the junction side.

Three different designs of "wedge" Double Sided detectors with different solutions for the ohmic side strip geometry are presented.

1. Introduction

The present study is part of the work of the construction of the silicon detectors to install on the forward part of the CMS inner tracker.

The choice of the detectors design is constrained by several factors as the high radiation working environment, the number of readout channels, the trapezoidal shape of the active silicon crystal. To fulfill all these requirements we started an R&D programme of detectors prototypes, the status of which is presented.

The work done concerns the design of the detector masks and the test of the processed detectors both in laboratory and on a particles beam.

The description and the preliminary tests results of the first small "wedge" prototype we have designed are reported in section 3 and 4 respectively. In section 5 we describe the design of three new "wedge" prototypes which are now being processed on the same batch.

2. The basic features of the CMS Forward detectors

The CMS silicon tracker is foreseen [1] to be confined in the region defined by 20.5 cm $\leq$ r $\leq$ 40 cm and $|\eta| \leq 2.6$. Its architecture is based on two parts: the "Barrel" and the "Forward", consisting of three detectors layers which enclose the interaction point. While the "Barrel" layers are placed around the beam axis with a cylindrical symmetry, the "Forward" layers (disks) are perpendicular to the beam axis and are ring shaped.

The circular geometry of the Forward disks suggests the use of trapezoidal detectors ("wedge") with one side finely segmented into radial strips, for a good resolution in the rϕ plane (fig. 1). The number of readout channels for this side has been fixed at 1024.

The CMS project foresees that two of the three layers are equipped with Double Sided (DS) detectors, in order to have two points with full spacial information for each particle track. According to the requirements of the track fitting procedure, the coordinate system, on the opposite side of the rϕ one, can have a low resolution and thus has been constrained to a maximum number of 256 readout channels. Futhermore the geometry of this coordinate system has not yet been frozen, and the optimal solution has still to be found, always with a maximum of 256 readout channels. One last degree of freedom for the design concerns the choice of either the junction side or the ohmic side to implant the high resolution rϕ strips. In the prototypes described in the following sections the junction side is the high granularity one. Nevertheless we are convinced it is necessary to test detectors with high resolution strip layouts implanted on the ohmic side and to compare their performance with that of the high resolution junction side ones at high levels of irradiation.

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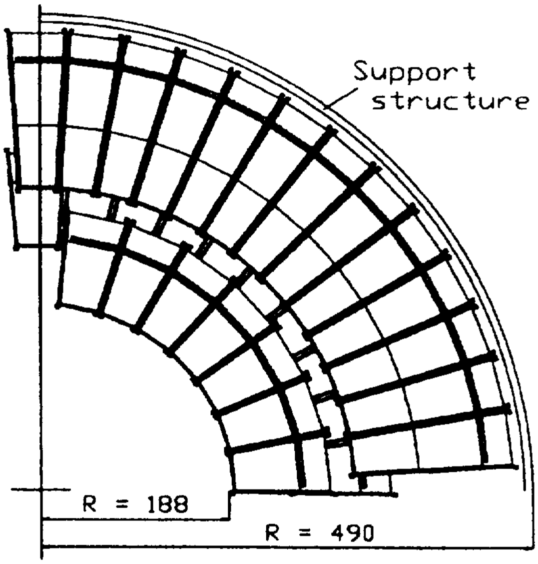

Figure 1. A quarter section of a forward silicon disk showing three rings of trapezoidal silicon modules.

3. The first "wedge" prototype

3.1. Technological Choices

For the fabrication of the first "wedge" prototype, as well as of the batch now being processed, we have used 4-inches n-type silicon wafers, 300 μm thick, with 5 $K\Omega$·cm resistivity and <111> orientation. The detectors have been processed at CSEM (CH).

The technological choices that have been made for the first prototype are: integrated AC coupling capacitors, polysilicon resistors for biasing the strips of the detector (both sides) and p-stops for insulating the n^+ strips on the ohmic side.

The readout aluminum strips are decoupled from the implant strips through a thin dielectric layer ($\sim$ 0.3 μm ofSiO_2 + Si_3N_4). The expected value of the capacitance is 15 pF/cm.

On the junction side the bias voltage is provided to the p^+ strips by using the polysilicon resistors, connected to the p^+ guard-ring surrounding the active area of the detector. The same bias method is adopted on the ohmic side to connect the n^+ strips to the n^+ guard-ring. The material used for such resistors is polycristalline silicon, whose resistivity has been tuned to achieve, by the varing the dopant concentration, a value of 40 $K\Omega$ square in our prototypes. The polysilicon resistors choice for the strips biasing is due to the observation [2][3] that this technique is more radiation resistant compared to other techniques, such as the punch-through for the junction side, and the channel sheet resistance for the ohmic one.

The third choice we made for the first "wedge" prototype, is to insulate each n^+ strip of the ohmic side by means of a p^+ frame surrounding it (fig. 3). The presence of two p^+ implantations between two neighbouring n^+ strips ensures a good insulation and in particular lowers the interstrip capacitance.

3.2. Design Choices

The first prototype we have designed and tested is a DS "wedge" detector inscribed in a 64mm × 8.6mm rectangle. While the height (64 mm) is comparable to the final value foreseen for the "Forward" detectors, the width is smaller ($\sim$ 1/8 of the final one).

The junction side has 128 p^+ strips, 62 mm long, with a pitch which varies from the narrower end of the detector (38μm) to the wider one (50μm), compatible with the use of 50μm pitch front-end electronics.

The junction side is divided into three regions: two with 44 strips and one with 40 strips. The latter one is placed at the center of the detector and its strips have constant $\frac{width}{pitch}$ ratio (0.37). The other two regions have respectively: constant strip width (14 μm) and constant gap between the strips (24 μm). The reasons of this design layout is that we wanted to study the influence of these three geometries on the signal-to-noise ratio (S/N) and to make a decision for the future detectors. In fact the noise of the charge measurement depends on both the resistance and the capacitance of the strips, which depend on the strip width, once the pitch and the length have been fixed. An estimate indicates that while the series resistance varies by up to $\sim$ 35% between

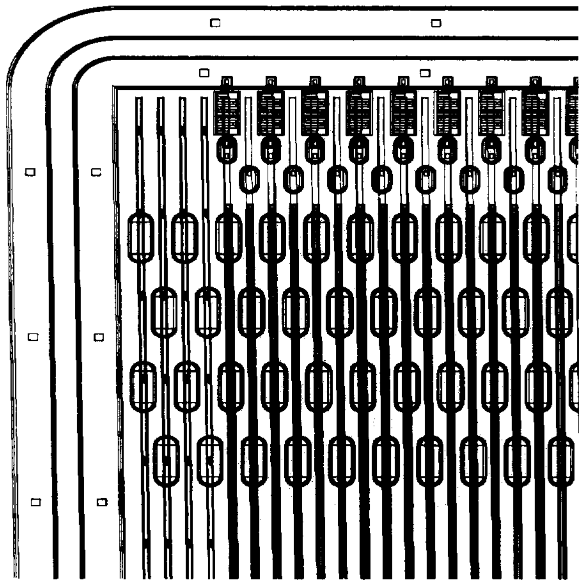

Figure 2. First "wedge" prototype (J-side). Details of the constant width region (see text). The polysilicon resistors (top) and the bonding pads of the strips are shown.

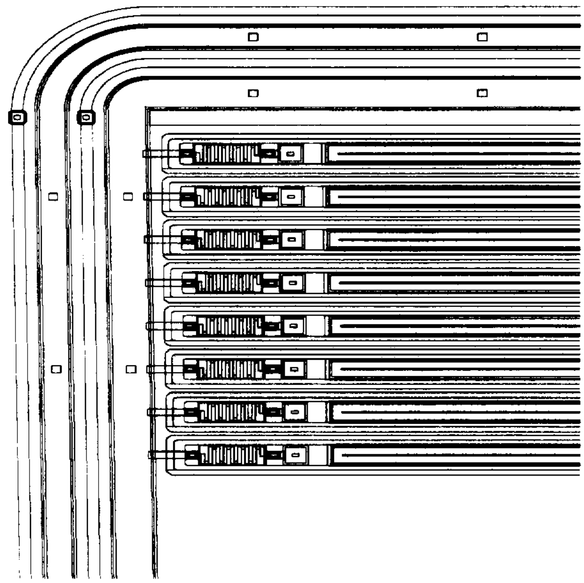

Figure 3. First "wedge" detector (ohmic-side). The polysilicon resistors and the p^+ frame surrounding each n^+ strip are shown.

the three different regions, the capacitance varies almost by a factor of 2, the worst case being the configuration with constant gap. This evaluation is in accordance with the experimental results that will be described in section 4. The p^+ strips and the front-end electronics are AC coupled by means of the built-in capacitors.

The ohmic side is segmented into 495 n^+ strips, 60μm wide, $\sim$ 5 mm long, with 125μm pitch. The strips are quasi-orthogonal to the junction strips; their pitch is different from the junction side one due to the lower resolution needed in CMS for the $r\theta$ coordinate ($\simeq 1mm$). As mentioned in section 3.1, each strip is insulated from the neighbouring ones by means of p^+ implantations and it is AC coupled via built-in capacitors.

On the ohmic side, as well as on the junction side, the n^+ strips are biased through polysilicon resistors connected to the guard-ring. Details of the structure of these detectors (both sides) are shown in fig. 2 and in fig. 3.

4. Experimental Results

After the wafer processing, the detectors have been tested in laboratory in order to verify the process quality, and to measure their electrical properties. We measured the total leakage current on the twenty detectors of the batch at 100 V bias voltage and at 27 C temperature. We found that only three of them have currents as high as a few μA, all the others having an average current of 100 nA. The full depletion voltage measured is 38 V. The measurements of the polysilicon resistors gave an average value of 18 MΩ on the junction side and 25 MΩ on the ohmic one: about 8 times greater than expected. The capacitors insulation has been checked by measuring the current flowing between each bonding pad and the guard-ring, with 10 V applied. In case of accidental shorts, currents of a few hundreds of nA are expected. Only 1.7 % of the coupling capacitors tested over the whole batch of detectors were found shorted. Two out of three detectors have shown a maximum of one short. In fig. 4 the scan of the capacitors insulation of one detector is shown.

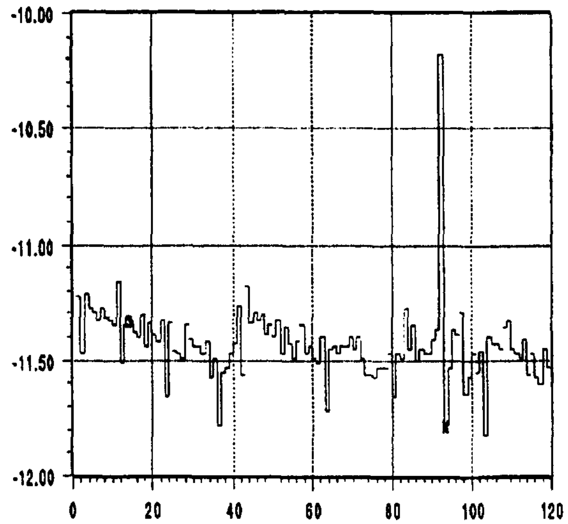

Figure 4. Example of the quality test for the capacitors: insulation currents (y axis) vs strip number. The y values are Log(I(A)).

One of the "wedge" prototypes tested (I_{leak} = 144 nA @100 V, no capacitors shorts) was equipped, to be exposed to a π beam, with front-end electronics (PREMUX128) [5]: one 128 channels chip on the junction side and two 128 channels chips on the ohmic one.

The front-end electronics used for the test-beam is the first generation of the one foreseen for the CMS experiment [4]. Data were taken for different bias voltages and for several angles of incidence of the particles. The overall S/N spectrum of the junction side, obtained with orthogonal tracks and 100 V bias voltage is shown in fig. 5. The analysis of the data obtained in these operative conditions for the three mentioned regions has led to the following S/N values: 35.15 $\pm$ 0.9 (constant width), 35.05 $\pm$ 0.9 (constant $\frac{width}{pitch}$), 32.37 $\pm$ 1.3 (constant gap). The results

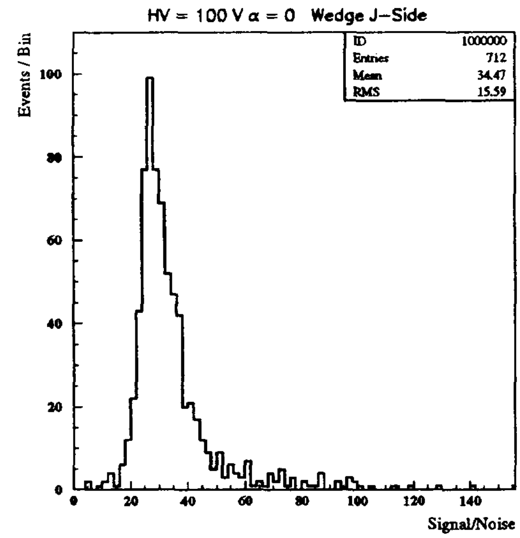

Figure 5. Signal-to-noise ratio spectrum (Junction side), at 100 V bias voltage and orthogonal tracks.

show that the constant gap layout gives the lowest value as expected. Therefore we have decided to exclude this layout from future designs.

The S/N ratio measured on the ohmic side is 50, maily due to the shorter strip length.

5. New Prototypes

A new batch of DS detectors, with three "wedge" detectors inscribed in 64 mm x14.8 mm rectangles, have been designed to investigate an optimal solution for the ohmic side geometry. The width of the active area of the detectors is about twice the one of the first prototype, while the height is the same.

These detectors have high granularity on the junction side and have been designed with constant $\frac{width}{pitch}$ ratio. They have 256 p^+ strips, with the pitch varying from 38 μm to 50 μm.

The new batch contains also two 60 mm x 8.6 mm wedge detectors with high resolution strips on the ohmic side. The following description will concern only the three largest detectors.

The technological choices made for the new detectors batch are the same described in section 3.1 with the addition of a second metal layer (met2) on the ohmic side. These detectors will be referred to as "double metal" (DM). This additional layer allows the connection of the readout electronics of the ohmic side on the same edge as that of the junction one, as will be described in the following sections.

The measurement of the rθ coordinate may be achieved by using either n^+ strips almost orthogonal to the junction ones (orthogonal geometry), or n^+ strips suitably angled to the junction side ones (stereo geometry) or n^+ pads (pads geometry). Three detectors, each with a different geometry, have been designed in order to test their performance and choose the best solution for the future ones.

5.0.1. Orthogonal Double Sided Double Metal Wedge Detector

This detector has the ohmic side strips almost orthogonal to the junction side ones. The measurement of the particle coordinates hitting the detector is given by the fired strips on the two sides. Nevertheless ambiguity problems arise when a few particles hit the detector at the same time.

The ohmic side has 495 n^+ strips, 60 μm wide, with 125 μm pitch. Each n^+ strip is insulated from the neighbouring ones by means of p^+ implantations, as described in section 3.1. The aluminum strips (met 1) of the capacitors are connected to the readout strips (met 2) through holes made in the thick oxide layer underneath. The readout strips (met 2) are orthogonal to the n^+ strips and have 50 μm pitch (fig. 6).

The drawbacks of this connection between the strips and the readout pads are the increase of the capacitance and the introduction of an additional aluminum resistance which varies up to $\sim$ 200 Ω, depending on the length of the met2 strips.

5.0.2. Stereo Double Sided Double Metal Wedge Detector

The ambiguity problem of the orthogonal double sided double metal detector can be minimized

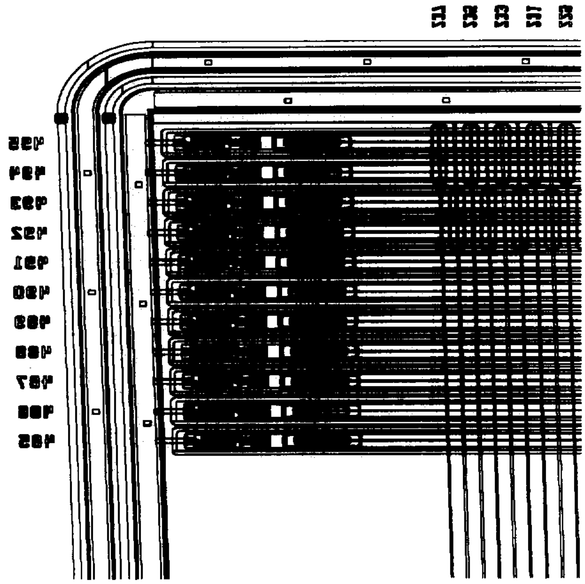

Figure 6. Orthogonal DSDM "wedge" detector (Ω-side). The connection strips (vertical) run above the n^+ and the capacitors strips (horizontal).

using the stereo coordinates system already experimented on rectangular detectors.

This technique consists on making the n^+ strips on the ohmic side slightly angled (much less than 90 deg.) with respect to the p^+ strips of the junction side. The angle between the two strips system is small enough ($\leq$ 10 deg.) that each strip of one side crosses a limited number of strips on the other one, ensuring a smaller number of ambiguities, when the detector is crossed by simultaneous particles.

Another advantage of this technique is that the n^+ strips run between the two edges of the detector. In this way the n^+ strips can be readout on the same end of the p^+ junction ones. Nevertheless by using this geometry some of the n^+ strips are interrupted by the lateral detector edges. These strips are confined into two triangular regions at two opposite corners of the detector, creating difficulties for their readout.

In our stereo prototypes we overcame these dif-

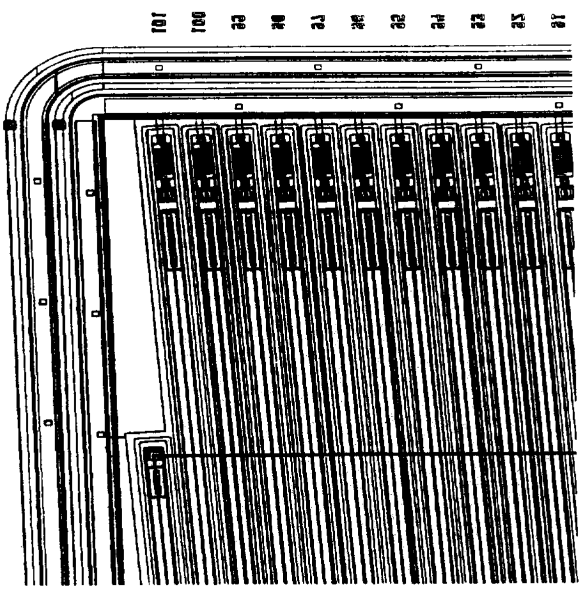

Figure 7. Stereo DSDM "wedge" detector (Ω-side). The cut strip (left) is connected to another cut strip at the other edge of the detector (not shown in figure) by means of a thin met2 aluminium strip (horizontal).

ficulties by connecting each cut strip, of one triangular region, to another one of the opposite region by the aluminum strips of the second metal layer (fig. 7). Due to the trapezoidal shape of our detectors, the n^+ strip slightly diverge going from the smaller end to the larger one. The angle between the n^+ strips and the junction ones varies between 20 mrad and 60 mrad. The pitch varies from 95 μm to 125 μm and the $\frac{width}{pitch}$ ratio is kept constant at 0.48. In this way we have obtained 131 n^+ strips, 60 of which are cut by the lateral detector edges. By connecting these strips two by two with Al strips (met2) we finally obtained 101 readout strips.

As can be observed in fig. 7 the detector has p^+ implantations surrounding the n^+ strips which are connected to the guard-ring through polysilicon bias resistors. As in the previous designs the AC coupling capacitors are integrated on the detector.

5.0.3. Pads Double Sided Double Metal Wedge Detector

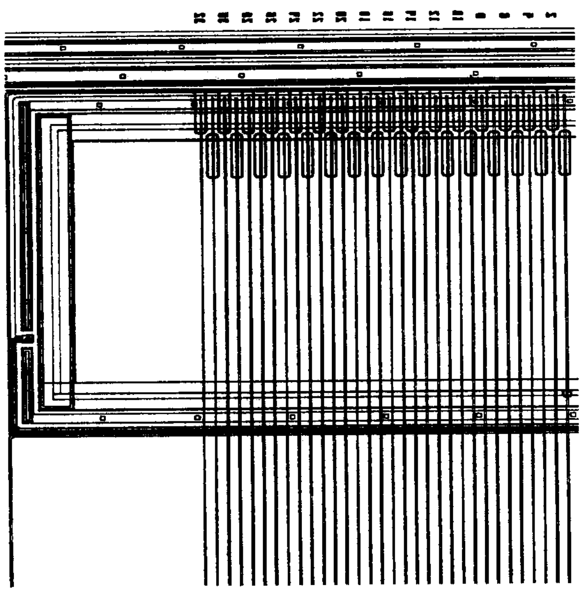

Figure 8. Pads DSDM "wedge" detector (Ω-side). A portion of pad is shown. The connection strips (vertical) run above the n^+ pad and the capacitor electrode.

The use of a two dimensional array of n^+ pads gives a simple unambiguous method to measure the particle coordinates.

Actually the limitation of the readout channels (section 2) forced us to design rather large pads with the consequence of low resolution and high capacitance.

The prototype we are dealing with has been designed with 64 n^+ pads arranged in a matrix of 2 columns and 32 rows. The pads dimensions range from 1.96 mm x 4.8 mm to 1.96 mm x 6.3 mm. The gap between two neighbouring pads is 70 μm. Each n^+ pad is surrounded by the p^+ stop implantations. Its bias resistor is connected to the n^+ guard-ring by a thin Al strip (met1). The coupling capacitors have a different design

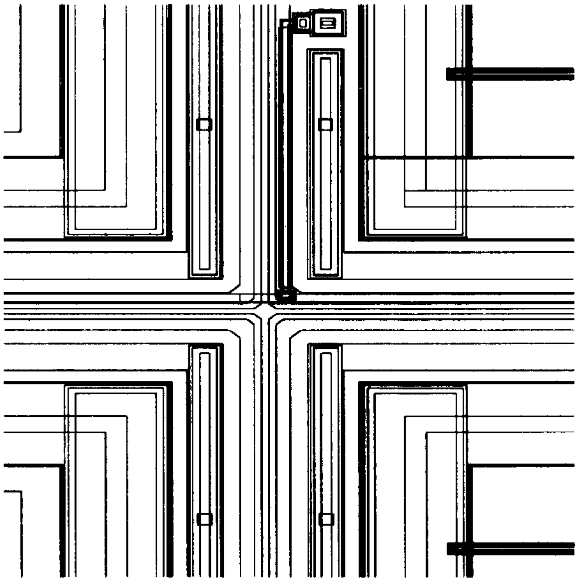

Figure 9. Pads DSDM "wedge" detector (Ω-side). Details of the contiguous corners of four pads.

in the two columns. In one column the Al electrodes have been designed as a frame of about the same dimension of the pads, 150 μm wide. In the other column the Al frame is filled with a grating pattern.

The reason of these two different geometries is that we want to find a solution which ensures a good charge collection, minimizing the capacitance between contiguous pads. The capacitors electrodes are connected to the readout contact at the wider edge of the detector by parallel Al strips (met2) with 50 μm pitch (fig. 8). An example of the masks design complexity is shown in fig. 9.

REFERENCES

1. CMS Technical proposal (1994)
2. Gill. et al, Nucl. Instr. and Meths, A322 (1992) 177-188
3. M. Edwards, G. Hall and S. Sotthinbandhu, Nucl. Instr. and Meths, A310 (1991) 283
4. Bingefors et al, Nucl. Instr. and Meths, A326 (1993) 112-119
5. LL. Jones, Internal CMS Report (1994)