PROCEEDINGS

International Europhysics Conference on HEP

The CMS Silicon strip sensors

Carlo Civinini* *On behalf of the CMS Tracker Collaboration*

Address INFN - Firenze, Via G. Sansone, 1 I-50019 Sesto Fiorentino (FI), Italy
E-mail: `Carlo.Civinini@fi.infn.it`

Abstract: The silicon strip tracker will be a key element for the discovery potential of the CMS experiment. The silicon strip sensors used in the CMS tracker consist of p+ strips on n bulk single-sided devices, as simple as possible so they can be reliably manufactured on a large scale but, at the same time, capable of performing well for at least ten years in the harsh radiation environment of LHC. The sensors design and specifications will be reviewed together with the measurements performed on the first pre-production batches.

1. Introduction

The CMS Silicon Strip Tracker (SST) [1, 2] will equip the inner region of the CMS apparatus. This system must function in a high radiation environment for at least 10 years, maintaining a satisfactory global performance despite the expected changes in the material characteristics due to irradiation. The level of irradiation coming from primary interactions will be very high around the collision region; in addition a high flux of back scattered neutrons evaporated from nuclear interactions in the material surrounding the tracker will be present. The innermost layer of SST will undergo to a fluence of 1.6×10^{14} 1 MeV-equivalent n/cm^2 during the first 10 years of operation.

The SST consists of about 19000 $500\mu m$ and 6000 $320\mu m$ thick, large area single-sided silicon strip 'p-on-n' sensors manufactured on 6" wafers. The crystal lattice orientation will be of $< 100 >$ type.

To avoid potentially critical degradation of the sensor performances due to irradiation the SST will be kept at a temperature of -10$°C$. This will drastically reduce the increase of sensor dark current and, consequently, the risk of thermal runaway of the detector modules. Furthermore keeping the irradiated sensors at low temperature substantially reduces the reverse annealing effect and helps keeping the full depletion voltage below a reasonable level.

---

*Speaker.

2. The CMS Silicon Strip Tracker

The SST layout is shown in fig. 1. The pseudorapidity coverage is $|\eta| \leq 2.5$. The detector modules are assembled using single-sided sensors with the strips parallel to the beam axis in a central or barrel region and with the strips orthogonal to the beam and nominally pointing to it in the two end-cap regions (TEC).

A double-sided module is made of two completely independent single-sided detection units mounted back to back; one of them precisely measures the main coordinate, the second one, being rotated of 100 mrad with respect to the first, gives a coarser measurement of the second coordinate. Pitches range from $80\mu m$ to $183\mu m$ in the barrel and from $81\mu m$ to 205 μm in the end-cap.

The barrel is subdivided into three parts: inner barrel (TIB), outer barrel (TOB) and inner disk (TID). The TIB has four layers assembled in shells; the two innermost layers host double-sided detectors. The two TIDs, each one made of three small disks, complement the TIB region. The outer barrel structure (TOB) consists of six concentric layers, also in this case the two innermost are double-sided. The TEC modules are mounted on nine disks on both side of barrel. The detectors of ring 1,2 and 5 are made of double-sided modules, all of them have a trapezoidal shape to follow the ring geometry.

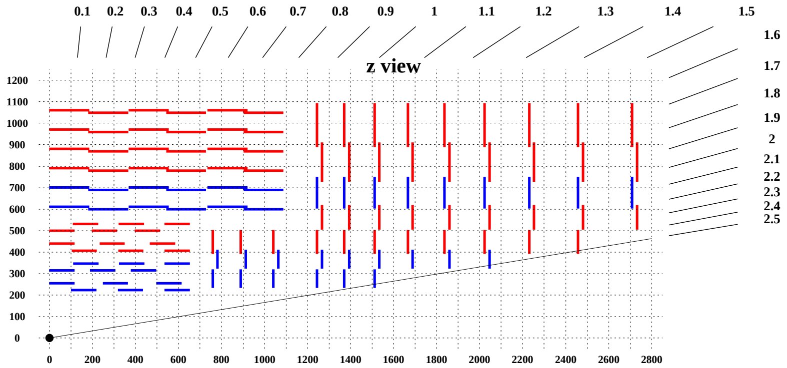

Figure 1: Longitudinal view of the CMS Silicon Strip Tracker (axis units are in mm, their origin is coincident with the nominal beam collision point; constant pseudorapidity directions are also shown).

Sensors used in the inner region (TIB, TID and TEC ring 1-4) are manufactured using $320\mu m$ thick substrates, the others make use of $500\mu m$ thick material. The read-out system, which makes use of optical analogue signal transmission, and the overall tracker performances are extensively described elsewhere [3, 4, 6].

3. Silicon Sensors

The need to instrument over 200 m^2 of active area is one of the main reasons behind the choice of single sided p-on-n silicon microstrip devices. These detectors can be manufactured using industrial 6” wafer lines leading to a reliable and cost effective production.

Besides cost considerations the tracker aims to survive at least ten years in a harsh radiation environment; appropriate design and technological choices have been taken to guarantee a stable and robust operation of the system.

Efficient charge collection of irradiated detectors can be achieved provided the sensors can be overdepleted [5]. This requirement drives the choice of substrate resistivity as well as the sensor design characteristics which improve the high voltage operation of the detectors. Furthermore detector surface damages due to irradiation may affect the capacitive coupling between adjacent strips; this can be kept under control using $< 100 >$ silicon material [7]. In order to reduce the total number of electronic channels the maximum strip length for the outer tracker is increased to 16cm with respect to 12cm in the inner tracker. This reflects in an increase of the expected noise by 15%, that is compensated through the use of $500\mu m$ thick sensors which will yield an increase of 30% in the charge collection.

In the following the main detector characteristics will be described and critically reviewed.

3.1 Sensors characteristics

Both thick and thin sensors will be manufactured using 6" technology. The sensors are single-sided, with p^+ strips on an n-type, phosphorus doped substrate, of a resistivity of 1.5$\div$4 KΩcm (thin sensors) and 4$\div$8 KΩcm (thick sensors). The crystal lattice orientation is $< 100 >$. A picture of a TOB sensor corner is shown in Fig. 2; inside the large border area the guard and bias rings are visible, together with the structures (bias resistors and bonding/test pads) located at the beginning of the strips.

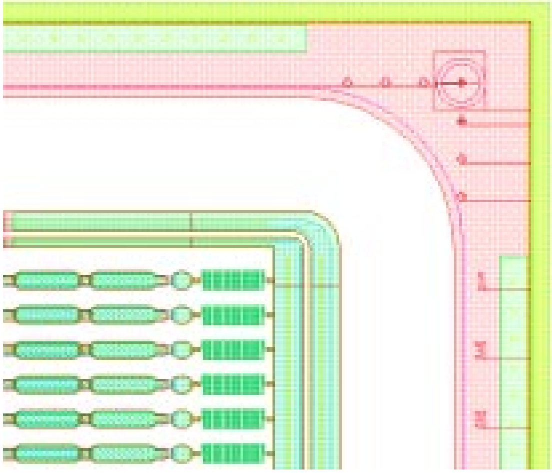

Figure 2: Close-up view of a sensor corner.

The relatively low resistivity substrate used in the inner region will help in keeping low the depletion voltage when the bulk will be type-inverted after irradiation. The high resistivity material used in the outer region, where the radiation effects will be lower, reduces the naturally higher depletion voltage of the thicker detectors ($V_{dep} \sim d^2/\rho$).

The width of the implant strips depends on the strip pitch; a constant width/pitch of 0.25 is used. Aluminum read-out strips, capacitatively coupled over the p-implants, will be wider than the implant underneath (metal overhang). This design choice will move the high edge electric field from the silicon into the much more resistant oxide layer reducing the risk of electrical breakdown[7]. The thickness of the metal layer is required to be greater than $1.2\mu m$ to reduce the noise contribution due to the resistance of the electrode.

An array of polysilicon resistors is used to bias the implant strips; these resistors are connected to each strip at one end of the sensor. Their values are centered around 1.5MΩ which is a compromise between two different needs: a low noise contribution which implies e high resistor value, and a low voltage drop across the resistor when the detector will be irradiated and the leakage current increases, which in turn implies the lowest possible value for the resistor.

An uniform, metallized, n^+ layer is present on the sensor backside providing an ohmic contact. In addition, on the junction side an n^+ implant is required over the entire cutting line as well as metallized p^+ guard and bias rings surrounding the active area of the detector. To protect the sensors during the assembly phase the front side of the detector, except some regions required for contacts and bonding to the metal layer, will be passivated. The alignment tolerances with respect to any mask is required to be $1\mu m$ maximum.

The total effective capacitance of each strip, measured as sum of coupling capacitance to the two neighboring strips on each side and the capacitance to the backplane, is expected not to exceed 1.3pF/cm at depletion voltage. This value directly determines the noise contribution of the front-end electronics.

The producers are left free to choose the appropriate technology for the integrated coupling capacitors provided they are able to satisfy the requirements on the number of defective strips. Multiple thin layers of SiO_2 and Si_3N_4 are anyway preferred as dielectric; the coupling capacitance is required to be at least 1.2pF/cm per μm of implanted strip width.

Sensors should be stable in time, without breakdown belows 500V and without excesses of noisy or faulty strips before and after irradiation. The goal is to have sensors that, once assembled in a module, will results in a fraction of bad strips that is below 2%. The leakage current for a 6" sensor ($\sim 80cm^2$) measured at room temperature and 450V reverse bias should not exceed $10\mu A$.

3.2 Tests on Sensors

Tests on the production will be performed by the producers and, on sample basis, by the CMS Tracker Collaboration. Some sensors will also be characterized before and after exposure to irradiation.

Some examples of the tests that are foreseen follow:

- Measurement of the leakage current as function of the reverse bias from 0 up to 600V;
- Measurement of the polysilicon resistance values;
- Measurement of the depletion voltage, either by the measurement of the capacitance between the back-plane and the bias ring at 1 KHz frequency as a function of the reverse bias, or by a similar measurement performed on a test diode belonging to the test structures on the corresponding wafer;
- Identification of the strips with the following defects:
  - Shorts of the metal line among neighboring strips;
  - Pinholes through the dielectric layer between the metal strip and the implant;
  - Leakage current above 100 nA.

Some sensors and test structures will be irradiated with a fluence of 1.6×10^{14} 1 MeV-equivalent n/cm^2 for thin sensors and 3.5×10^{13} 1 MeV-equivalent n/cm^2 for thick sensors.

After irradiation the sensors should not show a breakdown voltage less than 500V, a number of defective strips in a module greater than 4% and only a small increase of the strip capacitance is allowed.

3.3 Test Structures

The space that is left free by the detectors in the silicon wafers is allocated to host test structures. These devices are useful to measure parameters and features that cannot be tested directly in the full size detector (Fig. 3).

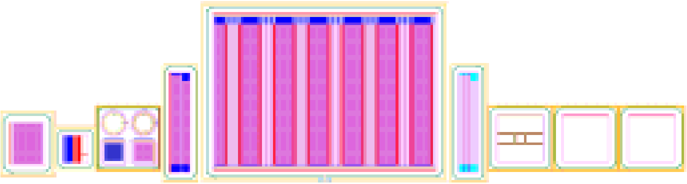

Figure 3: Standard test structures. From left to rigth: test capacitor, implant resistance measurement set, gate control diodes, strip structure for interstrip capacitance measurements, "baby" detector, strip structure for interstrip resistance measurements, one diode, two identical MOS structures.

The standard set is composed by an array of capacitors to measure their breakdown voltage; a sheet structure to measure the resistance of the implants; "Gate Control Diodes" and two MOS devices to study the charge trapped at the oxide-silicon interface; two structures, with 9 strips each, to measure interstrip capacitance and resistance, a diode and a small-size replica of the main detector. The quality of the production process will be monitored by constantly performing tests on 5% of these dedicated structure, chosen on a random basis from all the wafers used for CMS sensors.

3.4 Pre-production sensors

To validate the construction procedures the CMS Tracker Collaboration is presently involved in the realization of 200 detection modules identical to the final ones. In particular this exercise is very important to define the sensors manufacturing process details in view of the mass production. The pre-production devices are also used to setup and debug the test centres and to fine tune the control procedure and acceptance criteria before assembling them into final modules. In the following a summary of the sensors quality measurements, performed on devices manufatured at Hamamatsu Photonics and STMicroelectronics, is reported.

All of 160 sensors manufactured by Hamamatsu where accepted. Only 30 strips out of 79872 measured are defective; 18 because of broken coupling capacitors, the rest because of shorts or high currents. The total current of these large area sensors is in the 200-500nA range, while single strip current are in the 0.4-1.2nA range. The polysilicon resistor values are very homogenous among the entire sample, the mean value is slightly too high but it is easy to adjust tuning the process. The coupling capacitance spread around the mean value is only ±2% (Fig. 4); part of the structures visible in figure 4 are due to the different strip length across wedge shaped sensors.

Untill now 64 sensors from STMicroelectronics have been accepted. Out of 11362 strips tested 3 bad resistors and 5 bad coupling capacitances where found. The polysilicon resistor spread is of the order of 4-6%. A relevant fraction of the delivered sensors were kept under bias (400V in nitrogen atmosphere) for a few days to search for possible detector instabilities. No anomalous reverse current behaviour were observed.
Few sensors from both manufacturer were also tested after irradiation; similar behaviour in the laboratory electrical test was found before and after irradiation.

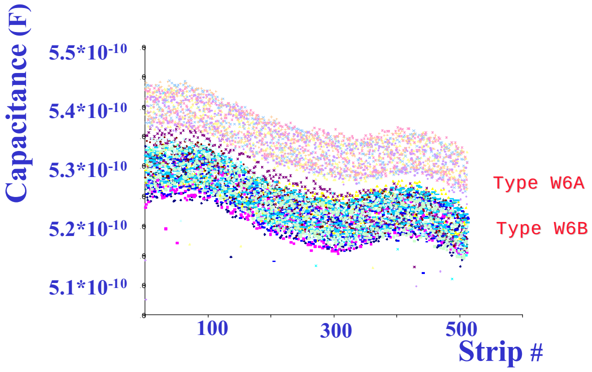

Figure 4: Coupling capacitor value for Hamamatsu sensors as function of strip number. Two kind of sensors (type W6A and W6B) of different geometry and strip length are plotted together.

4. Conclusions

The CMS Silicon Tracker Collaboration has completed the R&D programme and it is entering the mass production phase. The sensor characteristics have been defined while the production and test procedures are being tuned. Since the pre-production quality is very good we believe that the sensors needed to build the CMS tracker can be realized leading to a detector matching the strong LHC physics and radiation requirements.

References

[1] The Tracker Project, Technical Design Report, CERN/LHCC 98-6 CMS TDR 5

[2] CMS Collaboration, Addendum to the CMS Tracker TDR, CERN/LHCC 2000-016

[3] M. Raymond, *et al.* Proceedings of the 6^{th} Workshop on Electronics for LHC Experiments, Cracow, Poland, 11-15 Sept. 2000, CERN/LHCC/2000-041

[4] Optical links for the CMS Tracker, CERN/LHCC 99-033, October 1999

[5] A.Buffini *et al.* Characterization of neutron irradiated silicon microstrip detectors, presented at the 3rd Int.Conf. Radiation Effects on Semiconductor Materials, Detectors and Devices, to be published on Nucl.Instr.Methods A.

[6] M. Lenzi, Performance of the all-Silicon CMS tracker, NIM A473, 31-38, 2001

[7] S. Braibant *et al.* Investigation of design parameters and choice of substrate resistivity and crystal orientation for the CMS silicon microstrip detectors, CMS Note 2000/11, February 2000