Silicon microstrip detectors for future tracker alignment systems

D.Bassignana[a], G. Pellegrini[a], M. Lozano[a], M. Fernández[b], I. Vila[b], A.Virto[b], R.Jaramillo[b], F.J.Munoz[b]

[a]*IMB-CNM-CSIC Bellaterra, Barcelona (Spain)*
[b]*Instituto de Física de Cantabria, Santander (Spain)*

Abstract

The next experiments at particles colliders will demand stability of the tracking systems to the level of few microns. The available technology can not provide a supporting structure able to guarantee this degree of stability in working condition, when environmental changes will misalign the detectors out of their nominal position. Based on the successful experience of AMS and CMS tracker systems, we propose to use infrared laser beams traversing consecutive layers of silicon detectors to align them with respect to the beams. For such a laser track to reach the last sensor, high transmittance of microstrips sensors to infrared (IR) light is needed. We simulated the passage of a coherent beam of light through a microstrips detector and we identified the minimum set of changes to the design and technology that boost its transmittance while still respecting its tracking capabilities. The first prototypes are in process at IMB-CNM clean room facilities. We held the fabrication process at an intermediate step and we performed the first measurements of transmittance and reflectance on the sensors.

Key words: laser alignment system, microstrip tracker, diffraction, interference

---

1. Introduction

The new high energy physics experiments require high precision on the charged particles momentum measurements. For this purpouse high spatial resolution components are demanded to the tracking systems as well as high stability of the mecanical support on which the sensors are mounted. Due to environmental disturbances like local temperature gradients (produced by operation and cooling of detectors) or humidity changes, in this class of experiments, stability of any supporting structure is affected at the micrometer level. Therefore an alignment system is a solution to monitor constantly the reciprocal position of the sensors. The method proposed and implemented firstly in the AMS silicon tracker [1], and then in the CMS silicon tracker [2], is a laser alignment system. It basically consists on a IR laser beam, generated out of the tracker detectors nutshell, which traverses consecutive layers of silicon microstrip sensors. It plays the role of an infinite momentum track, not bent by magnetic field. Even if silicon is almost transparent to IR light, its absorption is enough to produce a signal the sensors DAQ electronics can read directly: beam position across several sensors can thus be monitored. Using the sensors as their own alignment system, no mechanical transfer errors between fiducial marks and the modules are introduced. In the same way, no additional material is needed, that assures a minimum impact on the system integration and no added cost.

The aim of this work is to upgrade the dedicated sensors for an equivalent laser alignment system, focusing the attention on the detectors transmittance to the IR light. The higher transmittance of the detectors, the more sensors can be aligned with a single beam and then the simpler the system becomes. In the cited previous experiences they only modified a set of sensors simply opening a circular window in their aluminum backplanes to allow the laser beam to pass through. With the idea of integrating the alignment concept in the standard production process of the detectors, we developed a complete model of a microstrips detector and we simulated the passage of a coherent beam of light through its active volume identifying the minimum changes in the design and technology to maximize the transmittance. Then we designed the mask and we started the fabrication process of the first prototypes at the IMB-CNM [3] clean room facilities in Barcelona, where we carried out a technology monitoring study during the production phases and the first measurements of the transmittance and reflectance at different intermediate steps. The experimental results are presented in this report.

2. First optical simulations

2.1. Starting point

A silicon microstrips detector, from an optical point of view, is a complex, inhomogeneous structure characterized by well defined obstacles as the metalized electrodes (microstrips) and by different materials layers (insulator or protective layers). When a laser beam hits the detector surface, the microstrips periodic segmentation causes diffraction. In addition the consecutive material layers (like SiO_2 or Si_3N_4), each one with its own refraction index and thickness comparable to the laser wavelength, contribute to split the beam into refracted and reflected waves. The beam intensity distribution across the detector finally shows interferential maxima and minima, due to the interference of the resulting different waves that travel through the sensor by different paths.

All these optical considerations, largely explaind in ref. [4] have been taken in account in our simulation work.

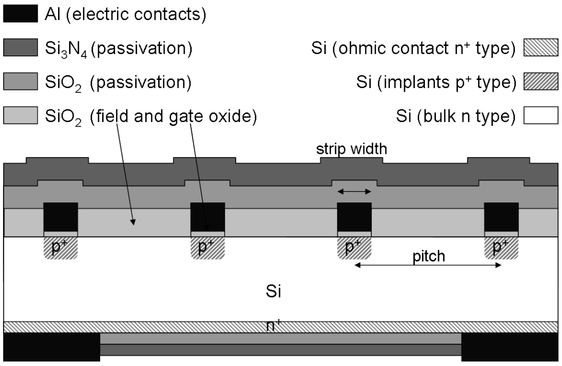


Figure 1: Schematic cross section of a microstrip detector. Geometrical and technological characteristics of optical interest are shown.The draw is not to scale.

2.2. *Simulation results*

In ref. [5] we presented the development of a detector model (see Fig. 1) and the simulation of the passage of a coherent beam through its active volume, taking into account the optical effects introduced in the section 2.1. The simulation has been validated with the use of test structures produced at the IMB-CNM facilities reproducing a strips set on silicon substrate. Figure 2 shows how the simulated transmittance changes as a function of the (metal) strip-width/pitch ratio of the sensor: the transmittance increases for larger strip pitches at a fixed value of the strip width and for a smaller strip width at a fixed pitch value. For a baseline pitch of 50 μm a metal strip width of 5 μm (strip-width/pitch ratio of 10%) optimizes the transmittance.

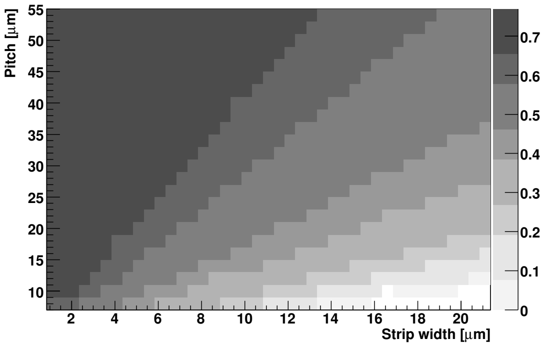


Figure 2: Simulation results of the strip-width/pitch ratio tuning.

In a second time we fixed these geometrical parameters and we simulated the same structure adjusting the thicknesses of the different material layers in order to improve the trasmittance of the detector and minimize the reflectance for a wavelength of 1085 nm. The results of these simulations for the best set of values are shown in figure 3.

3. Mask design

We designed the mask for the first prototype detectors respecting simulation hints (metal strip-width/pitch =10%) and adding test structures to validate simulation results or to study the effects of different geometries on the electrical behaviours of the sensors. All the twelve baby sensors included in the mask have 256 readout channels, a pitch of 50 μm, an active area of about 1.2 × 1.5 cm^2 and a hole (1 cm diameter) in the Aluminum backplane to allow the laser beam pass through. Half of the detectors have been completed with intermediate floating strips without metal coating, in order to improve the spatial resolution without affecting the beam passage. A short summary of sensors characteristics is shown in fig. 4. Finally, we added two diodes with 1.44 cm^2 active area and proper windows in the top and in the backplane metals and four optical test structures (with a 1 cm^2 area) consisting of different combinations of homogeneous material layers to validate the simulation model.

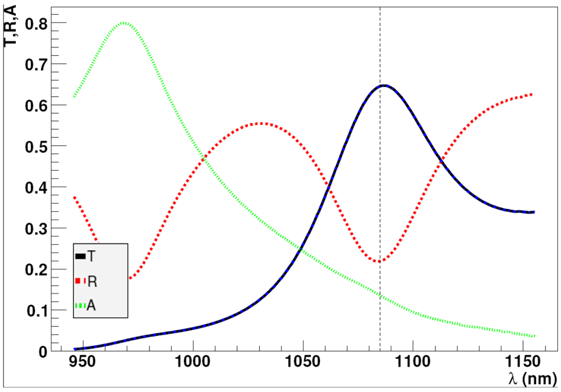


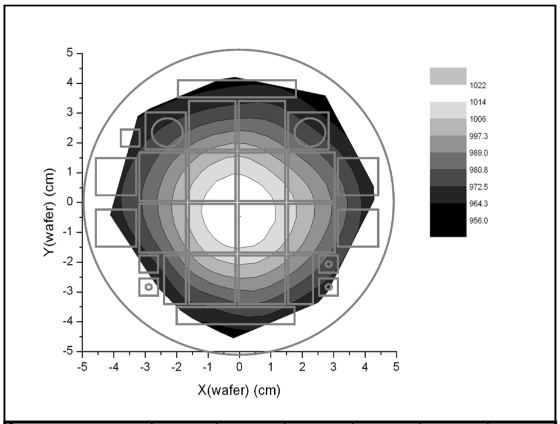
Figure 3: Transmittance, Reflection and Absorptance simulated for a microstrip detector with metal strip-width/pitch =10%. The set of thicnesses value of the different materials has been chosen to maximize transmittance for λ=1085.

	p^+ strip width	Metal width	Intermediate strips
1	15um	15um	1
2	15um	10um	1
3	15um	5um	1
4	15um	3um	1
5	12.5um	5um	1
6	17.5um	5um	1
7	15um	15um	no
8	15um	10um	no
9	15um	5um	no
10	15um	3um	no
11	12.5um	5um	no
12	17.5um	5um	no

Figure 4: Geometrical characteristics of the twelve baby detectors included in the mask design.

4. Fabrication Run

The fabrication run has been carried out at the IMB-CNM clean room facilities in Barcelona on six n-type FZ wafers. The



Wafer / Statistics	W1	W2	W3	W4	W5	W6
Mean (nm)	949	980	986	978	955	962
Uniformity (%)	3.3%	3.4%	3.1%	3.2%	3.5%	4.4%

Figure 5: Distribution of the measured thicknesses of deposited silicon oxide on the wafer upper surface (wafer 2). Values are expressed in nm.

standard process has been modified taking in account the simulation results for what concerne the layers thicknesses. To evaluate the quality of the processes in our facilities, we stopped the fabrication run after each oxidation, sputtering or deposition step and we measured the thickness of each layer: thermal and deposited silicon oxide with an ellipsometer and the sputtered Aluminum with a profilometer. The thicknesses measured are in agreement with the values expected with a tolerance of 5%. Furthermore the variation of the thickness values is ≤5% on the surface of each wafer, as shown in fig. 5. Figure 5 shows a thickness map of the passivation silicon dioxide on wafer 2. In this case the oxide is thicker in the center of the wafer than in the edge. In the wafer map it is possible to recognize the twelve detectors in the central zone, surrounded by different test structures. The four square structures (two in the left, two in the right near to the edge) are the optical test structures (homogeneous layers structures). Tolerance and heterogeneity combined will reduce the maximum transmittance value, since the expected thickness can not be matched exactly. For this reason we decided to start a new simulation using the values measured for each material layer up to the passivation silicon dioxide and tuning the thickness of the last nitride layer to choose a value that yields maximum transmittance within a 5% deposition tolerance. Actually it is possible to build up an AntiReflection Coating (ARC) (Fig. 6) tuning only the thickness of the passivation layer (SiO_2 and Si_3N_4) deposited on the top surface of the detectors, the first one the beam hits in traversing the detectors. So we held the fabrication run, just after the passivation SiO_2 deposition and before Si_3N_4 deposition.

5. First transmittance measurements

We performed the first transmittance and reflectance measurements with the use of a custom designed grating spectrometer optimized in a wavelenght range =[950,1150] nm with 1 nm spectral resolution, able to measure transmittance and reflectance acquired [4].

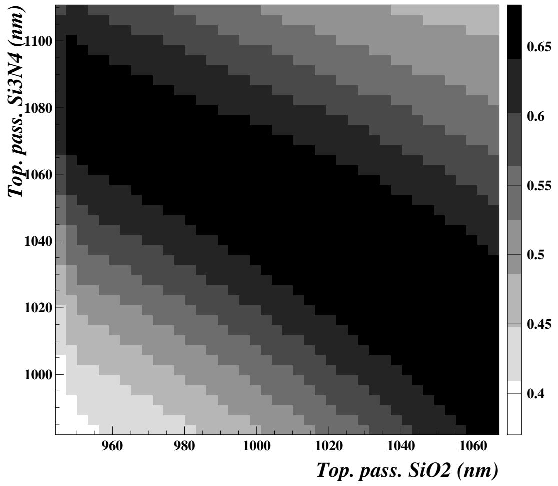


Figure 6: Simulation results of the AntiReflection Coating (ARC).

In figure 7 the results on all the twelve detectors and optical test structures are shown. For each structure, the transmittance value (%T) has been measured (ordinates) for the wavelenght range available (abscissa). The pointed vertical line is in correspondence to λ=1085.

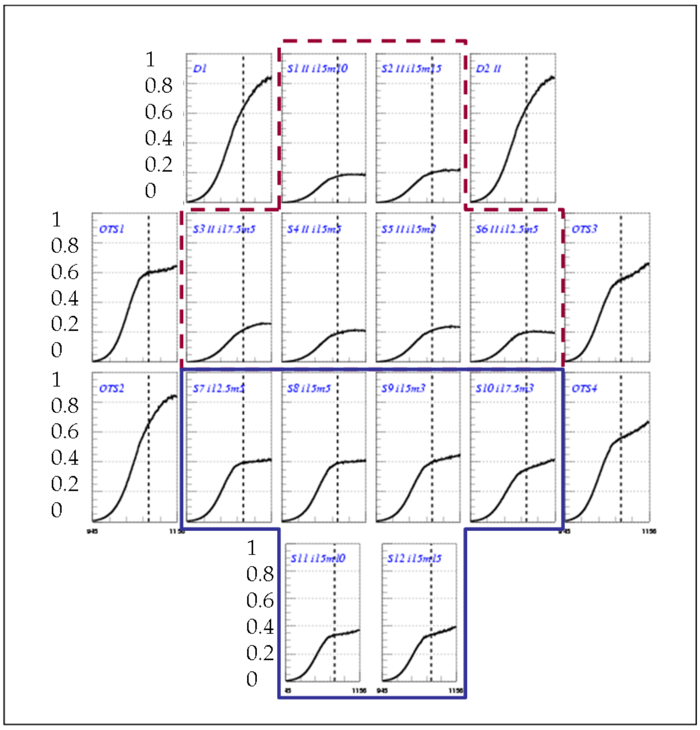


Figure 7: Transmittance measurements before depositing the Si_3N_4 layers.

The results included in the top (dotted line) frame refer to the detectors with intermediate implants, while the ones included in the bottom (continuous line) frame refer to the detectors without intermediate strips. The two upper graphs exterior to the dotted line frame, show the trasmittance of the diodes while the others four are the results for the optical test structures. All these homogeneous layers structures give the higher transmittance value (up to 70% for λ=1085) as predicted by simulation. The microstrips pattern reduce sensibly the beam intensity measured at the exit of the detector. Transmittance value is 40% for the detectors in the bottom frame and this value is cut in half for the detectors with intermediate implants (top frame), even if these strips do not have any metal covering. The metal strip width does not affect much the transmittance of infrared laser: changing from 3 μm to 15 μm the metal width, its value decrease only by 5%. Figure 8 shows Reflectance measurements results (%R) with the same correspondence between graphs and structures.

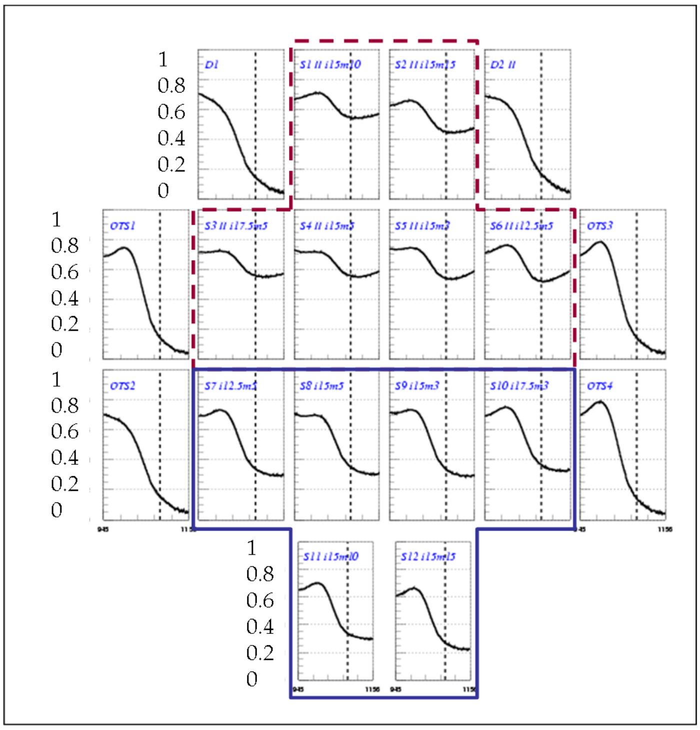


Figure 8: Reflectance measurements before depositing the Si_3N_4 layers.

For the particular wavelength λ=1085, homogeneous structures give a reflectance value <20%. The segmentation of the microstrips, with or without metal strips coating, is more influential on the Reflectance increase than the metal strip width. The break of the upper surface homogeneity, due to the process steps to create the strips implants (Fig. 9), results the main cause of the transmittance degradation and reflectance increase. All these results have been reproduced with the simulations, validating the quality of the model developed.

6. Conclusions

New silicon microstrip detectors optimized for future tracker laser alignment systems have been presented. We developed a full optical simulation model to investigate the changes in the design and in the technology of the device to maximize transmittance to the IR light without affecting tracking capabilities.

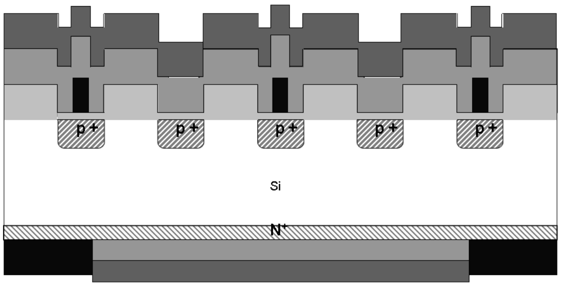


Figure 9: Schematic cross section of a microstrip detector with intermediate implants. The colors refer to the materials as in figure 1. The draw is not to scale.

We found the optimal metal strip-width/pitch ratio to be =10% when a set of thicknesses values for the material layers involved in the detector fabrication is chosen. A production method compatible with deposition tolerance of sensor manufacture has been described too. We performed the first transmittance and reflectance measurements at an intermediate step of the detector production. The results show the importance of the homogeneity of the upper surface in improving trasmittance. A maximum value of 40% has been reached in the detectors without intermediate strips. At the moment, new simulations are being carried out to choose the thickness of the last Si_3N_4 layer which will boost the expected transmittance up to a 70%.

7. Acknowledgements

This work has been supported by the Spanish Ministry of Education and Science through the GICSERV program ”Access to ICTS integrated nano-and micro electronics cleanroom”.

References

[1] W. Wallraff, ”TAS status”, AMS Tracker Meeting, CERN, February 9^{th} 2005 http://ams.cern.ch/AMS/Tracker/Meetings/20050209/Wolfgang 050113 TASww1a.ppt

[2] B.Wittmer et al., ”The Laser Alignment System for the CMS Silicon Microstrip Tracker”, Nucl. Instr. and Meth. A581 (2007)

[3] http://www.cnm.es/

[4] M. Fernández et al., ”R&D on Microstrip IR Transparent Silicon Sensors” Eudet Memo 2007-32 http://www.eudet.org/e26/e28/e182/e428/eudet-memo-2007-32.pdf

[5] M. Fernández et al., ”New silicon microstrip detectors optimized for tracker alignment” Nucl. Instr. and Meth. A, article in press, available online.