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Final production of novel IR-transparent microstrip silicon sensors

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Abstract

We report on the production and first optical measurements of novel infrared transparent microstrip detectors produced at CNM-IMB Barcelona, in collaboration with IFCA-Santander. The novel aspect of these detectors is the optimization of the thickness of the passivation layers to act as an antireflection coating. The transmittance to infrared light can thus be increased by almost a factor $\times 3$ with respect to standard microstrip detectors.

1 Introduction

For the particular case of tracking detectors, a very elegant alignment method has been recently proposed and implemented [1] at the Alpha Magnetic Spectrometer (AMS) [2] and subsequently adopted [3] by the tracking system of the Compact Muon Solenoid [4]. In a nutshell, consecutive layers of silicon sensors are traversed by IR laser beams which play the role of infinite momentum tracks (not bent by the magnetic field). Then,

the same sophisticated alignment algorithms as employed for track alignment with real particles can be applied to achieve few microns relative alignment between modules. Furthermore, since IR light produces a measurable signal in the silicon bulk, there is no need for any extra readout electronics. And all these advantages come to a minimum cost: a small circular window (few mm diameter) on the aluminum back-metalization must be open to allow the IR beam to pass through.
In previous works [5], [6] we identified the key parameters that determine the overall transmittance of a microstrip detector. These are divided into layout parameters (narrowing of the width of the aluminum electrodes) and structural changes (tuning of passivation thickness). These changes do not imply major modifications on the design of standard microstrip detectors.
This note summarizes the current choice of parameters, production process and first results of the first baby sensors produced within the GICSERV08 [7] access program to CNM clean room facilities.

2 Parameters for highly transparent IR microstrip detectors

The full optical simulation tool presented in EUDET memo [6] has been used to design a set of 5+1 wafers of baby sensors (each sensor is 1.5×1.2 cm^2) optimized for high transmittance at λ =1085 nm. Five of these wafers have openings of 1 cm diameter in the backelectrode to allow the transmitted light to propagate downstream. The last wafer however has a continuous back metalization and is used as a reference.
The choice of layer thickness was constrained by some CNM-IMB design guidelines. The thickness of field oxide, electrodes and gate oxide was fixed to standard values. Only top and bottom passivation thickness were allowed to vary. Furthermore, thick ($> 1\mu$m) layers of Si_3N_4 are not advised due to the different expansion coefficient of the nitride compared to silicon, leading to overstress of the wafers. The set of thickness values that fulfill these constraints and still lead to maximum transmittance are presented in table 1.
The choice of readout pitch was fixed to 50 μm. The width of the aluminum electrode and p-implant was varied from sensor to sensor within the wafer to study the dependence of transmittance on these layout parameters. Figure 1 shows the arrangement of sensors in the wafer. The 6 sensors in the upper half have one intermediate (capacitively coupled) implant within 2 readout strips (cross section shown in Fig. 2), thus doubling

Layer	Si_3N_4 (top)	SiO_2 (top)	Al	SiO_2 (field oxide)	SiO_2 (gate oxide)	SiO_2 (bottom)	Si_3N_4 (bottom)
Thickness (nm)	1046	1006	950	1000	47.5	1020	1005

Table 1: *Set of optimized thickness leading to maximum %T on 50 μm pitch microstrip detectors.*

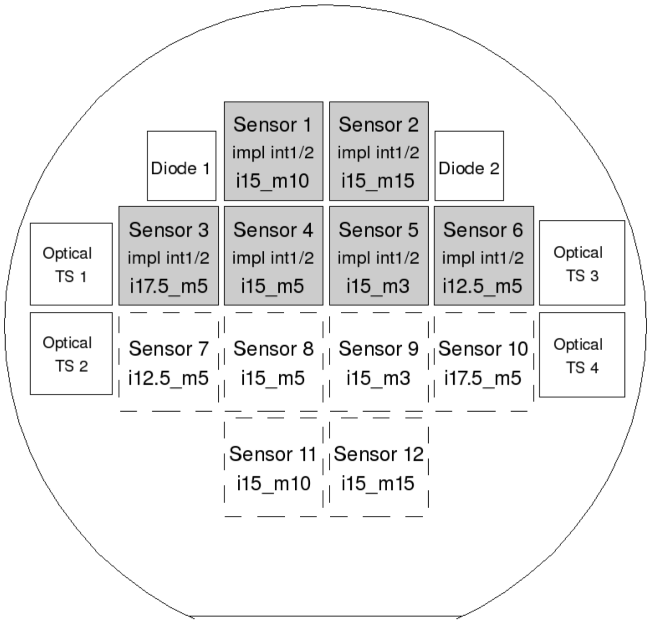

Figure 1: Overview of the sensor arrangement in the wafers. Sensors are labeled in increasing order, from top left to right bottom.

the periodicity of the implants to 25 μm. The remaining 6 detectors have implants each 50 μm (Fig. 3). One leftmost and one rightmost structure in the top row (Diode 1 and 2) are control diodes. Unpatterned optical test structures (OTS1 to OTS4) are placed in rows second and third. These structures allow to extract and monitor optical constants (refraction indexes and thickness) of the materials employed in the production. Table 2 summarizes the different layout geometries probed. Finally, these wafers also include test structures designed by HEPHY-Vienna used for direct measurements of the detector electrical parameters.

3 Transmittance of microstrip detectors without nitride passivation

As already mentioned, the thicknesses of the 2 top passivation layers (Si_3N_4 on SiO_2) determine the optical behavior of the sensor. Eventually, and for this first run only, the thickness of each layer was measured after each deposition process, thus having a full information on the cross section of the wafer. We then decided to pause the processing of the wafers one step before the deposition of the last layer of Si_3N_4. The purpose of this breakpoint is three-folded. First, the simulation can be crosschecked by comparison with measurements of the almost completed devices. Second, optical constants of the actual deposited materials can be extracted using the control OTS and fedback into the

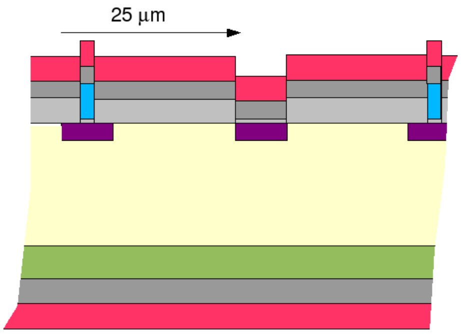

Figure 2: *Cross section of a sensor with an intermediate implant, 25 µm away from a readout electrode. Color code: red for nitride, gray for silicon dioxide, violet (green) for p (n) implant, yellow for Si. Not to scale*

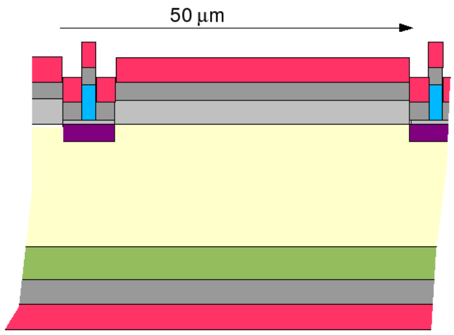

Figure 3: *Standard ILC baseline strip sensor cross section. Same color code as the figure in the left. Dimensions are not scaled.*

simulation. Third, we can re-tune the thickness of the last layer of nitride taking into account the measured thickness of all the previous layers.
Fig. 4 shows measured and calculated transmittance and reflectance for the OTS structures. The agreement between measurement and simulation is very good considering that no fit is involved in this computation. From this figure we can see that the transmittance of a raw slab of Si (T≈50% at 1100 nm) can be increased by almost 40% extra with just one layer of silicon dioxide, acting as an antireflection coating. The analysis of the OTS also confirmed that the refraction indexes of intrinsic silicon, doped silicon and silicon dioxide as used in the simulation must be very close to the actual deposited values.
The transmittance for the 12 sensors, 2 control diodes, and these 4 optical structures is shown in Fig. 5. The computed transmittance is also shown, overimposed to these plots. This transmittance is calculated as a far field approximation of the exact fields computed at the exit window of the detectors. The details of this approximation will be given in a nextcoming EUDET note.

3.1 Transmittance of microstrip detectors with nitride passivation

Prior to the deposition of the outermost passivation layer, a sample of Si_3N_4 on Si was characterized. The aim of this exercise was to compare the optical constants of the material produced at CNM with the set of tabulated standard indexes [8]. Figure 6 shows the transmittance and reflectance (black lines) of silicon nitride on Si. Measurements

Sensor Number	Implant width	Metal width	Int. strip
1	15	10	Yes
2	15	15	Yes
3	17.5	5	Yes
4	15	5	Yes
5	15	3	Yes
6	12.5	5	Yes
7	12.5	5	No
8	15	5	No
9	15	3	No
10	17.5	3	No
11	15	10	No
12	15	15	No

Table 2: *Layout of baby sensors. All sizes in microns.*

are compared to calculated optical functions (color lines). The agreement is remarkable (again the calculations do not use any fitting), indicating the good reproducibility of the material produced by CNM.
Using all the information cited above we have recalculated the maximum transmittance achievable for these specific set of indexes and thickness. Maximum calculated transmittance reaches 68%. Deposition of the last layer of Si_3N_4 is taking place at the time of writing this note. Once this layer is deposited, we will carry out measurements of transmittance and reflectance of the fully completed structure. These measurements will be followed by dicing of the structures, electrical characterization and a comprehensive test using a laser source and motorized stages. All these actions are envisaged during year 2010.

4 First test beam results on standard CMS microstrip detectors modified for alignment

Besides the set of optimized sensors for IR maximum transmittance, 2 CMS sensors produced by Hamamatsu Photonics were beam tested during 2009 campaign. These were normal CMS sensors with a hole in the Al back metalization to allow light to pass through. Details of optical measurements undertaken prior to the mounting on modules were already given in [6]. Signal to noise ratio (SNR) in the alignment passage was compared (using the particle beam) to the same ratio in other zones of the sensors having the Al intact. Fig. 7 shows this comparison. The first point is well within the alignment passage and its performance is not degraded compared to Al covered areas. Signal with particles was also compared to the signal with laser beam (λ=1082 nm). Further analysis of this data is still ongoing.

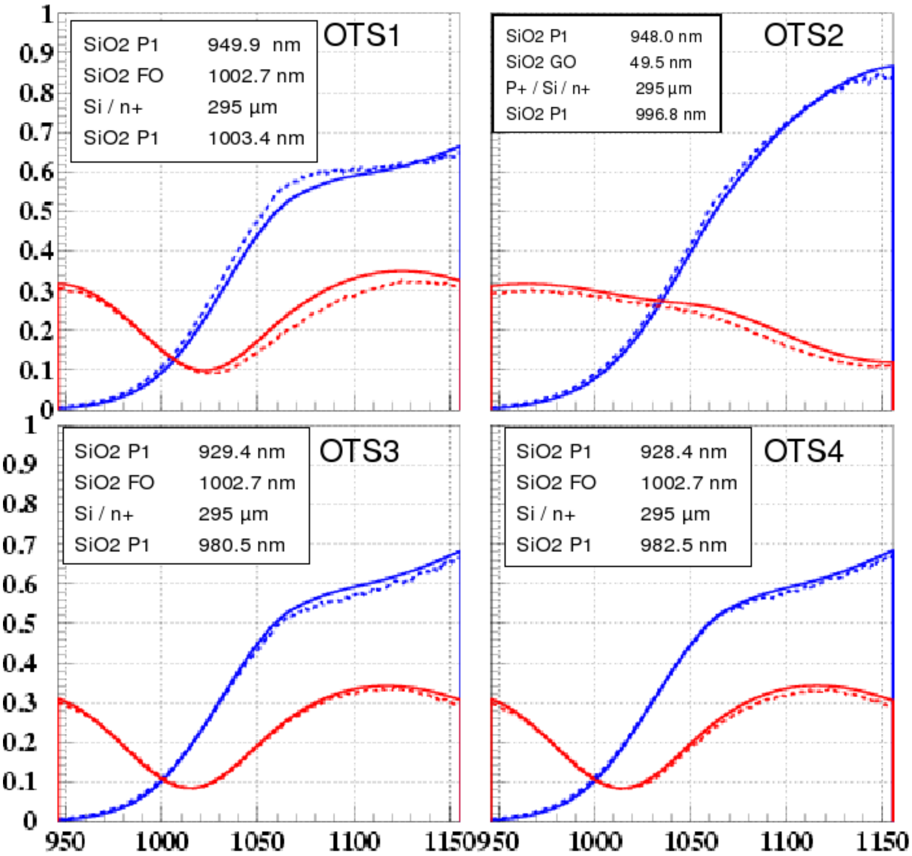

Figure 4: Measured transmittance (dashed line, blue) and reflectance (red) of the 4 OTS (ordinates axis) versus wavelength (in abscissas) compared to calculation (continuous lines).

5 Conclusions

First measurements of new IR-transparent microstrip sensors optimized for transmittance were presented. The transmittance without the final passivation layer is already 20% higher than the measurement of a CMS sensor with the same pitch. Beam test measurements of new CMS-like detectors showed no degradation when comparing the SNR of the central alignment passage to standard areas with full Al metalization.

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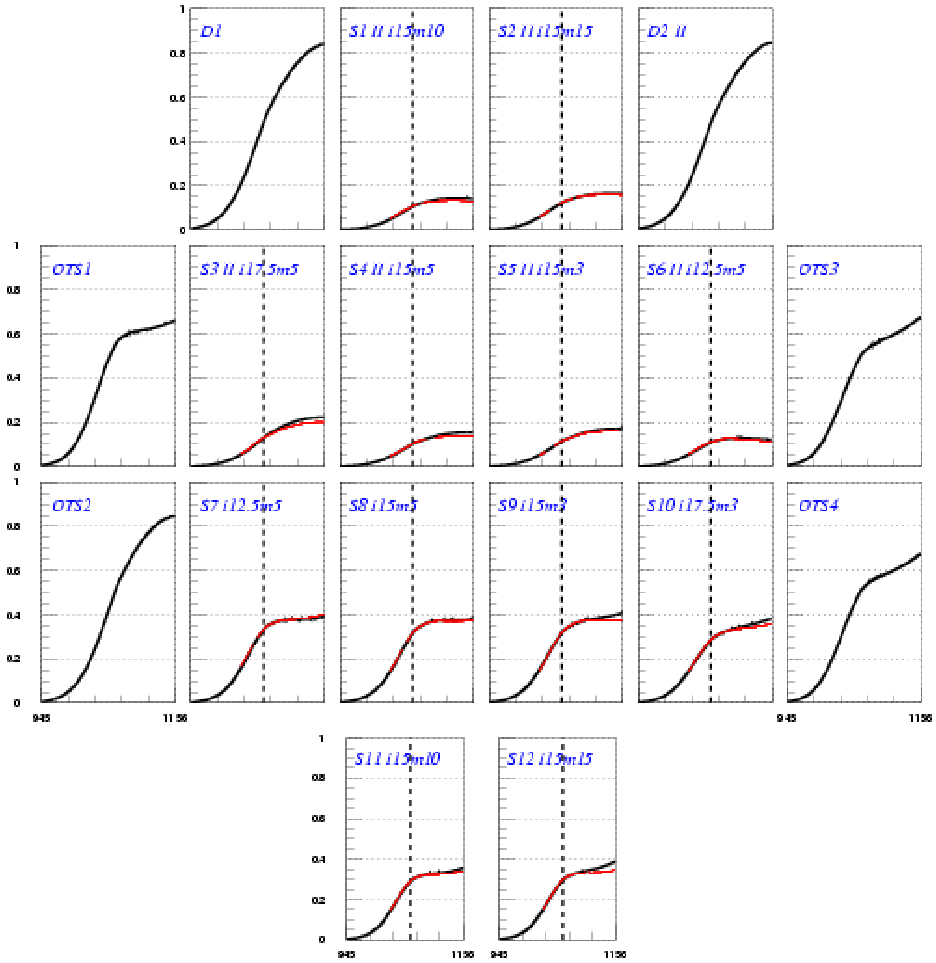

Figure 5: Measured transmittance (black) and calculated (red) for the 12 sensors of the wafer

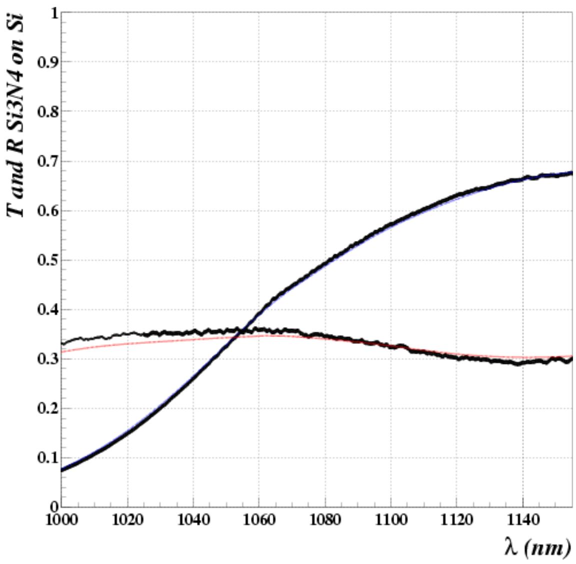

Figure 6: *Measured transmittance (black, slanted line) and reflectance (black trace, horizontal) of a 1 μm thick layer of Si_3N_4 on Silicon, compared to calculation. Blue graph for transmittance, red for reflectance.*

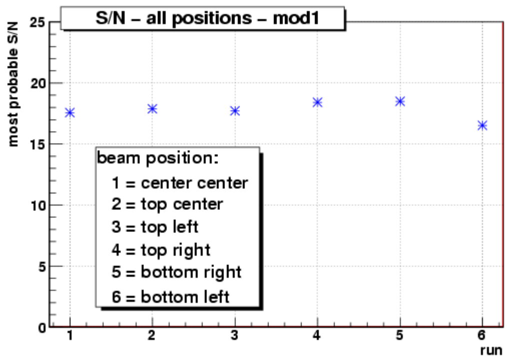

Figure 7: *SNR measured with particles in the center of the detector (point 1) without Al, compared to the areas around the alignment passage.*

that allowed access to the CSIC-CNM Clean Room. One of the authors would like to thank R. Bienstman (Univ. Ghent) for independent crosschecks of some of part of these calculations.

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