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Semitransparent microstrip detectors for infrared laser alignment of particle trackers

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Abstract

We have produced multigeometry silicon microstrip detectors (pitch=50 μm, strip width from 3-15 μm) that reach 50% transmittance in the near infrared region. Measurements of the wafers are presented.

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 infrared (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 the IR laser produces a measurable signal in the silicon bulk, there is no need for any extra readout electronics.

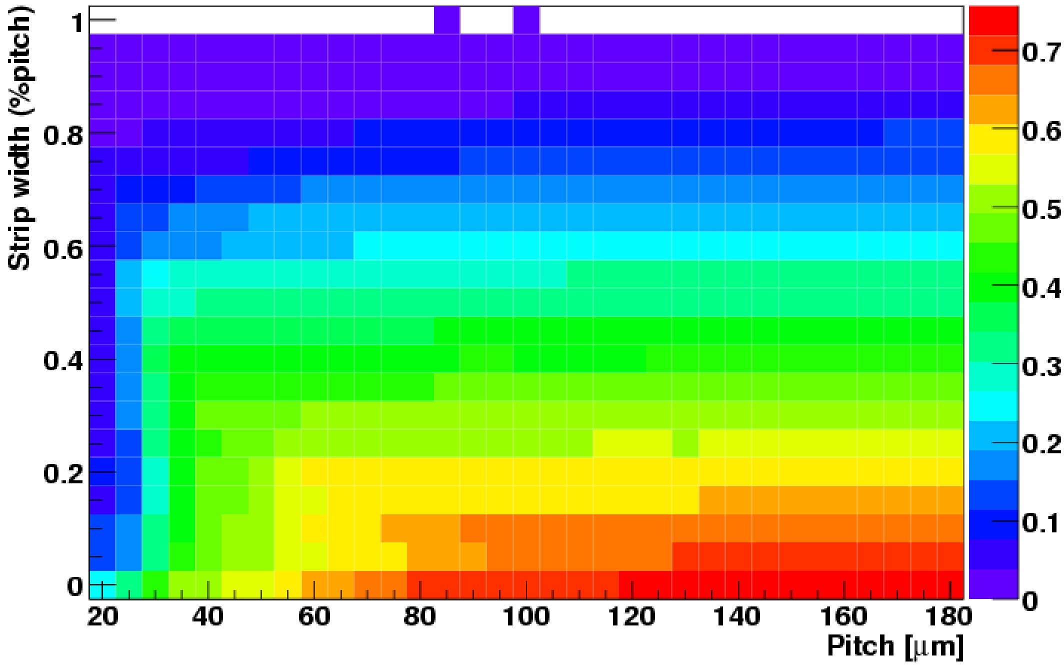

Figure 1: Transmittance coded in colors, as a function of the pitch (horizontal axis) and the strip width (expressed as a percentage of the pitch). The simulated sensor has no intermediate implants. Pitch refers to distance between electrodes. This figure depends on the set of thickness of the different layers.

1.1 Summary of former results

Details on the simulation tool developed to calculate the transmittance of a generic microstrip detector and details of the fabrication process were reported in [5, 6]. In summary, any microstrip detector can be made partially transparent to IR light by opening a small window (few mm diameter) in the aluminum backelectrode. The percentage of transmitted light is determined by the pitch of the implants (first order effect) and by the width of the metal electrodes (second order effect). Figure 1 shows the simulated transmittance as a function of pitch (abscissas) and strip width (expressed as percentage of the pitch). Transmittance drops for pitch values below 30 μm. For pitch<50 μm the maximum transmittance remains constant for strip width of up to 50% of the pitch and is T$\sim$50% maximum. For the sensor simulated in Fig. 1, the best transmittance (T$\sim$ 70%) is obtained for any pitch bigger than 80 μm and strip width lower than 10% the pitch. Once pitch and strip width are fixed, the transmittance can be increased by

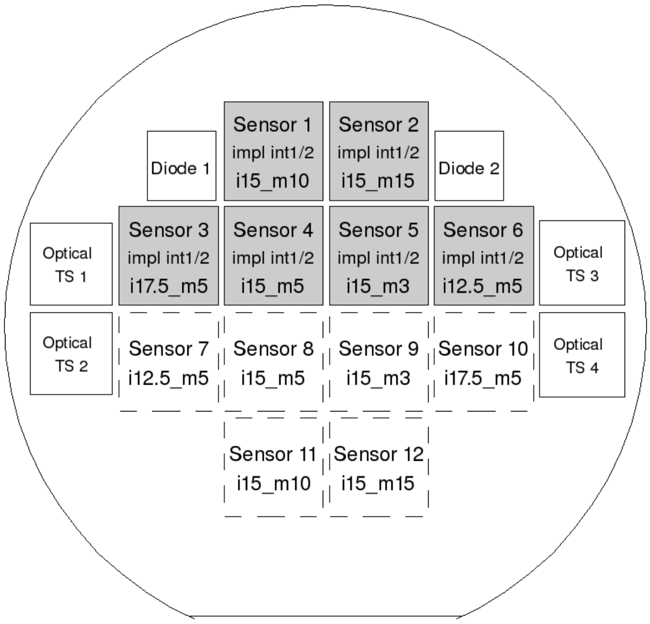

Figure 2: Overview of the sensor arrangement in the wafers. Sensors are labeled in increasing order, from top left to right bottom. Sensors 1-6 have an intermediate, capacitively coupled, strip. Notation: i15_m10 refers to a sensor with implant width of 15 μm and metal width 10 μm, for instance.

tuning the thicknesses of the topmost and lowermost layers.

1.2 Production of transparent microstrip detectors

During 2009 a run of 6 wafers containing 12 multigeometry baby sensors was processed at the Centro Nacional de Microelectronica CNM-IMB [7]. The run was paused before the deposition of the last (upper- and bottom-most) layers of silicon nitride. Then the simulation was crosschecked against the unfinished detector, measuring the transmittance of the sensors in the wafer and comparing it with the predicted values. This allowed to debug our software and re-use it to calculate the thickness of silicon nitride needed to achieve maximum transmittance.

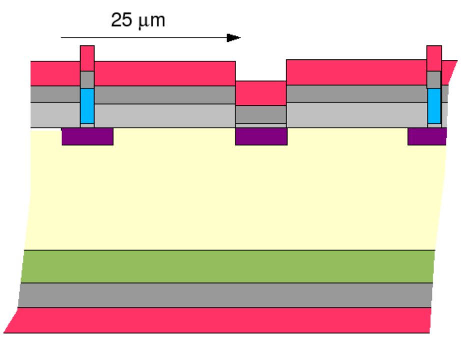

Figure 3: Cross section of a sensor with an intermediate implant, 25 μm away from a readout electrode. Color code: red for nitride, gray for silicon dioxide, violet (green) for p (n) implant, yellow for Si. Not to scale

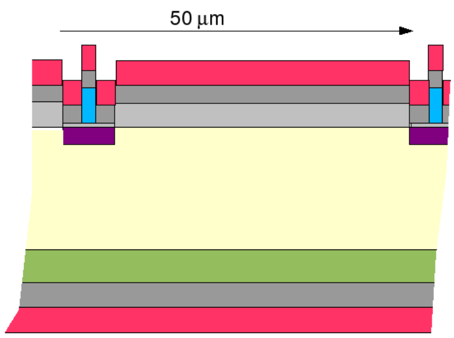

Figure 4: Standard ILC baseline strip sensor cross section. Same color code as the figure in the left. Dimensions are not scaled.

Sensor	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 1: Layout of baby sensors. Sizes in μm.

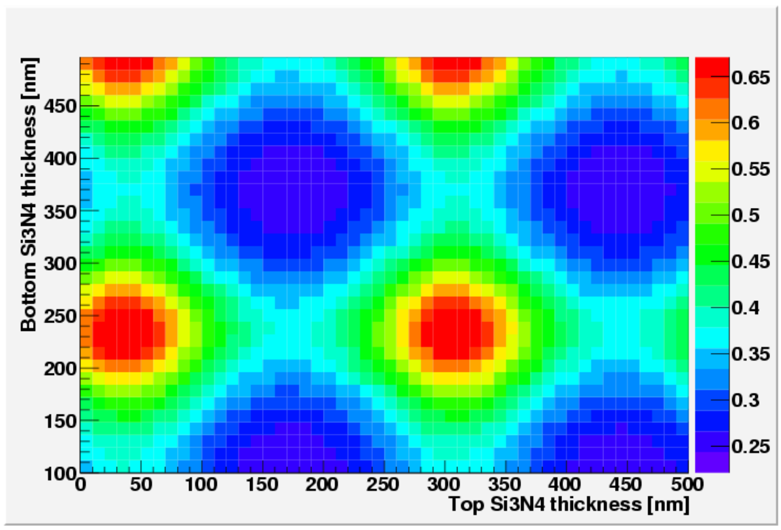

Figure 5: Transmittance as a function of the thickness of top (horizontal) and bottom (vertical) nitride layers (sensor 9, λ =1085 nm

The choice of readout pitch was fixed to 50 μm. The width of the aluminum electrodes and p-implants was varied from sensor to sensor within the wafer to study the dependence of transmittance on these layout parameters. Figure 2 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. 3), thus doubling the periodicity of the implants to 25 μm. The remaining 6 detectors have implants each 50 μm (Fig. 4). One leftmost and one rightmost structures 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 1 summarizes the different layout geometries probed. Finally, these wafers also include test structures designed by HEPHY-Vienna [8] (used for direct measurements of the detector electrical parameters) and prototype sensors with polysilicon strips (designed by IFCA and CNM) to investigate tracking by charge division.

2 Transmittance of microstrip detectors without nitride passivation

The thickness of some layers was constrained by CNM-IMB technological process. Only top and bottom passivation thickness were freely allowed to vary. The passivation film consists of a layer of silicon nitride on top of silicon dioxide. We apply a 2-sided passivation to the detectors: one double layer in the strip side (front) and another double layer in the ohmic contact (rear) side. The simulation showed that the total transmittance of the detector may be selected by careful choice of the thickness of the outermost layers of silicon nitride. Figure 5 shows the transmittance, coded in color, of one of the sensors in the wafer (sensor 9) as a function of the thickness of the top nitride layer (horizontal axis) and bottom nitride layer (vertical axis). The transmittance is periodical in both variables, as the "isles" where it is maximum (red areas in the plot) are equidistant along each coordinate separately. Besides, the absolute transmittance value (maximum T$\sim$60%) is also the same across islands. This is easy to explain since neither silicon dioxide nor silicon nitride have absorption in the near infrared range of interest.

The passivation process started with a deposition of 230 nm of nitride in the backside of wafers 3-5. Figure 6 shows the measured transmittance (red line), as a function of wavelength, for the 12 sensors of wafer 3 with 230 nm of Si_3N_4 in the backside. A 5% increase at λ =1085 nm is observed with respect to the wafer without nitride coating (black line). Indeed Fig. 5 shows that this configuration (top nitride=0 nm, bottom nitride=230 nm) is already close to the first island of maximum transmittance.

The factor 2 lower transmittance for the 6 sensors with 25 μm implant pitch is due to the higher diffraction angle of the transmitted beam, that removes light away from the incident direction. A calculation of the intensity of light as a function of distance for one sensor with intermediate strips is compared to a sensor without it, in Figures 7 and 8. The vertical scale corresponds to the size of the collimating lens we use in front

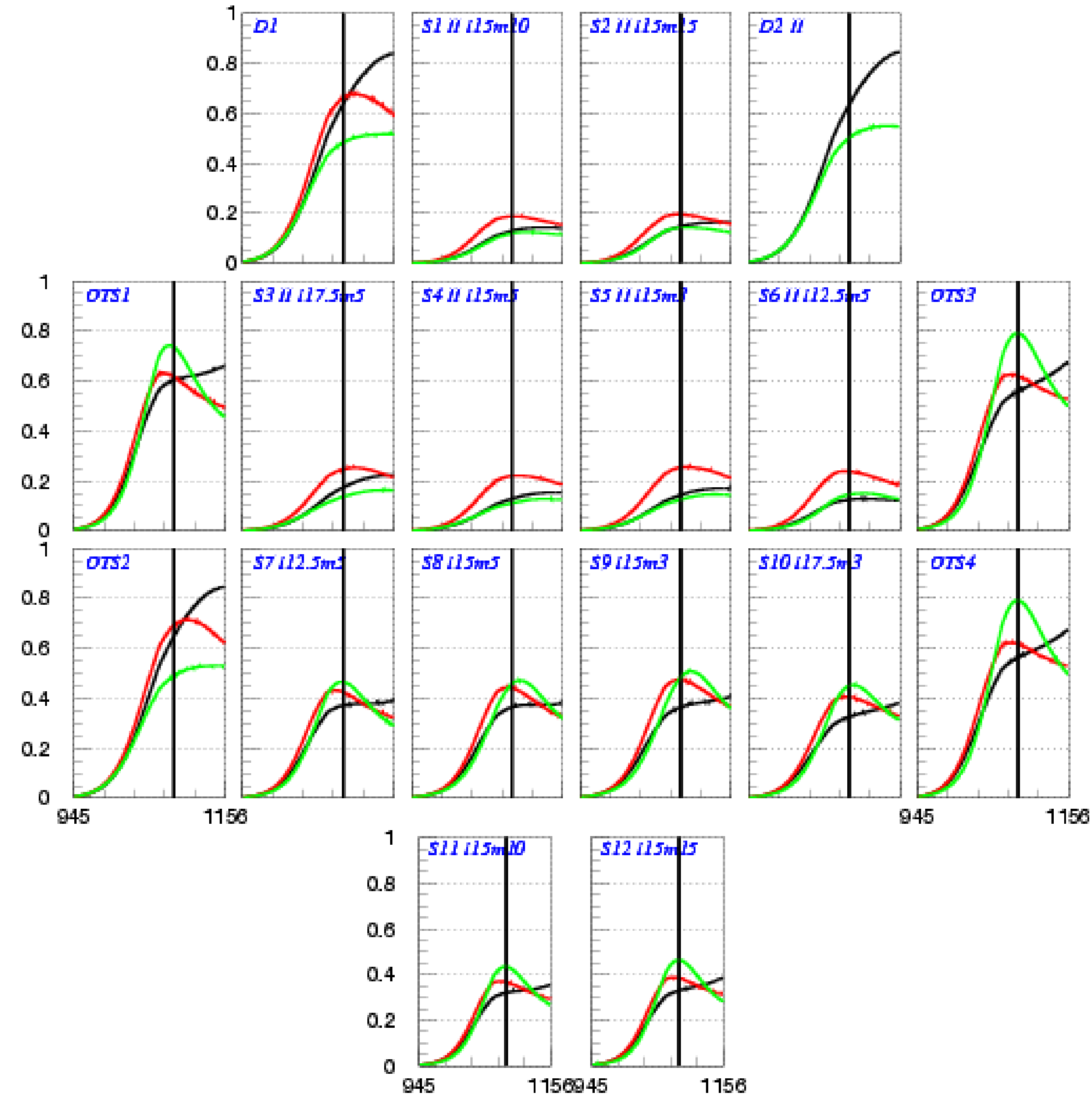

Figure 6: Measured transmittance for a wafer with no nitride passivation (black line) compared to the same wafer with (top=0,bottom=230) nm nitride thickness (red color) and (top=50,bottom=230) nm (green). The horizontal axis shows the wavelength in nm. The vertical line in each plot corresponds to $\lambda = 1085$ nm.

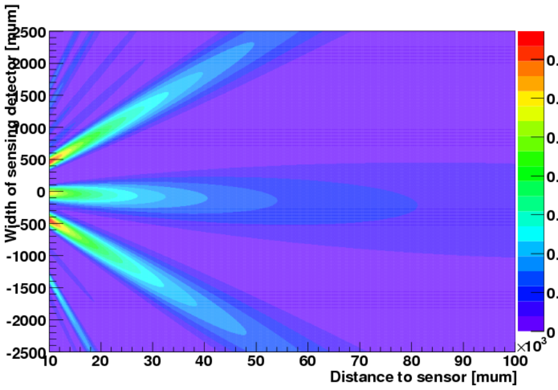

Figure 7: Development of the intensity profile (arbitrary units) as a function of distance (horizontal axis) calculated for a sensor with intermediate strips. The vertical coordinate shows a section of the beam perpendicular to the propagating direction.

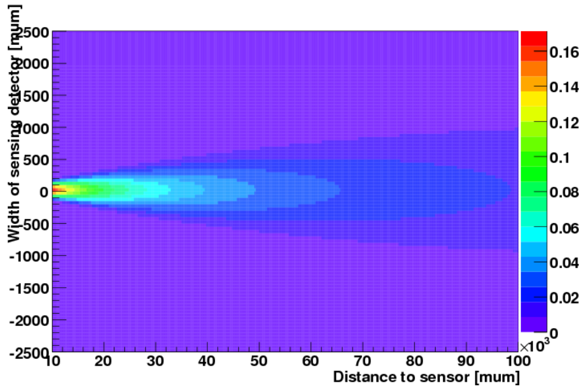

Figure 8: Same as Fig. 7 but calculated for a sensor without intermediate strips

of our detector. For the sensors with intermediate strips, part of the light is lost before reaching the lens placed at X= 60 cm. For sensors with 50 μm implant pitch, most of the energy goes forward. Black lines in Figure 6 show the transmittance of the wafer without before nitride deposition.
Next, we moved to the first island with maximum transmittance in Fig. 5, obtained depositing ~50 nm of top nitride. Transmittance T(λ=1085 nm) surpasses 50% (green line in Fig.6) which is a very remarkable achievement and confirms validity of this procedure.
At the time of writing this memo, a final deposition of extra 260 nm of top nitride is foreseen. Results of this deposition will be attached as an addendum to this note.

3 Comparison to other transparent microstrip detectors

A transmittance value of 50% with a pitch of 50 μm is a very good improvement with respect to other versions of transparent detectors. For instance, CMS obtained transmittance of 20% for a pitch of 189 mumm [3]. The comparison with AMS is less direct, since the detectors are double sided, with crossed strips. For reference, the maximum transmittance achieved there was 50% [1] with a 110 μm readout in one of the sides.

4 Conclusions

The transmittance of a microstrip detector depends on the periodicity of the implants. The closer the implants, the higher diffraction angles and the lower transmittance collected along the incoming propagation direction. Once the implant pitch is fixed, the thickness of the different layers can be selected to maximize the transmittance. If the deposited thickness of the layers are measured, then one can choose the thickness of the topmost and lowermost layers that leads to a maximum transmittance value. This procedure has been followed to produce sensors with a transmittance that surpluses 50%.

Acknowledgment

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