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JRA2 SiTRA Alignment activities during 2007 *

M. Fernández, J. González, S. Heinemeyer, R. Jaramillo,

A. López, C. Martínez, A. Ruiz, I. Vila

Instituto de Física de Cantabria, Universidad de Cantabria and CSIC, Santander (Spain)

M. Lozano, G. Pellegrini, E. Cabruja

Centro Nacional de Microelectrónica, IMB-CNM/CSIC, Barcelona, (Spain)

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Abstract

This note summarizes the year 2007 activities for the SiTRA alignment subgroup and gives a tentative planning for activities in year 2008. We report on the following issues: SiLC alignment overview, realistic optical simulation of silicon microstrip detectors, measurement of Si microstrip prototypes and alignment testbench.

*This work has been carried-out within the SiLC (Silicon for the Linear Collider) collaboration, a generic R&D collaboration to develop the next generation of large area Silicon Detectors for the ILC. It applies to all detector concepts and gathers teams from all proto-collaborations. The collaborators of SiLC which are also EUDET partners are forming the SiTRA (Silicon Tracking) group.

1 Introduction

The next generation of tracking systems, as the one envisaged for the International Linear Collider (ILC), will demand track momentum resolutions one order of magnitude better than current state-of-the-art trackers. Environmental disturbances like local temperature gradients (produced by operation and cooling of detectors) or humidity variations will affect the stability of any supporting structure at the micrometer level. This instability is comparable to the precision of position measuring devices as the microstrip silicon sensors. Independent alignment systems monitoring these changes are then needed.
Infrared light, though weakly absorbed in Si, produces a signal of about 100 MIPs in 300 μm of silicon. If the light is unobstructed, IR beams can sequentially traverse several detectors and be used as custom produced pseudo-tracks. Based on the successful experience of AMS and CMS tracker systems [1],[2], we propose to use this kind of infrared integrated alignment system for ILC Si tracking devices. Since the same detectors used for tracking are used to measure the IR beams, there is no need to monitor mechanized fiducial marks on the sensors. In integrated alignment systems, the transfer error between the actual sensor and the surveyed reference is therefore zero. Furthermore, since IR light produces a measurable signal in the silicon bulk, there is no need for any external readout related to the alignment system. This reduces the overall material budget due to the tracking system. And all these advantages come to a minimum cost: the aluminum metalization (backelectrode) of the sensor needs to be swept away in a circular window of $\sim O(mm)$ diameter size to allow the IR beam to propagate through. An overview of the alignment strategy of our group within the SiLC Collaboration is given in the next section. Section 3 summarises our simulation study of the passage of light through a silicon microstrip detector, taking into account effects as light diffraction by the strips, optical absorption due to doping and multiple reflections in the multilayer sensor. Automated characterization of the detectors and readout will be possible using in dedicated test bench described in section 4.

2 IFCA-CNM participation in SiLC alignment

The *Instituto de Fisica de Cantabria* (IFCA) group participates within the SiLC alignment task in two fronts. On one hand, we have proposed minor modifications to some of the new Si microstrip sensors produced by Hamamatsu [3],which will be used in the preparation of the EUDET alignment tracking prototype for the SiTRA activity. These changes ensure transmission of an IR laser through the detector. On the other hand, together with *Centro Nacional de Microelectrónica* in Barcelona (INM-CNM), we have a R&D line aimed to improve and validate modified microstrip sensors achieving high IR transmittance ($> 70\%$).
The set of changes requested to 5 of those new sensors were the minimum needed to allow propagation of an IR beam through the detector. The Al backelectrode has been removed in a circular window of 10 mm diameter. Further measures devised to increase

the transmittance to specific wavelengths were discarded this time. Namely: narrowing of the strip width within the alignment window and layer thickness optimization for constructive interference of the outcoming wave. The detectors, will be characterized optically in the alignment test bench at IFCA (see sect. 4).
Together with CNM-Barcelona we have established a new R&D line to improve current Silicon microstrips detectors to achieve maximum IR transmittance within moderate absorption. Taking profit from the flexibility offered by this research institute, we can test new materials and new strip layouts to improve the optical transmittance of the detectors without sacrificing their performance as tracking devices. As for new materials, we have proposed to use transparent electrodes [4] instead of Al strips. These materials could be Indium Tin Oxide (ITO) or Aluminum-doped Zinc Oxide (AZO). Changes in the layout consist in modifications of the width/pitch ratio in the sensors. In both cases, the thicknesses of the different layers will be properly tuned to pursue maximum transmittance.

3 R&D on optically improved Si microstrip detectors

This section summarizes the main results from [5]. From an optical point of view, a Si microstrip detector is a multilayer stack with an embedded linear diffraction grating on it. (see Fig. 1). As a result, the wavelength at which the transmittance is maximum, and its value, are different from the values calculated assuming a perfect planoparallel stack of materials.
We have carried out a very detailed optical simulation for maximizing the transmittance of the sensor. In our simulation, we also considered the effect of different doping levels in Si, since optical absorption of doped materials is very different from their intrinsic counterparts.
Figure 2 shows simulated transmittance (black), reflectance (red) and absorptance (green) of a sensor as that depicted in Fig. 1. The thicknesses of the different layers are optimized for maximum transmittance and minimum reflectance. The starting parameters of the optimization are shown as well as the final optimized thicknesses. The width of the electrodes and implants in the alignment window is 5 μm and the pitch is 50 μm for this design.
Finally, we have studied the transmittance improvement obtained by using transparent electrodes instead of Al ones. Optical absorption for ITO is one order of magnitude less than Al in the wavelength range of interest. Replacing Al by ITO and optimizing the new design around $\lambda = 1100$ nm improves transmittance by $\sim$5% if thick layers of ITO are used. The improvement is 10% if very thin layers are used [5].

3.1 Production and measurements of stacks of materials

The simulation summarized in the former section must be validated with real data. For that, we will first measure the refraction index of each material, as produced by IMB-

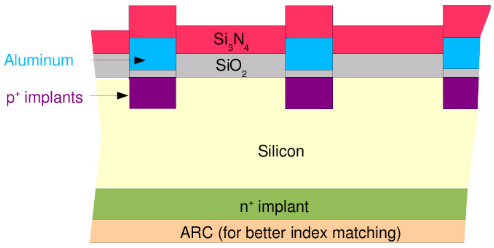

Figure 1: *Section of a representative silicon microstrip sensor employed for a realistic simulation of the beam propagation (drawing not to scale).*

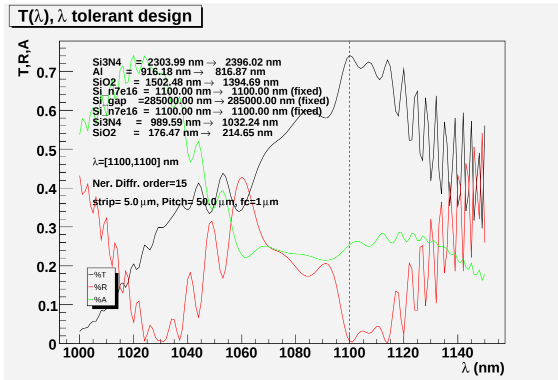

Figure 2: *Optimized optical performance at 1100 nm for a silicon microstrip detector*

CNM [1]. The flexibility of this centre allows us to produce from samples of each material to full sensors. Measurements with a spectrometer of the transmittance and/or reflectance of the material can be used to calculate its complex refraction index as a function of the wavelength. The thickness of the material is measured using an ellipsometer available at CNM.

Therefore, we will start studying the optical functions (transmittance, reflectance and absorptance) of several high resistivity (10 kΩ cm) double polished wafers of Si, with a known doping concentration. According to [6], increasing doping concentration in Si, diminishes its transmittance. We have calculated in [5] that doping concentrations of order $10^{16} - 10^{17}$ cm^{-3} are still transparent enough. Then, we will use these wafers as substrates, and divide them into 4 sectors 90 degrees each. In each sector we will deposit only one new material layer at a time and extract the optical properties of the added material.

Figure 3 shows a detailed view of the samples CNM has just produced. Sectors are numbered anticlockwise, starting from 0 deg. Wafer 1 is not doped. Wafers 2-4 are doped. Sector 1 in wafers 1 to 4 consists of undoped Si (wafer 1), p-doped 10^{16} cm^{-3} (wafer 2), p-doped 10^{17} cm^{-3} (wafer 3), and front p-doped 10^{16} cm^{-3} with back n-doped 10^{17} cm^{-3} (wafer 4). The thicknesses of the layers and identity of the materials are specified in the Figure. Using wafer 1 to extract refraction indexes of SiO2 and Si3N4 and the 4 first sectors of each wafer, we should have all input needed to simulate the rest of sectors from wafers 2-4.

For the measurement of the samples (see Fig. 4) we will use a custom designed grating

[1] refraction indexes depend on the producer and the deposition conditions

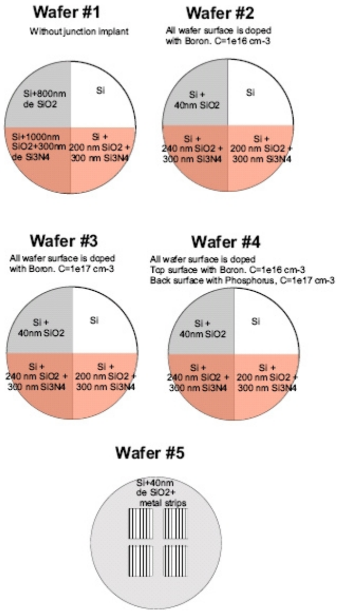

Figure 3: *Sample wafers produced by CNM.*

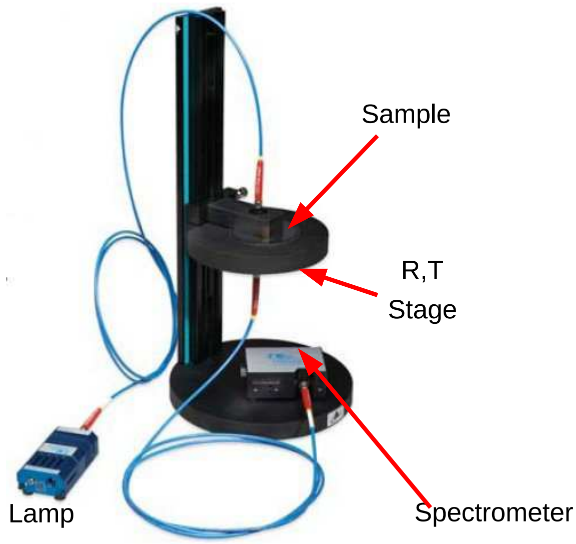

Figure 4: *Portable IR spectrometer experimental configuration*

spectrometer. The linear grating (produced by Control Development [7]) is optimized for the range 950-1150 nm. The sensing element is a T.E. cooled linear InGaAs array, and has 1 nm spectral resolution over the specified wavelength range. As light source, we use a halogen lamp [8] with a spectrum between 360 nm-2 μm. The spectrometer is coupled to fibers and is portable. Samples are positioned in a stage [9] that allows reflection and transmission measurements without having to remove the sample.

4 Alignment test bench

IFCA counts with a metrology laboratory where test of components of the link alignment system of CMS has been carried out [10]. The lab surface is 145 m^2, and has a free diagonal path of 27 m plus reinforced concrete floor independent of the structure of the building. The equipment includes 3 and 6 m long granite benches, antivibration tables with charge compensation systems, and a high precision 3D coordinate measuring machine.

Attached to it, there is a clean room (class 10000) that allows to work under controlled temperature and humidity conditions, with a conducting floor. Inside this room, the optical testing of the HPK and CNM alignment sensors will be executed. The testing will be completed with laser scanning, cosmic and β-source test in a dedicated test bench, currently being commissioned (see Fig. 5).

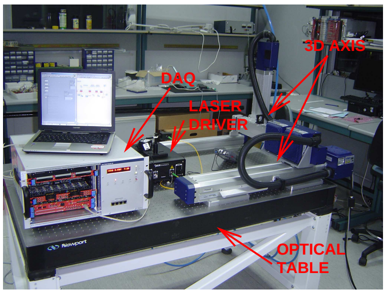

Figure 5: *Picture of the components that will be used for optical characterization and scanning of transparent Si microstrip-detectors.*

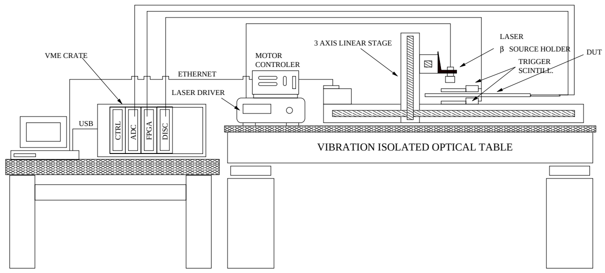

Figure 6: *Detailed sketch of the setup and connections between the components.*

Motorized 3D stages. The assembly consists of a 3 axes motorized linear stages for characterization of large modules, the moving head can scan a volume of 500mm x 300mm x 200mm with a nominal precision of 10μm. The linear stages [11] are controlled from the PC via an ethernet interface, see Fig. 6.
By standard interferometric techniques,used for the calibration of machine tools [12], we expect to achieve a sub-micrometric accuracy on the measurement of the moving head. A standard configuration for the calibration of linear displacements can be seen in Fig. 7; this calibration will allow us to measure with sub-micrometric deviations from the ideal stage displacement.

DAQ system. We are currently using a VME based DAQ system for the readout of sensor prototypes. The VME master is a CAEN-V1718 module that can be operated from the USB port of the standard PC. The DUT is readout by the ADC module CAEN-V895B, a 14 bits, 100 MS/s digitizer; the readout sequence is driven by the CAEN-V1495 board a multipurpose programable board interfacing a FPGA chip to the VME bus; the DAQ system is completed with a leading edge discriminator board CAEN-V895 implementing the trigger logic.

Laser system. Laser characterization of the sensor prototypes will be carried out both in the previous described test bench and on the granite bench. In the former test bench, the overall sensor response and single strip characterization will be carried out. The granite bench will be used for measurement of the the deflection angle of the transmitted laser beam going through the DUT. The precise determination of the deflection angle requires a long distance between the DUT and the "reference sensor", see Fig. 8
For single strip laser testing, a 1060 nm DFB diode laser [13] coupled to a fiber and using a *microfocus* collimator that will allow to create beam spots with a diameter of

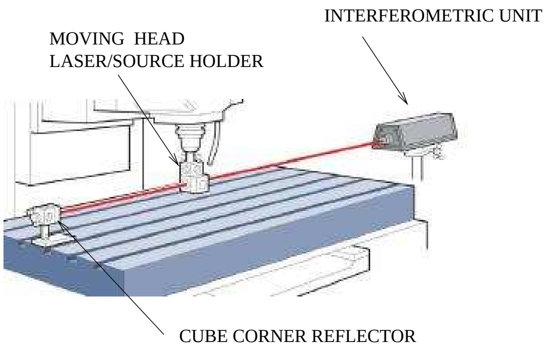

Figure 7: *Using interferometric techniques to calculate displacement of a moving source with submicron precision.*

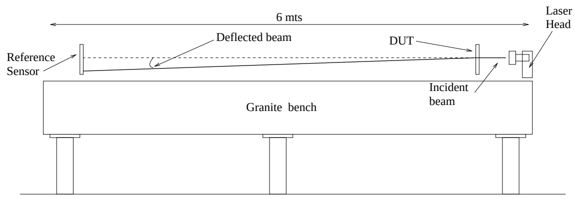

Figure 8: *Alignment bench configuration for measurement of beam deflection introduced by the DUT. The DUT is mounted in a 2D or 3D linear stage.*

few microns.

4.1 Optical characterization of Si microstrip detectors

Alignment sensors will be measured in a test stand which is being setup in the laboratories from IFCA-Santander. The calibration of the alignment sensors will make special emphasis in the optical characterization of the detector. Spatial linearity and position resolution will be measured using a linear scan of the detector using the 3D motorized platform and a fixed pointing IR laser. In turn, the transmitted beam will be measured in CCD detector placed behind the sensor under test. The CCD will measure the intensity of the transmitted beam and the beam deflection, that is, the change in direction of the transmitted beam with respect to the undisturbed beam. The effect of different laser polarization will be also studied. Similar tests were performed by this group [10] for the ALMY sensors of the CMS link alignment system.

Acknowledgment

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