Status of the ALICE Silicon Pixel Detector

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Abstract

The Silicon Pixel Detector (SPD) forms the two innermost layers of the ALICE Inner Tracking System (ITS). The SPD consists of 120 detector modules (half-staves) on two barrel layers at mean radii of 3.9 cm and 7.6 cm, respectively. The SPD contains in total nearly 10^7 pixel cells which provides the high spatial precision, efficiency and granularity required to reconstruct secondary vertices of charm and beauty particles decays in a region where the track density could reach 80 tracks/cm^2.

In this paper, the status of the construction and integration of the SPD are overviewed. Results on the detector performance with test beam data and results on the SPD performance with the response simulation model in the ALICE scenario are discussed.

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1 Introduction

ALICE [1] (A Large Ion Collider Experiment) is the LHC (Large Hadron Collider) experiment devoted to investigate the strongly interacting matter created in nucleus-nucleus collision at the LHC energies.

The ALICE Inner Tracking System [2] consists of six cylindrical layers of silicon detectors in three different technologies: pixels in the two innermost layers (SPD), drift in the two intermediate layers (SDD), and strips in the two outer ones (SSD). The SPD will play a key role in the ALICE apparatus providing a track impact resolution better than 100 μm in the $r\phi$ plane for the the primary vertex reconstruction and the detection of secondary vertices from weak decays of open charm and beauty particles. The total material budget is constrained to 1% X_0 for each SPD layer in order to minimize the multiple scattering for low p_t particles (100 MeV) which can be tracked with the ITS thanks to the ALICE moderate magnetic field (0.5 T).

Preprint submitted to the XIth VCI 2007 *29 June 2007*

2 Components

The SPD consists of 120 detector modules (half-staves) attached to a 200 μm thick carbon-fiber support configured in two half-barrels, each consisting of 5 sectors, surrounding the beam pipe.

Each half-stave (see figure 1) consists of two ladders (each consisting of one sensor and five front-end chips) and a multi-chip module (MCM), glued and wire bonded to an aluminium-polyimide multi-layer laminate (pixel bus).

A grounding foil, consisting of an aluminium-polyimide laminate (25 μm and 50 μm thick, respectively), is included to provide electrical isolation with respect to the carbon fibre. The grounding foil has openings for the thermal coupling of the chip substrates to the cooling ducts via thermal grease pads. The cooling ducts run in grooves embedded in the carbon-fibre support. The total power dissipated in the SPD on-detector electronics is about 1.5 kW; the detector operating temperature is 24°. The SPD cooling system is based on an evaporative C_4F_{10} system [3].

A ladder is an assembly of a silicon sensor matrix of 256 (ϕ) x 160 (z) cells bump-bonded to five front-end chips. The dimensions of the pixel cell are 50 μm ($r\phi$) x 425 μm (z). The native thickness of the sensor is 200 μm while the front-end chips are diced from wafers thinned down to 150 μm after bump deposition. The front-end chip is a mixed analog-digital signal ASIC produced in a commercial 6 metal layer 0.25 μm CMOS process, made radiation tolerant by design layout [4].

The MCM is a Multi Chip Module placed next to the ladders at one end of the half-stave. It contains the on-detector electronics which distributes timing signal, provides the required analog references and performs the data multiplexing and serialization [5]. The communication between the MCM and the counting room is via optical links with three single-mode fibers, while the communication between the MCM and the front-end chips is through the pixel bus.

The pixel bus is a 280 μm thick aluminum-polyimide multi layer flex which integrates the data, control and power lines. For each half-stave the pixel bus is glued on the two ladders and the MCM with special attention to the alignment of the pads of the chips with those on the bus. The MCM and the front-end chips are wire bonded to the pixel bus.

3 Overview of the construction procedure

The half-stave assembly is performed on a Mitutoyo coordinate measuring machine equipped with jigs and tools developed for this purpose. The half-stave assembly and mounting on the sector has required the development of specific procedures and tools for the components manipulation and for the glue dis-

pensing. The requirements in component alignments are very demanding.
The half-stave assembly is a two steps procedure based on the micrometric component alignment and on their gluing. Precisions of few μm in the components alignment and planarity better than 100 μm have been obtained. In the first step the 2 ladders and the MCM are aligned and glued onto the grounding foil. In the second step the pixel bus is aligned and glued on top of them [6]. The selected glue is the bicomponent epoxy adhesive Eccobond45 with Catalyst15 produced by Emerson and Cuming[1]. This glue is electrically insulating with acceptable thermal conductivity. After the half-stave assembly, more than $1,000$ wire-bonds are necessary to establish the electrical connection of the MCM and the ladders to the bus. All half-staves are tested and qualified before they are mounted onto the sectors. The test procedure checks the detector performance and functionality (threshold uniformity in the pixel matrix, noisy pixels, dead pixels, etc.
The procedure developed for the sector assembly is described in reference [7]. The main steps of this procedure can be summarized as follow:

- The sector is equipped with six cooling ducts (Phynox) and then it is mounted on a micrometric measuring machine (Johansson Topaz). It is surveyed and aligned with the first plane in the reference position;
- thin pads of thermal grease (AOS 52029[2]) are dispensed with a syringe in the required thickness as determined from the survey of the sector and the half-stave. The pads match the openings in the grounding foil for the best thermal coupling between the cooling duct and the chips;
- two half-staves are aligned with respect to each other to form the stave, are lifted by means of a vacuum suction tool, and are gently pressed in place on the plane of the sector ;
- the half-staves are attached to the sector by means of glue dots (Norland NEA 123[3]) cured with UV light. Carbon fibre clips are also used to increase the mechanical stability of the half-stave attachment.

Each half-stave is tested before and after being attached to the sector. In figure 2 a sector placed on the micrometric measuring machine after the assembly procedure is shown.
At the end of the half-staves mounting, the sector is equipped with all the services necessary for the cooling connection and it is shipped to the test facility at CERN where it is extensively tested and characterized before the half-barrel integration.

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[1] www.emersoncuming.com
[2] Produced by AOS
[3] Produced by NORLAND

4 SPD construction status

At the time of writing, all the half-staves have been assembled and tested. The first half-barrel has been fully tested and commissioned, the second one is being completed (see figure 3). The half-barrel test is performed with the final cooling plant and read-out electronics. The detector control system, based on PVSS - a commercial Supervisory Control And Data Acquisition (SCADA) used in all LHC detectors - has been developed [8] and is used in the commissioning. The temperature safety interlock is of vital importance in the SPD, due to the very low thermal mass, it must be fully reliable and it must switch off the power supply without any delay; this system is implemented using a PLC.

5 Performance and response model simulation

The pixel detector assemblies have been tested in various runs with particles in secondary beams at CERN. Detailed measurements were already done in 2002 with a 350 GeV/c proton and pion beams in the H4 line at the SPS. Data have been collected at different threshold settings and with tracks impacting at different angles with respect to the short pixel dimension. The analysis method and the pixel detector performances in the test beam geometry are extensively described in reference [9,10]. The efficiency measured for this detector with normal incidence track is greater than 99% with a wide plateau (from 2000 e^- to 8000 e^-) [4] . The main contribution to the detector inefficiency would derive from defects such as missing bump-bonds, damaged wire bonds, noisy pixels etc. The total number of defects has been set at less than 1%. The dead and noisy pixels (which can be masked) are mapped and stored into a data base to take them into account during the data correction for the physic studies.

A SPD realistic response model is required both for simulation studies and for correction procedures of the data. An electron-hole diffusion model was developed in the ALICE simulation framework since long time. Some modification in the parameter structure and their fine tuning was recently performed using the data collected in the beam tests. Detailed description of the model strategies and preliminary comparison with the data can be found in reference [11].

The parameters of the model have been tuned on the basis of the cluster pattern distribution obtained with normal incidence tracks at the typical detector threshold. The final result is shown in figure 4. In this plot the bar of the histogram represents the Monte Carlo data and the marker the experimental one.

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[4] The normally working threshold for this detector is 200 DAC units which corresponds to 3000 e^-.

For each bin a sketch of the cluster fired and its frequencies in percentage is printed. In the top of figure 4, the ratio of the Monte Carlo to the experimental data is plotted with the corresponding statistical errors. The plot shows that the simulation model well reproduces the experimental data. Details on the tuning strategies and its effect in the comparison with the experimental data can be found in [12] where the comparison at different track angles is also discussed.

After the model tuning the comparison of the spatial precision was performed. For the experimental data the residual distribution has been fitted to a convolution of a rectangular function and a Gaussian with $\sigma = \sigma_{track} = (6 \pm 1)$ μm. For the simulation data the rms value is used. This model well reproduce the spatial precisions measured in the test beam geometry for tracks at normal incidence angle and at typical detector threshold setting for all clusters fired and separately for the main two patterns: single and double. As an example we report the results in the short pixel size for the experimental and the Monte Carlo data:

$$\sigma_{Exp}^{allcls}(r\phi) = (\ 10.0\ \pm\ 0.7\ )\ \ \mu m \qquad rms_{MC}^{allcls}(r\phi) =\ 10.2\ \ \mu m. \tag{1}$$

The optimized simulation model has been also used to study the SPD spatial precision in the ALICE realistic scenario. A production of Monte Carlo pp data in the ALICE geometry has been performed for this purpose. Due to the SPD geometry the tracks impact the detector with a great spread in angle both in ϕ and z direction. The Range of impact angles in ϕ-direction was found to be $[-7°,+12°]$ for the inner layer and $[-20°,-30°]$ for the outer one. Those spreads introduce great differences in the cluster pattern distribution influencing the spatial precision. In order to determine it, we evaluate the residuals in the $r\phi$ plane between the track impact point (known in the simulation) and the center of the associated cluster for several cluster patterns. As an example, the residuals of the inner and outer layer of the SPD are reported in figure 5 convoluted over all cluster patterns and all incidence angles in the ALICE bending plane ($r\phi$). The peaks of the distribution are well fitted by a Gaussian function. However to take into account the tails of the distribution in the determination of the SPD spatial precision it is better to use the rms values. Those values must be used in the tracking algorithms to associate the cluster fired to the candidate track. The rms values are truncated at ±7 rms with an iterative procedure to be consistent with the ALICE tracking algorithm criterion. Also in this case a better description of SPD spatial precision can be obtained if we take into account for the main cluster patterns fired (see [12]).

6 Conclusion

The SPD assembly and test are nearly completed and the detector is being commissioned for installation.
Based on the results from the analysis of beam test data collected with an assembly of the ALICE silicon pixel detectors, we have performed a fine tuning of the diffusion model of the SPD.
We have estimated the intrinsic precision of the two layers of the SPD in the ALICE geometry to be 12 μm and 20 μm in the $r\phi$ direction for inner and outer layer, respectively, and 100 μm in the z direction for both layers.

7 Figure captions

Fig. 1: All components which form the half-stave are shown: from the bottom the grounding foil, the 2 ladders and the MCM (in the middle) and the pixel bus on the top.

Fig. 2: The sector after the assembling procedure, placed on the micrometric measuring machine is shown.

Fig. 3: The inner layer of the half-barrel, composed by 5 sectors, is shown.

Fig. 4: Comparison of cluster type distribution between experimental data (marker points) and the Monte Carlo (bar histogram). The parameter setting has been tuned to match the data. The percentages of the cluster pattern frequencies in the data are also printed.

Fig. 5: Distribution of the residuals in the inner (left panel) and outer (right panel) layer of the ALICE SPD. All cluster patterns are considered, see text for details.

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