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The Assembly of the ALICE Silicon Pixel Detector

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Abstract. The Silicon Pixel Detector (SPD) is the innermost part of the Inner Tracking System (ITS) of the ALICE experiment at LHC. It consists of 240 detector ladders containing in total about 10 million 50 x 425 μm^2 pixel cells that have to be assembled on ten carbon fibre support and cooling sectors. The mounting procedure of the basic SPD modules (Half-Staves) and the assembly of the barrel sectors are presented. Results on the assembly of the first sector are reported.

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1. Introduction

ALICE is an experiment presently under construction at the CERN Large Hadron Collider (LHC). It is primarily designed to investigate the behaviour of strongly interacting matter under the extreme high energy density that will be reached in ultra-relativistic nucleus-nucleus collisions at the LHC. The ALICE experimental apparatus is described in reference [1]. The ALICE Inner Tracking System (ITS) will be installed in the innermost region of the experiment, with a radius of 0.4 m. It will provide high precision, high granularity tracking close to the primary interaction vertex [2]. The ITS will be crucial for the detection of weak decays of strange, charm and beauty particles [3]. The ITS will consist of six concentric layers of silicon detectors: two layers of Silicon Pixel Detectors (SPD), two layers of Silicon Drift Detectors (SDD) and two layers of Silicon Strip Detectors (SSD). Physics performance constraints have determined the choice of carbon fibre for the support structure, aluminium-based technology for the flex circuitry and low thickness for the silicon sensors and integrated circuits. A description of the ITS system is given in [4].

The SPD will consist of two barrel layers of silicon pixel detectors located at 39

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mm and 76 mm from the beam line. The length of the active part of the detector along the beam direction will be 286 mm. Each detector module (ladder) consists of a silicon sensor having a sensitive area of 12.8 mm (rϕ) x 69.6 mm (z). It includes 256 (rϕ) x 160 (z) cells each measuring 50 μm (rϕ) x 425 μm (z). Each cell is bump-bonded to a contact of the ALICE1LHCb read-out chip, five chips are used for each ladder. The thickness of the sensor-chip assembly is 350 μm. Two ladders are mounted along the beam direction to form a Half Stave (HS) [5], as shown in Fig. 1.

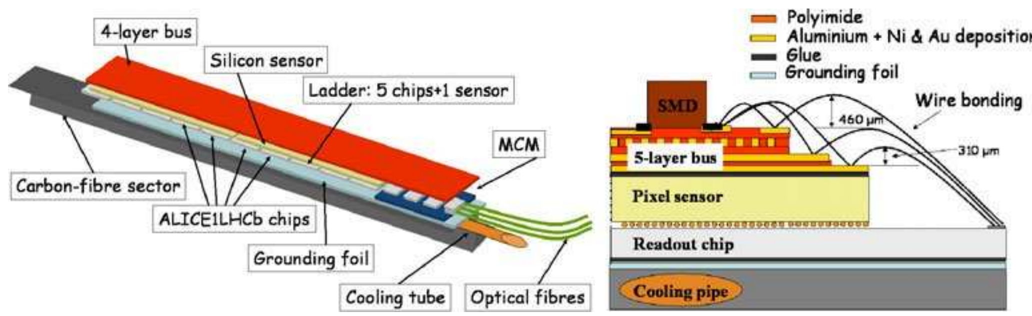

Fig. 1. The ALICE SPD Half Stave: conceptual design on the left and a sketch of the wire-bonding connections on the right.

Recent status reports on the SPD project, including details on the development of the on-board electronics, can be found in references [6–9]. The average material crossed by a particle hitting perpendicularly the SPD corresponds to about 2% of a radiation length. The results from the 2003 and 2004 test beam runs [8,9] show that the measured spatial resolution and efficiency of the ALICE silicon pixel detector are in good agreement with the ALICE requirements [10].

2. The half stave assembly procedure

In view of the very tight tolerances on the positioning of the components, to the severe material budget constraints and to the relative fragility of the Half Staves, the assembly of the SPD HS and the mounting of the HS on the barrel sectors have required the development of specific tools and mounting techniques for components manipulation, assembly and testing.

The half-stave assembly procedure has been developed at INFN Bari and extensively tested in a first step with dummy components. The micrometric relative alignment of the components is performed on a MITUTOYO coordinate measuring machine, equipped with specific jigs and tools designed and built in-house. The material for gluing together the HS components has been chosen, following extensive laboratory tests, to achieve good mechanical strength and high elasticity and to reduce the mechanical stress due to different thermal expansion of the various parts.

The selected glue exhibits good thermal conductivity and high electrical resistivity. The HS assembly procedure takes place in two steps. The first step consists in gluing two ladders and one MCM onto the 70 μ m thick Al-polyimide grounding foil. Openings in the grounding foils ensure good thermal contact between the pixel chips and the cooling ducts embedded in the carbon fibre support sector (see below) by using a suitable thermal compound. Once the two ladders and the MCM are aligned to within a few microns, the adhesive is deposited on the grounding foil and the ladders together with the MCM are glued. The second step of the procedure consists in setting the Al-polyimide multilayer laminate (pixel bus) onto the two ladders and the MCM, using the thermally conductive adhesive. The carrier bus is aligned with respect to the two ladders and the MCM, using as reference the wire-bonding pads on the read out chips. Proper positioning of the carrier bus is crucial to ensure good wire-bonding between the detector and the bus itself. The attachment procedure must ensure that the glue is well distributed underneath the carrier bus, in particular where the wire-bonding pads are located, and does not flow onto the detector modules and the MCM wire-bonding pads. All the handlings of the HS components as well as the glue depositions are performed on the coordinate measuring machine. At the beginning of 2005, final HS with working components have been assembled and successfully tested validating the whole procedure. Since then, the HS production has been performed continuously in Bari.

3. The SPD barrel sector assembly procedure

After the assembly phase and functionality tests, the Half Staves are transferred to the Padova Clean Laboratory for mounting onto the 200 μm thick Carbon Fibre Support Sectors (CFSS). The CFSS is the mechanical support structure of the barrel and has an embedded cooling system. The CFSS are built at INFN Padova and mechanically qualified with respect to the tolerances for the final mounting and integration of the barrel. The main steps involved in the assembly of the SPD sectors are summarized as follow:

- The CFSS, equipped with the cooling ducts, is aligned parallel to the working reference frame of a coordinate measuring machine;
- A thin layer (about 150 μm) of thermal grease is dispensed in rectangular pads, each pad corresponds to the back side of an ALICE1LHCb readout chip;
- Two Half Staves are aligned to form a Stave and positioned on the CFSS using a vacuum holding tool;
- The aligned Stave is finally glued to the CFSS using a UV curable glue. The upper part of the stave is fixed using carbon fibre clips, to protect the wire-bonding and to ensure good mechanical stability.

In the following, details are provided about each assembly step.

4. The SPD Barrel Sector Assembly System (BSAS)

The Clean Laboratory, operated by the Alice Pixel Group of INFN Padova, is equipped with a JOHANSSON TOPAZ measuring machine. A Barrel Sector Assembly System (BSAS) dedicated to the assembly of the Half Staves on the Carbon Fibre Support has been built and is in operation since the beginning of 2005. Its components are mounted directly on the working plane of the TOPAZ machine. The majority of the assembly tasks are performed by using stepping motors, computer-controlled by two NATIONAL INSTRUMENTS PCI-7334 Motion Control Cards hosted on a P4 computer running WINDOWS XP, and by two modules NI MID-7604 4 Axis Integrated Stepper Drive. The control software has been developed under LabView. The main components of the BSAS are:

- The Rotating Sector Support (RSS);
- The Stave Alignment System (SAS)
- The Grease and Glue Tower (GGT);
- The Stave Jig Tower (SJT).

The components of the BSAS are briefly described in the following sub-sections.

4.1. The Rotating Sector Support (RSS)

The Rotating Sector Support is used to align and rotate the CFSS mounted on two removable forks. The alignment of the first plane, out of the six that will hold the Staves in each sector, is performed on the measuring machine by acting on micrometric screws that control the forks positions. The alignment is relative to the TOPAZ working plane. The angular precision of the software-controlled positioning is better than $6{\cdot}10^{-4}$ ($\Delta\theta$ / θ). The reproducibility of the angular position after a full rotation cycle has been measured to be within 3.2 μrad.

4.2. The Stave Alignment System (SAS)

The Stave Alignment System is used to adjust the relative distance and the planarity of the two HS. The HS are positioned with the grounding foils on two independent surfaces where they are retained by a vacuum system. Micrometric movements are used to control their position with respect to the TOPAZ machine reference plane.

4.3. The Stave Jig Tower (SJT)

The Stave Jig Tower is used to transfer the complete Stave from the SAS to the CFSS and to hold it in place on the CFSS during the gluing phase. The jig position is controlled by two motorized slits along the vertical z-axis (LIMES 200) and the y-axis (LIMES 250), perpendicular to the mounting plane. The typical movement precision was found to be better than 20 μm with respect to the nominal position.

4.4. The Grease & Glue Tower (GGT)

The Grease and Glue Tower is the heart of the BSAS having the tasks of distributing both the thermal grease for the thermal contact between the HS and the cooling duct and the UV glue used to secure the HS on the CFSS and to fix the carbon fibre clips. The tower allows precise positioning of the working head all along the CFSS length (600 mm along the x-axis) as well as along the vertical z-axis (60 mm, mod LM60) and the y-axis (100 mm, mod LM100). The overall accuracy is within 100 μm for the the 600 mm movement along the x-axis and within 20 μm for the movements along the y and z-axis. The glue dispenser I&J Fisnar DD305 and the UV lamp EXFO Lite 3000 are used.

A detailed study of the compounds to be used in the assembly of the SPD was performed. A detailed description of the selection of the gluing compounds for the barrel sector assembly can be found in reference [10, 12, 11]. The best results have been achieved using two compounds: the AOS 52029 thermal grease for the thermal contact, and the Norland NEA 123 UV curable glue for the mechanical assembly.

5. Results

The assembly protocol has been extensively tested during the first quarter of 2005. Quality Control tests are performed in Padova when the HS arrives from the Bari production plant and after the mounting on the CFSS. Moreover, a specific reworkability test has been performed demonstrating the possibility of replacing a given HS without damaging the rest of the Sector. A first Barrel sector (SPD Sector#0) has been completed. Up to now, all HS delivered by the Bari production plant have been accepted and assembled on CFSS.

6. Conclusions

The Silicon Pixel Detector is the innermost part of the ITS tracking system of the ALICE experiment at LHC. The 240 ladders, hosting almost 10 million pixel cells are being assembled on a lightweight carbon fibre support with micrometric precision. To reach this purpose, two dedicated high-precision computer-controlled tooling systems have been developed. The assembly protocol has been extensively tested during 2005 and the first SPD Barrel sector has been completed, as shown in Fig. 2, and transferred to CERN for final testing. The assembly of the SPD is now in production, with the goal of having the full barrel ready for the installation inside the ALICE experiment at CERN at the end of 2006.

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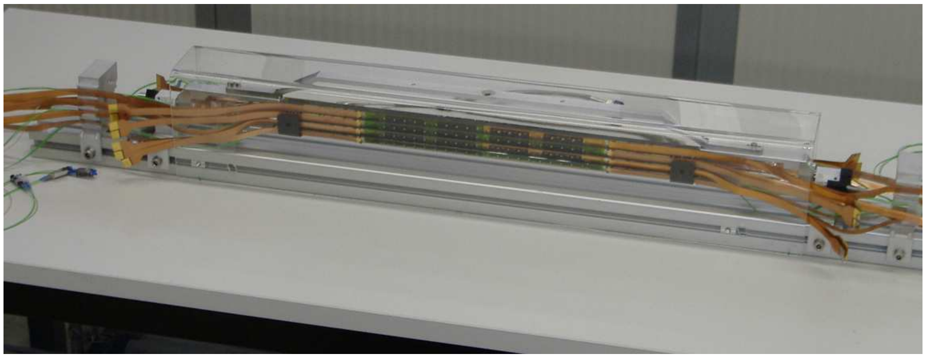

Fig. 2. The Sector#0 of the SPD ready to be tested at CERN .

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