The Assembly of the first Sector of the ALICE Silicon Pixel Detector

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\textbf{Abstract.} The Silicon Pixel Detector (SPD) is the innermost part of the Inner Tracking System (ITS) of the ALICE experiment at LHC. 240 detector ladders containing in total about 10 million pixel cells with dimension 50 x 425 \( \mu \text{m} \)^{2}, have to be assembled on a carbon fibre support. 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.
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 conditions of heating and compression that will be reached in ultra-relativistic nucleus–nucleus collisions at the energy of the LHC. The ALICE experimental apparatus is described in [1].

The inner region of the experiment, within a radius of about 0.45 m, will be instrumented with the Inner Tracking System (ITS) [2, 3] providing high precision, high granularity tracking close to the primary interaction vertex. The ITS will be crucial for the detection of weak decays of strange, charm and beauty particles. The ITS is designed to allow full tracking in the pseudo-rapidity range $|\eta| < 1$ and a measurement of the charged multiplicity out to $|\eta| < 2$. It will consist of six concentric layers of silicon detectors: two layers, named outer and inner, of Silicon Pixel Detectors (SPD), two layers of Silicon Drift Detectors (SDD) and two layers of Silicon Strip Detectors (SSD). A schematic view of the ITS structure is presented in figure 1.

![Figure 1: Schematic layout of ITS.](image)

Physics performance constraints have determined the choice of carbon fibre for the support structure, aluminum-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 mm and 76 mm from the beam line. The sensitive length 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 ($r\phi$) x 69.6 mm ($z$). It includes 256 ($r\phi$) x 160 ($z$) cells each measuring 50 $\mu$m ($r\phi$) x 425 $\mu$m ($z$). 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 $\mu$m. Two ladders are mounted along the beam direction to form an Half Stave (HS) [5], as shown in figure 2.
An aluminum-polyamide multi-layer flex (the pixel bus) containing both a data control bus and power lines is glued to the sensors and wire-bonded to the read-out chips and to the MCM (Multi Chip Module as shown in figure 2 (right)). The MCM, located at one end of the half-stave, contains all the auxiliary readout and control ASICs. A 70 μm thick Al-kapton grounding foil is also glued to the chips.

The assembled HS are mounted on a Carbon Fibre Support Sector (CFSS) with integrated cooling lines [6]. Each CFSS holds four outer layer Staves and two inner layer Staves. Ten Sectors will be mounted around the beam pipe to form the full barrel. Consequently, the SPD will consist of 60 Staves, 240 ladders, 1200 chips, about 10^7 pixel cells. The average material traversed by a particle hitting perpendicular to the SPD will correspond to about 2% of a radiation length.

Recent status reports of the SPD project, including details on the development of the on-board electronics, mainly constituted by the Multi Chip Module (MCM), can be found in [7-9].

The bump deposition and the flip-chip bonding of the ALICE ladders are carried out at the VTT Center for Microelectronics, Espoo, Finland. After a three years R&D activity, including the thinning down to 150 μm of the 200 mm diameter readout wafers, the production of the ladders for the SPD construction was started last year and it is now proceeding on schedule.

Several flip-chip bonded assemblies have been tested at the CERN SPS in test beam runs during 2001-2004 years. In particular, during the 2003 and 2004 test beam runs several detectors have been tested [8, 9]. The results from the ongoing data analysis show that the performance of the ALICE silicon pixel detector in terms of achievable spatial resolution and efficiency are in good agreement with the ALICE requirements [10].

2. The half stave assembly procedure

Due to strong requirements on the relative positioning of the components, to severe material budget requirements and to the fragile nature of the Half Staves, the assembly of the SPD HS and the mounting of the barrel require the development of specific tools and mounting techniques for components manipulation, assembly and testing.

The half-stave assembly procedure has been worked out at the INFN Bari and extensively tested in a first step with dummy components. Gluing tests have been performed in order to ensure good mechanical strength and high elasticity. The micrometric alignment of the components (with respect to each other) is performed on a MITUTOYO coordinate measuring machine, equipped with specific jigs and tools which were designed and built in house.

The characteristics of the glue have been chosen in order to have good mechanical strength and high elasticity and to reduce the mechanical stress due to different thermal expansion between several components.

The gluing procedure takes place in two steps. The first step consists in gluing two ladders and one MCM onto the 70 μm thick Al-kapton grounding foil which is very thin and fragile. The grounding
foil is designed to also ensure good thermal conductivity from the front-end chip to the cooling duct. To optimize the detector cooling, number apertures are machined in the grounding foil in the positions corresponding to the read-out chips mounted on each ladder. After a micrometric alignment of the two ladders and the MCM, the electrically non-conductive glue is deposited on the grounding foil and then the two detector modules and the MCM are placed in sequence.

The second step of the procedure consists in gluing the multilayer carrier bus above the two ladders and the MCM. Electrically non-conductive glue is again deposited on the top of the ladders and the MCM. 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. The proper mounting of the carrier bus is crucial for the wire-bonding of the detector. The gluing 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 half-stave components as well as the glue depositions are performed on the coordinate measuring machine. At the beginning of 2005, final half-staves with working components have been assembled and successfully tested validating the whole procedure. Since then, the production of the HS has been performed continuously in Bari.

Due to the complexity and the compactness of the SPD, a special effort has been devoted to the definition of several functional test procedures of all components before the assembly. A test protocol has been specifically defined for quality control of the detectors at the end of the HS assembly, after the wire-bonding.

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 are the mechanical support structure of the barrel with an embedded cooling system. The CFSS have been built at INFN Padova and mechanically qualified to check the tolerances required for the final mounting and integration of the barrel.

![Figure 3: A picture taken during the assembly procedure of the first SPD sector. In the upper plane of the CFSS, thermal grease pads on the cooling duct and UV dots are visible. Such material is dispensed before the assembly of the HS. In the lower CFSS planes, three already assembled HS are shown. The HV are fixed to the CFSS by using carbon fibre clips and UV glue dots.](image)

As far as the assembly of the SPD sectors, the main steps of the procedure can be 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 as shown in the figure 3, each pad corresponds to the back side of an ALICE1LHCb readout chip;
• two Half Staves are then 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 a good mechanical stability, as shown in figure 3.

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 view of the complete system mounted on the working plane of the TOPAZ machine equipped with the BSAS is reported in figure 4.

All the BSAS components have been calibrated before the whole assembly procedure. The components of the BSAS are briefly described in the following sub-sections.

![Figure 4: View of the complete system mounted on the working plane of the TOPAZ machine equipped with the BSAS.](image-url)
4.1. The Rotating Sector Support (RSS)
The Rotating Sector Support is used to align and rotate the CFSS, already equipped with cooling ducts, 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. Once the first plane is aligned, all other planes are selected by rotating the CFSS with a computer-controlled stepping motor (mod. DMT-6b).

The angular precision of the software-controlled positioning is better than $6 \times 10^{-4}$ \((\Delta \theta / \theta)\). After this automated positioning, a fine adjustment of the planarity of each CFSS plane with respect to the reference plane is performed manually. The reproducibility of the angular position after a full rotation cycle among the six stave planes has been measured to be within 3.2 \(\mu\)rad.

4.2. The Stave Alignment System (SAS)
The Stave Alignment System is used to adjust the relative distance and the planarity of the two Half Staves.

The Half Staves are positioned with the grounding foils on two 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. The TOPAZ machine measuring head and an additional optical head are used to control the alignment.

4.3. The Stave Jig Tower (SJT)
The Stave Jig Tower is used to transfer the complete Stave from the SAS to the CFSS, to position it 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 precision was found to be better than 20 \(\mu\)m with respect to the nominal position.

The part of the jig that holds the stave is made by six independent parts, each with its own independent, computer controlled vacuum system. Two out of the three jig portions that hold each Half Stave are centered on the two ladders and the third one on the Multi-Chip Module (MCM) housing the auxiliary electronic components. Such a jig design allows the dismounting of a single part without releasing the entire Half Stave. This feature is essential for the gluing procedure described below.

4.4. The Grease & Glue Tower (GGT)
The Grease and Glue Tower is the heart of the BSAS with the tasks of:

- distributing the thermal grease that will ensure the thermal contact between the half-staves and the cooling duct;
- distributing the UV glue used to fix the half-staves directly to the CFSS or, in some positions, to fix the carbon fibre clips;
- curing the UV glue by a suitable light system.

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). As for the previous components, all individual movements of GGT have been calibrated. In addition, tests have been performed to verify the overall accuracy and reproducibility of the positioning of the needle of the glue syringe. Such tests have demonstrated that the overall accuracy is within 100 \(\mu\)m along the 600 mm long movement (x-axis) and within 20 \(\mu\)m for the y and z-axis.

The GGT is equipped with a syringe for the thermal grease, a syringe for the UV glue and a light fibre for the UV curing. The glue dispenser I&J Fisnar DD305 and the UV lamp EXFO Lite 3000 are used.
5. Selection of the gluing compounds for the barrel sector assembly
In the past, we performed a study of the compounds to be used in the assembly of the SPD. The main initial requirements were:
• a good thermal contact between the half-staves and the cooling ducts;
• the possibility to remove an underperforming Half Stave without damaging the entire sector;
• radiation hardness characteristics of the compounds.
The best solution has been found using two compounds:
• a thermal grease for the thermal contact;
• a UV curable glue for the mechanical assembly.
As far as the UV glue is concerned, the Norland NEA 123 resin has been tested with very good results. The high viscosity of this glue allows dispensing it both on the top and on the bottom of the object to be assembled, depending on the specific mounting steps [10].
In the case of the thermal compound, several candidates have been evaluated, by measuring the thermal conductivity of a thin layer (about 100 μm), and studying the mechanical properties and the radiation hardness.
To test the radiation hardness, the four best candidates have been irradiated at LNL by using 27 MeV protons up to a fluence of $5 \times 10^{12}$ proton/cm$^2$. This irradiation is equivalent to the dose of about 500 kRad, as expected for the SPD detector in 10 years of running at LHC [12]. Results from the irradiations were satisfactory for all samples [11]. Consequently the selection of the thermal grease was made looking also to the general properties of the materials. The AOS 52029 thermal grease has been finally selected.

6. Results
The assembly protocol has been extensively tested during the first quarter of 2005, including the Quality Control HS tests that are performed in Padova when the HS arrives from the Bari production plan and after the mounting on the CFSS. Moreover, a specific reworkability test has been performed demonstrating the possibility of dismounting a specific HS without damage for the rest of the Sector and for the dismounted detector. A first Barrel sector (SPD Sector#0), as shown in figure 5a and 5b, has been completed with working components. During the production of this first Sector, the assembly efficiency has been of 100% (all accepted HS have been assembled on the CFSS without any lost or damage).

Figure 5: The first sector with final components has been finalized: the outer layer on the left panel and the inner layer on the right panel.

7. Conclusions
The Silicon Pixel Detector is the most inner part of the ITS tracking system of the ALICE experiment at LHC. The 240 ladders, hosting almost 10 millions of pixel cells have to be assembled on a light...
carbon fibre support with micrometric precision. To reach this result, two dedicated high-precision computer-controlled tooling systems have been developed.

The gluing compounds to be used in the assembly of the individual Half Staves on the carbon fibre sector support have been selected on the basis of their mechanical, thermal and radiation hardness characteristics.

The assembly protocol has been extensively tested during 2005 and the first completed Barrel sector has been completed, as shown in figure 6, and transferred to CERN for final testing. The assembly of the SPD is now in process, with the goal of having the full barrel ready for the installation inside the ALICE experiment at CERN at the end of 2006.

Figure 6: The Sector#0 of the SPD ready to be tested at CERN.

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