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Production and assembly of the ALICE silicon drift detectors

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Abstract

The ALICE experiment at the LHC will study collisions of heavy-ions at a centre-of-mass energy ~5.5 TeV per nucleon. The main aim of the experiment is to study in detail the behaviour of nuclear matter at high densities and temperatures, in view of probing deconfinement and chiral symmetry restoration. Silicon Drift Detectors (SDDs) have been selected to equip the two intermediate layers of the ALICE Inner Tracking System (ITS) [ALICE Collaboration, Technical Design Report, CERN/LHCC 99–12], since they couple a very good multi-track capability with $\mathrm{d}E/\mathrm{d}x$ information and excellent spatial resolution as described in [E. Gatti, P. Rehak, Nucl. Instr. and Meth. A 225 (1984) 608; S. Beolé, et al., Nucl. Instr. and Meth. A 377 (1996) 393; S. Beolé, et al., Il Nuovo Cimento 109A (9) (1996)]. In this paper we describe the different components of the SDD system as well as the different procedure of the system assembly.

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1. Introduction

The ALICE ITS, as described in detail in Ref. [1], consists of six layers of silicon detectors. Because of the high particle density, up to $90\,\mathrm{cm}^{-2}$, the four innermost layers ($r \leqslant 24\,\mathrm{cm}$) must be truly two-dimensional devices. For this task silicon pixel and silicon drift detectors were chosen. The outer two layers at $r \approx 45\,\mathrm{cm}$, where the track densities are below $1\,\mathrm{cm}^{-2}$, will be equipped with double-sided silicon microstrip detectors. The ALICE SDDs, $7.0 \times 7.53\,\mathrm{cm}^2$ active area each, will be mounted on linear structures called ladders, each holding six detectors for layer 3, and eight detectors for layer 4. The layers will sit at the average radius of 14.9 and 23.8 cm and will be composed of 14 and 22 ladders respectively. The front-end electronics is mounted on rigid heat-exchanging hybrids, connected onto cooling pipes running along the ladder structure. The connections between the detectors and the front-end electronics are assured with flexible upilex+Al microcables. The same technology is used to connect the detector and its read-out hybrids to the interface boards connected at the ends of the ladder. The microcables are Tape Automatic Bonded (TAB) to the detector and to the boards and carry both data and power supply lines. Each detector will be first assembled together with its front-end electronics and high-voltage connections as a unit, hereafter referred to as a *module* (see Fig. 1(a)),

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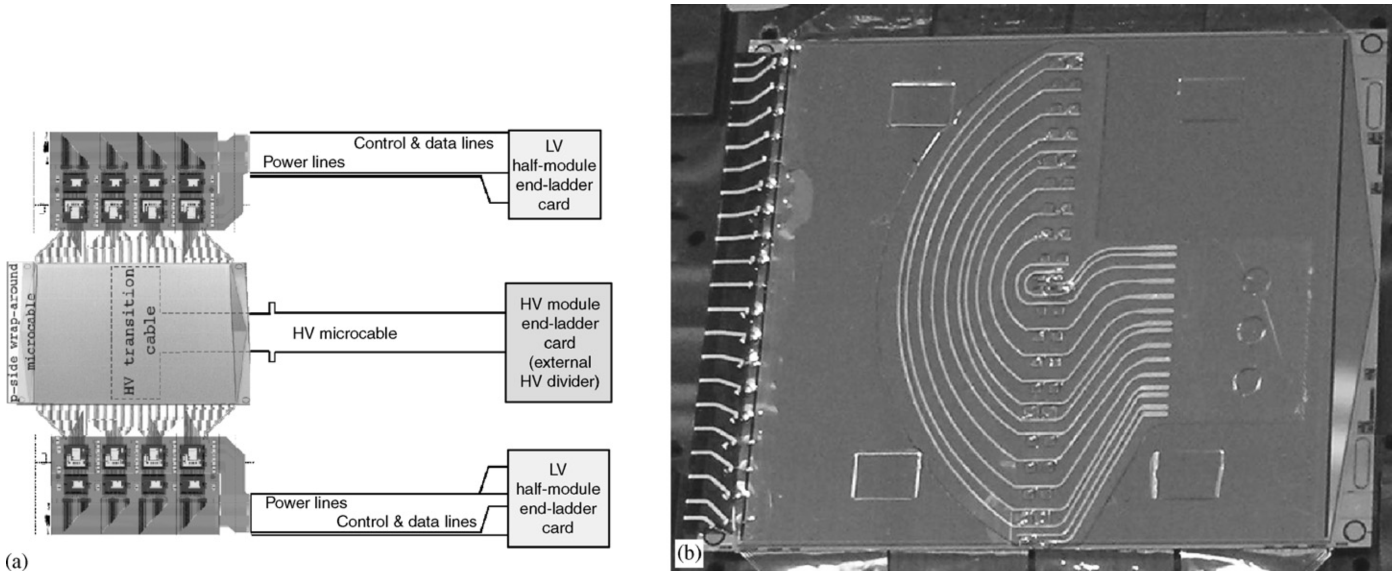

Fig. 1. (a) SDD module scheme; (b) detector equipped with the wrap-around (on the left) and transition microcable.

which will be fully tested before it is mounted on the ladder. All the assembly steps are performed in the Technology Laboratory of INFN Torino.

2. The sensor

The detectors are produced on 5-in. diameter neutron transmutation doped (NTD) silicon wafers with resistivity of 3 kΩ cm and a thickness of 300 μm. The detector has a bidirectional structure, where electrons drift from the central p^+ cathode towards two linear arrays of 256 anodes (anode pitch 256 μm). The length of the sensitive area is 70.0 mm, and the sensitive-to total area ratio is 83%. A detailed description of the detector can be found in Ref. [2]. The detector bias voltage is provided by specially designed microcables. The connections to the central bias cathode and to the injectors lines is provided by microcable called *transition cable*, glued on the detector p-side. The bias lines are then bonded to the corresponding bonding pads. The high voltage is then brought to the n-side using the so-called *wrap-around cable*. The transition cable is then TAB bonded to the long HV cable connected to the corresponding HV end-ladder board. The final assembly is visible in Fig. 1(b). The tests on the SDD are performed in Trieste and after being accepted they are equipped with *transition* and *wrap-around cables* and sent to Torino were they are connected to the hybrids.

3. The front-end electronics

The front-end electronics, fully developed in the VLSI Laboratory of INFN Torino, consist of two integrated circuits both designed in the 0.25 μm CMOS technology. The first one, named PASCAL, performs the preamplification of the signals, their analog storage at a sampling frequency of about 40 MHz, and the analog-to-digital conversion. The second integrated circuit, AMBRA, is a digital four-event buffer which allows data derandomization and handles the communication protocol. Each end-ladder module serves one half-ladder (i.e. three or four detectors) and implements the data compression, the interface with the optical fibre channel to the DAQ system, the clock and trigger distribution and the fine voltage regulation. A slow control system based on the JTAG protocol takes care of the monitoring of voltages and currents, while a second JTAG link, DAQ controlled, is devoted to the configuration and calibration procedures. A detailed description of the SDD front-end system can be found in Ref. [3]. The production of 48 8-in wafers holding about 150 potentially good pairs of PASCAL and AMBRA finished in 2004. The validation tests started in the CL100 CleanRoom of INFN Rome, using a Cascade Rel-6100 Probe station, in February 2005. The yield for AMBRA is 74%, while for PASCAL is 89%. At the end of October 2005, ~1500 AMBRA and ~1800 PASCAL were available for assembly, corresponding to ~72% of the AMBRA and ~86% of the PASCAL chips needed. The testing of all available chips, including a considerable contingency, will finish in February 2006.

3.1. Microcables

The large number of channels in the layers of the ITS requires a large number of connections from the front-end electronics to the detector and to the readout. The requirement for a minimum of material within the acceptance does not allow the use of conventional copper cables near the active surfaces of the detection system. Therefore TAB bonded aluminium multilayer microcables are used. This type of cables are produced by the Scientific Research Technological Institute of Instrument Making Microelectronic Department, Ukraine, and are used both for signal and power supply lines. A detailed description can be found in Ref. [4].

3.2. Chip cables, sub-hybrid and hybrid production and assembly

Each SDD is coupled to two hybrids each consisting of four couples of PASCAL and AMBRA chips. Each couple of chips is TAB bonded to a circuit printed on a aluminium multilayer microcable called *chip-cable*. This circuit provides connections of data lines between AMBRA and PASCAl as well as the connections to the sub-hybrid circuit. The bondings on the chip-cables are protected by a thin layer of glue, a thermally-conductive two-component alumina-filled epoxy (adhesive H70E-2), dispensed automatically with a Champion 3700 glue dispensing machine. The production yield of chip cables is very high both before and after the encapsulation process (~90%). After the encapsulation process the chip-cables are glued on a sub-hybrid circuit. The relative alignment of the four chip-cables needed for each hybrid is obtained using the SDD anodes array as a reference. Special jigs have been developed in INFN Trieste to perform this assembly. The sub-hybrid is glued onto a rigid carbon-fiber heat-dissipator called *heat-bridge*. This will be clipped to the cooling tubes running along both sides of a ladder.

4. The SDD module

A SDD module consists of one silicon drift detector, two front-end hybrids each connected to the corresponding end-ladder LV boards. A microcable specially designed to carry high voltage (up to 2.4 kV) connects to the HV end-ladder board. The complete module ready for electrical tests can be seen in Fig. 2. Up to now four modules have been assembled and successfully tested. The test confirmed the reliability of the TAB bonds. Due to the large number of bonds on the hybrids it is very important to avoid that the inevitable occasional weak bonds lead to failure of the hybrid after only a few operational cycles. For this purpose, and following the experience of the ALICE SSD development [4], a thermal cycling test has been introduced in the production sequence. Sample hybrids have been demonstrated to withstand 200 thermal cycles from 20 to 65 °C (the likely extremes that the hybrids can be expected to experience), and survive 10 cycles up to 100 °C despite the mismatch in the thermal expansion coefficients between the different layers of the hybrid. The hybrids are therefore exposed to ten thermal cycles from 20 to 65 °C.

5. Assembly of SDDs on a ladder

Each SDD module is handled using a special box equipped with vacuum holders. In fact the different elements of each module (sensor, hybrids, end ladder boards) are connected one to the other by microcables, resulting in a completely flexible structure. Thus each element needs to be firmly held while handling to avoid mechanical stress on TAB bonding connections. This connections, even if protected by glue deposition, are one of the critical items of the SDD system. A special mechanical tool has been developed to position and align SDD modules, as visible in Fig. 3(a). It consists of eight supports for the sensors that can be moved in the z coordinate to allow the positioning of overlapping detectors. The SDDs are positioned so that the electrons drift orthogonally to the beam axis. The anodes therefore are aligned along the ladder length. The modules are mounted at different distances from the ladder structure both in the $R\varphi$ and in the Rz planes. This is in order to allow the overlap of the guard regions and a small overlap of the active areas. Each module is lifted by a tool equipped with vacuum cups which can be moved along the structure and placed on the corresponding base, visible in Fig. 3(b). In the mean time the end-ladder boards are placed on dedicated supports. After being placed on its base each SDD must be aligned. The alignment is performed using the Mitutoyo measuring machine in INFN Torino Technological Laboratory. The reference point is a ruby sphere placed on the ladder foot (see Fig. 5). This same

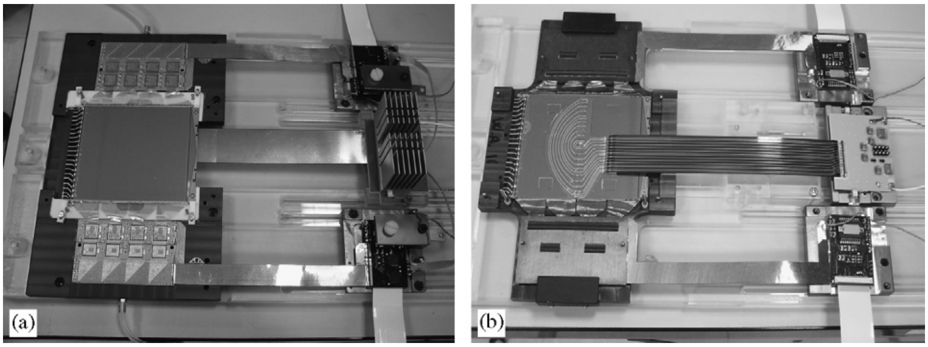

Fig. 2. SDD module ready for electrical test: (a) n-side, front-end electronics visible, (b) p-side: HV cables visible.

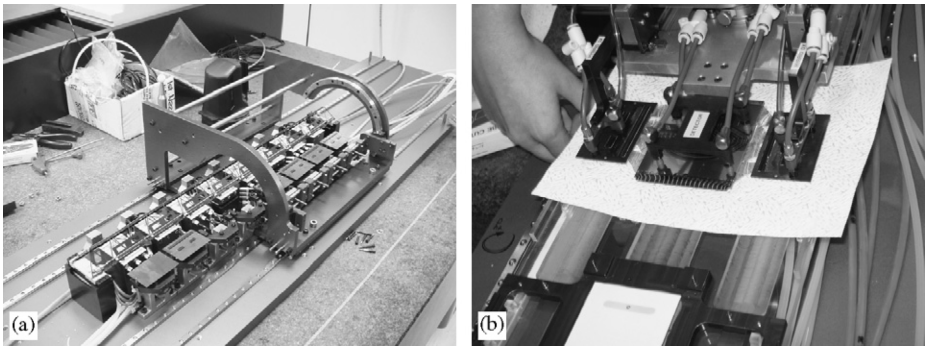

Fig. 3. The ladder assembly jig: (a) the eight support for sensors and the hybrid folding tool; (b) the tool for module positioning.

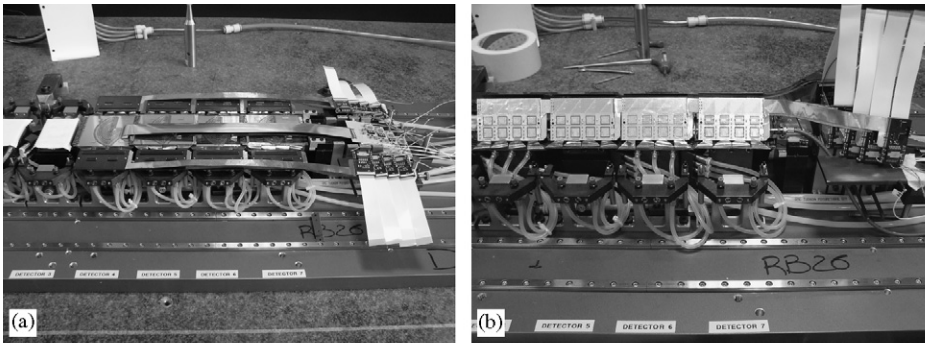

Fig. 4. The four SDD modules assembled under the Mitutoyo machine: (a) before placing ladder on top of them, (b) with hybrids clipped to the cooling tubes.

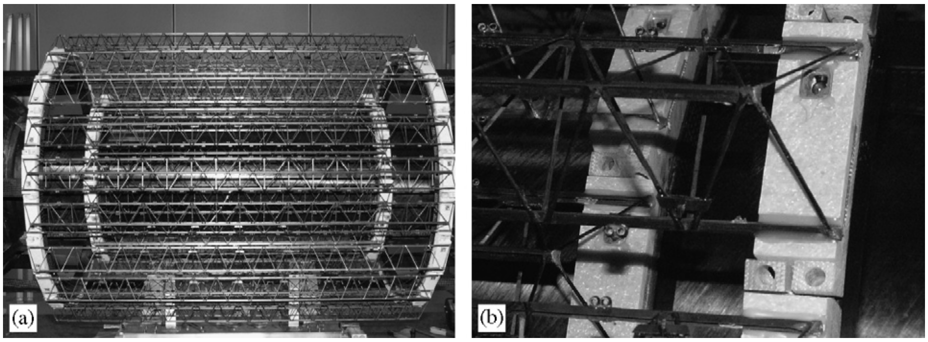

Fig. 5. (a) SDD ladders positioned on the support cones; (b) the ruby spheres used as reference point both for modules and for ladders alignement.

point is used for ladder positioning on the ITS support structure. The positioning and alignement operation must be repeated 4 times for each half-ladder for ITS layer 4. In Fig. 4(a) the four modules leaning on the corresponding bases are shown. At this point the ladder is placed on the modules and four small pillars are glued to each SDD. The last operation consists is the folding of the hybrids and their clipping to the cooling tubes. In Fig. 4(b) you can see the first ALICE SDD half ladder assembled and ready for tests.

6. The SDD support structure

The four outer layers of the ITS detectors are assembled onto a mechanical structure made of two end-cap cones connected by a cylinder placed between the SSD and the SDD layers. Both the cones and the cylinder are made of lightweight sandwiches of carbon-fibre plies and Rohacell$^{\mathrm{TM}}$. The carbon-fibre structure includes also the appropriate mechanical links to the TPC and to the SPD layers. The SDD modules are mounted on linear structures called ladders, each holding six detectors for layer 3, and eight detectors for layer 4. The layers are composed of 14 and 22 ladders, respectively. The ladder structure consists of Carbon-Fibre Reinforced Plastic (CFRP). Each ladder holds also the arteries of the water cooling system. At both ends of the ladder special mechanical devices allow the precise positioning of each ladder on the support cones. They ensure accurate repositioning, within $\pm 10\,\mu\mathrm{m}$, after a ladder has been removed for maintenance and, of course, during the assembly of the ITS. The positioning device has been constructed, used to position all the SDD ladders (Fig. 5) and tested with repeated installations on the supports. The ladder position was recovered within an error below the design value of ±10 μm, within the measurement machine resolution (±6 μm).

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