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Nuclear Instruments and Methods in Physics Research A 552 (2005) 208–211
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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Production of endcap modules for the ATLAS semiconductor tracker ☆

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Available online 1 July 2005

Abstract

The ATLAS SemiConductor Tracker (SCT) will consist of a barrel and two endcap parts equipped with modules made from single-sided p-on-n silicon microstrip detectors. The detectors are mounted back-to-back, with a 40 mrad stereo angle, on a support structure, the spine, and readout in binary mode by custom made ASICs.

For the modules of the endcap part of the SCT, the detectors are glued to a graphite support structure and the ASICs are mounted on a double-sided hybrid produced from a six layer copper/kapton flex.

From mid-2003 the mass production of 1976 SCT end-cap modules has been started at various production sites. I will report on the experiences and problems during the production at the Max-Planck Institute for Physics (MPI). This includes mechanical and electrical issues as well as results on quality assurance.

PACS: 29.40.Gx

Keywords: LHC; ATLAS; Tracking detector; Silicon microstrip; Quality control

1. Introduction

The ATLAS experiment will be one of the two multi purpose detectors at the Large Hadron Collider (LHC) at CERN. The inner detector, which is enclosed in a 2 T magnetic field, provides precision measurements of the momentum of the particles and the position of secondary vertices. This will be achieved by the combination of silicon pixel and strip detectors as well as a straw tube detector with transition radiation detection capability.

The silicon strip detector SCT [1] consists of a barrel region with four layers and 2112 modules and 1976 endcap modules, mounted on 2 times 9 disks. This article focuses on the production of SCT endcap modules and in particular on the production at the assembly site at the Max-Planck Institute for Physics in Munich (MPI).

☆Presented by Jochen Schieck at the 5th International Conference on Radiation Effects on Semiconductor Materials Detectors and Devices, Florence, Italy, October 10–13, 2004.

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0168-9002/$ - see front matter
doi:10.1016/j.nima.2005.06.032

In Section 2 the sensors and modules are described, Section 3 explains the assembly and quality assurance of the modules at the MPI production site, and the overall status of the SCT project is described and summarized in Section 4.

2. Sensors and modules for the endcap region

2.1. Sensors

The sensors [2] for the SCT endcap module are wedge-shaped single-sided p-on-n detectors with 768 strips. The strips are about 6 cm long and AC-coupled to the readout electronics. There are five different sensor designs, depending on their radial position and the strip pitch ranging between 55 and 95 μm.

The sensors used for the module assembly at the MPI are manufactured by CiS.[1] These CiS sensors have implanted bias resistors instead of polysilicon bias resistors used for sensors produced by Hamamatsu.

2.2. SCT endcap modules

Three different types of endcap modules, outer, middle and inner vary according to their radial position in the disk design. There are 52 modules on a outer, 40 on a middle and 40 on a inner ring. At the MPI only modules for the middle ring are assembled. These middle modules consist out of 2 times 2 sensors glued back-to-back on a spine. Some of these middle modules (80) are build out of two sensors only and two sensors are replaced by a glass plates to achieve mechanical stability. These short middle modules will be placed on one of the disks 2.5 m away from the interaction point (disk 8) with the position of the glass plate below $\eta = 2.5$ and therefore not used for tracking. A hybrid is attached to the sensor spine assembly. The readout electronic consists of a carbon structure with 12 radiation hard ASICS with binary readout. The control of the module as well as the readout of the data is performed via optical links. A picture of a short middle module assembled in Munich is shown in Fig. 1.

2.3. Mechanical precision of the modules

To achieve good tracking performance strong requirements on the mechanical precision of the modules are imposed. The strongest is a 5 μm tolerance on the positioning of the sensors perpendicular to the strips. Overall the metrology of the module in the sensor plane (XY) can be described with 13 parameters (7 for the short middle ones). The thickness of the module (Z) is measured with an array of 25 points per sensor relative to the supporting surface. The tolerance in Z for each side of the module is 115 μm. Modules with only one parameter out of tolerance, but still within 1.5 times the tolerance, will be also used in the experiment and they will be mounted in locations with less stringent tracking requirements.

2.4. Electrical performance of the modules

The most important parameter for the binary performance of the modules are the efficiency and the noise occupancy at the operating threshold. The module specifications are $>99\%$ for efficiency and $<5 \times 10^{-4}$ for noise occupancy. In the testbeam it was shown that these benchmark numbers can be reached for a corrected threshold around 1fC for non-irradiated as well as for

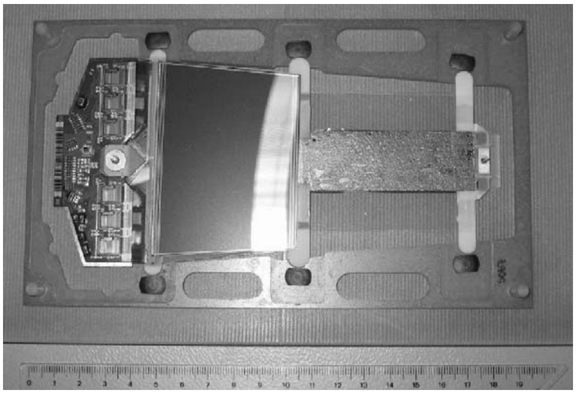

Fig. 1. A short middle module with one sensor replaced by a dummy sensor out of glass.

[1] Eighty five percent of all sensors used in the SCT project are produced at Hamamatsu with slightly different design.

modules irradiated with reference fluence of 3×10^{14} protons/cm^2 [3]. The results are based on modules build with Hamamatsu sensors. However, the performance is expected to be identical to modules build with CiS sensors.

3. Production of middle endcap modules at the MPI

The MPI is responsible for the construction of 480 middle modules, including 20% contingency. Out of these, 96 modules will be short middle modules. The production of the short middle modules started in January 2004. They were produced with a rate of up to two modules a day.

3.1. Assembly process of the modules

The assembly steps and the required times are:

- A visual inspection of the components and IV measurements of the sensors are performed (~45 min /sensor).
- The alignment of the sensors is done for each module side separately. For this the sensors are placed on computer controlled stages and positioned. The aligned sensors are moved with vacuum to transfer plates. Both sides are then glued back-to-back on the spine (~2 h and 12 h for curing).
- After this the spine–sensor assembly is surveyed in *XY* and *Z* (~45 min) and the IV curve of the sensors are measured (~45 min /sensor).
- The hybrid is glued to the spine–sensor assembly and the high-voltage connection between the hybrid and sensors is established (~1 and ~12 h curing time).
- Survey of the module in *XY* and *Z* (~45 min) and measurement of the IV curve (~45 min /sensor).
- The 768 channels are connected to the readout electronic via 6×768 (4×768 for short middle modules) wire bonds using an automatic bonding machine (~2–3 h).
- The module is subject to 10 thermal cycles between $-30\,^{\circ}$C and $+35\,^{\circ}$C (~24 h).
- A final survey of the module after the thermal cycling (~45 min) and a final measurement of the IV curve (~45 min) is performed.
- Various electrical tests of the module are executed. This includes tests of the digital part of the hybrid and chip as well as the analog performance (~1 h).
- The module is shipped to Prague for a detailed electrical characterization. From there the completely tested modules are shipped to the disk assembly sites.

3.2. Status of the production at the MPI

The production of the 96 short middle modules was finished in October 2004. The assembly efficiency was 92%, delivering 88 modules without any mechanical defects.

Out of these 88 modules two modules have two or more *XY* or *Z* metrology parameters out of tolerance, 9 modules are within the 1.5 tolerance band. The distribution for the parameter with the tightest tolerance (position of the center of the sensors perpendicular to the strips) for one coordinate of the mounting position of the module at the hybrid and the distribution of the *Z* survey parameter on the front side are shown in Fig. 2. An increased noise for a small number of strips is seen for 19 out of the 88 modules (13 modules have less than 25 strips effected). A measurement of the bias resistors of the channels with high noise shows a clear correlation between low resistance values and high noise. The efficiency of the noisy channels, tested with a laser setup, is not reduced. The noise for the effected channels is still below the noise for a channel of a middle modules with two daisy chained sensors. Therefore these modules are still used in the experiment. For the production of long middle modules the bias resistors of all sensors will be screened and sensors with low bias resistance values are rejected. Two modules have problems with the electronic located on the hybrid and can possibly be recovered. This leads to 84 usable short middle modules, equivalent to an efficiency of 87.5%.

The production of the remaining 384 middle modules is well under way. Already more than 50 middle modules are build with an increased assembly efficiency of >97%, due to improved handling during the assembly.

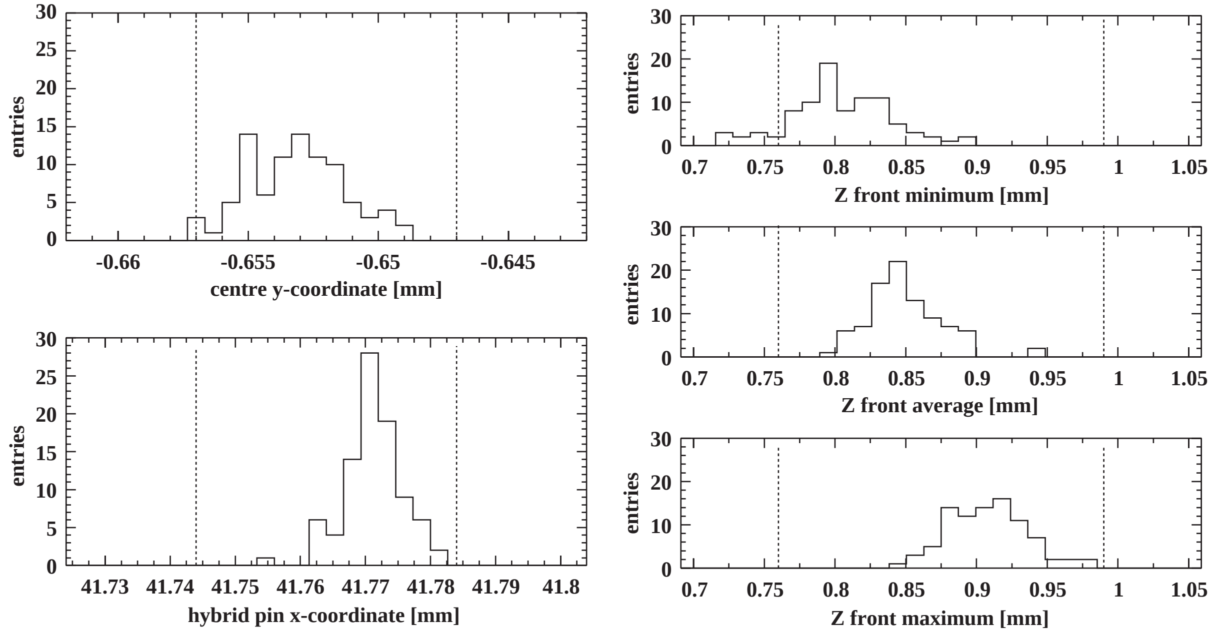

Fig. 2. The left figure shows two out of seven XY metrology parameters of the 88 short middle modules. The upper plot shows the position of the center of the sensors perpendicular to the strips and the lower one the mounting position of the module close to the hybrids along the strips. The dashed line indicates the tolerance for these parameters. The right figure shows the Z survey parameters of the front side of the short middle modules. The upper plot shows the lowest position of the sensors, the middle one the average position and the lower one the highest position with respect to the mounting surface. The dashed lines indicate the tolerance for these parameters.

4. Overall status of the SCT module assembly

The production of the SCT barrel modules is nearly finished with an overall efficiency more than 90%. More than 800 out of the 1976 endcap modules have been build and tested with an overall yield of 92.3%.[2] The SCT endcap module production is estimated to be finished by June 2005. One of the 18 SCT endcap disks most far away from the interaction point (disk 9C) is already equipped with modules and tested successfully.

The mass production of the endcap modules for the ATLAS SCT detector has started. The Max-Planck Institute in Munich is responsible for the production of 480 middle modules, including 96 short middle modules. The 96 short middle modules are built with a yield of 87.5%. Half of the short middle modules are already at the disk assembly site and will be mounted on the endcap disks soon.

References

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[3] F. Campabal et al., Nucl. Instr. and Meth. A 538 (2005) 384.

[2]Information last updated 18th October 2004.