PROCEEDINGS OF SCIENCE

ATLAS ITk pixel module assembly and testing experience

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The entire tracking system of the ATLAS experiment will be replaced during the LHC Phase II shutdown. The new silicon Inner Tracker will contain five innermost pixel layers equipped with new sensors and readout electronics capable to improve the tracking performance, cope with the high particle multiplicity and work in a high luminosity environment. In order to standardize modules of the Inner Tracker, the idea of a common hybrid module was introduced to be used in all regions of the detector. The common hybrid module assembly and testing techniques will be presented. The module construction, metrology and electrical testing results will be discussed.

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1. Introduction

The pixel detector [1] is the innermost silicon tracking device in the ATLAS experiment [2] at the Large Hadron Collider (LHC). It is a high granularity, radiation hard detector, which provides high spatial resolution. The pixel detector plays a central role in the event reconstruction and momentum measurement at low p_T in the ATLAS experiment. The current inner detector is not suitable for operation at the High Luminosity LHC (HL-LHC), where the luminosity will be significantly increased with respect to the current conditions. Thus, a completely new, silicon-based Inner Tracker (ITk) [3, 4] will be installed. The new pixel detector consists of about ten thousand pixel modules in the hybrid scheme [5]. Each module carries a silicon sensor segmented into pixels and connected to Front End (FE) readout chips, developed by RD53 Collaboration [6], by bump bonds with a high density of about 40 000 contacts/cm^2. Each module provides 150 000 readout channels with 50 x 50 µm^2 or 25 x 100 µm^2 pixels, depending on the place in the detector. The signal transmission from these readout channels, as well as the power distribution for the modules, is achieved using a flexible hybrid PCB (“flex”). The sensor bias voltage (100 V before and 600 V after irradiation) is also provided by the flex PCB. Depending on the geometrical position of each module inside the pixel detector, a sensor is bump bonded to one (inner layer) or four FE readout chips (outer layers). In order to limit time and effort, a common flex PCB design for the outer layers is preferred. One of the solutions for this concept is to use detachable pigtails, which are flexible PCBs with different lengths, to connect the common flex hybrid in the different detector regions. Taking into account that about ten thousand pixel modules have to be assembled and working for years in harsh conditions, the choice of the common flex hybrid design and the module assembly procedure are most important for the detector upgrade. Other very important parameters such as the amount of dead material in the sensitive area, the power dissipation of the module and a possible Coefficient of Thermal Expansion (CTE) mismatch of different module materials are also taken into account. In this proceedings we show the various assembly and testing steps for an RD53B module as built at the University of Siegen.

2. Pixel module assembly procedure

The module assembly procedure requires the mounting of a bare module (FE chips bump bonded to the sensor) on the flex hybrid. This is a multi-step process. After visual inspection, passive components are mounted on the flex hybrids in industry. The flex PCBs are then kept in a dry box in order to prevent possible corrosion of the pads. After that, each of them undergoes metrology with a Coordinate Measuring Machine (CMM), as shown in Figure 1, and is then glued to the bare module. The glued module must be inside the defined envelope for the Inner Tracker. A stable connection between the flex hybrid and the silicon sensor is achieved by covering 80% of the module surface with epoxy glue. During the gluing procedure, the module is aligned by dowel pins and held in place by vacuum provided by an oil free pump. A special tool for gluing is used. For the wire bonding, an automatic wire bonder is used. About 800 wires are connected for each module with four readout chips. The strength of the wire bonds is controlled by a pull tester and measured to be 7 g on average, as shown in Figure 2. In order to avoid the risk that some wire bonds touch each other or the edge of the silicon sensor, causing electrical shorts, a careful visual inspection is performed at the end. For the Outer Barrel demonstrator at CERN (with RD53A front-end-chips), module encapsulation has been the final assembly step. During this process, areas with wire bonding pads (including HV pads) are covered by silicone two-component elastomer Sylgard 186 glue, which is outgassed in a desiccator beforehand, so that no bubbles remain, and then distributed using a manual dispenser. Once the glue has dried, it protects wire bonds against mechanical and chemical damages. This part of the assembly was done for the RD53A ITk Outer Barrel demonstrator at CERN only. Due to high irradiation at HL-LHC, the wire bonds in the real detector will be covered by CFRP (carbon fiber-reinforced plastic) canopies. The assembled RD53B module is shown in Figure 3.

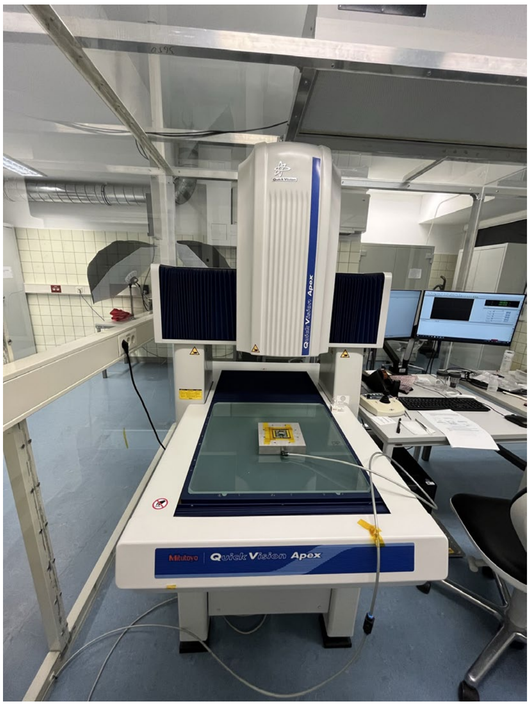

Figure 1 The Mitutoyo CMM in Siegen with 1.5 μm precision.

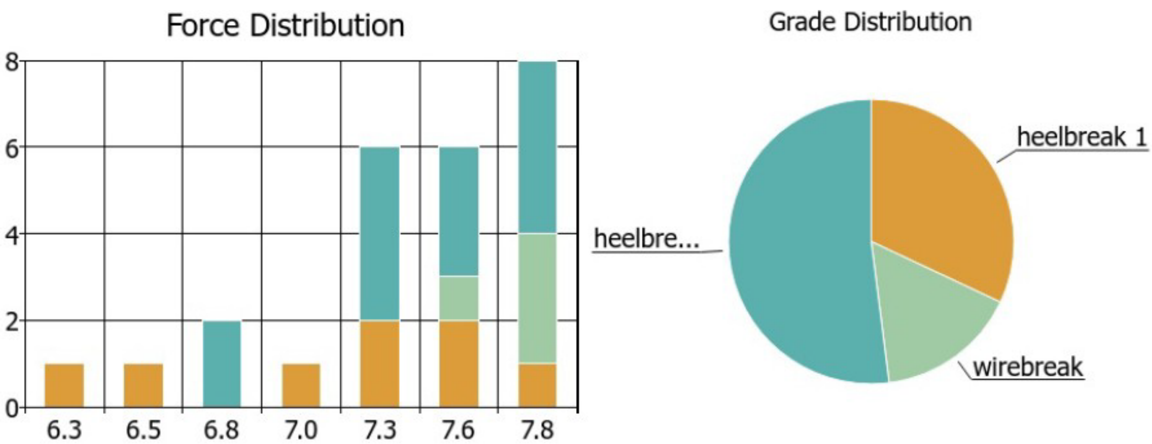

Figure 2 Pull force distribution in grams obtained for the assembled RD53B module. Heelbreak distribution from flex PCB (heelbreak 1) and from chip (heelbreak 2) sides is also shown.

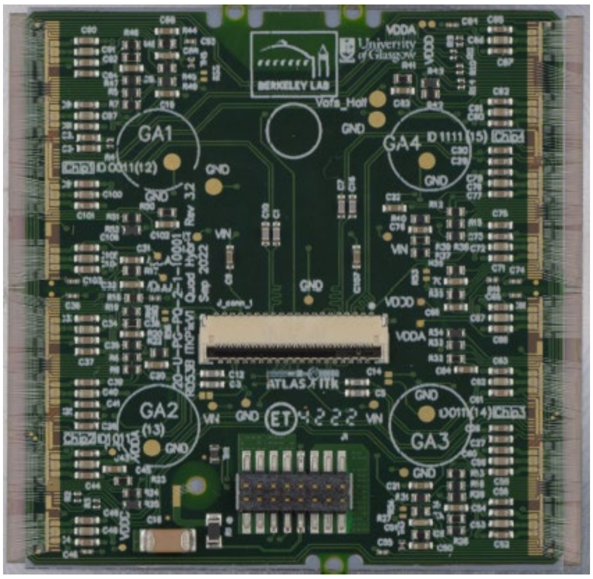

Figure 3 RD53B module assembled in Siegen.

3. Module testing and results

Once the module is assembled, it undergoes several tests. Module characterization is done twice, before and after the encapsulation step. The module is placed inside a module carrier with dry air flow, cooled in a climate chamber and connected via specially designed adapters to the YARR readout system [7]. This readout system consists of a readout board driven by an FPGA and C++ - based software. Basic functionality tests, which are used to check the digital and analog parts of the chips, are followed by FE chip tuning, masking of noisy pixels and a threshold scan. The basic tests mostly check the wire bond connections, while further tests allow to probe the quality of the assembled module. A final test is performed using a Sr-90 source, to check the ability of the module to register signals and transmit the data correctly. In this case, the module is working in self-triggering mode, i.e. the trigger signal is generated by the FE chip every time a hit is registered. Typical results of the tests in Siegen are shown in Figure 4. The modules are transported to CERN in dedicated boxes and tested there in the serial powering chain. The modules with low quality are tested for delamination and other possible defects. The tests are performed within the framework of the Outer Barrel layers demonstrator program ongoing at CERN.

3. Summary

A prototype module for the common flex hybrid design based on four RD53B chips has been successfully built and tested. The concept of common ITk pixel modules has been proven in the Outer Barrel demonstrator at CERN. The pre-production phase for the pixel detectors has been started and the first modules are being produced. The production of pixel modules will start after the qualification of the assembly and testing procedure.

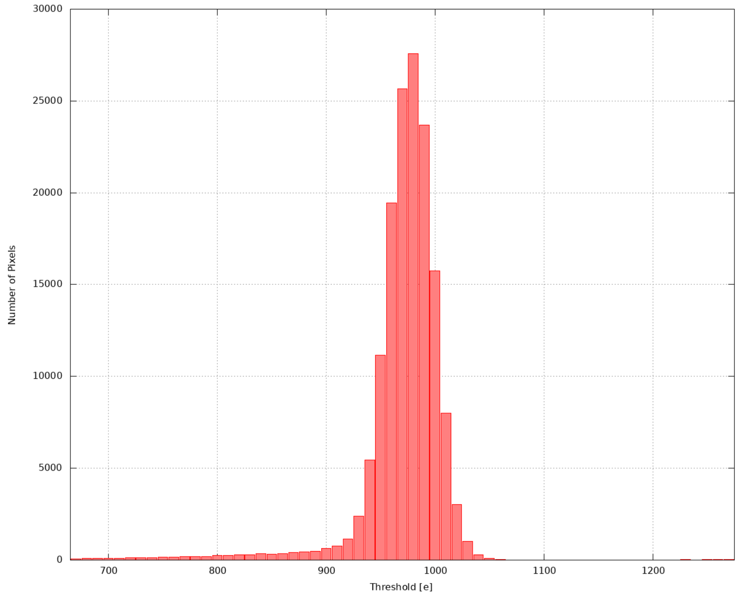

Figure 4 RD53B module thresholds after tuning.

References

[1] ATLAS Collaboration, *ATALAS pixel detector electronics and sensors, JINST 3* (2008) P07007 DOI: 10.1088/1748-0221/3/07/P07007.

[2] ATLAS Collaboration,, *The ATLAS experiment at the CERN Large Hadron Collider, JINST 3* (2008) S08003. DOI: 10.1088/1748-0221/3/08/S08003.

[3] ATLAS Collaboration, *Technical Design Report for the ATLAS Inner Tracker Pixel Detector*, CERN-LHCC-2017-021, 2017.

[4] ATLAS Collaboration, *Technical Design Report for the ATLAS Inner Tracker Strip Detector*, CERN-LHCC-2017-005, 2017.

[5] L. Rossi, *Pixel detectors hybridisation, Nucl. Instrum. Meth.* A 501 (2003) 239. DOI: 10.1016/S0168-9002(02)02041-7.

[6] RD53 Collaboration, *RD Collaboration Proposal: Development of pixel readout integrated circuits for extreme rate and radiation,* CERN-LHCC-2013-008, 2013.

[7] T. Heim, *YARR - A PCIe based Readout Concept for Current and Future ATLAS Pixel Modules, J. Phys.: Conf. Ser.* 898 (2017) 032053. DOI 10.1088/1742-6596/898/3/032053.