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Experiences with module-production and system tests for the ATLAS Pixel Detector

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Abstract

The ATLAS pixel detector is built from 1744 modules which are organized in three barrel layers and three disk layers in forward direction. The modules consist of an oxygen-enriched silicon sensor with an active area of $60.8 \times 16.4\,\mathrm{mm}^2$. Its 46 080 pixels are read out by 16 frontend chips, bump bonded to the sensor using a state-of-the-art hybridization technique. After extensive characterization of the single modules they are mounted on support structures, made from a carbon–carbon composite material, which make up the barrel or the disc layers. The first of these assemblies are used to study the behavior of the modules outside the lab environment.

Keywords: Pixel detector; Semiconductor detector; ATLAS-pixel

1. Introduction

The ATLAS Inner Detector [1] is constructed for high-precision tracking of charged particles at a bunch crossing frequency of 40 MHz. It combines 36 tracking points from tracking straw tubes in the transition-radiation tracker (TRT) with four points from the microstrips of the semiconductor tracker (SCT) and three points from the Pixel Detector.

The ATLAS pixel detector [7] consists of three barrel layers around the beam-pipe, the innermost at a radius $r = 50.5\,\mathrm{mm}$, and three disk layers on either side in forward direction. With a total length of approximately 1.3 m this results in a three hit pixel system for particles up to $|\eta| = 2.5$.

The main components of the pixel detector are 1744 identical hybrid modules, corresponding to 8×10^7 readout channels. The modules have to be radiation tolerant for an ATLAS lifetime dose of 500 kGy or 10^{15} n_{eq}[1]$/\mathrm{cm}^2$.

2. Module layout

A module consists of 16 readout chips (*FE*) which are connected to a single oxygen enriched n-in-n silicon sensor using the fine pitch bump bonding technique. The sensor material was chosen due to the very high radiation dose it has to withstand during the lifetime of ATLAS. The sensor has an active area of $60.8 \times 16.4\,\mathrm{mm}^2$, a thickness of 250 μm and is divided into 46 080 pixels which are individually connected to the readout chips by bump bonds. Glued to the backside of the sensor is a flexible Kapton PCB (*Flex*) which routes the supply voltages to the readout chips and their signals to the module controller chip (*MCC*). The readout chips are connected to the *Flex* through 22 μm wire bonds. Fig. 1 shows a schematical cross-section of a module.

The *MCC* connects to the ATLAS supply and readout system via an aluminum microcable, which is either directly soldered to the *Flex* for the disk modules, or plugged into a connector on the *pigtail*, another flexible Kapton PCB wire bonded to the *Flex* on the barrel modules.

Fig. 2 shows a schematic view of a barrel module looking at the *Flex* and the *pigtail*.

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[1] 1 MeV neutron equivalent.

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The sensor is subdivided into 41 984 "standard" pixels of $50 \times 400\,\mu m^2$ thus providing a high spatial resolution of approximately $12\,\mu m$ in $r\phi$ direction and $115\,\mu m$ in z direction. To cover the $400\,\mu m$ gap between adjacent readout chips 5248 "long" pixels of $50 \times 600\,\mu m^2$ are introduced. Fig. 3 shows the arrangement of these special pixels. As there is also a $400\,\mu m$ gap between readout chips on opposite sides of the module, 2× four pixels in the middle of the sensor have to be bridged to each of the two readout chips ("ganged" pixels) to avoid a dead area. They are connected to four out of the eight topmost pixels on these readout chips. The remaining four pixels are called "inter-ganged" pixels.

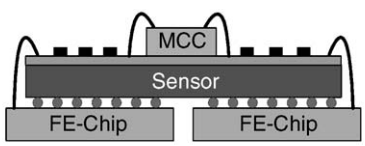

Fig. 1. Schematic cross-section of an ATLAS Pixel module.

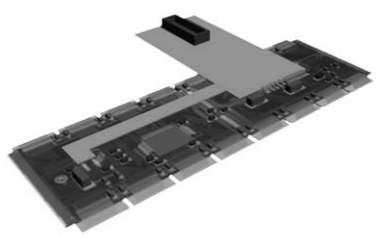

Fig. 2. Schematic view of a barrel module.

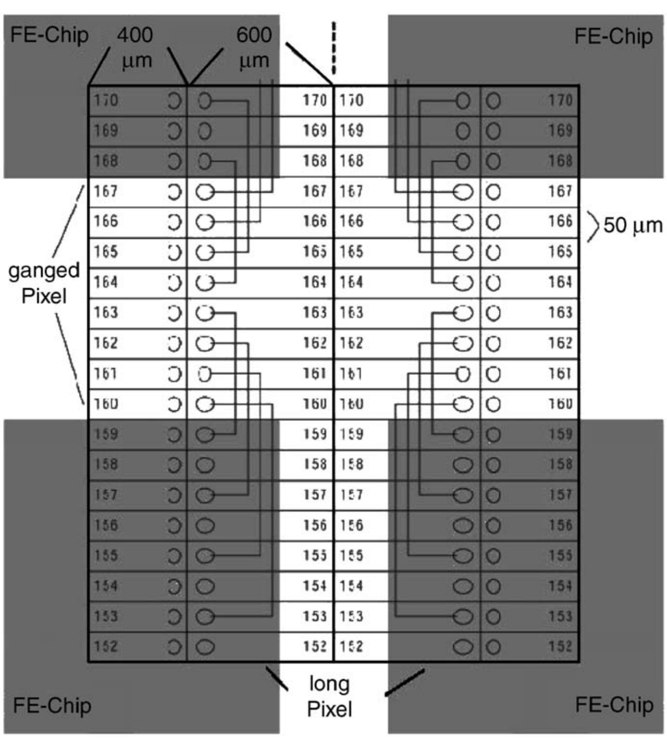

Fig. 3. Arrangement of special pixels in the gaps between FE chips.

The *FE* contains 2880 individual pixel cells. The analog part consists of a high-gain, fast preamplifier, followed by a DC-coupled second stage and a differential discriminator. The discriminator threshold ranges up to approximately 1 fC, the nominal value being 0.5 fC. It is individually adjustable for each pixel using a 7 bit DAC. When a hit is detected, the pixel address is provided together with the time over threshold information (ToT, in units of 25 ns), which is an indirect measure of the charge deposited in the sensor. The pixel detector consists of 1744 such modules which are currently in production.

3. *BareModule* production

Connecting the sensor to the readout chips is the most crucial part of the module assembly. This is done using 46 080 bump bonds with a diameter of $25\,\mu m$ and a pitch of $50\,\mu m$ at two different companies, the Fraunhofer Institute for Reliability and Microintegration IZM in Berlin and Selex Sistemi Integrati (former Alenia Marconi Systems, AMS) in Rome.

The vendors use different interconnection techniques. AMS deposits cylindrical indium bumps on the sensors and readout chips and connects those by thermo-compression while IZM uses lead–tin bumps which undergo a reflow process forming spherical connections.

Out of a total of 2600 *BareModules* ordered, by now 1500 have been delivered. Fig. 4 shows the number of delivered modules as well as the numbers of modules accepted immediately (virgin accepted) and after reworking plotted against the delivery date. The rate of delivery for both vendors is about 17 *BareModules* per week.

The vendors ship the *BareModules* to the testing labs, where the bump quality is measured using charge injection circuits on the readout chips. *BareModules* with poor bump quality, i.e. more than 50 unconnected bumps on one chip

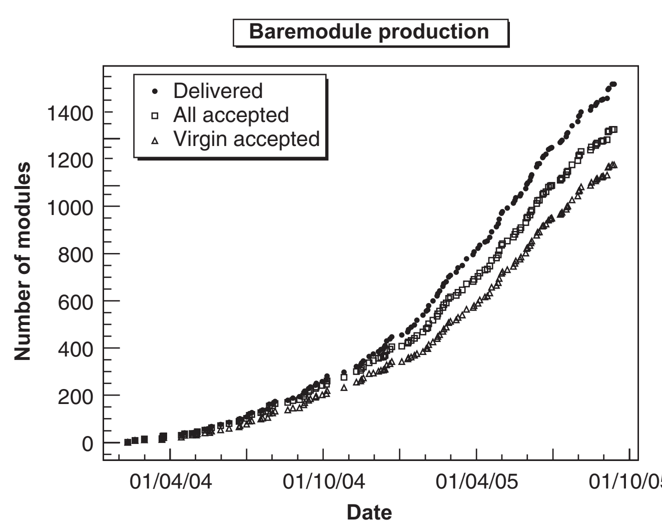

Fig. 4. Produced BareModules at IZM and AMS together. Virgin accepted are modules accepted immediately, all accepted are virgin accepted and modules accepted after reworking.