Module development for the ATLAS ITk Pixel Detector

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Abstract. In HL-LHC operation the instantaneous luminosity will reach unprecedented values, resulting in about 200 proton-proton interactions in a typical bunch crossing. The current ATLAS Inner Detector will be replaced by an all-silicon system, the Inner Tracker (ITk). The innermost part of ITk will consist of a state-of-the-art pixel detector. Several different silicon sensor technologies will be employed in the five barrel and endcap layers. Based on first modules assembled using the RD53A prototype readout chip, numerous issues are being studied. These include production ones like bump bonding of large area, thin modules, as well as the optimization of the bandwidth and sharing of links between multiple chips and modules. These proceedings will present results of many of these studies, which directly impact the construction and assembly of modules using the first production version of the readout chip ITkPixV1, which will become available shortly.[1]

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1. Introduction

The ATLAS[1] experiment will upgrade its tracking detector during the Phase-II LHC shutdown to take advantage of the increased luminosity of the HL-LHC, with data-taking expected to start by 2027. The upgraded tracker will consist of a barrel of concentric layers (5 pixel + 4 strip, with several endcap rings) and will likely cover an extended η range, where η is the pseudo-rapidity defined as $-ln\left(\tan\frac{\theta}{2}\right)$ and θ being the angle between a particle and the beam axis. It is foreseen to cover up to $|\eta| = 4.0$. Substantial developments are taking place in the area of silicon hybrid module technologies to optimize their assembly and integration techniques in order to acquire the necessary expertise for the detector's commissioning. To validate the numerous production, assembly, integration tests and wider infrastructure necessary in preparation for the commissioning of the ITk[2], the first stages of these developments are being conducted using RD53A[3] hybrid modules. Diced to match the final production sensor size (ITkPixV2[4]), these will assist towards optimizing the tooling and testing infrastructure needed for the final commissioning stage.

2. Assembly

A module consists of a silicon sensor bump-bonded to one or more front-end (FE) chips, forming a bare module glued to a flexible PCB that relays the data and power connections to dedicated pigtail cables. A module formed of four FEs is referred to as a quad module. The module

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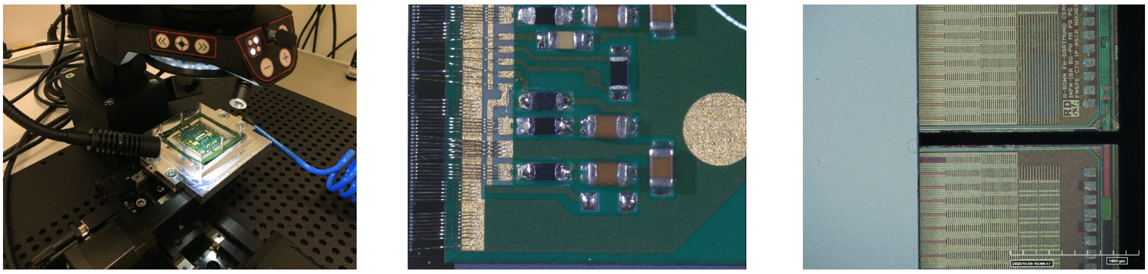

Figure 1. Automated visual inspection setup (left), close-up image of wire-bonded assembly (centre) and bare module showing neighbouring front-ends (right).

assembly process comprises of several key stages. The first is visual inspection which involves assessing all components upon reception and at every assembly and testing stage to ensure no defects are present. Figure 1 shows its dedicated setup as well as sample images take during this process.

The next stage is metrology in which all components' weights and dimensions, including their planarity are measured. The latter has to be achieved through non-contact methods in order to avoid introducing any defects. Figure 2 shows the optical-based measurement instrument as well as a sample 2D scan of an assembled module.

Figure 2. Optical metrology measurement system along with a milligram weighing scale (left) and an example of a 2D scan conducted on an assembled quad module (right).

Next, the step known as flex-attach takes place, which involves gluing the bare module onto the flex PCB using custom-made tooling. The current version of this assembly tooling (V1.0, shown in figure 3) requires the manual setting of fine-adjustment screws to fix the gap between the flex bottom surface and bare module top (sensor) surface. This gap is in part controlled by temporarily placing precision gauge sheets with a total thickness of 40μm, the target glue thickness.

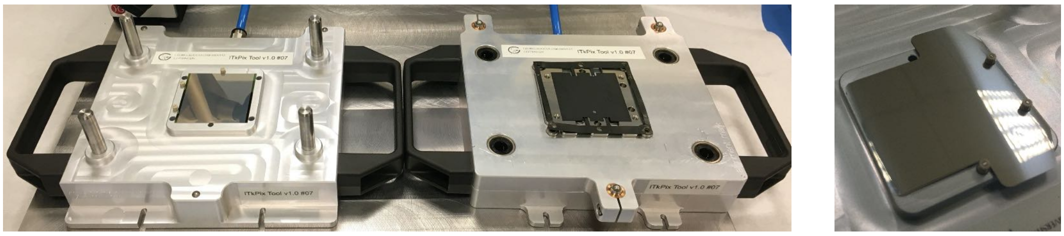

Figure 3. Quad module assembly tooling V1.0 (left) and 2×20μm stainless steel gauge sheet spacers used for glue layer thickness control (right).

Once this is achieved, the glue, namely Araldite 2011A, is dispensed onto the flex back side using a stencil which controls the glue pattern. Finally both halves of the tooling, the bare module jig and the flex jig are mated and left securely overnight for the glue to cure. These steps are illustrated in figure 4.

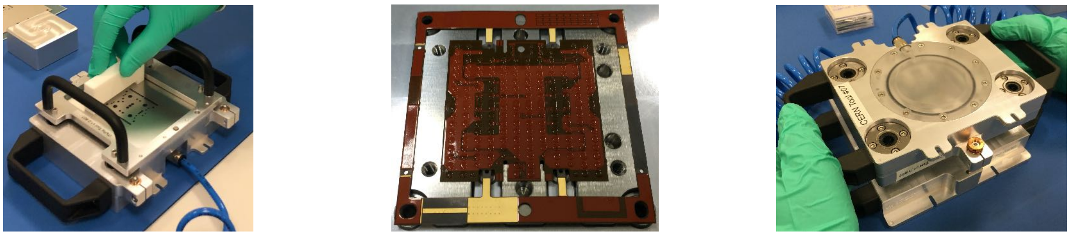

Figure 4. Glue application through stencil (left), glue pattern on flex back side post-dispensing (centre) and mated bare module and flex jigs left for glue curing (right).

The module is then wire-bonded using aluminium wedge wire-bonds followed finally by parylene coating. This coating is necessary as it provides a degree of mechanical robustness to the delicate wire-bonds but also provides protection against high-voltage sparks possible at the vicinity of the sensor edges. In addition this coating also ensures protection against atmospheric corrosion. Though the parylene coating surface should be maximised across the entire module area, three key regions must be masked. These are the data-connector, the electrical connection pins of which would be compromised if coated as well as four pick-up points on the module flex in order to maintain good adhesion and finally also the sensor back side. The latter is necessary in order to ensure that the module can be safely secured onto its mechanical support (also known as cell on a local support) as well as thermal conductive properties. To this end masking tape is manually applied on the sensor back side and flex pick-up points and a 3D-printed cover encloses the data connector. Figure 5 shows these different masking steps.

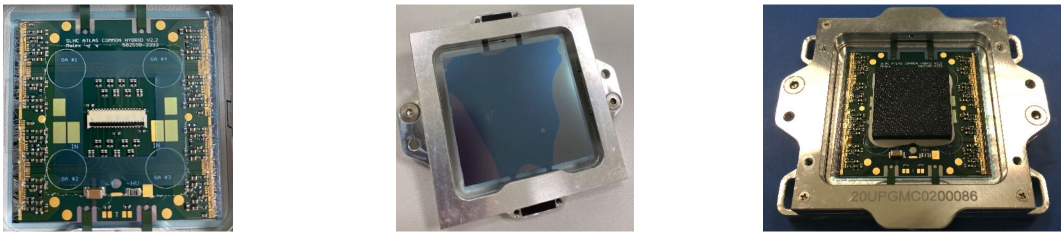

Figure 5. Masking tape applied across flex pick-up points (left), sensor back side (centre) and data connector masking cap (right) prior to parylene coating.

As part of systematic tests being conducted to qualify various vendors across the globe offering parylene coating services, thickness measurements as well as “scratch-tests” are performed on samples post-coating to assess their suitability towards the specification as well as level of adhesion. In addition bond pull-strength tests are also conducted before and after this coating process to assess the degree of mechanical protection offered.

3. Testing

Once assembled, the modules undergo electrical testing. This begins with performing scans and tuning the front-ends. Next the ability to monitor the high-voltage, low-voltage and currents as well as environmental temperature, humidity, dew point and module NTC temperatures must be ensured. This includes the implementation of software interlocks which can for instance alert for module temperatures exceeding 40^oC and leakage currents lower than -1 μA. Subsequently, thermal cycling is necessary to ensure the operation of the module after 10 cycles down to -45^oC, temperature profiles of which are also shown on figure 6. Finally, source scans must be performed to display the functionality of unmasked pixels, also shown on figure 6 where the empty columns correspond to the RD53A's differential front-end, disabled in this particular quad module's scan.

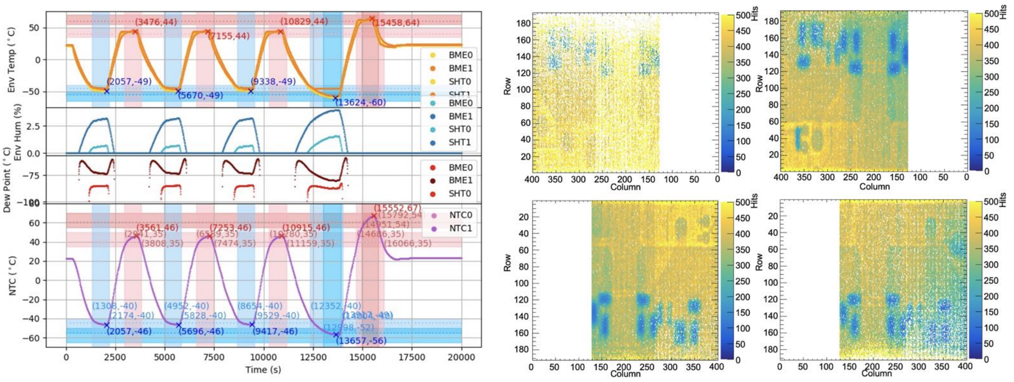

Figure 6. Thermal cycling profiles (left) and a 54 MBq^{90}Sr source scan over one hour at a 50kHz trigger rate (right).

4. Tools facilitating a global production

Several additional tools have been developed in order to ease the extensive module assembly effort. Two of which are described here. The first is the production database, which has been designed to act as a central repository housing all bare component registration information such as past and present locations, measurement data from sensor and front-end electrical tests, metrology measurements and even visual inspection data.

Another tool developed to assist with the transportation of these delicate modules is a metal carrier. This allows their secure transportation between different sites all whilst allowing electrical testing to continue via pigtail connectors further reducing the need for their direct handling.

5. Summary & Outlook

With these developments in the module production stages, the quad module assembly process is gathering pace across the different participating institutes with a first batch of RD53A quad modules now undergoing extensive electrical testing to verify their operation. Each of the different production stages, from reception, assembly, wire-bonding, parylene coating and electrical testing are foreseen to converge by the second half of 2021. The production using the final ITkPixV2 readout chip is expected to begin the following year once all these stages have been adapted for it.

References

[1] ATLAS Collaboration, 2008 JINST 3 S08003.

[2] ATLAS Collaboration, Technical Design Report for the ATLAS Inner Tracker Pixel Detector, CERN, Geneva, CERN-LHCC-2017-021, ATLAS-TDR-030, Sep, 2017, `https://cds.cern.ch/record/2285585`.

[3] RD53 Collaboration, The RD53A Integrated Circuit, CERN, Geneva, CERN-RD53-PUB-17-001, Oct, 2017, `https://cds.cern.ch/record/2287593`.

[4] RD53 collaboration `rd53.web.cern.ch`.