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Manufacture and QC of the ATLAS ITk quad pixel module flex PCB

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ITk hybrid pixel detector consists of about 10,000 planar "quad"modules formed from 4 ASICs, (developed within the RD53 collaboration) bump bonded to a single sensor.
The flexible PCB attached to the sensor connects the ASICs to the system and provides the module's electrical environment.
To guarantee long-term reliability in the harsh HL-LHC environment, a tight quality control is mandatory.
Using three bare flex and three population vendors the populated flexes are manufactured as per IPC standards, Quality Control (QC) protocols were developed to maintain quality and maximise module yield.
We describe in detail the QC process and results.

Summary (500 words)

The bare flex and population vendors perform their QC measurements. Three bare flex and seven populated flex institute QC sites perform additional QC.

Some tests are per batch and others up to a 100% sampling fractions. Additional destructive tests are performed: peel, thermal cycle, and irradiations.

QC covers signal transmission, wirebondability, impact on module assembly, HV performance, copper content and to confirm overall flex build.

To confirm signal transmission the track and gap of flex traces and impedance measurements on test coupons are measured at the bare flex vendors and QC sites. After population the S-parameters of the flex is measured. During prototyping the impedance measured at the QC site was out of specification (100 ± 10 Ohm), but not at the vendor which incorrectly measured it before the last etch stage. This was corrected and is well behaved during production.

Bare flex metrology controls the flex size and dowel hole diameter (specification 3.0 +0.1/-0.0 mm) to allow flex to bare module alignment to the required tolerance of ±100 µm. Several iterations were required to obtain the correct dowel size. The cut edge accuracy is important as data lines run around the flex perimeter and the copper set-back guarantees transmission line impedance. This is comfortably within specification.

AOI and flying probe measurements at the bare flex vendors confirm circuit formation. At the population vendors AOI controls component placement. Visual inspection at QC sites double checks the vendors QC and confirms wirebonability. Several issues were found and resolved including defects in the ENIG, and solder flux contaminating wirebond pads. Wirebond pads are the highest cause of failure. The bare flex vendors have struggled with defects in the ENIG including scratches, nodules and poor plating, resulting in failures as high as 50% internally at one vendor and 30% at one bare flex QC site. At one population vendor contamination from flux residuals (no-clean flux used) caused significant issues and required additional cleaning at the institutes for all pre-production flexes.

Maximum operational HV is 650V and every populated flex is tested at 975V. Also, a 10-day soak test on 10 flexes is performed per batch. The HV test measures leakage current (specification below 20nA) to confirm the filter components, circuit realisation, connector population, and no pin-holes in the backside dielectric. Of the 2000 flexes tested less than 1% fail. During the HV test, the resistance of the LV circuit is measured between test points on the flex and the NTC is verified.

Copper thickness is critical as excess weakens the module bump bonds due to thermal mismatch between flex and module local support. It was impossible to obtain acceptably priced quotations for the desired maximum copper thickness. Therefore, the order stated the design value and the vendor's manufacturing tolerance. To control copper thickness each flex is measured using dedicated test points on the frame, which is cross-checked against the LV circuit resistance. The specification is an equivalent thickness less than 31um, with the percentage failing varying significantly between batches from 0% to 10%.

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