Assembly Process of the Innermost Modules of the ATLAS ITk Pixel Detector

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Abstract

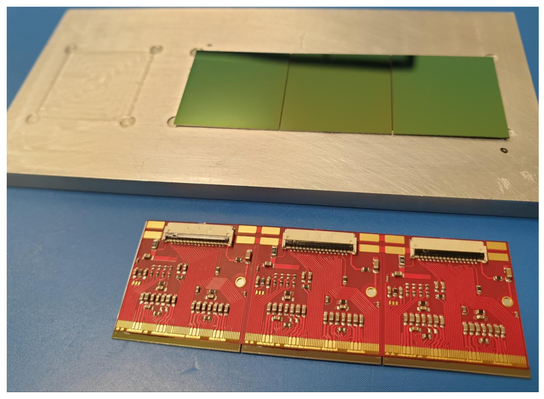
- The High-Luminosity (HL) phase of the LHC targets unprecedented levels of luminosity that have strong implications on the experiments. ATLAS will be improved to face the increased radiation damage and occupancy.

- The most demanding sub-detector system of the ATLAS HL-LHC upgrade is the Pixel Detector of the Inner Tracker (ITk).

- The compactness of the pixel detector system is crucial to obtain the desired performance: each pixel detector module must meet rigorous requirements of space and alignment.

- The method to assemble the modules developed at IFAE is tested with dummy samples, and shown to (1) satisfy the envelope constraints, (2) meet the specifications on the amount and coverage of glue and total module thickness, and (3) fulfil the wire-bond pull-test requirements.

Triplet Assembly



- The ITk pixel detector for the ATLAS HL will include 3D sensors in the inner most layer.
- The space available for 3D modules (or triplets, as they contain 3 sensors per unit) is very tight.
- We assembled 3 triplets using silicon dummies. These dummies have similar dimensions as the final bare modules (which will consist ITkPixV2 chips bump-bonded to 3D pixel sensors)
- The dummies are glued on the hybrid flex, a flexible PCB that allows the operating of the front-end modules.
- This work shows the assembly method and the results of 3 triplets (fabricated in a row) in terms of the accuracy obtained in view of the specifications

Assembly specifications

The assembly process has several requirement and specifications on geometry and gluing methods that we must follow. These are some of the most relevant parameters that we must achieve:

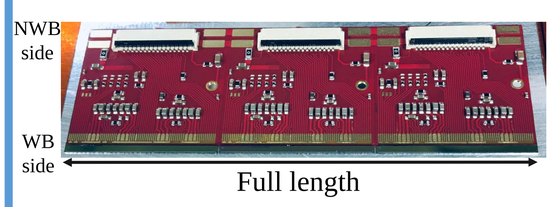
Geometry and envelope:
- Triplet full length: **between 6.19 and 6.34 mm**.
- Nominal distance between dummy and the flex edge: **180 µm**.
- Nominal gap between dummies: **larger than 50 µm, our nominal target is 180 µm.**
- Align edges: **± 25 µm**.

Wire bonding:
- Pull test strength: **above 5 g (per wire)**.
- Average strength: **above 8 g**.

Glue and thickness:
- Covered area: **above 80%**.
- Glue thickness: **between 25 and 55 µm**.

Metrology

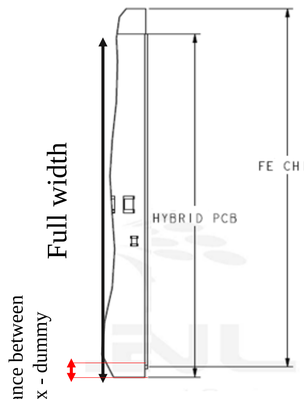
Full triplet length



- We measure the full length on both edges, the wire-bonding (WB) and in the other side, no-wire-bonding (NWB).
- We can see that on both edges, the length meet the specifications.

	WB side [mm]	NWB side [mm]
Module 1	61.243	61.242
Module 2	61.288	61.285
Module 3	61.265	61.264

Triplet width



To place the dummies on the flex in a systematic way:
- Align the dummy to the flex along the NWB edge.
- Displace the dummy by 180 µm.
- Place (glue) the dummy.

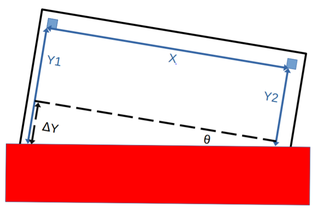
We measure the full width and the average distance between the flex edge and the dummy on several places along the triplet.
Table 1 shows the average and maximum full widths of the assembled dummy triplets.
Table 2 shows the accuracy of the method and the deviation with respect the nominal value (180 µm).

Table 1	Average full width [mm]	Maximum full width [mm]
Triplet 1	21.348	21.419
Triplet 2	21.342	21.355
Triplet 3	21.350	21.371

Table 2	Average flex edge-dummy distance [µm]	Deviation wrt nominal [µm]
Triplet 1	178	-2
Triplet 2	171	-9
Triplet 3	187	7

Dummy rotation

- The sketch shows the two variables that we need to measure to determinate if the dummy is rotated with respect the flex.
- To calculate the angle, we use the next formula: θ=arc tan(ΔY/X). Y1 and Y2 are the distances between the dummy pads to the flex.



Triplet 2	Dummy pads to flex rotation					
Dummy 1		**Dummy 2**		**Dummy 3**		
ΔY [µm]	10	ΔY [µm]	12	ΔY [µm]	6	
θ [°]	0.028	θ [°]	0.035	θ [°]	-0.018	

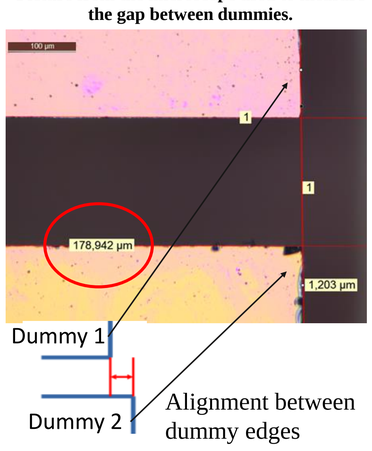
Rotation for the dummies in Triplet 2. We can see that the angle is small, so the dummies are not rotated wrt the flex.

Gap between dummies

- We measure the gap between dummies after the assembly.
- NWB and WB gap values between two adjacent dummies are similar, confirming the rotation is very small.
- The deviation wrt the target of 180 µm is between -20 to 10 µm.

Triplet 1	Gap 1- 2 [µm]	Gap 2- 3 [µm]
WB	172	162
NWB	183	163
Triplet 2	**Gap 1- 2 [µm]**	**Gap 2- 3 [µm]**
WB	190	182
NWB	187	184
Triplet 3	**Gap 1- 2 [µm]**	**Gap 2- 3 [µm]**
WB	177	168
NWB	179	161

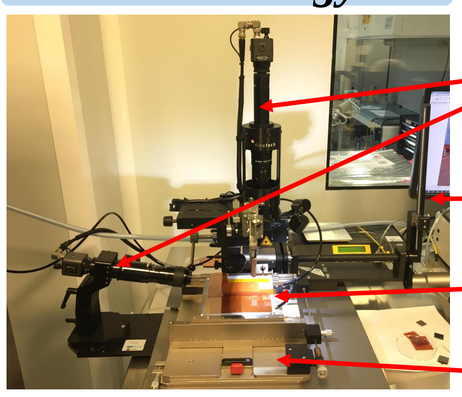
Picture from the microscope used to measure the gap between dummies.



- We also measure the alignment between adjacent dummy edges.
- All the values meet the specifications.

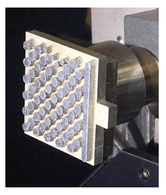
Triplet 1	1- 2 [µm]	2- 3 [µm]
WB	9	22
NWB	14	23
Triplet 2	**1- 2 [µm]**	**2- 3 [µm]**
WB	12	5
NWB	16	8
Triplet 3	**1- 2 [µm]**	**2- 3 [µm]**
WB	1	10
NWB	1	8

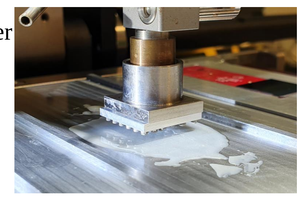
Methodology



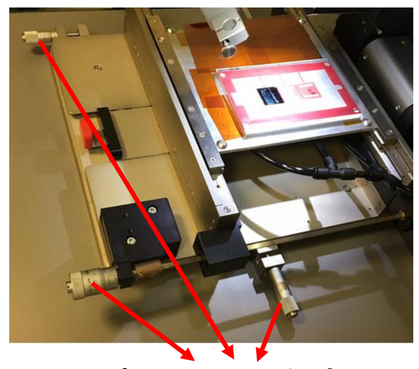
To assembly the triplets it is necessary to perform the following steps:

1. Prepare the glue and place the hybrid flex on the vacuum chuck
2. Place the stamp in the pick and place vacuum header, soak the stamp in the glue layer and stamp the flex in the first position.
3. Remove the stamp, pick the dummy with the header and align it to the first position.
4. Place the dummy in the first position and apply pressure.
5. Once the glue is sufficiently dry, repeat the process for the next dummy.

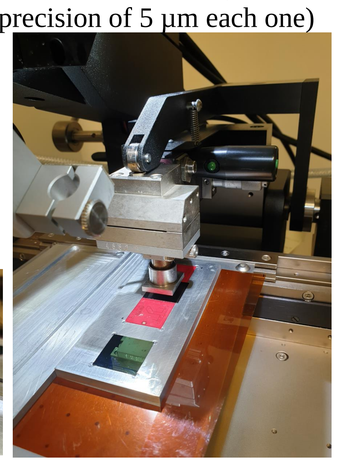




- **Top left**: Picture of the stamp
- **Bottom left**: Soaking the stamp in the pool of glue.



Set of micrometers (with a precision of 5 µm each one)



- **Right**: Picture of the placing process of the dummy on the flex.

Glue study and thickness.

Amount of glue and covered area

- To measure the amount of glue we use an analytical balance (0.1 mg error).
- We measure the weight of all the components before and after the assembly process.
- After the assembly, there were no glue seepages.

	Dummy 1 [mg]	Dummy 2 [mg]	Dummy 3 [mg]
Triplet 1	5.0	5.1	6.8
Triplet 2	8.4	7.7	6.9
Triplet 3	7.4	8.9	7.9

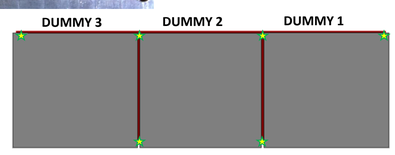
- To determine the area of glue we use glass dummies.
- In the picture we can see the covered area.
- The table shows the amount of glue and the covered area per chip.

	Dummy 3	Dummy 2	Dummy 1
Weight	6 mg	7 mg	8 mg
Coverage	83.8%	83%	83.1%

Picture of the covered area on each glass dummy

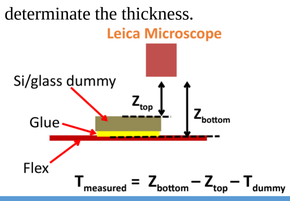
Glue thickness

- We estimated the glue thickness, measuring the difference between the Z coordinate on the flex and the dummy.
- All the measurements marginally meet the specifications.
- We are forced to measure along the edges, where the flex shows many irregularities. This limits the precision of the method.



The upper sketch shows the position where we are able to measure the thickness.

The bottom sketch shows the calculus to determinate the thickness.

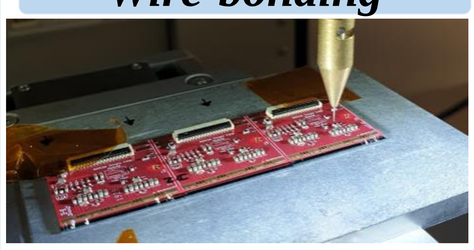


Triplet 1	DUMMY 1	DUMMY 2	DUMMY 3
	Thickness [µm]		
Top left	39	49	33
Top right	26	30	51
Bottom right	-----	28	21
Bottom left	57	50	------

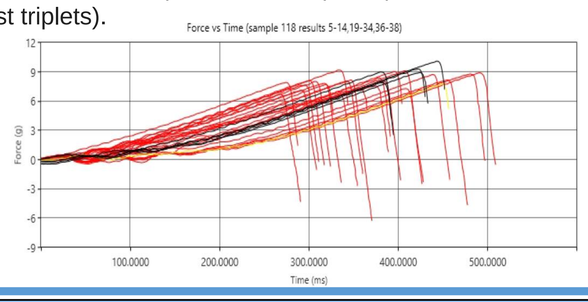
The table shows the thickness for the triplet 1.

Because the limitations of the measuring method, a large error (no lower than ± 20 µm) should be considered.

Wire-bonding



- Wire-bond pull tests done on an early triplet module (Dec 2020).
- We noticed that it is critical to have a good glue coverage, specially below the WB area.
- Glue coverage improved since Dec 2020.
- But even the first triplets met the specs (to be checked in latest triplets).



Specs	This triplet
All above 5 g	Min 6.7 g
Average > 8 g	8.2±0.8 g
Heel breaks > 90%	97% (38/39)

Conclusion

Geometry and Envelope
- Our assembly process satisfies all the geometry requirements.
- We are able to achieve a ±20 µm positioning accuracy.

Wire Bonding
- The wire-bond pull-tests, measured in earlier triplets, are within the specifications.

Glue and thickness
- A good coverage over 80% has been demonstrated with glass dummies. Having followed the same procedure, the same coverage is expected for these silicon dummies.
- No Glue seepage has been observed.
- The measurement of the glue thickness is especially difficult: The results are marginally within the specifications, but we plan to improve the glue thickness measurements with a profilometer.