Long-term humidity exposure of ATLAS18 ITk strip sensors

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Abstract

The ATLAS collaboration is upgrading its detector for High-Luminosity LHC operations scheduled to start in 2029. This involves making a new all-silicon tracker, called Inner Tracker (ITk), with instrumented strip area of 165 m^2.

The strip sensor type is n-on-p, chosen because of its radiation hardness and a relative fabrication simplicity. So far it has not been used in large-scale experiments. Many years of R&D investigations and pre-production experience showed that it works well, with the specification of the maximum operational voltage of 500 V. The sensors, however, show sensitivity to ambient humidity, e.g. reduced breakdown voltage at relative humidity (RH) values of about 40% and above. This is an issue for testability, but not real operations, where RH is very low. Therefore, the collaboration adopted the strategy of dry storage, testing, and shipment for sensors and related assembled components: modules, staves, and petals. A few days long exposure to ambient air during assembly was shown to be tolerable.

The dry handling strategy becomes much more difficult to implement during the tracker integration, when barrels and disks are put together in large-size cleanrooms with RH range between 50 and 70%. The duration of each of numerous integration steps is several weeks, followed by testing. The effect of such long humidity exposures on the sensor properties was unknown. Therefore, we commenced a study of repeat sensor exposures to 75% RH. We chose 32 sensors for the study from different deliveries, and with different pedigrees in terms of initial performance on reception and recovery procedures used. Progressively longer exposures ranged between 4 and 266 days in duration. The cumulative exposure time was up to 2 years. No performance deterioration was seen, as evaluated by the visual inspection, IV characteristics, and other checks. We report the details of the tests, results, and implications.

INTRODUCTION

The ATLAS ITk Strip Sensors are in the middle of the full-scale production. The design version called ATLAS18 satisfies the project Specification requirements [1]. The sensors have a feature that the breakdown voltage (Vbd) is dependent on the ambient humidity. Typically, Vbd is reduced at the relative humidity (RH) levels of 40-50% [2-3]. This is not a problem for operations, where a very dry environment is anticipated.

During the sensor tests where humidity matters, such as IV, CV, and Long-Term Stability (LTS) tests, RH is maintained under 10% [1]. This is straightforward to achieve in relatively small enclosures required for sensor, module and stave/petal tests, using either dessicant units or external gas line hookup to dry air or nitrogen.

The setups for the large-scale tracker objects, such as disks and cylinders, are different. They need large cleanroom volumes, which are impractical to keep dry at all times. Therefore, it is important to investigate a question of the long-term sensor tolerance to the ambient humidity. Given the Specifications for the cleanrooms and the construction plans, we formulate the question in the following way: **After a several months long exposure to RH of 50% to 70%, would the ATLAS18 sensors still have the acceptable Vbd > 500 V, as shown by the IV tests performed in a dry environment (RH<10%)?**

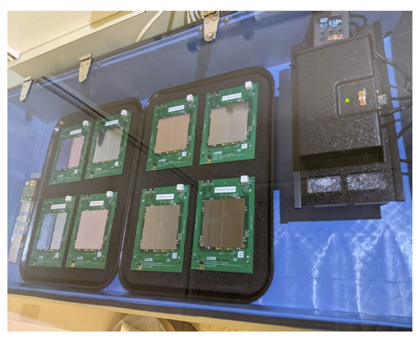
Sensor Samples and Exposure Setups

The sensor selection:

- At first, 8 devices from 5 pre-production batches. Their exposure started in March 2021.
- In July 2022, additional 16 devices from 13 production batches were added. Their selection targeted sensors after performance recovery methods applied, UV irradiation or "baking" [4].

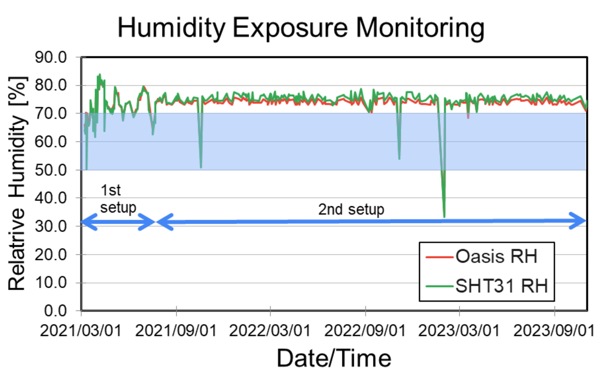
The setups:

- For the first 4 months, the "flatbed" setup was used. It was not scalable to the larger quantity of sensors.
- A dedicated hermitized cabinet was commissioned and used for the rest of the exposure, to scale up the total number of sensors to 24. They were arranged in vertical holding shelves.
- To control the humidity, Oasis Humidor unit was used with a set point at 75% RH, above the expected humidity range. The setup temperature varied between 19 C and 23 C.



Initial "flatbed" setup for 8 sensors

Final setup with 24 sensor positioned in vertical shelves

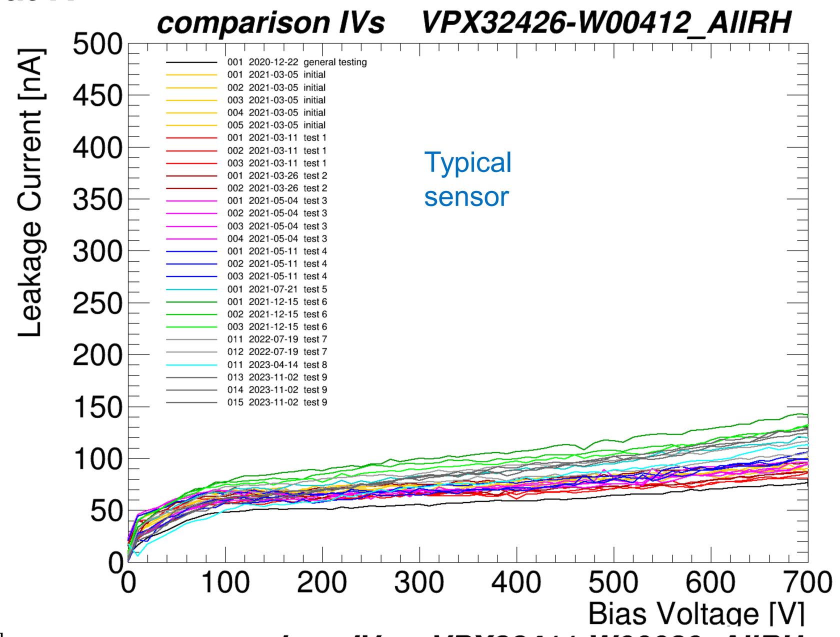


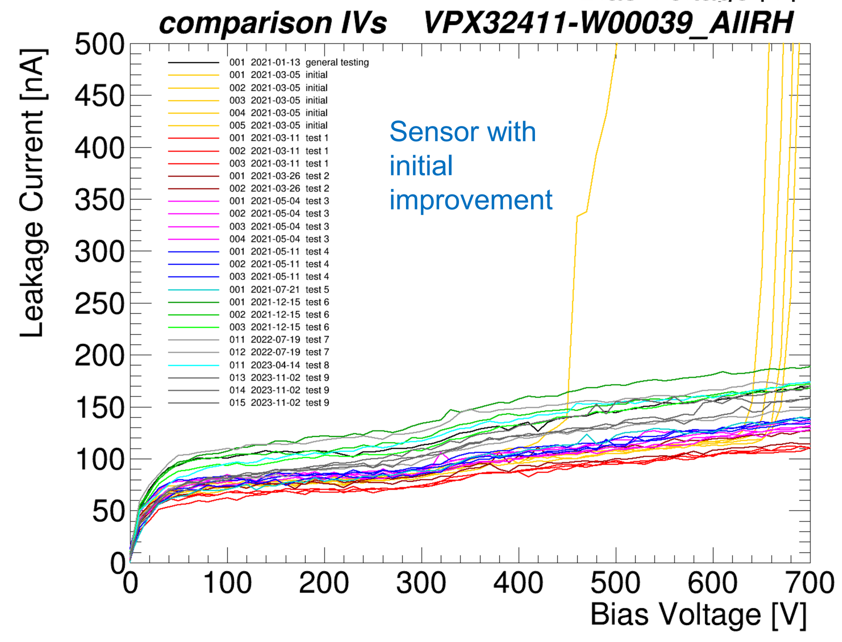
Exposure Number	Start Date	Individual Exposure [days]	Cumulative Time [days]	Average RH [%]	Ambient Lights
Initial 8 sensors					
1	2021-03-07	4	4	66.9	ON
2	2021-03-11	16	20	66.9	ON
3	2021-03-27	39	59	74.8	ON
4	2021-05-05	7	66	77.5	OFF
5	2021-05-12	70	136	72.6	OFF
6	2021-07-22	146	282	74.5	OFF
7	2021-12-17	214	496	75.7	OFF
8	2022-07-20	266	762	74.4	ON
9	2023-04-14	201	963	75.3	ON
Additional 16 sensors					
1	2022-10-20	15	15	75.4	ON
2	2022-11-04	67	82	74.7	ON
3	2023-01-10	90	172	73.0	ON
4	2023-04-14	201	373	75.3	ON

Batch	Wafer	Initial problem	Recovery method
VPX32411	W00039	None	None
VPX32418	W00146	None	None
VPX32418	W00151	None	None
VPX32418	W00180	None	None
VPX32419	W00186	None	None
VPX32420	W00234	None	None
VPX32426	W00383	None	None
VPX32426	W00412	None	None
VPA38186	W01307	None, IV feature	Dry storage
VPA37911	W00997	None, IV feature	Dry storage
VPA38692	W01757	None, IV feature	Dry storage
VPA38186	W01591	IV	Dry storage
VPA38700	W01308	IV	UV (2hr)
VPA38701	W01961	IV	UV (1 hr), baking (17.5 hr)
VPA38886	W01989	IV	UV (1 hr), baking (17.5 hr)
VPA39550	W02630	LTS/Vbd	Baking (17.5 hr)
VPA38901	W02436	LTS/Vbd	Baking (18.3 hr)
VPA38901	W02443	LTS/Vbd	Baking (18 hr)
VPA38901	W02464	LTS/Vbd	Baking (17.4 hr)
VPA39577	W02990	LTS/Vbd	Baking (19.5 hr)
VPA39578	W03010	LTS/Vbd	Baking (19.4 hr)
VPA39576	W02957	LTS/variance	Baking (19.5 hr)
VPA39576	W02972	LTS/variance	Baking (19.5 hr)
VPA41724	W04399	LTS/variance	LTS repeat

MAIN Tests: Repeat IV

The repeat IV tests are the main method in our investigation. They were done for our sensors at several stages: during the usual sensor QC verification, after performance recovery attempts (if any), before the humidity exposures, after each exposure. We observed the effect of the performance recovery work, and, in some cases, the initial Vbd improvements with repeat tests, a typical occurrence. However, Vbd in dry environment was very stable in the course of the repeat humidity exposures.





Sensor reference		Test, Issue	Recovery Method		Vbd [V]										
Batch	Wafer		Main	Others	QC tests	pre-exposure	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
VPX32411	W00039	None	None	None	>700	450 -> 660	>700	>700	>700	>700	>700	>700	>700	>700	>700
VPX32418	W00146	None	None	None	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700
VPX32418	W00151	None	None	None	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700
VPX32418	W00180	None	None	None	>700	310 -> 640	>700	>700	>700	>700	>700	>700	>700	N/A (*)	>700
VPX32419	W00186	None	None	None	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700
VPX32420	W00234	None	None	None	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700
VPX32426	W00383	None	None	None	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700
VPX32426	W00412	None	None	None	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700	>700
VPA38186	W01307	None, IV feature	Dry storage	Ion blower	290 -> 530	>700	>700	>700	>700	>700					
VPA37911	W00997	None, IV feature	Dry storage		490 -> >700	>700	>700	>700	>700	>700					
VPA38692	W01757	None, IV feature	Dry storage	Ion blower	510 -> >700	>700	>700	>700	>700	>700					
VPA38186	W01591	None, IV feature	Dry storage		170 -> >700	>700	>700	>700	>700	>700					
VPA38700	W01308	IV, Vbd	UV		130 -> 660	>700	>700	>700	>700	>700					
VPA38701	W01961	IV, Vbd	UV	Baking	280 -> >700	500 -> >700	>700	>700	>700	>700					
VPA38886	W01989	IV, Vbd	UV	Baking	180 -> >700	>700	>700	>700	N/A (*)	>700					
VPA39550	W02630	LTS, Vbd	Baking	UV	350 -> >700	>700	>700	>700	>700	>700					
VPA38901	W02436	LTS, Vbd	Baking	UV, ion blower	250 -> 530	530	530	530	530	540					
VPA38901	W02443	LTS, Vbd	Baking	Ion blower	260 -> >700	>700	>700	>700	>700	>700					
VPA38901	W02464	LTS, Vbd	Baking	UV	180 -> >700	>700	>700	>700	>700	>700					
VPA39577	W02990	LTS, Vbd	Baking		390 -> 670	680 - >700	>700	>700	>700	>700					
VPA39578	W03010	LTS, Vbd	Baking		610 -> >700	>700	>700	>700	>700	>700					
VPA39576	W02957	LTS, Variance	Baking		480 -> >700	>700	>700	>700	>700	>700					
VPA39576	W02972	LTS, Variance	Baking		>700	>700	>700	>700	>700	>700					
VPA41724	W04399	LTS, Variance	LTS repeat		400 -> >700	>700	>700	>700	>700	>700					

Additional Tests: Visual Inspection

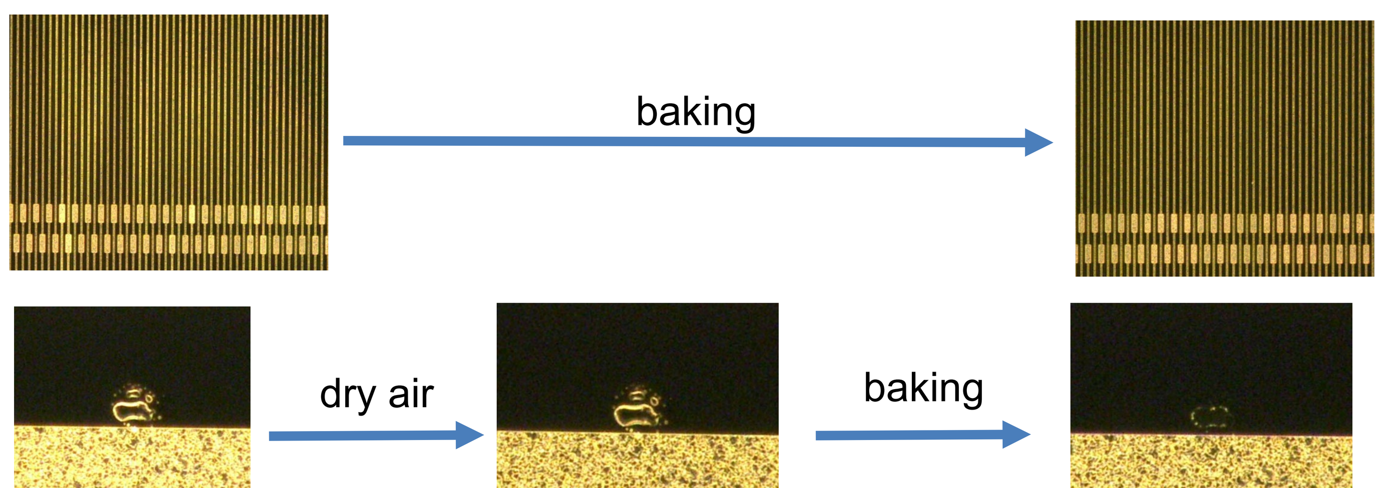
The sensors were Visually Inspected along with the IV tests. The inherent motivation was to check for any signs of corrosion that was seen in the past with a different vendor [5]. It can appear in case of chemical residue remaining after some of the processing steps.

We have not observed any sign of the corrosion, on any sensor. This observation affirms the high quality of the fabrication.

Somewhat confusingly, we initially saw small "bubbles" on the surface of the first set of sensors. They were eventually tracked to small-scale intermittent oil contamination in the dry air lines used in some of the test setups (but not the main IV and humidity-exposure cabinet). The reason for the contamination is likely temporary storage of the sensors in a different setup during the cabinet change. The following observations confirm the nature of the oil contamination, as tested on one of the sensors from the original set:

- The droplets were "wipable" with a cleanroom Q-tip
- They did not disappear in dry storage, but we could "bake" them away at 150 C

Finally, we could reproduce the contamination size and features by spraying the oil. They could also be removed by baking. In contrast, de-ionized water droplets typically evaporate in seconds.



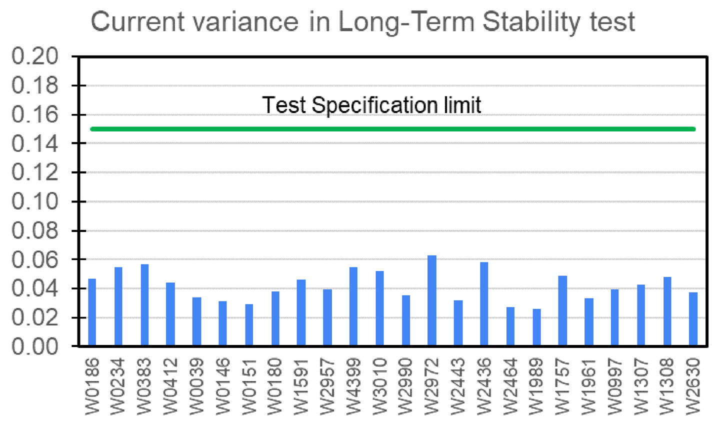
Additional Tests: LTS and Humidity dependence

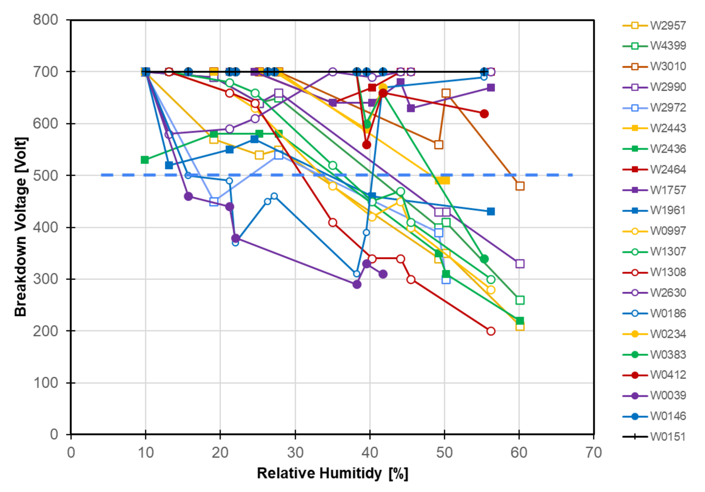
LTS

- After the last humidity exposure we performed a Stability test as an additional check on the sensor operation. The current variance during the standard 40-hour test was well within the specification of < 15%

Humidity dependence:

- During some of the testing periods we varied the humidity environment in the test enclosure to re-assess the influence of the humidity on Vbd. As expected, Vbd typically is reduced at higher RH values, although non-uniformely.





CONCLUSIONS

We investigated the ATLAS ITk Strip Sensors susceptibility to long-term humidity exposure. This performance aspect is relevant to the large-scale assembly of the final tracker parts, which will be exposed to the high ambient humidity for several months at a time. The target RH of 75% was intentionally maintained above the 50%-70% specification for the final assembly rooms. The longest single exposure was 266 days, and the longest cumulative exposure was 3 years. The following features were observed:

- **The breakdown voltages tested in dry atmosphere did not change during the exposures.**
- There was an expected dependence of Vbd on RH in humid environment.
- LTS tests after all the exposures showed typical good results.
- **In repeat inspections we have seen no sign of corrosion.**

We attribute the results to the high sensor quality and dedicated passivation features design to reduce the humidity sensitivity.

References

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2) J. Fernandez-Tejero et al, "Humidity sensitivity of large area silicon sensors: Study and implications", NIM A 978 (2020) 164406
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4) P. Federicova et al, "Setups for eliminating static charge of the ATLAS18 strip sensors", Presented at 24th International Workshop for Radiation Imaging Detectors (iWoRID2023), Submitted for publication in JINST
5) F. Hartmann, T. Bergauer, J.C. Fontaine, M. Frey, A. Furgeri, M. Krammer, "Corrosion on silicon sensors", NIM A 569 (2006) 80-83

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