Analysis of humidity sensitivity of silicon strip sensors for ATLAS upgrade tracker, pre- and post-irradiation

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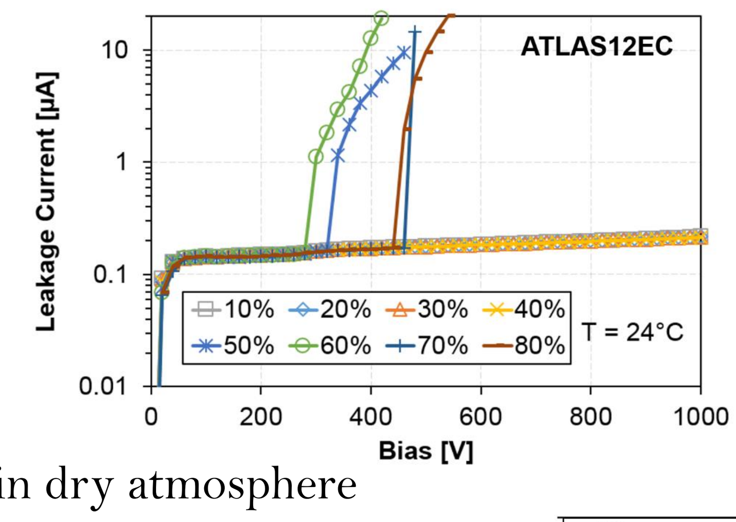
Abstract

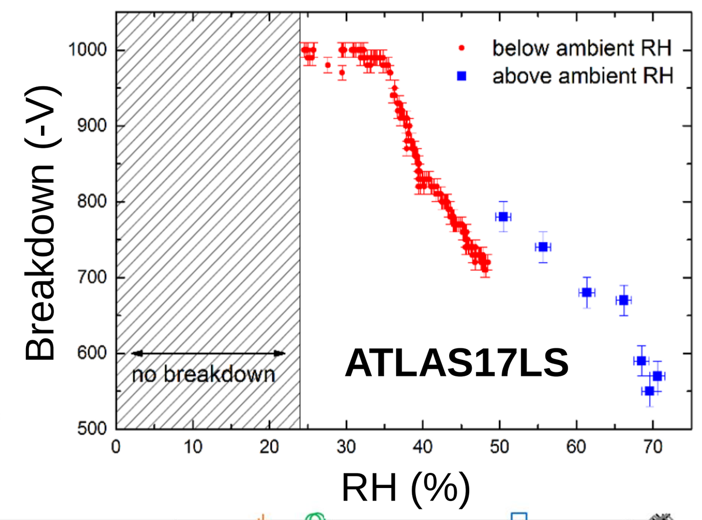
During the prototyping phase of the new large area ATLAS ITk silicon strip sensors, the community observed a degradation of the breakdown voltage when the devices with final technology options were exposed to high humidity, recovering the electrical performance prior to the exposure after a short period in dry conditions. In 2020, the ATLAS strip sensor community started the pre-production phase, receiving the first sensors fabricated by Hamamatsu Photonics K.K. using the final layout design. The work presented here is focused on the analysis of the humidity sensitivity of production-like sensors with different surface properties, before and after irradiation, providing new results on their influence on the humidity sensitivity observed during the prototyping phase.

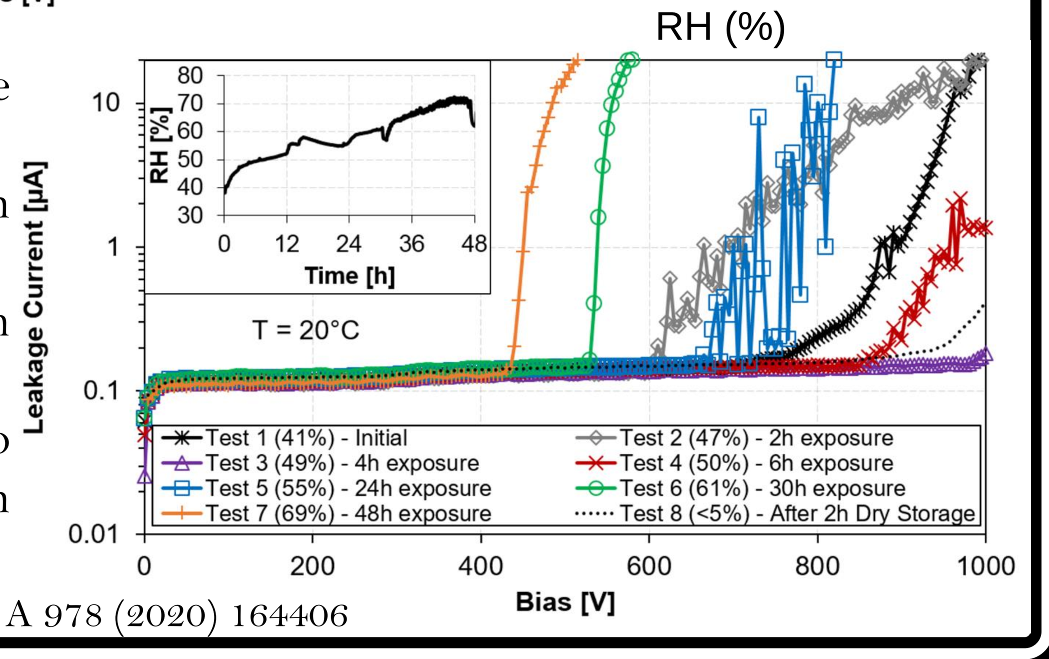
Humidity Sensitivity

ATLAS ITk prototype sensors (ATLAS12 and ATLAS17) showed a breakdown voltage degradation in presence of humidity. A previous extensive study* demonstrated:

- Fast recovery of performance in dry atmosphere
- Baking or cleaning treatments accelerate the recovery, but do not mitigate sensitivity
- Prolonged biasing of sensors at high humidity can cause irreversible degradation
- Thermal images in breakdown behavior at high humidity revealed hotspots in the edge region
- Possible mechanisms responsible could be related to characteristics and conformity of the passivation layers (triggering the study presented here)







* J. Fernandez-Tejero, et al., NIM A 978 (2020) 164406

Devices Under Test

Special batch fabricated by Hamamatsu Photonics K.K. using the final layout design, but implementing variations during the fabrication process to obtain different surface characteristics, such as special masking, thicker passivation or p-spray treatment. Several sensors tested for each type: 3 Type A, 3 Type A', 5 Type B, 5 Type C, 2 Type D high and 3 Type D low.

	Special treatment	Additional treatment	Special masking	Thicker passivation	p-spray addition
Pre-production					
Type A (Production)	X				
Type A'	X	X			
Type B	X		X		
Type C	X			X	
Type D high	X				X (high)
Type D low	X				X (low)

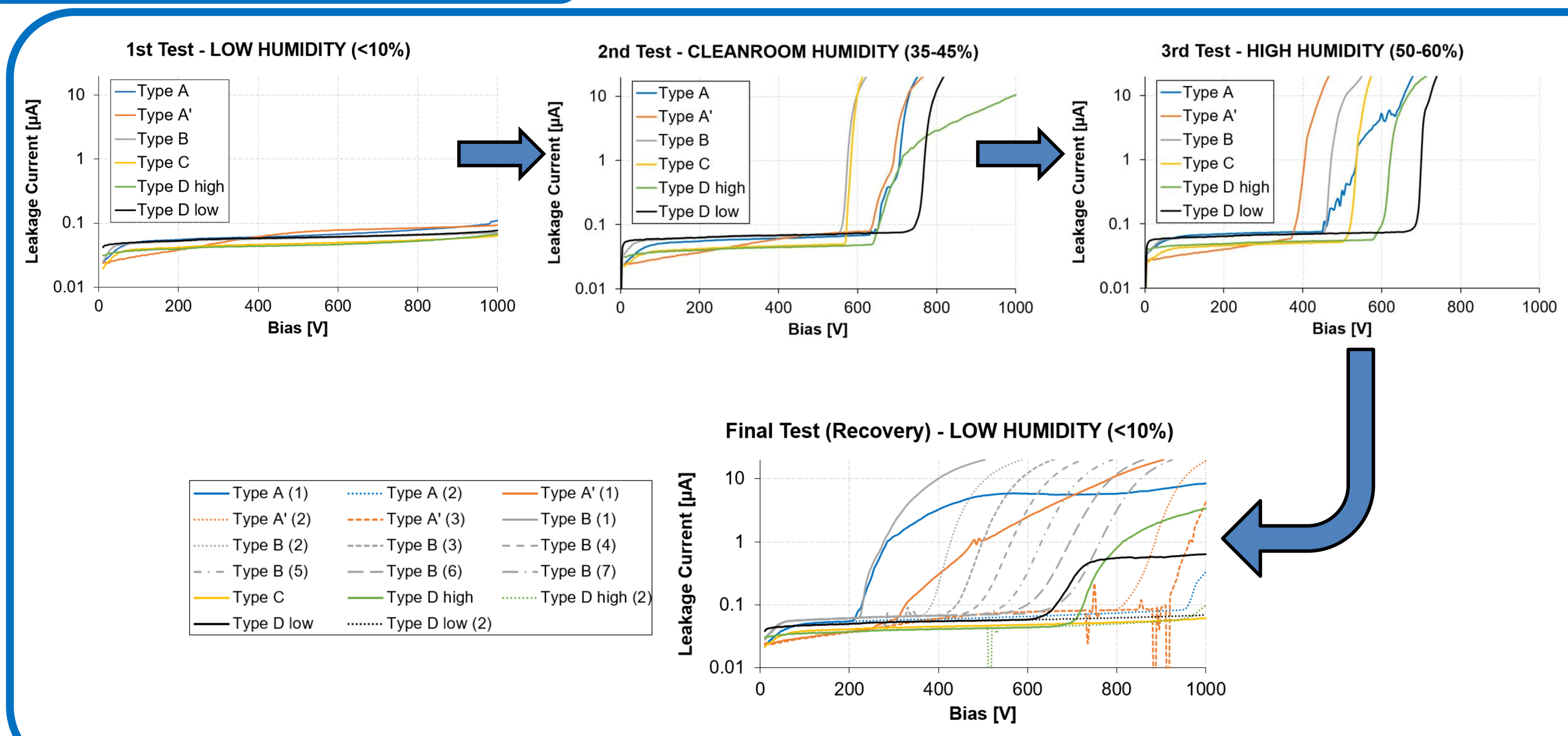
Results

Pre-irradiation

Humidity sensitivity and training effect

All sensor types tested at low (<10%), cleanroom (35-45%) and high (50-60%) humidity. After high humidity exposure, test repeated at low humidity several times to study the benefits of the "training".

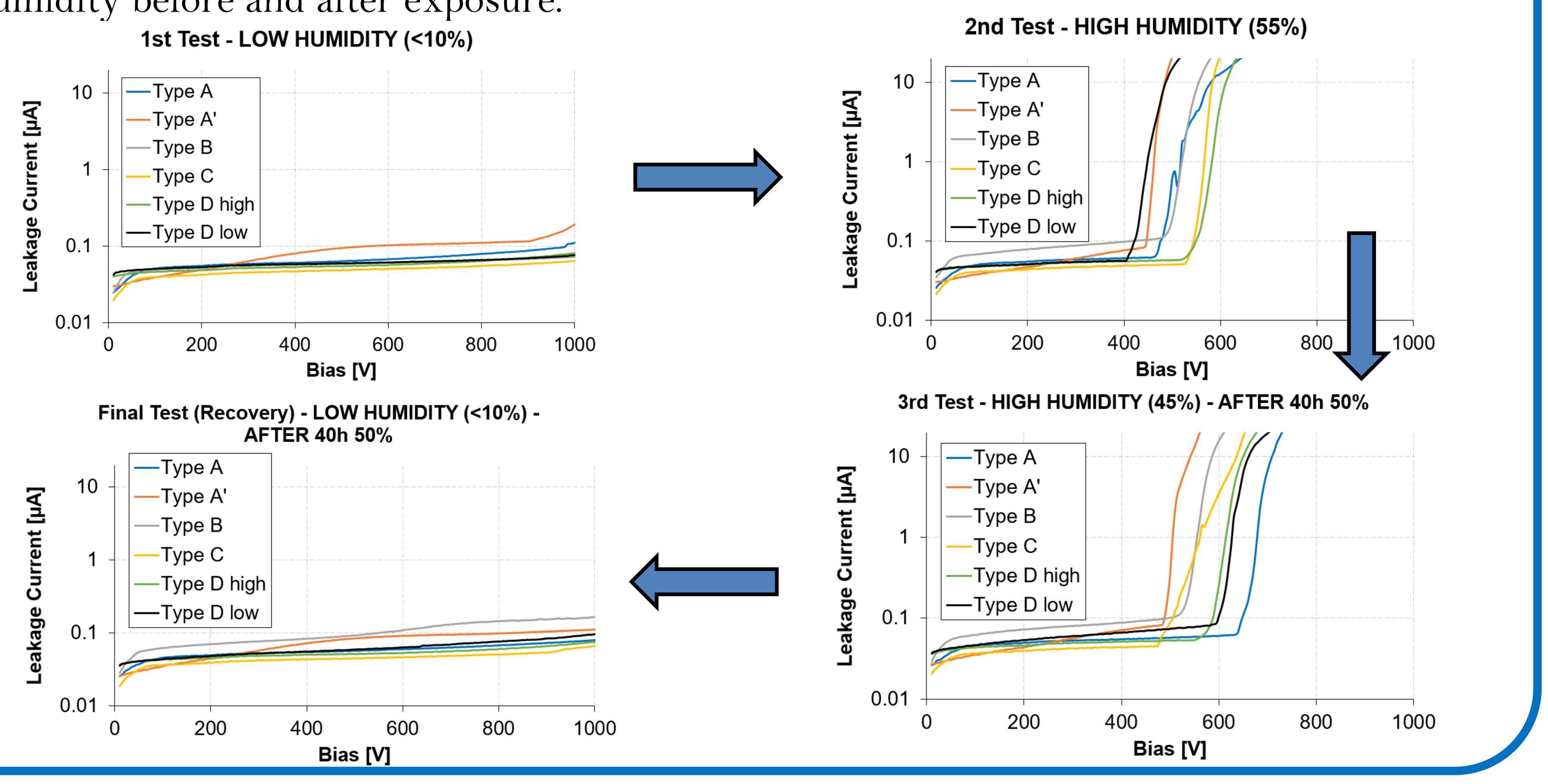
The table below shows in green/red the best/worst types for each case, respectively:



	Breakdown at Low RH	Breakdown at Cleanroom RH	Breakdown at High RH	Consecutive IVs needed to recover ("training")
Type A (Production)	>1000 V	600 ± 100 V	530 ± 120 V	2 IVs
Type A'	>1000 V	575 ± 75 V	410 ± 40 V	3-4 IVs
Type B	>1000 V	590 ± 60 V	490 ± 110 V	>5 IVs
Type C	>1000 V	560 ± 60 V	450 ± 50 V	1 IV
Type D high	>1000 V	600 ± 50 V	550 ± 50 V	2 IVs
Type D low	>1000 V	725 ± 25 V	625 ± 75 V	2-4 IVs

Short-term (40h) high humidity exposure

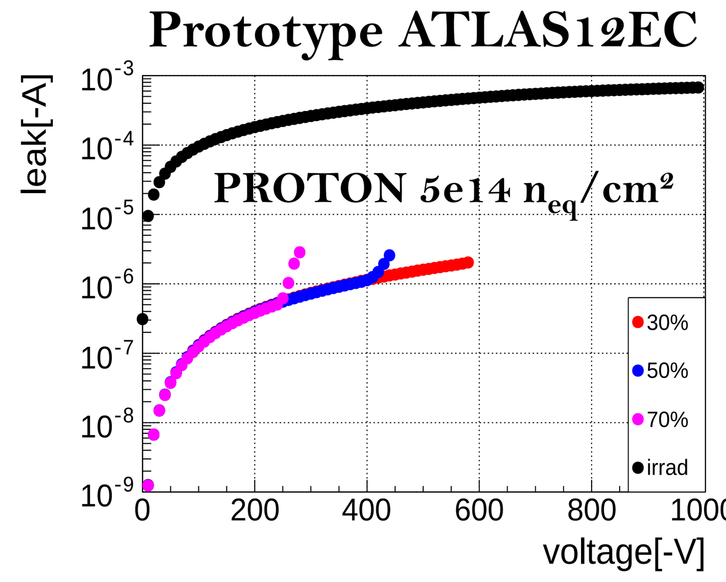
All sensor types tested at low (<10%) and high (50%) humidity. Then, exposed 40h to high humidity and re-tested at high and low humidity. All sensor types showing similar breakdown at high humidity before and after exposure.



Post-irradiation

ATLAS12 prototype sensor irradiated with protons up to 5e14 n_{eq}/cm^2 was tested at different humidity levels, showing no sensitivity after irradiation.

Prototype ATLAS12EC



At the time of preparing this poster contribution, the sensor community is testing irradiated sensors with different surface characteristics. Results will be incorporated in the manuscript.

Conclusions

None of the different processing splits seems to completely mitigate the humidity sensitivity, but some surface characteristics can improve the breakdown voltage dependence and recovery:

- ✓ A low dose of p-spray (Type D low) substantially improves the breakdown voltage deterioration at cleanroom and high humidity. P-spray could prevent the accumulation of hydrogen ions in presence of humidity, reducing the sensitivity
- ✓ Sensors with thicker passivation (type C) show the fastest performance recovery after humidity exposure
- ✓ All sensor types show similar breakdown voltage before and after 40h of humidity exposure, also showing a fast recovery at low humidity
- ✓ Prototype sensor irradiated with protons shows no sensitivity to humidity changes, suggesting a progressive improvement during irradiation. Sensors with different surface characteristics and irradiated to different fluences are currently under test, and results will be incorporated in the manuscript

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