Hot spot visual evaluation of breakdown locations in ATLAS18 ITk strip sensors and test structures

CERN | ATLAS ITk | SFU | TRIUMF

A. Fournier [a,b,*], V. Fadeyev, J. Fernandez-Tejero [a,b], Bart Hommels [g], C. Jessiman [c], J. Keller [c], C. Klein [c], T. Koffas [c], S. O'Toole [a,b], J. Osieja [a,b], L. Poley [a,b], E. Staats [c], B. Stelzer [a,b], M. Ullan [d], Y. Unno [e]

[*] Corresponding Author (afournie@sfu.ca)

[a] Simon Fraser University, 8888 University Dr, Burnaby, BC Canada
[b] TRIUMF, 4004 Wesbrook Mall, Vancouver, BC V5A 1S6, Canada
[c] Carleton University, 1125 Colonel By Dr, Ottawa, ON V6T 2A3, Canada
[d] Instituto de Microelectronica de Barcelona (IMB-CNM), CSIC, Campus UAB-Bellaterra, 08193 Barcelona, Spain
[e] High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
[f] SCIPP, University of California, Santa Cruz, 1156 High Street Santa Cruz, CA 95064, US
[g] University of Cambridge, The Old Schools, Trinity Ln, Cambridge CB2 1TN, United Kingdom

Abstract

An important characteristic of silicon-based particle detectors, like those used for the forthcoming ATLAS ITk upgrade for the HL-LHC, is the leakage current. This characteristic is evaluated in the quality control stage of the new ITk strip sensors performing an IV measurement, where the sensors are biased up to -700V, typically showing low and stable leakage current. However, some sensors can exhibit a sudden leakage current increase during the IV measurement, so-called early breakdown, making the sensor unusable.

The analysis of these early breakdown conditions typically consists of visual inspection of the sensors using a microscope, as often this is caused by physical damage, be it a deep scratch, chipping on the edges of the sensor, or other damage. But up to this point, the association of the observed damage with the early breakdown is not definitive. Rather, this is an association by correlation, due to the limits of verification by observation with standard equipment.

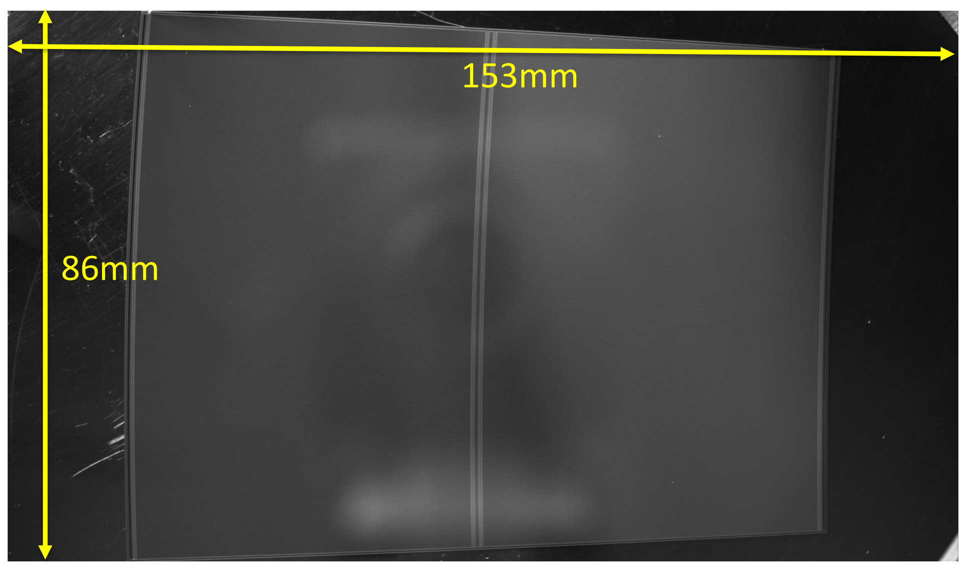
A hot spot imaging setup has proven to be a valuable diagnostic tool to identify and understand these early breakdown conditions and elaborate on former understandings of these emissions. The regions responsible for the breakdown can be properly located by imaging the infra-red-light emissions produced by them in breakdown conditions. These regions of interest can also be imaged at magnification to evaluate the more precise structure of the breakdown to better understand the damage. The regions discovered, which have improved our understanding of breakdown damage and its symptoms, include scratches, chipping, static charge buildup and manufacturer defects in the ATLAS18 strip sensors and test structures.

The Setup

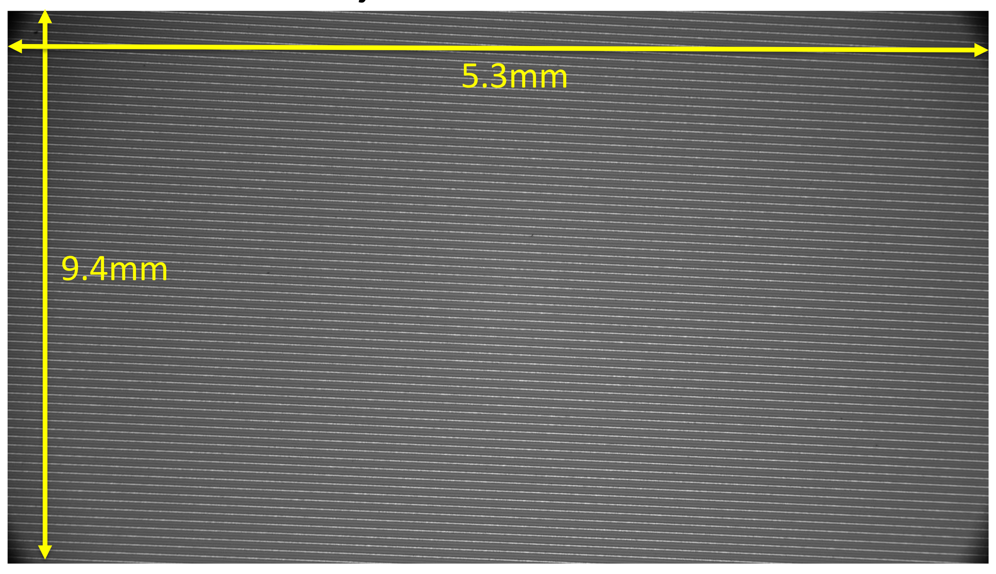
The Hot Spot setup was adopted into our existing sensor probing station. This consists of a dark chamber, dry air source, and several instruments for biasing and testing ATLAS18 sensors.

The **Hamamatsu Orca Quest** provided the primary imaging, featuring high resolution, sensitivity, and exposure time with exceptionally low noise levels. Some images will be noted as using another camera, the **Teledyne Photometrics Retiga E7.** These are very low noise scientific back illuminated CMOS (capturing hot electrons). The captures are primarily in the NIR and IR wavelengths.

Wide Angle imaging was done with the Kowa LM25XC 25mm lens. This lens provided roughly 0.13x magnification allowing us to image the full surface of the sensor to spot regions of interest while the sensor is breaking down.



Magnification imaging was done with our probe station PSM-1000 microscope, using a PLAN APO lens providing 2x magnification. This allowed us to image located regions of interest in very high detail so we could study the structure of the breakdown.



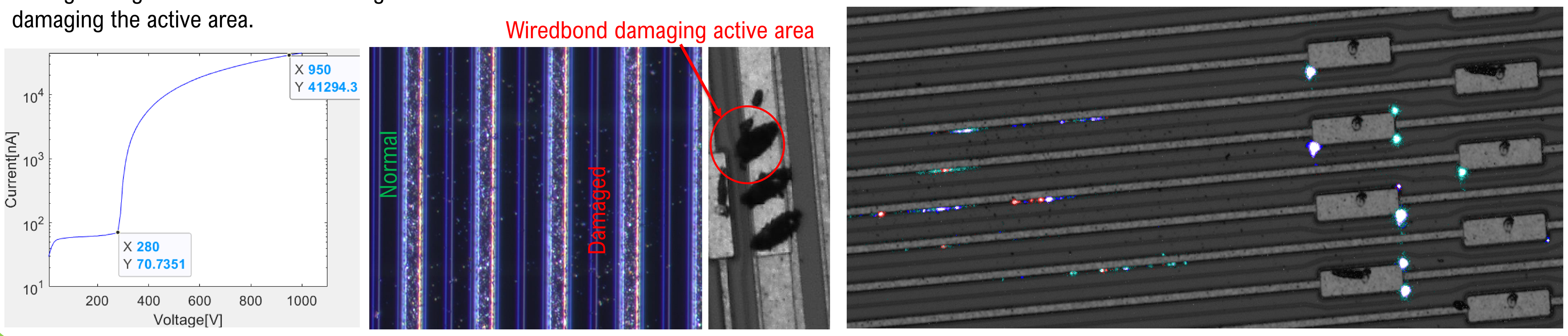
Results!

This section will explain findings on several samples. Samples are presented using illuminated captures with emission captures overlayed and colorized. Imaging typically requires breakdown current in the 10's of μA to be visible, typically above 800 V. These pictures confirm that the breakdown is caused by something on the surface, for example static charge in a localized area, if not by apparent physical damages.

ATLAS18 R1 Wafer 297

This sample had a very large breakdown area shown (Right) at 950V and 41μA of current. Microscope imaging (middle) of the area shows speckling in the damaged region which was later agreed to be the result of a wirebond damaging the active area.

This newer composite image using the Retiga E7 shows 3 different captures about 10 minutes apart colored in Red, Blue and Purple. This demonstrates the non-static nature of the breakdown with breakdown distributed in different areas.



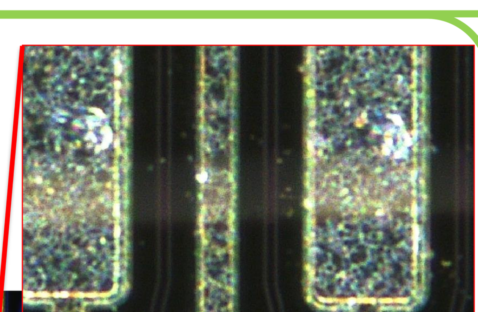
ATLAS18 R4 Wafer 500

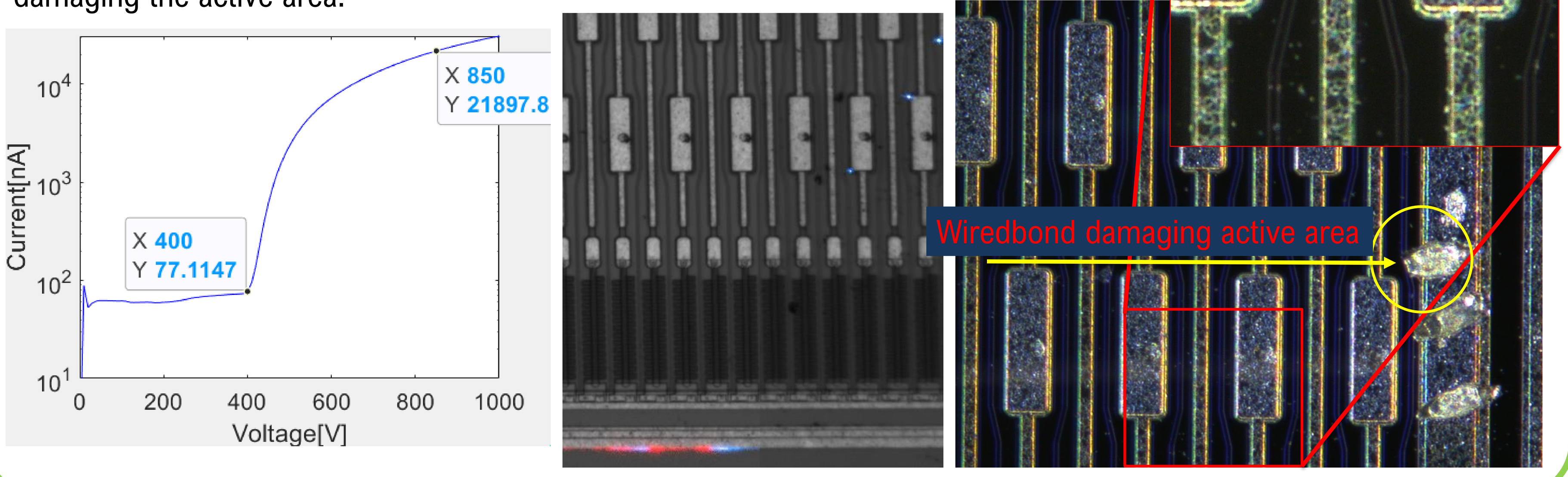
Breakdown was captured on the strip biasing resistors (bottom right), captured at 600V, 20μA. It seemed to be spread across a section about 700μm long.

The area observed with a microscope below shows a speckling, which may be correlated with the damage.

ATLAS18 R1 Wafer 281

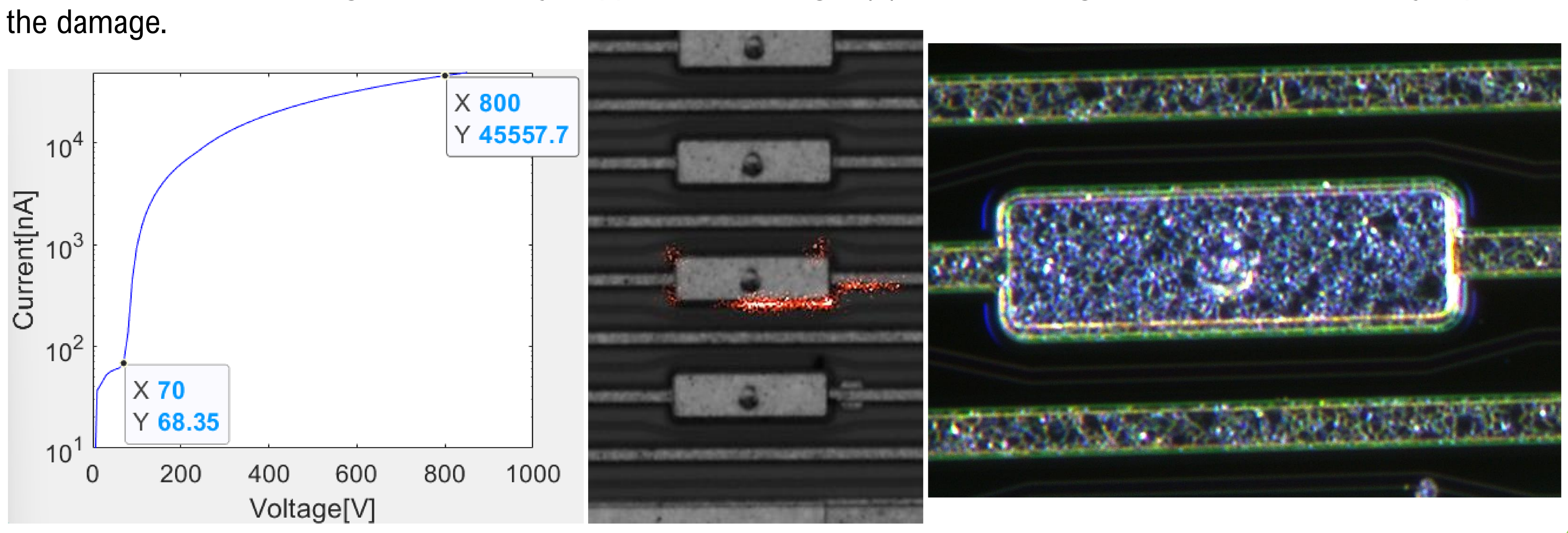
This sample has a breakdown region that changed over time, left biased at 850V, 22μA. Two captures were taken 2 minutes apart (Middle) shown in red and blue showing an evolution in the breakdown region. Microscope imaging (Right) shows a speckling in the damaged area which was later assumed to be the result of a wirebond damaging the active area.





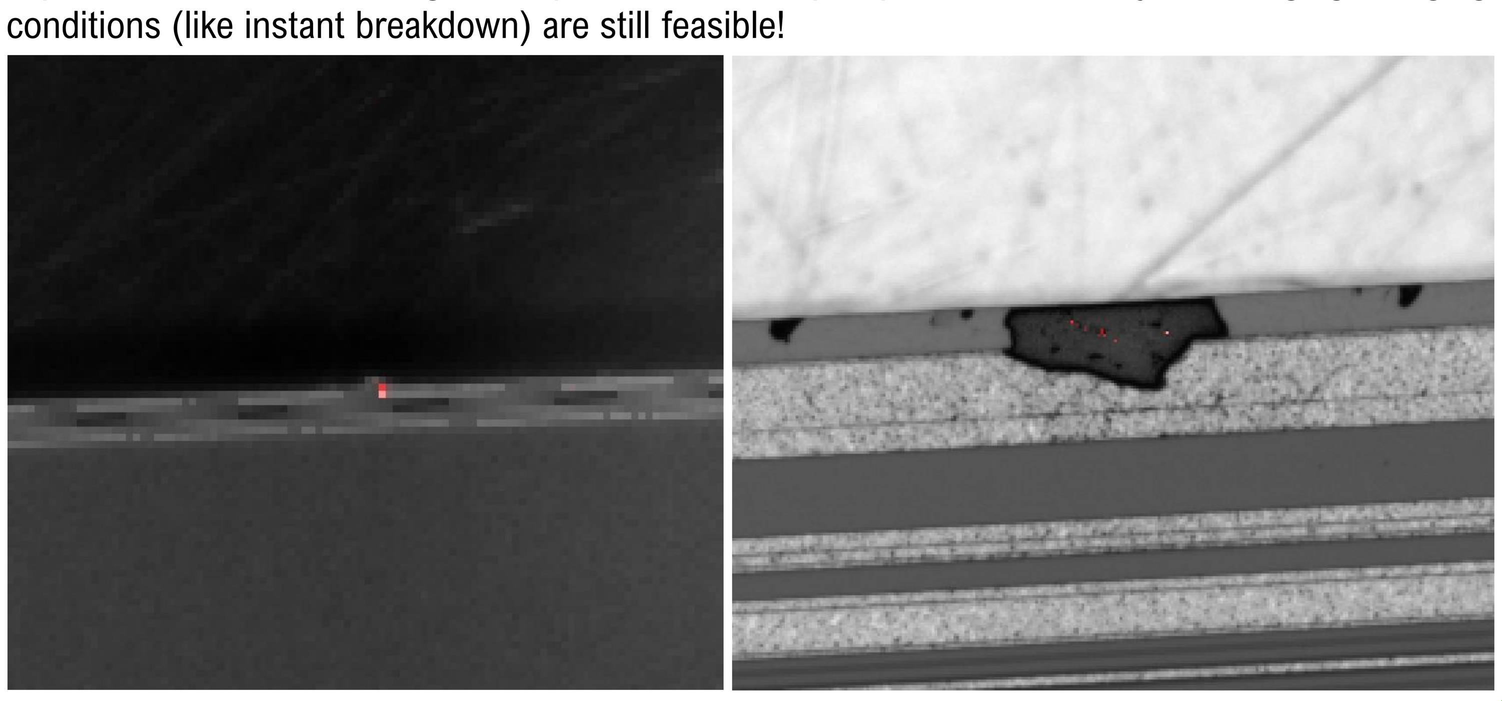
ATLAS18 R4 Wafer 517

This sample has a breakdown area surrounding a pad in the active area (Middle) captured at 800V, 45μA but still requiring a long 3-minute exposure. Microscope imaging (Right) shows no obvious defects on the area. Therefore, it was concluded this damage is caused by trapped static charge. (1) 400nm UV light treatment successfully repaired the damage.



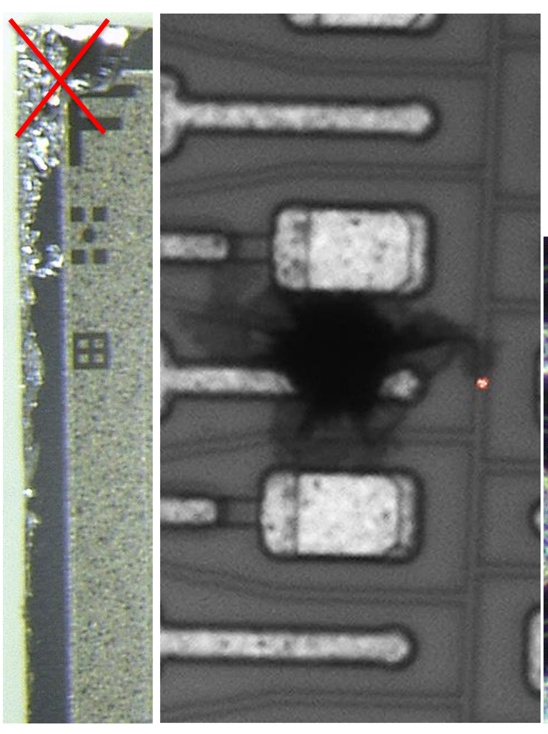
ATLAS18 R5 Wafer 82

This sensor had instant breakdown conditions on reception for quality control. It underwent several procedures to attempt to repair it. Recently, the Retiga E7 was used to locate the damage. The wide-angle image (Left) showed an extremely dim illumination on the edge of the sensor, requiring several minutes of 2x2 binned exposure at 950V 24μA. Magnified imaging of the area (Right) shows a chip on the edge producing a faint glow, also requiring several minutes of exposure with 2x2 binning to capture. This sample proved extremely challenging imaging conditions (like instant breakdown) are still feasible!

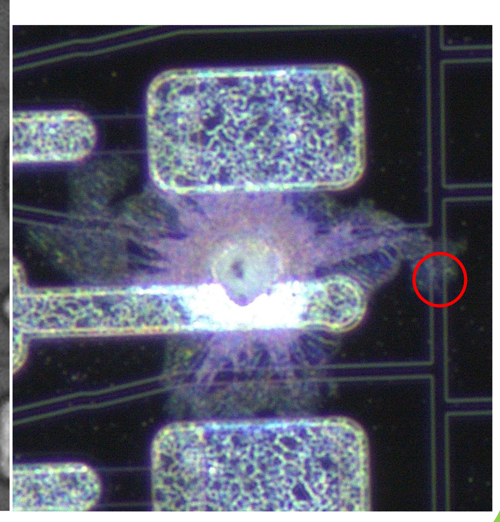


ATLAS18 R1 Wafer 585

This sensor was chipped badly in one corner as shown bottom left. It was assumed the breakdown would occur in this region, but it was found that a manufacturing defect in the active area was more significant, captured at 800V 11μA.

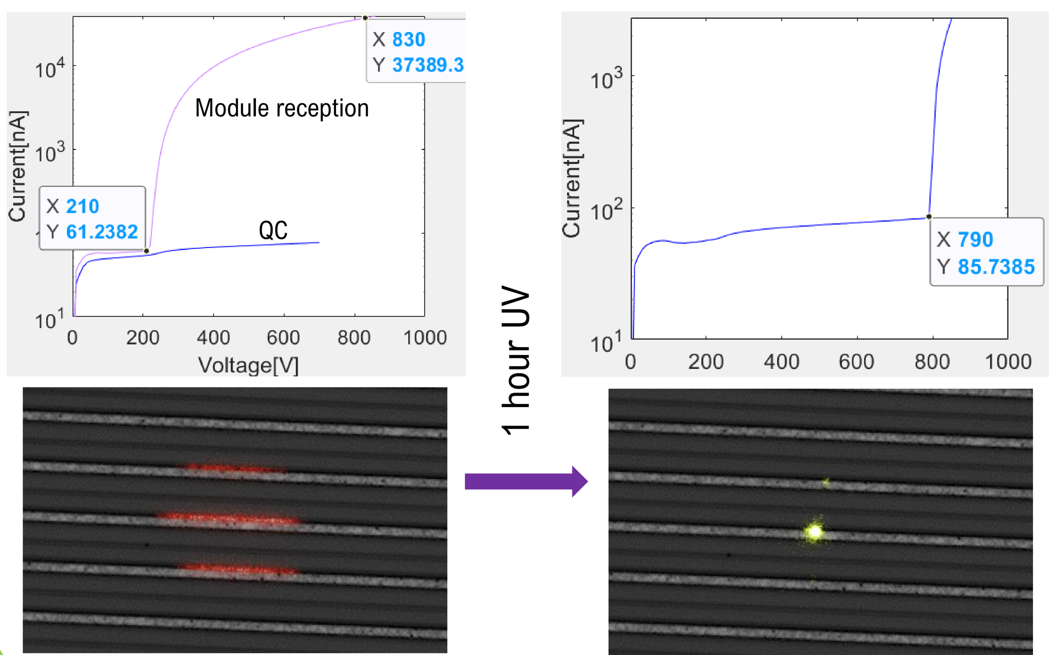


The area observed with a microscope below shows a defect branching to and shorting the p-stop.



ATLAS18 R4 Wafer 501

This sensor initially passed quality control but started breaking down after the sensor was shipped and received. Breaking down at 220V and imaged at 830V 37μA, emissions were found in the middle of the active area (Left) with no visible damage. Using a 1-hour 400nm UV light treatment (1), the breakdown no longer occurs until 790V and produces a much smaller breakdown region at the same location (Left) confirming this was static charge buildup.



Reference

(1) Identification and Recovery of ATLAS18 Strip Sensors with High Surface Static Charge, Ezekiel Staats, in the same session/proceedings

HSTD13, Vancouver B.C. Canada, Dec 3rd – Dec 8th, 2023