SW Test Workshop
Semiconductor Wafer Test Workshop

Forget the Paschen and Embrace Turbulence!

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Outline

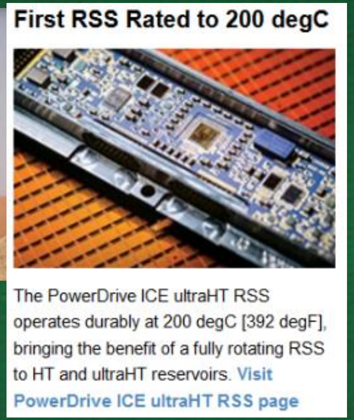
- **Introduction to High Voltage and its' applications**
- **What's the problem?**
  - Damaging devices during high voltage testing
- **Models**
  - Should we be so "Paschen-ite?"
  - Streamers or Townsend?
- **Reality – show me the data!**
  - Let's try and keep it simple
- **Revised models**
  - Weakest link distribution
- **Conclusion and Future Work**

Introduction

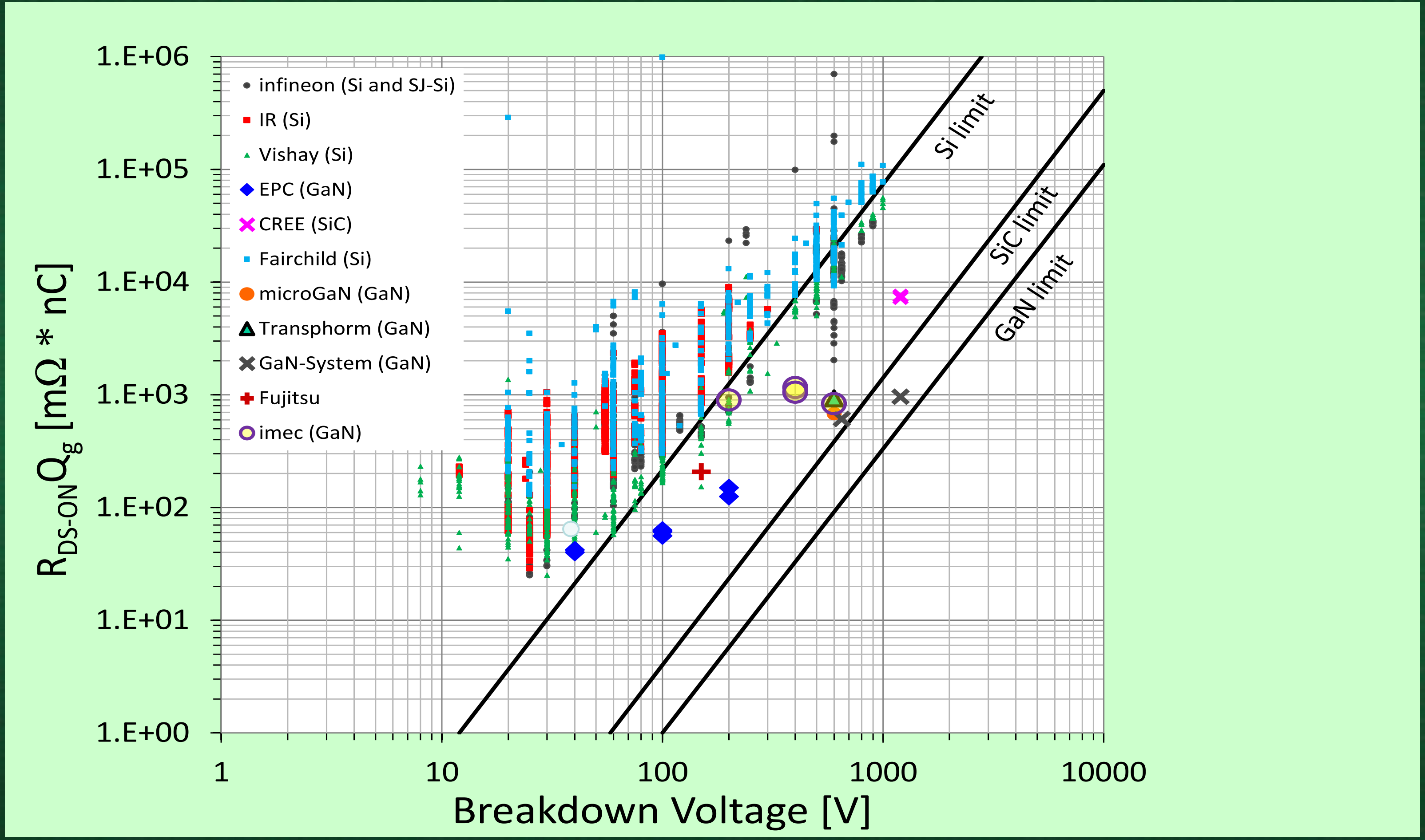
High power and high voltage devices are growing in volume significantly. Voltages are getting higher and higher.

Power switching applications are a common presence in our daily-life.

- Down Hole Oil Drilling, Geothermal Instrumentation
- Switched-Mode Power Supply (SMPS)
- Electric Vehicles (EV)
- Power Factor Correction (PFC)
- Uninterruptible Power Supply (UPS)
- Solar Inverters
- Induction Heating
- Motor Drives



Applications for High Voltage transistors



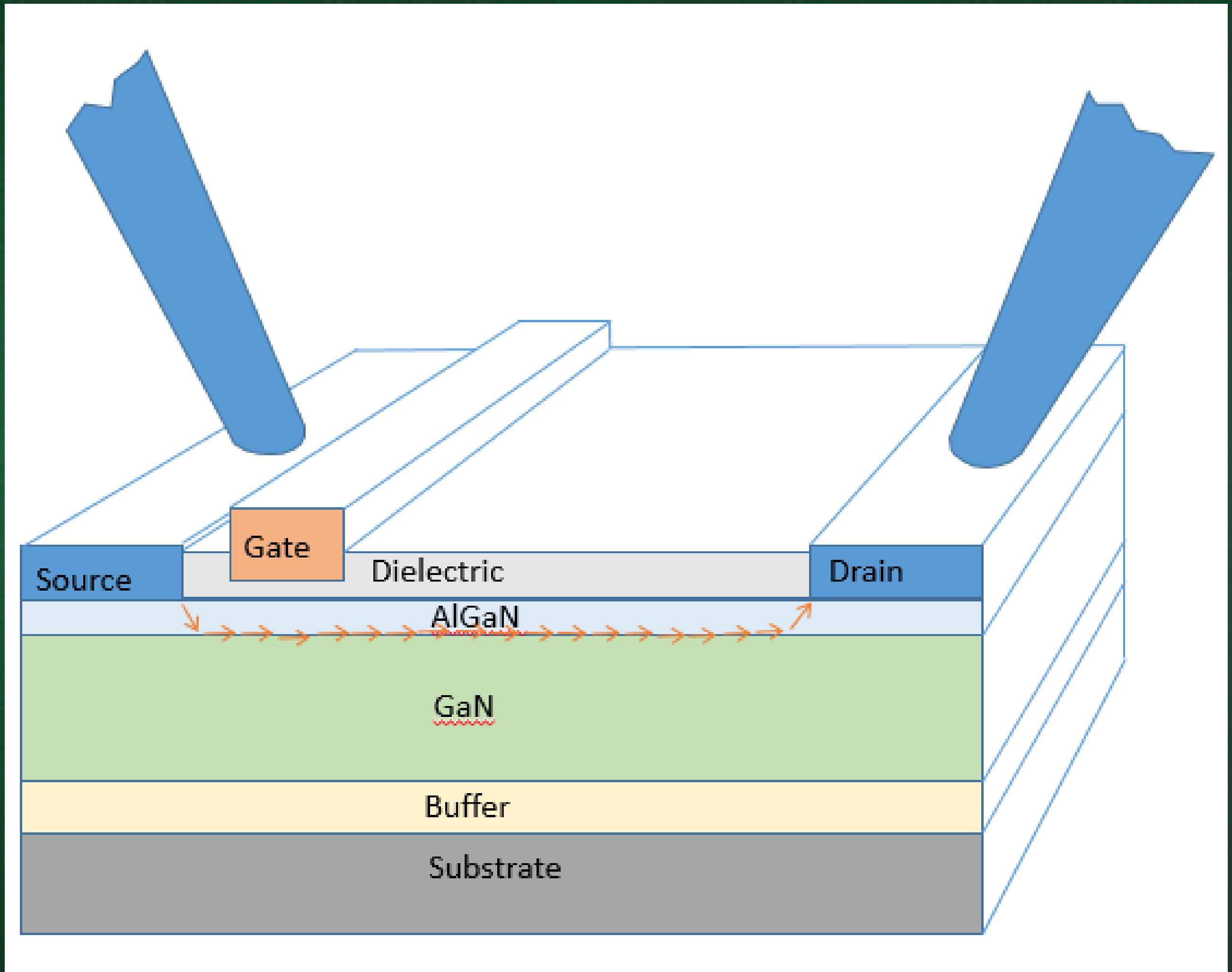
Silicon which is the most mature technology is pushing its theoretical limits.

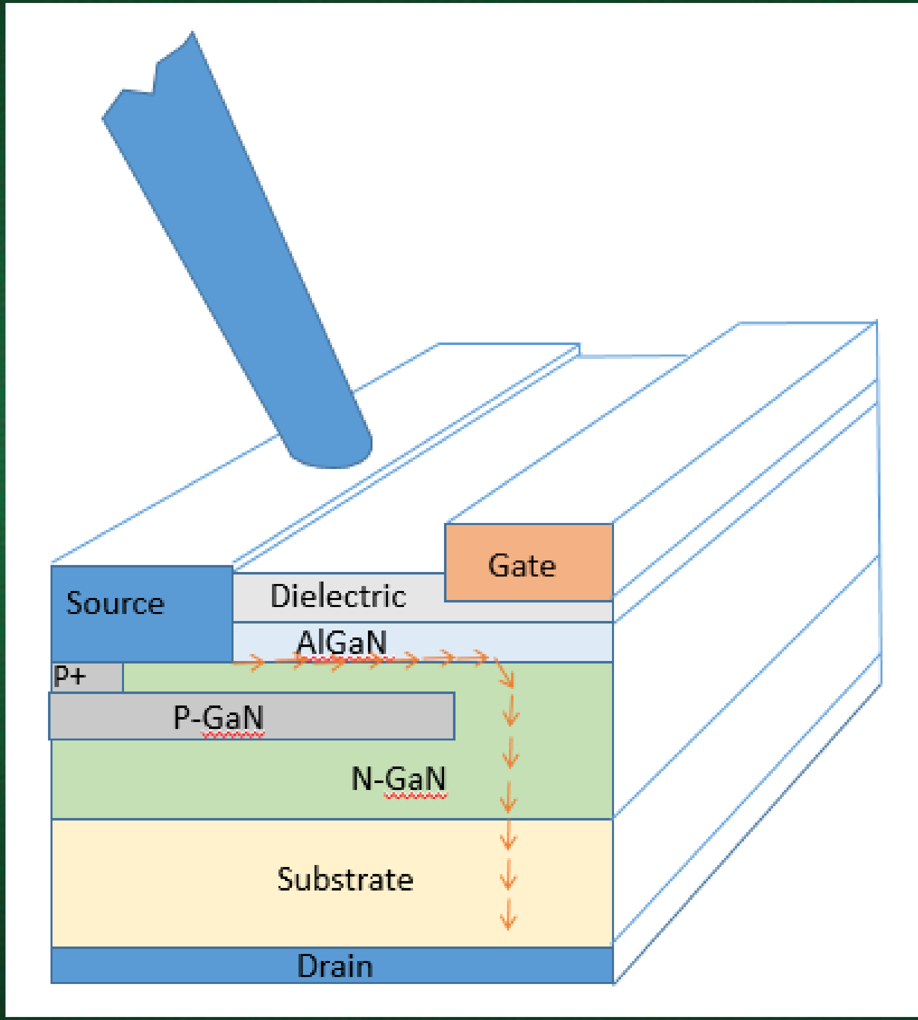
We are seeing SiC and GaN in more power switching applications.

So, what is the problem with high voltage devices?

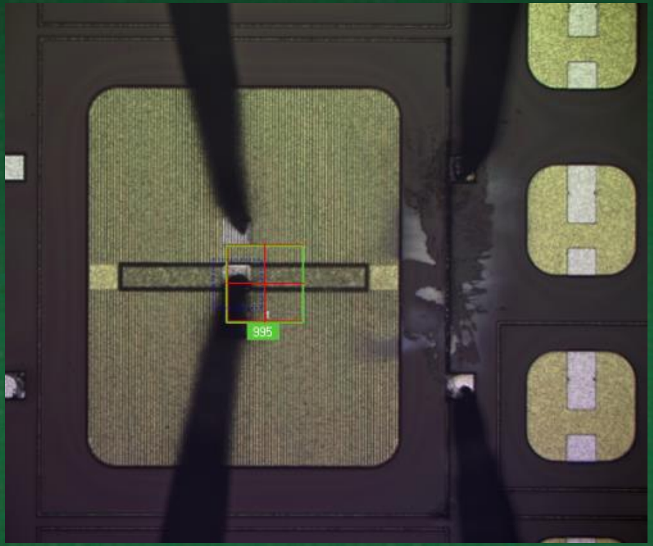
- **How do we test these devices without:**
  - Degrading (or destroying) the devices
  - Degrading (or destroying) the probe card
  - Degrading (or destroying) the prober or test system
- **We must understand the physics**
- **The biggest issue – no walking wounded**

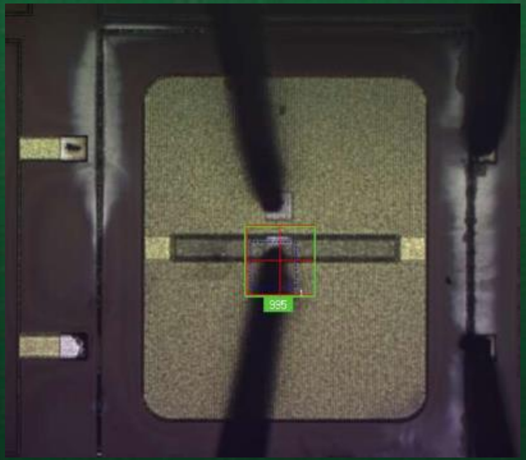
Device types Planar and Vertical devices

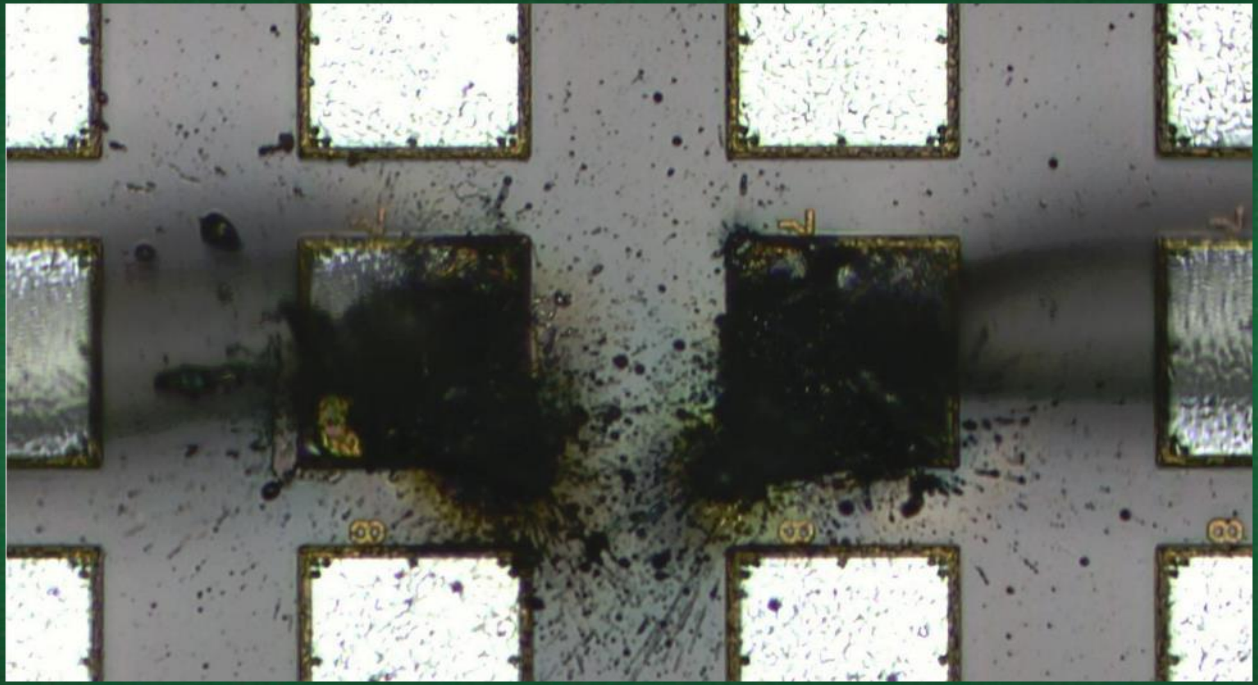




Testing High Voltage devices……

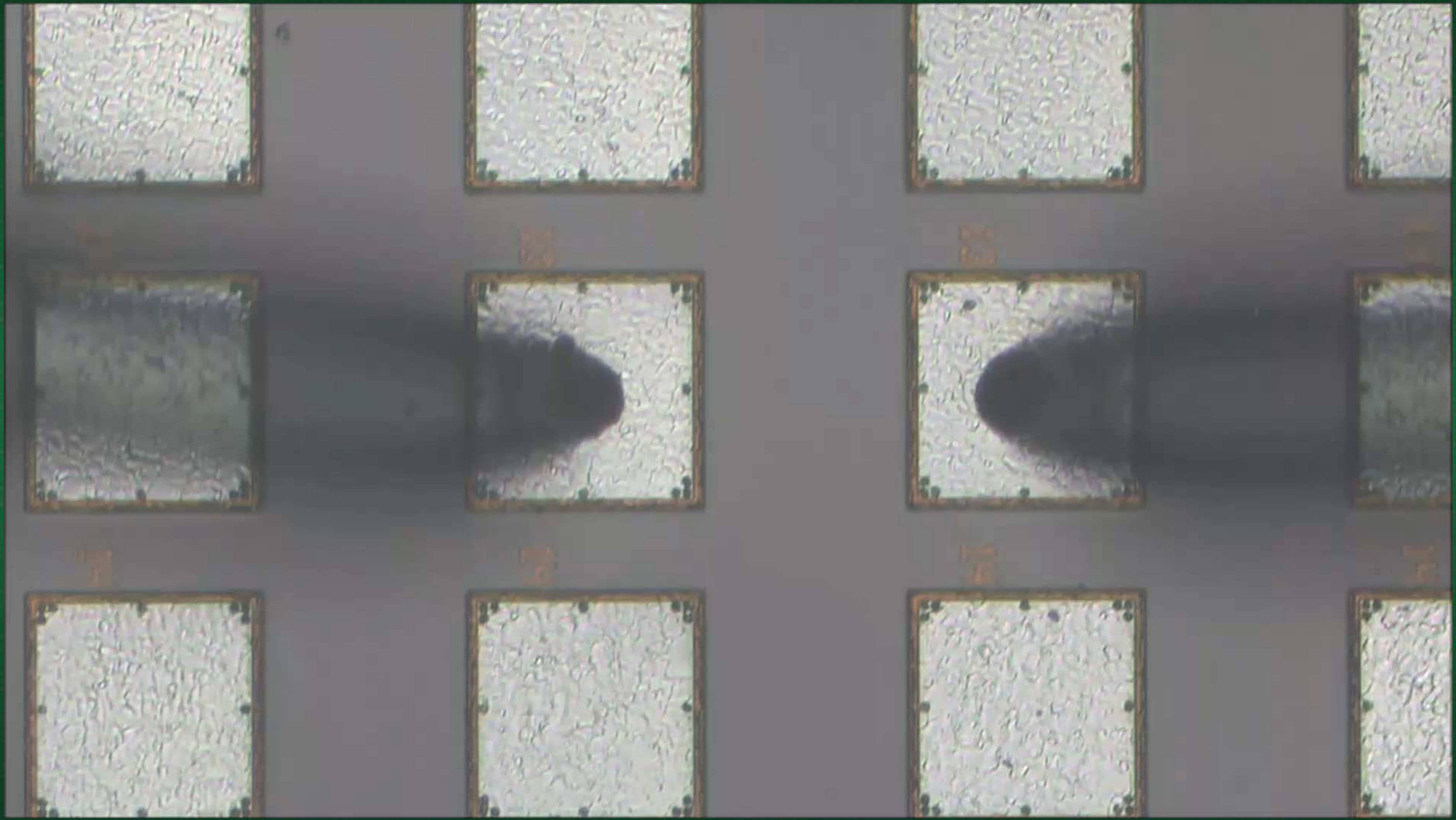




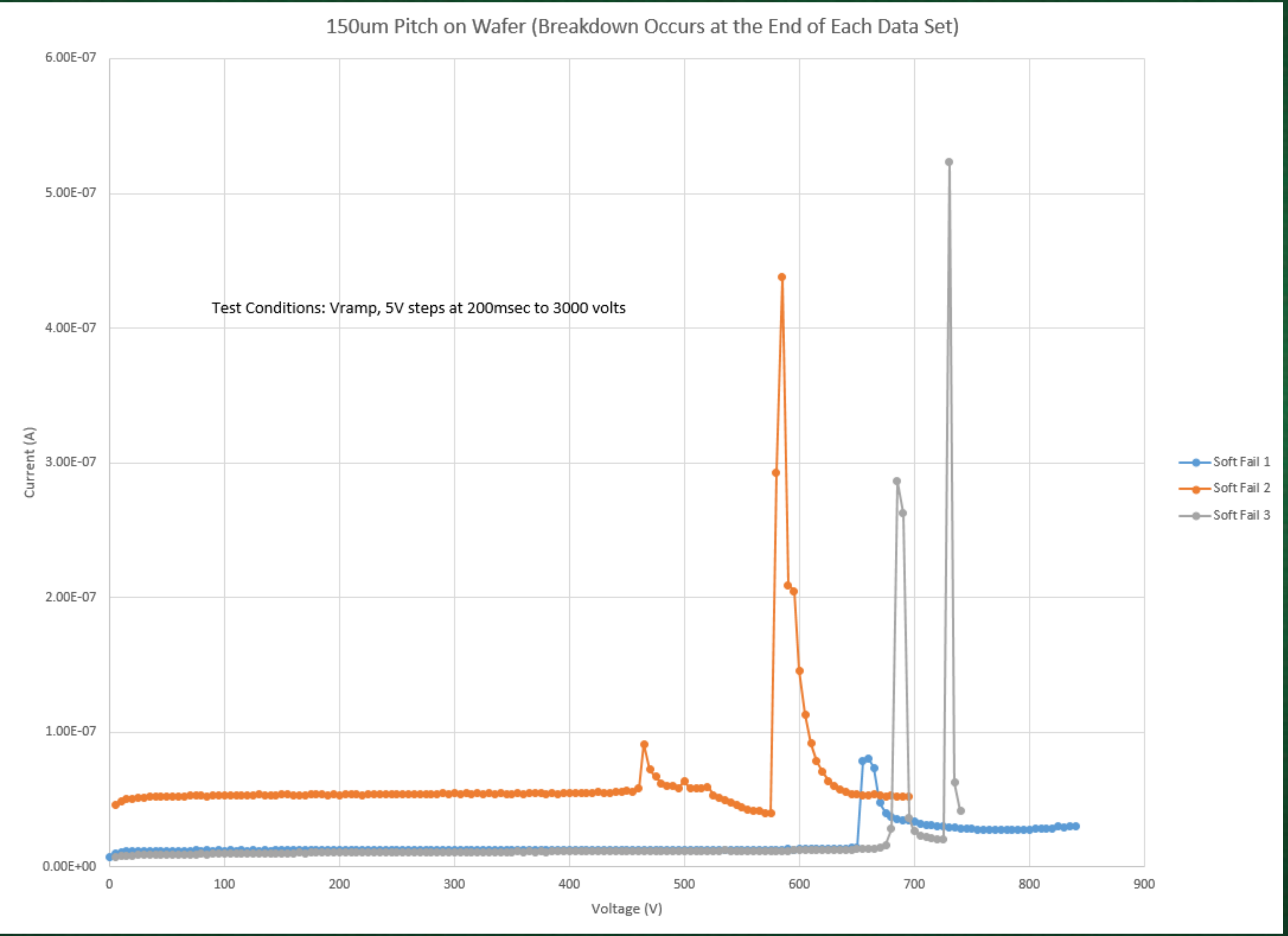


….Can be a challange

Video



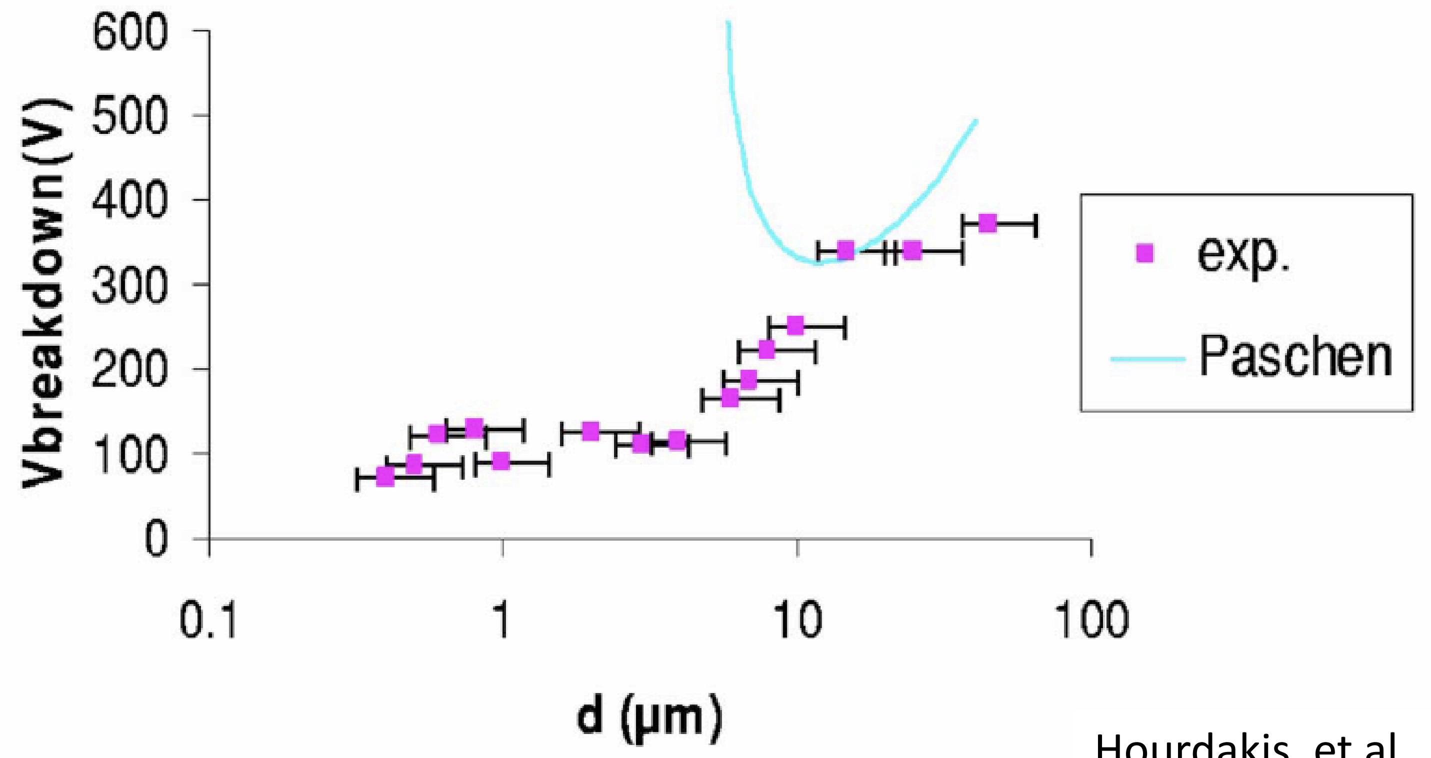
Soft Fails followed by hard breakdown



1. Current is preferentially flowing along the surface of the device.
2. Soft fails are extrinsic "defects." They are current streamers forming that heal themselves.

During a hard breakdown surface arcing occurs. The discharge follows a filamentary and irregular pattern as opposed to the Townsend effect in an ideal gas.

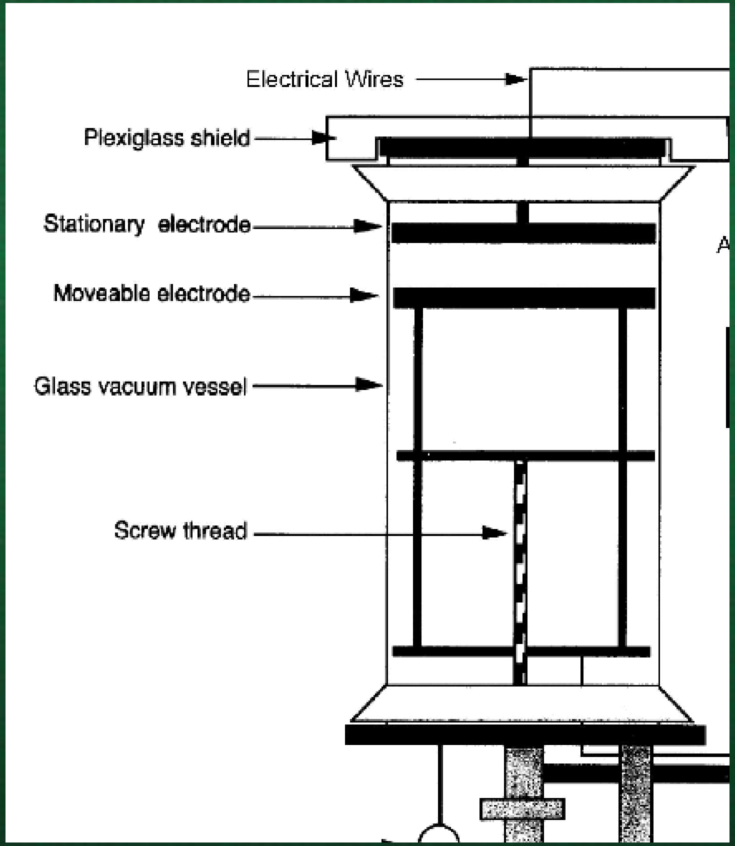
Paschen's incorrectly estimates the breakdown voltage especially at geometries typical in semiconductor devices



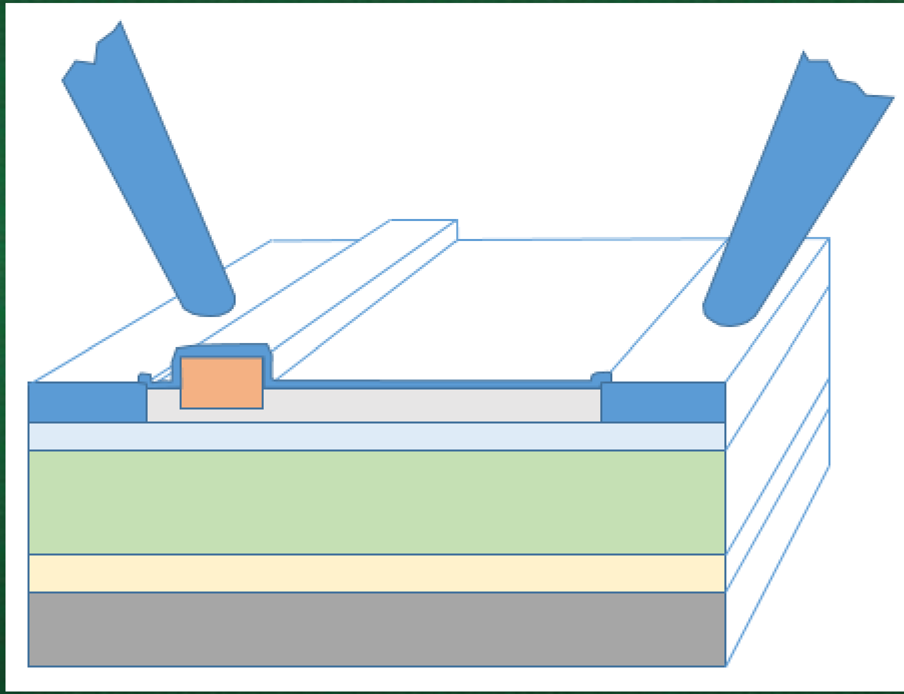
Hourdakis, et al.

What about Paschen's Law?

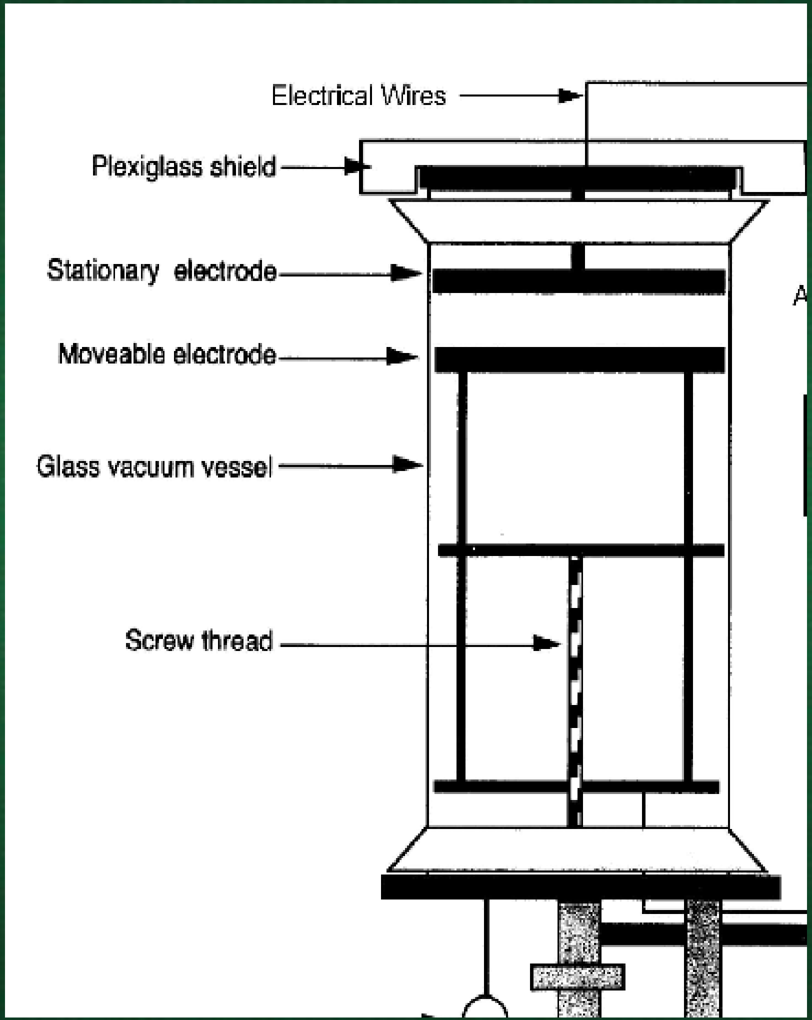
How can two flat plates in a bell jar with a controlled gas relate to.....

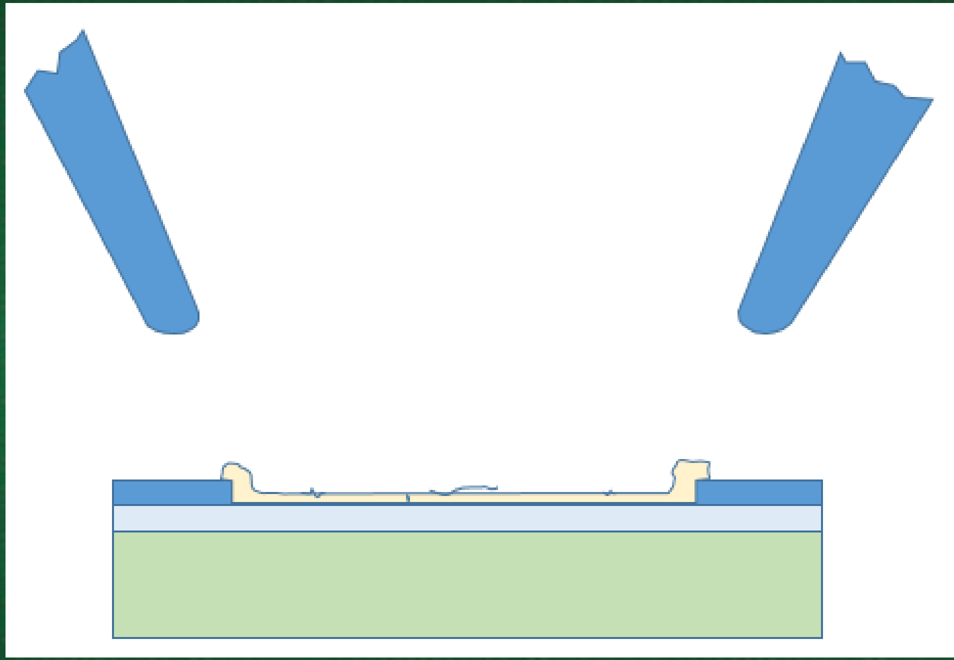


.....two probes on the surface of a semiconductor device in a non-ideal environment?



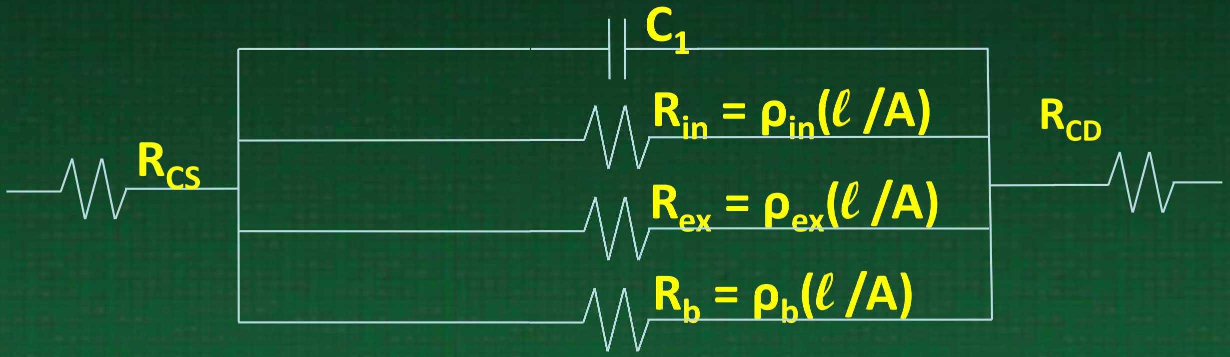
How about here?

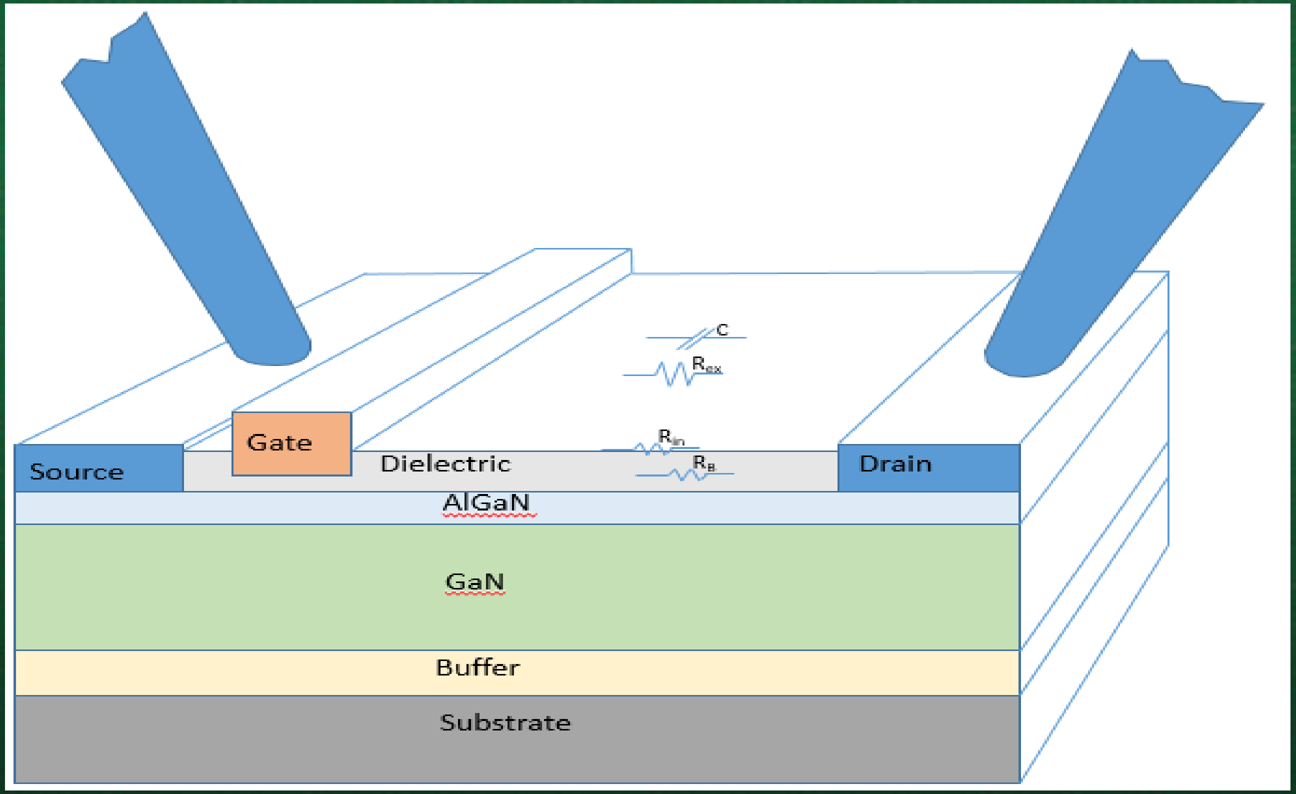




The data does not support Paschen's in either case.

Planar device





C_1 = Drain to Source Capacitance

ρ_B = Bulk Resistivity

ρ_{in} = Intrinsic Surface Resistivity

ρ_{ex} = Extrinsic Surface Resistivity

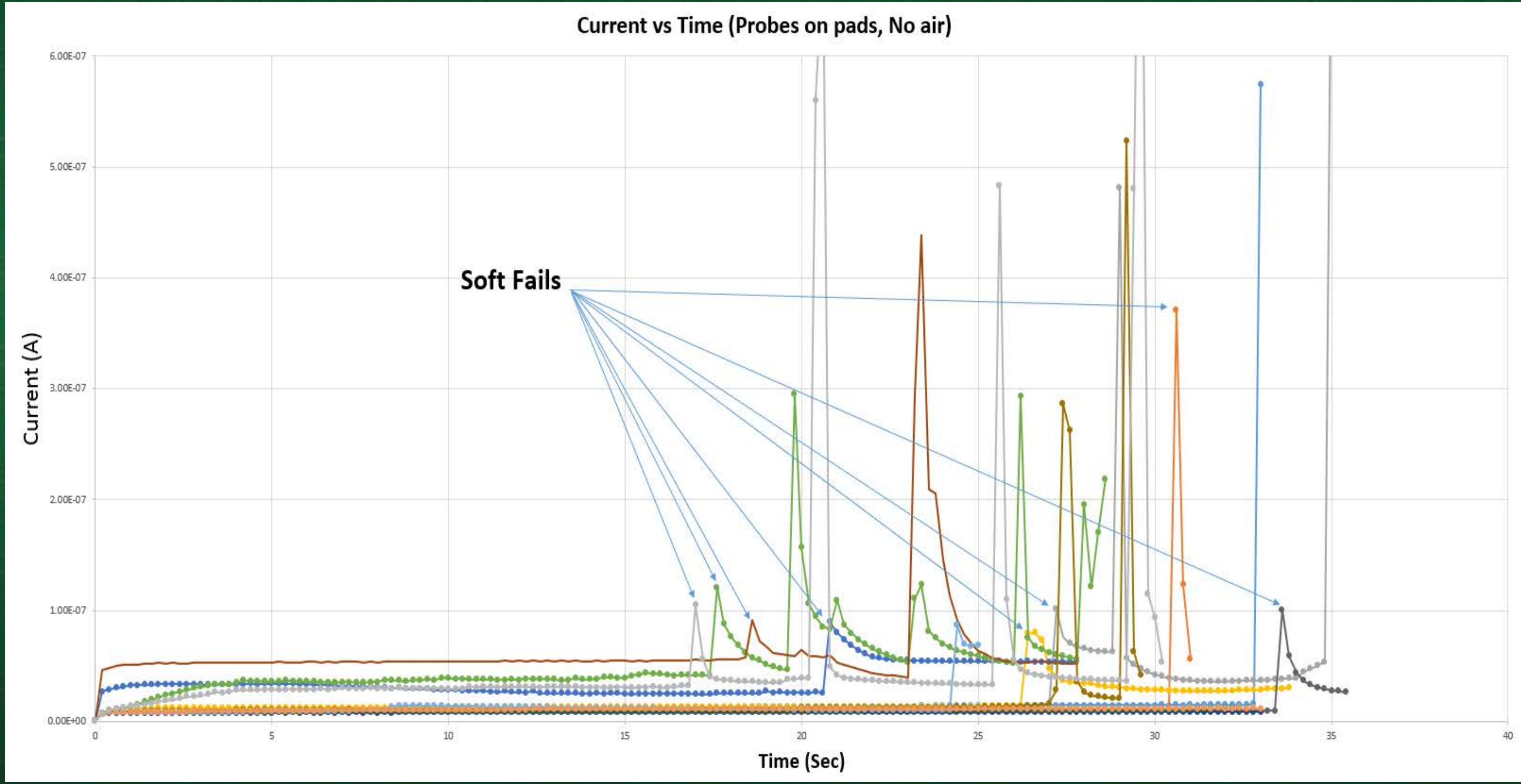
R_{cs} = Source contact resistance

R_{cd} = Drain contact resistance

Similar to Fast tests for Device Reliability

TDDB, Electromigration

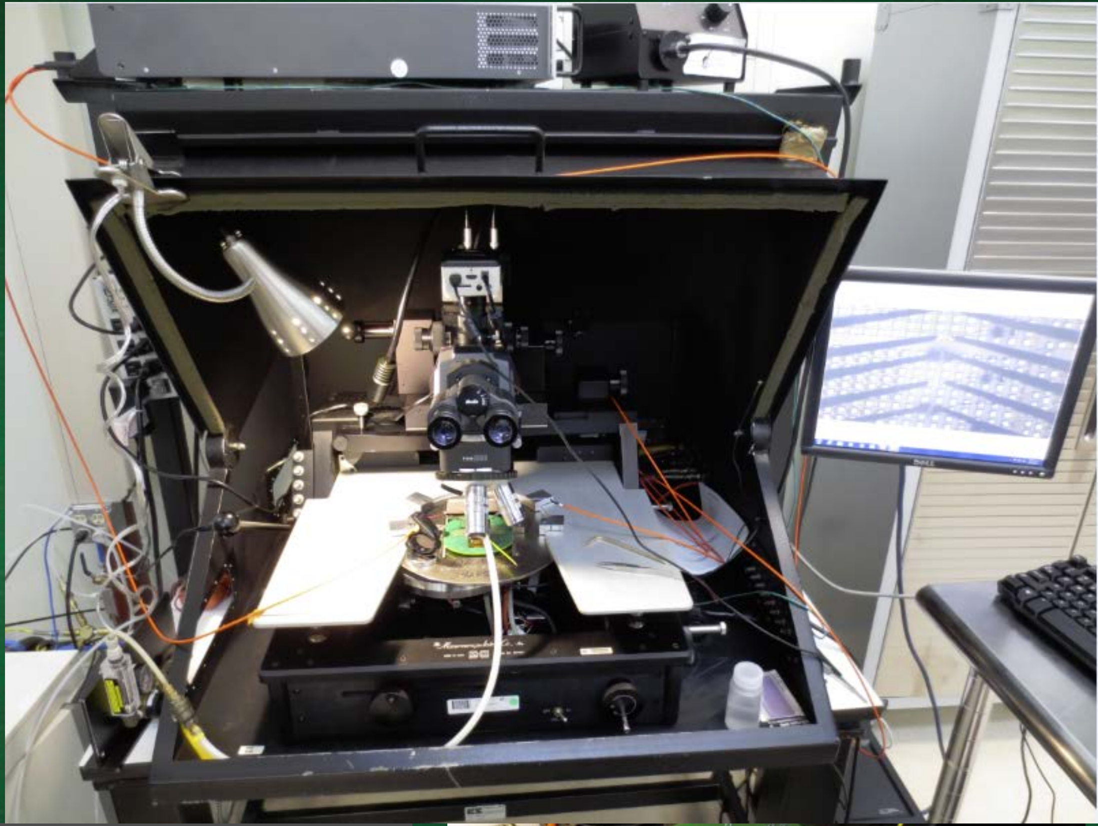
- V ramp
- I ramp
- Isothermal
- Constant Current
- Constant Voltage



Thousands of probes sacrificed themselves for this research project

1. **Probes on the wafer**
    1. Normal ambient 14.7 PSI
    2. Air jet (14.7PSI)
    3. Air pressure 14.7PSI + 20PSI
    4. In Fluorinert
2. **Probes off the wafer 250um**
    1. Ambient
    2. Air
    3. In Fluorinert

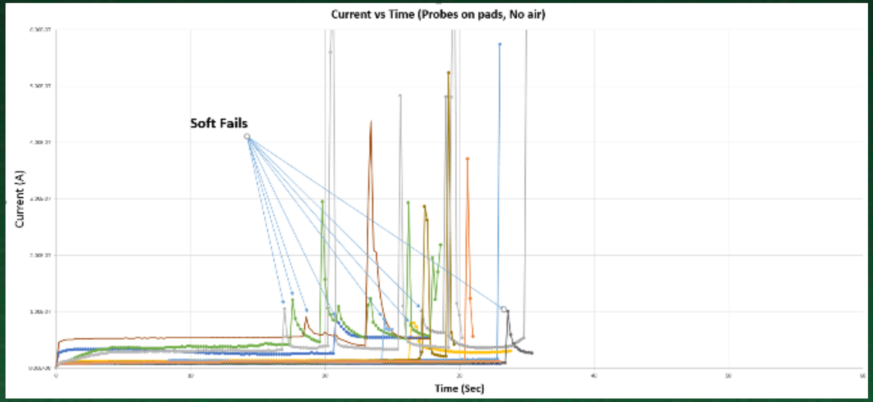
Test Apparatus



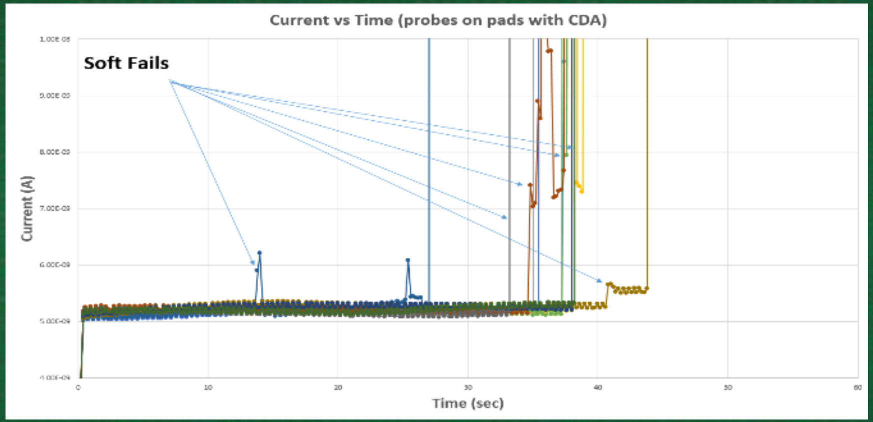
- **Keithley 2657A**
  - 5 volt steps every 200msec
  - 0 to 3000 volts or until breakdown
- **Manual Prober**
  - Hot chuck
- **Custom Celadon Ceramic probe card**
  - 60 probes (30 pair)
- **Cleanroom**
  - RH: 30% - 40%
  - CDA

Current vs Time
Soft Fails

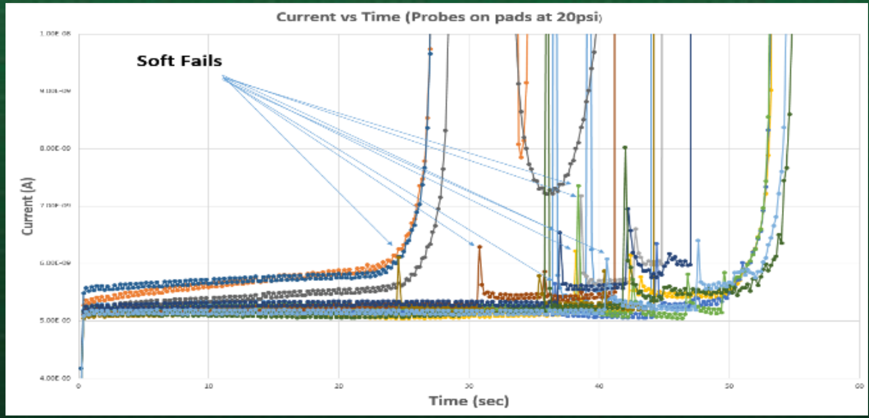
Ambient air



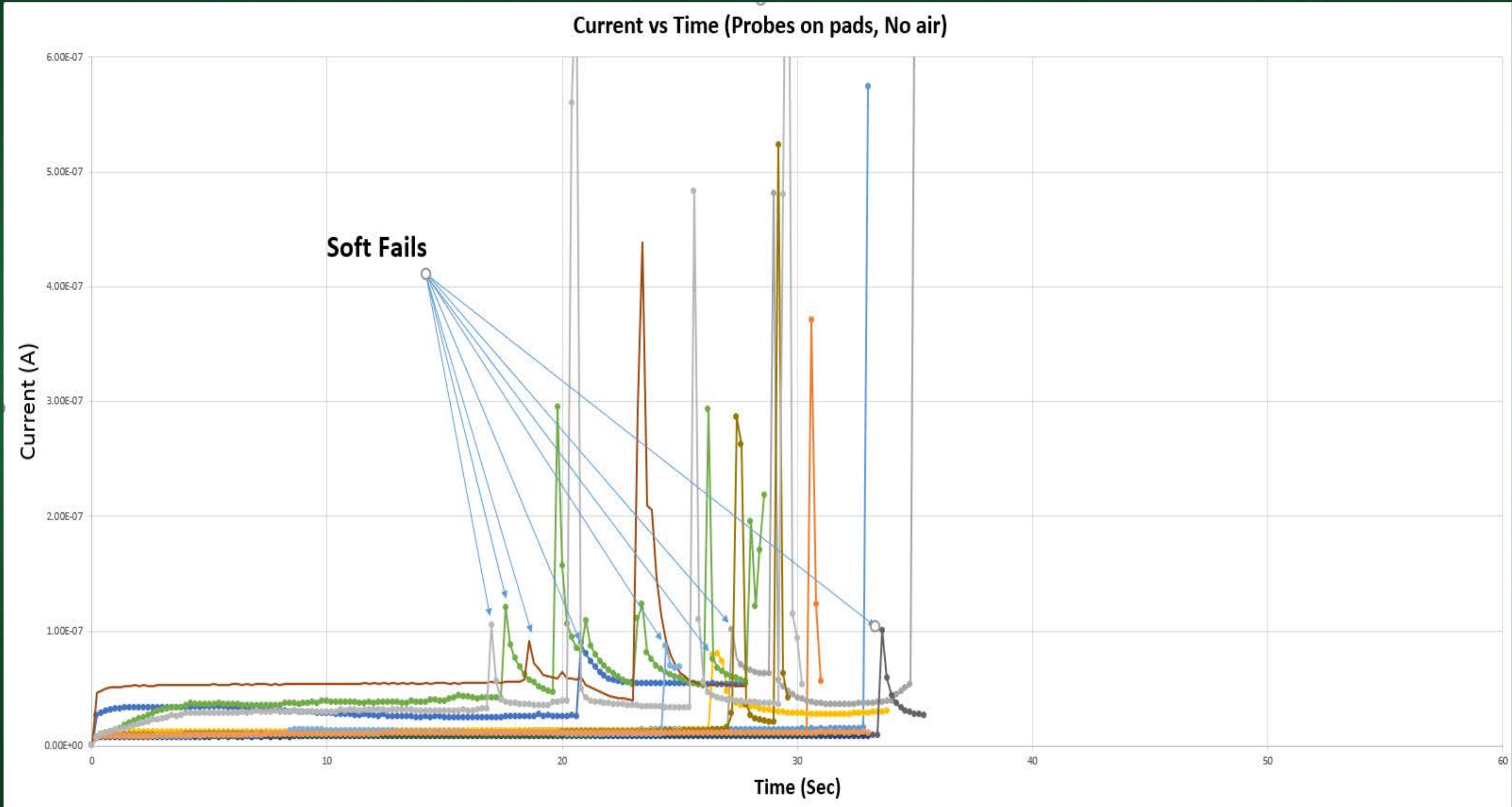
Air Jet (CDA)



20 PSI, no air flow



Current vs Time
Soft Fails

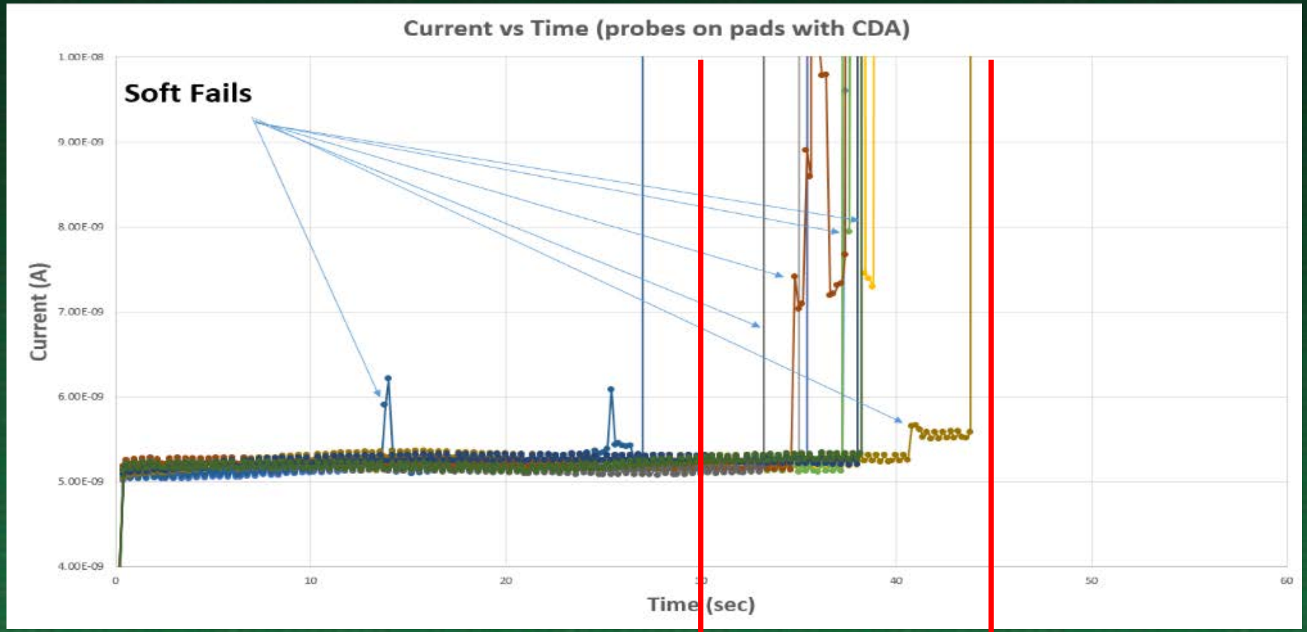


Ambient air

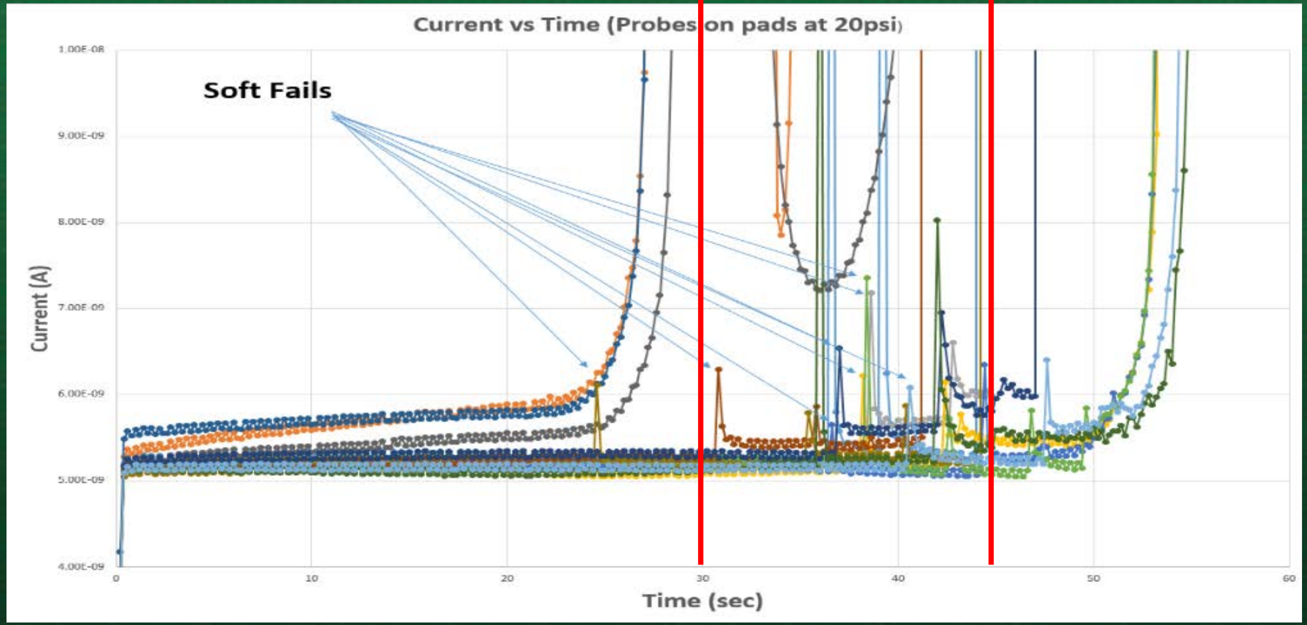
Lower ρ_{ex}

Current vs Time
Soft Fails

Air Jet (CDA)



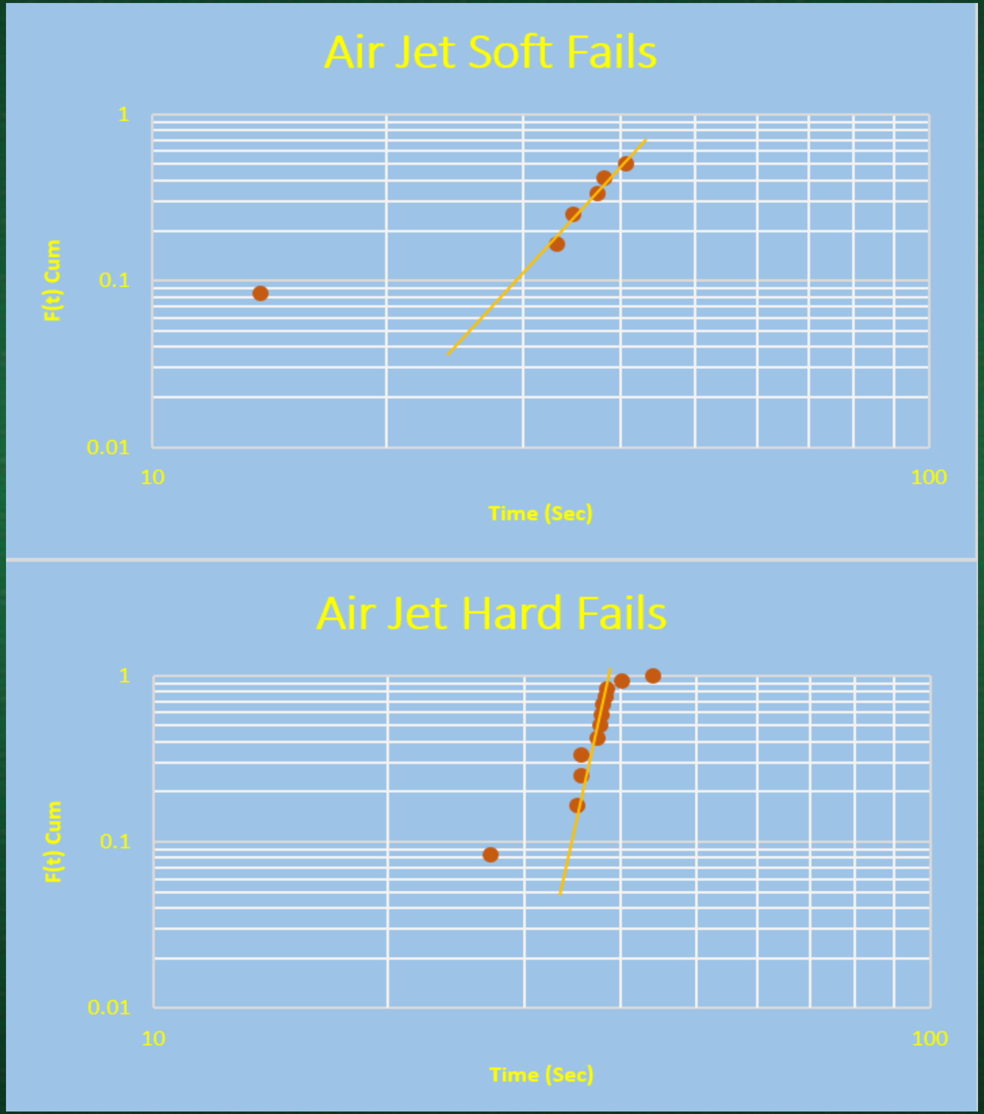
20 PSI, no air flow



Weibull Distribution of Air Jet Fails

- Single distribution for soft fails
- Intrinsic

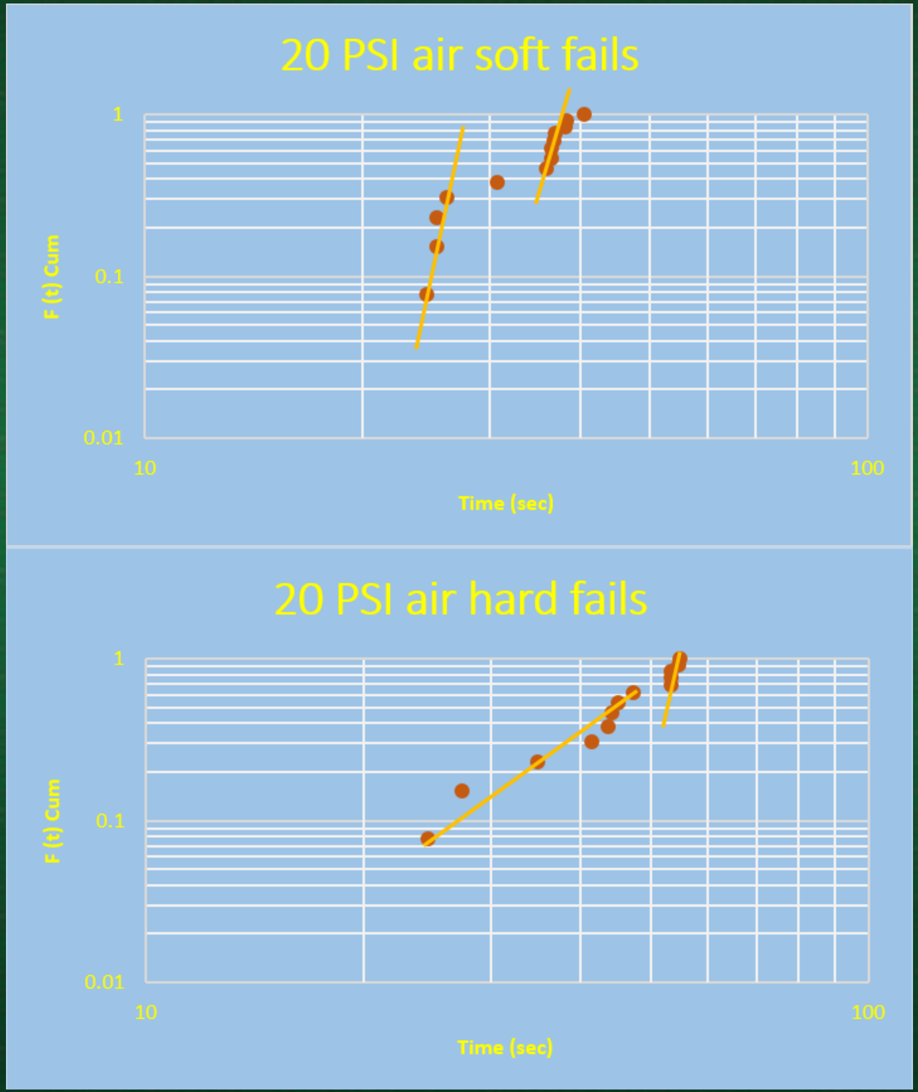
- Single distribution for hard fails
- Intrinsic



Weibull Distribution of high pressure fails

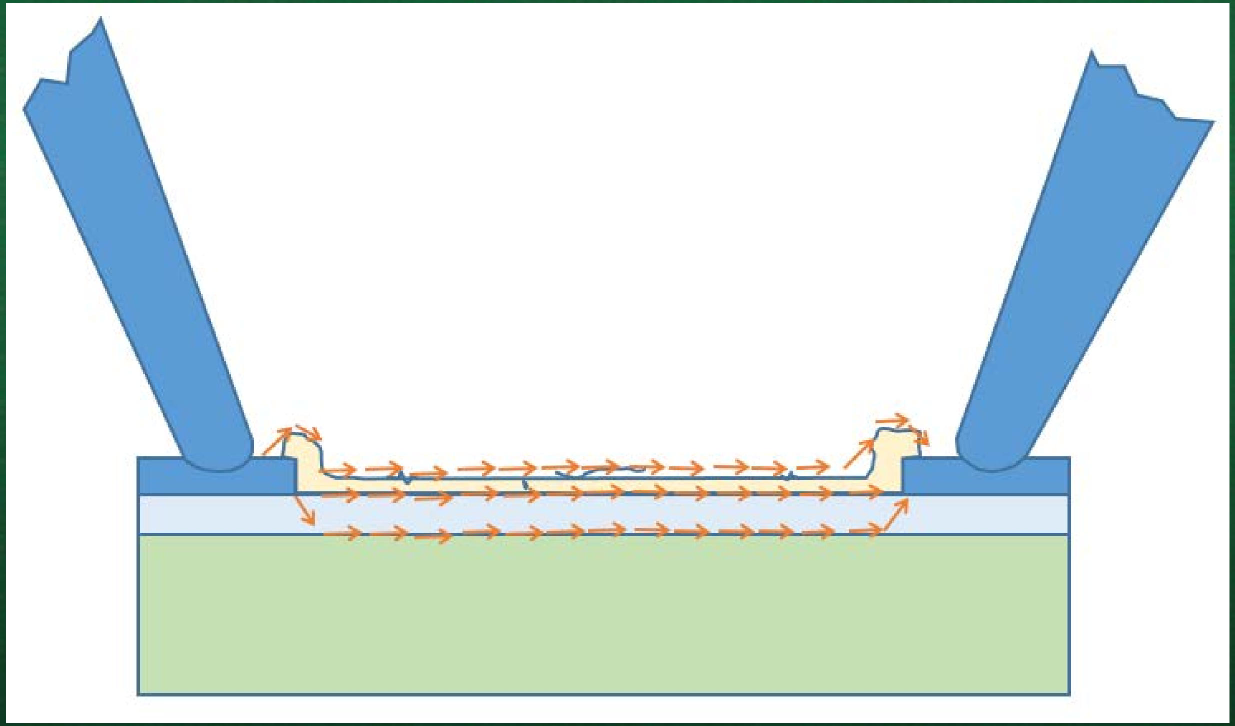
- Two separate distributions for soft fails
- Intrinsic and extrinsic

- Two separate distributions for hard fails
- Intrinsic and extrinsic



Soft Fails are a key parameter

A device that has experienced a soft fail during test is damaged and thus has a higher probability of early failure under normal use.



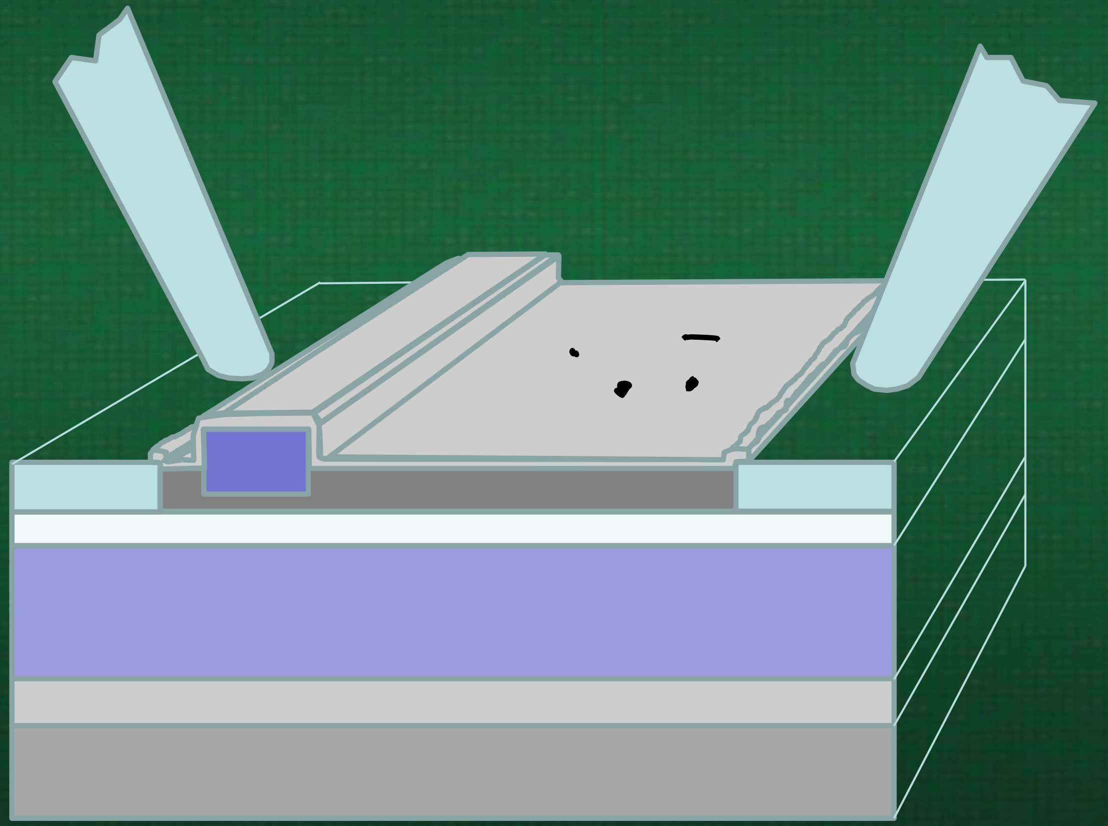
How to predict soft fails?
=>> Highly influenced by extrinsic defects
How to suppress soft fails?

Don't forget about the crud on the device

The breakdown voltage is dominated by the material with the lowest dielectric strength and the statistical probability of high field strength point defects

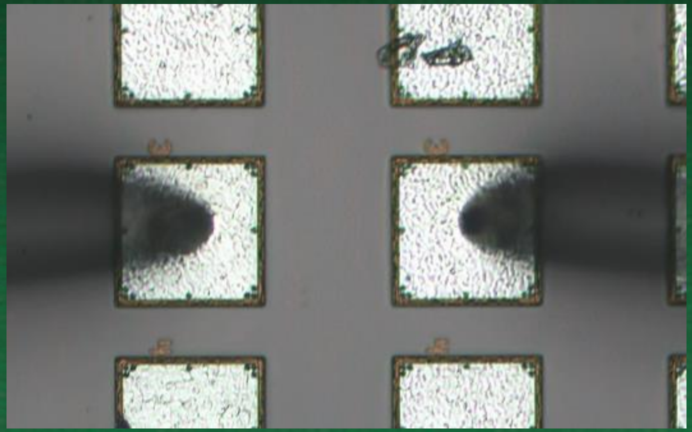
....and crud on the surface of the device

- **Krile, et al observed that**
  - Breakdown occurred on the surface in air
  - Breakdown occurred over the surface in N2
  - Breakdown voltage was lower with higher humidity
  - Observed Soft breakdown

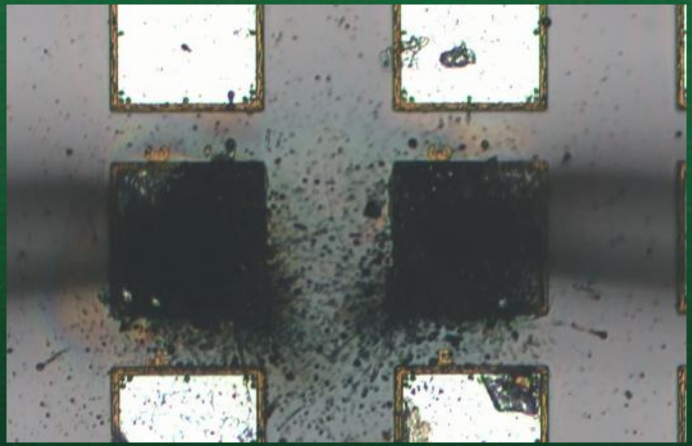


Pictures of test stopped at soft fail/hard fail

Soft Fail



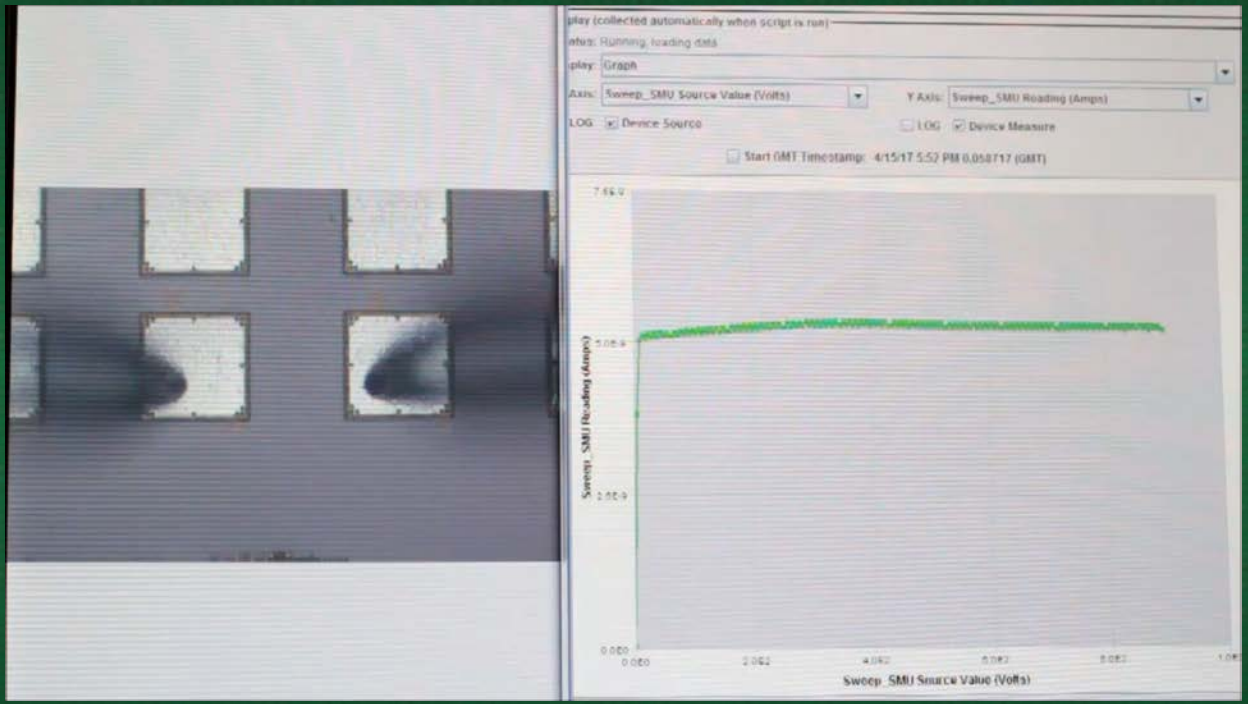
Hard Fail

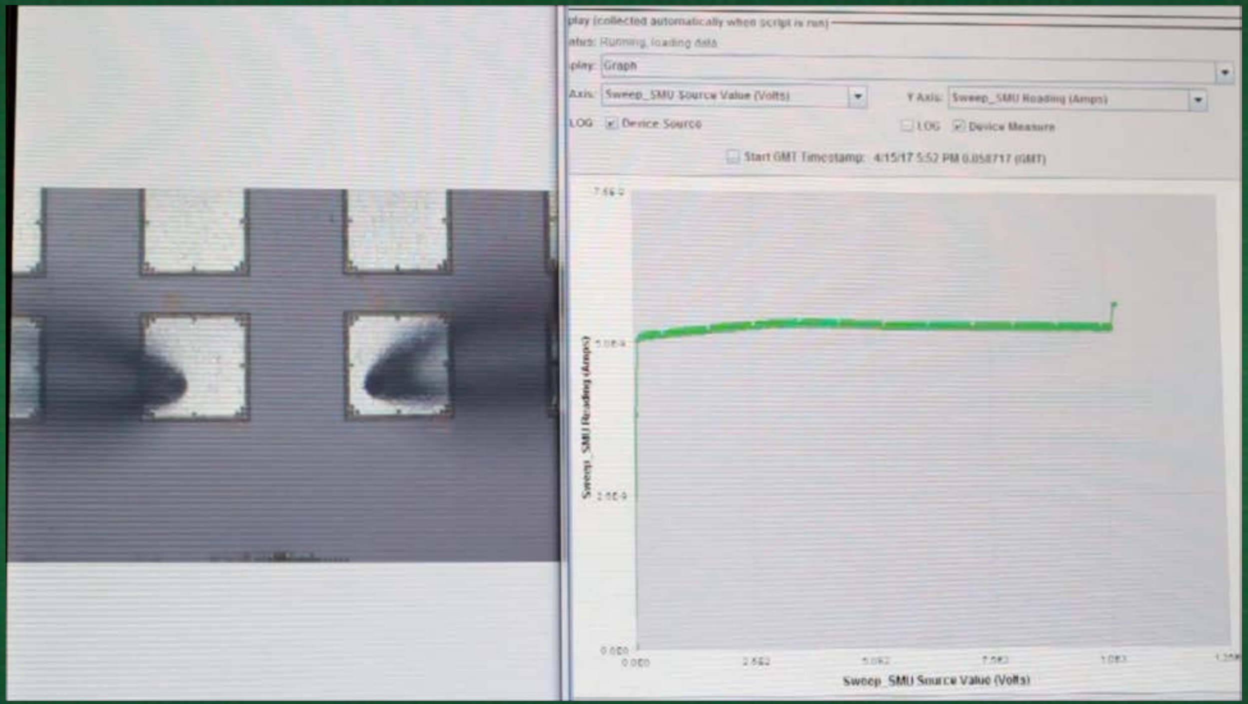


Pictures of test stopped at soft fail/hard fail

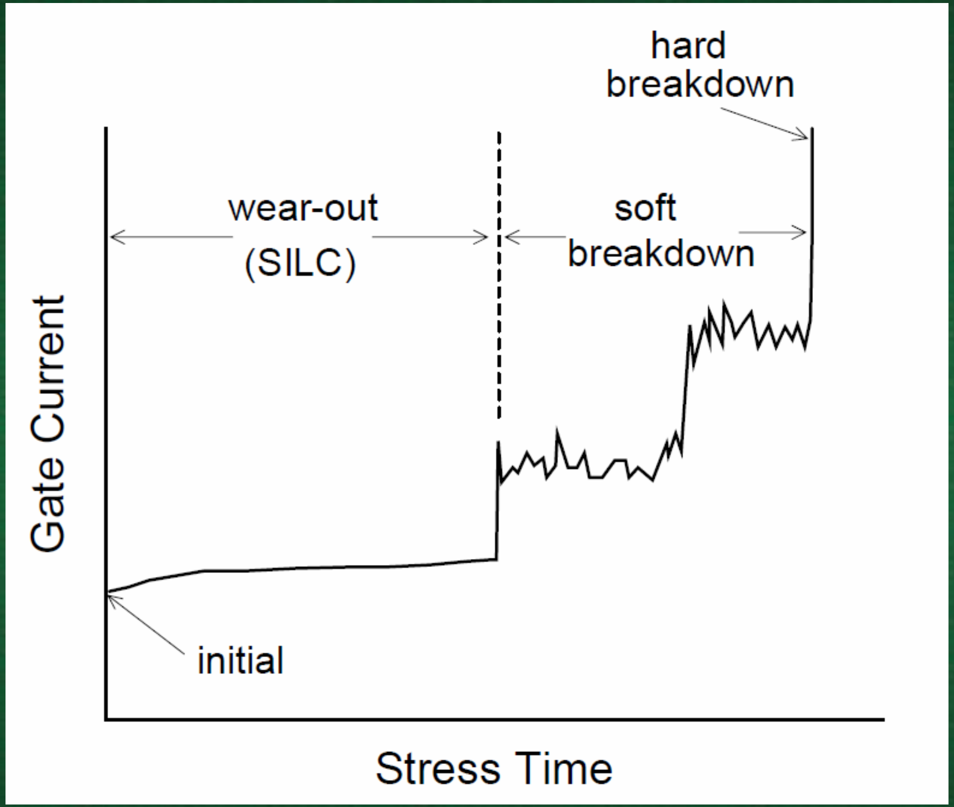
Soft Fail

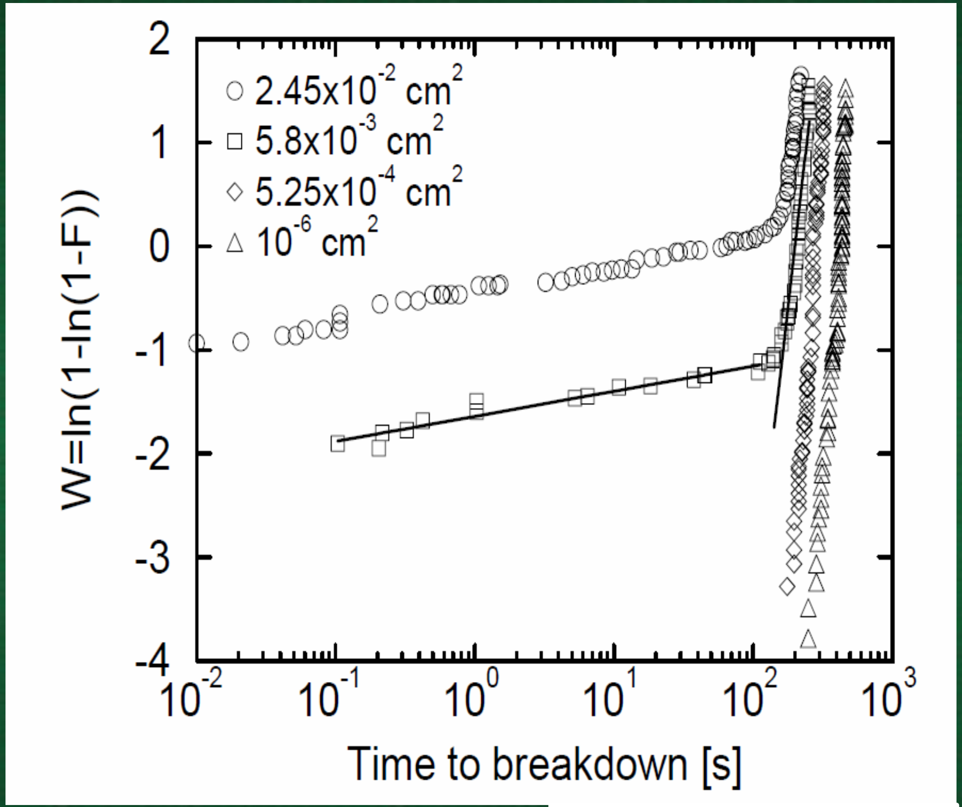
Hard Fail





Prior research supports soft breakdown model





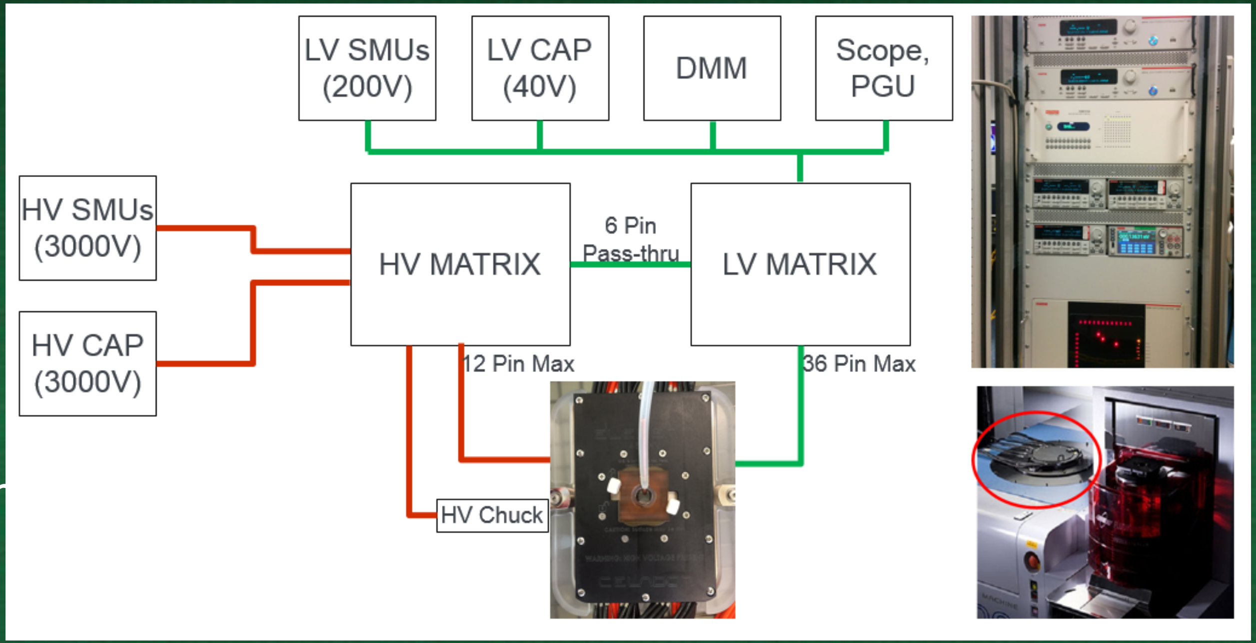
Ghetti et al.

- At 10V or at 5000V Soft Fails can damage the device

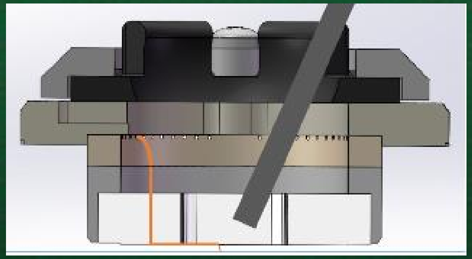
Direct Jet™

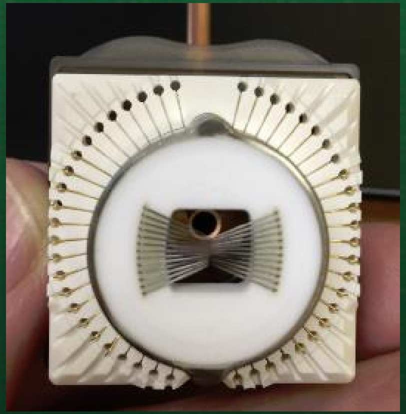
- **VersaCore™**
  - Direct Jet™
  - Pressure bubble
  - Turbulent flow
  - Minimal gap to enhance pressure bubble
  - Prevent beam arcing to the wafer

    =>>Patented AttoFast™ probes can touch at 3000V without shorting.



- **Software control**
  - Heat
  - Air on/off pressure





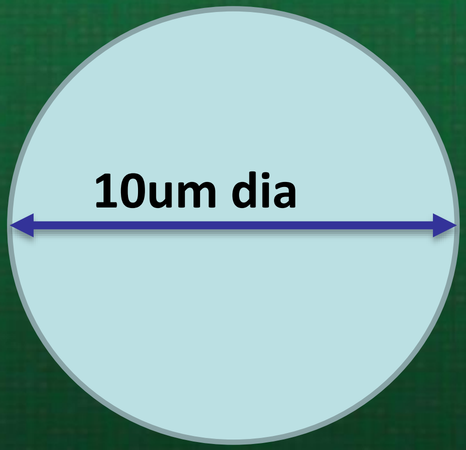
What about contact resistance?

- **A-spot model?**
- **Extreme heat and thermal runaway**
- **Similar to highly accelerated Electromigration**
  - Critical Current Density in A/cm^2
    - 1×10^5 A/cm^2 normal current density (years)
    - 1×10^6 to 2×10^6 A/cm^2 Accelerated current conditions (weeks to months)
    - 1×10^7 to 2×10^7 A/cm^2 Highly accelerated conditions (seconds)

Critical Current density

Critical Current Density in A/cm^2

- 1×10^5 A/cm^2 => 1 mA/um^2 Okay
- 1×10^6 A/cm^2 => 10 mA/um^2 Accelerated
- 1×10^7 A/cm^2 => 100 mA/um^2 Highly accelerated



= 78.5um^2

Conclusions

- **Embrace Passion and forget about Paschen and Townsend**
- **Voltage breakdown follows a defect dominated failure distribution**
  - Extrinsic defects
    - Related to contamination
    - Weakest link
    - High field strength defects
  - Intrinsic failures
    - Design related
  - Surface moisture and contamination heavily influence fails

Future Work

Special Silicon Wafer

- Pad shape
- Pad distance
- Single crystal silicon
- Field oxide
- Passivation

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  - Keithley Instruments
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