Achieving 3000 V test at the wafer level

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Outline

- Introduction
    - Si, SiC and GaN Power Devices
- Background

    Power devices, what are they and where do they go?
- The Challenge of Wafer Test at 3 kV
    - Test, Automation, and Safety
- Device Test
    - Celadon Probe Card, Keithley Tester, Cascade Tesla Prober
- Results
- Conclusion

Power Switching Applications

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

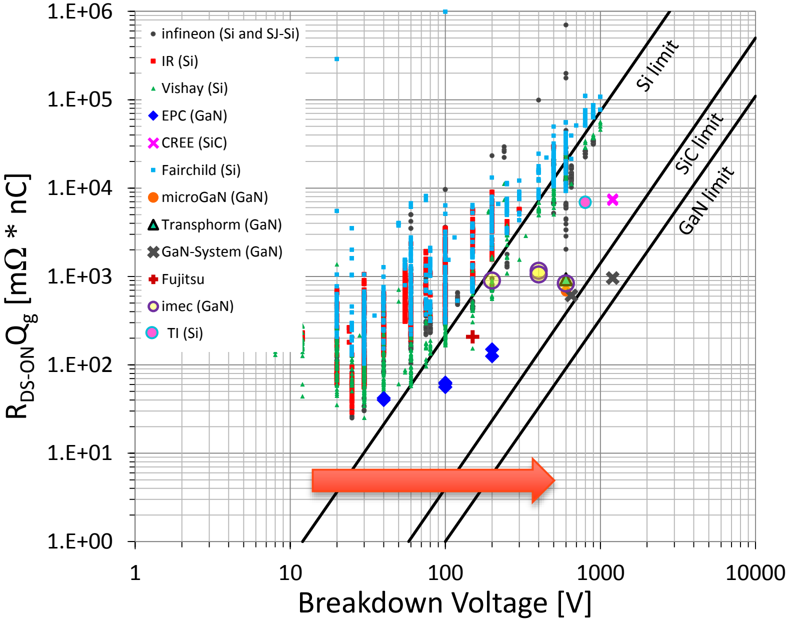
- Down Hole Oil Drilling, Geothermal Instrumentation
- Switched-Mode Power Supply (SMPS)
- Electric Vehicles (EV)
- Power Factor Correction (PFC)
- Uninterruptible Power Supply (UPS)
- Solar Inverters
- Induction Heating
- Motor Drives

First RSS Rated to 200 degC

The PowerDrive ICE ultraHT RSS operates durably at 200 degC [392 degF], bringing the benefit of a fully rotating RSS to HT and ultraHT reservoirs. Visit PowerDrive ICE ultraHT RSS page

Figure of Merit

Devices with better $R_{DS\text{-}ON}Q_g$ and higher breakdown are needed to improve the circuit performance.



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

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

Why SiC and GaN devices?

Why are we moving away from Si for power?

- SiC and GaN offer wide energy band-gap (high breakdown)
- good heat conductivity

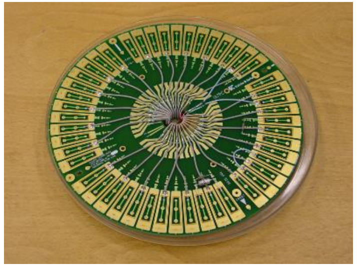
Property	Units	Si	GaAs	4-SiC	GaN
Bandgap	eV	1.1	1.42	3.26	3.39
Relative dielectric constant	-	11.8	13.1	10	9
Electron mobility	cm^2/Vs	1350	8500	700	1200-2000
Breakdown field	10^6 V/cm	0.3	0.4	3	3.3
Saturation electron velocity	-	1	1	2	2.5
Thermal conductivity	K	1.5	0.43	3-3-4.5	1.3

Parameters for High Voltage

Parameter		200-3kV	< 200V	C-Meter	Pulsed IV
Rdson	Drain to Source Resistance when transistor is 'On'		✓		
Vt	Threshold voltage		✓		
Vdss	Maximum drain to source voltage, in the Off state	✓			✓
Id	Maximum DC and Pulse current rating		✓		✓
Idss	This is drain leakage current with Vgs = 0, at a specified drain voltage	✓			✓
Ciss, Coss, Crss	3-terminal device capacitances	✓		✓	
Gate Charge	Charge accumulated at the gate to switch it On				✓

A new measurement challenge

These new high current and high voltage devices require new measurement techniques, <u>especially with automation.</u>

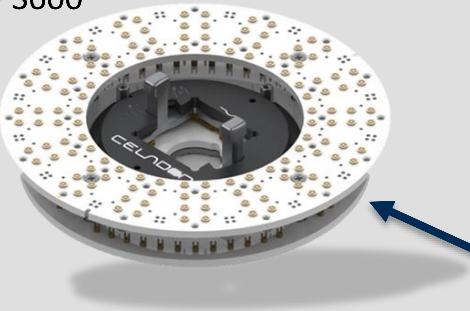


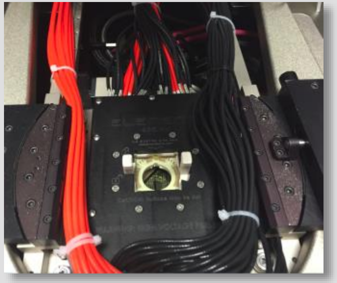
“Traditional” approaches:

- Limited Voltage
- Limited current
- Low reliability at high temperature
- Short life time

VersaCore™ Formats

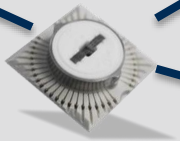
Keithley S600





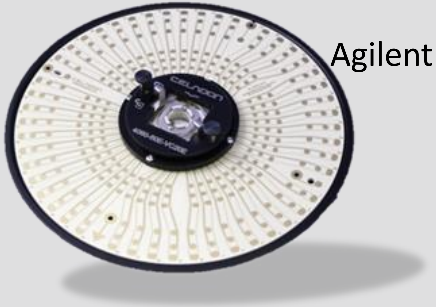
45E Modeling and Characterization to 3000 volts

45E Modeling and Characterization To 1500 volts



Celadon Indexer

Agilent 407X/408X



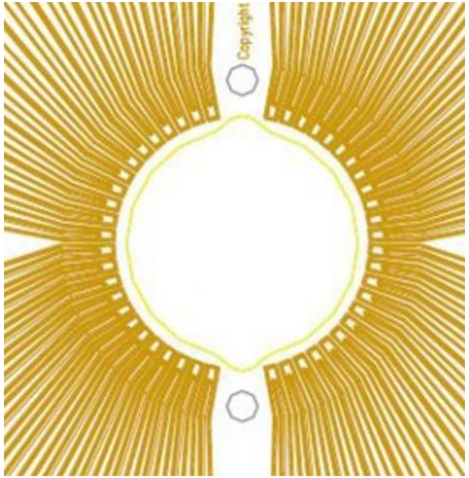
Standard 45E “VersaCore™ Holder

Typical 45E

- High Voltage to 1500 volts.
- Low leakage less than 5fA/V
- Easy to swap between different probe card cores using Celadon’s insertion tool
- Low to High temperatures (ceramic core) -65°C to 200°C

Probe Card Connections

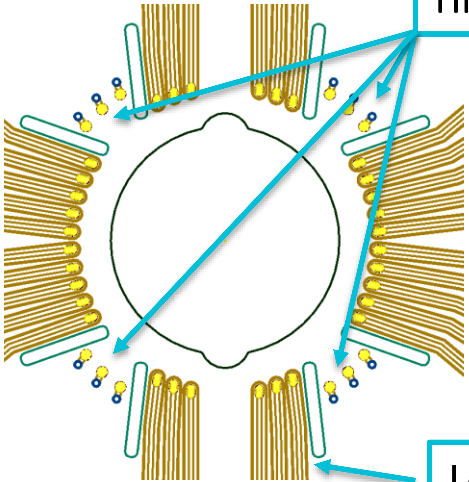
Standard 1500V 45E Chassis

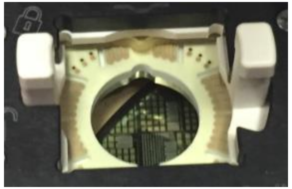


48 low leakage (fA) pins

3000V 45EHV Chassis

High Voltage pins





Low leakage Pins

32 low leakage (fA) fully isolated pins
12 3000V pins

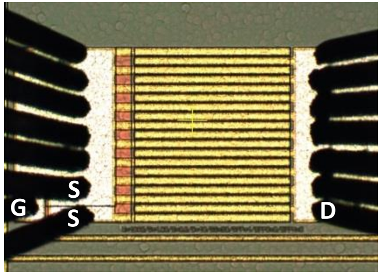
45E HV

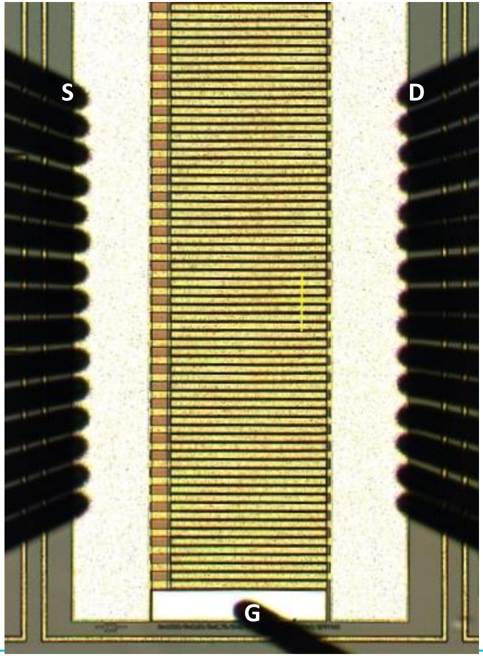
- 12 Quasi-Kelvin 3000 volt pins
- 32 Quasi-Kelvin Low leakage pins

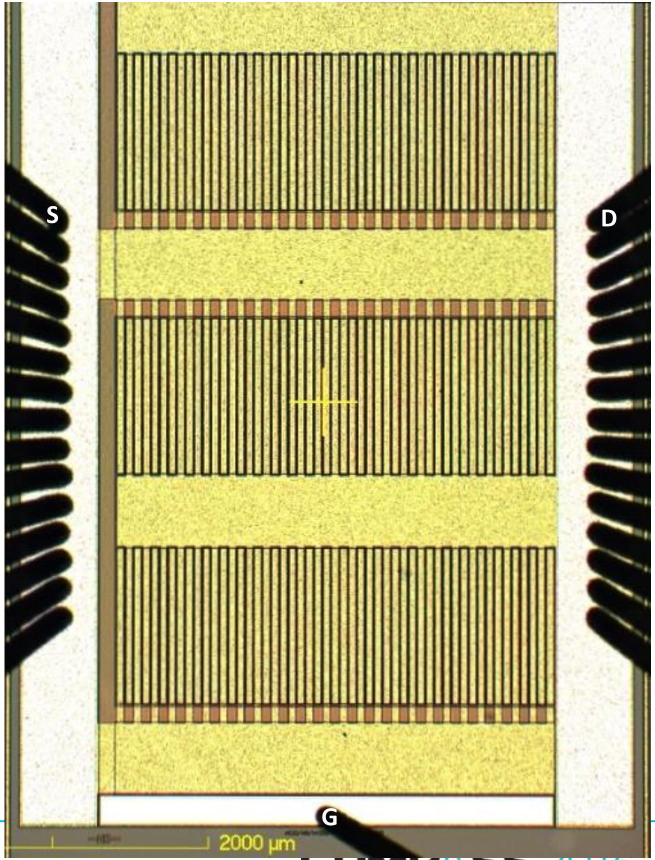
Different Cores for Different Layouts

The cores are designed to satisfy the device specifications (layout, position of bond-pads, maximum current expected).

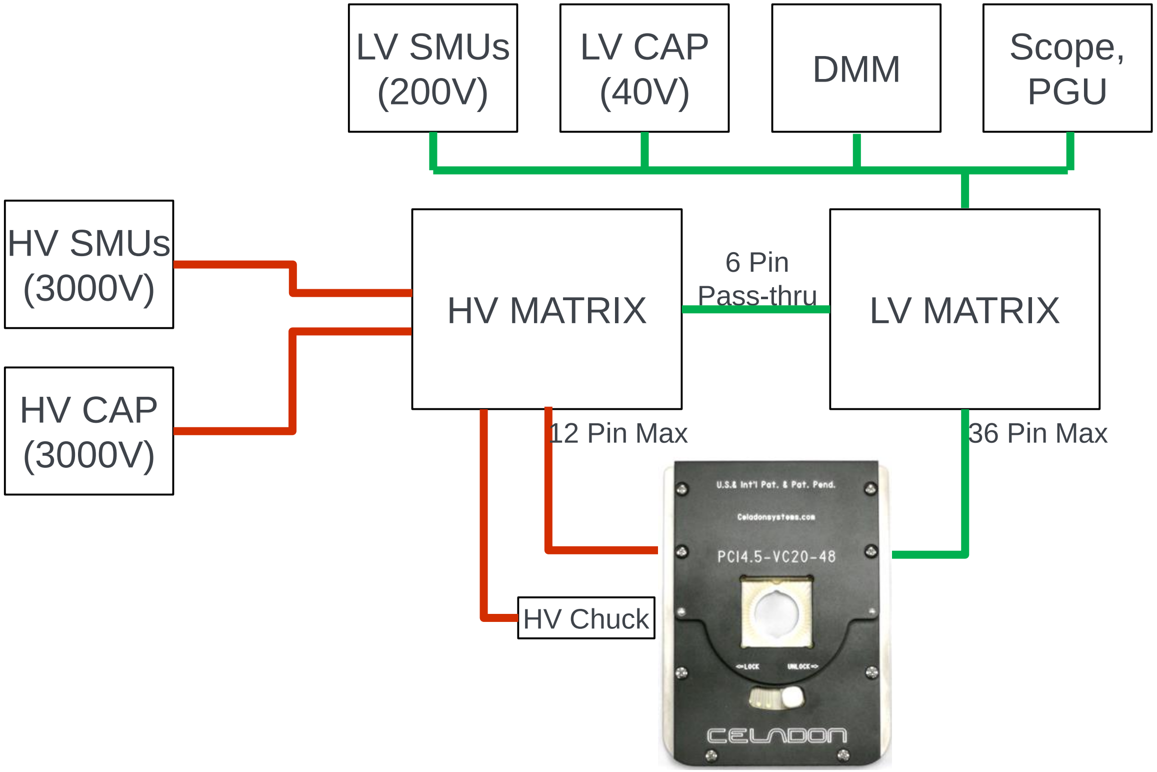
The large number of needles guarantees:
↓ lower contact resistance
↓ lower inductance
↑ higher maximum current

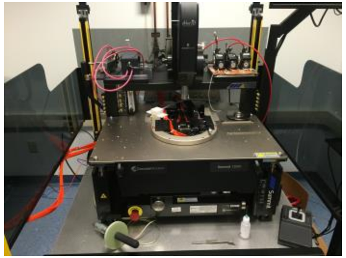






Measurement Setup





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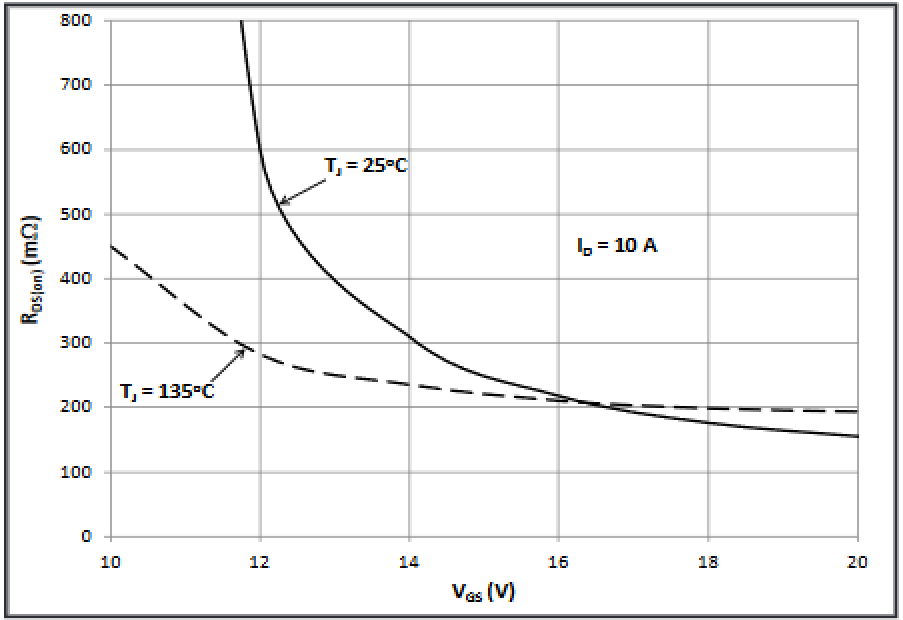
RDSon

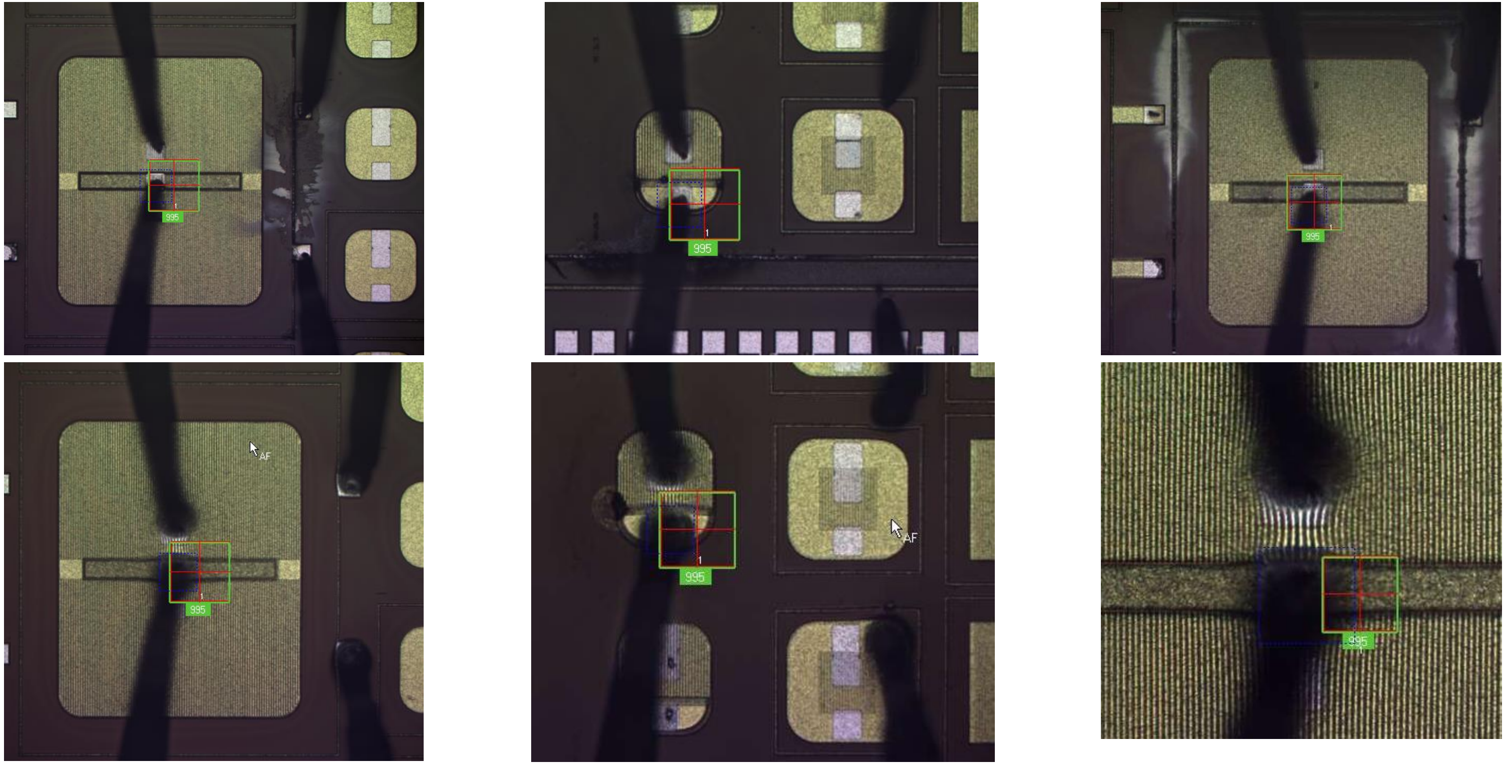
Using the Low voltage Switch.



Cree CMF10120D-Silicon Carbide Power MOSFET

Breakdown Voltage

Surface Breakdown



Preventing Surface Breakdown

Sample Data

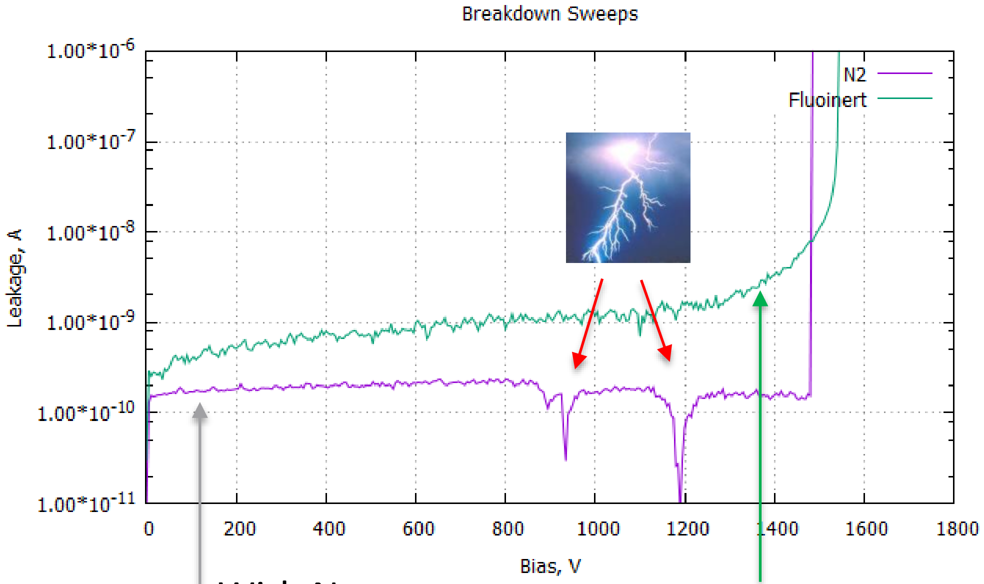
With Fluorinert – not a realistic solution

In dry N_2

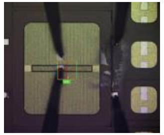
Non-destructive discharges

Can be identified by lower current spikes and can indicate:

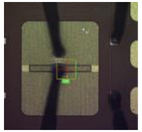
- Moisture present
- Small device spacing



With N_2

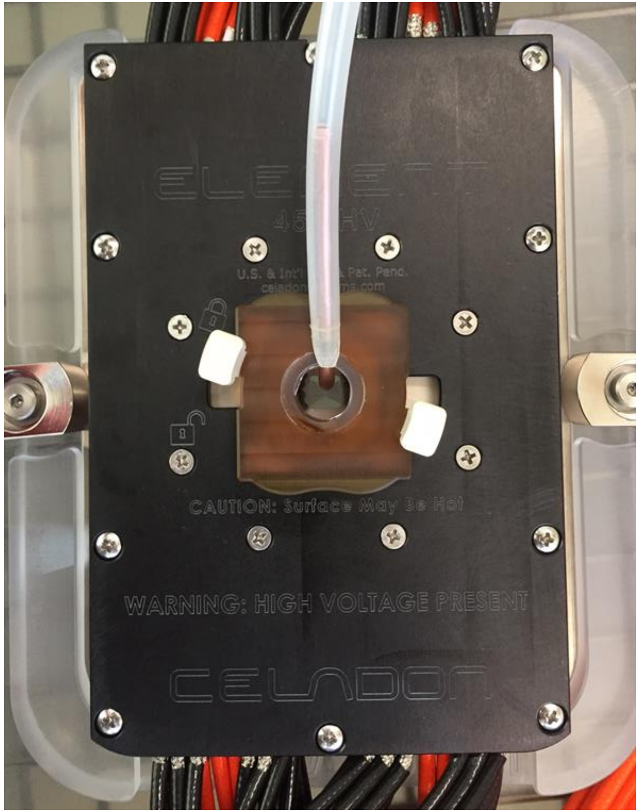


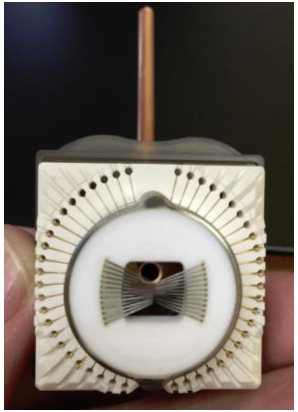
With Fluorinert

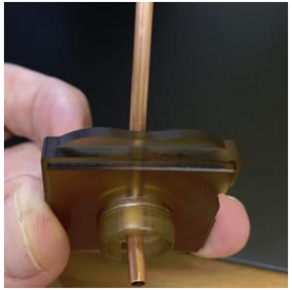


Preventing Surface Breakdown

- **Disrupting the ionization path**
  - Directed air
  - Temperature controllable
  - Snaps onto VersaCore™
  - Adjustable air volume
  - CDA or N2
  - Not a high volume of gas 7 Liters/min



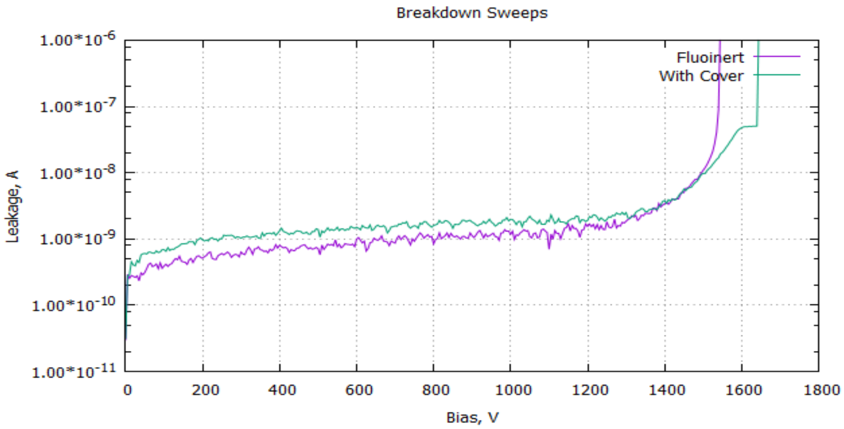


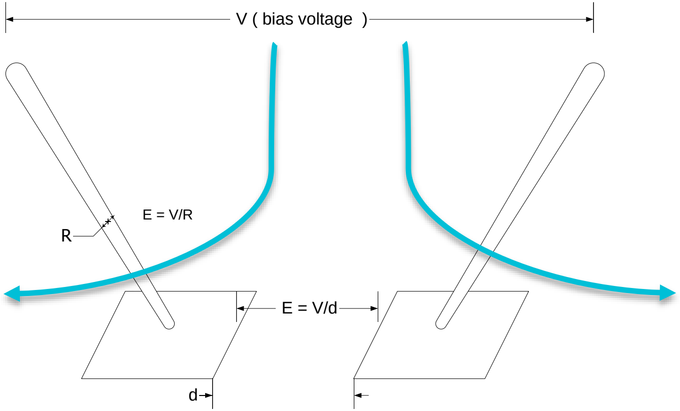


Preventing Surface Breakdown

Sample Data

High velocity jet





	N2 Stream Only	N2 stream and Pressurized cavity	With Fluorinert
MAX	1470	1530	1510
MIN	1285	1435	1445
MEAN	**1382**	**1496**	**1465**
STDEV	70	29	24

Automation

High Voltage

- Breakdown Tests
- Isolation and Protection of LV components

HV Capacitance

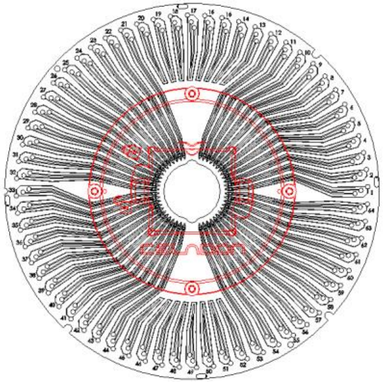
- HV bias tee
- **Compensation techniques in Automation**

Automation

- **Matrix**
- **Probe Card, Multiple pins**

Sensitive Measurements

- Guarding & Triax cables
- Kelvin remote sense
- Minimize Dielectric Absorption



Safety

Interlocks

Single interlock system disabling the HV

On any door, PCA access, prober

Protection Modules

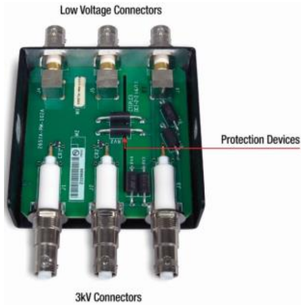
Interface between LV and HV

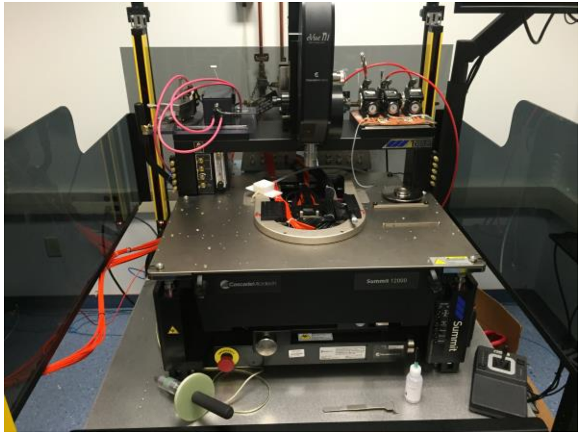
Fully guarded Kelvin connection

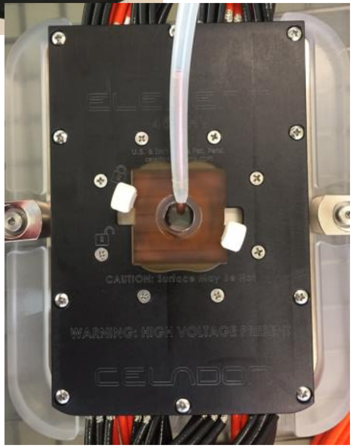
Limits LV to 200V

HV Matrix Discharge

An automated circuit discharge







Conclusions

In this presentation we have demonstrated the successful implementation of Hybrid HV/LV system suitable for the lab or the fab up to 3000V Celadon VC20 VersaCore™, 45EHV probe card holder, and Keithley's S540 test system. In particular, we have shown:

- On-wafer high voltage and high current measurements
- The versatility of the Keithley S540 test system
- The versatility of Celadon's VersaCore™ probe cores
- Overcoming the challenges of testing at high voltages
- Safety concerns of testing at high voltage
- Ease of use

Acknowledgements

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