COMPASS

a **FormFactor** users' group conference

FormFactor™

Overcoming the Wafer Test Challenges of Advanced Power Semiconductor Devices (GaN, SiC, Si)

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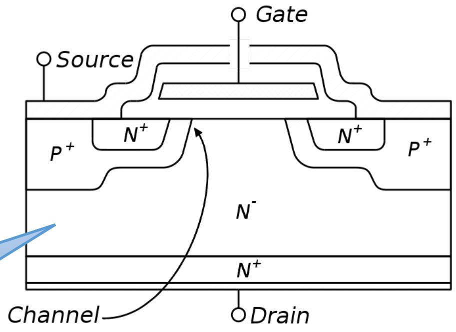
FormFactor

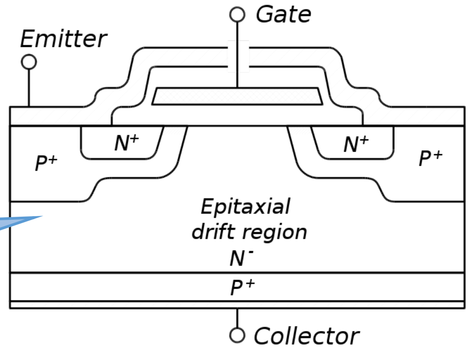
Power Semiconductor Device Definition

- Semiconductor devices used as Switches or Rectifiers in power electronic circuits
- Also known as power device, power IC, power module
- Some common power devices:
  - power diode
  - power MOSFET
  - IGBT (Insulated Gate)
- Device Measurements
  - Breakdown voltage
    - Low leakage measurement @ high V
  - On-resistance (Rds-on)
    - High current
  - Rise and fall times for switching
  - Safe-operating area (thermal dissipation / "latch-up")
  - Thermal resistance

Power MOSFET (V/L)
Si, SiC, GaN, GaN-on-Si (& SiC)

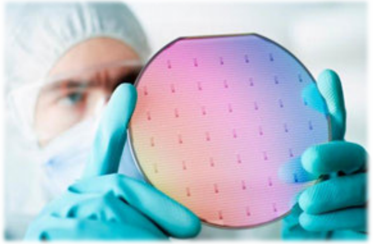


IGBT (V only)
Si

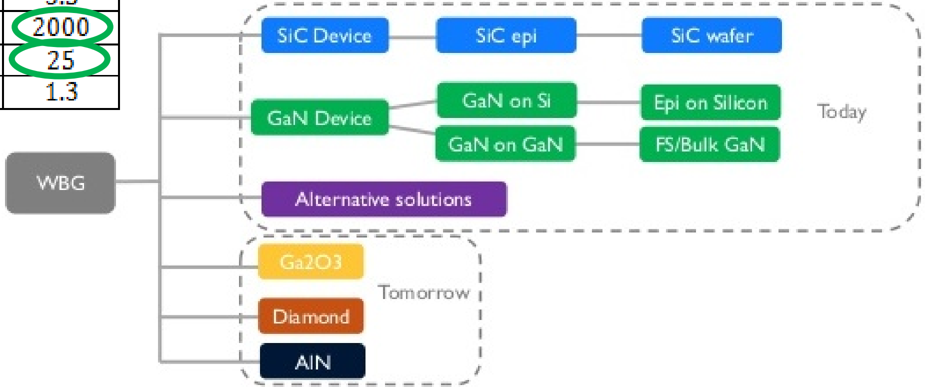


Wide Band-gap Materials

- Newer SiC & GaN material devices are “disrupting” the older Si devices
  1. Higher power (voltage, current, breakdown)
  2. Greater efficiency (higher switching speed)

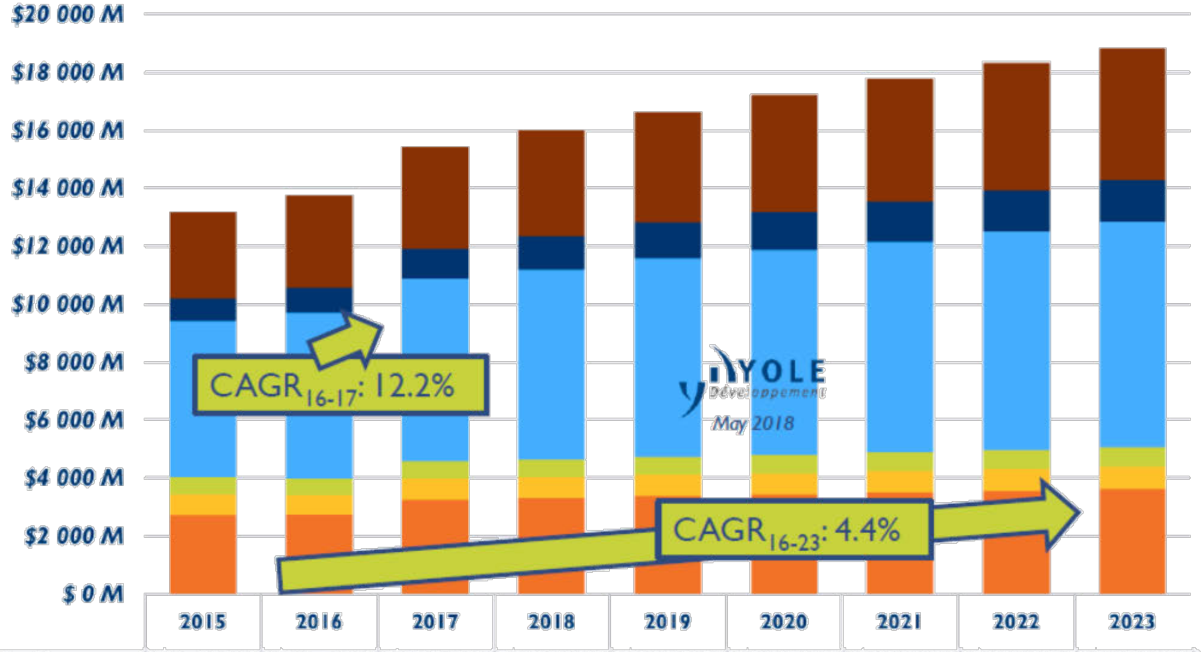


Material property	Si	SiC	GaN
Band Gap (eV)	1.1	3.2	3.4
Critical field 10^6 V/cm	3	3	3.5
Electron Mobility (cm^2/V-se)	1450	900	2000
Electron Saturation Velocity (10^6 cm/sec)	10	22	25
Thermal Conductivity (Watts/cm^2 K)	1.5	5	1.3



Power Device Market (2015-2023 by type of device)

2017 has been a healthy year for power electronic devices, mainly IGBT (both discrete and module).



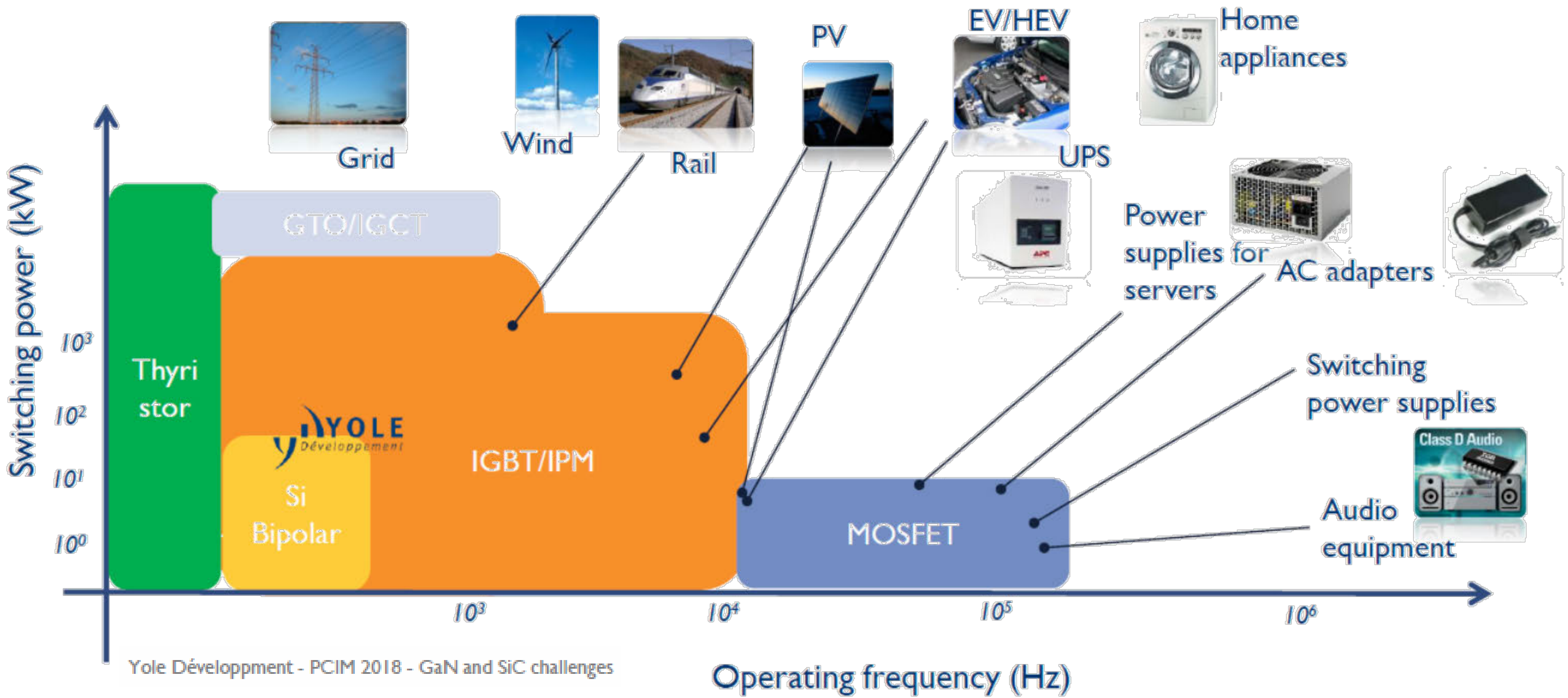
	2015	2016	2017	2018	2019	2020	2021	2022	2023
Total	$13 165 M	$13 752 M	$15 430 M	$16 025 M	$16 644 M	$17 230 M	$17 789 M	$18 323 M	$18 841 M

2017 has been an exceptional good year for all power electronic sectors

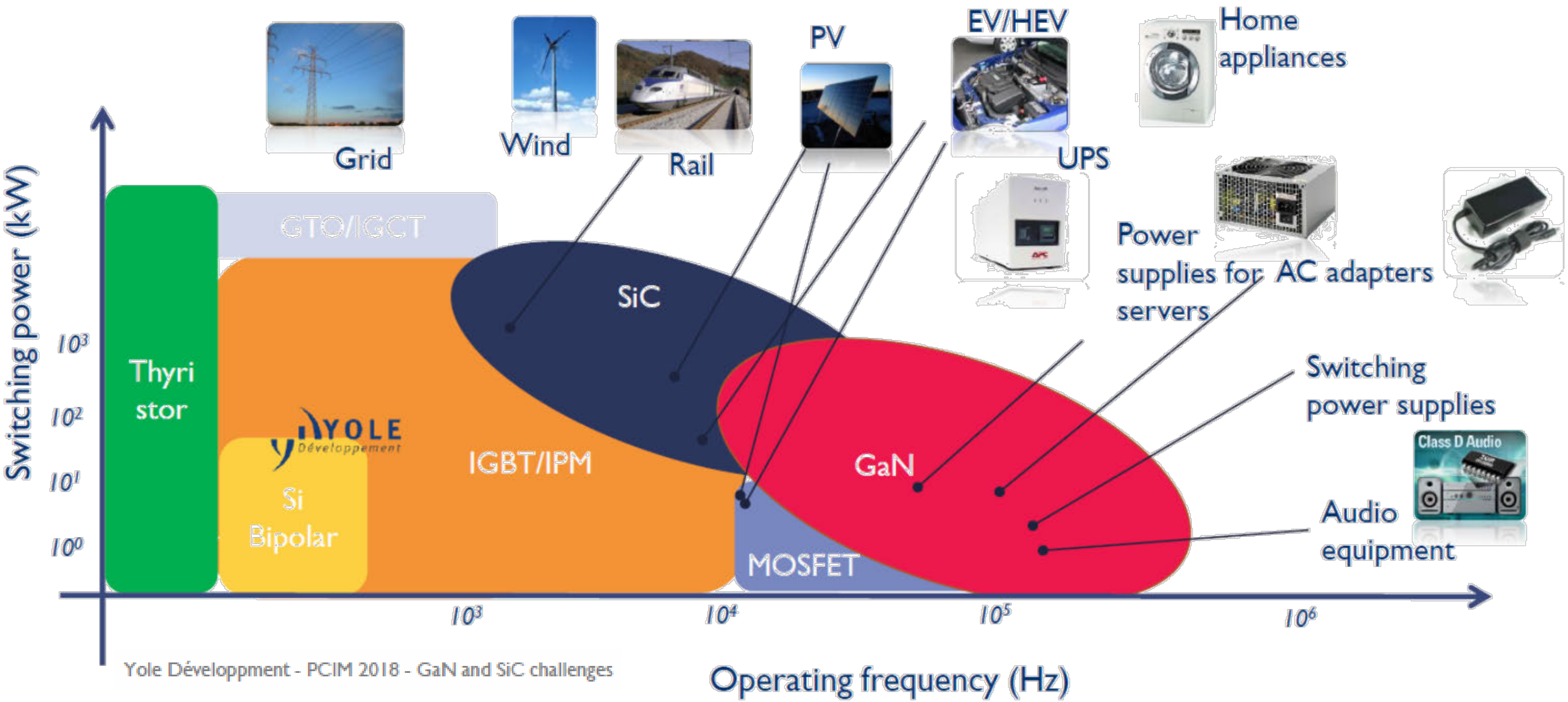
	CAGR 16-17
Modules & IPM	10.3%
IGBT	20.0%
X-FET	10.5%
Bipolar	1.2%
Thyristors	10.5%
Rectifiers	18.3%
Total	12.2%

Yole Développment - PCIM 2018 - GaN and SiC challenges

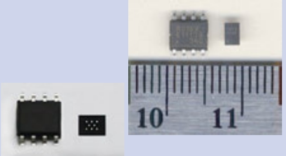
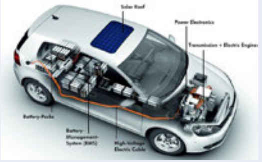
Power Semiconductors (Applications and Technologies)



Power Semiconductors (Applications and Technologies)

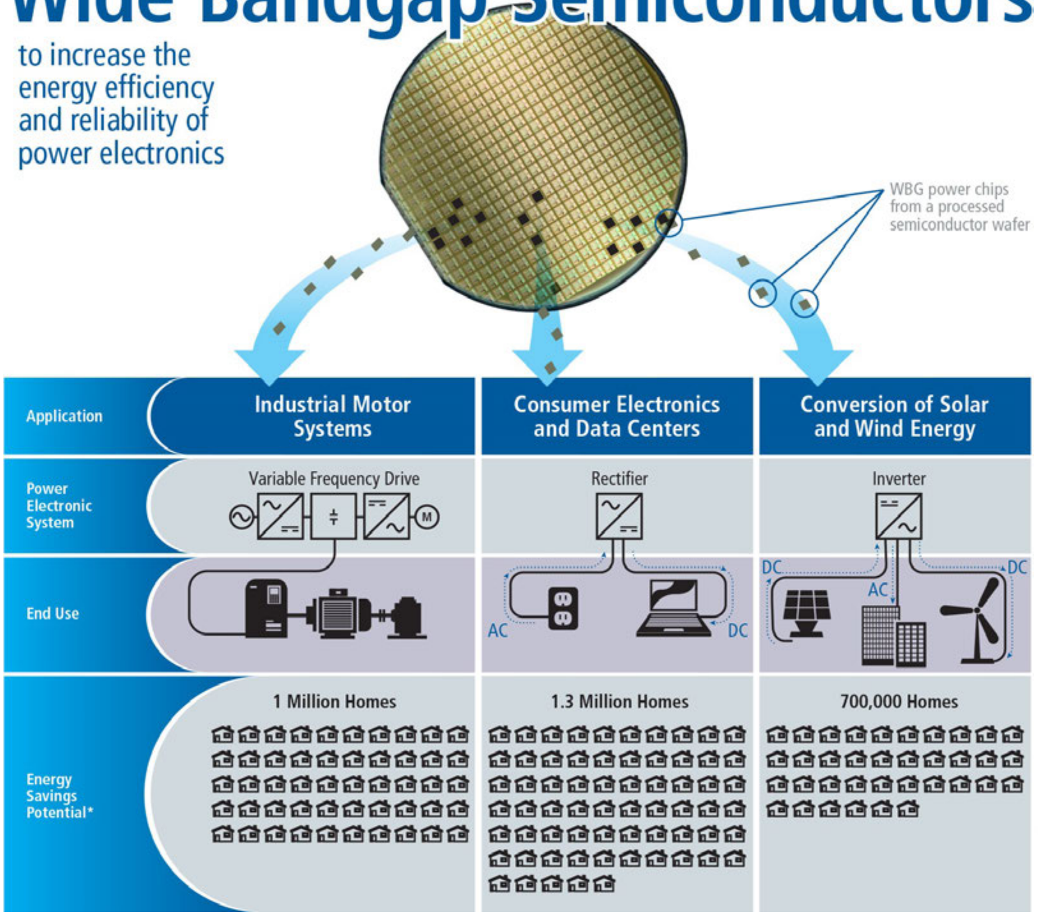


GaN / SiC Technology in the real world

GaN / SiC Devices	Technology benefit	Applications
Devices can be smaller	*Smaller packaging* into consumer products	 
Devices can support higher temp	*Increaser reliability* in Automotive EV	 
Devices are more efficient *(higher switching speed)*	*Lower energy loss / heat* in industrial uses	  

Wide Bandgap Semiconductors

to increase the energy efficiency and reliability of power electronics

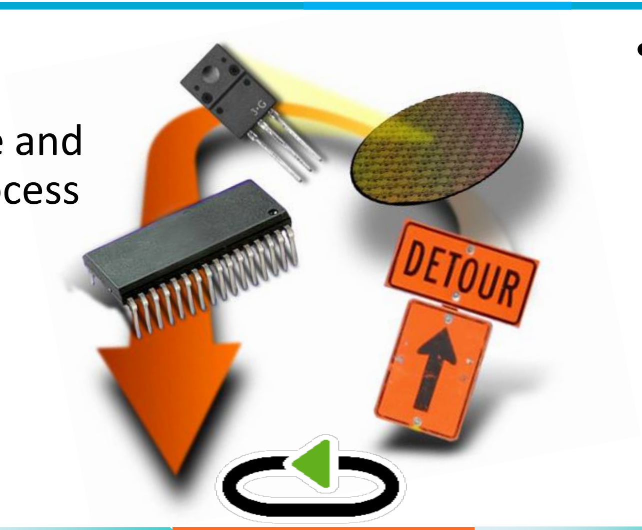


*in annual U.S. household electricity use. = 20,000 Homes

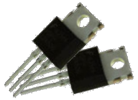
Data Courtesy of U.S. Department of Energy

Package vs On-Wafer

Package and Test process

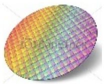


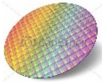
- On-wafer measurements <u>reduce</u>:
  - eng design cycle time
  - eng design cycle packaging costs
  - mfg packaging costs (only KGD)
  - mfg packaging time (only KGD)
  - delayed time-to-market for new products



Design → Wafer Fab → Packaging → Parametric Test → Sort Test → KGP → Final Test

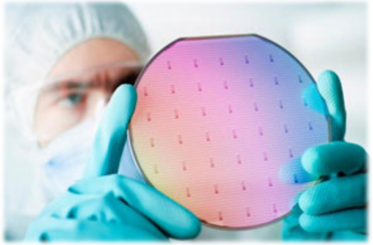
Design → Wafer Fab → Parametric Test → Chip Sort Test → KGD → Packaging → Final Test

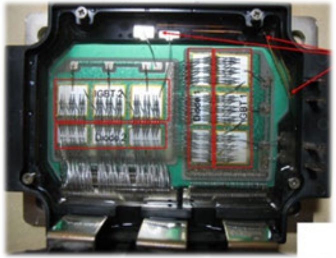




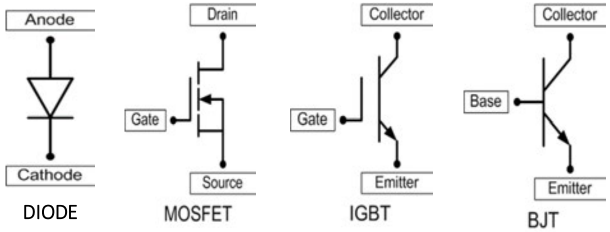
On-wafer High Power Test

- Industry Needs
  - Material Characterization: SiC, GaN, Si, and SOI versions
  - Device Characterization: on-wafer accuracy (SiC, GaN, Si)
  - Reliability tests - higher operating V / I, higher temps
  - Commercial: reduce Cost Of Test (pkg to wafer)
  - Production prober for “Specialty high perf. devices”



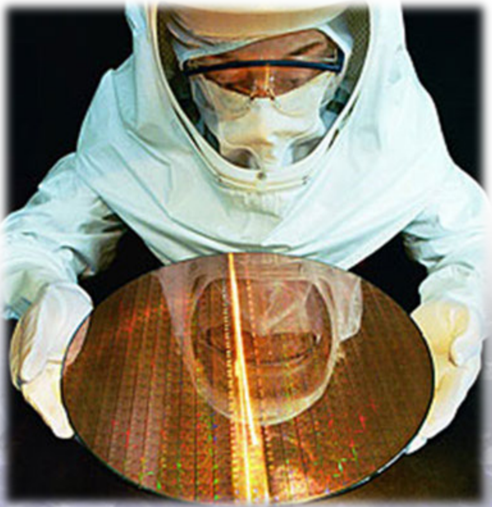


- Key on-wafer Measurement Needs
  - Accurate/consistent Rds data on Single / Volume wafers
  - Full temperature support -55….+300/400oC
  - Voltages up to 10kV DC, Currents up to 600A
  - Support for engineering probes AND probe cards
  - Easy setup for lateral and vertical devices
  - Safe thin wafer autoloading
  - Low Inductance for dynamic power tests



Wafer-Level Test Challenges

- Safety for operator and system
- System isolation for high voltage applications
- Low resistance contacts and path for high current applications (chuck & probe tips)
- High-voltage arcing
- Thin-wafer handling
- Integration of different measurement instruments with emphasis on measurement accuracy and safety requirements
- High temperatures
- Low inductance for high switching speeds



TESLA200

Power Semiconductor Probing System

Up to 10kV / 600A with thin-wafer loading

Accurate Rds(on) with constant Rc at ALL temperatures with Contact Intelligence

Anti-arcing solutions for wafer and probes

Modular Semi /Full-auto upgradeable

New high performance eVue 4 Digital imaging system, and programmable microscope travel increase die-to-die test speed

TUV certified high power safety enclosure

Integrated High Thermal Stability (HTS) for enhanced probe contact

Next generation MicroChamber and easy access Top-hat covers

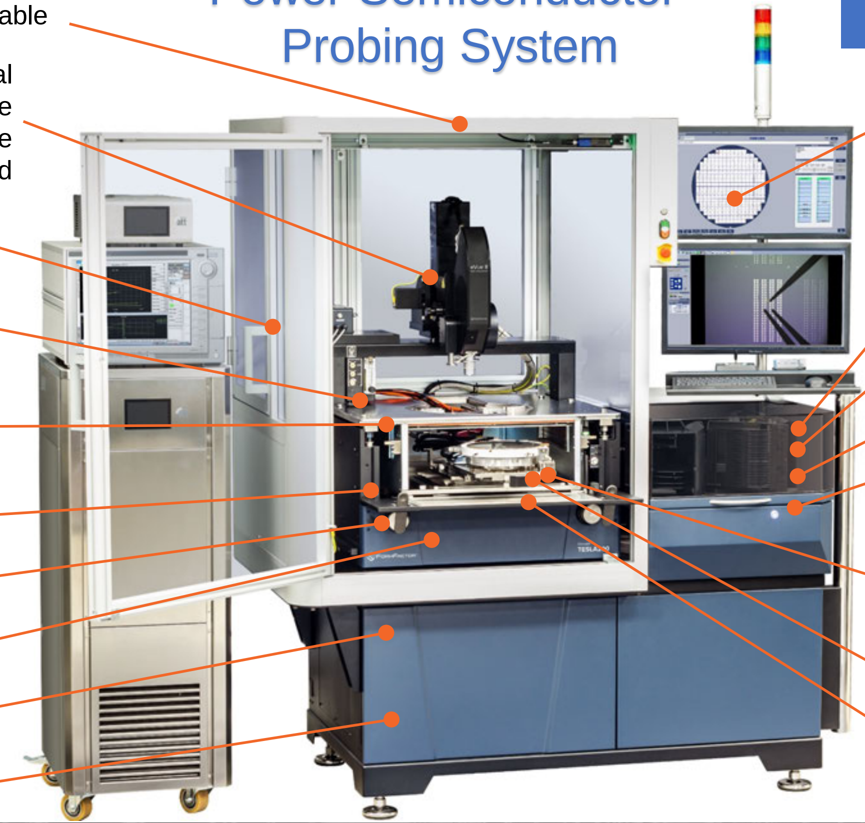
Easy MicroChamber / wafer access

Multi-speed manual XY controls

Precision wafer stage – 2x faster

Integrated vibration isolation & system electronics

Small footprint



New Velox software with easy operation "Guided mode" (version 2.3)

Auto Wafer loader (4,6,8") enables testing 50 wafers with 2nd Cassette

Thin/warped wafer handling (50um) with top-lift end effector

Automated probe cleaning

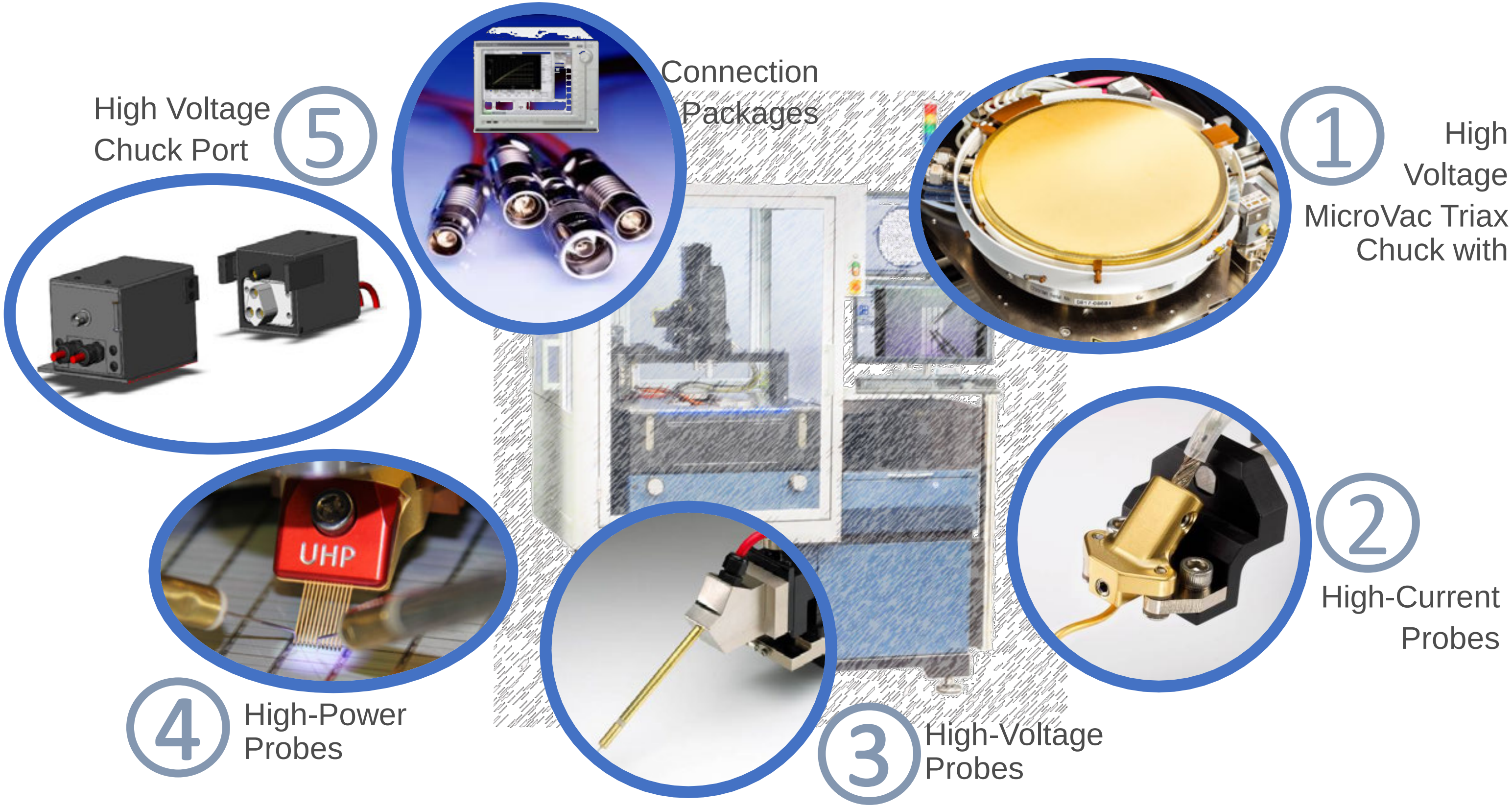
Wafer Quick Access Port for increased throughput

Patented TESLA Chuck Technologies
- FemtoGuard Triax
- Coax, and High Current
- 3kV low cost versions
- Wide temp -55..+300oC

Specialty chucks for +400oC, and low inductance/Cap(res) for UIS

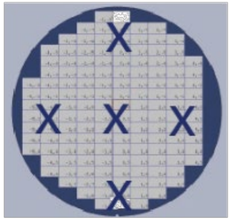
New manual hot wafer unload/load

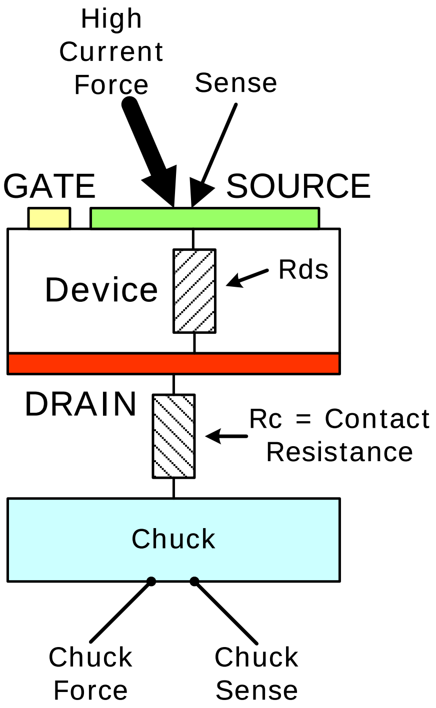
TESLA Probing System Solutions



Probing Challenge: Measuring Rds(on) for Vertical Devices

- Need high-current pulse on the source/drain
- Need Kelvin measurement capability
- Backside drain/source require minimal contact resistance (Rc) between the wafer and chuck for accurate Rds(on) measurement
- Need wafer Rc uniformity for accurate device statistical data

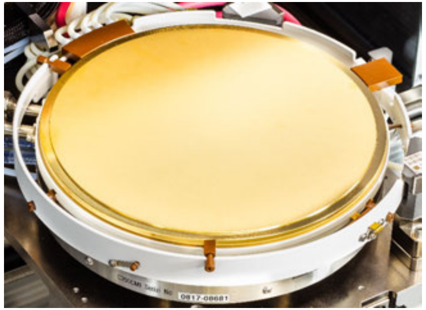




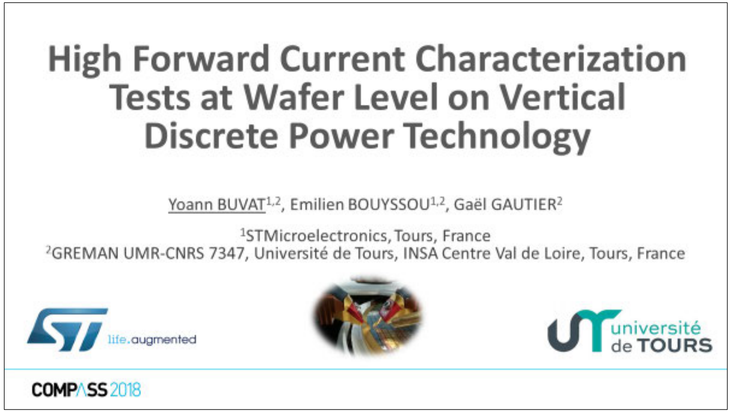
Low Resistance wafer contact (Rc)

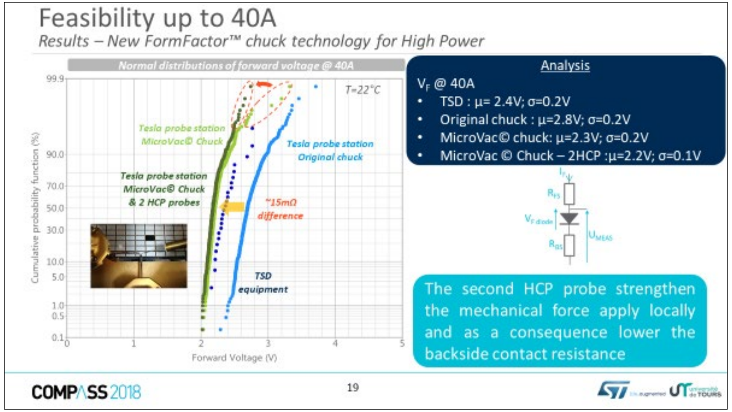
- Tesla chucks with MicroVac
  - Patented technology
  - 2nd generation version for thinned wafers
  - Stronger vacuum system for uniform wafer "hold down"
  - Uniform low contact resistance
  - BENEFIT: More accurate test data

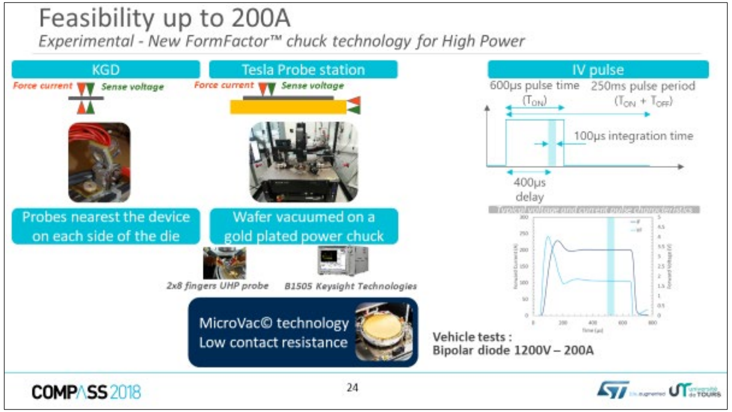
TESLA	MicroVac Triax chucks	2nd Gen. MicroVac Triax chucks
Chuck Surface	Flat	Flat
Plating	Gold (Au)	Gold (Au)
Vacuum System	Standard	Next Generation
Vac. holes	495	495
Hole size	400um	200um
Supply channel	Standard	Flow optimized
Tyco support	Yes	Yes
Tyco vacuum	Reduced	Full

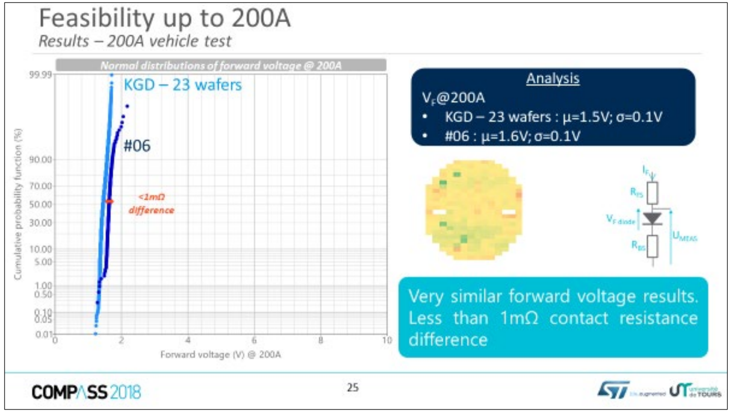


Case Study: Package vs On-wafer + low Rc wafer chuck

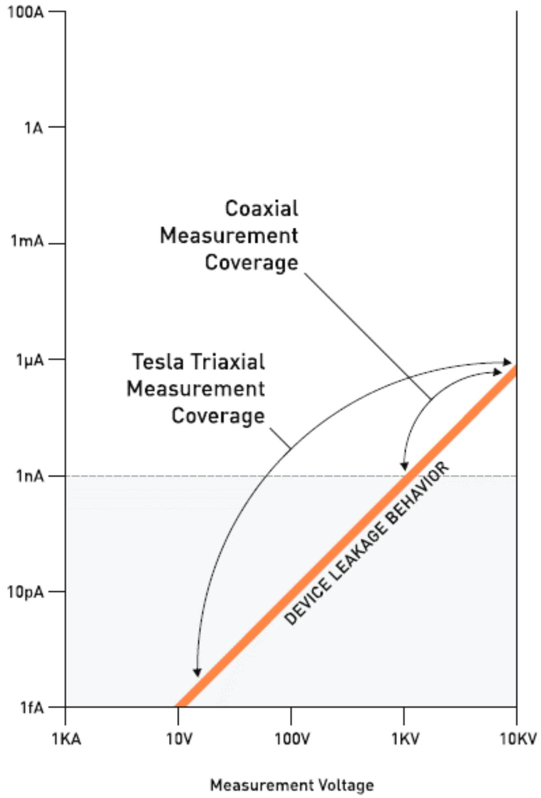








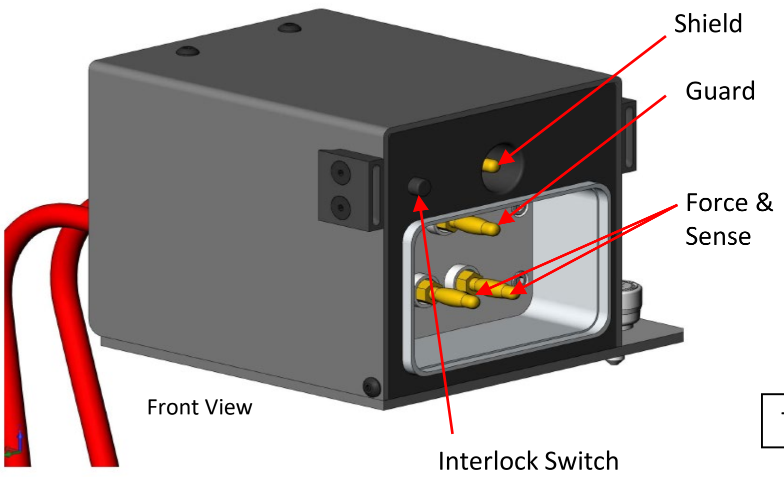
Probing Challenge: Low Leakage Measurements at HV

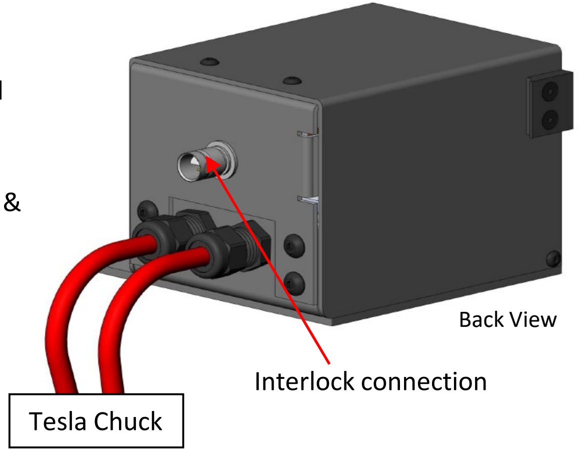


Situation	**Engineers need to understand device leakage current behavior at high voltages.**
Solution	**TESLA200 provides a patented High Power triaxial chuck system for measuring leakage levels as low as 10fA.**
Benefits	**Helps engineers understand their devices leakage behavior for currents under the 10 pA range and to increase the application value of their devices**

High-Voltage Chuck Port **(Patent Pending)**

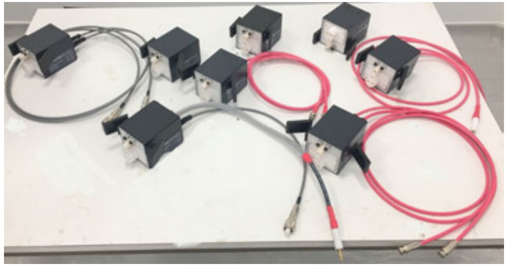
- Chuck side connector:
  - 3 kV Triax, 10 kV Coax
  - Force and Sense connection, Femto Amp leakage
  - direct connection to service loop, sits on bridge, easily accessible
  - Interlock connection of safety

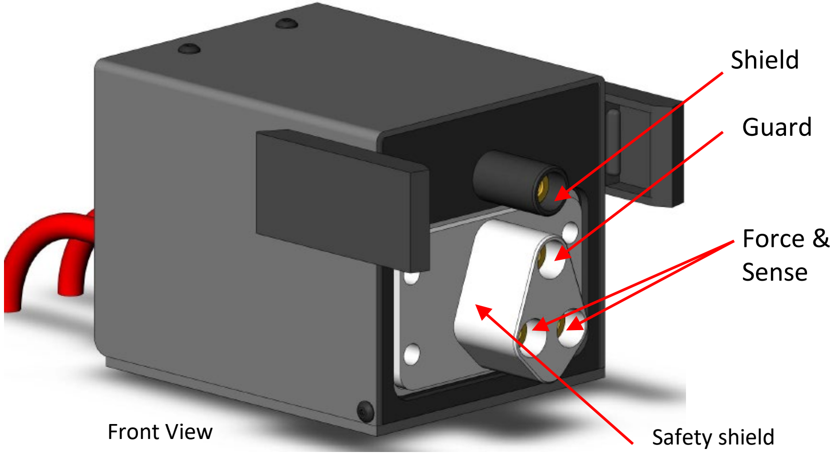




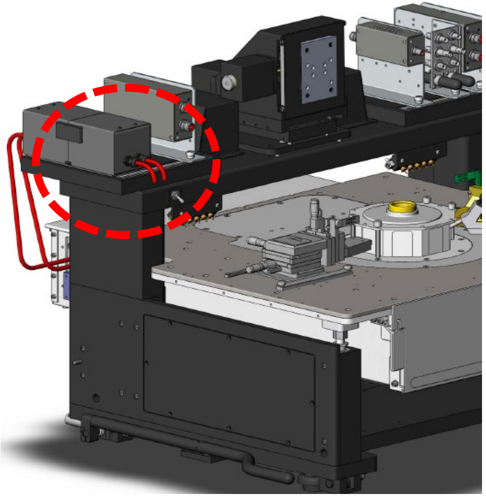
High-Voltage Chuck Connection Cable

- Instrument side connector:
    - 3 kV Triax , 10 kV Coax (max), voltage rating depends on end connector
    - Force and Sense connection
    - Available end connector: HV Triax, Std Triax, CMI Triax, BNC, Banana, SHV
    - Shorting and Floating plugs
    - Interlock connection of safety



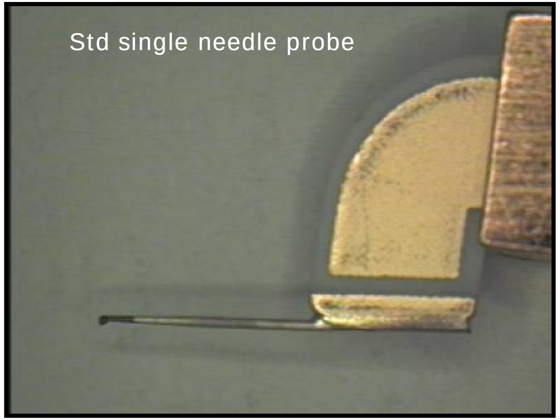


Front View



Probing Challenge: Probe/Pad Burnout @ High-current

- Catastrophic damage on both the probe and pad
- Device/Pad could heating at the tip due to probe contact resistance at high-current measurement



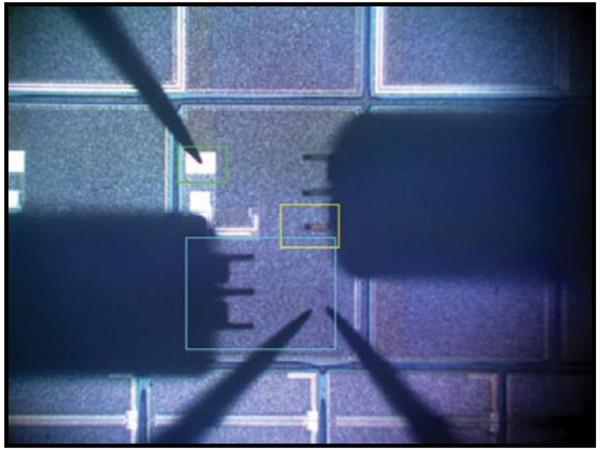
$$Id^2 \times (Rds + Rc) = \text{Total Device Heating}$$

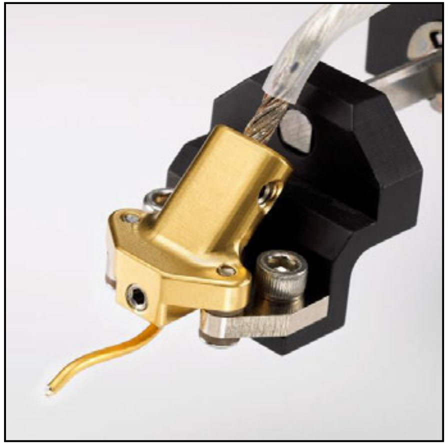
Thermal runaway

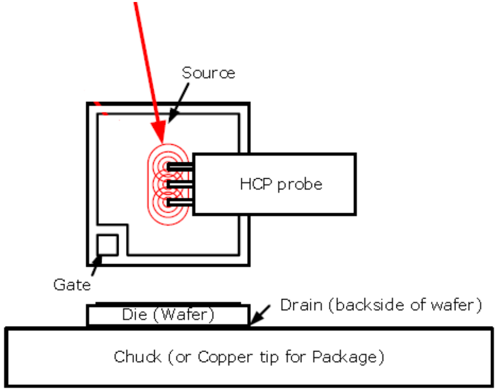
Heat at probe tip → Tip temp increase → Tip R increase → Heat energy increase

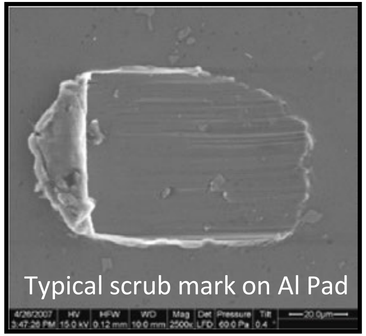
Solution: Reduce probe contact resistance

- Tesla's HCP high current Probe
- Novel Multi-finger design
  - Reduced contact resistance
  - Good distribution of current
  - Minimal pad damage
  - Emulate Multiple bond wires







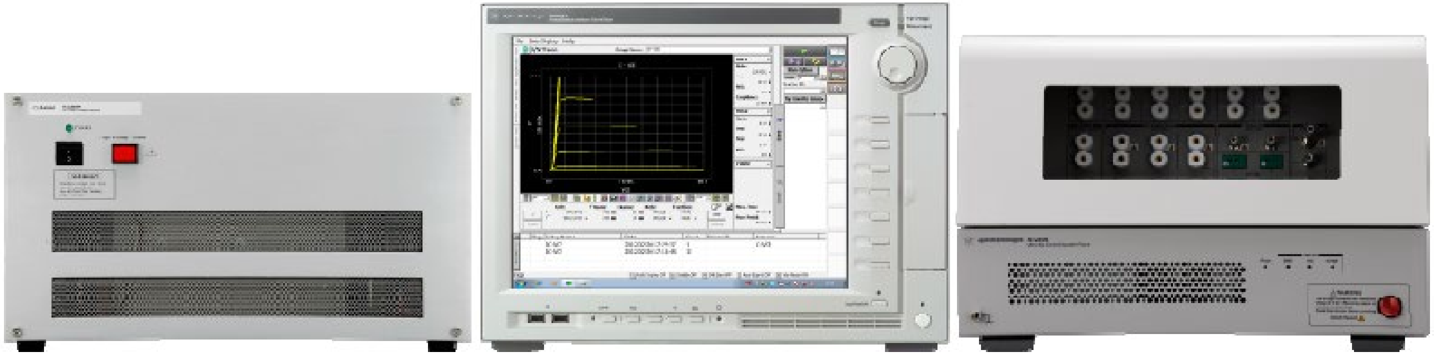


Typical scrub mark on Al Pad

- Suitable for all pad material (tungsten tips)
- Replaceable Probe Tips
- Up to 10A DC/60A Pulsed (1ms)

Probing Challenge: Utilizing test equipment on-wafer

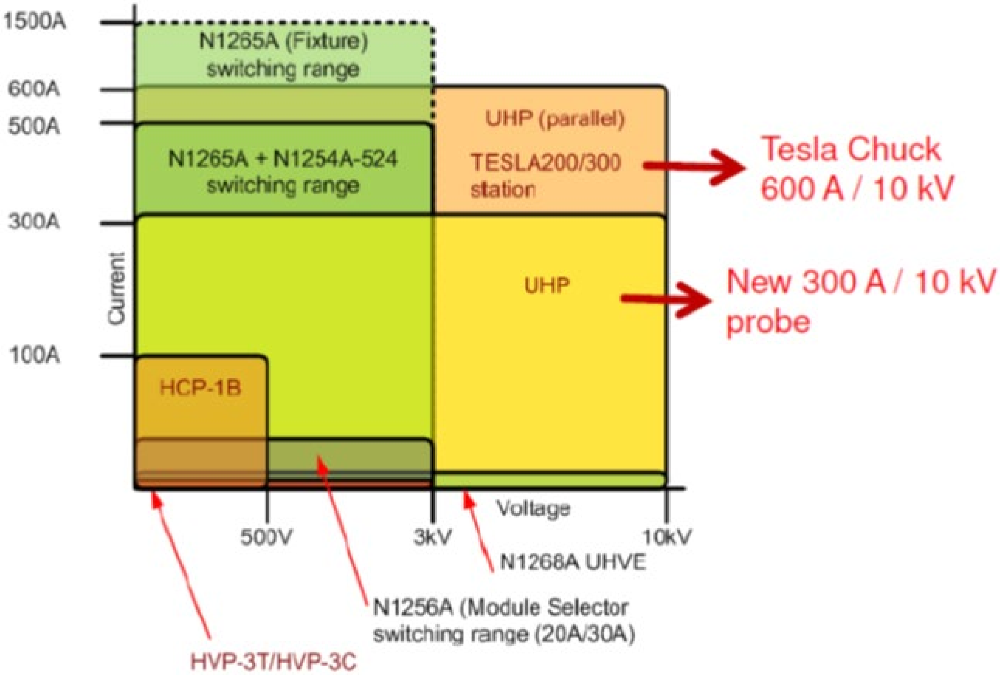
- Ultra High Voltage / Current
  - Keysight B1505A Power Device Analyzer 3KV/40A
  - Keysight N1265A UHC Expander/Fixture 600A*
  - Keysight N1268A UHV Expander 10KV
  - Requires N1254A-524 (Prober Interface)

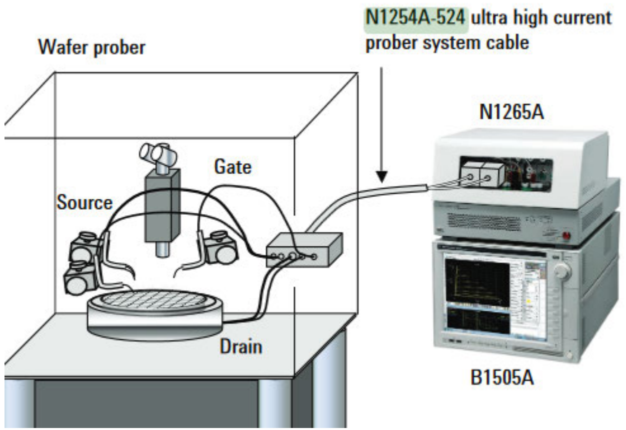


UHVE N1268A   B1505A   UHCE N1265A

Extended Current Capabilities

- Complete Probe Solutions covering entire 10kV / 600A measurement range

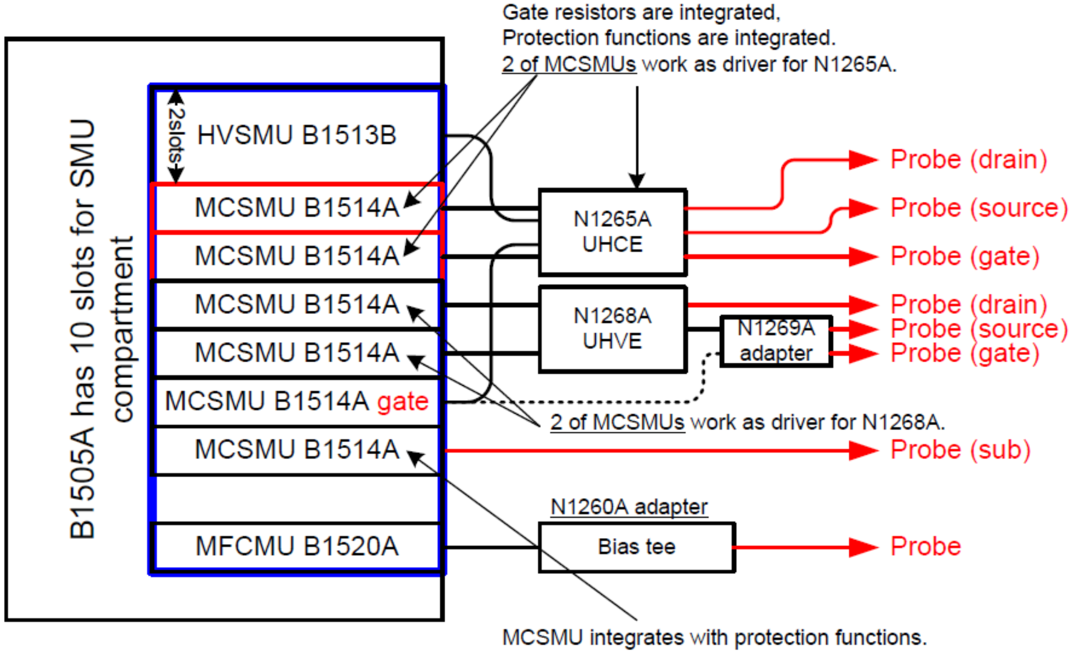


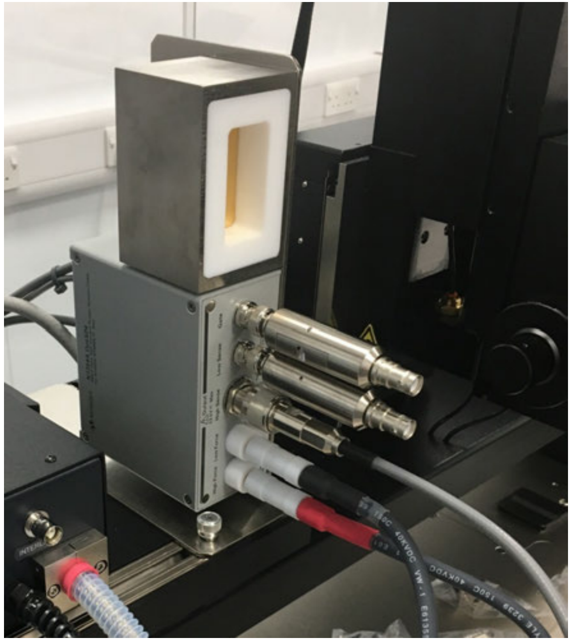


Extended Current Capabilities / Integration

B1505A Gen2 UHCE/UHVE

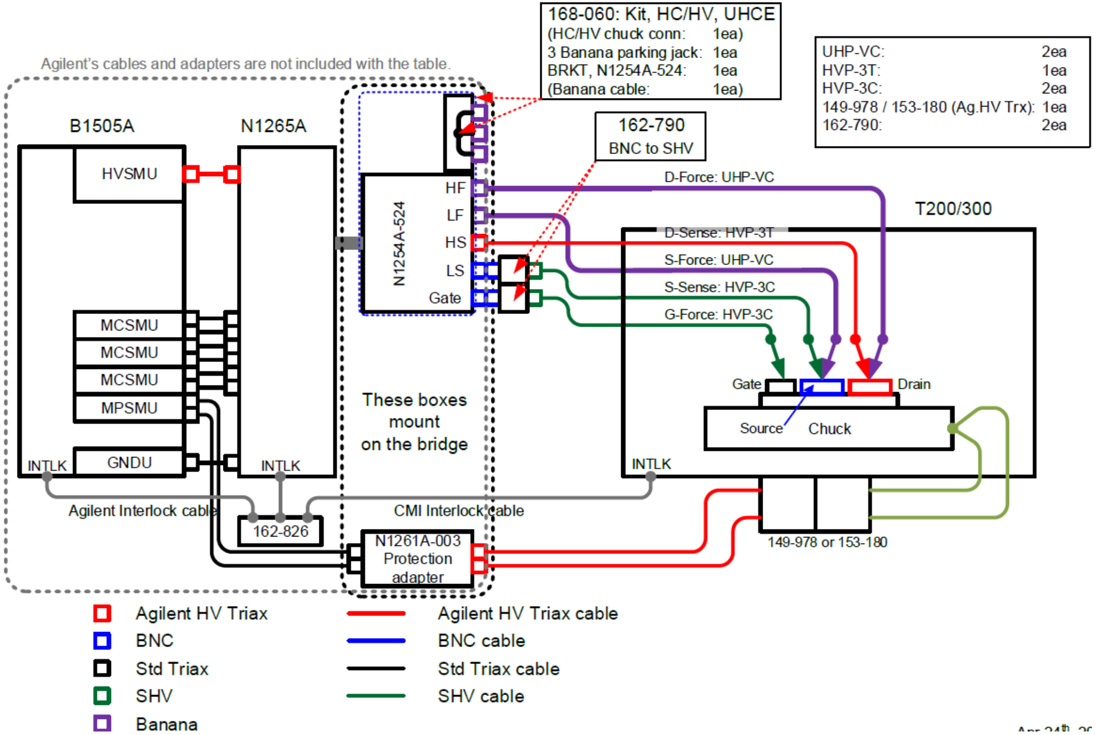
- N1265A UHCE and N1268A UHVE are optional





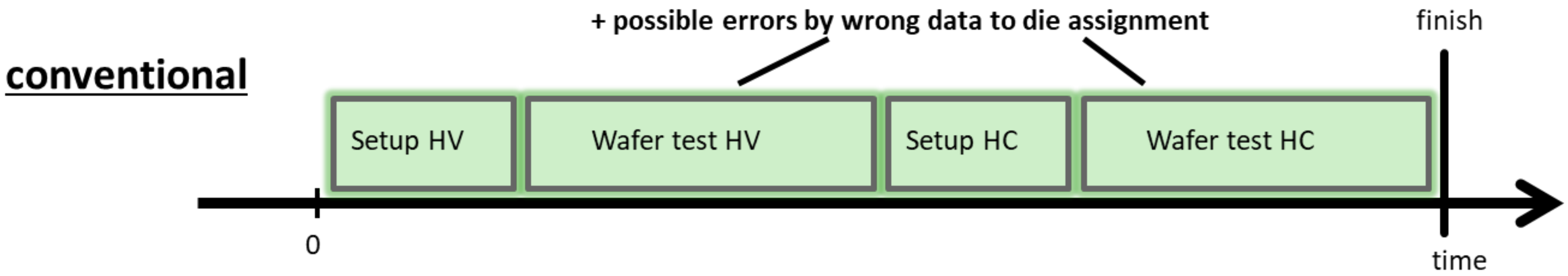
3KV, 300A Lateral Connection diagram

3kV, 300A Automated measurement with N1265A UHCE
for T-200/300 Lateral device



Probing Challenge: Increase HC/HV test throughput

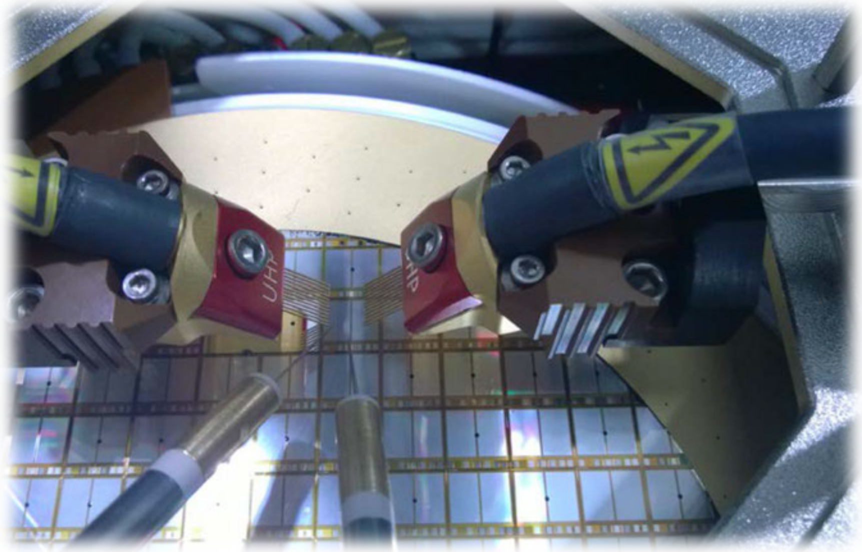
- Reduce test time to measure both high voltage and high current on the same device
- Reduce setup time (HV & HC)
- Reduce time / errors with potential die mismatching



Solution: UHP Probe

A single probe to use in both high-voltage and high-current applications – no need to change probes and measurement setups

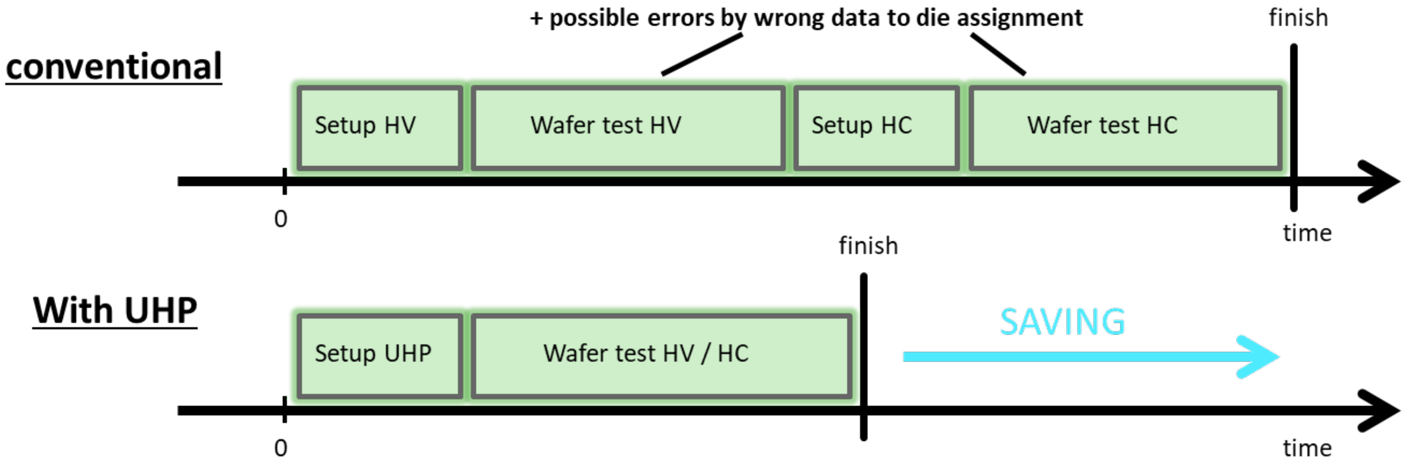
- Up to 300 A per probe (thus 600 A by a pair) or 10 KV on one probe
- Minimal damage to the wafer due to probing
- High-current testing needs high probe forces to reduce contact resistance
- Special tip shape, pad penetration is minimal



Solution: UHP Probe

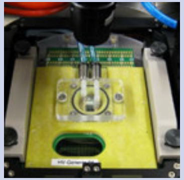
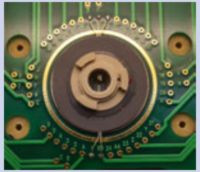
Higher test throughput via <u>reduced testing time</u>

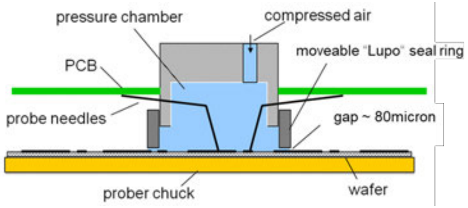
- Up to 100% throughput improvement when reducing two wafer runs to one
- Additional savings by one setup only



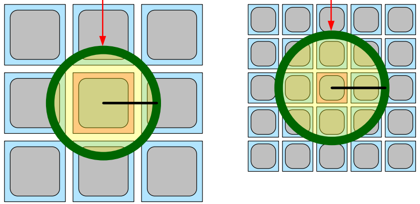
Probing Challenge: Using HV Probe cards without arcing

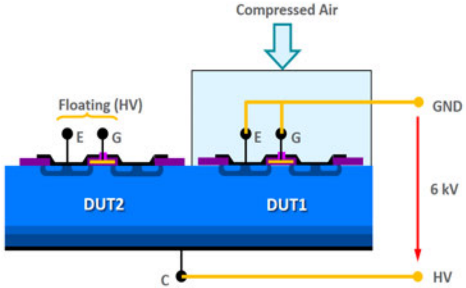
- Solution with TESLA200 and T.I.P.S HV probecards

T.I.P.S. Probe Cards	Non-thermal	Engineering High Temp	Production High Temp
Max Voltage	10,000V	10,000V	10,000V
Max temperature	85°C	200°C	150°C
Anti-arcing pressure chamber	Yes	Yes	Yes
Air seal to wafer	Hovering (~80um gap)	Contacting	Hovering (~80um gap)
			



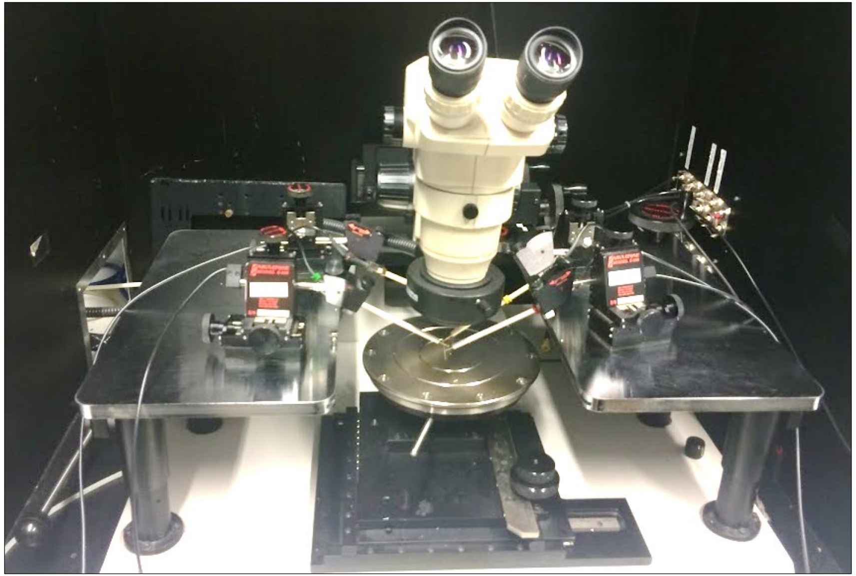
Pressurized chamber with one needle



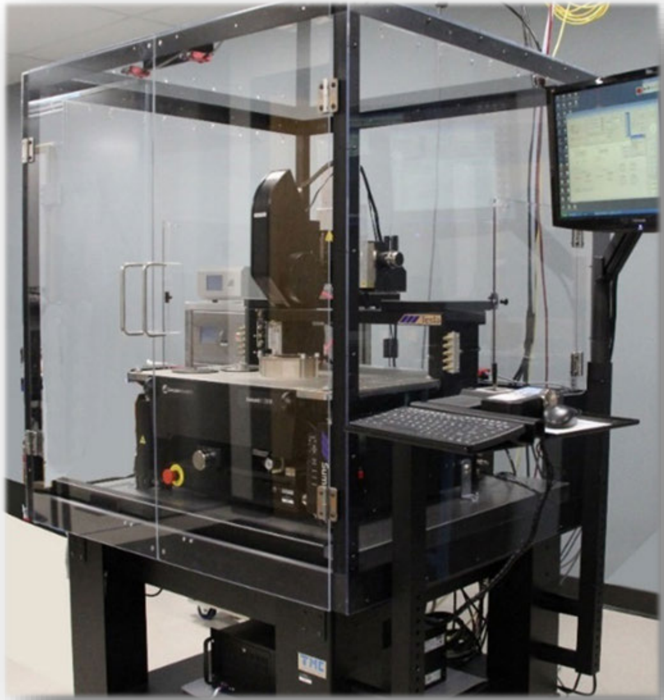


Cambridge University Case Study – Before

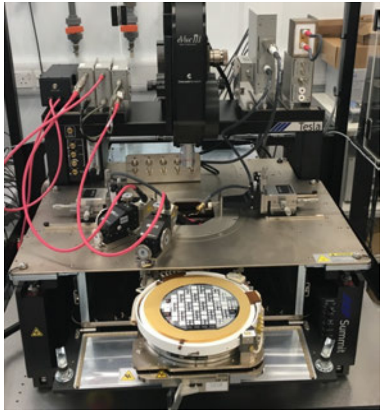
- No thermal capability
- Upper voltage limited by safety concerns
- No ability to measure substrate currents accurately
- Upper current capability limited by probe and station service loop
- Not possible to switch from High voltage low current to High current low voltage for Current Collapse measurements
- Manual



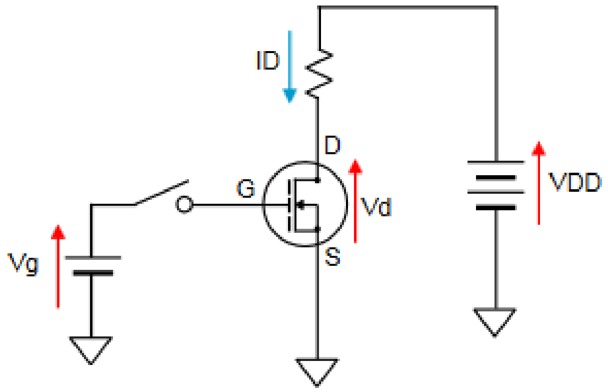
Cambridge Case Study – After

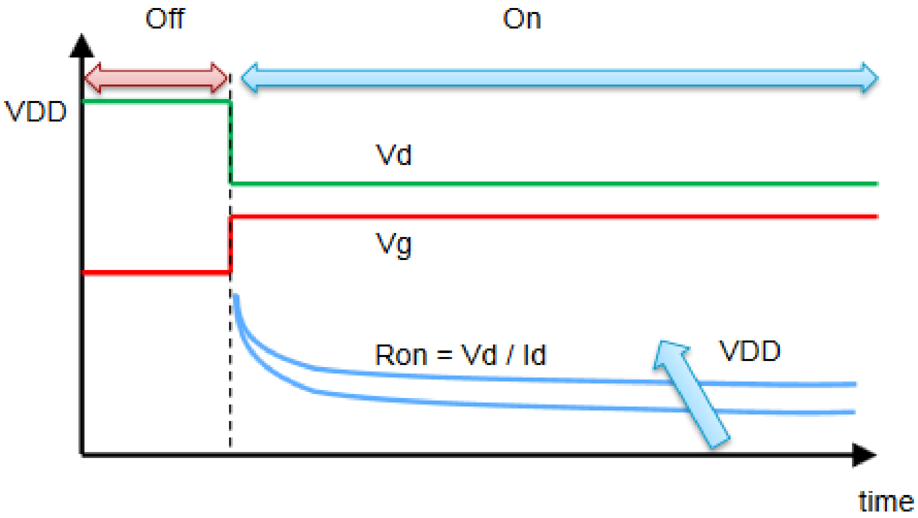


- Implementation with B1505, UHCE and UHVE allows automatically switched testing for high voltage and high current setups
- Chuck currents can be accurately resolved
- Safe and easily accessible system
- 10KV capability
- Current collapse for GaN devices
- Semi automatic for rapid data collection



Current collapse measurements

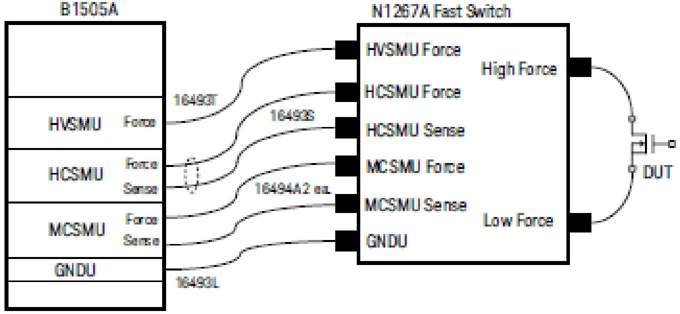




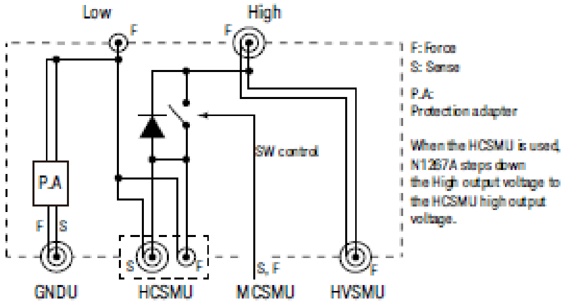
- In some devices, the on state Ron resistance is degraded, after a high voltage Vdd has been applied in the 'off' state
- Device recovers to expected values, but takes time after going into on state
- Measuring this transition is of interest

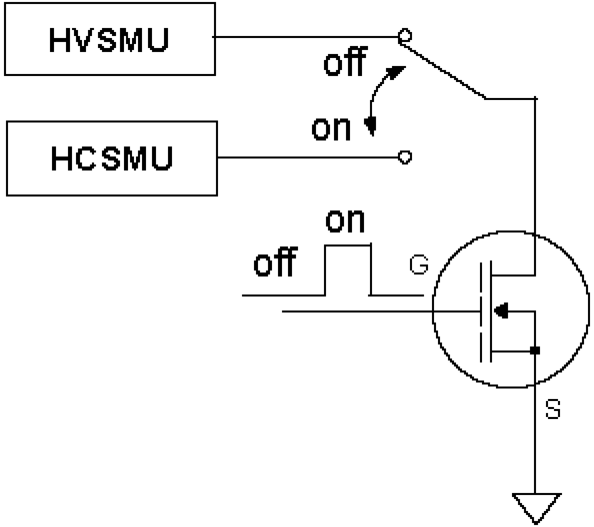
N1267A Fast Switch – Current Collapse Measurements

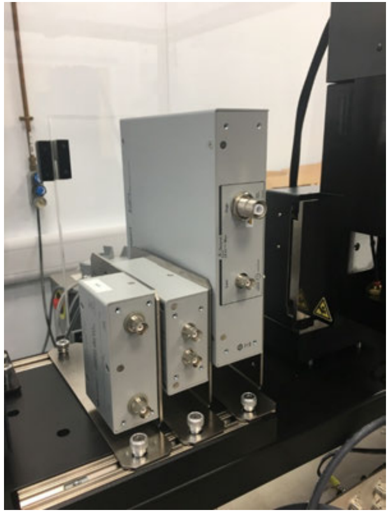
To Connect HVSMU/HCSMU Fast Switch



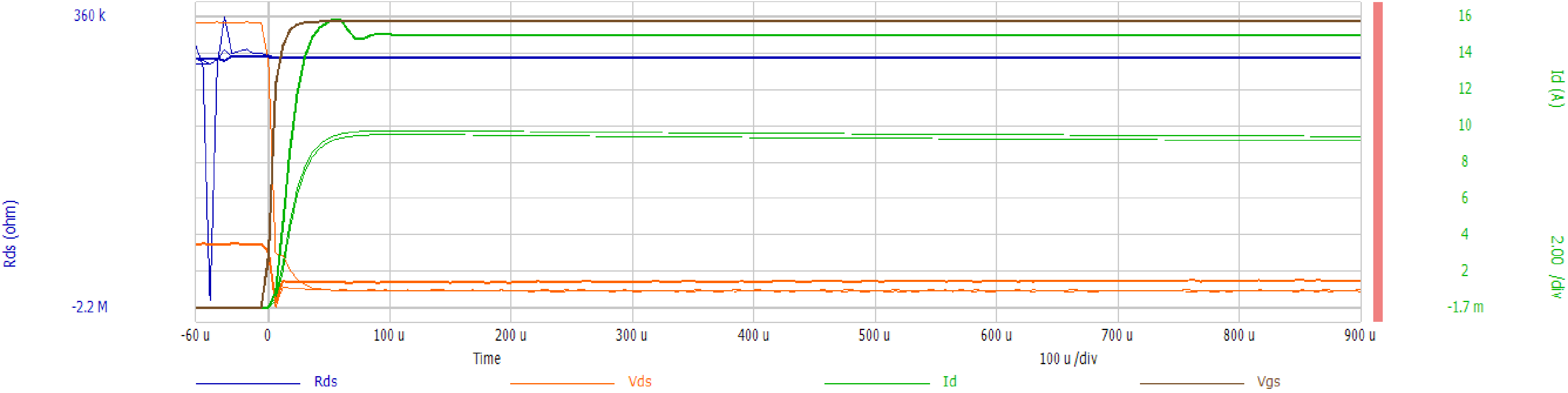
N1267A Simplified Internal Connections





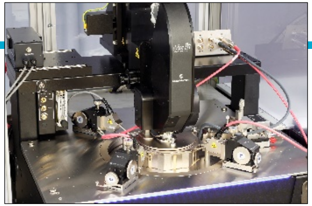


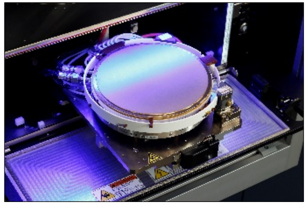
Current collapse measurements

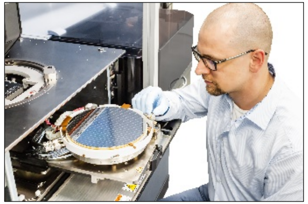


Summary

- Applications using Power Semiconductors see continual strong growth
- GaN and SiC devices enable increased performance over Si
- On-wafer testing of GaN & SiC devices have additional challenges for
  - Higher Voltage / Current
  - High temperature
  - Switching speed
- TESLA200 provides complete solution
  - for high power GaN, SiC, & Si device testing @ temperature
  - with seamless integration with UHV / UHC implementations from Keysight
  - and safe, accurate, device data collection







COMPASS

a FormFactor users' group conference

Thank You