Silicon Carbide Thermal Transient Measurement and Reliability testing

Where today meets tomorrow.

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Simcenter T3Ster Technology

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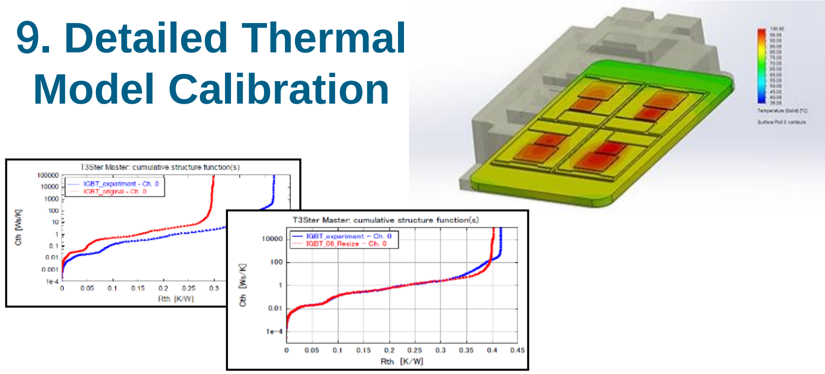
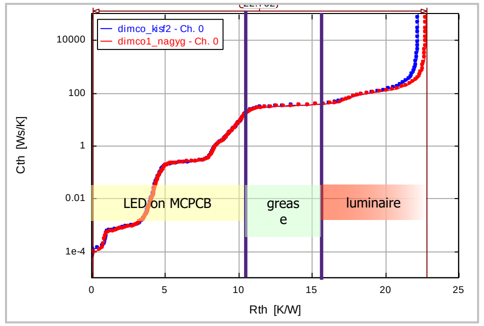
Key Simcenter T3STER Strengths

9. Detailed Thermal Model Calibration

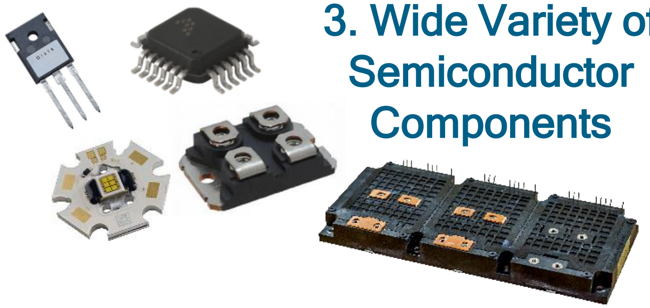


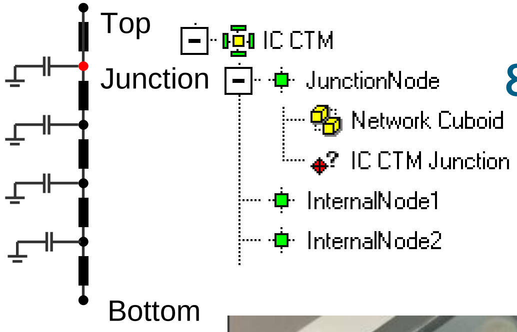
1. Simple & Easy

2. Repeatable & Reproducible

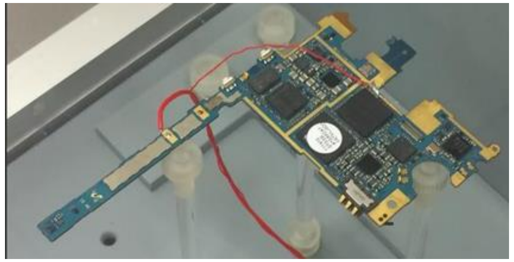


3. Wide Variety of Semiconductor Components

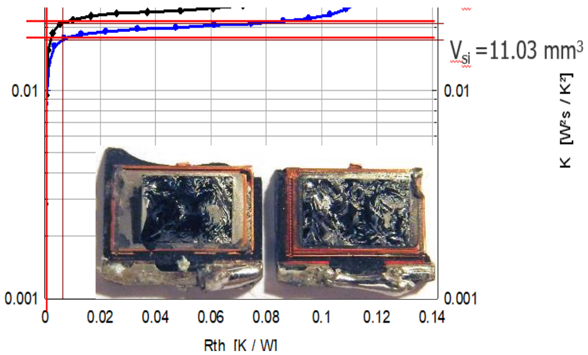




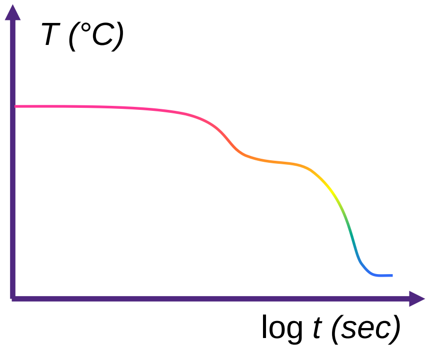
8. Test-Based Compact Thermal Models



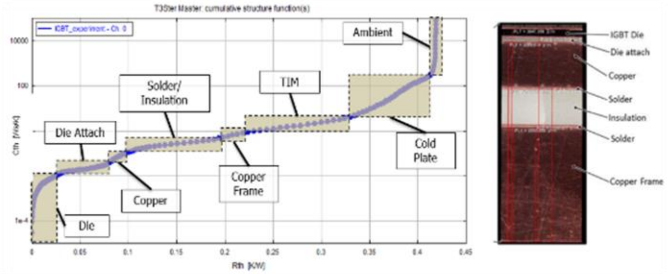
7. Tests Components in Situ



6. Non-Destructive



5. Fast Throughput (non-Repetitive)



4. Insight into Thermal Structure

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Simcenter Testing Portfolio

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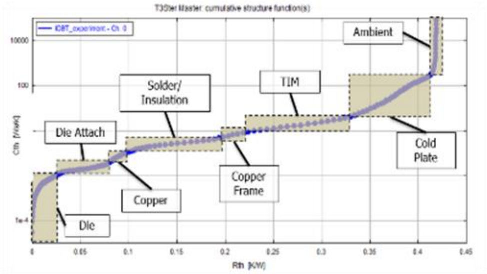
MicReD Products list and Major Milestones

R&D | Production

Startup years, Introduction of T3Ster

T3Ster Thermal Transient Tester



T3Ster-Master Structure Functions

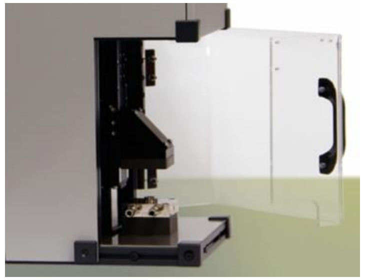
Early 2000

Flomerics Acqusition TeraLED (LED Tester)

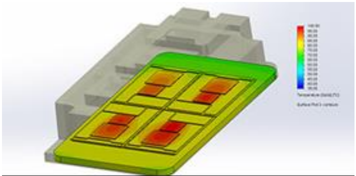
TeraLED

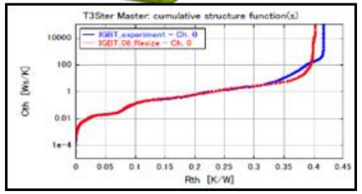
2005

Thermal Interface Materials (TIM) testing



DynTIM





CFD model calibration

2010-2011

POWERTESTER Family (Power cycling of power semiconductors)

PWT (600A, 1500A, 1800A, 2400A, 3600A)
Standard and custom

2014

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2017

New Generation T3Ster

T3Ster SI

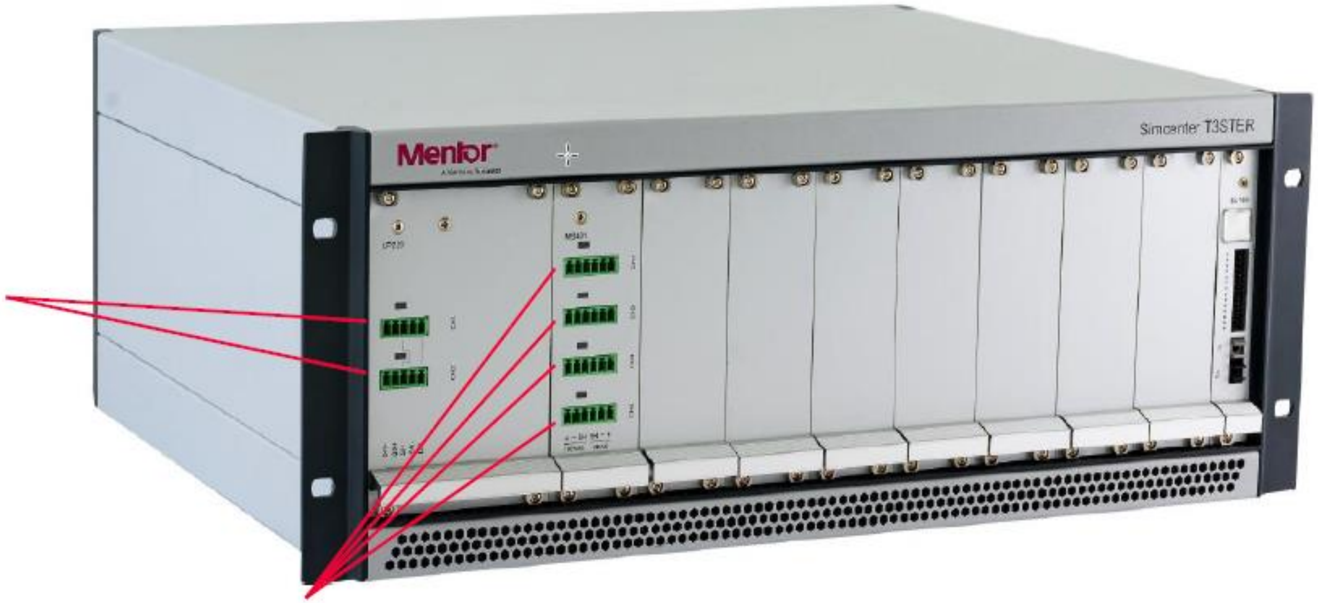
For Production Floor

Quality Tester (Detection of defects)

Today and Beyond

Thermal Transient Tester – Simcenter T3STER SI

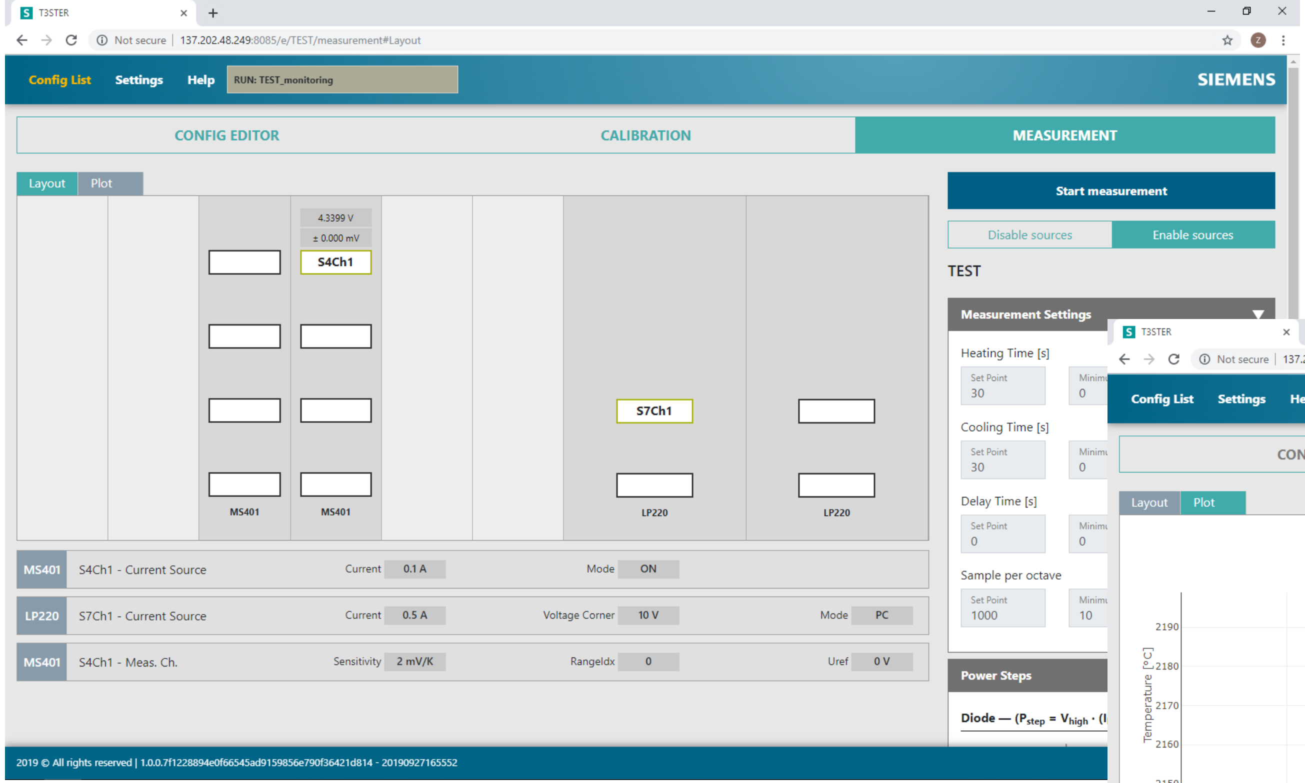
Powering unit:
- 20W combined output power
- User programmable:
  - 2A/10V, 1A/20V, 0.5A/40V
- Up to 10 channels can be installed
- Configurable as voltage source
  - Floating gate driver

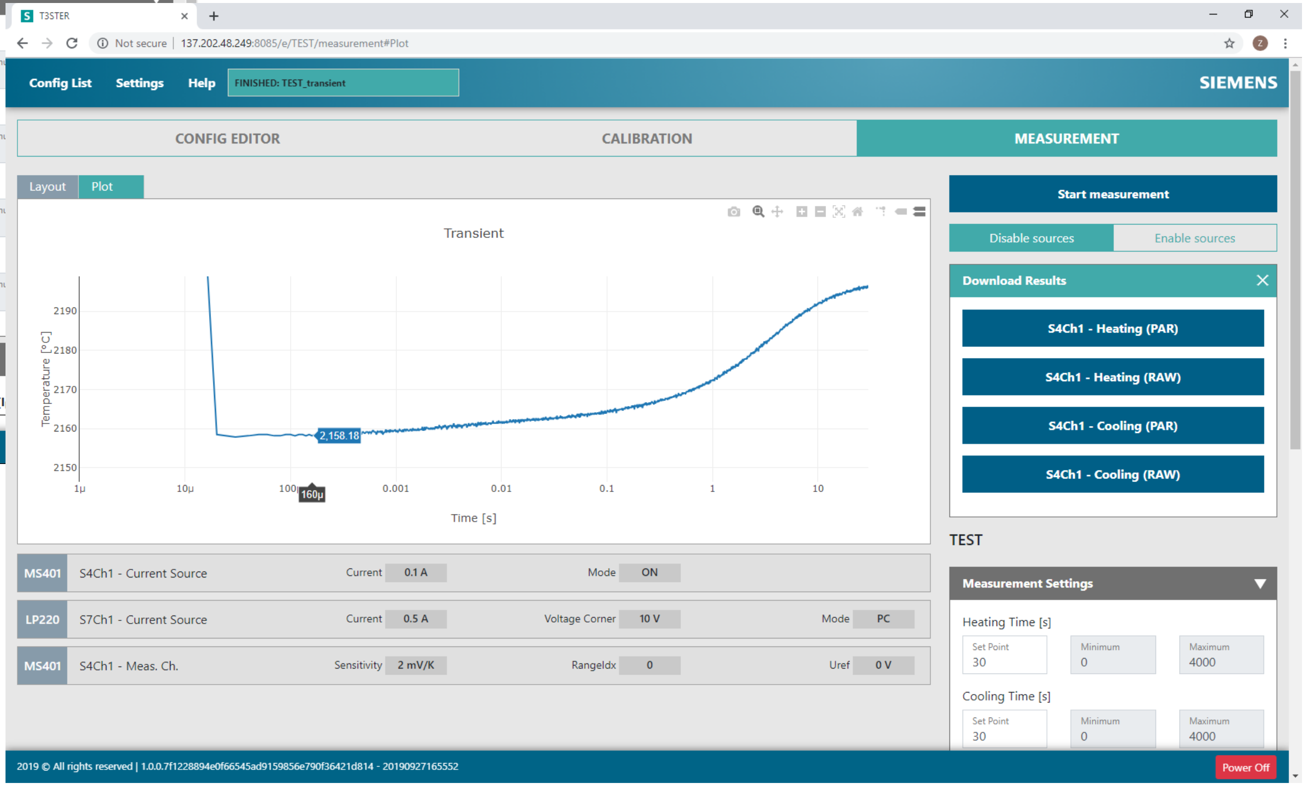


Transient voltage measurement channels:
- Include floating sense current sources
- 18bit, 0.002°C, 1MSample/s
- Up to 40 channels can be installed

*Front panel appearance and features dependent on chosen configuration.

Improved usability - Software





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Introduction to WBG Semiconductors

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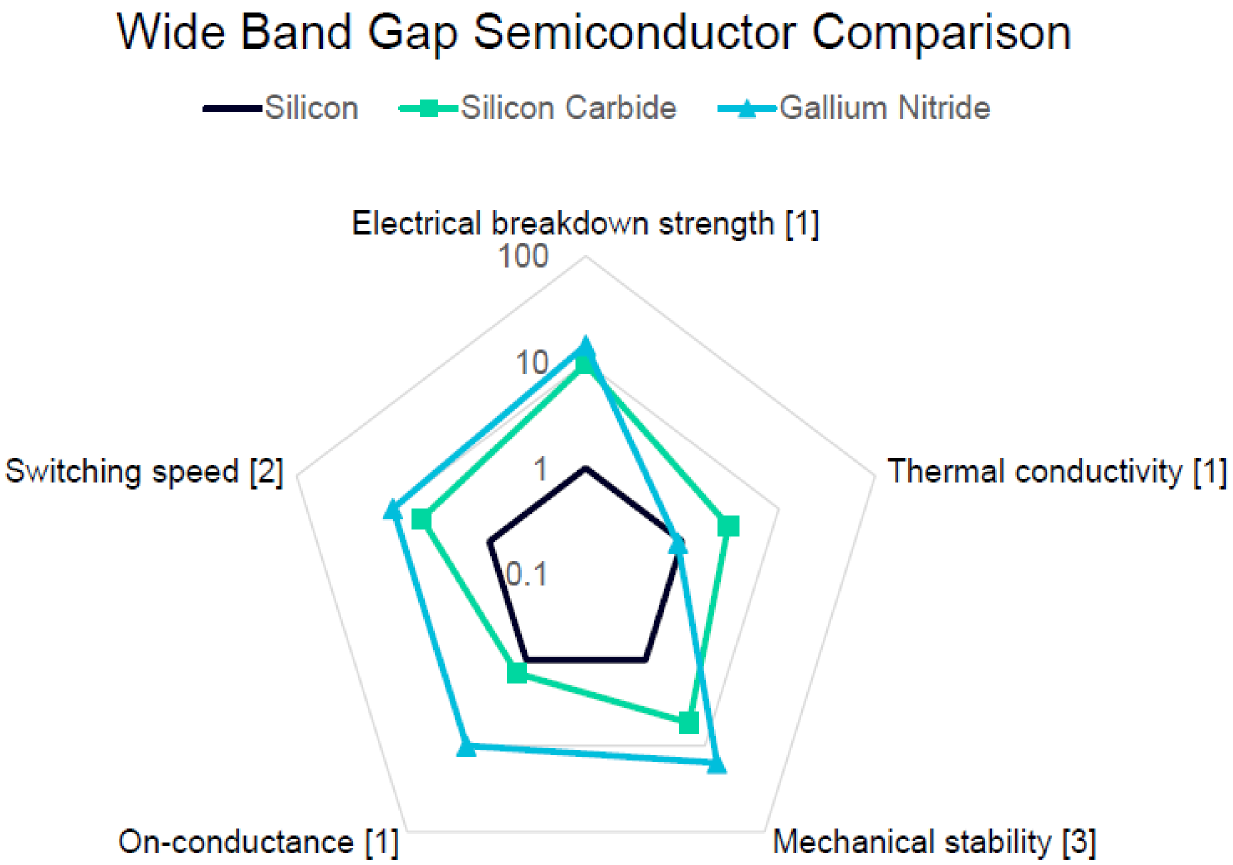
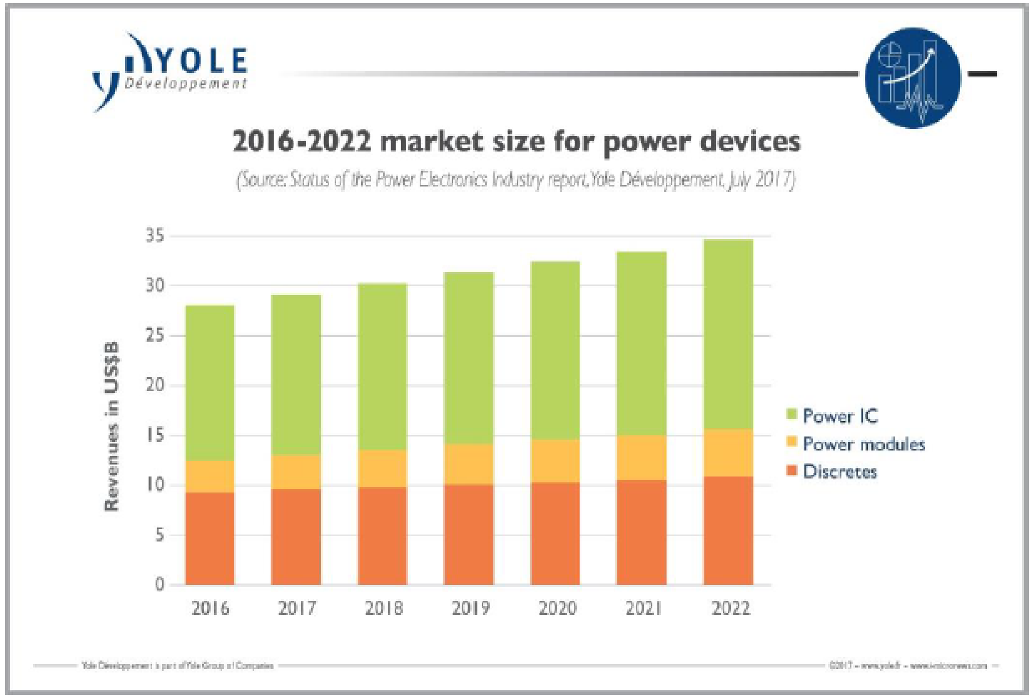
WBG Semiconductors



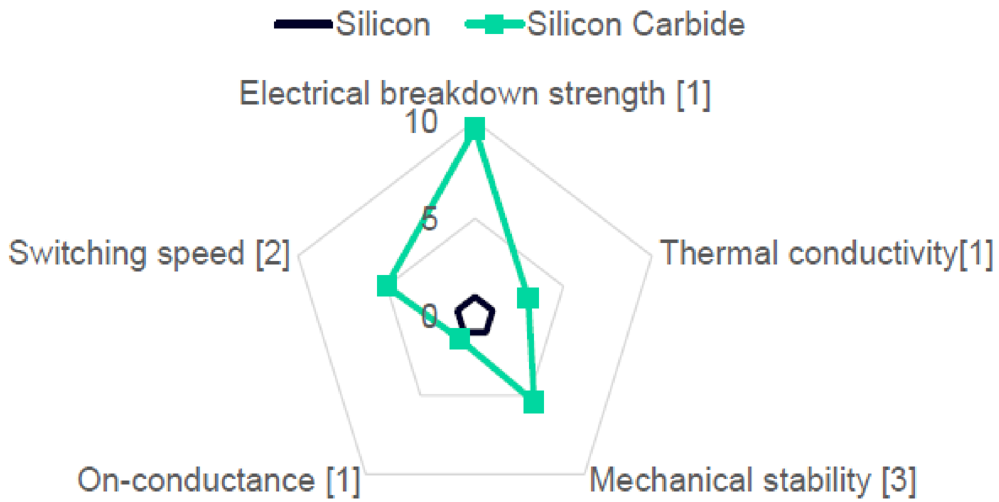


1 Comparison Between Competing Requirements of GaN and SiC Family of Power Switching Devices", Yuanhang Zhang et. al, 2020, doi:10.1088/1757-899X/738/1/012004
2 The Difference Between GaN and SiC Transistors, ON Semiconductors, 03, 2020, https://www.onsemi.cn/pub/Collateral/TND6299-D.PDF
3 Group III nitride and SiC based MEMS and NEMS: Materials properties, technology and applications, V. Cimalla et. al., October 2007, Journal of Physics D Applied Physics 40(20):6386-6434, doi: 10.1088/0022-3727/40/20/S19

SiC MOSFET Advantages

Silicon Carbide (SiC) based devices offer advantageous electrical and thermal properties for power electronics especially automotive electrification e.g EV/HEV power electronics modules

- wide band-gap, high breakdown voltage, and high thermal conductivity
- higher efficiency, lower dissipation, smaller overall system size, and the opportunity for higher temperature operation

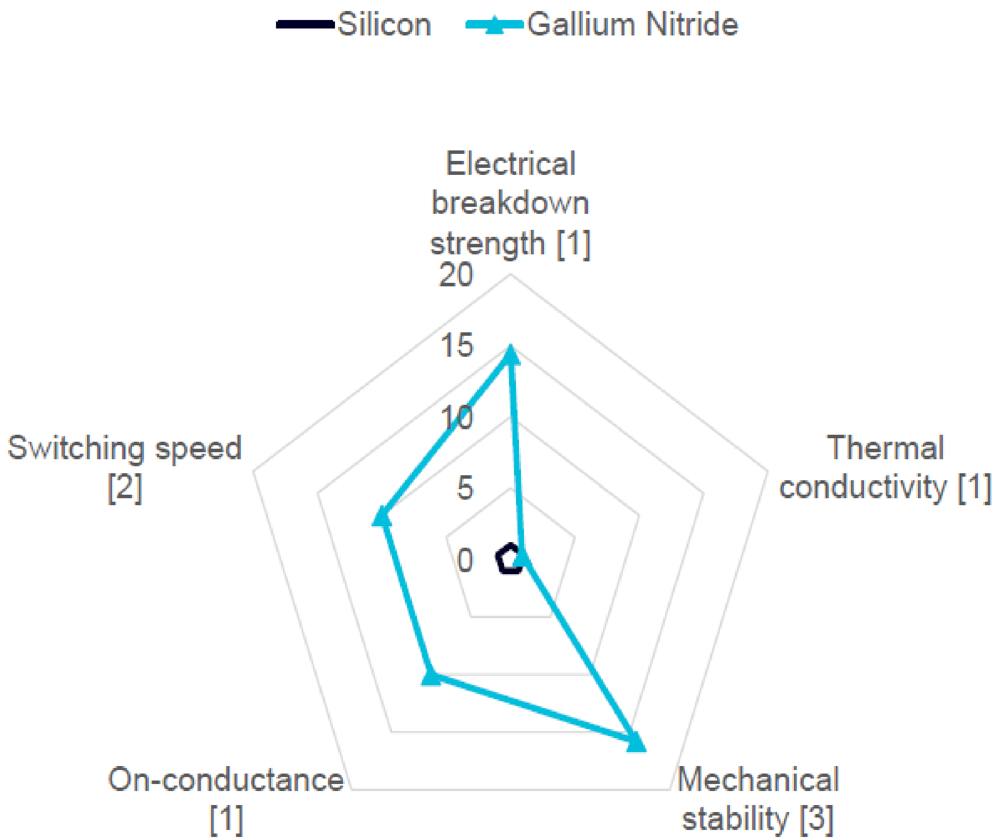


GaN Advantages and Challenges

In contrast to SiC, Gallium Nitride (GaN) shows advantages in most, but not all properties revelant for power electronics in the automotive industry:

- wide band-gap, high breakdown voltage, high mechanical stability and excellently low $R_{ds,on}$ but

- higher thermal resistance and normally-on behavior



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WBG Semiconductor Thermal Characterization Methods

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Traditional Thermal Transient Measurement Modes for Si

MOS diode (Threshold mode) – current step method

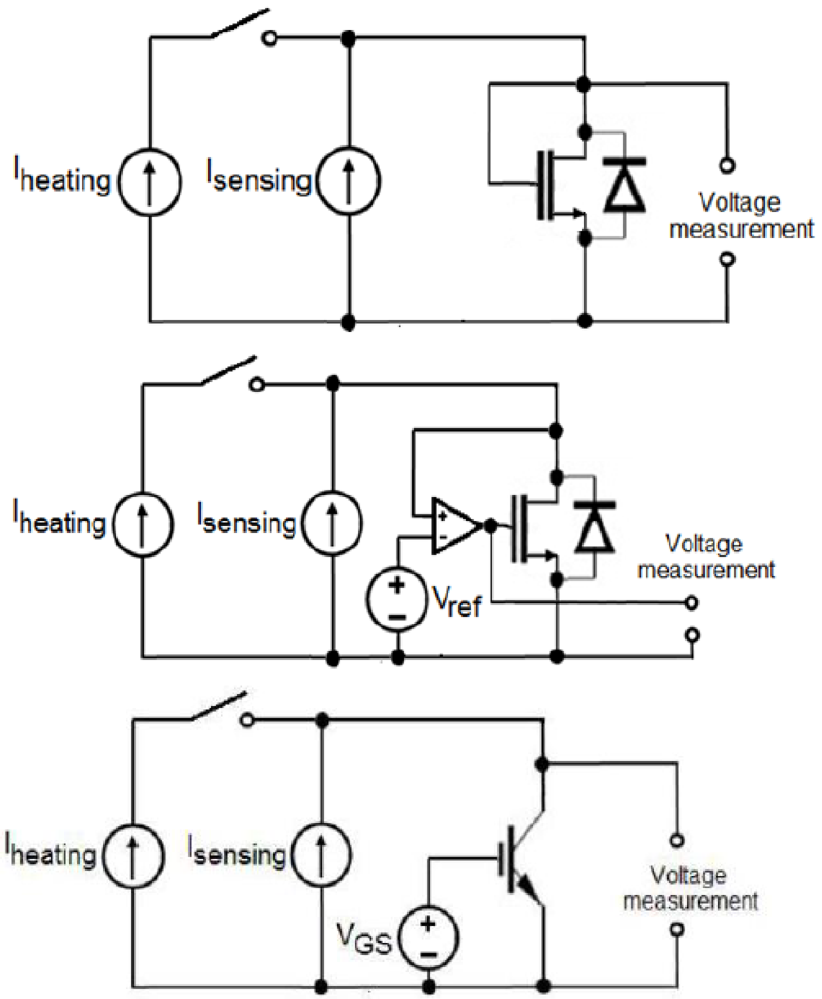
- Gate connected to the Drain
- The threshold voltage can be higher than 5V

Fixed VDS mode

- Gate voltage is regulated ➔ $R_{ds,on}$ is kept constant
- The TSP is the V_{GS} Voltage as it changes in order to keep the V_{DS} constant
- The circuit is less sensitive to the oscillation, but the appropriate compensation still needs to be selected

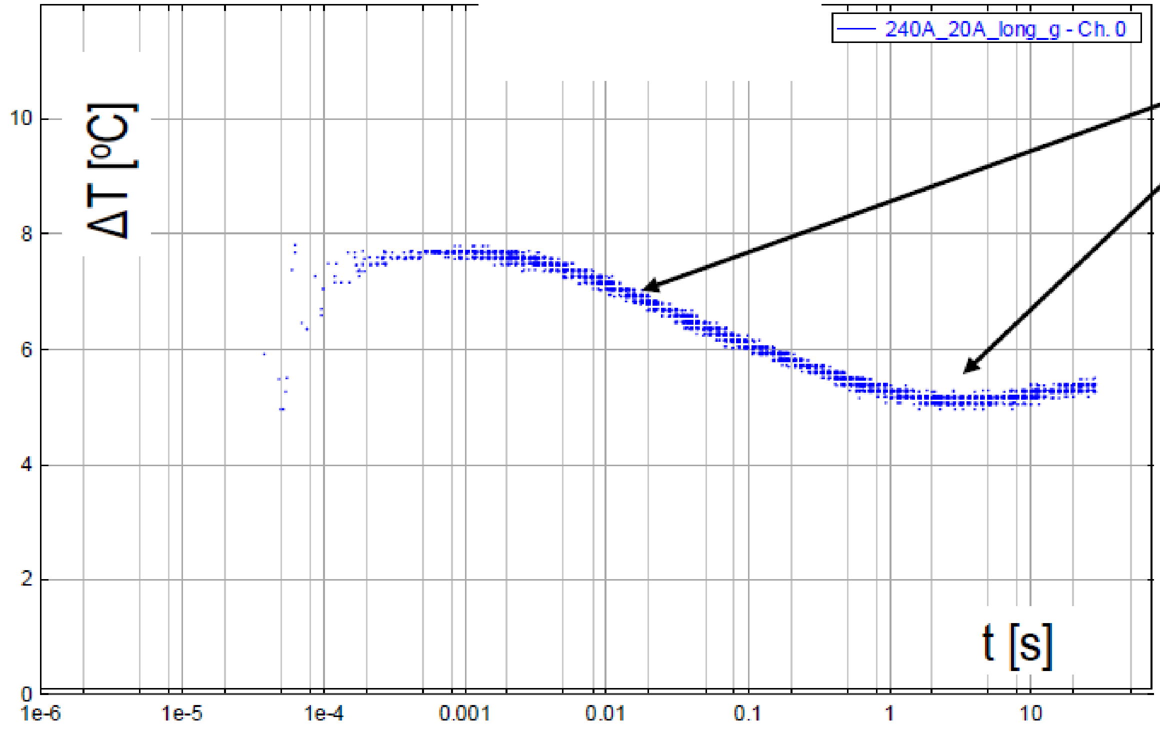
IGBT saturation mode

- Heating and sensing current are flowing through the channel
- Constant V_{GE} during heating and sensing
- V_{CE} is sensed

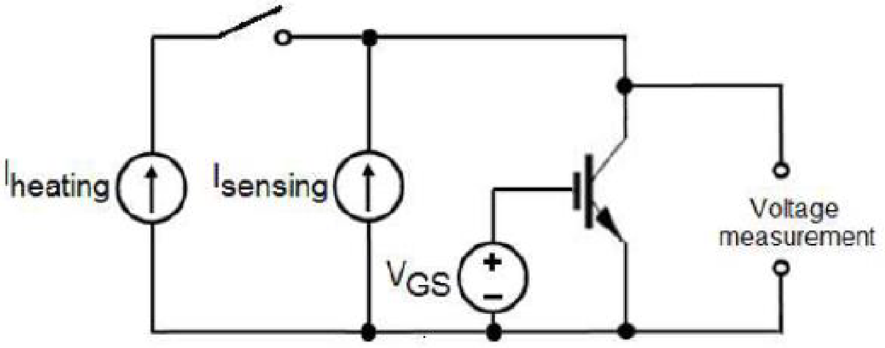


Testing conventional Si measurement methods on SiC MOSFETs

SiC MOSFET measured with 20A sensor current, 240 A heating current and 15V V_{GS}



Strong non-monotonous behavior, even at larger time constants



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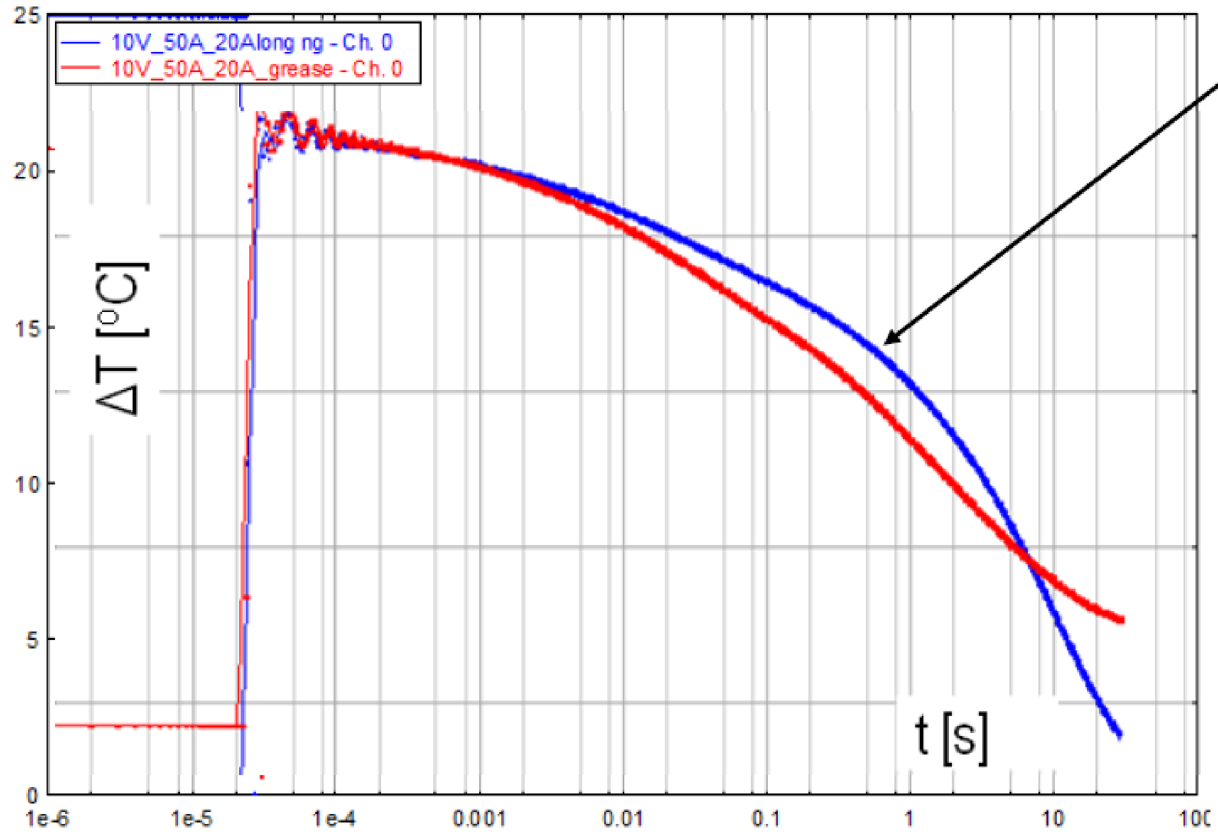
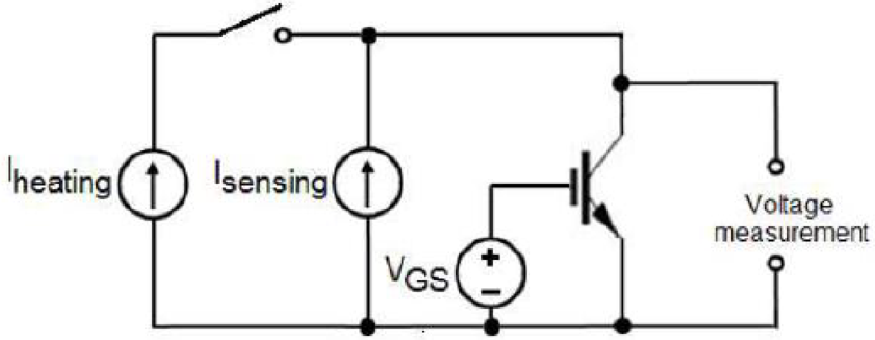
Examples of Electrical Parasitic Response

SiC MOSFET measured with 20A sensor current, 50A heating current and 10V VGS



No ideal fit if dual-interface technique is used – not pure thermal signal



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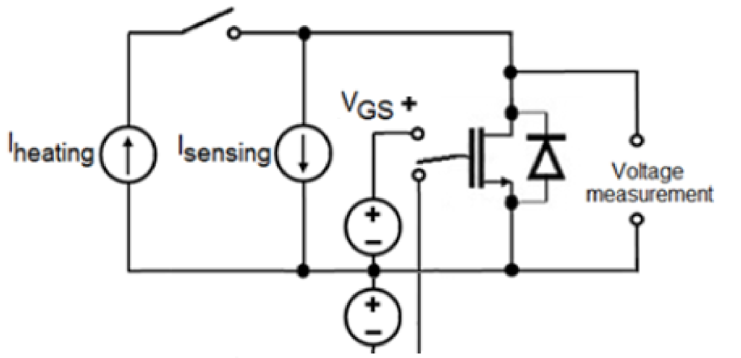
Advanced Thermal Transient Measurement Modes for SiC

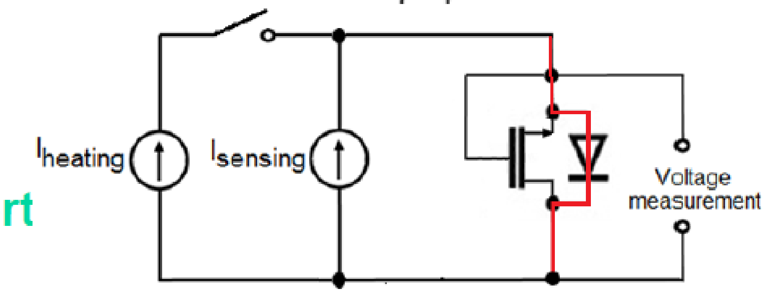
MOSFET sat. mode

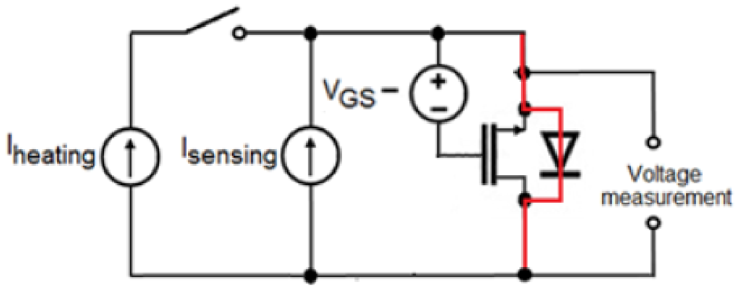
- Heating via MOSFET channel and positive gate voltage
- Measurement via Body Diode with open channel and negative gate voltage

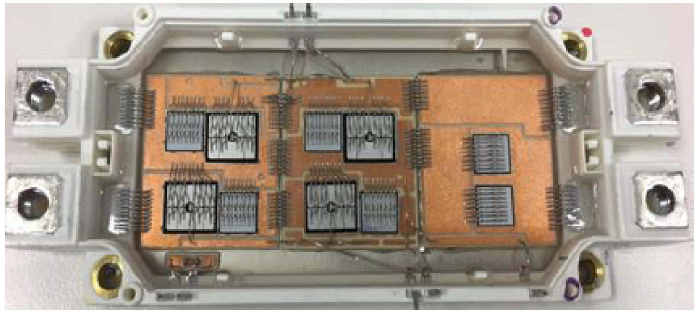
For parallelly connected SiC chips i.e. in half-bridge modules:

- Leakage on gate too high due to bad oxide isolation ➔ channel does not fully close or oscillation
  Heating and sensing via Body Diode possible with gate-source short or negative gate ➔ channel disabled









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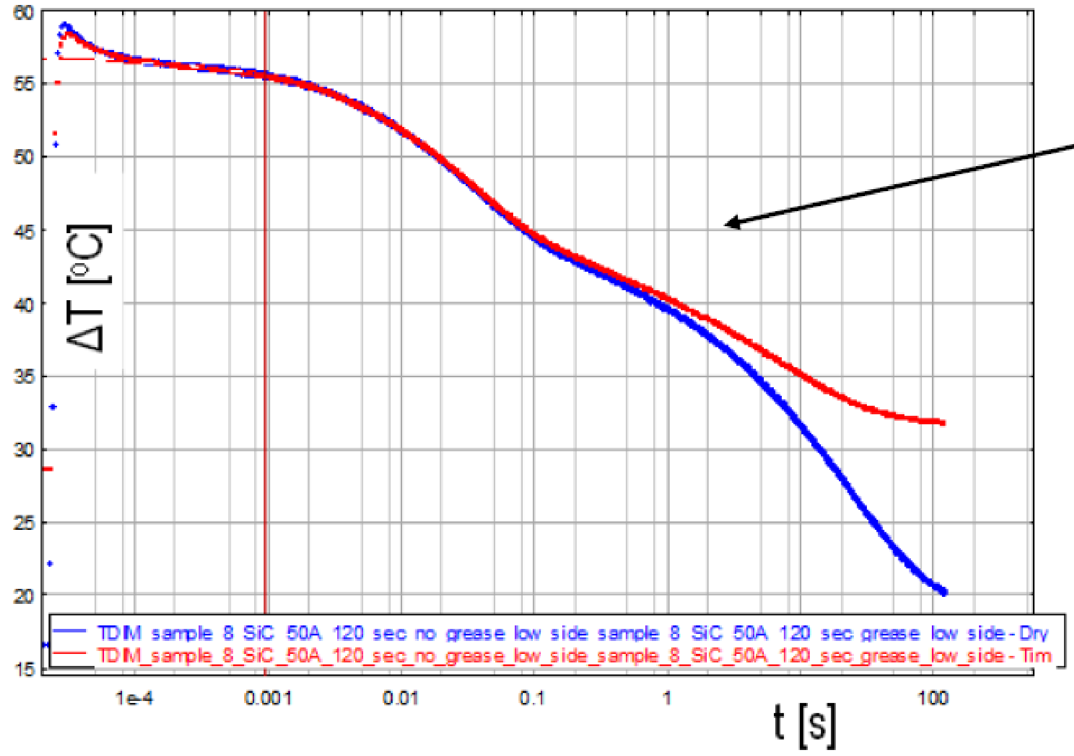
Why do standard Si measurement methods not work?

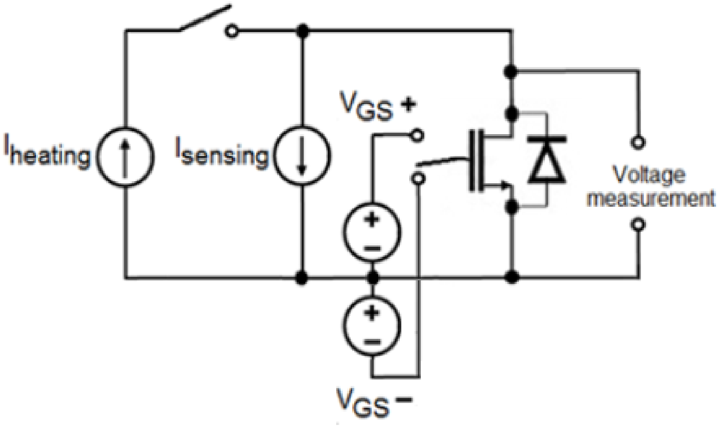
- The SiO_2 – SiC transition, may contain trapped charge carriers due to the large concentration of crystalline errors at the interface
- Some techniques, such as post-oxidation annealing of the gate oxide in nitric or nitrous oxide (NO or N_2O) may improve the device performance
- In some structures the movement of these trapped charges cause electrical disturbances up to the several seconds range after the switching
- Thermal transient tests should be carried out in connection modes, where the gate potential remains unchanged during the process.
- This makes common test procedures, such as the “MOS diode” setup and the fixed VDS arrangement unsuitable for testing SiC devices.

Example: MOSFET saturation mode

As the issues demonstrated before most likely correspond to a gate charge related phenomena, the SiC diodes are not affected



Separation is of pure thermal origin



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GaN Device Challenges

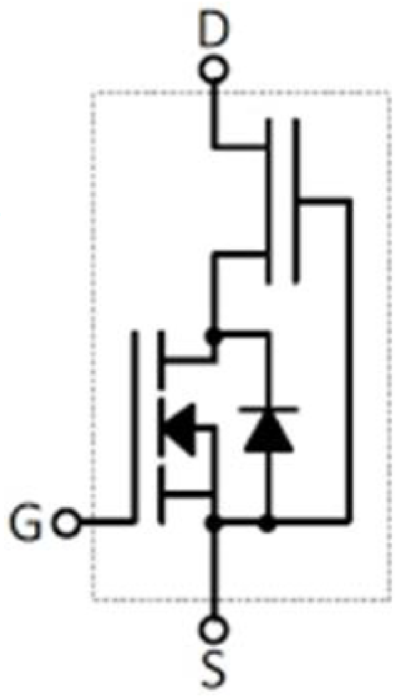
- As for SiC devices the Rds,on for GaN is very low resulting in a very low voltage drop at regular sensing currents (≤1A)

- The „standard“ GaN device has not been established yet ➔ manufacturers introduce different approaches
  - Enhancement type GaN HEMTs
  - Si MOSFET cascode GaN HEMTS
  - Standard-on HEMTs for high frequency applications

- Atomic scale effects at the gate result in similar „strange“ behavior which is known from SiC devices
  - Charge carrier capture and emission on traps create virtual gate up the minute range

Si-MOSFET Cascode GaN Normal-Off Device

- HEMT needs negative gate voltage for off state
- Forward drop on MOSFET is negative HEMT gate ➔ switch-off MOSFET results in negative HEMT gate ➔ HEMT switches off as well
- No access to MOSFET drain terminal ➔ structure not separable!



Depletion type HEMT

Silicon MOSFET

Assume IGBT sat. mode (heating and sensing in forward direction):

- $R_{ds,on}$ MOSFET: ~1mOhm
- $R_{ds,on}$ HEMT: ~10mOhm

Pros: HEMT voltage drop is dominant, heating power is distributed 10/1 on the HEMT
Cons: Signal amplitude is very low (high sensing currents needed (>>1A)

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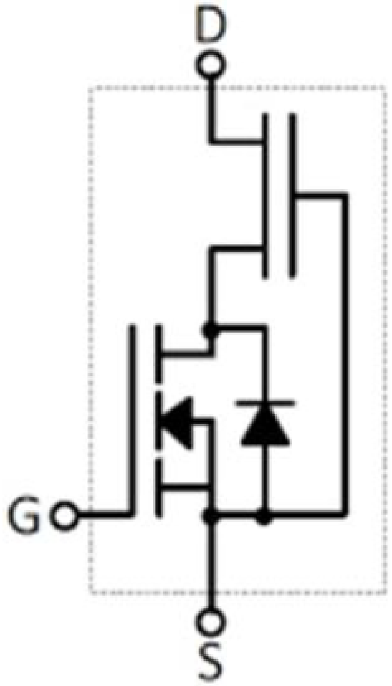
Si-MOSFET Cascode GaN Normal-Off Device

GaN HEMTs commonly show a very similar behavior in forward and reverse direction



Assume MOSFET diode mode (heating and sensing in reverse):

- Si Body diode: ~600mV @ 100mA
- $R_{ds,on}$ HEMT: ~10mOhm

Pros: Signal amplitude is perfect and low sensing currents are sufficient
Cons: Sensing on MOSFET diode ➔ Only feasbile if MOSFET is not seperated from GaN structure

Use Case: GaN HEMT Cree CGH40025F Thermal Characterization

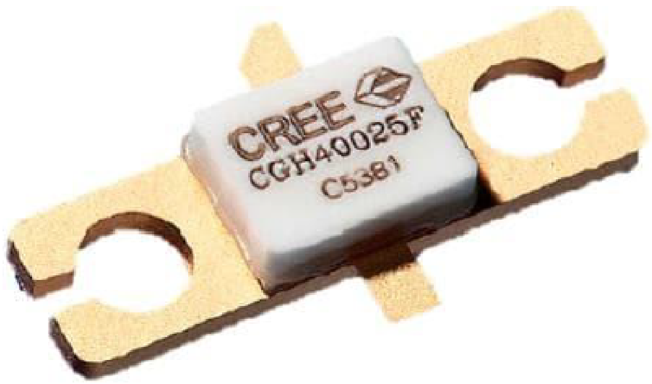
- The goal of the study was to examine the possibility of doing thermal transient tests on a high frequency HEMT transistor using elevated Drain to Source voltage for heating.

- The tests were carried out on CREE CGH40025F HEMT transistor purchased by Mentor – A Siemens Business

Proposed thermal characterization method is not generally applicable on GaN devices

Difficulties:

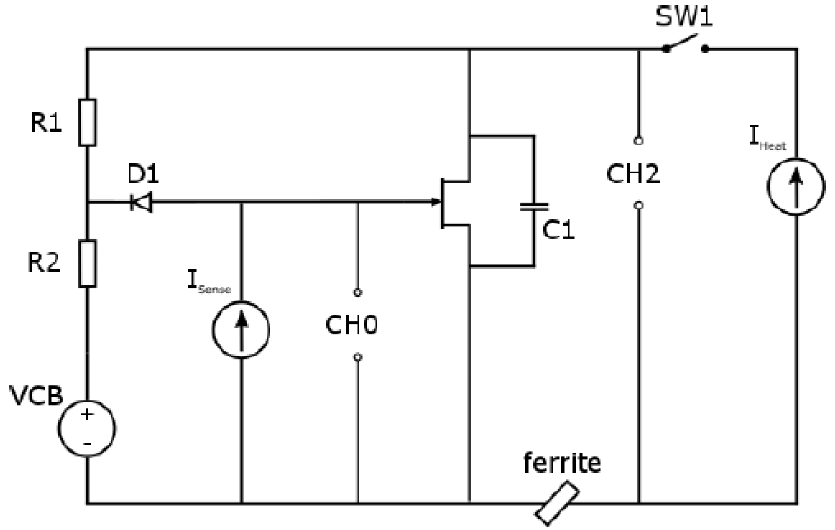
- In order to elevate the drain-source voltage the gate potential needs to be pulled close to the threshold voltage of -3V
- In this operating point the RF component tends to oscillate at very high frequencies that is hard to control



Measurements by: Zoltan Sarkany, Product Manager

GaN Threshold Mode Measurement – Schottky Diode Gate

- V_{CB} to switch HEMT channel from on (closed channel close to threshold) to off state (open channel)
- D_1 to isolate V_{CB} and I_{sense} during sensing



Temperature sensing:

- Sensing via schottky gate diode with constant current (I_{sense})
- V_{CB} is positive so D_1 isolates gate ➔ GaN HEMT is off

Heating

- Heating current (I_{heat}) from drain to source
- During heating the transistor is in on state (closed channel, near threshold voltage) with negative voltage on gate
- R1 stabilizes operation point
- C1 and the ferrite bead eliminate oscillation

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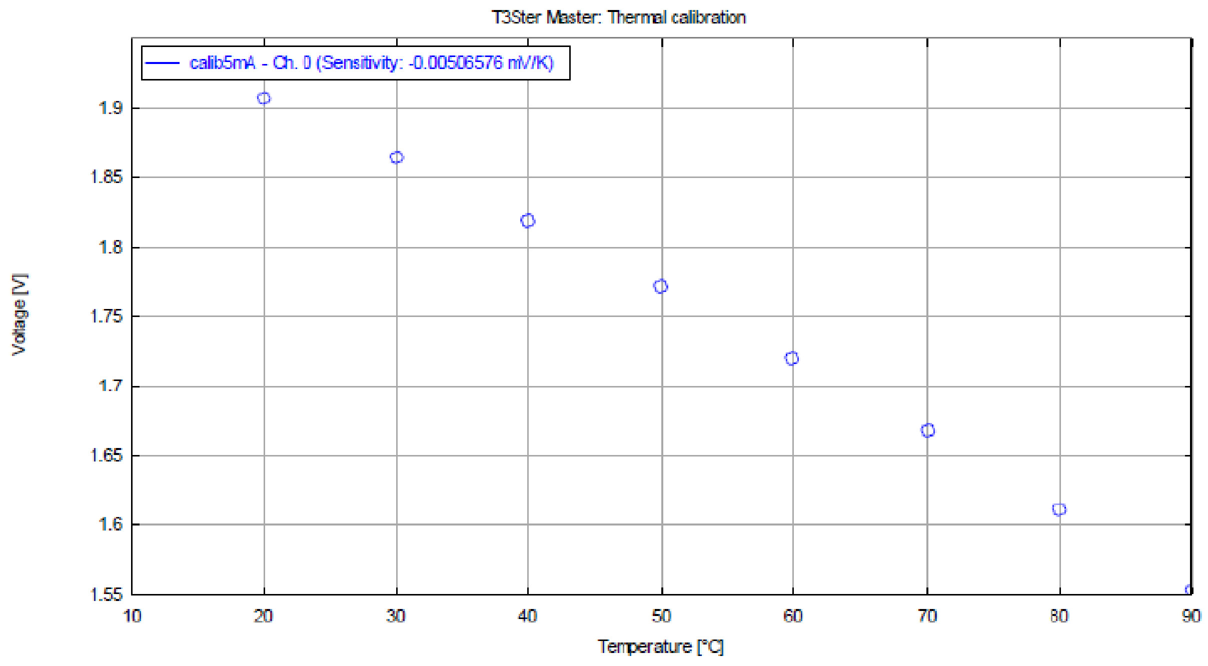
Thermal Calibration

DUT environment temperature was controlled by regulating the cold plate temperature with a fluid thermostat (chiller)

- Temperature sensitivity calibration was carried out between 10 and 90 °C in 10°C steps
- The measured TSP = 5.066 mV/K



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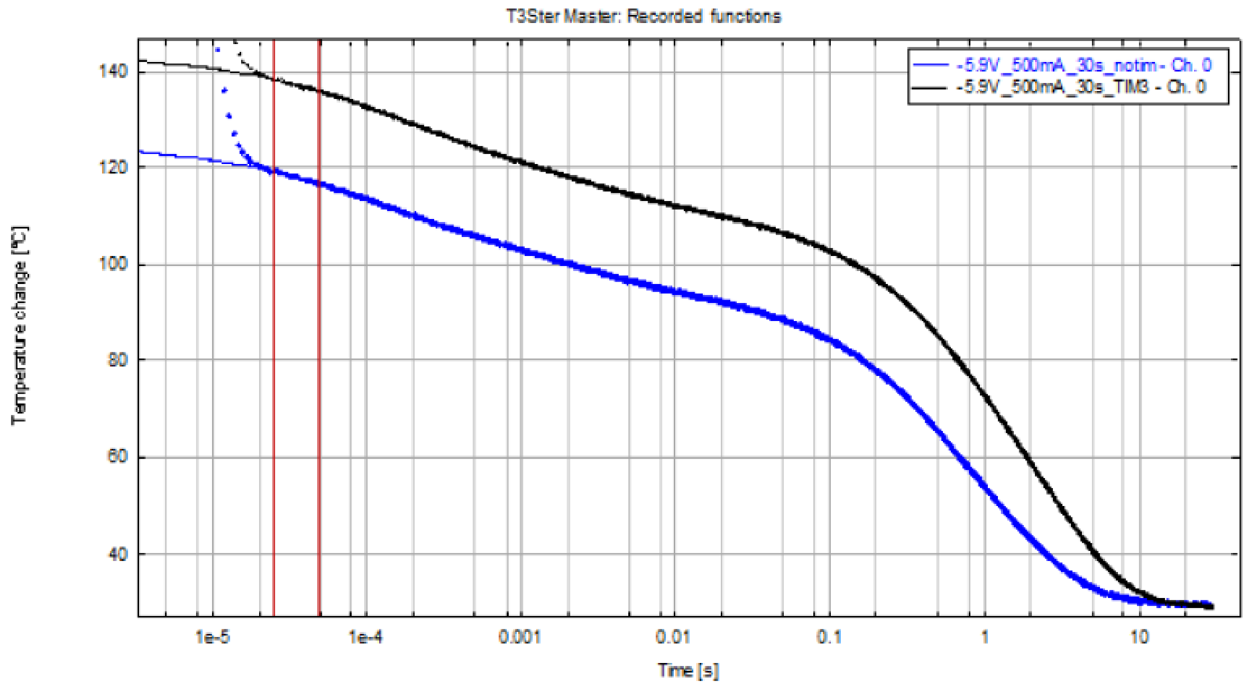
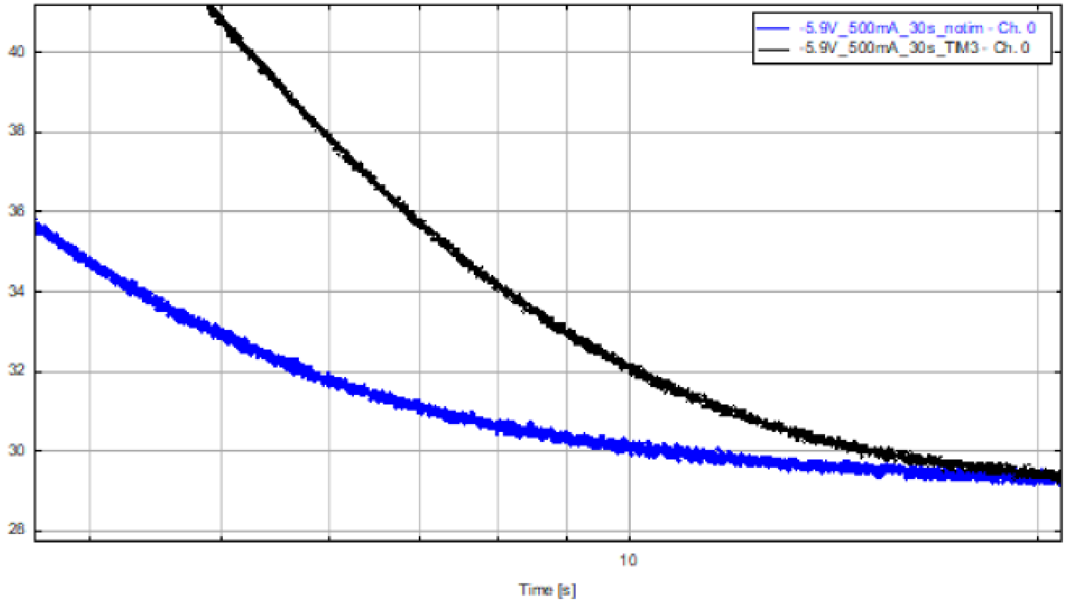
Results – Raw Transients



- Electric transient ends before about 25us
- Measurement noise is low
- Initial transient was approximated with square root curve fitted between 25 and 50 µs



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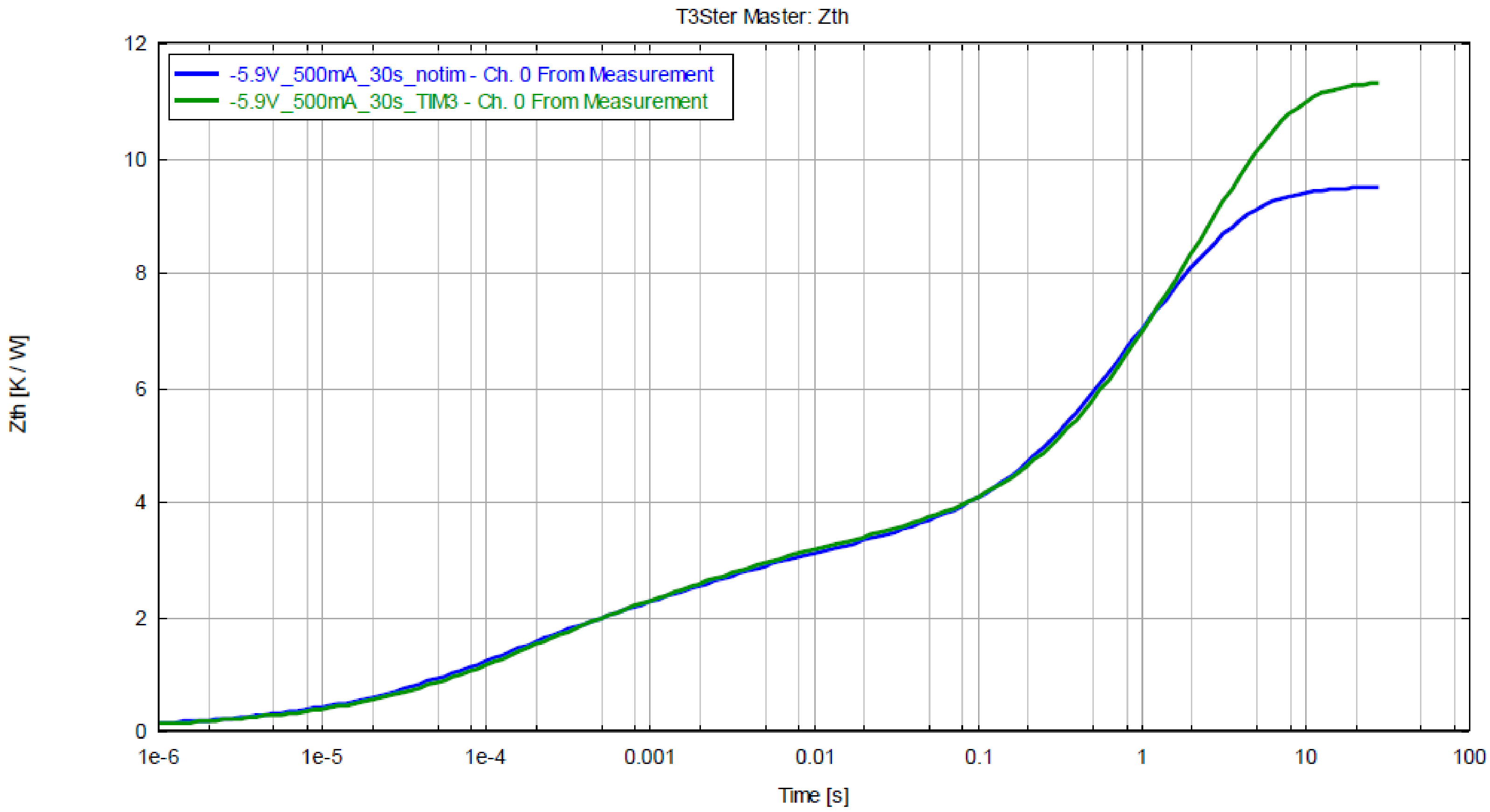
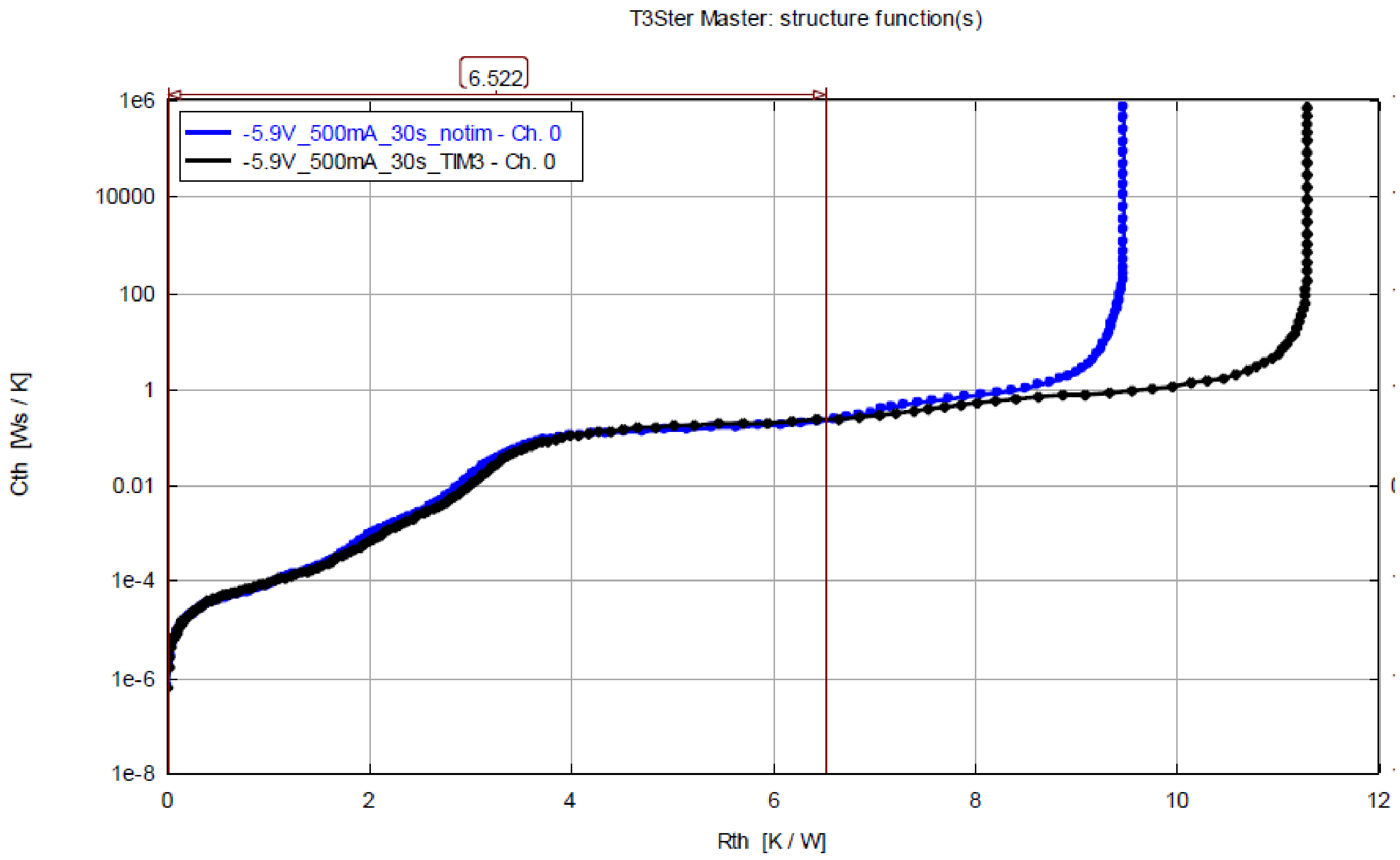
Results – Z_{th}



Two curves fit well until about 1.5 seconds, until the heat reaches the component cooling surface

Results – Structure Functions

- Structure functions fit fairly well at the package level, splitting up around **6.5 K**
- $R_{th,J\text{-}C}$ can be determined



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Conclusion

- As for Si, **SiC is fully supported** by various measurements methods from Simcenter Testing portfolio:

Simcenter T3STER and all new T3STER SI

Simcenter Powertester

- For GaN characterization a general statement is not possible yet

If you are interested in GaN thermal characterization or powercycling with Simcenter T3STER or Powertester please contact our application engineers

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Thank You

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Ingenuity for life