Addressing Thermal and Electromagnetic Challenges with Today's Advanced Devices

Dustin Kendig, Microsanj LLC

Sedina Wane, eV Technologies

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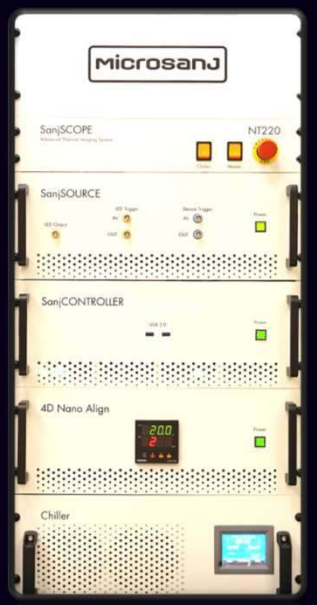
Objective

- To introduce the audience to thermoreflectance & its applications to failure analysis, thermal characterization, & EM analysis
- To detect thermally dependent failures/defects
  - Submicron defects
  - Time dependent thermal events (ESD, latch-up, etc)
  - 3D effects (3DIC, Voids, buried defects)
  - AiP defects

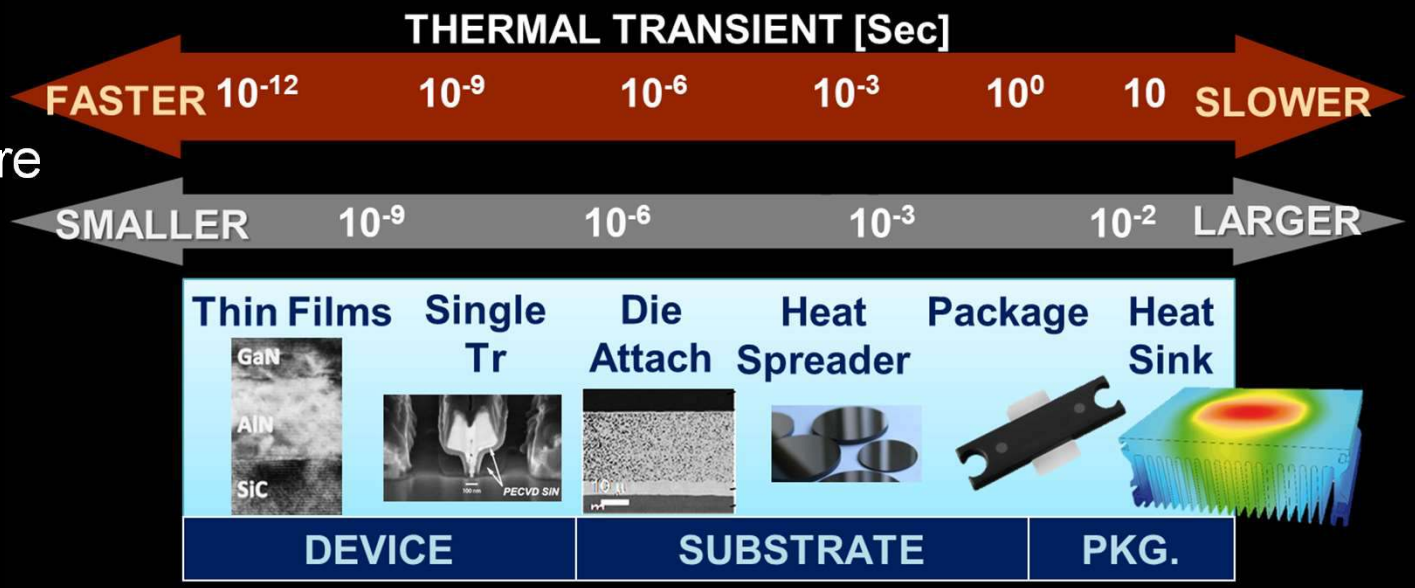
Outline

- Introduction to Thermoreflectance
- Spatial Resolution
- Temporal Resolution Applications
  - TBR
  - Latch-up
  - ESD
  - 3D defect depth
- Over-the-Air (OTA) testing
- Conclusion



Thermal Characterization Challenges

- Smaller features
- Low Power/Temperature
- Buried Defects/Voids
- Higher Speeds
- New Materials
  - Diamond, MoS2, etc



Thermoreflectance (TR) Imaging

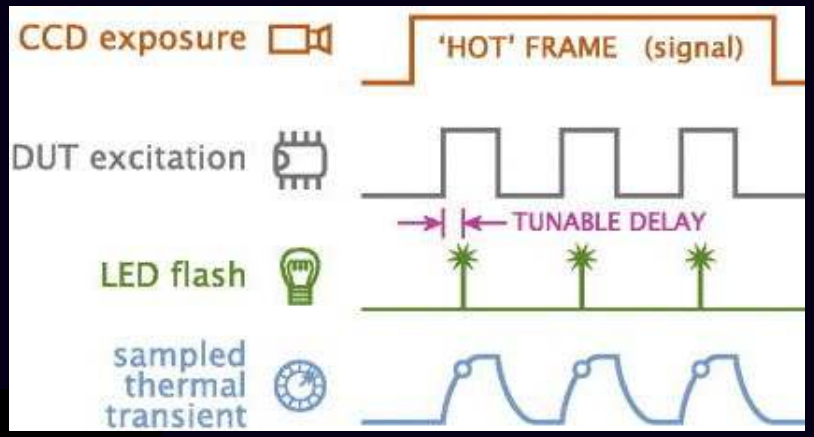
- Reflected light intensity is dependent on temperature

$$\frac{\Delta R}{R} = C_{TR}\,\Delta T$$

C_{TR} = Thermoreflectance Coefficient

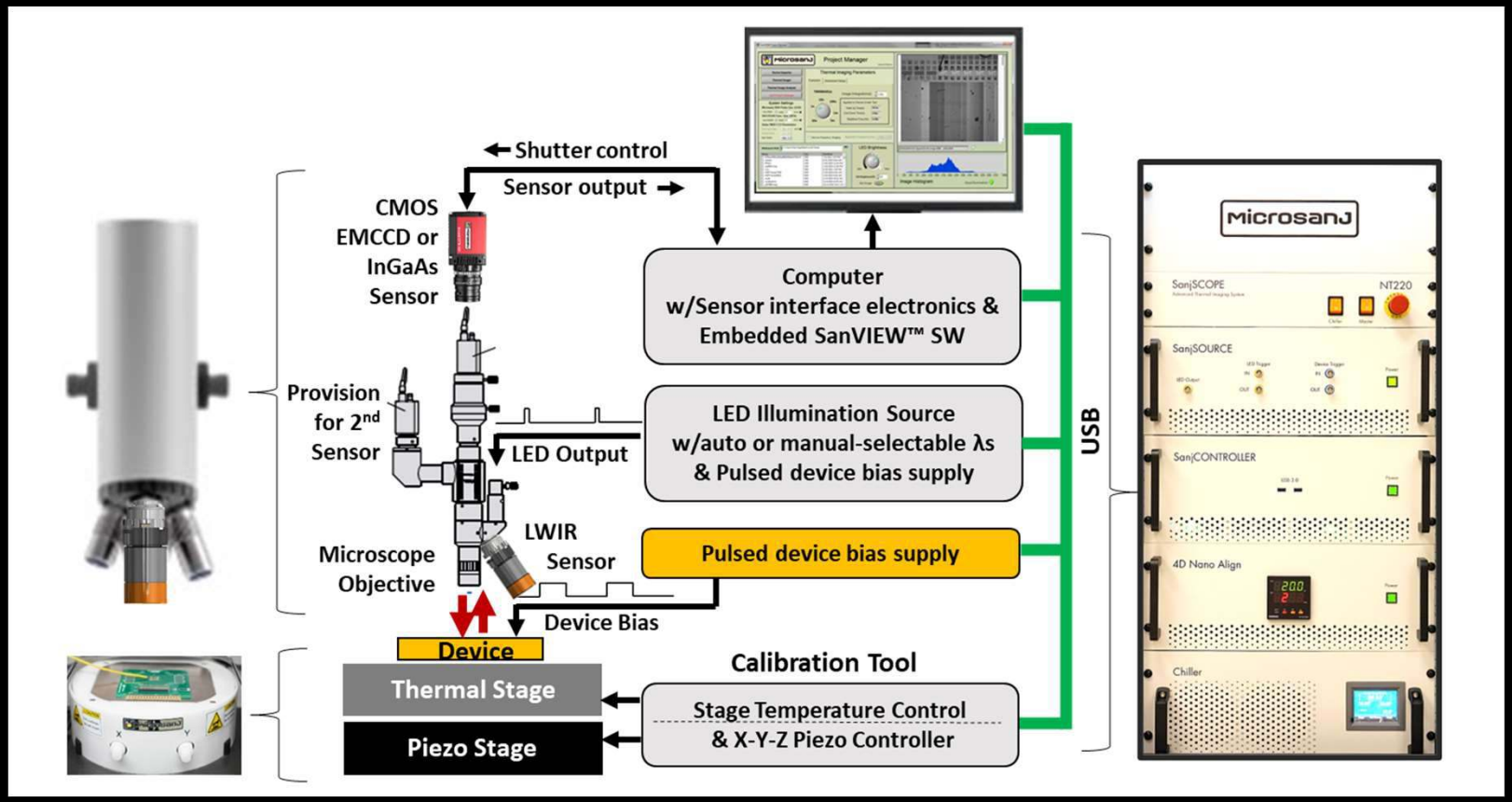
- A pulsed light source can be used to probe a sample surface using **UV**, **NUV**, VIS, or NIR light

- Spatial: **100's nm** (with UV & VIS)
- Time: **800 ps** (Laser) or **50 ns** (LED)
- Temp. Resolution: **1-100mK**



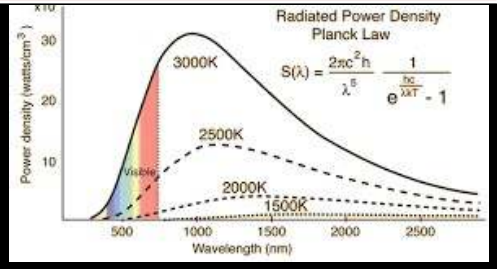
J. Christofferson, A. Shakouri, ***Rev. of Scientific Instruments***, 2005
K. Yazawa, A. Shakouri, ***Electronics Cooling Magazine***, Vol. 3, p.10, March 2011

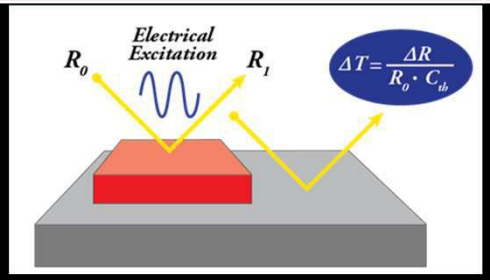
Building Blocks for TR & IR Imaging

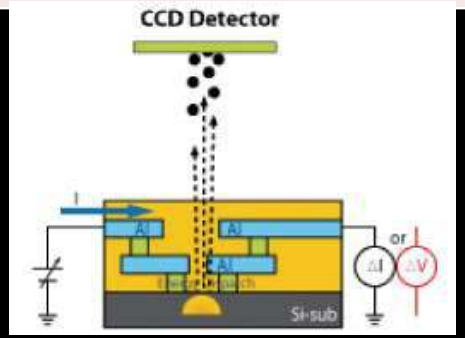


IR, TR, & EMMI

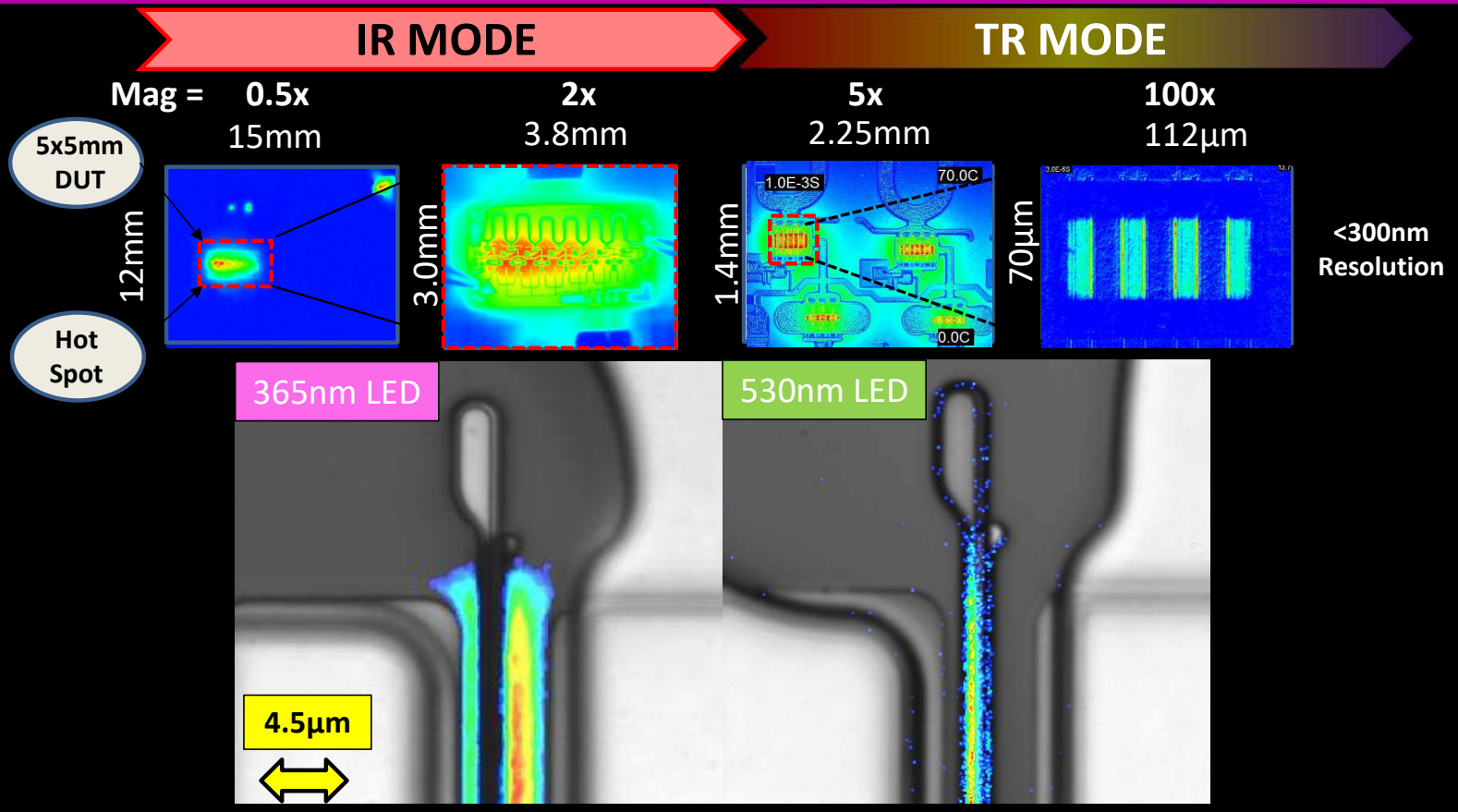
	Infrared Emission (IR)	Thermoreflectance (TR)	Emission (EMMI)
Spatial	2-10 µm Diffraction limited	250 to 700 nm Diffraction limited	>700 nm Diffraction limited
Sensitivity (NETD)	~10-100 µK	~1-250 mK	No temperature
Transient Analysis	ms	ps to µs	ms
Notes	Metals have very low emissivity	Equally applicable for metals or semiconductors	Transistor/diode leakage only
Physics	Planck Law / Blackbody Radiation	Reflection / Fresnel / Maxwell's Equations	Electron-Hole recombination
Non-Invasive?	Yes, unless coating used	Yes	Yes



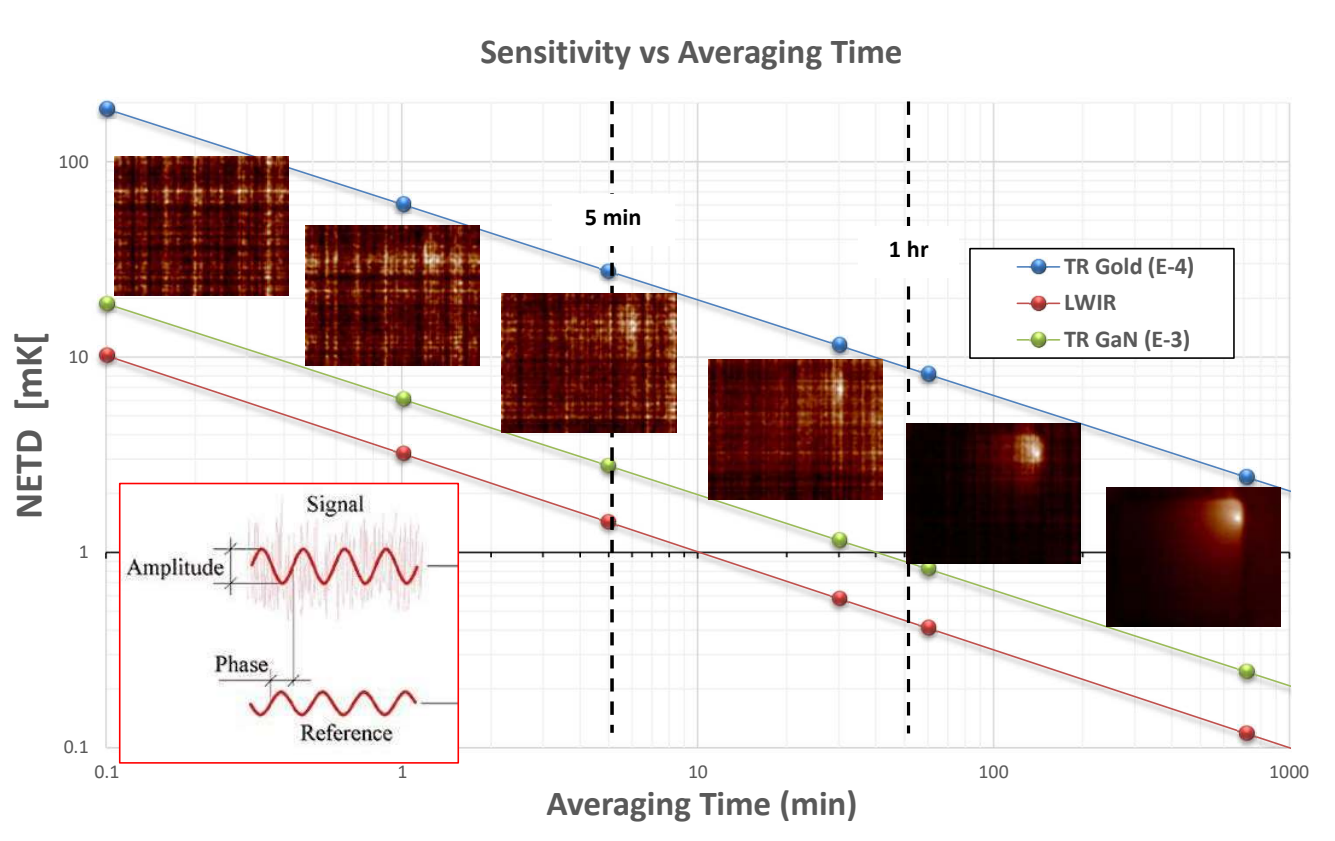




Full Spectrum Thermal Imaging: UV to IR

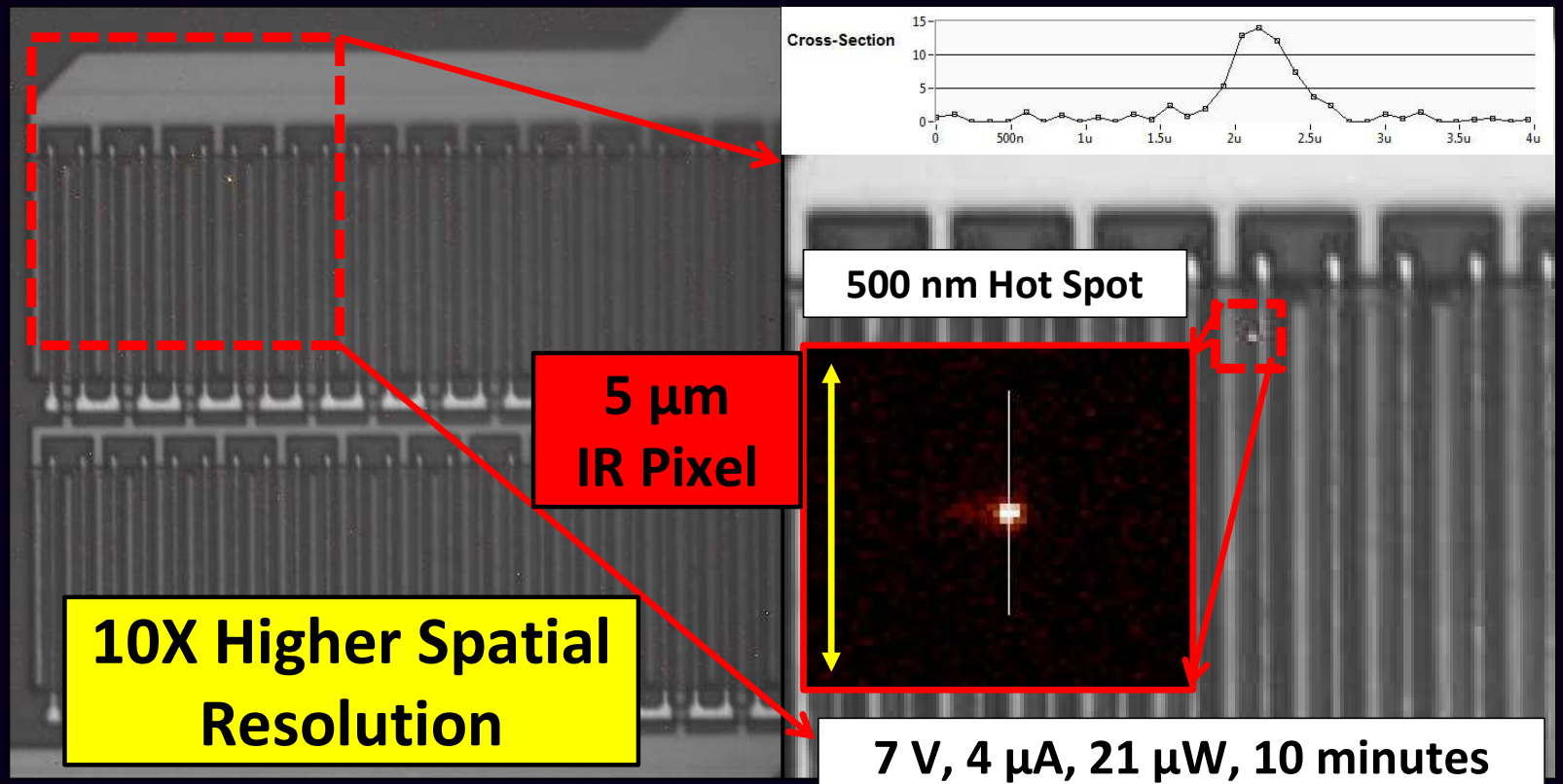


Lock-in Thermography (LIT)



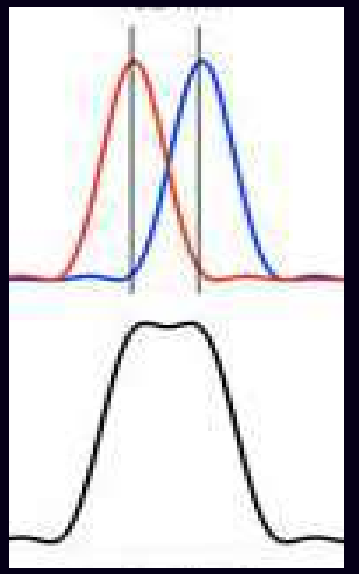
- LIT is a non-destructive averaging technique that can be used to improve detection of low power defects
- Resolution can be improved by
  - 1/√N (N is the number of pixels)
  - 1/√t (t is the averaging time)

High Spatial Resolution



Abbe diffraction limit

$$d = \frac{\lambda}{2(n \sin \theta)}$$



Transient Measurements

Transient (dynamic) thermal response contains all information about a linear system. Heating and cooling curves contain all the information about the heat-conduction path.

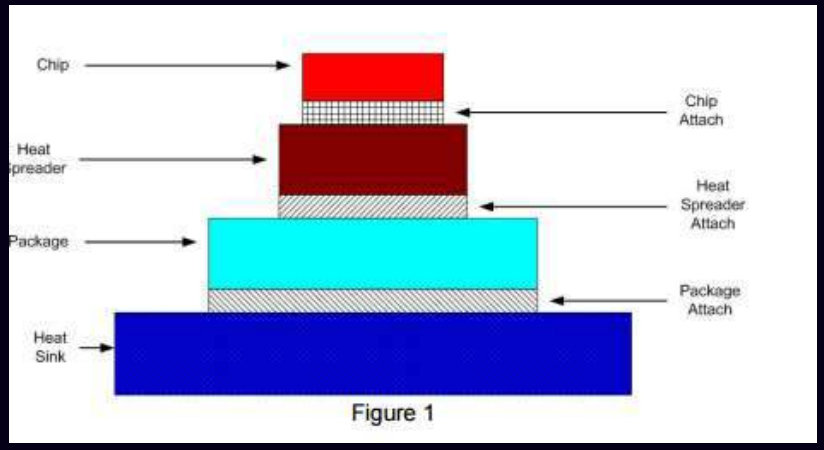
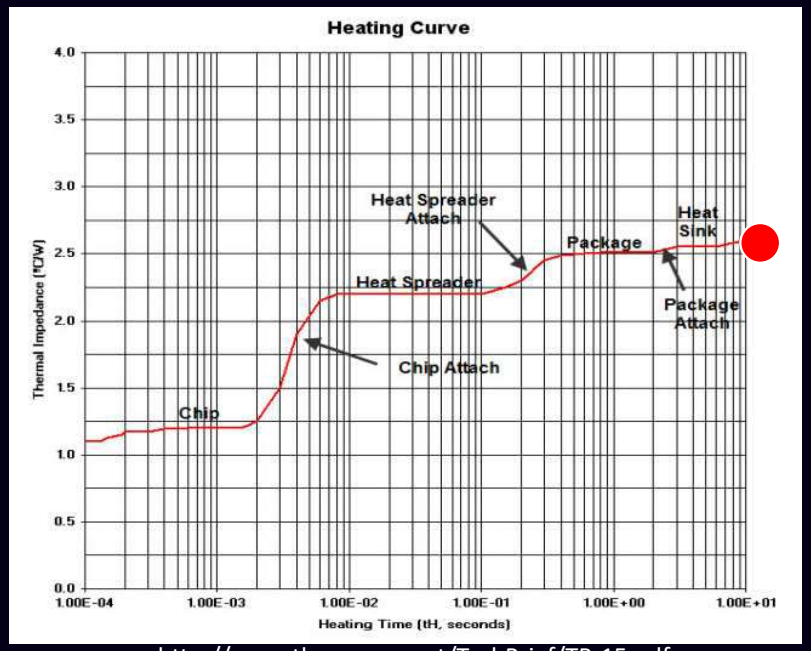


Figure 1

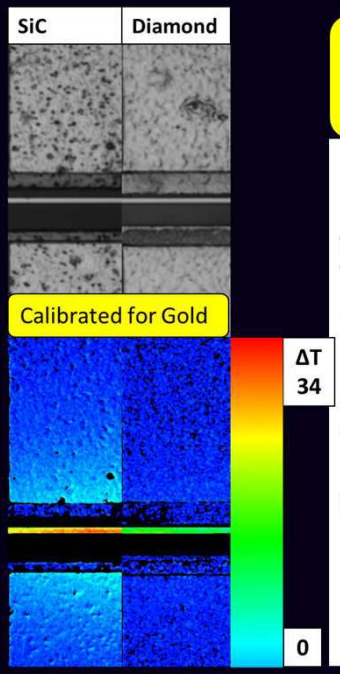
Transient Measurements to Extract Resistances & Material Properties
András Poppe SEMITHERM 32 Short Course 4



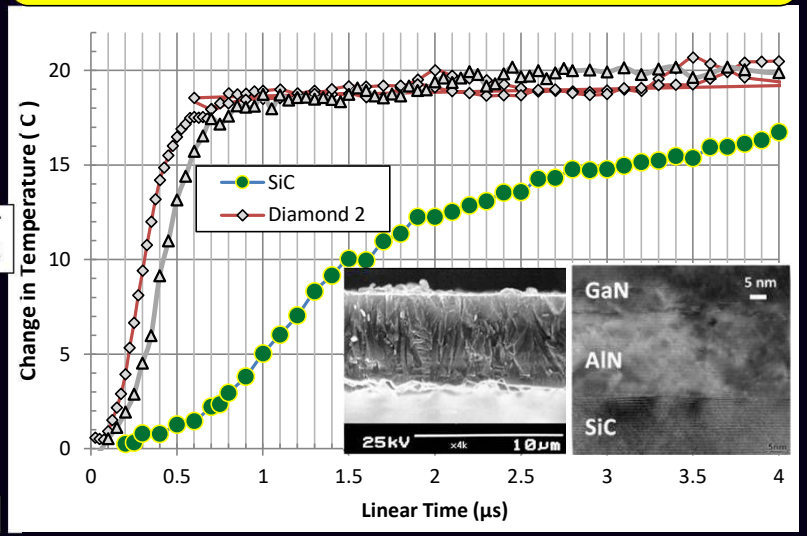
http://www.thermengr.net/TechBrief/TB-15.pdf

Improving Thermal Interfaces (TBR)

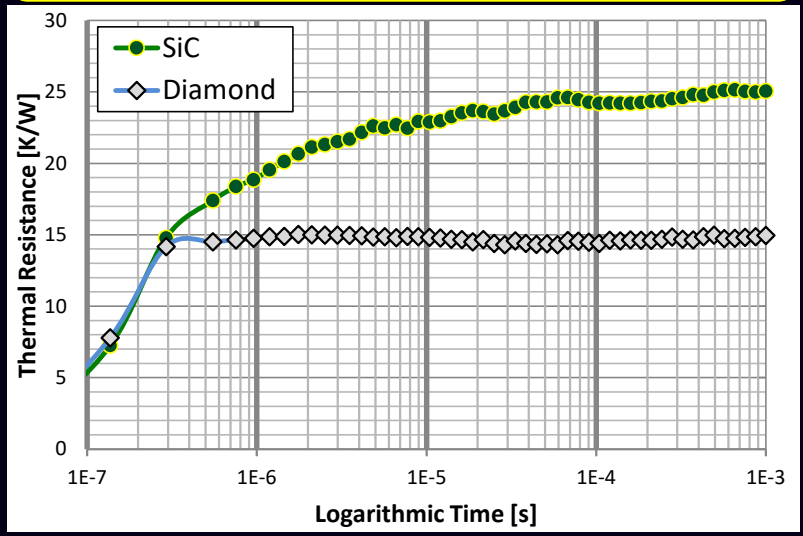
- Transient Temperature measurements help isolate dominant thermal interfaces
- Thermal Boundary Resistance (TBR) can be obtained from the heating curve



Large TBR for old diamond process

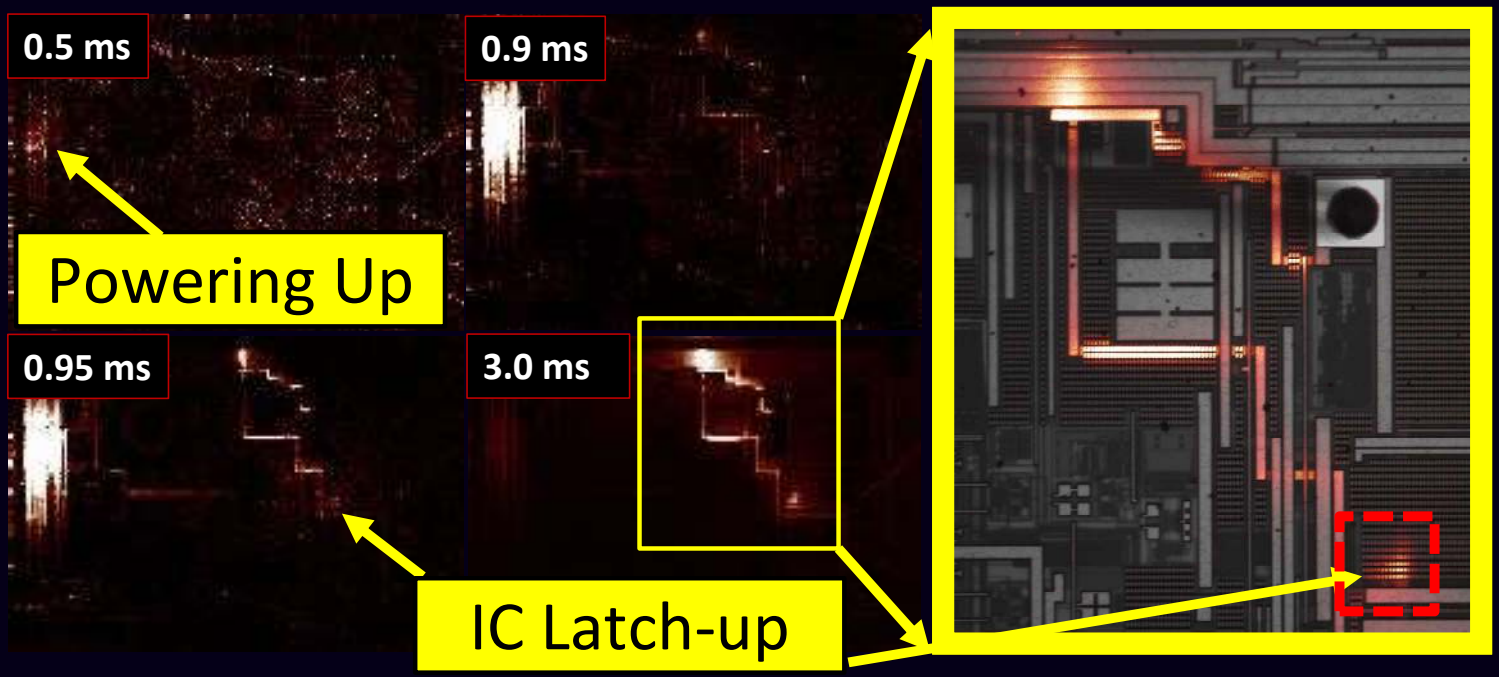


Newer diamond process improved TBR Device in steady state after 300ns



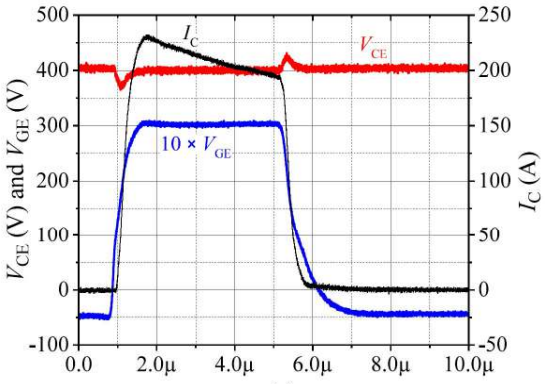
Transient Thermal Imaging of Latch-up

- High speed imaging allows you to view the progression of the failure
- Pulsing at kHz or MHz localizes the failure location and prevents damage

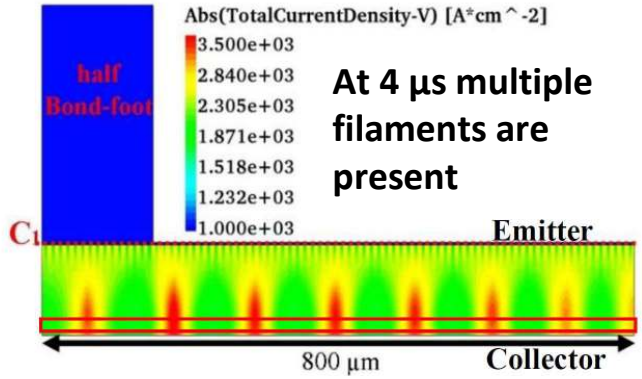


Investigating Short-Circuit Destruction

- Nanosecond thermal imaging allows for imaging of current filaments



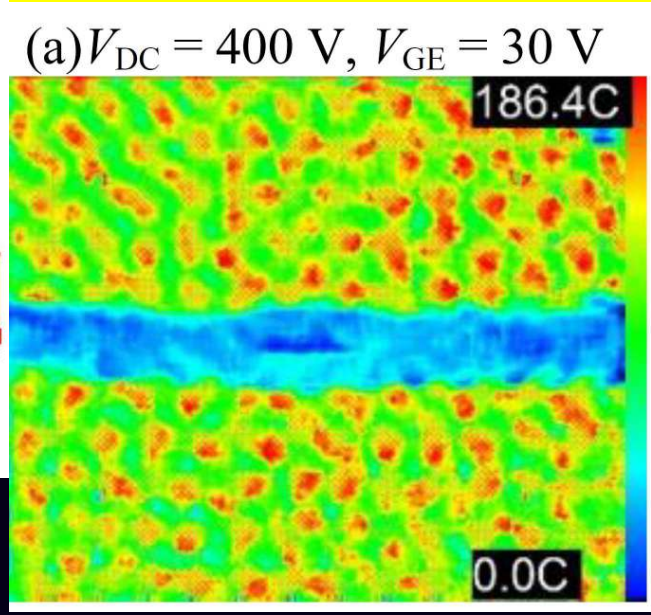
Transients of $V_{CE}(t)$, $V_{GE}(t)$, & $I_C(t)$ for SC type-1 event at V_{CE}=400 V, V_{GE}=30 V, T=300 K, L_{par}=60 nH, & R_G=220 Ω



At 4 µs multiple filaments are present

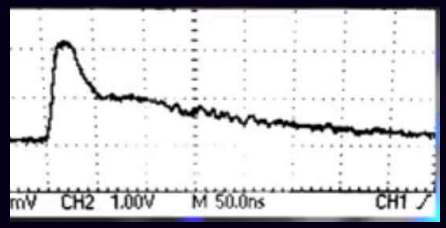
Current density distribution in IGBT at 4 µs

Surface Temperature after 4µs pulse

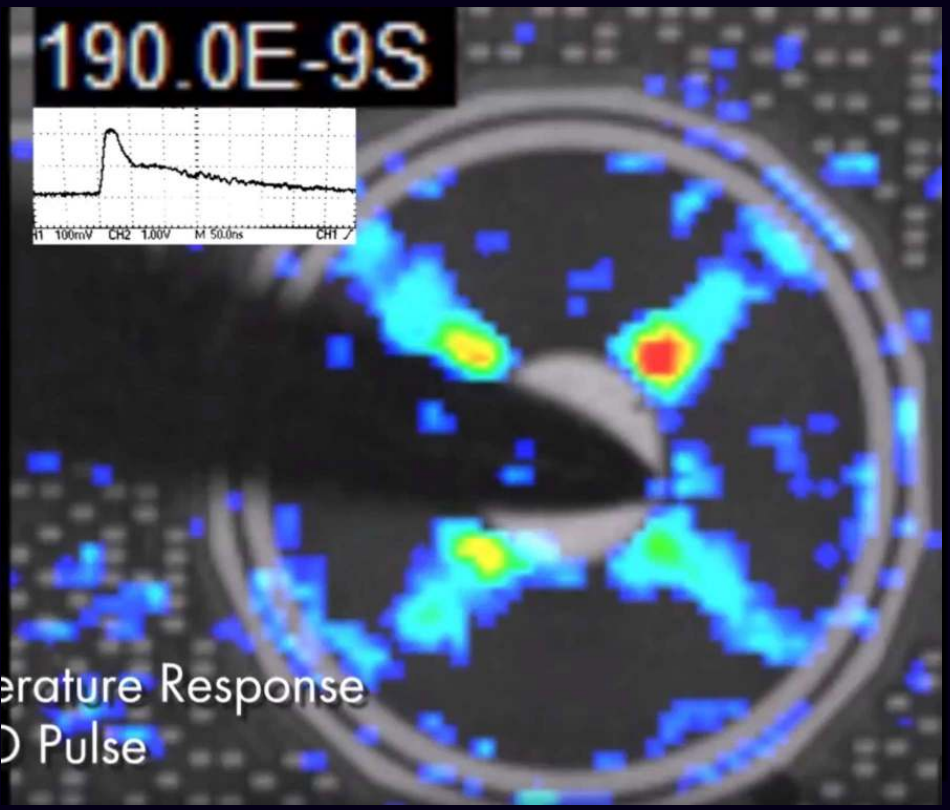


HBM ESD Current Filaments

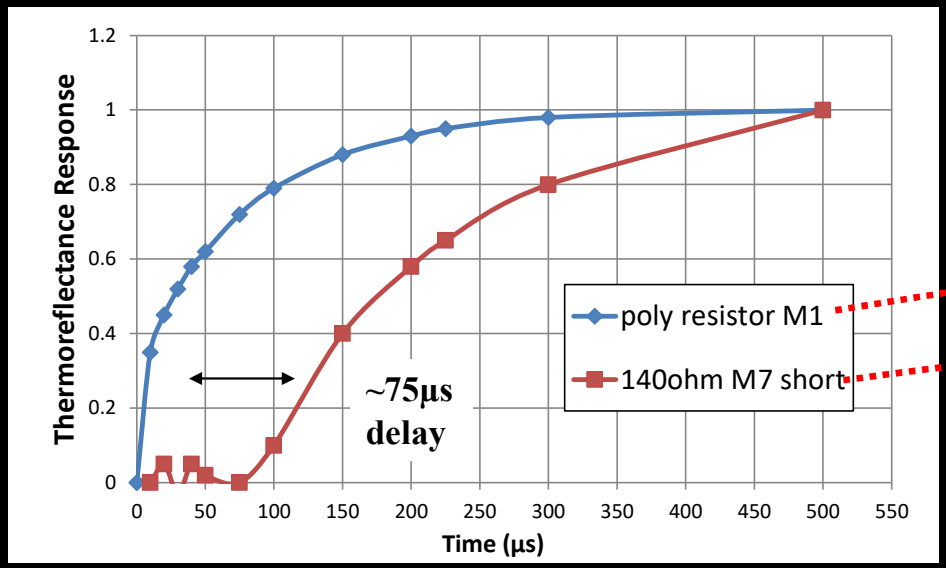
1700V HBM ESD Waveform

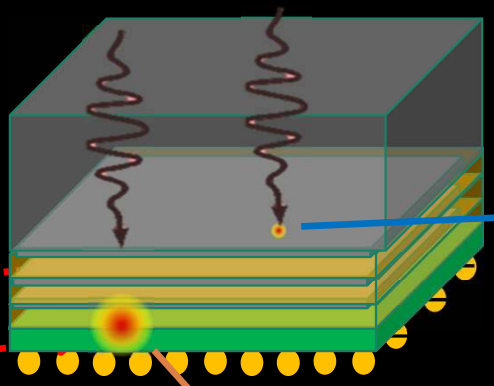


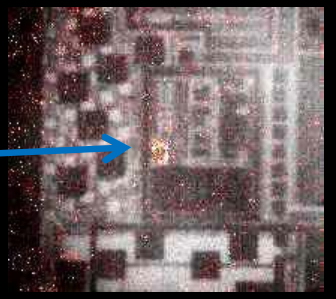
Transient thermal response

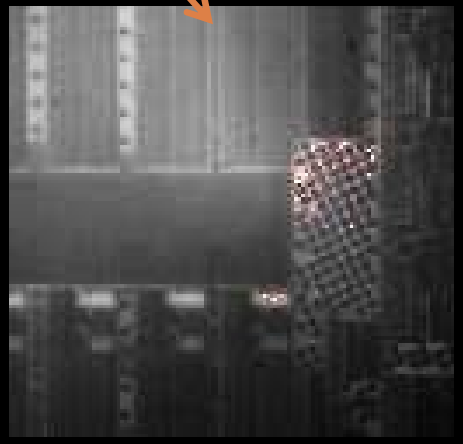


Defect Depth in 3D Structures





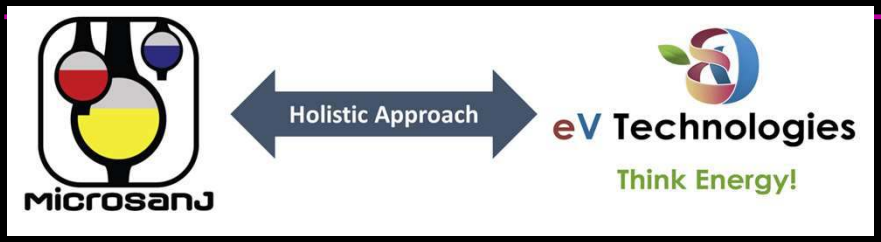




Diffusion Time: $\tau = d^2/4\alpha$

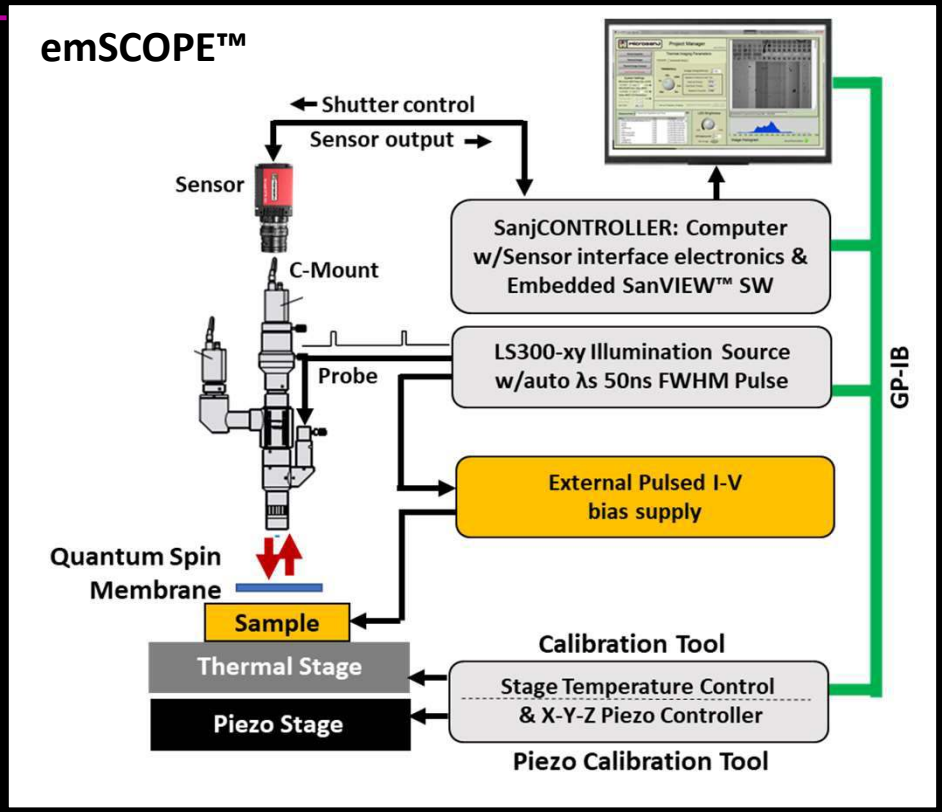
Delay in thermal signal for the 140Ω short indicates the defect is buried below the metal layers

Thermal Imaging to Electromagnetic Field Analysis



- Chip Level
- Package Level
- PC Board Level
- System/Antenna Level

- 2x Performance Benefit



eV-Technologies & Microsanj Demonstrate Unified OTA-Testing Solutions

Linking Thermal-Imaging to Electromagnetic-Field Sensing

eV Technologies
Think Energy!

- ✓ **Unified functional and reliability testing solution**
  Based on a holistic Chip-Package-PCB-Antenna vision
- ✓ **Ultra-fast test-time compliant with industrial requirements**
  No need for mechanical positioner/step-motor system
- ✓ **High accuracy absolute temperature calibration**
  Using Quantum-Spin thin-film coating with Sub-µm spatial resolution

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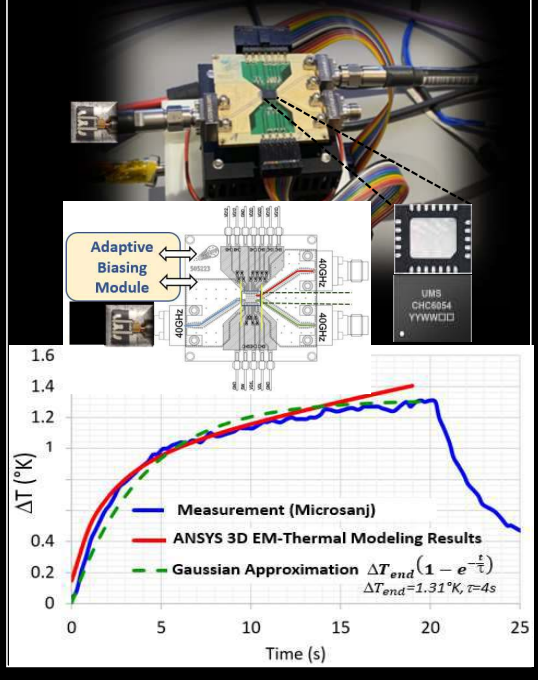
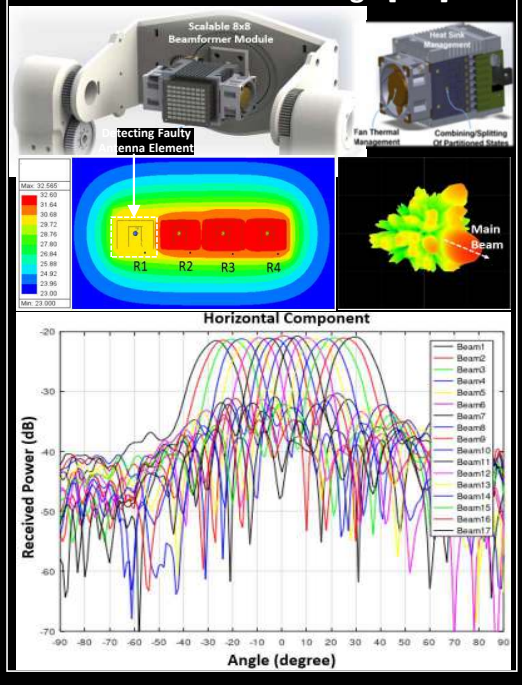
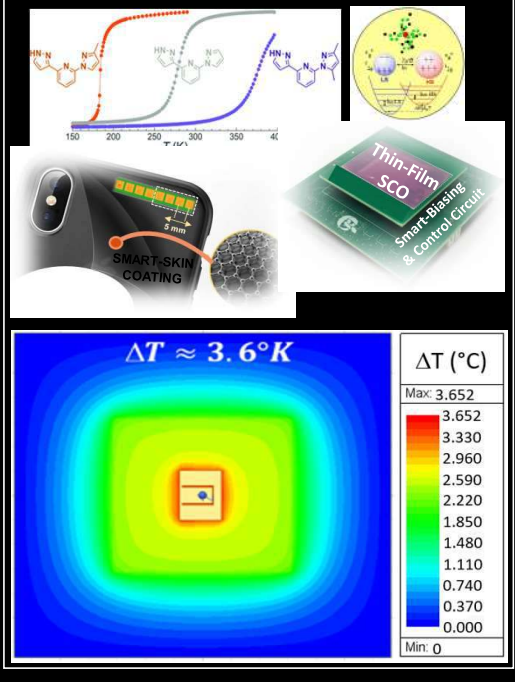
GaN -based Front-End-Module with Energy-Efficient Adaptive-Biasing



Beamforming-Module & Antenna-in-Package [AiP]



Absolute-Temperature Calibration Using Quantum-Spin Materials



eV-Technologies & Microsanj Evaluate new OTA-Testing Solutions for 77GHz Radar Systems based on TI-Chipset

eV Technologie
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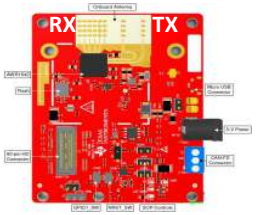
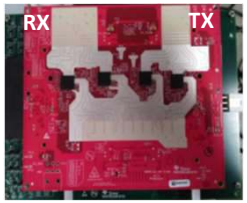
Two Radar Modules assessed:

- ✓ **Standard: 2 TX & 4 RX Antennas**
  Baseline TI- Demoboard+Processing
- ✓ **Custom: 12 TX & 16 RX Antennas**
  Custom-Antennas using TI-Chipset

Standard



Custom



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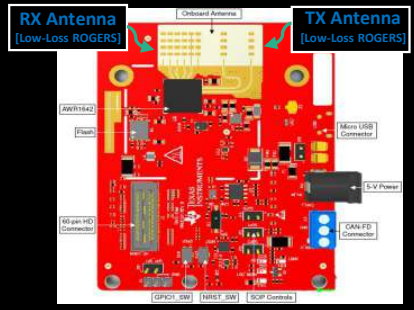

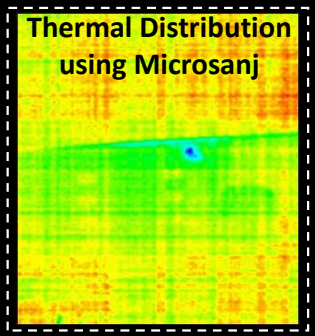

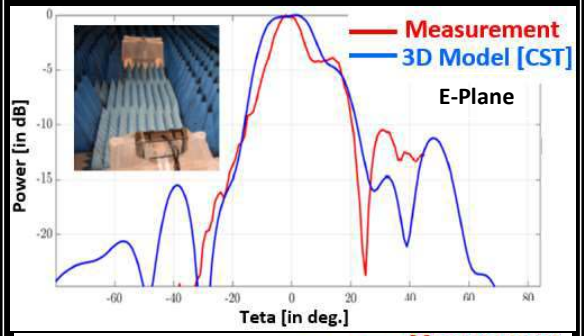

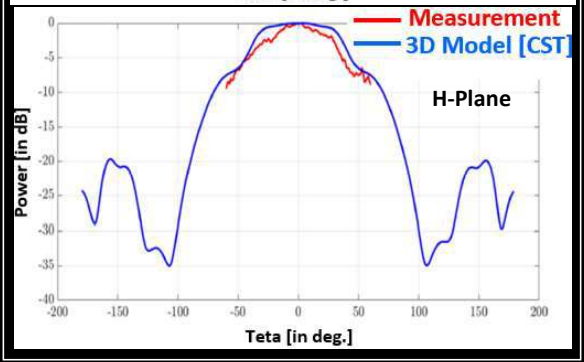

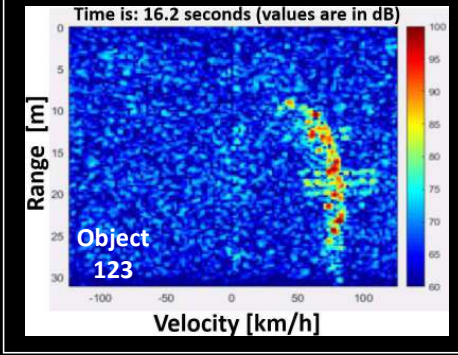

Very Fast and Easy Detection of Faulty Antenna Elements [Radar Chipsets Testing]

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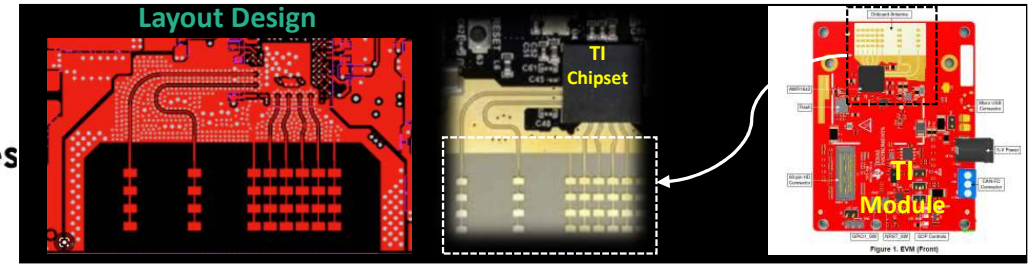

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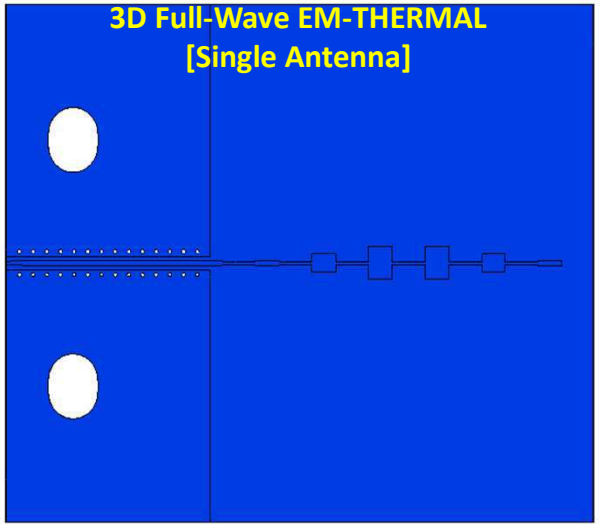
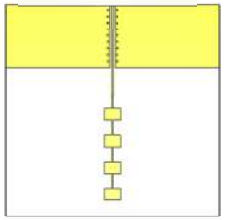
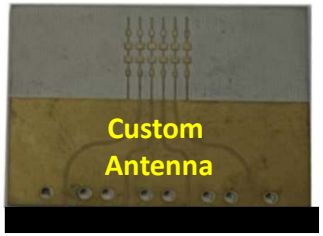
temperature (EM-Thermal coupling)

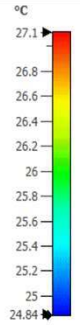
Orientation	Inside
Sample	1/4
Time	0 s
Maximum (Sample)	25 °C
Minimum (Sample)	25 °C
Maximum (Global)	27.1049 °C
Minimum (Global)	24.8399 °C



0.3 W @ 77 GHz, leading to 2.5 degrees heat increase mainly in the antenna part







Conclusion

- Sub-micron thermal defects are detected with TR
- Nanosecond thermal images show current filament location & propagation
- Transient analysis discloses defect depths in 3D structures

Thermoreflectance Imaging can validate Electromagnetic Performance