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Silicon Valley Chapter

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Chapter of the Year
2021

Microsanj
The Future of Thermal Imaging

Submicron Nanosecond Thermoreflectance Imaging for Thermal and Failure Analysis

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Objective

- To introduce thermoreflectance & its applications to failure analysis & thermal characterization
- To detect thermally dependent failures/defects
  - Submicron defects
  - Time dependent thermal events (ESD, latch-up, etc)
  - 3D effects (3DIC, Voids, buried defects)
  - GaN, SiC,….
- To characterize thermal properties of thin films and interfaces
  - Interfaces in IC packages
  - Thermal Boundary Resistance of GaN on SiC, Diamond, etc.

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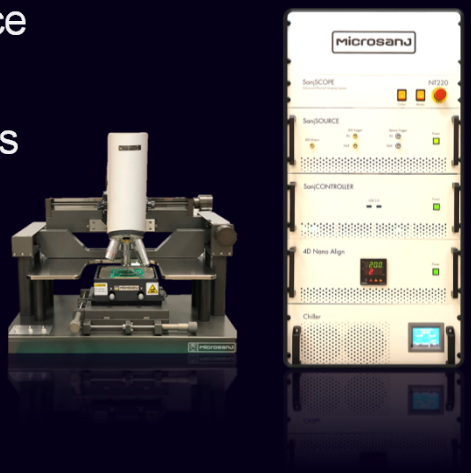
Outline

- Introduction to Thermoreflectance
- Spatial Resolution
- Temporal Resolution Applications
  - TBR
  - Latch-up
  - ESD
  - 3D defect depth
- Conclusion



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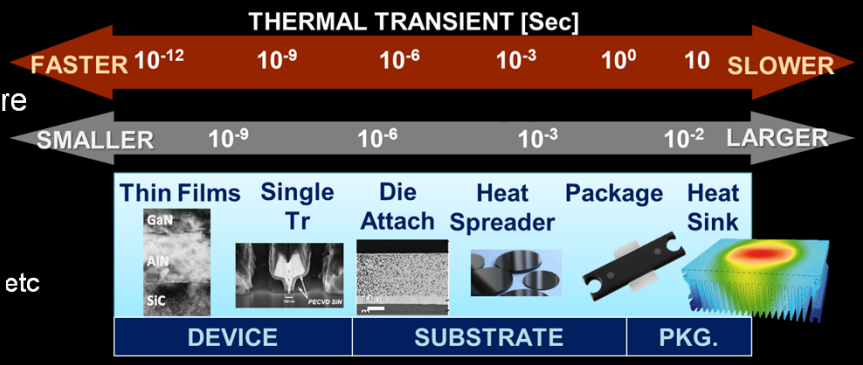
Thermal Characterization Challenges

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



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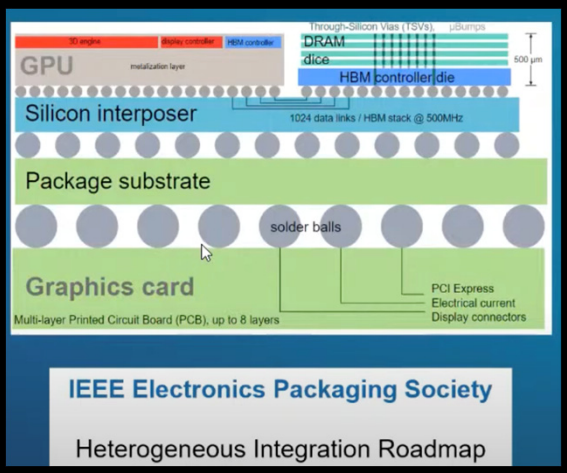
Thermal Characterization Challenges



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Thermoreflectance (TR) Imaging

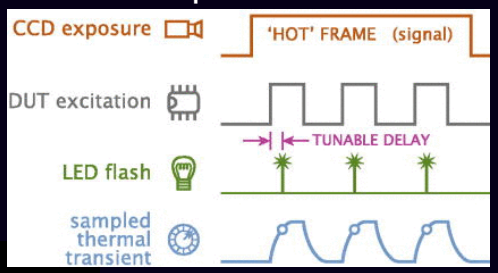
- Reflected light intensity is dependent on temperature

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

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

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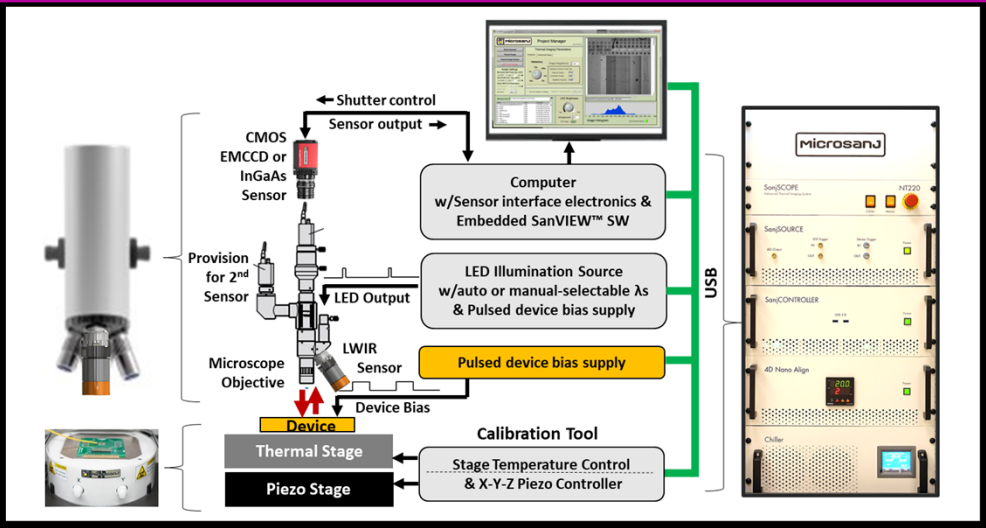
Building Blocks for TR & IR Imaging



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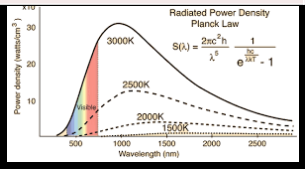
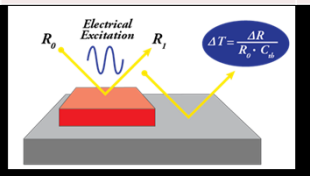
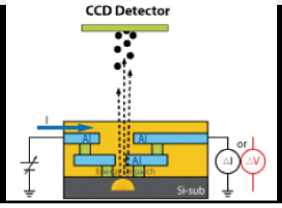
IR, TR, & EMMI

	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







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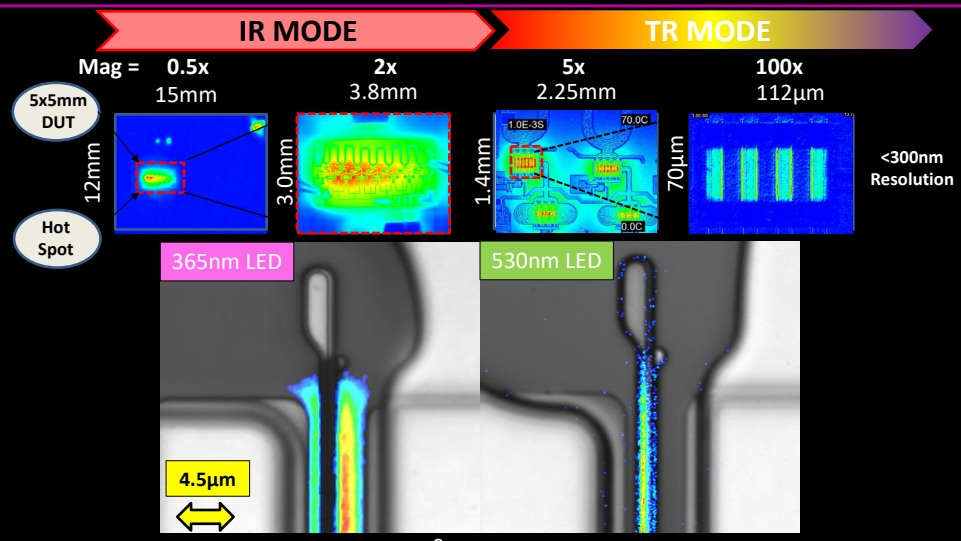
Full Spectrum Thermal Imaging: UV to IR



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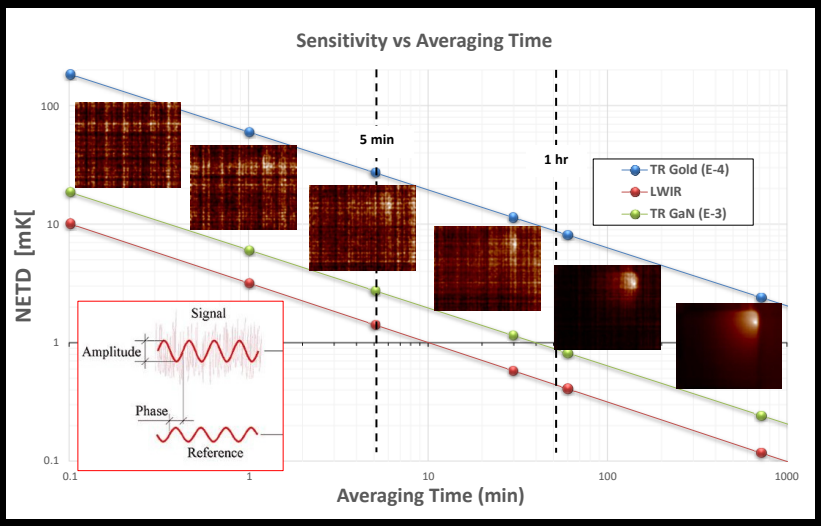
Lock-in Thermography (LIT)



- 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)

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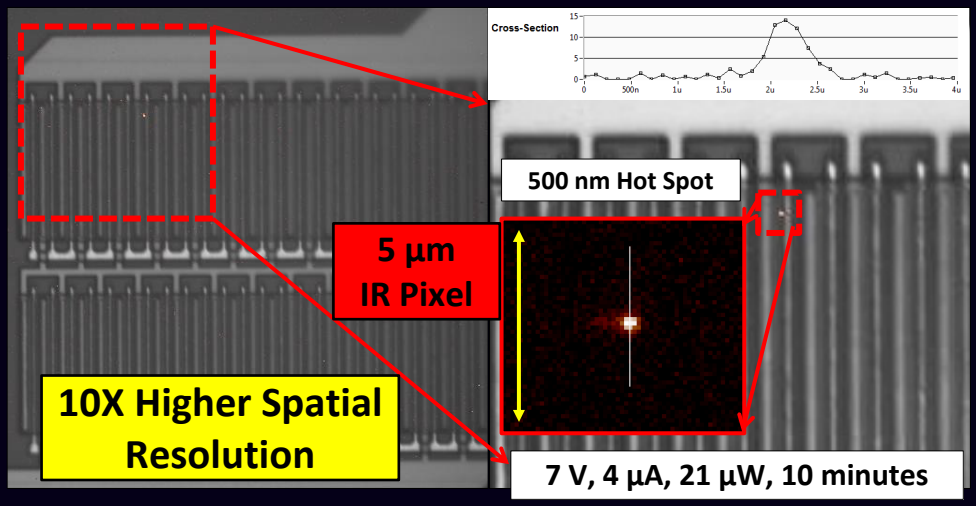
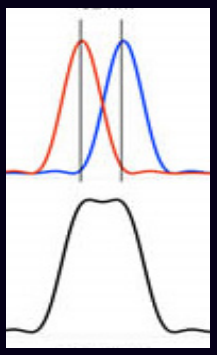
High Spatial Resolution



Abbe diffraction limit

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



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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.

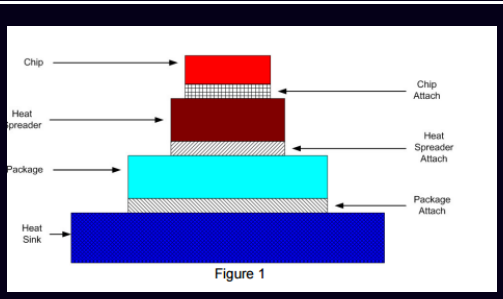
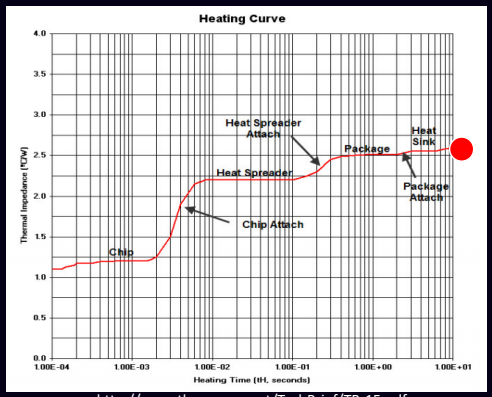


Figure 1

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



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

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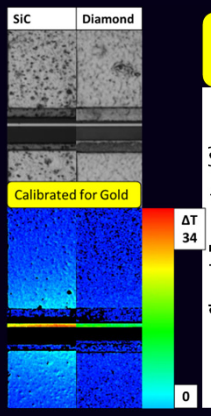
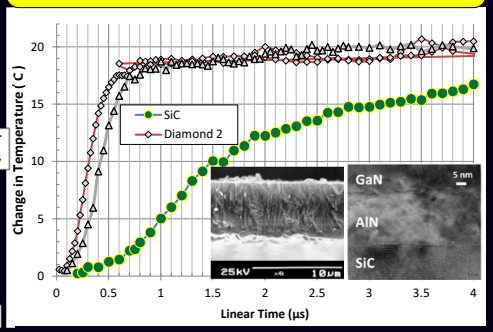
Improving Thermal Interfaces (TBR)

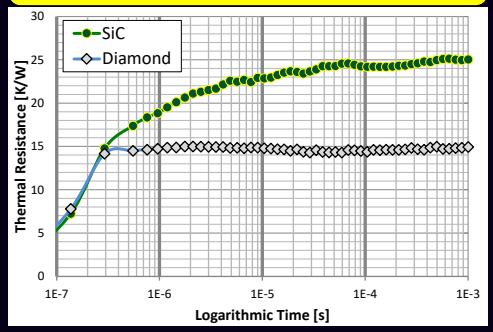
- Transient Temperature measurements help isolate dominant thermal interfaces
- Thermal Boundary Resistance (TBR) can be obtained from the heating curve



Large TBR for old diamond process



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



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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

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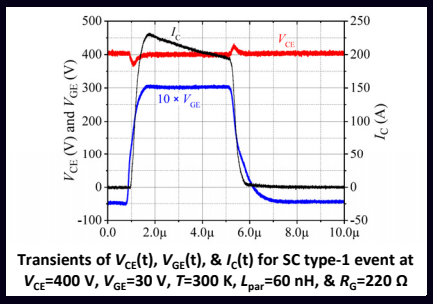
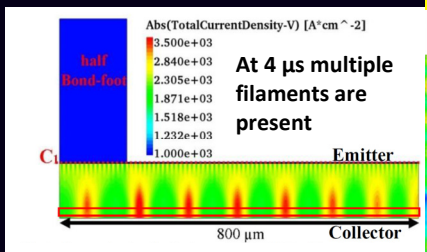
Investigating Short-Circuit Destruction

- Nanosecond thermal imaging allows for imaging of current filaments

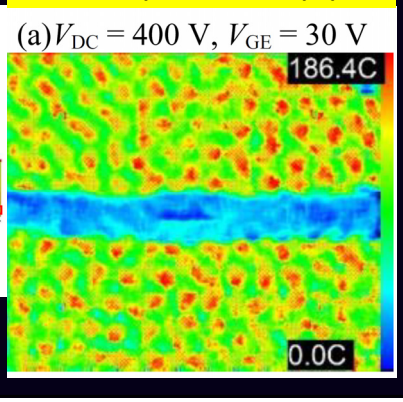


Transients of V_{CE}(t), V_{GE}(t), & I_C(t) for SC type-1 event at V_{CE}=400 V, V_{GE}=30 V, T=300 K, L_{par}=60 nH, & R_G=220 Ω



Current density distribution in IGBT at 4 µs

Surface Temperature after 4µs pulse



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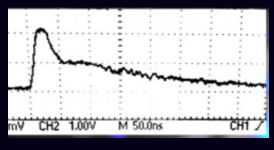
HBM ESD Current Filaments

1700V HBM ESD Waveform



Transient thermal response

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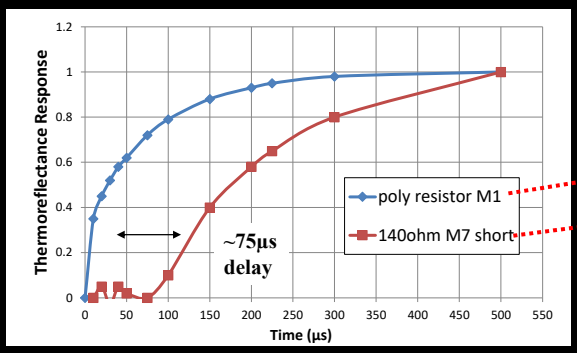
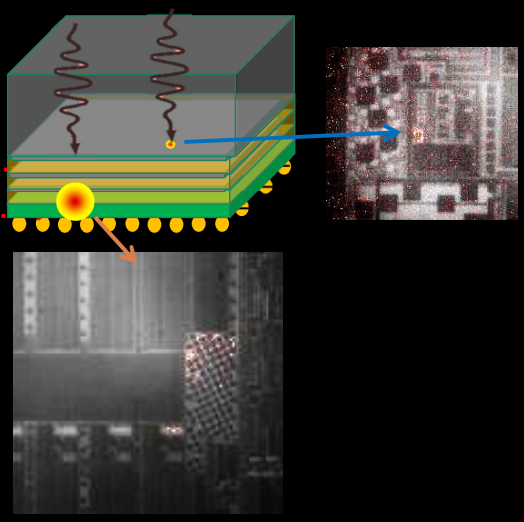
Defect Depth in Metal Layers





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

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

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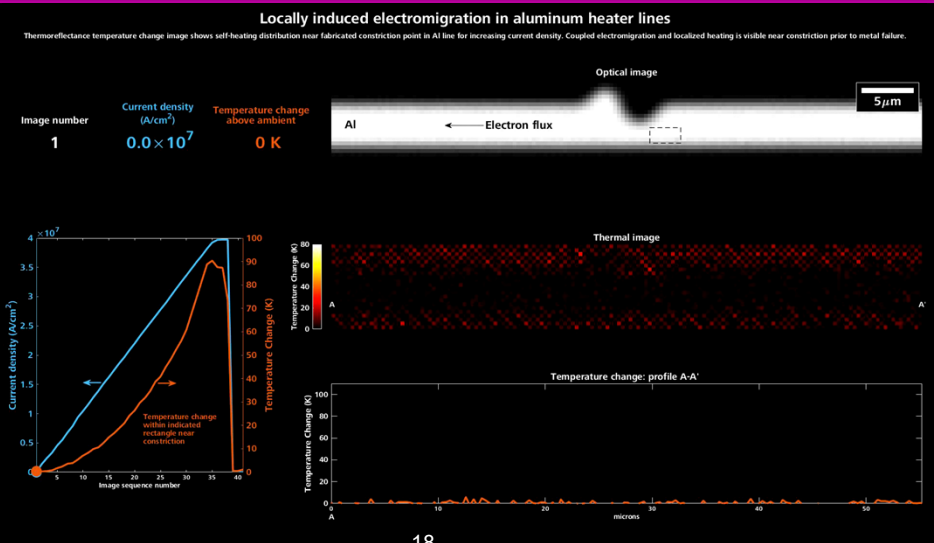
Electromigration & Localized Heating



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Optical pump/probe thermoreflectance imaging

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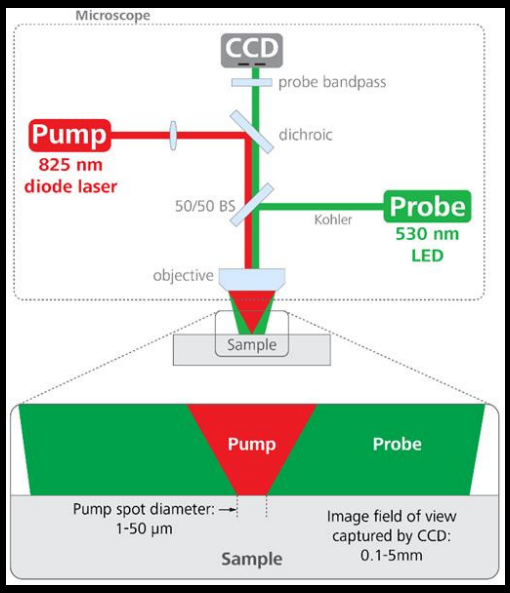

- ***Fully non-contact*** → **no electrical probing needed**
- ***Thin-films and heterogenous samples can be studied***
- ***Multi-scale thermal imaging is easy*** → **Laser size can be varied from 1μm up to cm**

Optical Pump-Probe Thermoreflectance Imaging for Anisotropic Heat Diffusion

K. Yazawa , J. León Gil, K. Maize, D. Kendig, and A. Shakouri

IEEE ITherm 2018
DOI: 10.1109/ITHERM.2018.8419524

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Thermal characterization of 3D ICs

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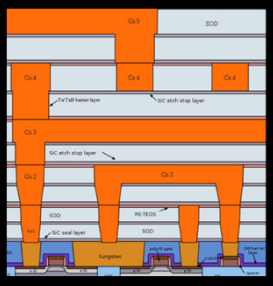

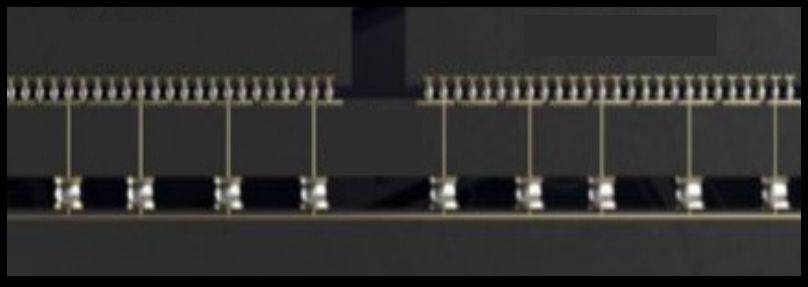

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Conclusion

- Thermoreflectance is shown as another valuable FA technique
- Sub-micron thermal defects are found with TR
- Nanosecond thermal images show current filament location & propagation
- Support analysis of next generation 5G and 3DIC Semiconductors

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