Thermal Test Chip for Thermal Characterization and Qualification of Materials and Semiconductor Packages

44th Symposium & Exposition

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NANOTEST

Berliner Nanotest und Design GmbH

In cooperation with

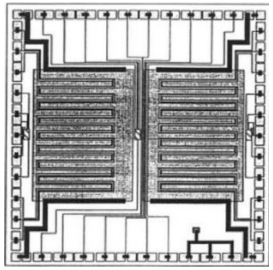
DS&A™

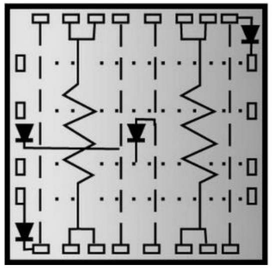
Outline

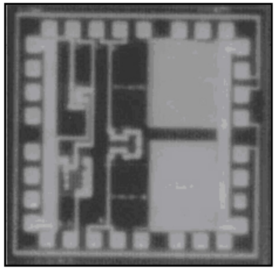
- Motivation
- Design of the Thermal Test Chip
- Qualification and Calibration
- Application examples
    - » Material characterization at TIMA™
    - » Material characterization at TransTIMA™
    - » Highly conductive die attach characterization
    - » Load profile generation
    - » Optical reference heat source
    - » Fluidic analysis
- Conclusion & Outlook

Motivation

- What is a Thermal Test Chip (TTC)?
  - » Basic chip for testing and characterization
  - » Each consists of:
    - a heat source
    - a temperature sensor
    - contacting pads
- Why did we create an own Thermal Test Chip?
  - » Limited availability and selection of TTCs on the market
  - » Available chips do not fulfill requirements:
    - Low power density
    - Inhomogeneous heat dissipation
    - Low temperature accuracy
  - » TTCs are the mainly used tool for thermal characterization and qualification of materials and packages in electronics
  - » A gap in the market


IMEC PTCA TTC


TTD-1000 of TEA.NMRC

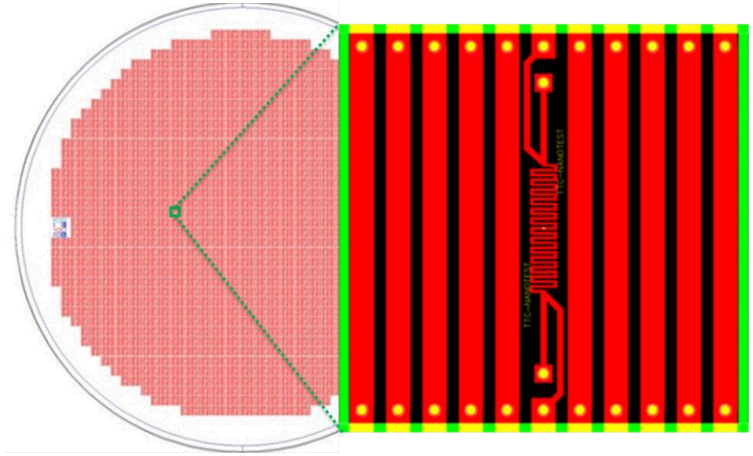

DELPHI PST102


NT16-3K

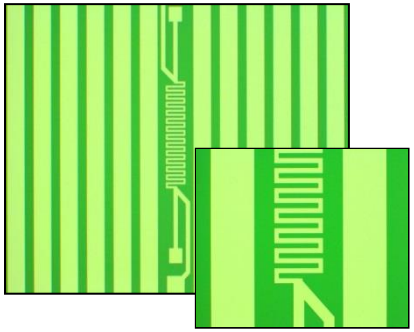
Design » Requirements

- Modularity
  - » Different chip sizes available to meet most requirements
- Homogeneity
  - » Uniform heater structures for homogeneous heat dissipation up to 1 W/mm²
- Resolution
  - » Thermal resolution of temperature sensing up to ± 0.2 K
  - » Spatial resolution of temperature sensing up to ± 500 µm
- Reliability
  - » Suitable for long-term load cycle testing to > 100,000 cycles
- Cost-Effectiveness
  - » Suitable as consumable rather than as invest
- Assembly
  - » Available for different assembling technologies
- Metallization
  - » Available with different backside metallization

Design » Layout

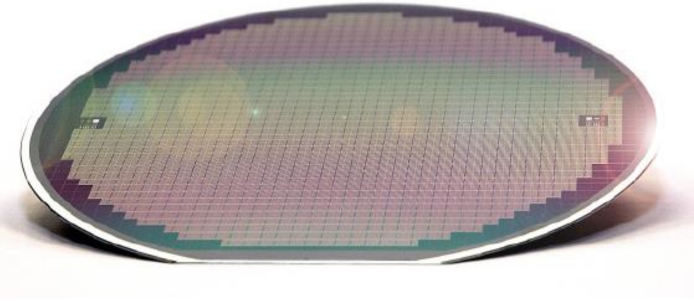


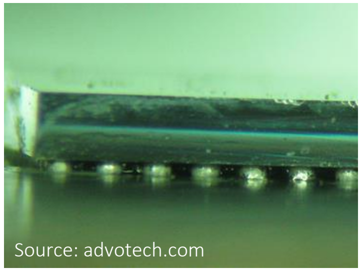
- Wafer
  - » Standard 150 mm Si wafer
  - » Thickness
    - Bulk silicon: 675 µm
    - Oxide coating: 1 µm
  - » 1200 chips per wafer
- Masks
  - **» Use of only 3 masks for the full process:**
    1. Mask for lithography of the temperature sensor and heater structures
    2. Mask to open the vias for contacting the structures
    3. Mask for the deposition of the contact layer metallization



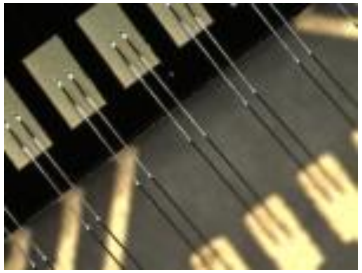
- The Edge
  - » Few masks for the whole process
  - » Si wafers in standard size
  - » Processing steps with small tolerances
  - » Fully modular wafer layout for custom chip sizes

Design » Wafers



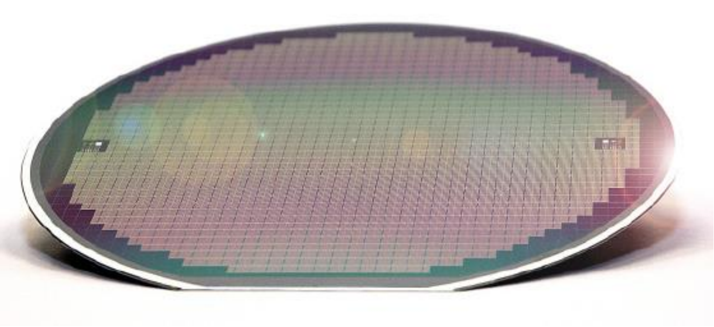


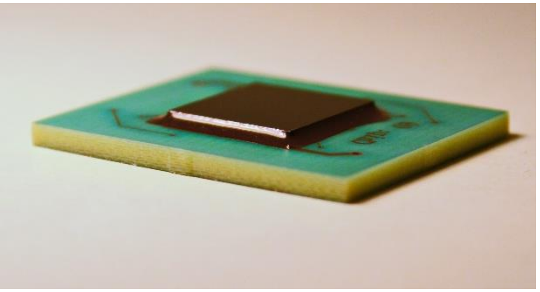
Source: advotech.com

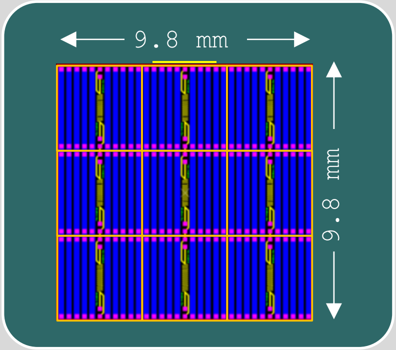


Assembling technology	Flip Chip Assembly	Wirebond Assembly
Fabrication technology	Thin film	Thin film
Wafer diameter	150 mm	150 mm
Wafer thickness	**675 µm**	**400 µm**
Cell size	3.2 x 3.2 mm^2	3.2 x 3.2 mm^2
Cell count	1200	1200
Heaters per cell	10 resistors (160 Ω each)	10 resistors (160 Ω each)
Sensors per cell	1 resistor (3 kΩ each @ RT)	1 resistor (3 kΩ each @ RT)
Backside metallization	**None**	**Ti/Pt/Au (100 nm each)**
Contact pad	**Cu pillar (40 µm) & AgSn (30 µm)**	**Al metallization**
Pad size	**80 µm**	**150 µm**
Pad raster	300 µm	300 µm

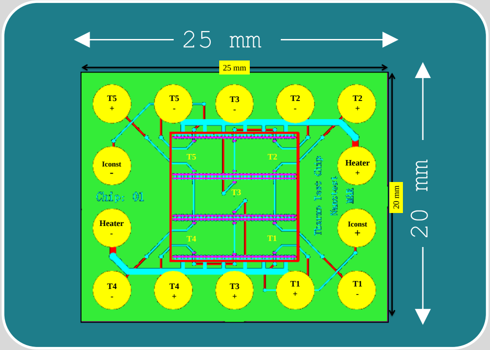
Design » Flip Chip Assembly



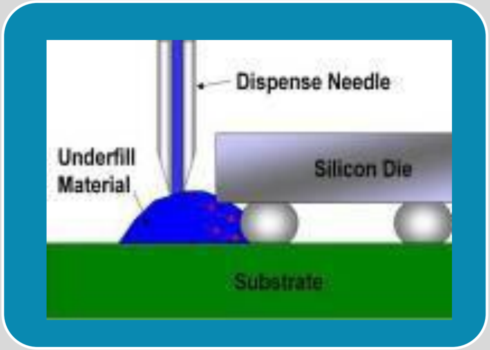




Wafer dicing



Flip-Chipping & Soldering



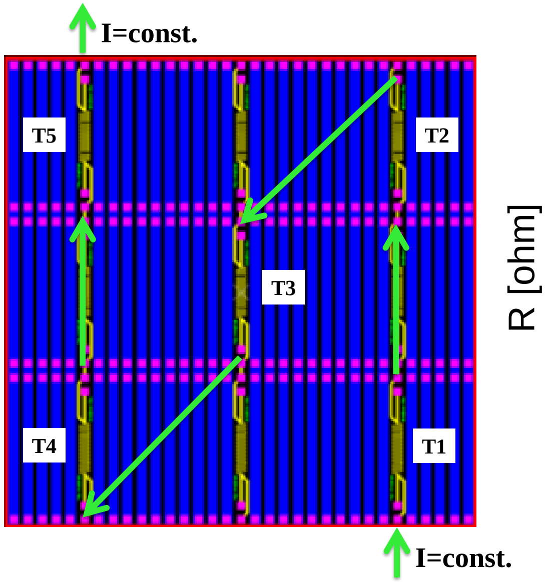
Underfilling

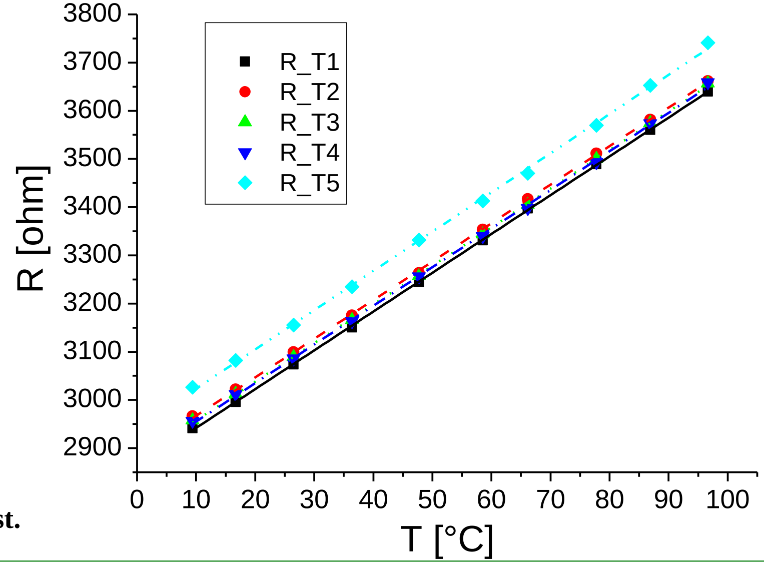
- Standard semiconductor process with low defect rate
- Default package for Nanotest applications:
  - » Full-area heater and five temperature sensors
- Highly reliable package that is suited for cycle testing

Temperature Calibration

- Calibration with Nanotest HK200™
- Calibration of 5 sensors simultaneously
- Four-wire termination
  - » 1 mA sensing current
- Resistance perfectly proportional to the temperature
  - » $R^2 > 0.9998$

Nanotest HK200™





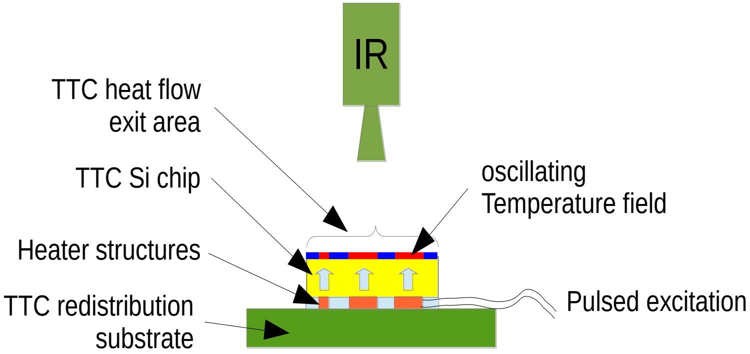
#	Slope [Ω/K]	axis intercept [Ω]
T1	8,049	2861
T2	7,994	2887
T3	8,013	2878
T4	8,009	2875
T5	8,140	2942
mean	8,041	2889

sensitivity: 8 Ω/K

→ 4X higher sensitivity
compared to Si diodes
(@ 1 mA)

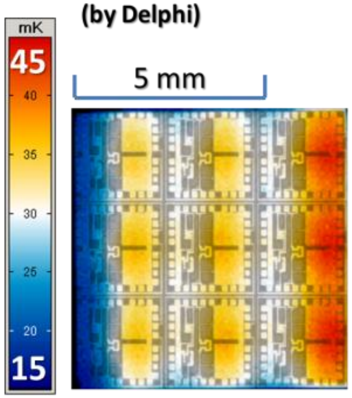
Temperature Homogeneity

- Homogeneity is of very high importance for TIM characterization:
  - » Inhomogeneous heat flow leads to faulty thermal analysis results
- Use of thermal imaging for transient modulated technique
  - » At steady-state (Q = 0), non-homogeneities are not detectable
- Lock-in thermography amplitude image for quantification of the heat flow distribution

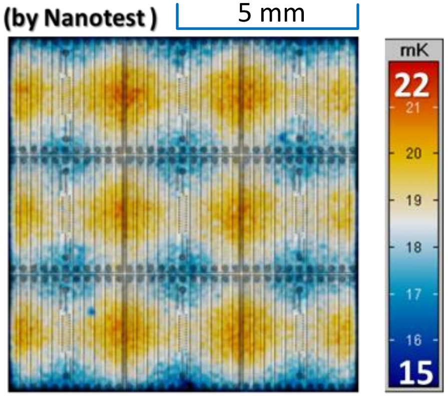


NT16-3K is a 4X improvement over earlier test die previously used in thermal characterization.

PST102
(by Delphi)



NT16-3K
(by Nanotest)

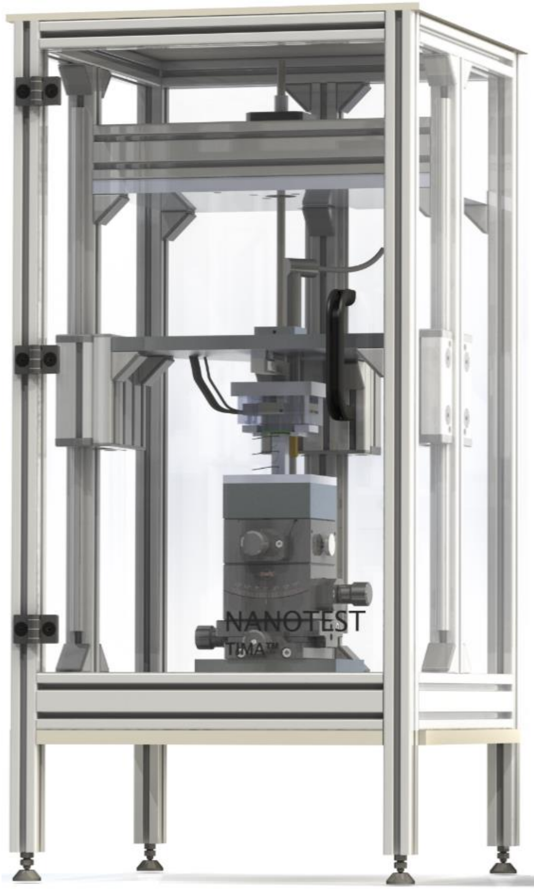


Applications I » TIMA™ Pt. 1

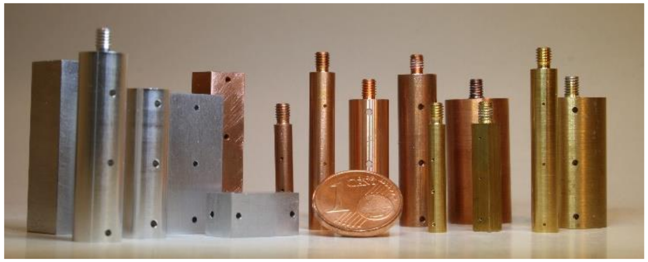
TIMA™

Steady state measurement technique

- Measurement of bulk thermal **conductivity** of low to medium thermally conductive material
- Measurement of thermal **interface** resistances
- For solid and viscous materials
  - Substrates (FR4, IMS, LTCC, HTCC etc.)
  - TIMs (greases, adhesives, gap fillers, films etc.)
  - Isolation layers (foils, foams etc.)
- Cyclic testing for **ageing** investigations
  - Thermal and/or mechanical cycling
- Advanced **customized** thermal investigations



Selection of feasible samples

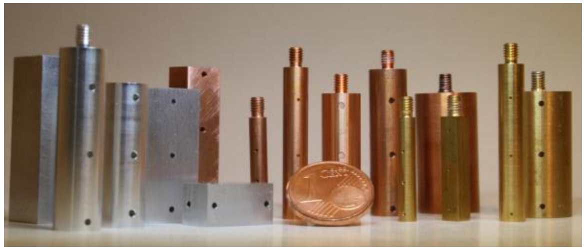


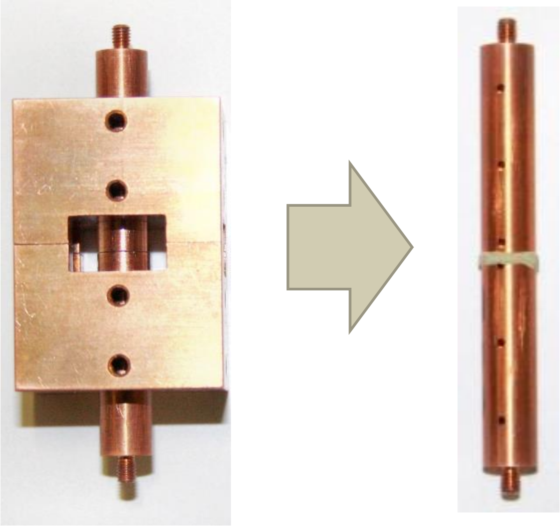
Selection of metal test heads for characterization

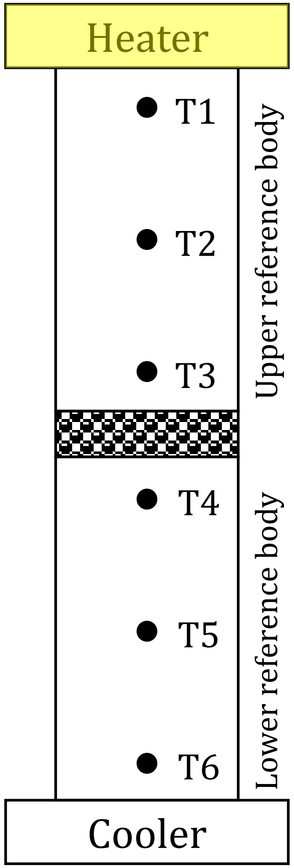
All-round steady-state characterization platform

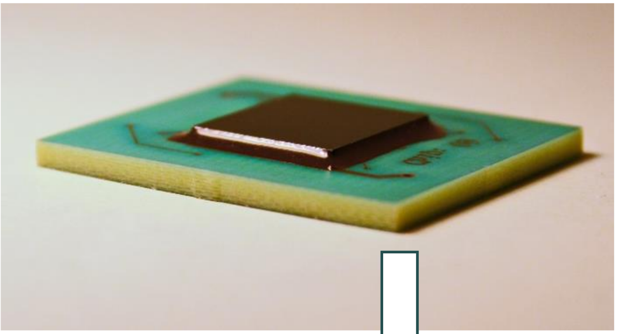
Applications I » TIMA™ Pt. 2

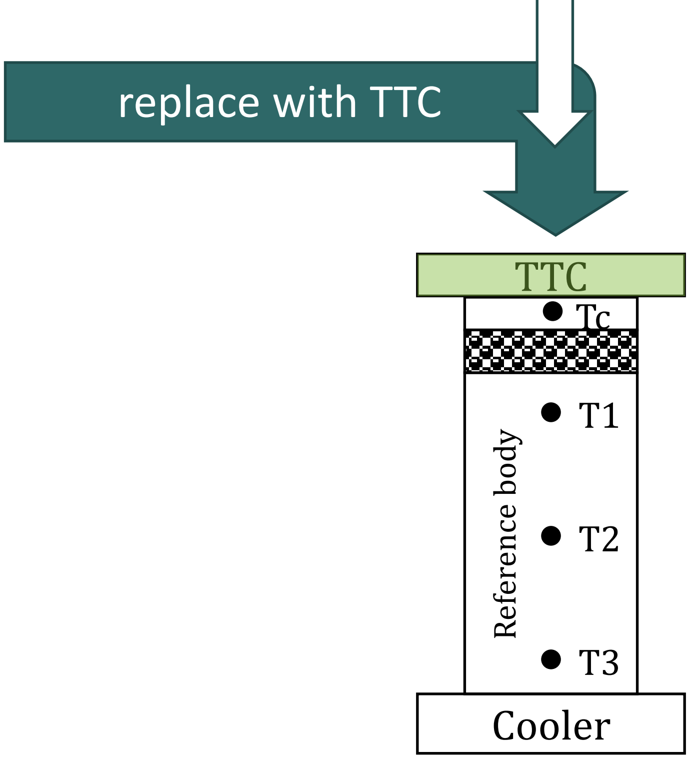
- Method based on ASTM D-5470
  - » Advanced studies with die surface



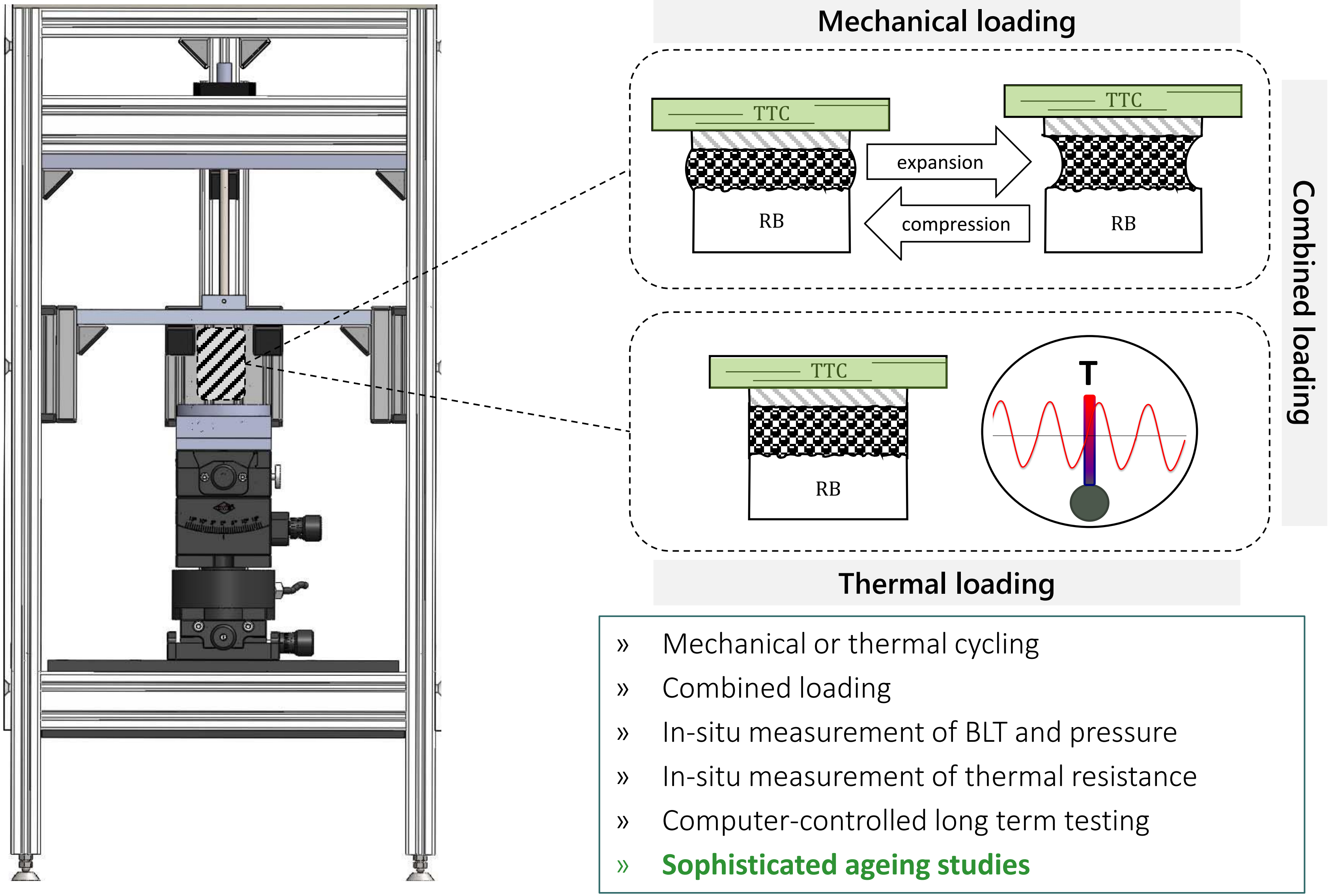








Applications I » TIMA™ Pt. 3

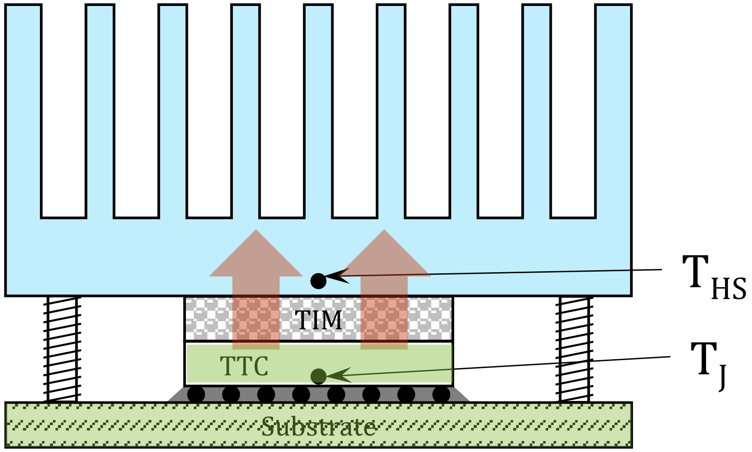


- Mechanical or thermal cycling
- Combined loading
- In-situ measurement of BLT and pressure
- In-situ measurement of thermal resistance
- Computer-controlled long term testing
- **Sophisticated ageing studies**

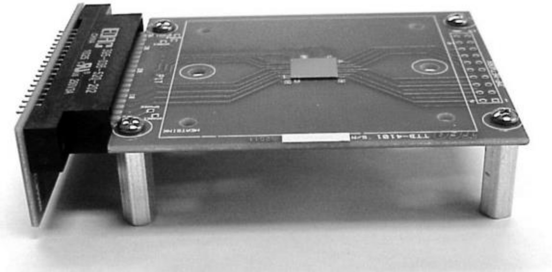
Applications II » Effective thermal resistance

- Implementation of the JEDEC standard JESD51-3
  - » Determination of the effective thermal resistance of TIMs
  - » In-situ and ex-situ investigation of ageing behavior
- Highly compact, affordable and easy to build

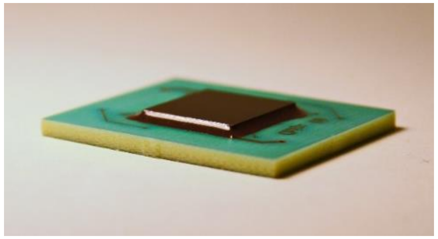
$$R_{th} = \frac{T_J - T_{HS}}{\dot{Q}}$$



schematic of method



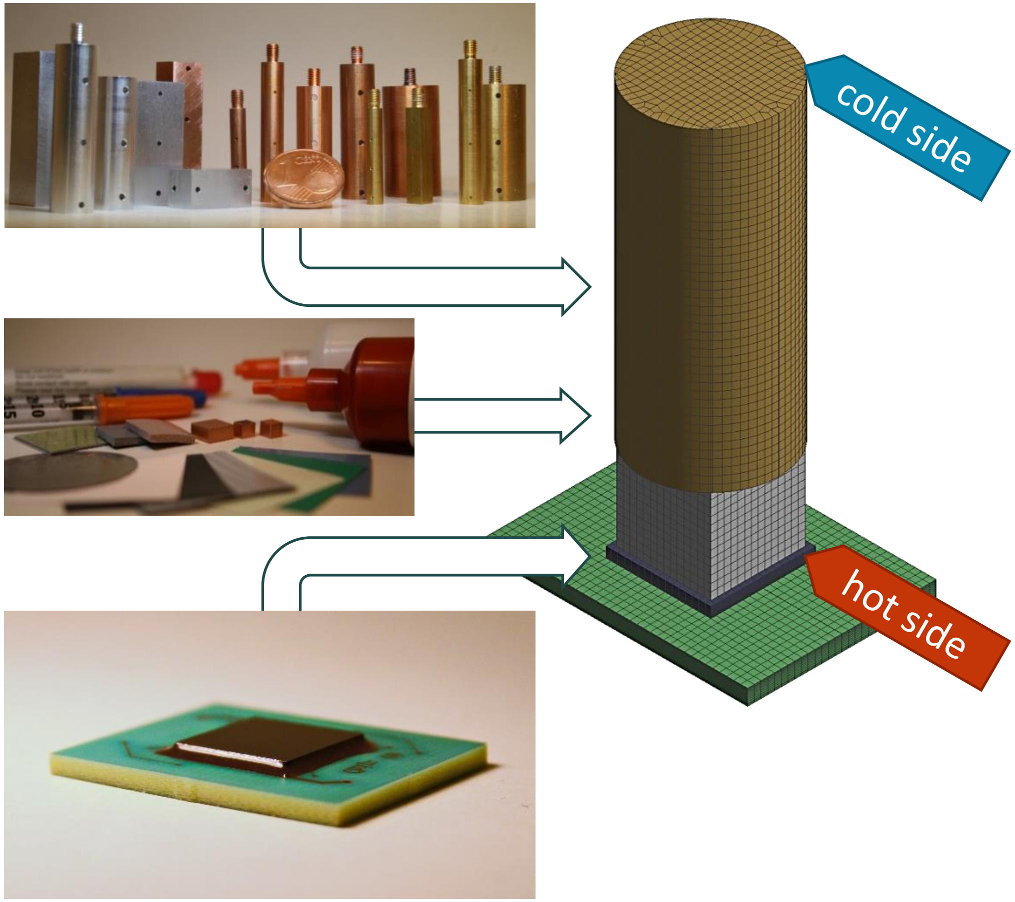
TTV-410X by TEA

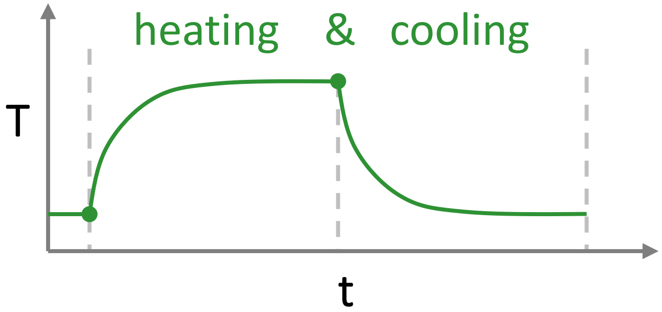


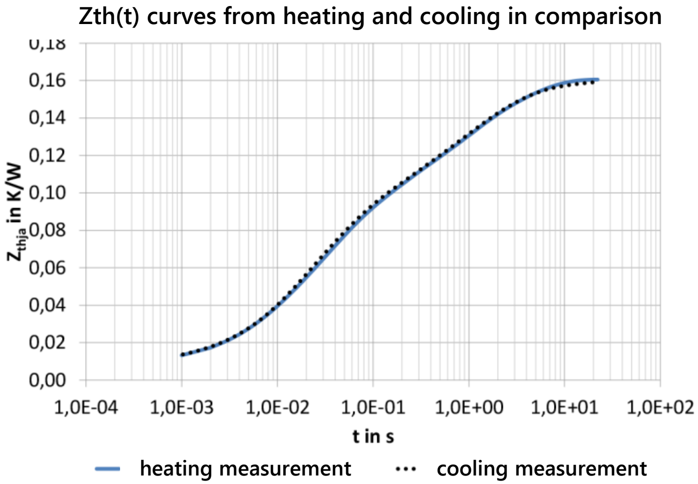
TTV by NANOTEST

Applications III » TransTIMA™ Pt. 1

- Combination of TIMA™ and thermal transient methods
  - » The edge of the TTC: <u>separation of heating and sensing</u> allows for temperature measurement regardless of the power state



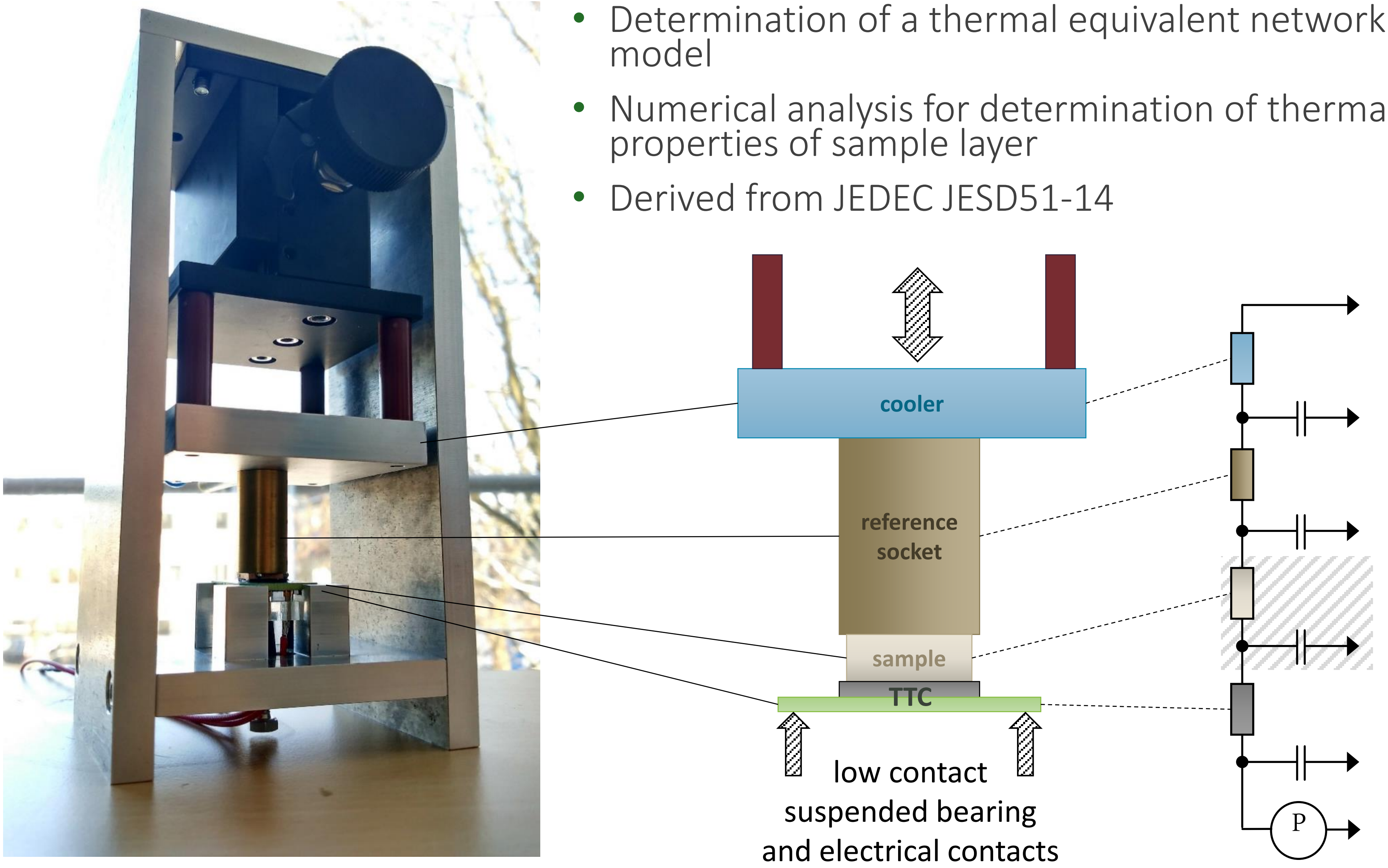




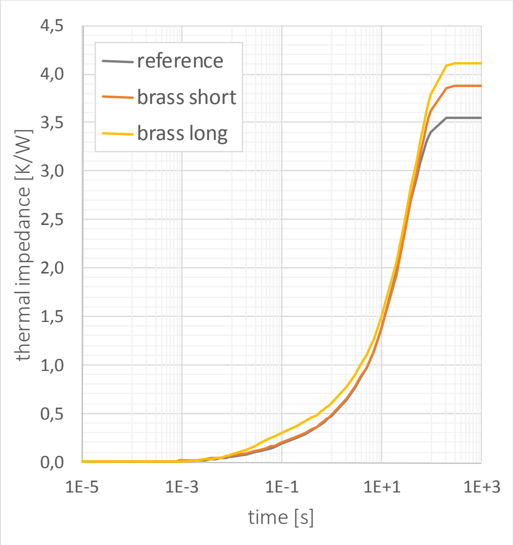
(Source: PhD. Alexander Hensler)

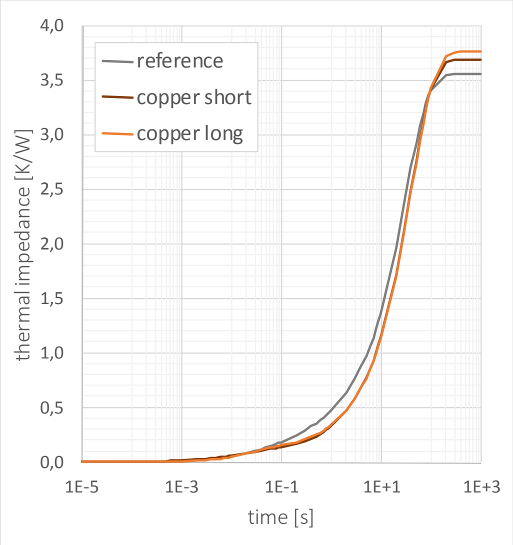
Applications III » TransTIMA™ Pt. 2

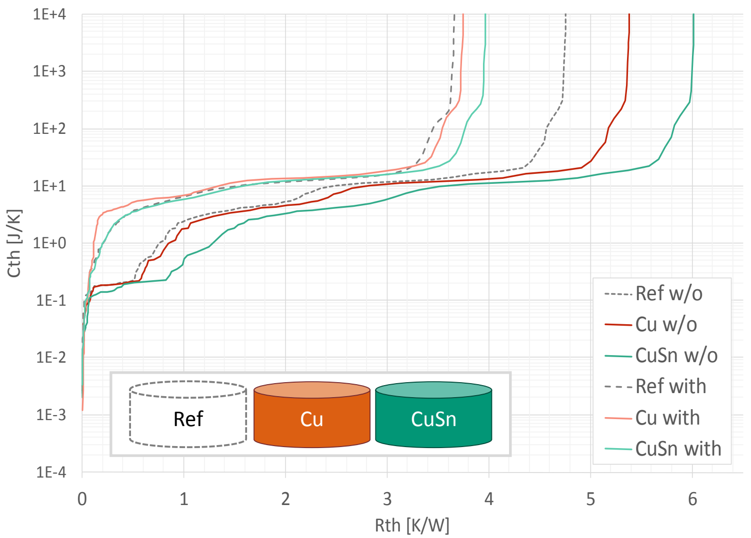
- Determination of a thermal equivalent network model
- Numerical analysis for determination of thermal properties of sample layer
- Derived from JEDEC JESD51-14

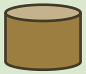


Applications III » TransTIMA™ Pt. 3







#	$R_{th,J\text{-}A}$ [K/W]
	3,58
	3,88
	4,12

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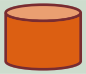
	3,76

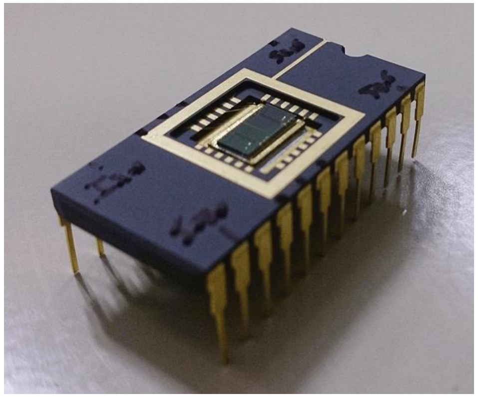
- Metal samples -- evaluation study (published at IMAPS France ATW Thermal, La Rochelle FR 2016)
- Structure function for detailed analysis on multilayer-samples

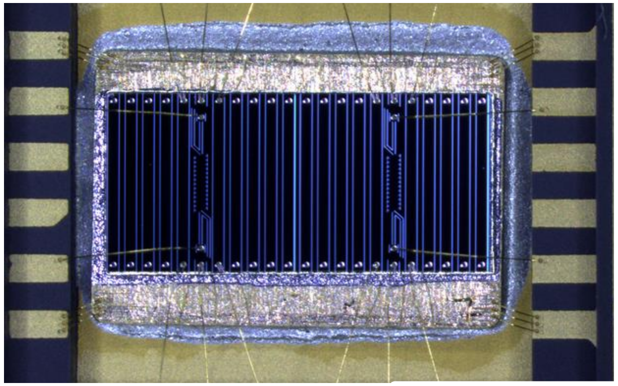
» Highly compact and efficient tool for transient thermal characterization of thermal interface materials

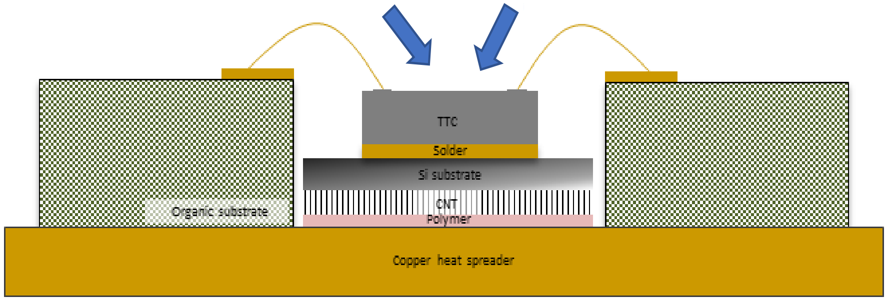
» Directly application related results, determined with direct contact to die surface.

Applications IV » Die Attach Characterization

- Characterization of vertically aligned carbon nanotubes (VACNTs)
- TTC as replacement for the real application target chip
- Used for excitation (heating) and temperature sensing
- Measurement of the transient step response
- Comparison to reference measurement with standard adhesive

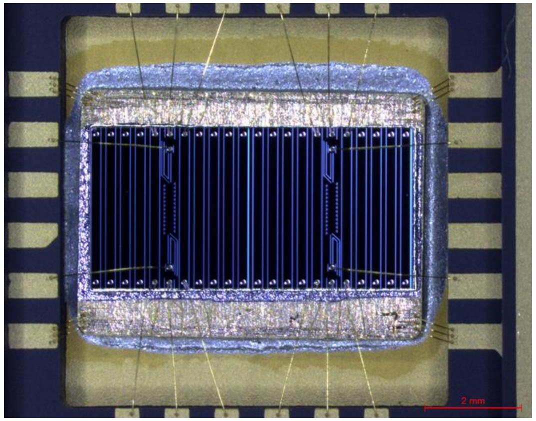


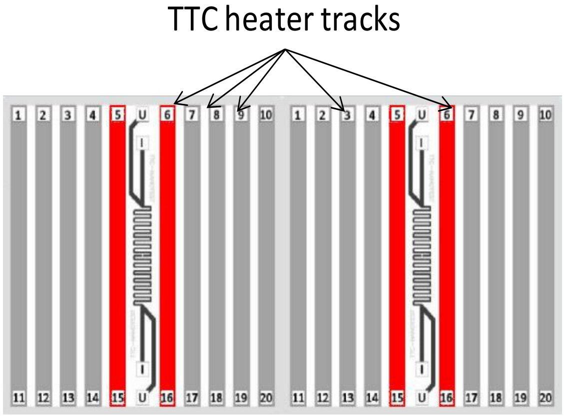


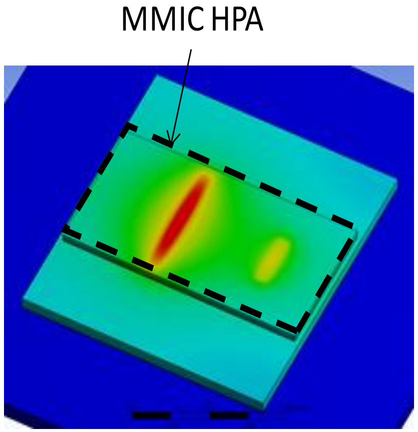


Applications V » Load profiles

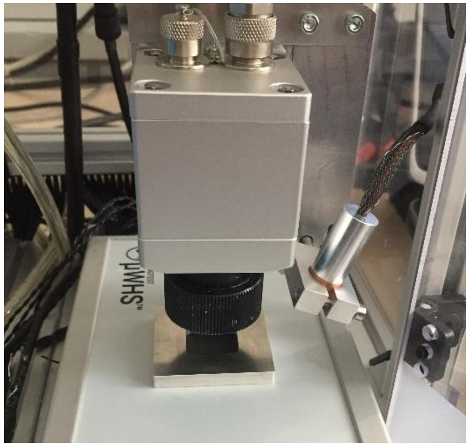
- Separate contacting of heater lanes allows recreation of various custom load profiles
- Heater lanes can be individually contacted and controlled to generate
  - » Custom hot spots
  - » Defined temperature gradients / fields
  - » Application case-specific heat density distributions can be incorporated in testing



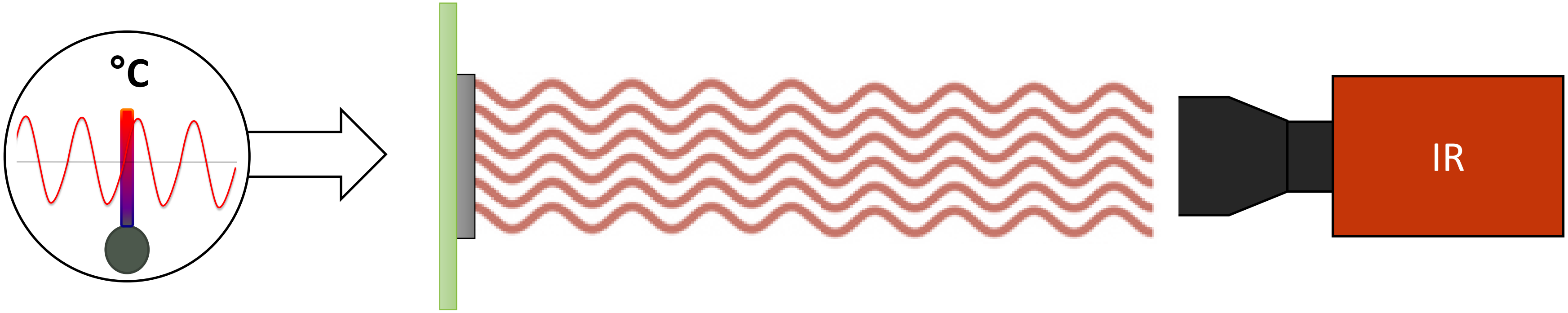




Applications VI » Use as optical reference

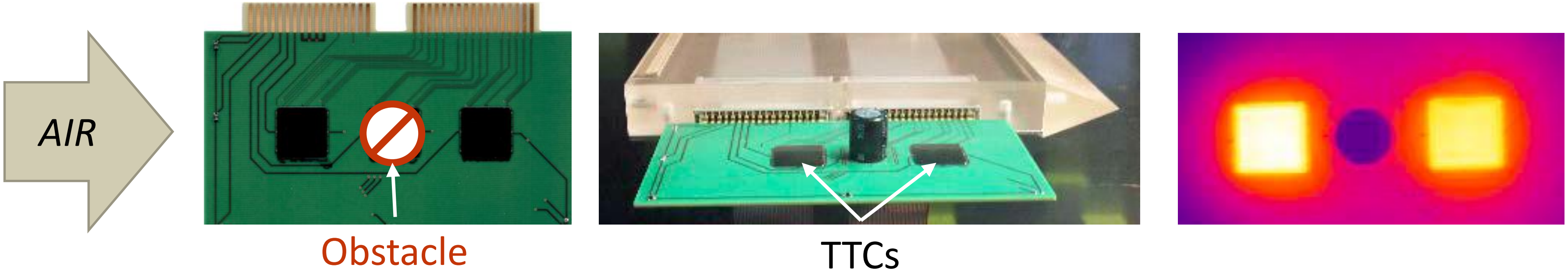


- Chip-surface ideal for reference measurements close to application
  - » Coatable with any metal / material of choice
  - » Reflecting (native) or matte (camera paint)
- Multiple purposes
  - » Infrared & thermoreflectance thermography
  - » Controlled and precise temperature reference
    - Homogeneous or temperature gradients
  - » Time-domain for lock-in analysis



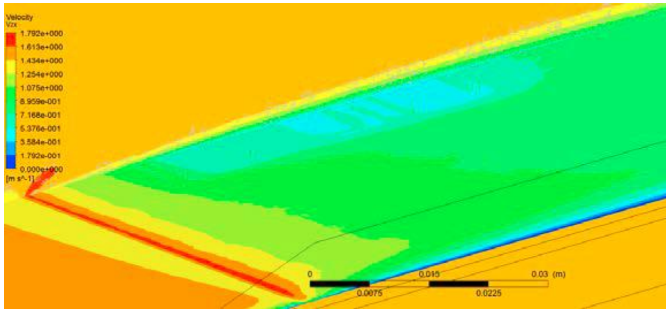
Applications VII » Fluidic analysis

- Influence of obstacles in air flow on active air cooling
- Two TTCs in air flow direction with obstacle in between

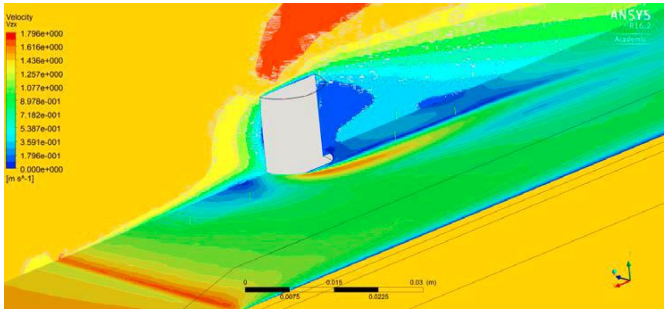


- TTC as both heat source and temperature sensor

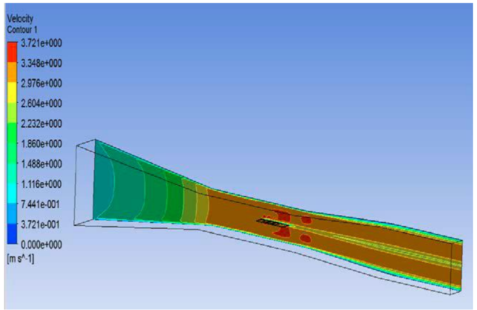
W/o obstacle



With obstacle



Simulation



- Good correlation between simulation and experiment

Conclusion

- Available TTCs did not fully meet our requirements
  - *Very* limited availability and/or quality.
- We created a TTC that meets our requirements:
  - High precision, suited for accurate thermal characterization
  - Available for different assembly and packaging technologies
  - Highly configurable and flexible
- Numerous different application examples prove the diverse feasibility and flexibility of these TTCs:
  - In-situ material and system characterization
  - May be used for both transient and steady-state analyses
  - Optical calibration or referencing is practicable
  - Capable for use in sophisticated analyses and complex studies

Contact Information

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