13th LEIBNIZ CONFERENCE OF ADVANCED SCIENCE
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**NANOSCIENCE 2012**

# Test stand for the Characterisation of Thermal Interface Materials from the macro level up to the nano level

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# Outline

- Application of Thermal interface Materials
- Characterization of thermal interface materials
- New platform for different modules for the characterization of TIM
- Characterization capabilities
- Interesting results
- Summary

# Motivation

# Applications of thermal interface materials

## Examples of TIM applications

- TIM1 (die to package or to heat spreader)
- TIM2 (package or heat spreader to heat sink)
- Solder and Underfill

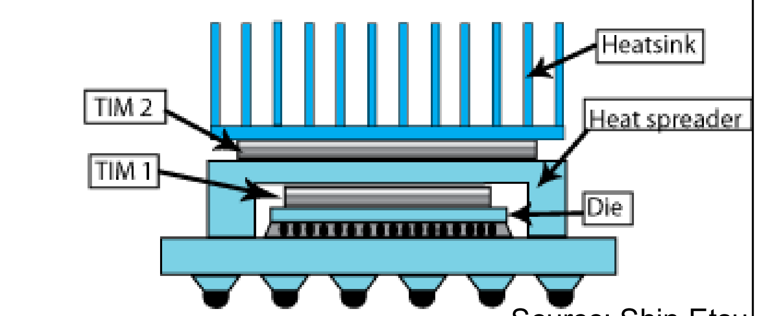
## Type of TIMs:

- Grease, adhesive, pad, gap filler, solder, mono metal, etc.
- Electrical conductive, electrical insulating

## Aims & Challenges

- High thermal conductive
- Low thermal interface resistance
- Low bond line thickness
- Large contact area

Cooling configuration of a typical CPU




Source: Shin-Etsu


Source: Nanopack

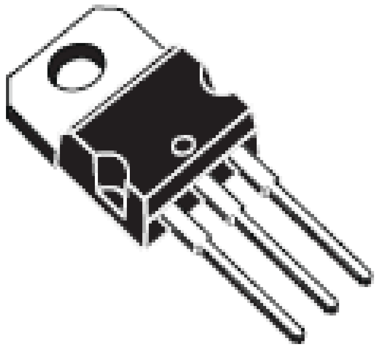
# Importance of Thermal Interface Materials

- Market analysis for Thermal Interface Materials & Thermal Management Technologies
  - **Market size: +10.3%/year: 6.8 B€ in 2008 → 11.1 B€ in 2013**
  - Market share:
    - In 2007: Computer industry: 57%, Telecom: 16%
    - In 2013: Medical: 12%, Office electronics: 12%
  - Main actors: Bergquist, Chomerics, Thermalloy, Lytron, Power Devices, DoW Corning, Shin Etsu, Denka, Arctic Silver, Wacker Chemie, Thermarcore, Hereaus, ...

- field of application
  - Avionics
  - Aerospace
  - High Brightness – LEDs
  - Power electronics.
  - Microprocessor
  - Data centers
  - Automotive
  - Etc.

# Example: Power Transistors

TO-220 Package: typically used for power MOSFETs, IGBTs, Bipolar Transistors, etc.



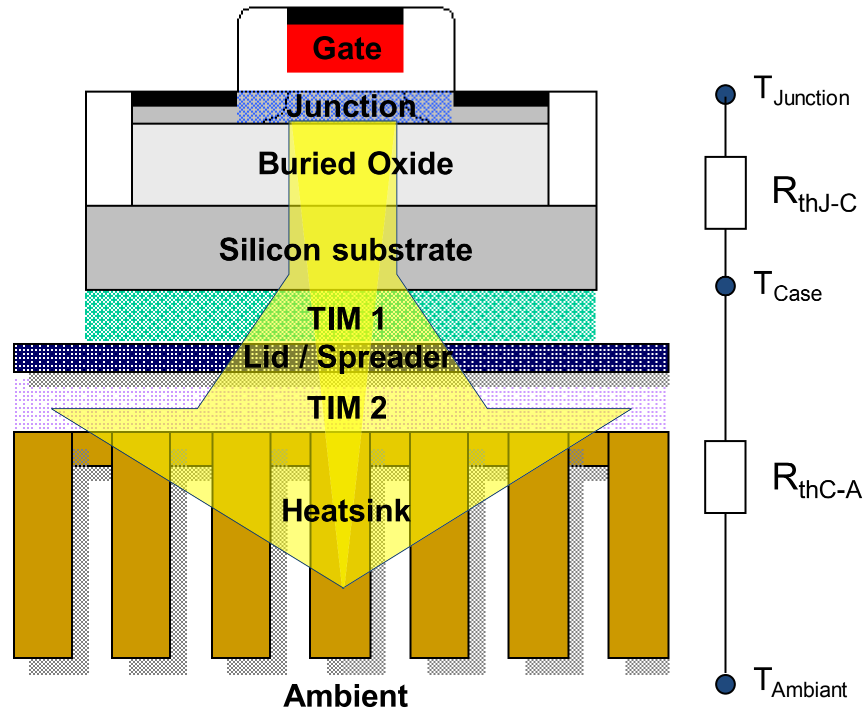


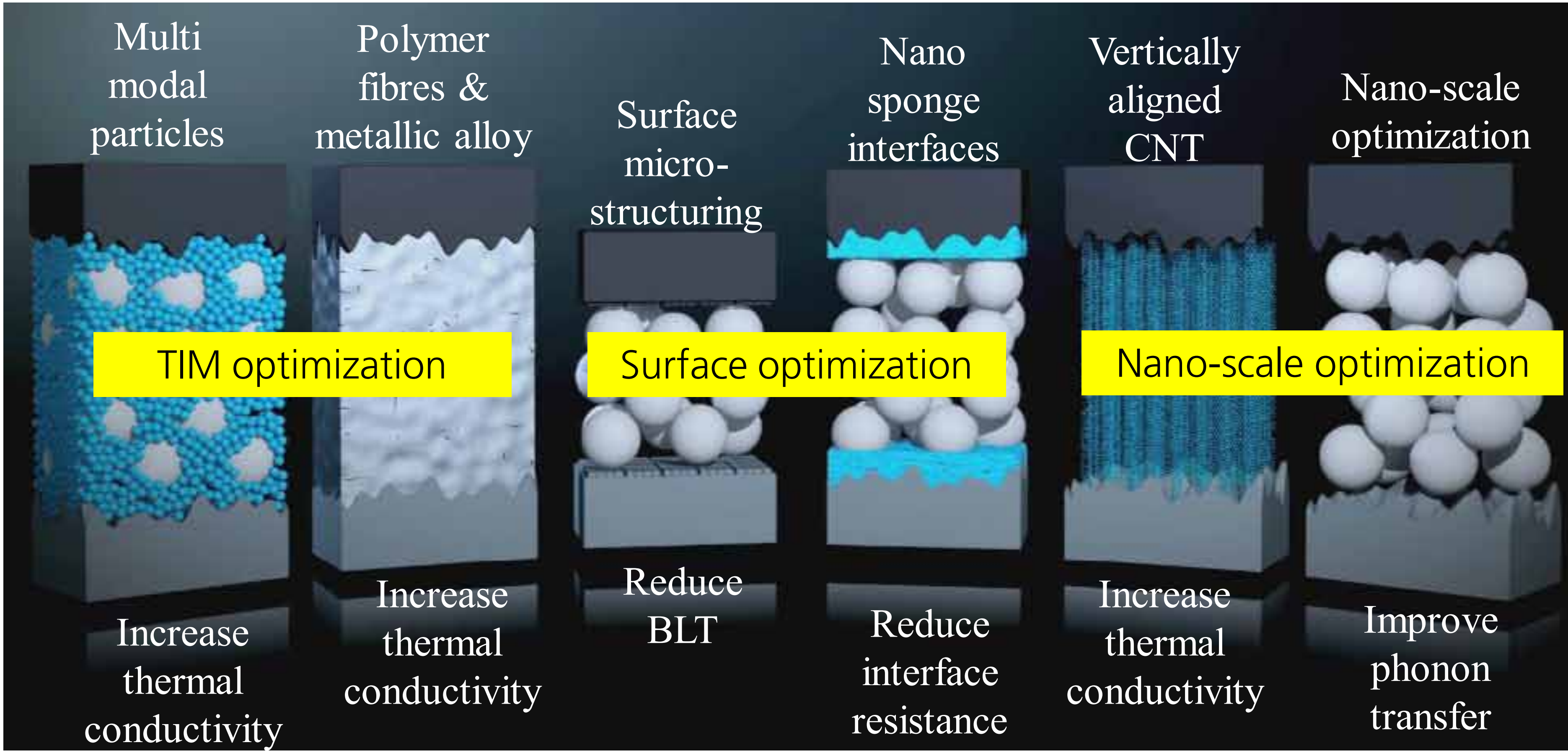

**Table 3. Thermal data**

| Symbol | Parameter | TO-220 | Unit |
|---|---|---|---|
| $R_{thJC}$ | Thermal resistance junction-case | 3 | °C/W |
| $R_{thJA}$ | Thermal resistance junction-ambient | 50 | °C/W |

*Sources: specification sheet of ST Microelectronics L78xxAB series of regulators*

Thermal Interface Materials and Heatsinks represent more than 90% of the thermal resistance

# Nanotechnologies to improve heat transfer




**→ Advanced technologies need advanced test systems**

# Characterization of Thermal Interface Materials

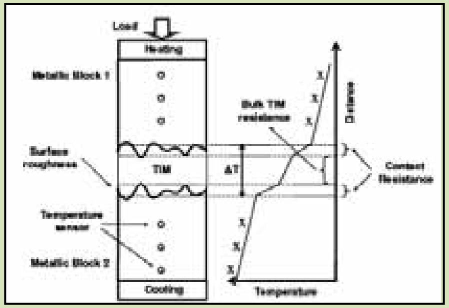
# Methods for Characterization of TIMs

## Transient methods

- Transient Flash
- Synthesized dynamic models
- JESD 51: Thermal measurement of component packages
- …

## Steady state methods

ASTM-D5470

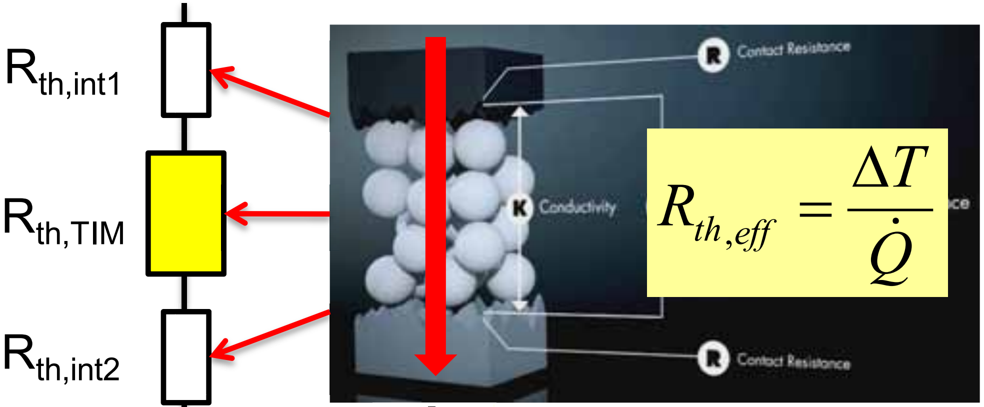



**Disadvantage of ASTM D5470:**

- No real conditions, use two Cu bar
- No characterization of adhesives or solders
- No in-situ measurement of BLT
- Samples are tested under high pressure

# Characterization of Thermal Interface Materials

## Basic principle




$$R_{th,eff} = \frac{\Delta T}{\dot{Q}}$$

$\dot{Q}$

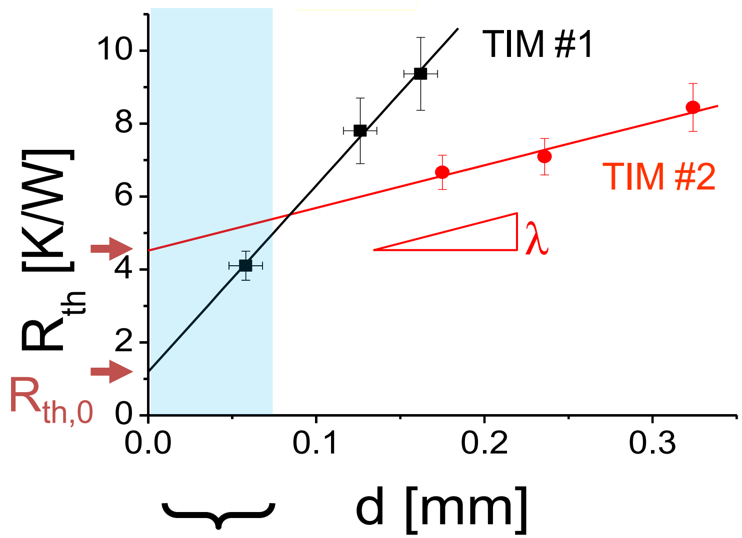
$$R_{th,eff} = R_{th,\text{int1}} + R_{th,TIM} + R_{th,\text{int2}}$$

$$R_{th,eff} = R_{th,0} + \frac{1}{\lambda_{bulk} \cdot A} \cdot d$$

$$y = b + a \cdot x$$

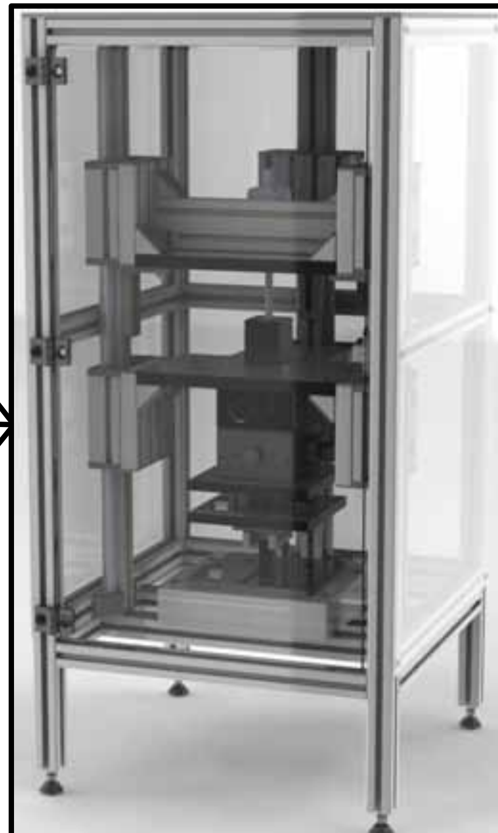
→ Bulk and interface contribute to Rth

Linear function



# The New Platform with different Modules

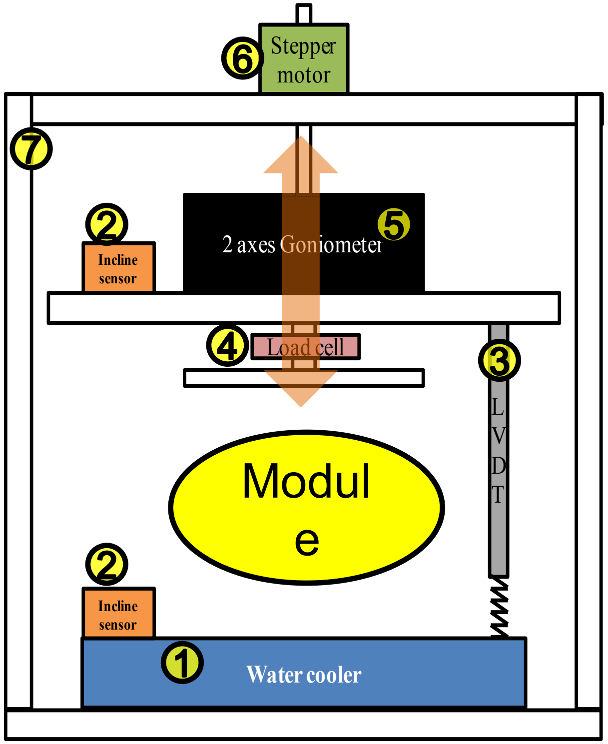
TIMA-Platform



- Testing of non-adhesive TIMs
- High accuracy testing
- Reliability testing of TIMs
- Testing of adhesive TIMs
- Testing of highly conductive TIMs
- Costumer specific modules

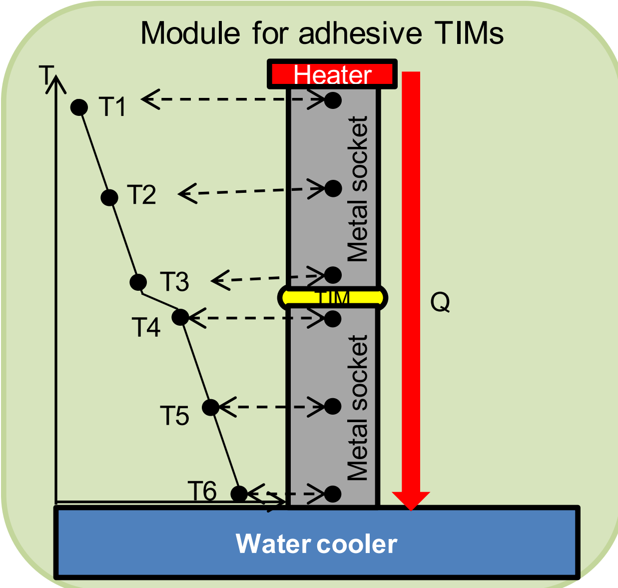
# TIMA Platform

| | | |
|---|---|---|
| 1 | Water cooler | |
| 2 | Incline sensors | 30 arcsec resolution |
| 3 | LVDT Distance mester | 1µm resolution |
| 4 | Load cell | ± 200N |
| 5 | 2 axes-goniometer | 30 arcsec resolution |
| 6 | Stepper motor | 0,25µm steps |
| 7 | case | PMMA |



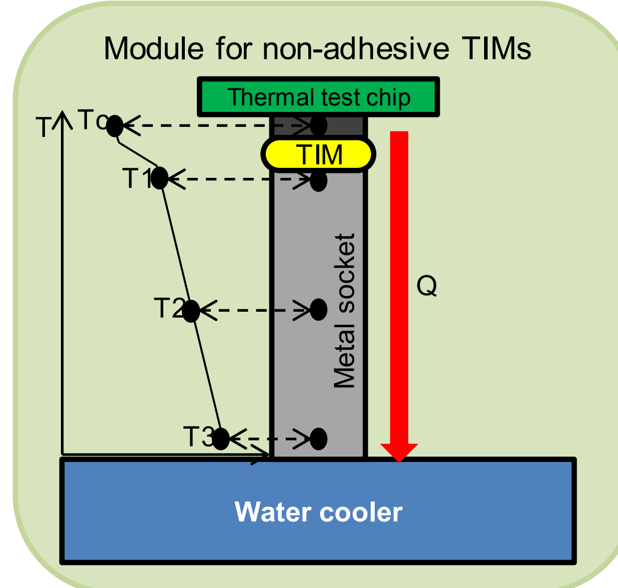

→ Universal platform for different modules for characterization of all types of TIMs

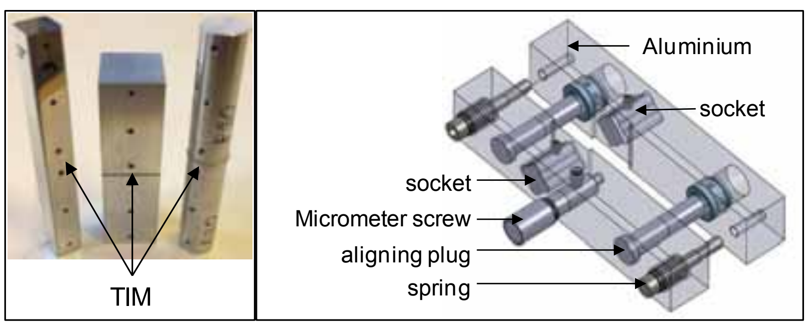
# Standard characterization of TIMs




Following values and dependences can be calculated by these modules

| | |
|---|---|
| $\lambda_{bulk}$ | $Rth = f(T)$ |
| $\lambda_{eff}$ | $Rth = f(p)$ |
| $Rth_0$ | $Rth = f(Rz)$ |
| $\alpha$ | $\alpha = f(p)$ |



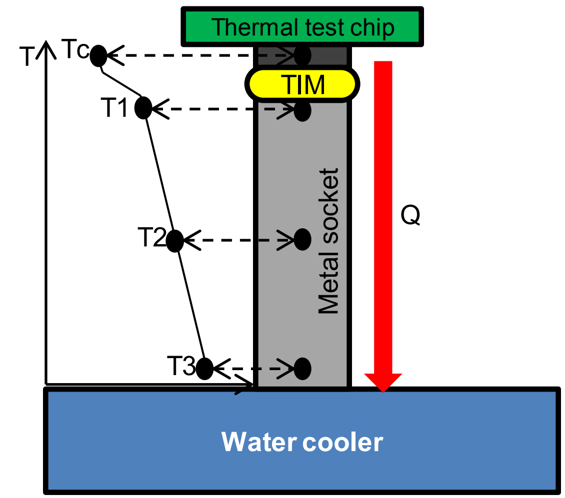

Tool for assembling of thermal adhesives

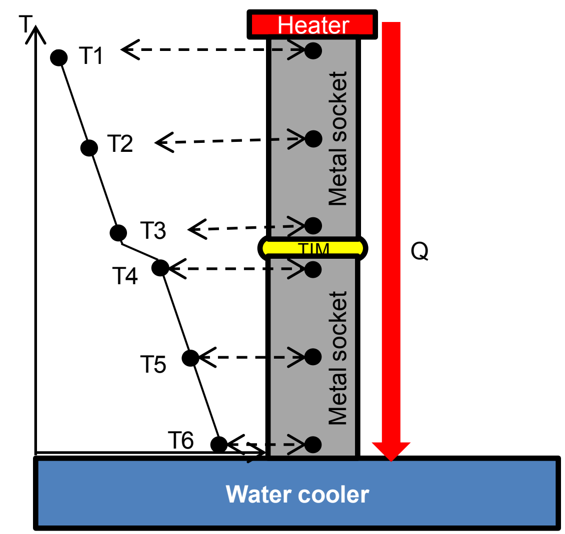
- Characterization under real conditions
- Different configurations possible depending on desired contact partners, i.e. Al, Cu or Si
- Measuring the actually heat flux
- Design allows to incorporate analysis by FIB, SEM and/or EDX
- Rapid test method using a test socket
- Curing at high temperature is possible T=180°C
- Low cost testing (test socket < 50€)
- In situ measurement of BLT and pressure

# Assessment of Accuracy and Parasitic of TIMA Tester

## Total Error Evaluation

| Error source | Influence |
|---|---|
| • Temperature measurement by TTC and NTC<br>• Need high accuracy calibration<br>• Need precise constant current source | Very High |
| • Heat flux measurement<br>• Geometry of metal socket<br>• Thermal conductivity of metal socket<br>• Form of T-sensors (NTC)<br>• Accuracy of T-Sensors | High |
| • BLT measurement<br>• use high accuracy LVDT | High |
| • Tilt<br>• use goniometers and tilt sensors | High-medium |
| • Convection and radiation<br>• Free convection by use protective case<br>• Radiation checked by IR-Camera | Low |

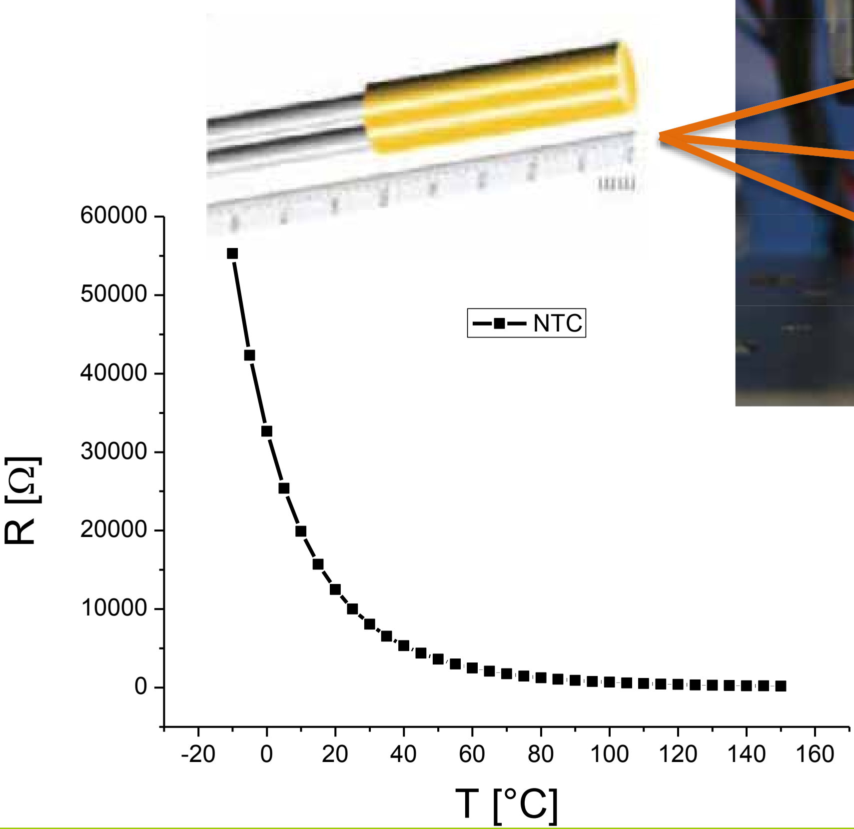


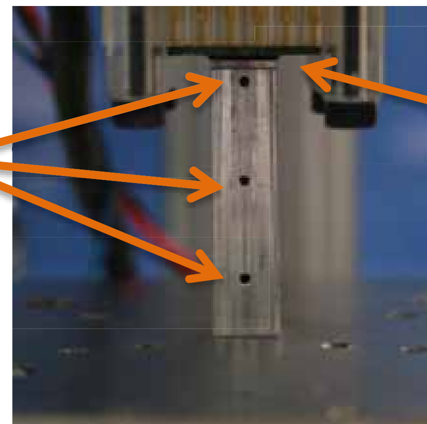



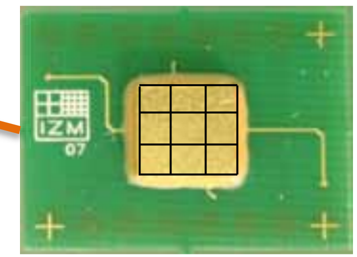
# Accuracy of temperature measurement

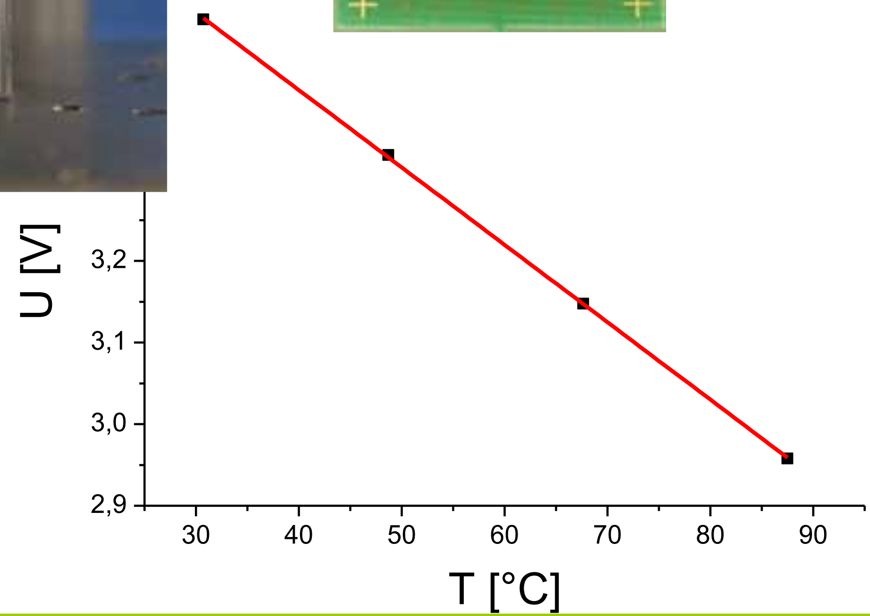
NTC-Sensors:
- Adapted design (Cylinder, 1mm diameter)
- Non-linear behavior (should be calibrated for the range of use)

TTC-Sensors:
- Adapted design (flat, full area heater)
- Diode as T-sensor, linear behavior

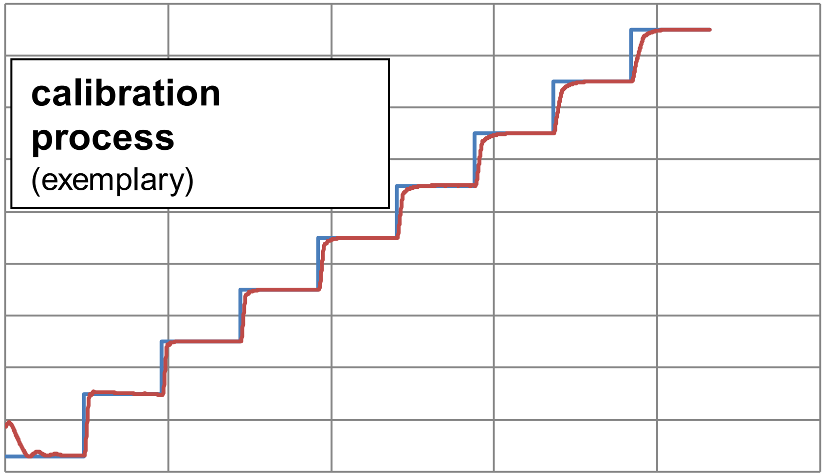




# High precision calibration chamber




- -20°C < T < 175°C
- Avg. heating rate 10 K/min
- Avg. cooling rate 5 K/min
- Accuracy < 0.01 K
- multiple parallel measurement

greatly insulated chassis (< 0.01 W/mK)

water cooling

37-pin data bus

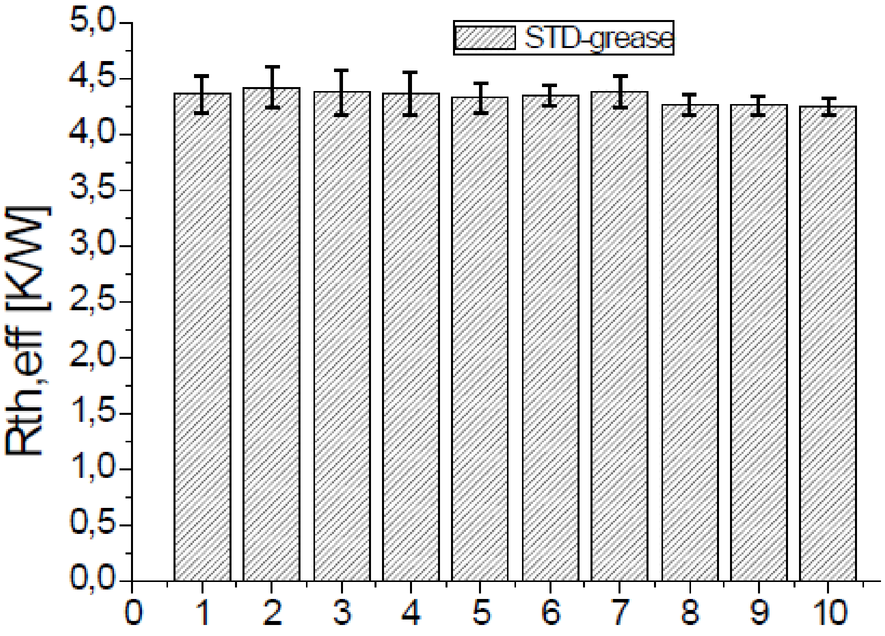
350W power (heating / cooling)

# Reproducibility of the measurement

One TIM was measured 10-times under:

- Same BLT
- Same pressure
- Same temperature
- In different times

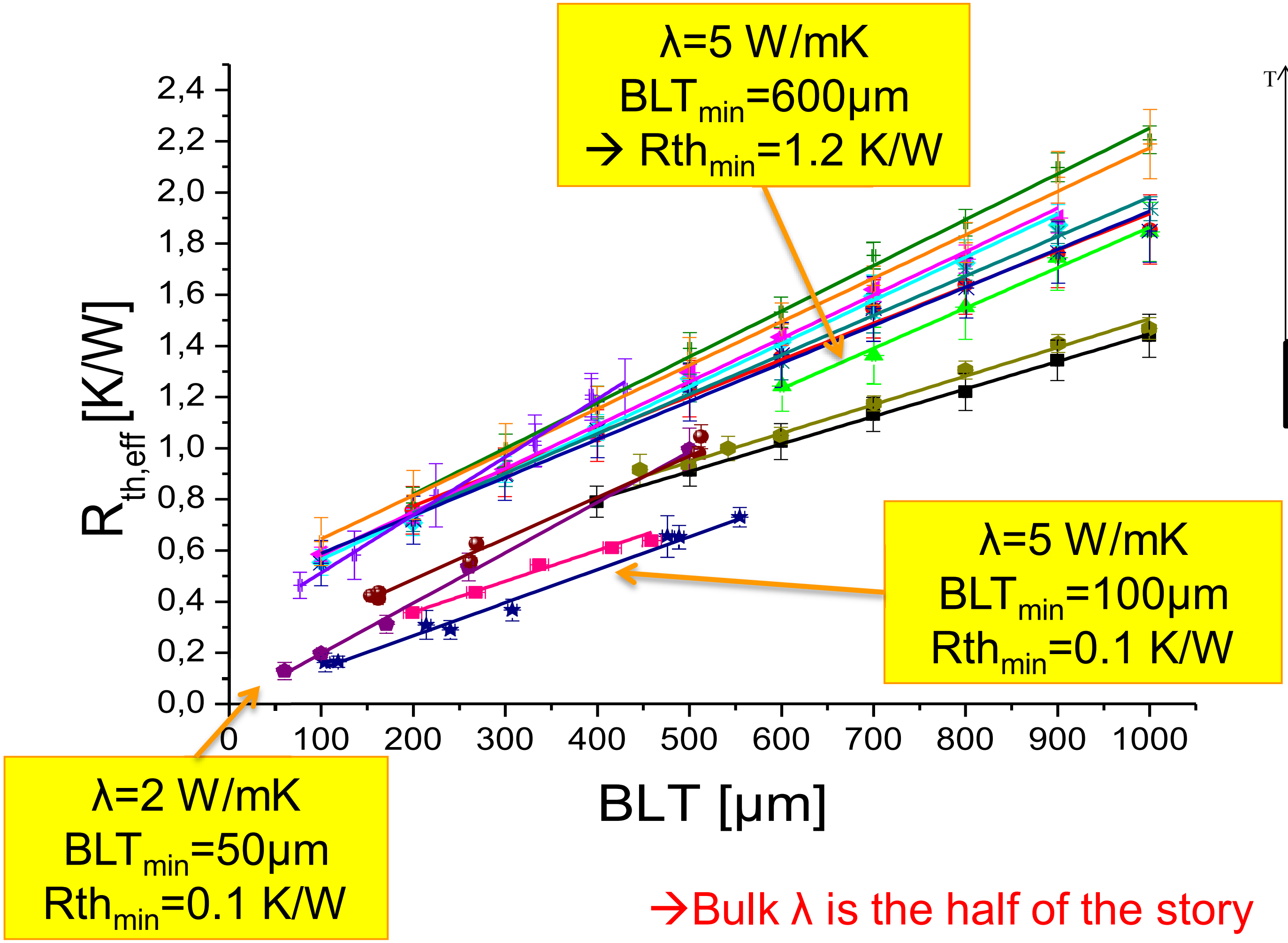
→ **Variation < 5%**

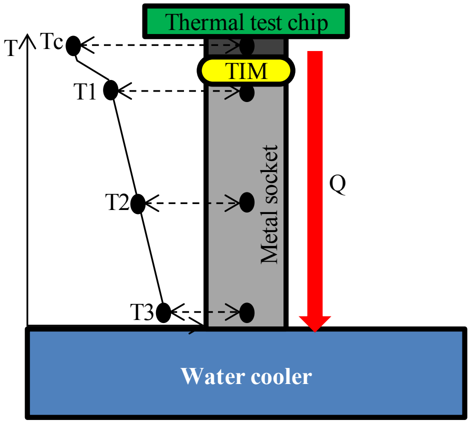


# Interesting results measured by standard modules

What can be measured by these modules?

# Standard characterization of greases




→Bulk λ is the half of the story

→$Rth_0$ and min BLT are very important

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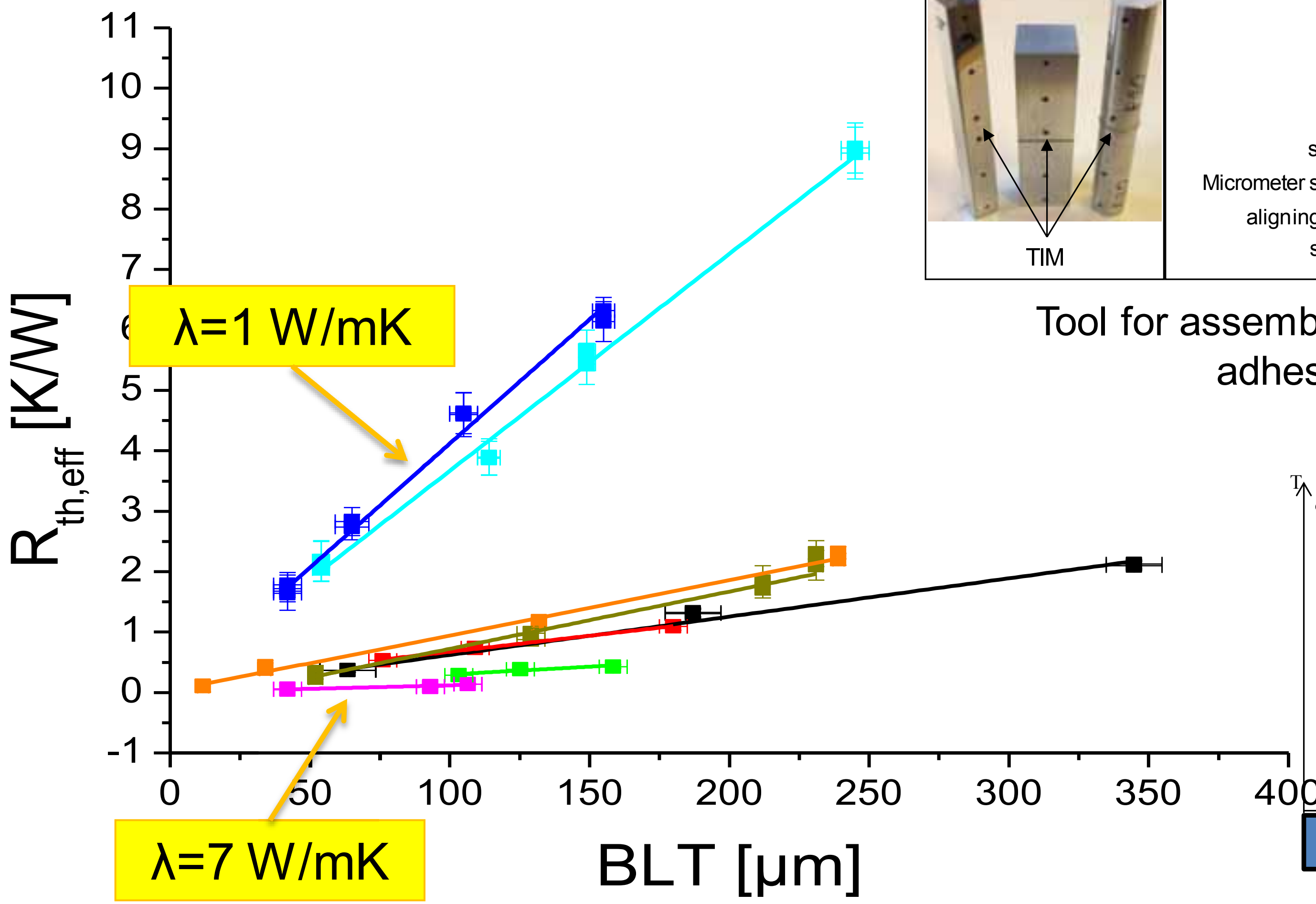
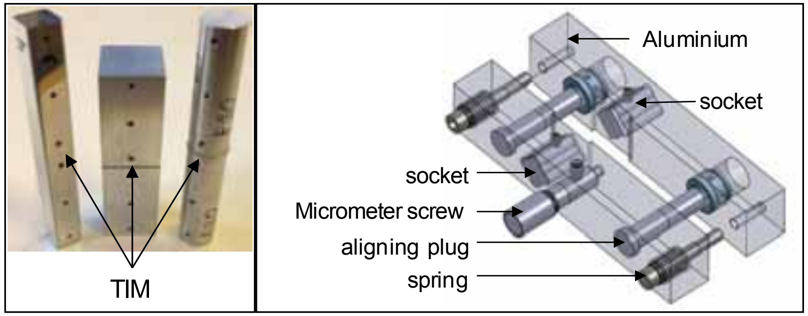
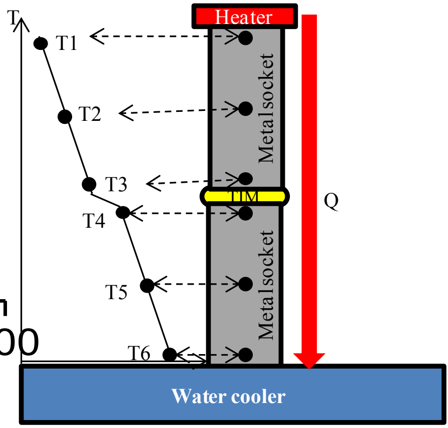
# Standard characterization of adhesives



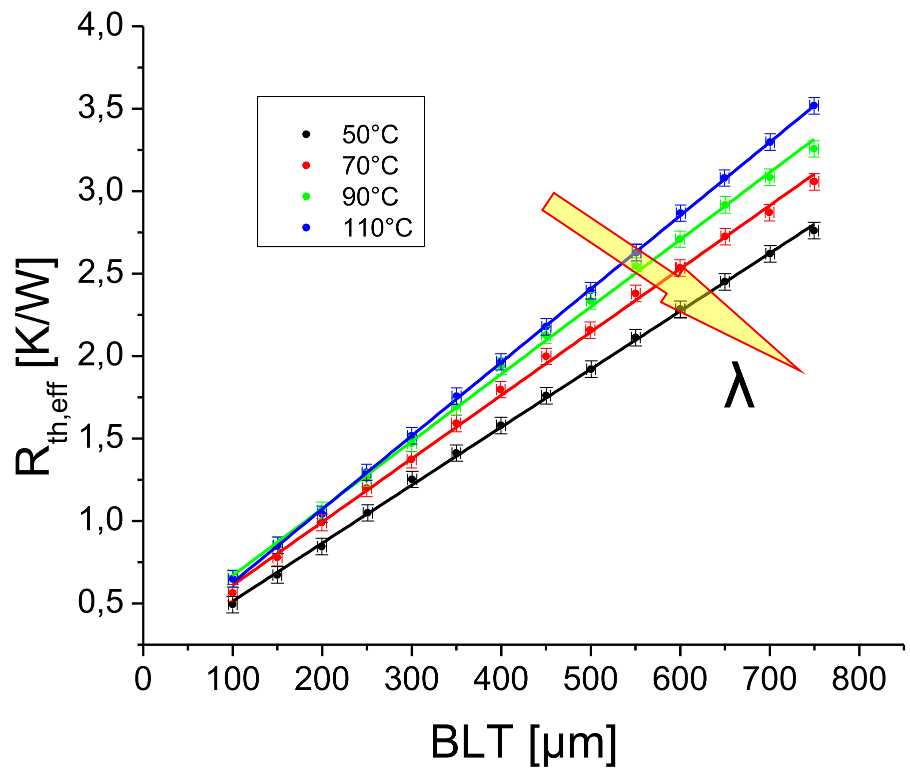

Tool for assembling of thermal adhesives



# Influence of temperature on thermal conductivity

- One thermal grease
- Measured at different temperatures (50°C, 70°C, 90°C and 110°C)

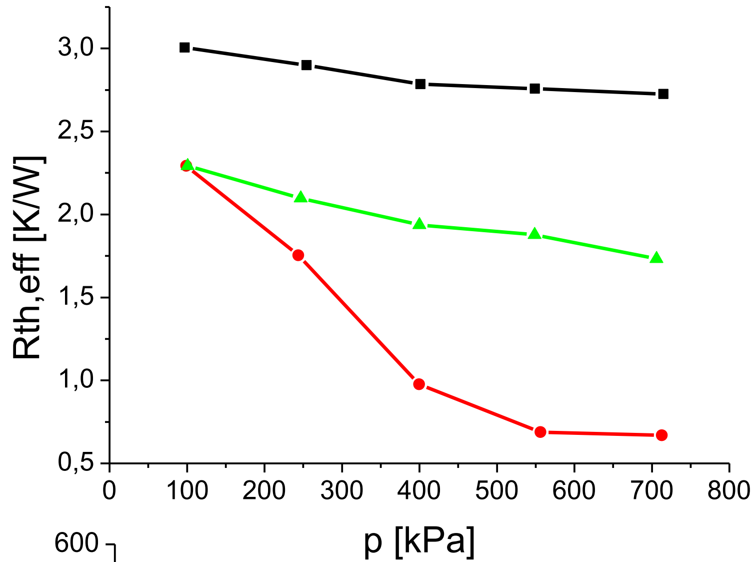
| T on TIM [°C] | $\lambda_{bulk}$ [W/mK] | $Rth_0$ [mm² K/W] |
|---|---|---|
| 50 | 4,9±0,1 | 10±3 |
| 70 | 4,5±0,1 | 13±3 |
| 90 | 4,2±0,1 | 14±3 |
| 110 | 3,9±0,1 | 11±3 |

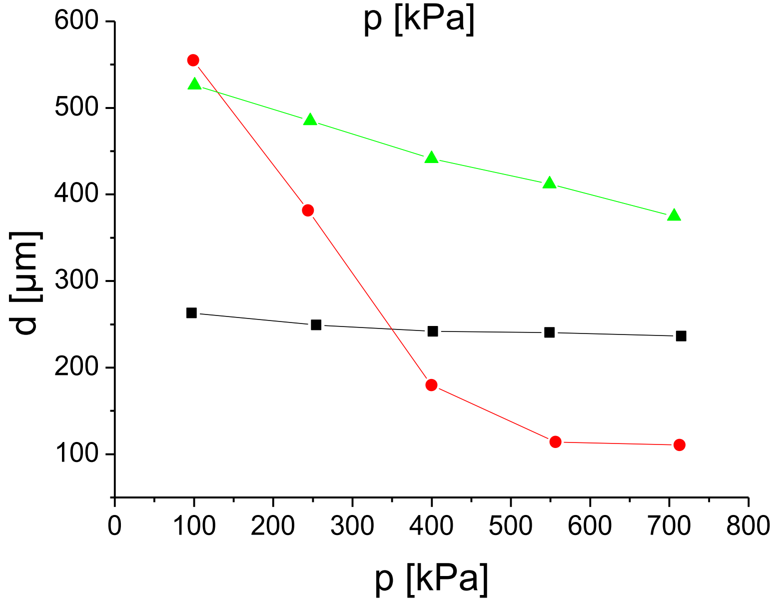



→ 25 differences at thermal conductivity between 50°C and 110°C
→Unfortunately lower performance at higher temperature

# Thermal resistance as function of pressure

- Three thermal greases were measured under different pressures 100 kPa… 700kPa
- Rth=f(p)
- d=f(p)

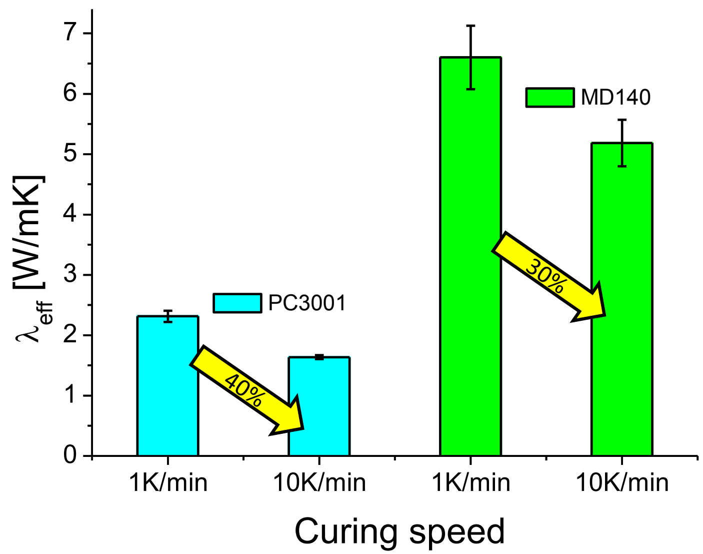


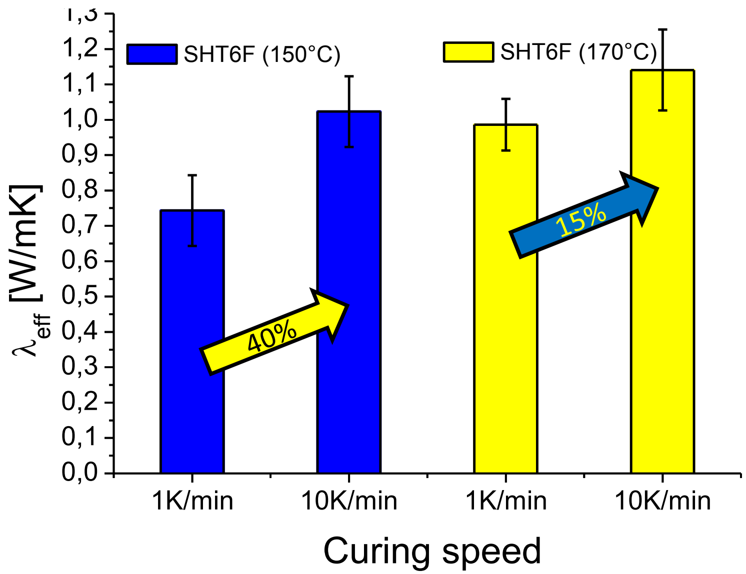



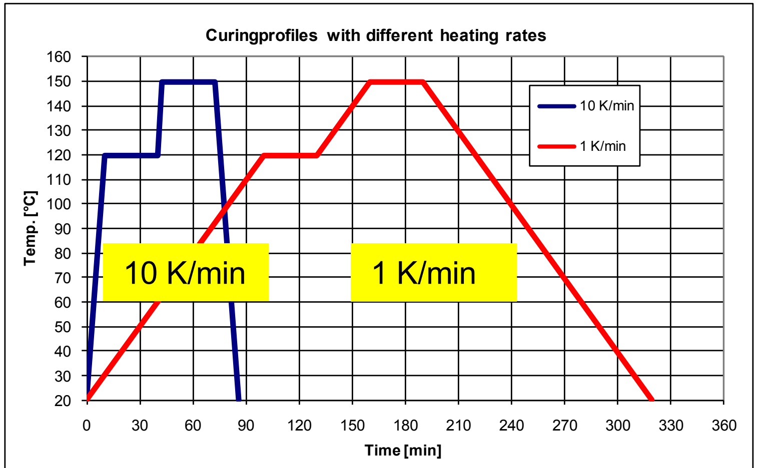

Further options:

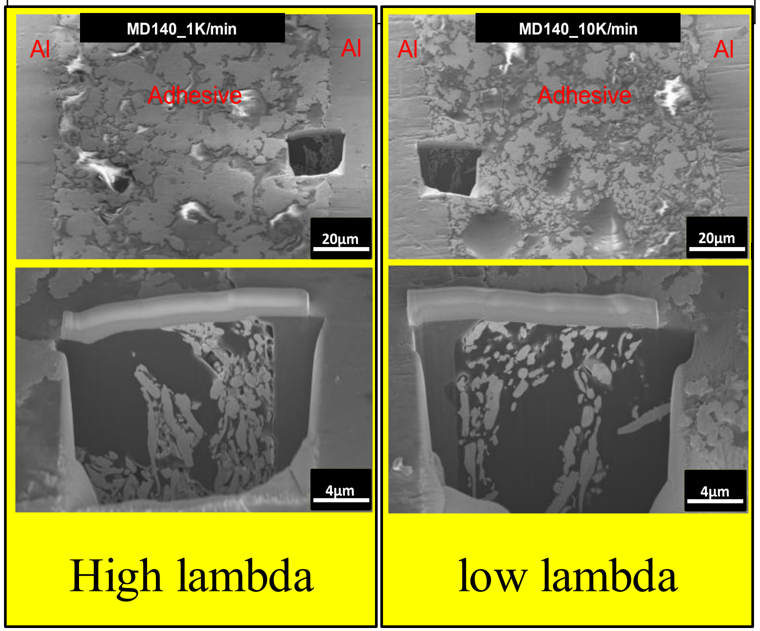
- Pressures from 0 to 2 MPa are possible
- Bond line thickness as function of pressure at different temperatures

# Influences of curing conditions on thermal conductivity of thermal adhesives



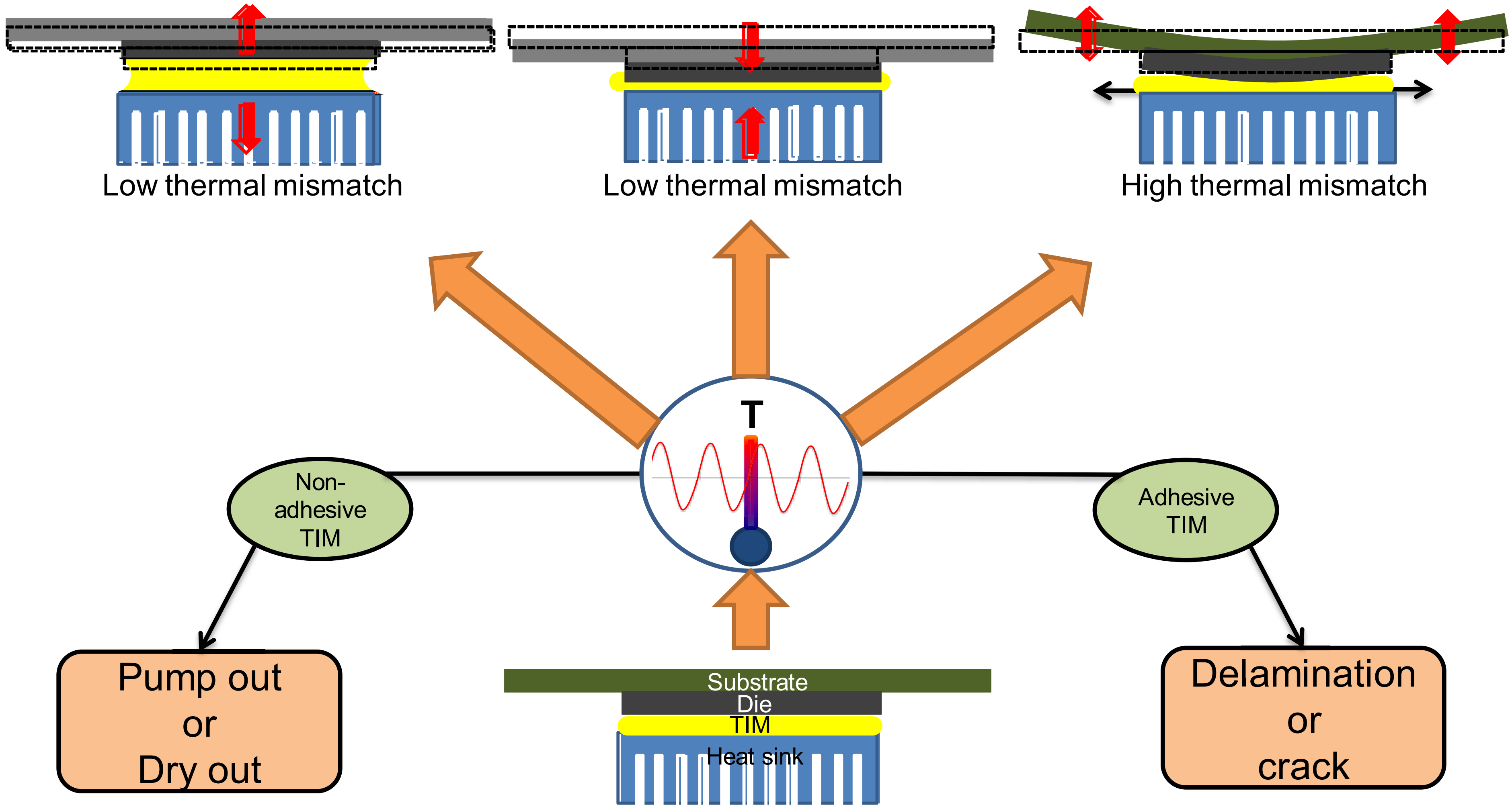



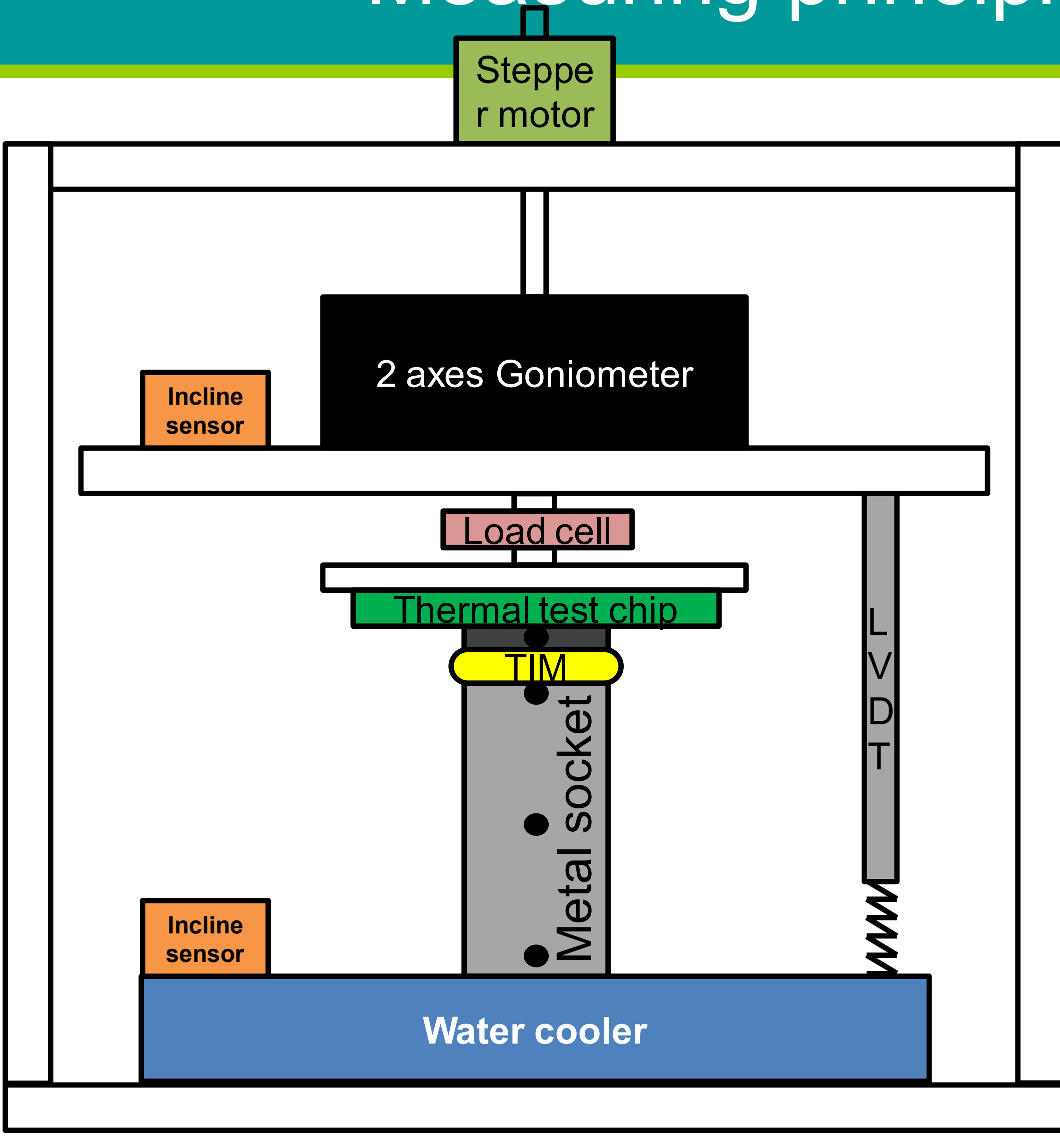
## Further module

accelerated in-situ measurement of reliability and aging behavior of thermal interface materials

# Background

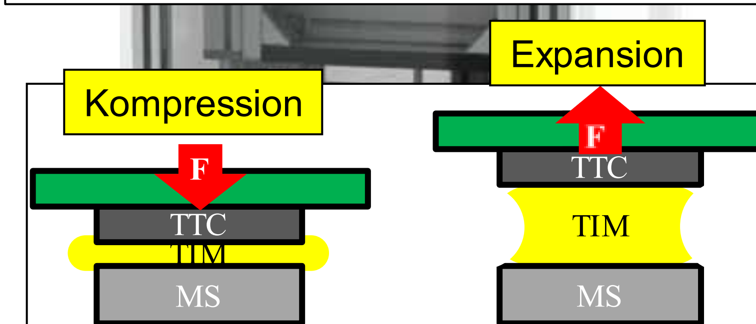

Low thermal mismatch
Low thermal mismatch
High thermal mismatch
T
Non-adhesive TIM
Adhesive TIM
Pump out
or
Dry out
Substrate
Die
TIM
Heat sink
Delamination
or
crack

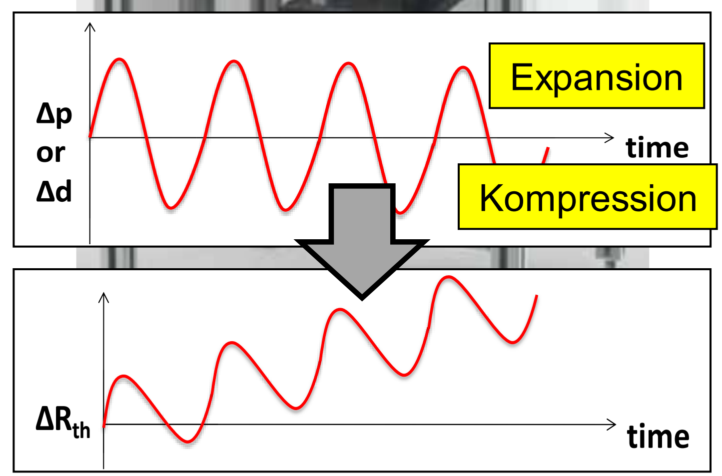
# Measuring principle (Patented)




Schematic of the long term testing

- Variation of BLT or pressure by stepper motor
- In situ measurement of BLT and pressure
- In situ measurement of thermal resistance of TIM
- Computer controlled long term testing

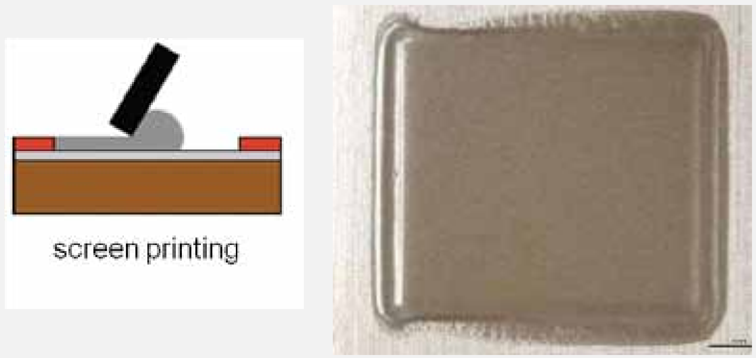


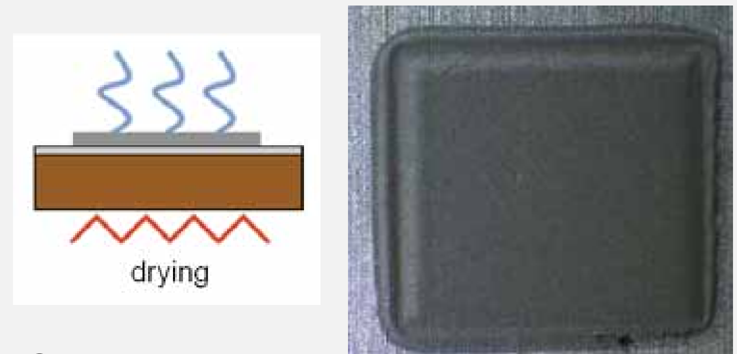
## Further module

Characterization of highly conductive TIMs

# Silver Sintering for High-Lambda Connection

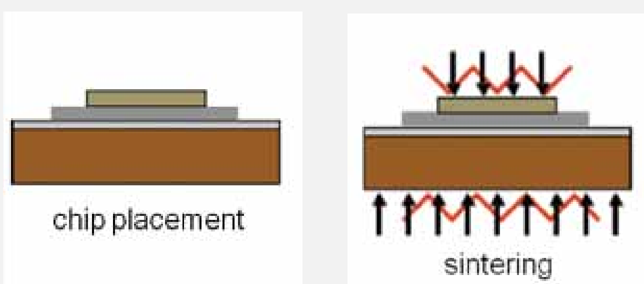



1



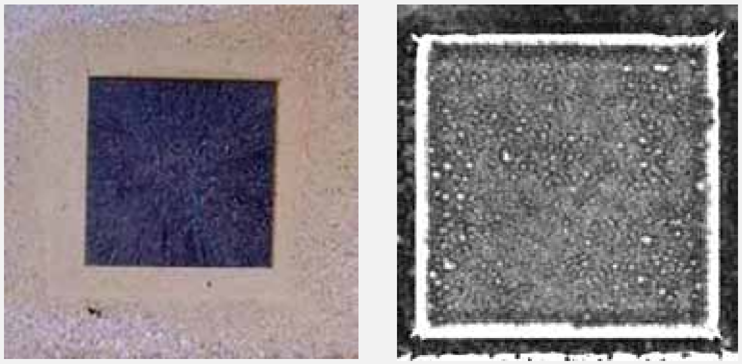

AlN

2




3

T, p, t



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Chip on DCB

SAM

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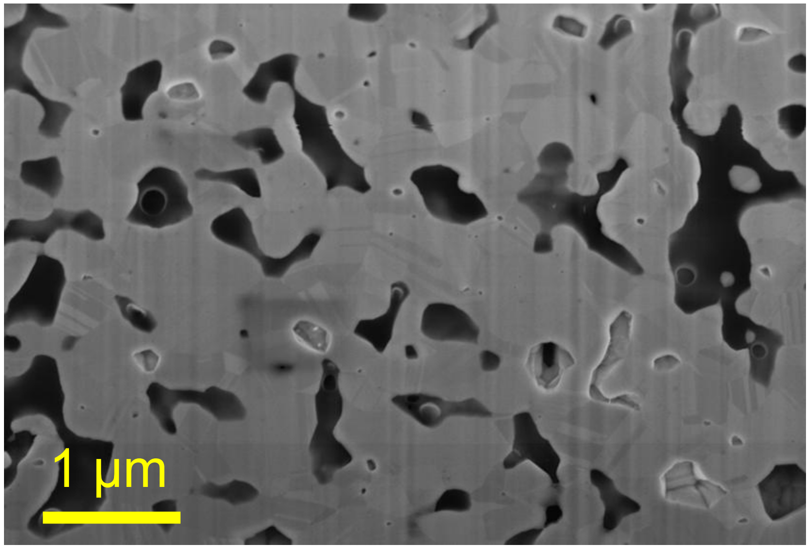
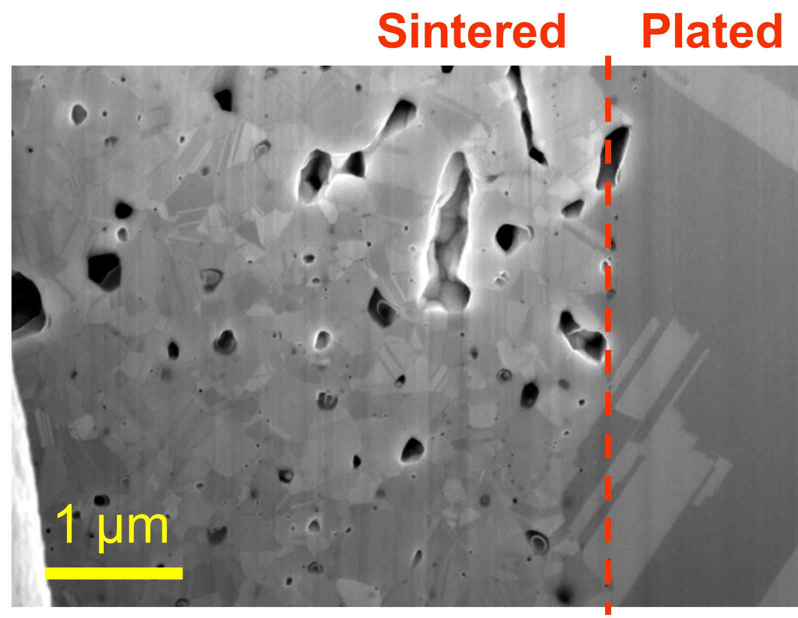
# Microstructure of Silver - Die Bond, Sintered




Low T,p,t sintering

→ highly porous

High T,p,t sintering

→ continous µ-structure, grain formation

→ Different process parameters (T, p, t) produce different microstructrures

→ Technology development necessary

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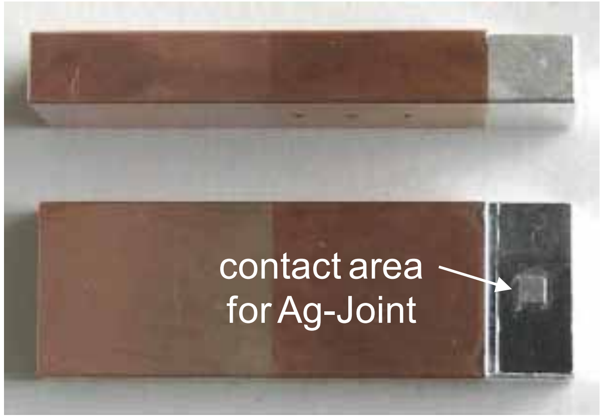
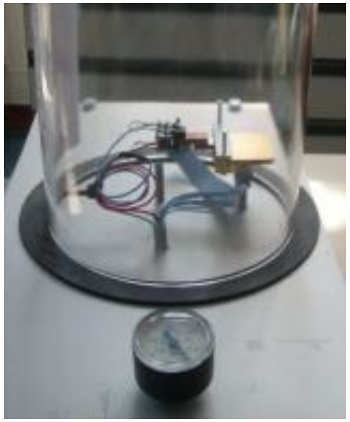
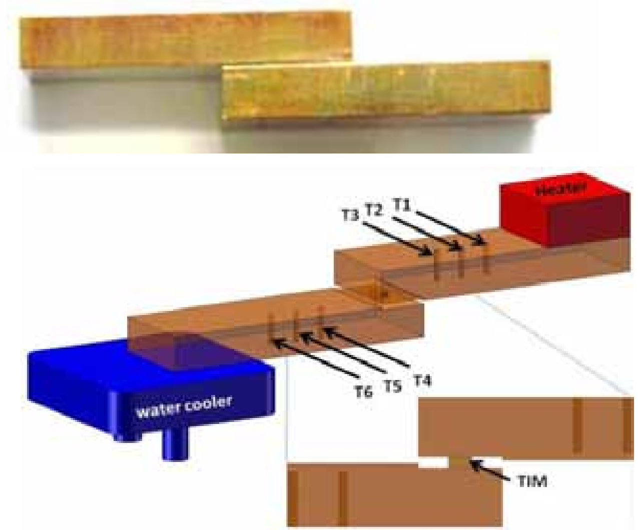
# Characterization: High – Lambda Test stand



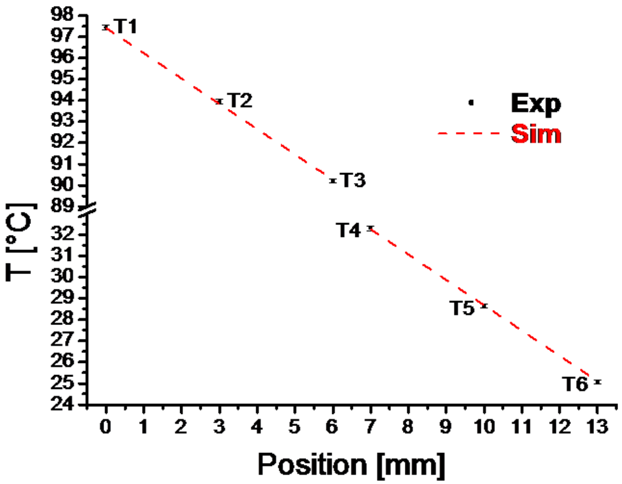

**Specimen**, used as in real die-bonding process with Ag-metalisation, d by x-sect



**Vacuum chamber** for thermal char (1 mbar)



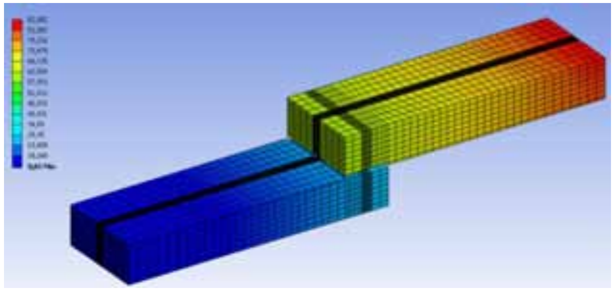

**Schematic** for high-Lambda Tester (Cu meas. by laserflash)




**T** along Cu-bars of Specimen

Accuracy < ± 5 %,

equivalent to ± 10 W/mK at possible 420 W/mK for pure Ag

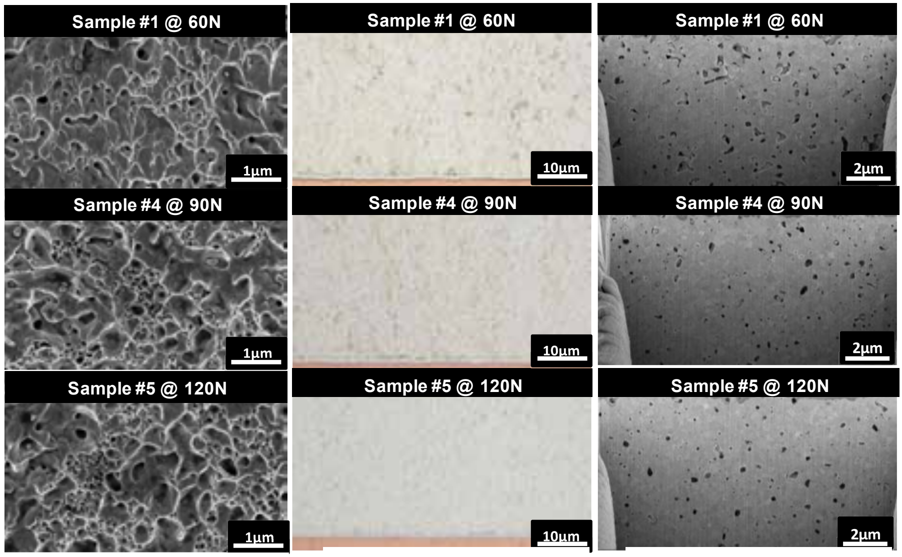


Correlation to **simulation**

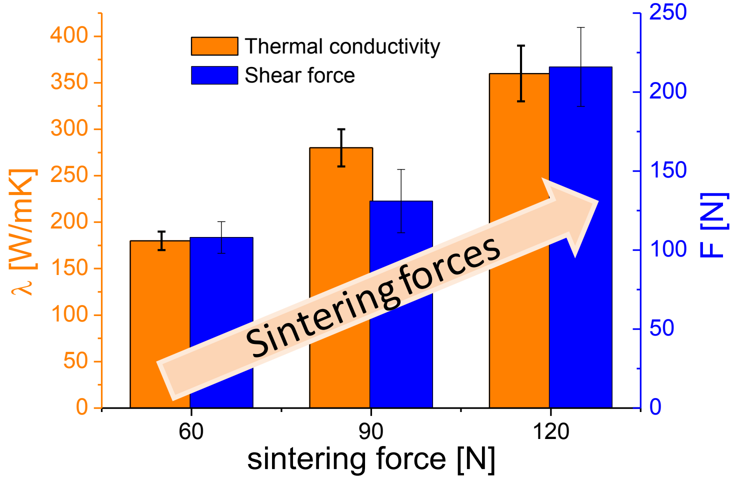
# Influences of sintering forces on thermal and mechanical properties of sinter silver

## Sintered at 270°C

| Sample # | Sintering force [N] | Shear force [N] | BLT [µm] | Area [mm²] | λ [w/mK] | **λ [w/mK]** |
|---|---|---|---|---|---|---|
| 1 | 60 | 109 | 64 | 1,96 | 175 | **180±10** |
| 2 | | 107 | 120 | 2,13 | 185 | |
| 3 | 90 | 150 | 53 | 2,20 | n.a. | **280±20** |
| 4 | | 112 | 95 | 2,20 | 280 | |
| 5 | 120 | 240 | 74 | 2,77 | 390 | **360±30** |
| 6 | | 193 | 91 | 2,41 | 330 | |




LM of shear area | LM of gross section | FIB of gross section




Higher sintering forces lead to:

→ higher thermal conductivity

→ higher shear forces

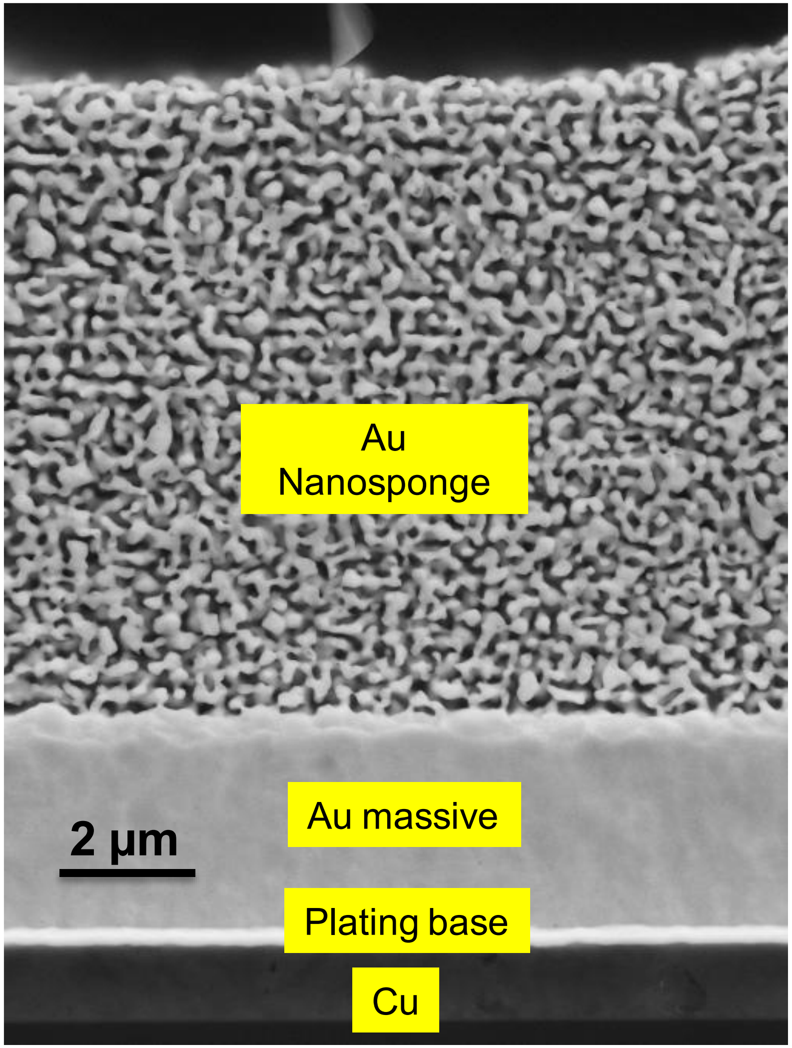
due to densification and microstructure evolution

**Further module**

High Accuracy Characterization Module

Characterization of small effects
e.g. surface modification by
nanotechnologies

# *Nanosponge* Technology




Oppermann, Wunderle, IZM Berlin

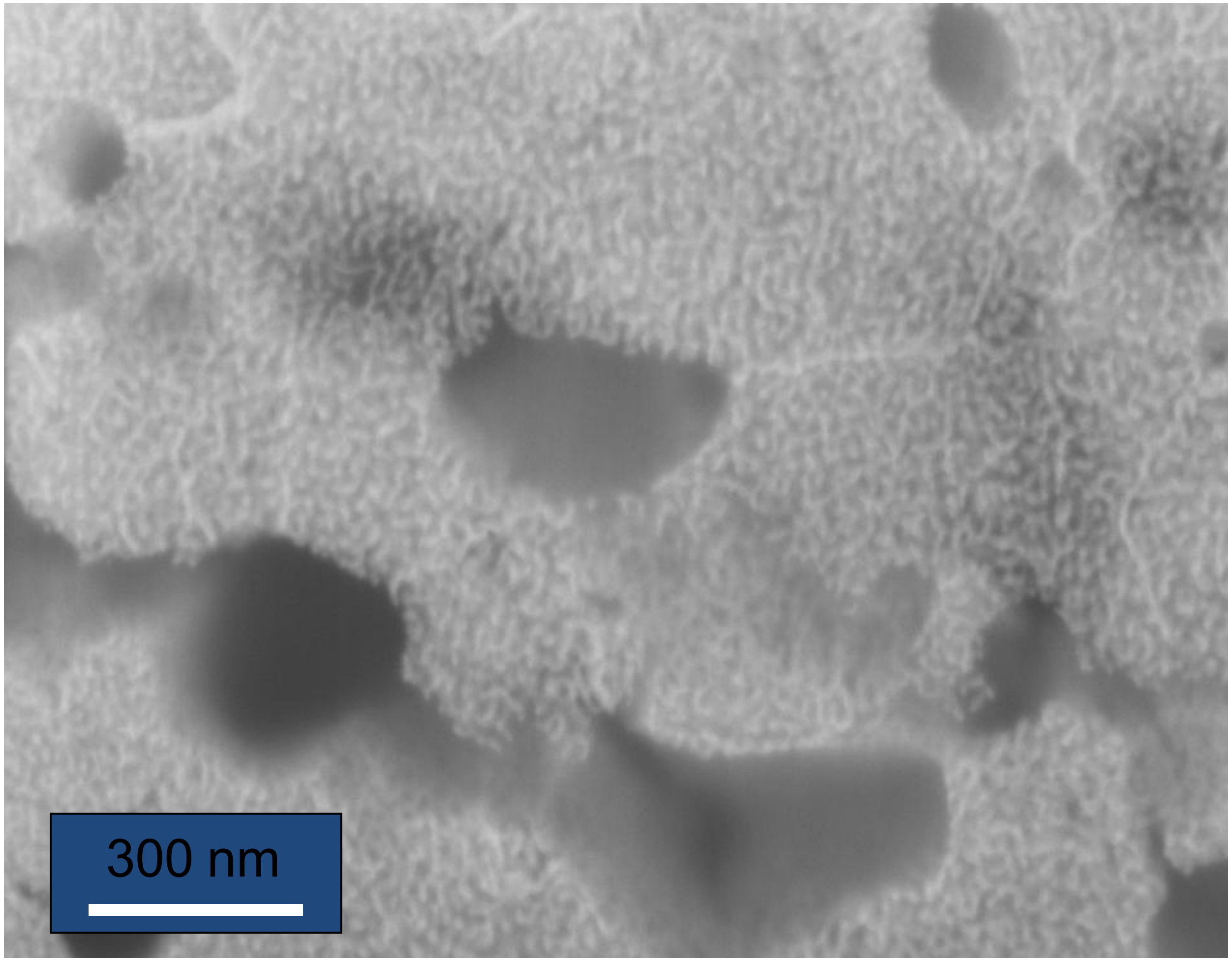
Apply on Si-die on wafer level

Plating Alloy

↓

Dealloying

# *Nanosponge* Structure




FIB image of the nano-sponge Au-structure

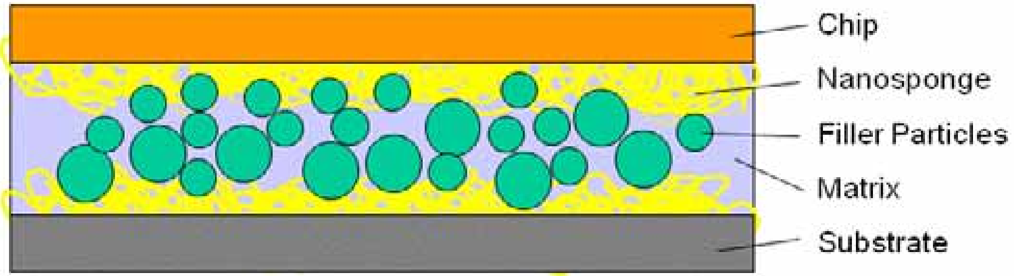
→ open porous

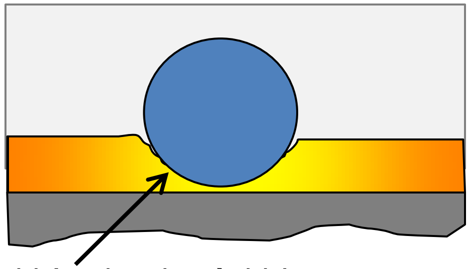
→ **15 nm** pores

→ 20 %vol Au

Oppermann, Wunderle, IZM Berlin

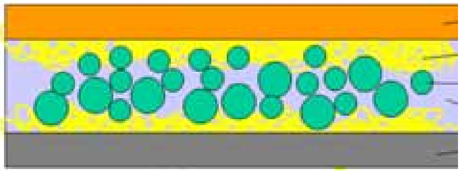
# Thermal Enhancement by Nanosponge



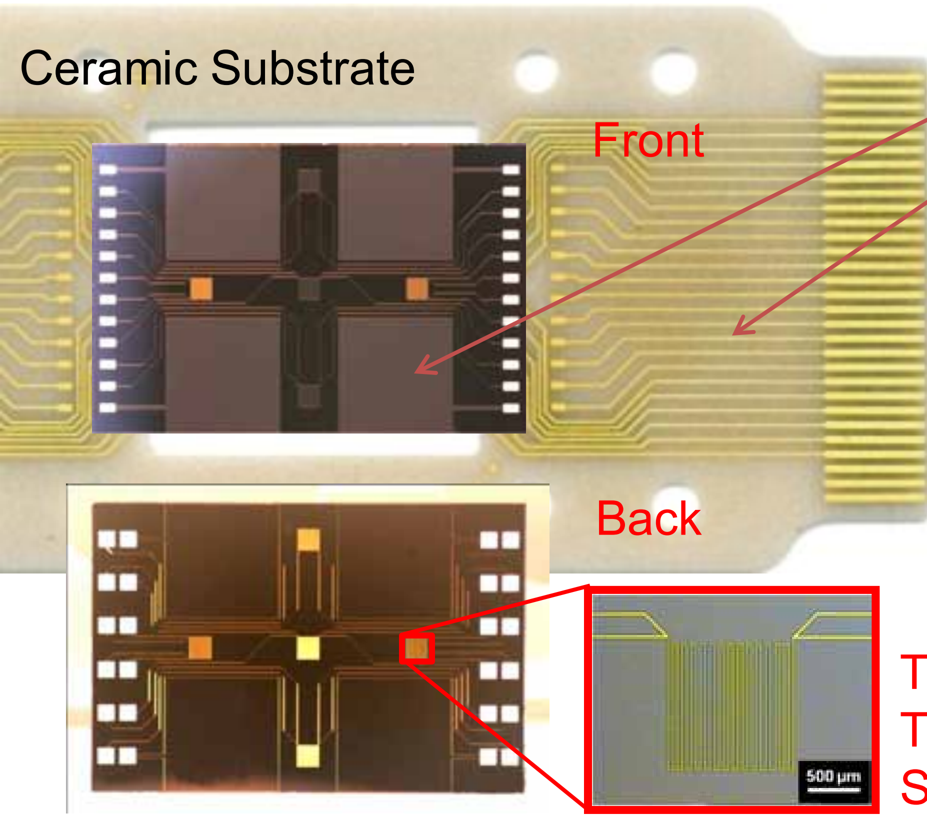




| Thermal Enhancement Potential | |
|---|---|
| Compressibility | Conforming to filler particles reduces $R_{th,0}$ at interfaces, excess adhesive can be aborbed <> point contact |
| Roughness | Increased mechanical interlocking for Adhesives on Au Surfaces (few 10 nm are enough) |
| Surface Energy | Interdiffusion possible for contact formation (nano-scale effect) |
| Structure tuneable | mechanical properties tuneable |

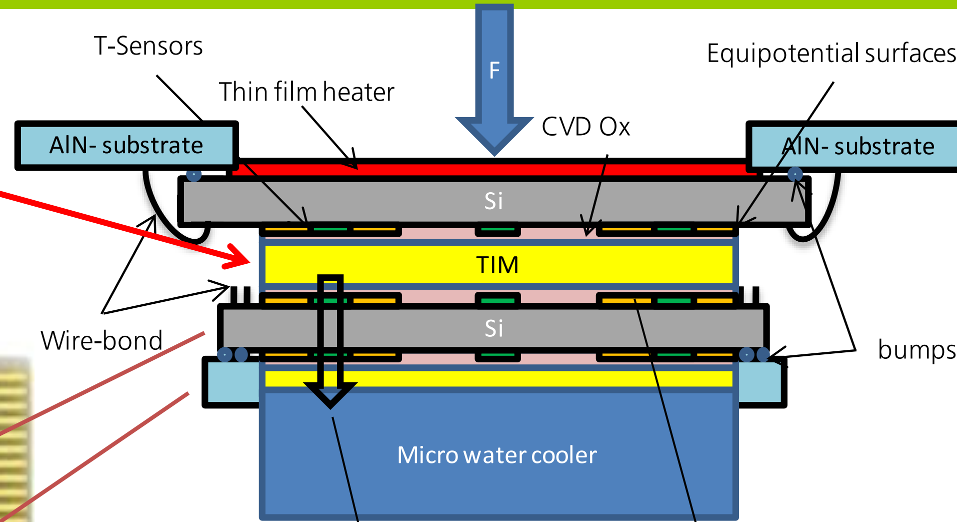
# Most Accurate Characterization Method: Si-TIM-Si



Nanosponge both sides

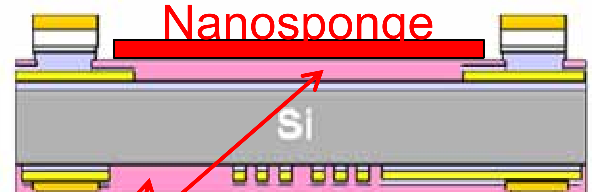



Thin film T- and j - Sensor




Local heat flow sensor
Local T sensor

Local thickness sensor




Glass passivation, double sided

# Summary

## TIMs can be measured

- Adhesives
- pads
- Substrates
- Greases
- PCM
- Solder
- Film
- Mono metal
- Gap Filler

## Values can be measured

- Rth=f(T)
- $Rth_{eff}$
- Rth=f(p)
- $Rth_0$
- Rth=f(Rz)
- $\lambda_{Bulk}$
- Rth=f(t)
- Rth=f(process)
- $\lambda_{eff}$

Thank you very much for your attention!

Time for questions?

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