Thermal Management and Thermo Mechanical Reliability

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Micro Materials Center

Head: Prof. Bernd Michel

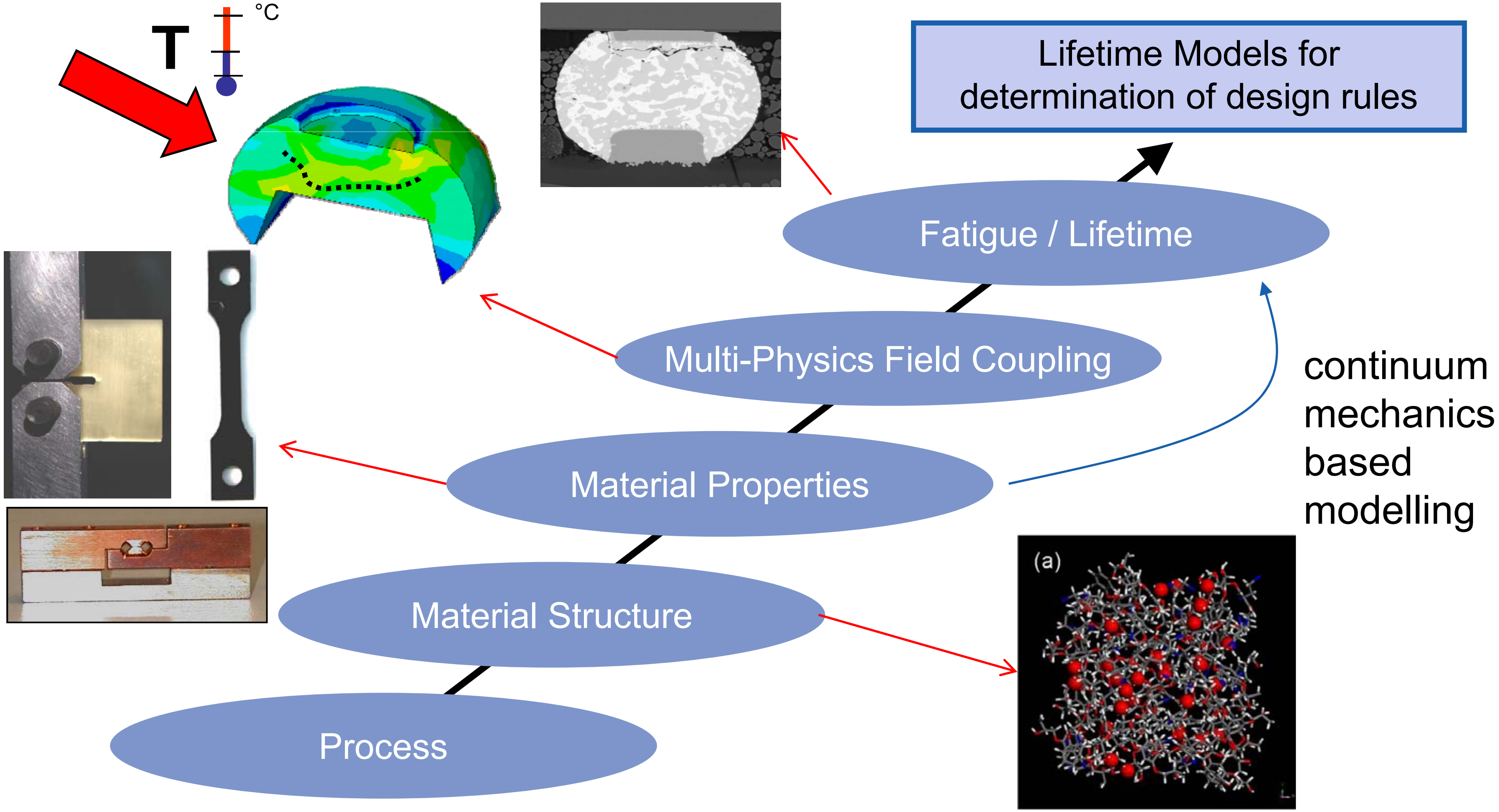
Micro Materials Center Berlin

- 4 Research Groups
  - Prof. Bernd Michel
  - Dr. Ole Hölck / Dipl.-Ing. Daniel May
  - Dr. Hans Walter
  - Dr. Olaf Wittler
- 1 PhD Group: Prof. Bernhard Wunderle
- Lab Locations
  - Berlin-Wedding
  - Berlin-Adlershof

Micro Materials Center Chemnitz → Fraunhofer Einrichtung ENAS

- 3 Research Groups

Lifetime Models and Design for Reliability



Lifetime Models for determination of design rules

Fatigue / Lifetime

Multi-Physics Field Coupling

Material Properties

Material Structure

Process

continuum mechanics based modelling

Olaf Wittler

Fraunhofer Institut Zuverlässigkeit und Mikrointegration

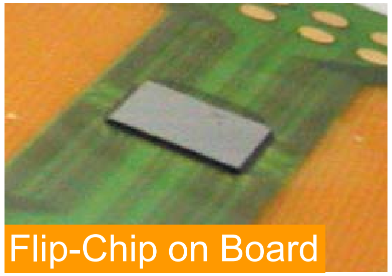
Micro Materials Center Berlin and Chemnitz
Head: Prof. B. Michel

IZM Program

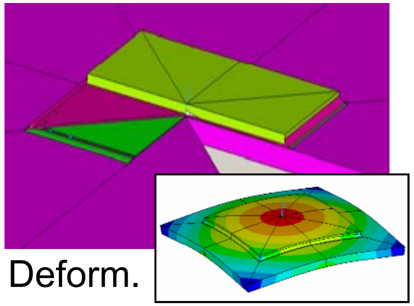
Micro Reliability & Lifetime Estimation

Fraunhofer Institut
Zuverlässigkeit und
Mikrointegration

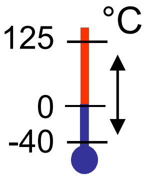
Lifetime Prediction for Advanced Packaging Solutions

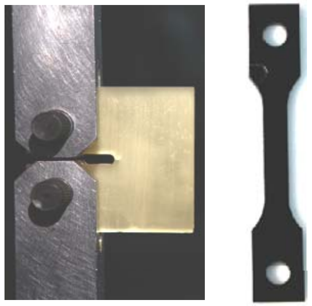


Thermo-mechanical reliability testing

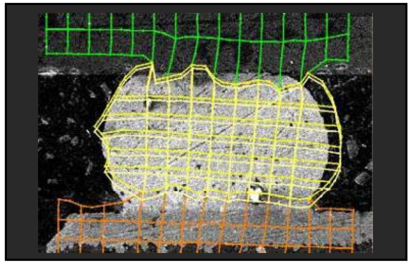


Parametric Finite Element simulation

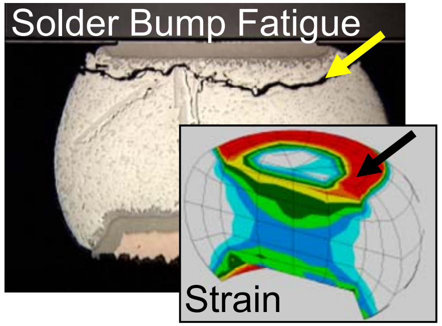




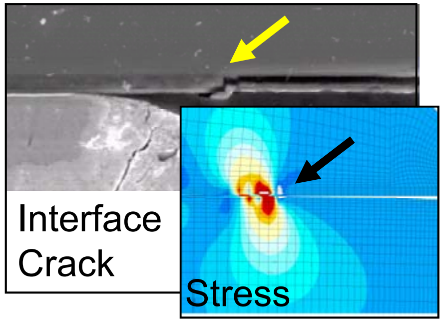
Material characterisation



μ-Deformation measurements



Failure Analysis & Mechanisms



Lifetime prediction & theory

$$\bar{N}_f = c_1 (\bar{\varepsilon}^{cr})^{c_2}$$

Contact: Prof. Dr. B. Michel, Mail to: bernd.michel@izm.fraunhofer.de
Dep. Mechanical Reliability and Micro Materials, Head: Prof. Dr. B. Michel, Fraunhofer IZM, Berlin, Germany

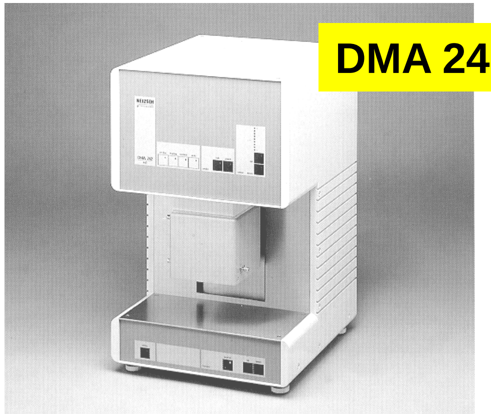
Material Characterisation

Methods/Equipment for Material Characterisation - Mechanical Testing Lab

Zwick 1446

Tytron 250

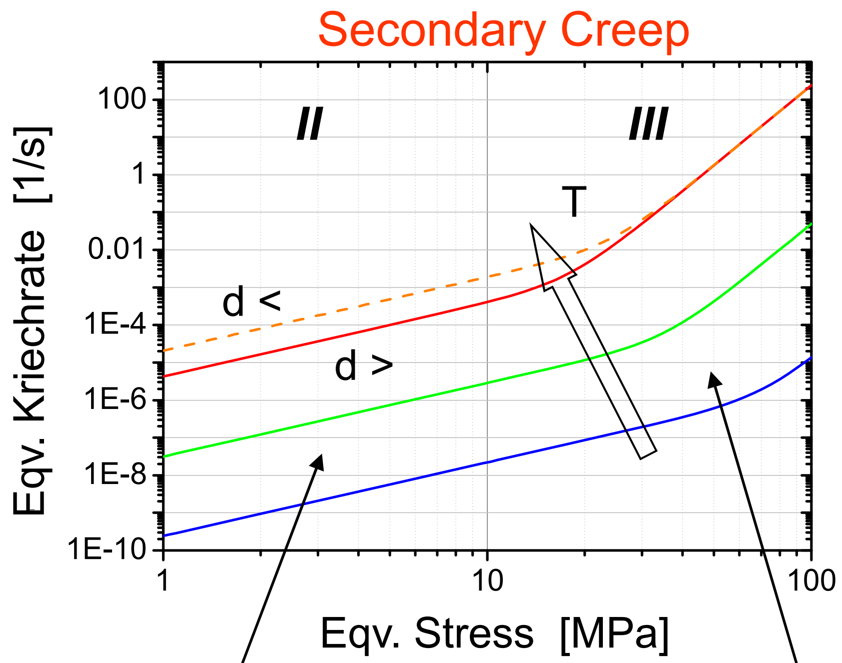
- CTE Measurement with TMA
- Time, Temperature and Humidity dependent Properties
  - Elasticity
  - Viscoelasticity
  - Creep
- Fatigue behaviour
  by dynamic measurements
- Nano-Indentation



DMA 242

TMA 202

Creep Law (Eut. SnPb), Viscoplasticity



Grain Boundary Sliding
Stress <

Matrix Deformation
Stress >

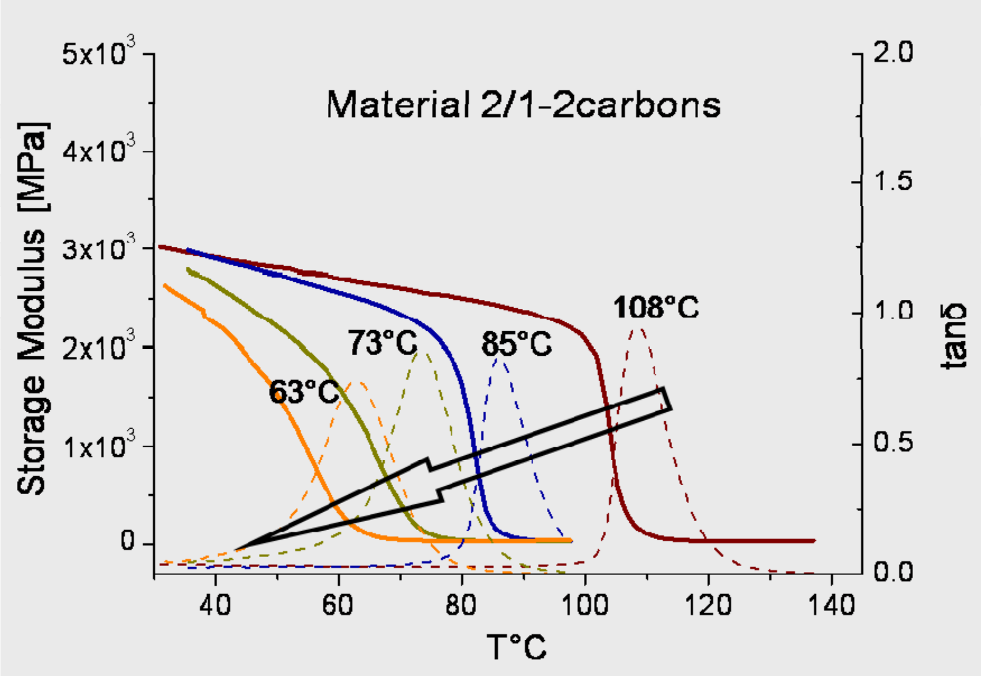
Activation Energy

Grain size

Absolute temperature

$$\dot{\bar{\varepsilon}} = \frac{1}{\sqrt{3}}\frac{A_{II}}{T}\frac{1}{\boxed{d^p}}\left(\frac{\bar{\sigma}}{\sqrt{3}}\right)^{n_{II}} \exp\left\{\boxed{-\frac{Q_{II}}{kT}}\right\} + \frac{1}{\sqrt{3}}\frac{A_{III}}{\boxed{T}}\left(\frac{\bar{\sigma}}{\sqrt{3}}\right)^{n_{III}} \exp\left\{\boxed{-\frac{Q_{III}}{kT}}\right\}.$$

Moisture Temperature Dependent Material Characterisation



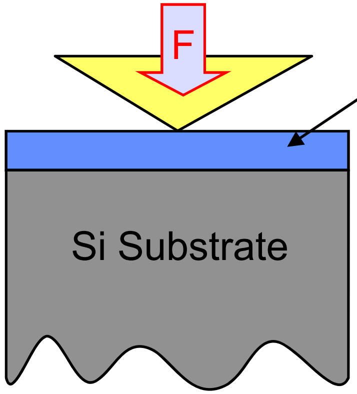
E. Dermitzaki, H. Walter, J. Bauer, B. Wunderle

→ Viscoelastic Material Data for Polymers

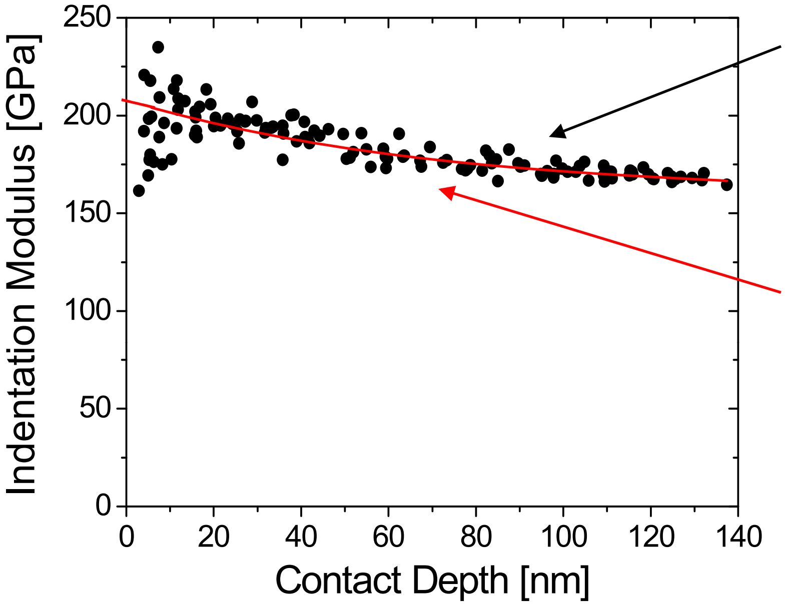
Examples for test specimen

Material Characterisation by Nanoindentation

Example: Thin film chracterisation for MEMS applications
Material: SiN



SiN thickness: 300 nm



Depth dependent indentation modulus due to effect from the softer substrate

Modulus estimation by extrapolation of results:

$E \approx 207$ GPa

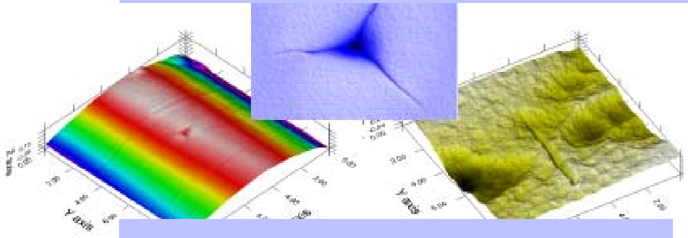
Olaf Wittler

Measurement System: Hysitron Triboindenter

Options available at IZM

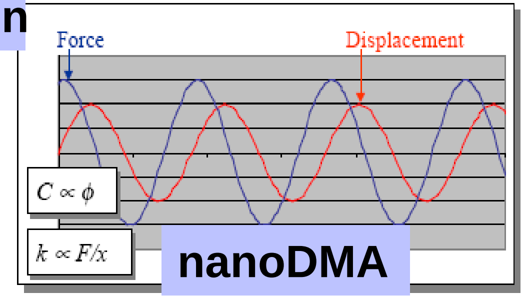
Classical Nanoindentation

In-situ scanning of indents



Scratch and wear testing

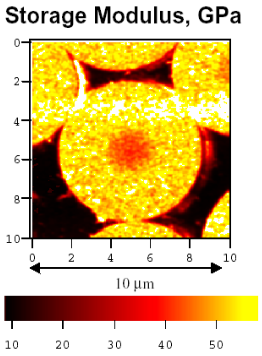
Triboindenter in acoustic/thermal enclosure



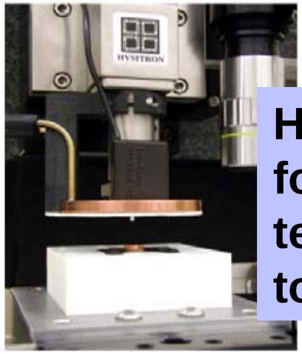
nanoDMA

$$E' = \frac{{}_s\sqrt{\pi}}{\sqrt{A_c}} \qquad E'' = \frac{\omega C_s\sqrt{\pi}}{2\sqrt{A_c}}$$

Analysis of sinusoidal force/displacement data.



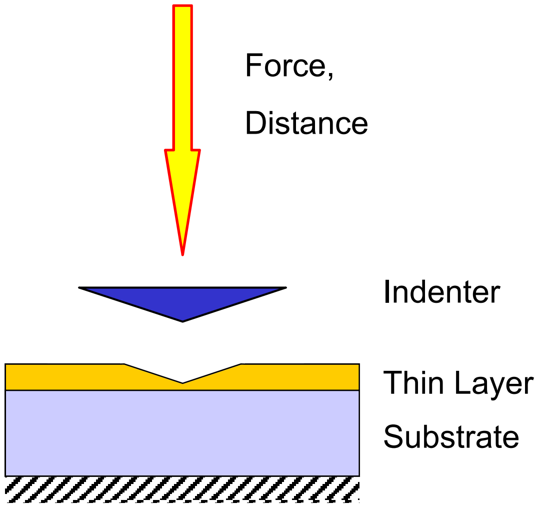
Modulus mapping

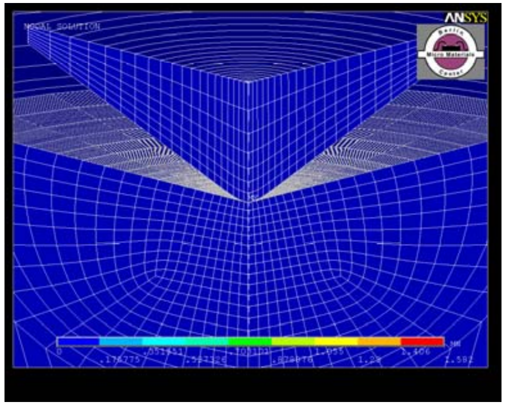


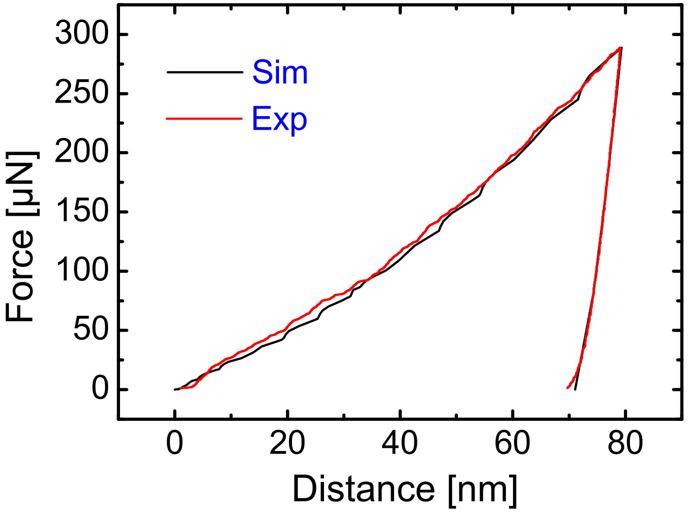
Heating stage for temperatures up to 200°C

Image Source: Hysitron Product Information

Material Characterisation in the Nano-Region

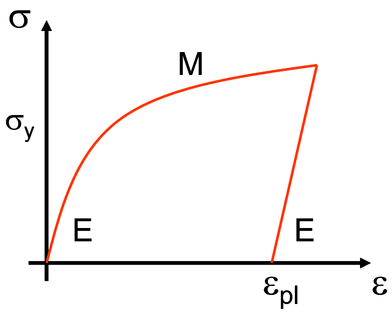


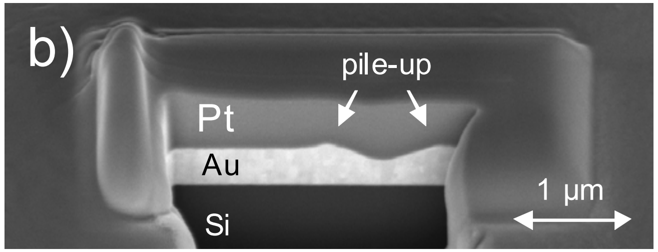




Experiment → Simulation → until Agreement reached

→ Determination of Parameters only in Coupling to Simulation possible



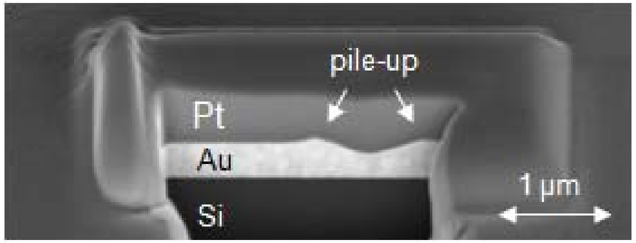


B. Wunderle, R. Mrossko, E. Kaulfersch, O. Wittler, P. Ramm, B. Michel and H. Reichl. MRS Fall Meeting, Boston, USA, Nov. 2006

Main Relevant Properties

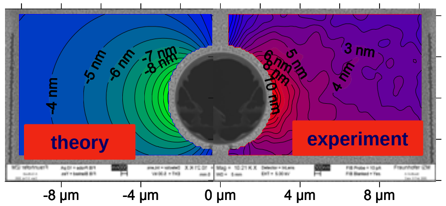
Deformation Behaviour

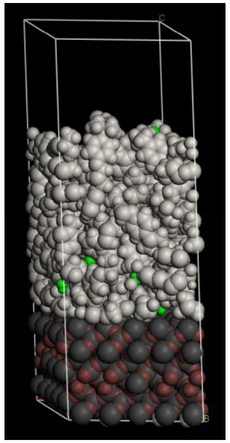
Nanoindentation / nanoDMA



Residual Stresses

nanoRaman / fibDAC / …

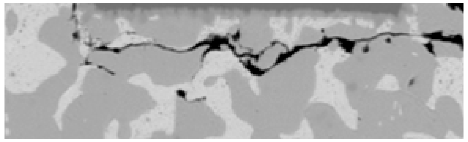




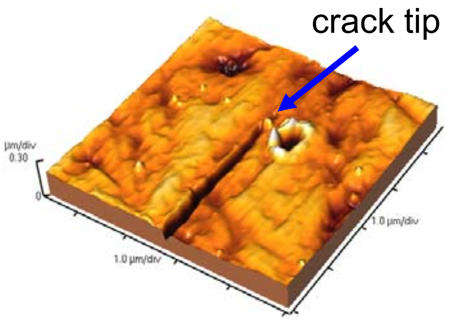
Interfacial Fracture Toughness and Moisture

○ MC
● H_2O
● SiO_2

Metal Fatigue



Fracture Toughness (Cohesive Strength)



Methods Overview – Interfacial Fracture Toughness

Methods for interfacial fracture toughness of thin films

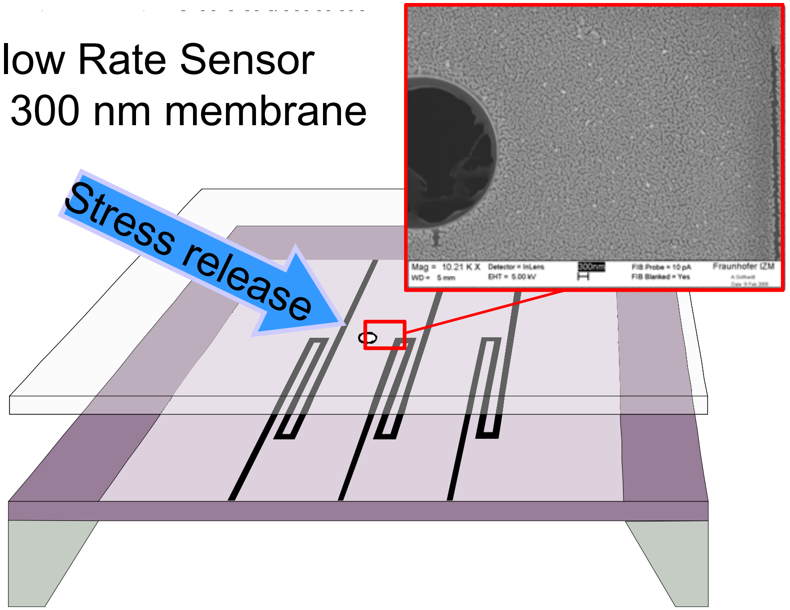
- Scratch Testing
  - \- Only qualitative in nature
  - \+ No sample preparation

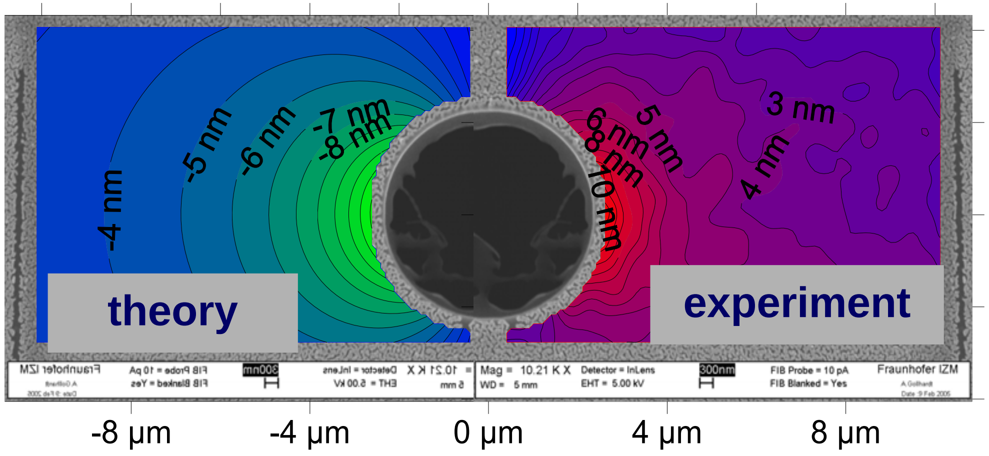
- Modified Edge Lift Off Technique
  - \+ Quantitative G_c determination
  - \- Measurements only at low temperatures
  - \+ large quantitative numbers to be measurable

- Four-Point-Bending
  - \+ Quantitative G_c determination
  - \+ Temperature dependent measurement possible
  - \- Specimen preparation

fibDAC – Residual stresses at sub-µm Scale

Flow Rate Sensor
with 300 nm membrane





- Stress release by ion milling in focused ion beam equipment
- ***Stress determination from measured deformation field*** (right)
- Material data by nano-indentation

Fraunhofer Prize 2005

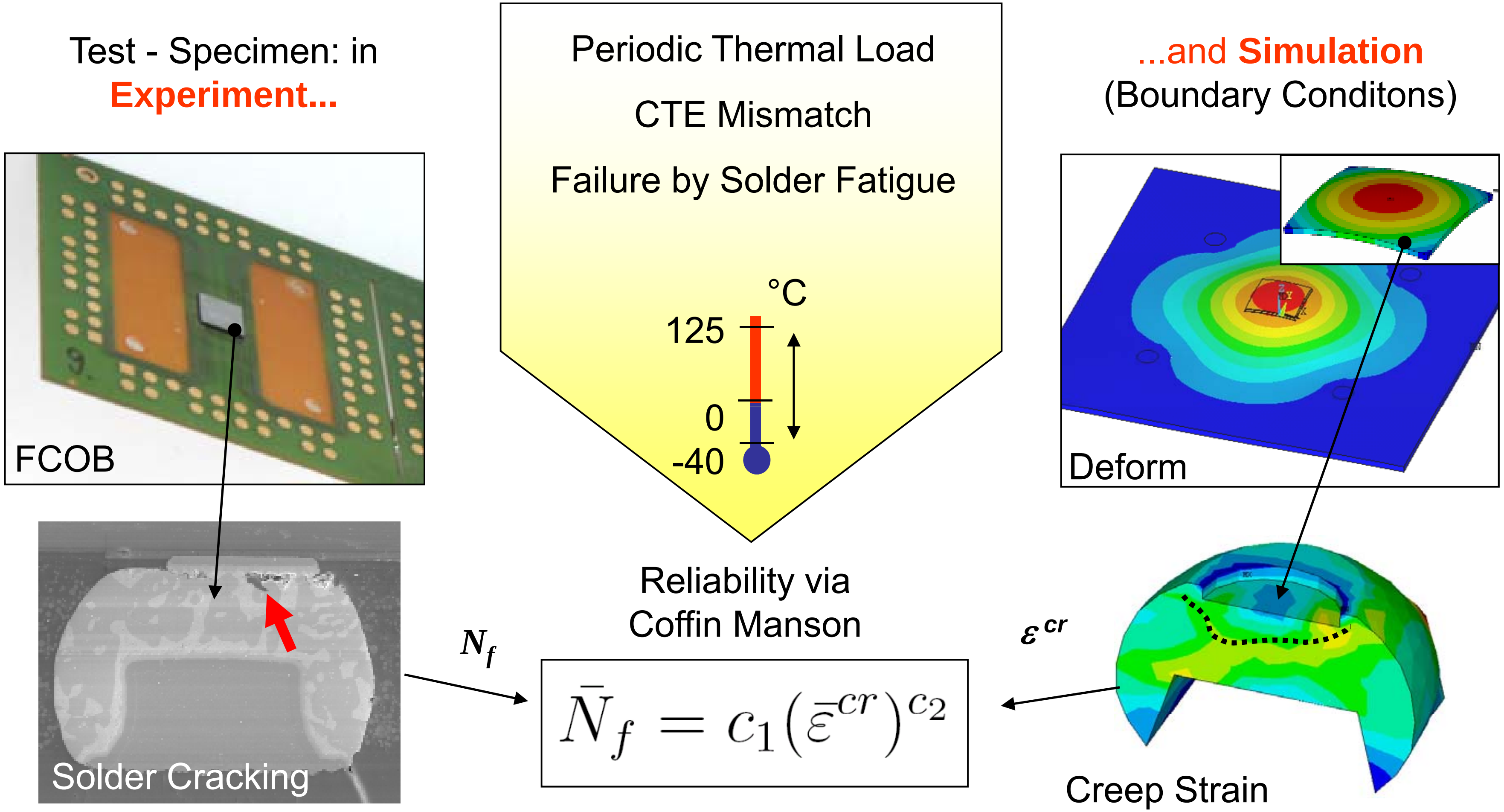
D. Vogel, N. Sabate, J. Keller, B. Michel,

Methoden Übersicht – Residual Stress Testing

- Wafer Curvature
- Röntgenbeugung (Winkel- / Energiedispersiv)
- fibDAC
- Ramanspectroskopy
- EBSD (Elektron Back Scatter Diffractometry

Modelling
and Reliability Estimation

Solder Fatigue in Experiment and Simulation



Test - Specimen: in
Experiment...

Periodic Thermal Load

CTE Mismatch

Failure by Solder Fatigue

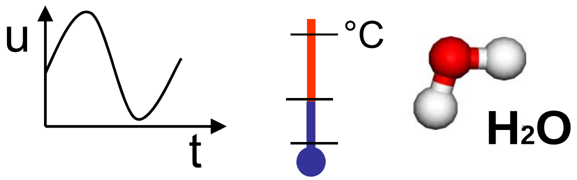
...and **Simulation**
(Boundary Conditons)

Reliability via
Coffin Manson

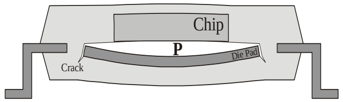
$$\bar{N}_f = c_1\left(\bar{\varepsilon}^{cr}\right)^{c_2}$$

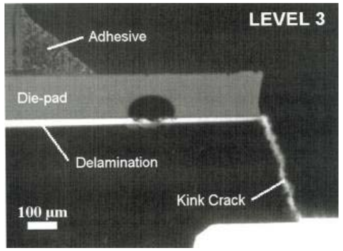
- c1, c2 = f(Mat. , Cycle)
- Char. Curve for Material at T(t)

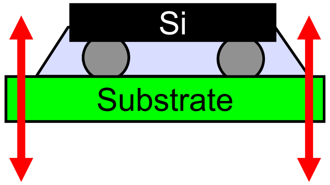
Load Combination

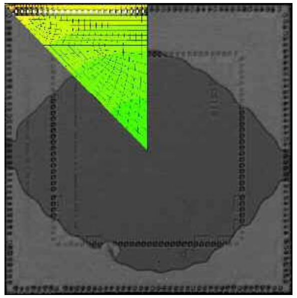


Example failure mechanisms





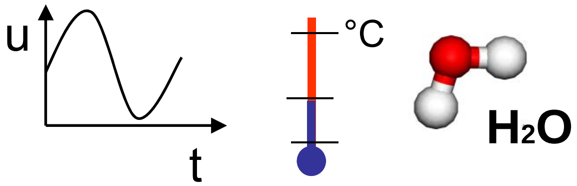


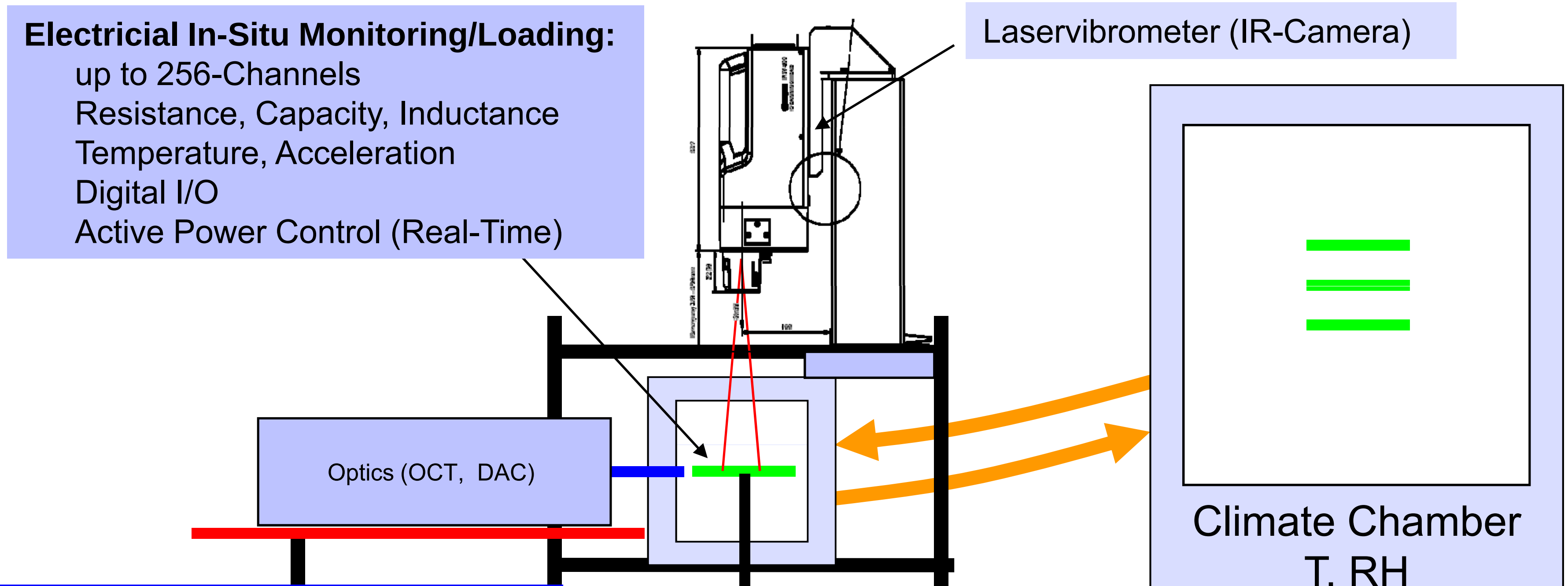


- Moisture + Temperature
  - Accelerated moisture transport
  - Popcorning
- Moisture/Temperature + Vibration
  - Reduction of interfacial adhesion
  - Mechanical interface load
- Temperature Cycling + Vibration
  - Initial degradation by Temperature cycling
  - Instable crack growth during vibration

The combination of loads can be more critical than the single loads.
→ Combined testing

Test Set-up



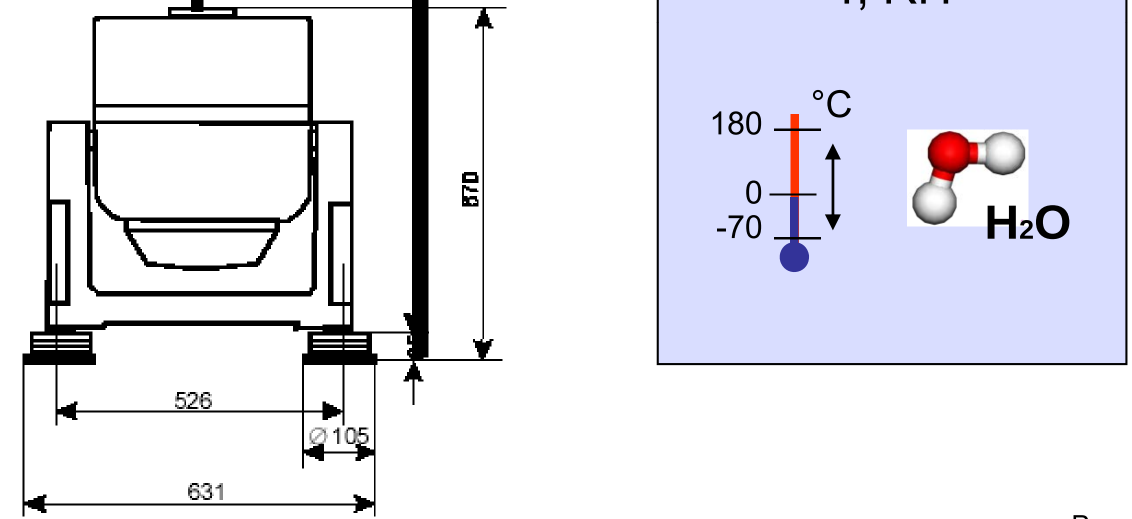


Electricial In-Situ Monitoring/Loading:
- up to 256-Channels
- Resistance, Capacity, Inductance
- Temperature, Acceleration
- Digital I/O
- Active Power Control (Real-Time)

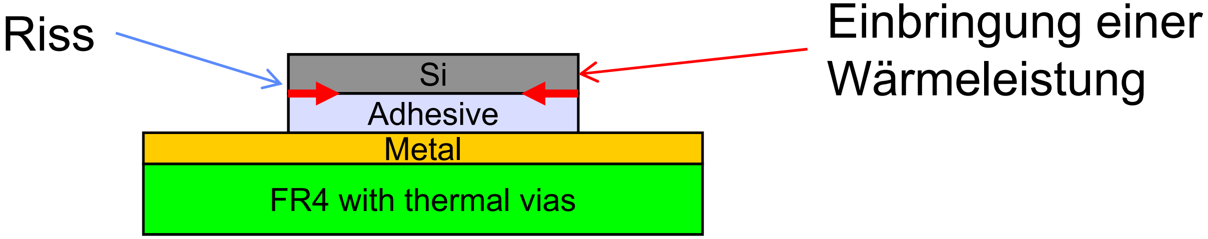
Laservibrometer (IR-Camera)

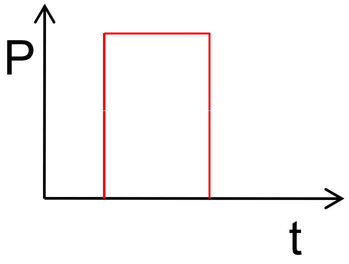
Optics (OCT, DAC)

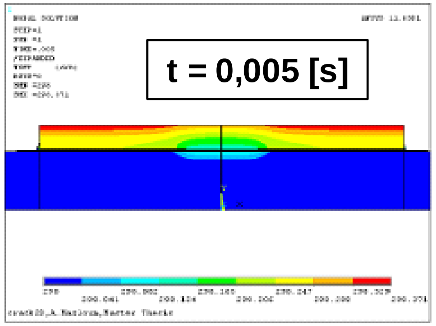
Climate Chamber
T, RH

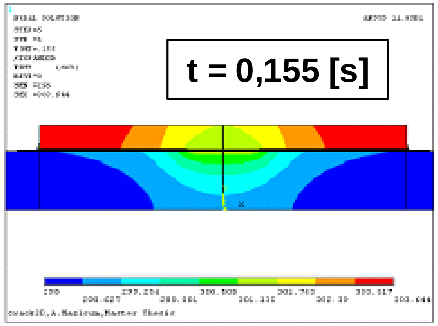


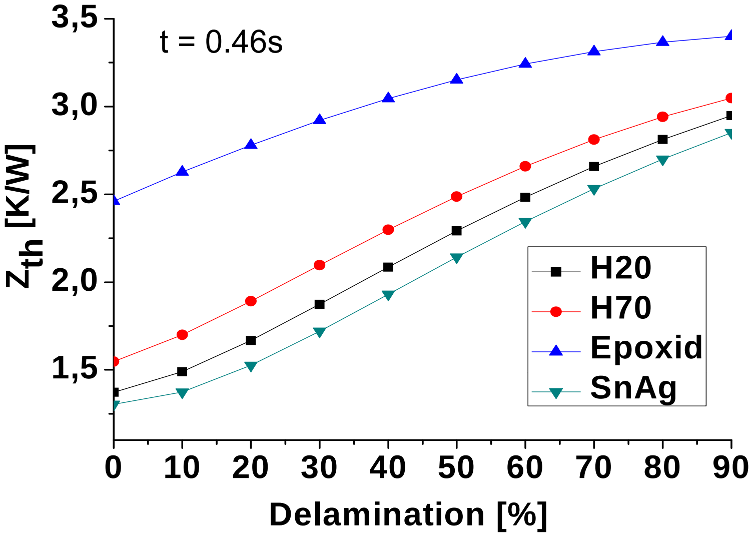
In-Situ „Health Monitoring“ für Die Attach Verbindungen











Fast lineare Relation von Risslänge und transientem Thermischem Widerstand Z_{th}

Fraunhofer Institut
Zuverlässigkeit und
Mikrointegration

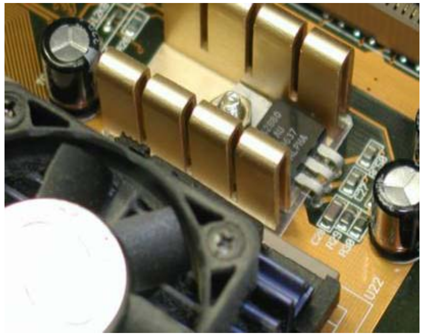
Micro Materials Center
Berlin and Chemnitz
Head: Prof. B. Michel

Thermal Modelling and Characterisation

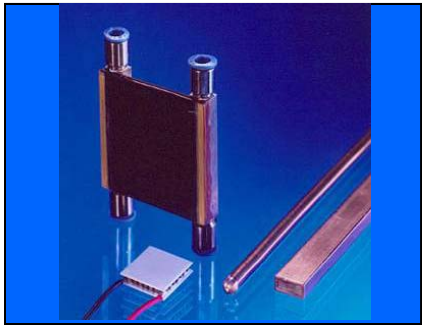
IZM Program

Thermal Management

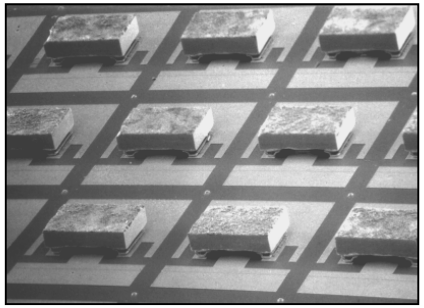
Fraunhofer Institut
Zuverlässigkeit und
Mikrointegration



Reliability & cost-optimised design for cooling systems

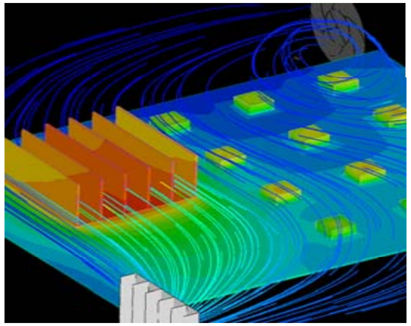


Implementation of advanced cooling concepts

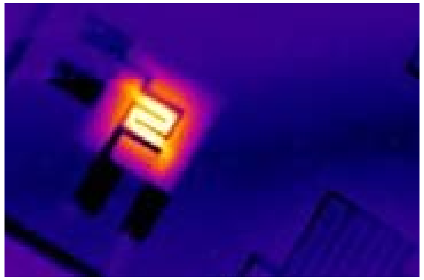


Technological support and processes:
from *hand-held* up to *high-performance*

Material characterisation



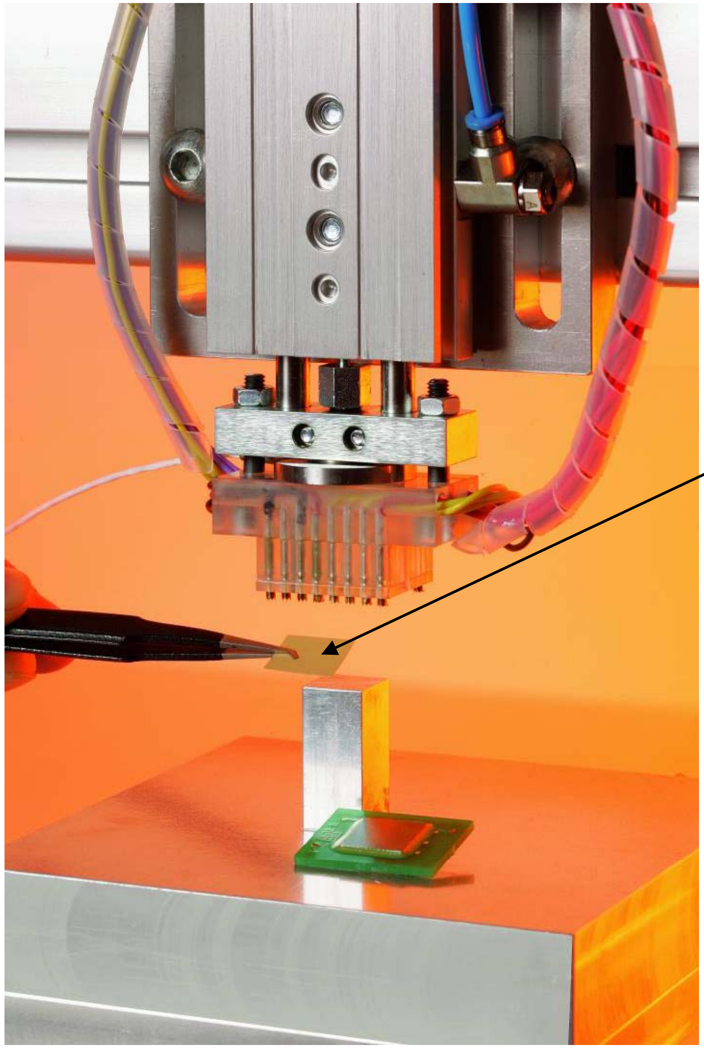
Virtual prototyping



Verification and testing

Contact: Dr. B. Wunderle, Mail to: bernhard.wunderle@izm.fraunhofer.de
Dep. Mechanical Reliability and Micro Materials, Head: Prof. Dr. B. Michel, Fraunhofer IZM, Berlin, Germany

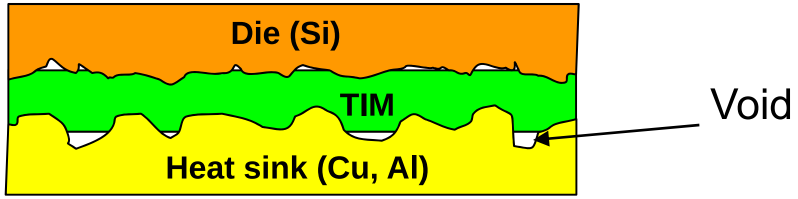
Thermal Characterization of Materials



$$\vec{j} = -\lambda \, grad \, T$$

Thermal Conductivity

Probe (TIM)



<u>At IZM developed method</u>

to characterize all classes of TIMs incl. interface resistance under real application condition (pressure, thickness, temperature)

R. Schacht, E. Auerswald, J.P. Sommer, B. Wunderle, B. Michel and Reichl.
ESTC 2006, Sep 5-7, 2006, Dresden, Germany

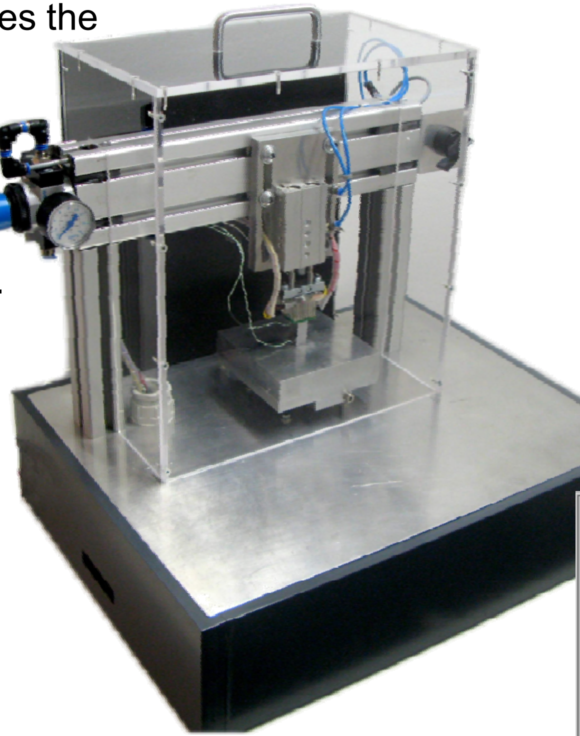
Characterization of Thermal Interface Materials (TIM)

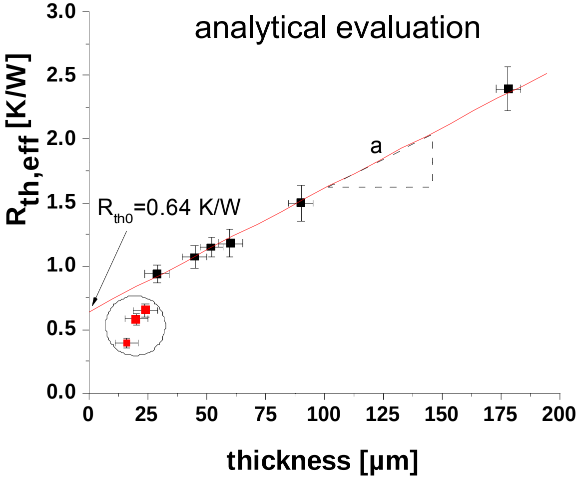
New measurement method determines the

- **Effective thermal resistance**
- **bulk conductivity**
- **interface resistance**

of all commercially available TIM e.g.

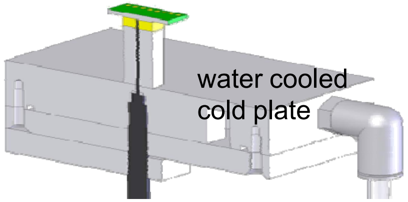
- **Greases**
- **Elastomeric Pads**
- **Phase Change Materials**
- **Adhesives**
- **Solder and etc**





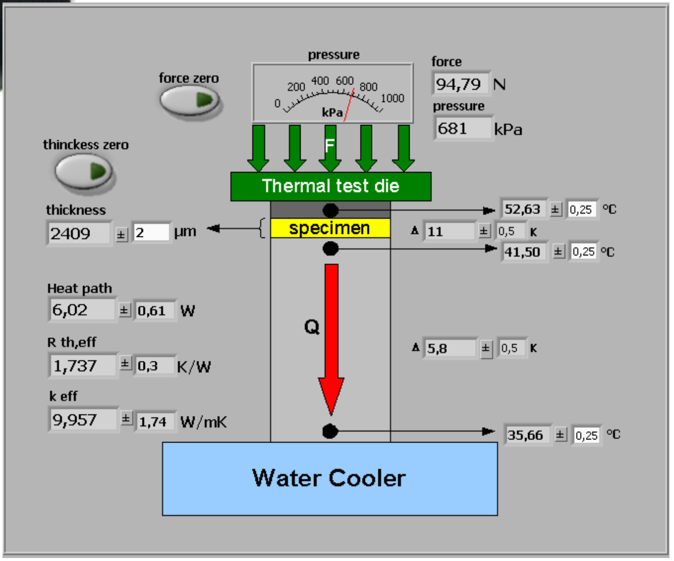
Operational conditions:

- **Chip temperature: $T_J = (50…130)°C$**
- **Pressure: p = (0,1…1) MPa**
- **Layer thickness: d = (5…5000)µm**
- **Thermal conductivity: λ_{bulk} < 10 W/m K**



Thickness determination by integrated displacement transducer (LVDT)

Computer controlled measurement



force 94,79 N
pressure 681 kPa
thickness 2409 ± 2 µm
Heat path 6,02 ± 0,61 W
R th,eff 1,737 ± 0,3 K/W
k eff 9,957 ± 1,74 W/mK
52,63 ± 0,25 °C
Δ 11 ± 0,5 K
41,50 ± 0,25 °C
Δ 5,8 ± 0,5 K
35,66 ± 0,25 °C

Abo Ras, May, Schacht , Wunderle

Thermo-Electrical Testing

Fachhochschule Lausitz
University of Applied Sciences

Fraunhofer IZM
Institut
Zuverlässigkeit und
Mikrointegration

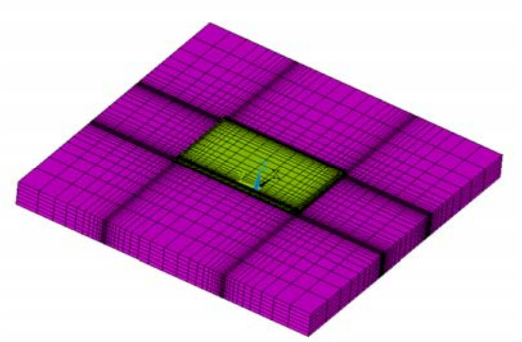
Reliability
Micro Materials
Center

Micro Materials Center
Berlin / Chemnitz
Head: Prof. B. Michel

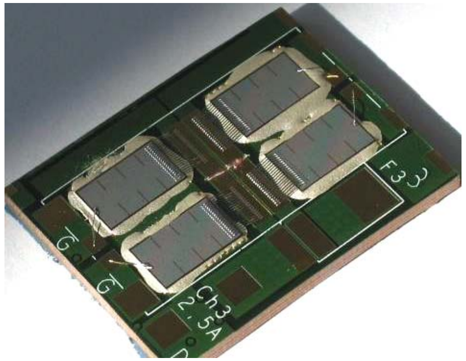
Measurement & Simulation - Transient Thermal Load

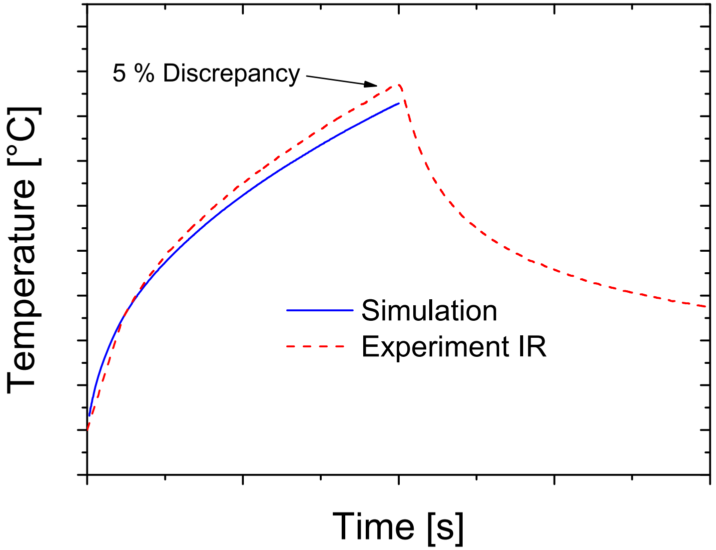
COB on LP

Model



Experiment





Goal

- Design optimization

Result

- Transient load is important, → more Cu necessary !!

Important criterions:
Diffusivity, Geometry, Voids,
Eff. Material data, hotspot distribution

Schacht, Wittler