Thermo-Mechanical Reliability of Micro and Sub-Micro-Applications

J.-Peter Sommer, Bernd Michel
Micro Materials Center Berlin/Chemnitz
Fraunhofer Institution for Electronic Nano Systems (ENAS)

- Introduction: The Micro Materials Center Berlin/Chemnitz
- Reliability and design process
- Numerical simulation: Examples
- microDAC and related techniques
- X-ray computer tomography
- Summary: Feasible contributions to upcoming projects

Fraunhofer
Reliability and Microintegration IZM

Berlin

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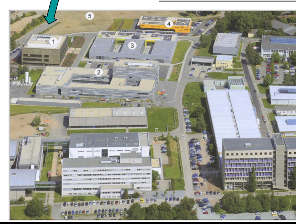
Electronic Nano Systems ENAS

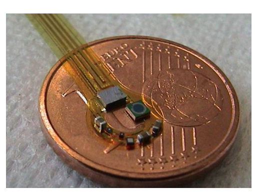
Chemnitz



- Opening: June 2009

ENAS: Smart Systems Integration Applying Micro and Nano Technologies

- Integration of different functionalities
  - Signal processing
  - Sensors
  - Actuators
  - Photonics
  - Power
  - Coolers
- High degree of miniaturisation and flexibility
- Reasonable costs
- In one unit (e.g. package)



- Target:
  Bridging the gap between nano electronics and application

Trends in MEMS Technology

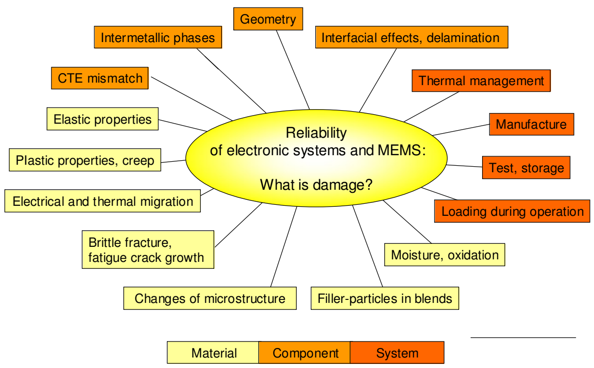
- Cheaper, smaller, extended functionality
- No malfunction, no failure during lifetime

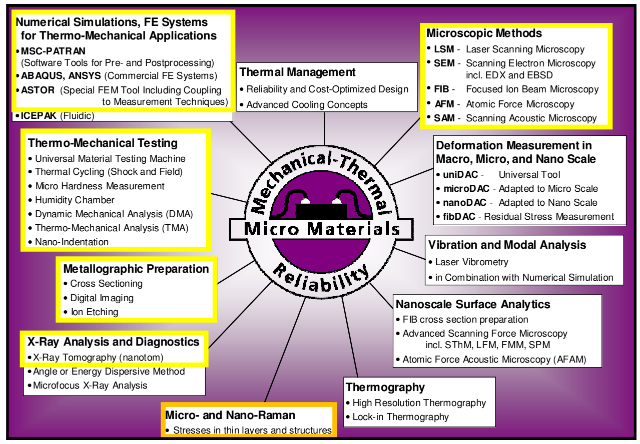
→ Need for an increased reliability

Aspects: electrical thermal mechanical chemical .....

- Role of the Micro Materials Center Berlin & Chemnitz
  - Thermal and thermo-mechanical analyses
  - Reliability assessments
  - Physics of failure

What is Essential for Reliability and Damage?





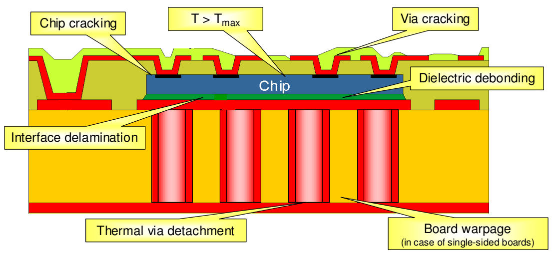
Direct Co-Operations with Industrial Enterprises (Selection)

- Electronic / MEMS for automotive suppliers
  - BMW AG Munich
  - Continental-Automotive AG Nuremberg
  - Robert Bosch GmbH Stuttgart
  - Siemens AG Munich
  - Infineon AG Munich/Regensburg
  - Valeo GmbH Bietigheim-Bissingen
  - AB Elektronik GmbH Werne
  - Sensitec GmbH Lahnau
  - Schlumberger (F)
  - Sensor Dynamics Oberpremstetten (A)
  - Siemens VDO Toulouse (F)
- Other applications
  - Robert Bosch GmbH Stuttgart
  - Siemens AG Munich
  - Qimonda Dresden
  - AMD Dresden
  - EPCOS Munich
  - Freescale (former Motorola) Munich
  - Intelligent Medical Implants GmbH Bonn
  - Microelectronic Packaging Dresden GmbH
  - Intel (USA)
  - Philips Eindhoven (NL)
  - NXP (Philips Semiconductors) Hamburg

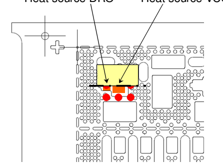
International Co-Operations within the Framework of EU Projects (Selection)

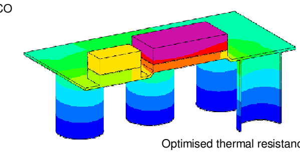
- Blue Whale — Thermo-mechanical design support for a Bluetooth package (Shellcase)
  - Philips (NL), DEK (UK), Shellcase (IL), TU Delft (NL)
- Hiding Dies — Active dies embedded into an organic board
  - Philips (NL), Nokia (FIN), AT&S (A), Datacon (A), IMEC (B)
- MEVIPRO — Thermo-mechanical optimisation / virtual prototyping methodology
  - Philips (NL), TNO (NL), Leuven MeasurementsSystems Intl. (B), TU Delft (NL), Kitron Development AB (S), Thales Microelectronics (F), TU Wroclaw (PL)
- nanoInterface — More efficient engineering for reliable electronic components in micro- and nano-scale
  - Philips (NL), NXP (NL), Accelrys Inc. (USA), Centre National de la Recherche Scientifique (F), TU Delft (NL), Georgia Institute of Technology (USA), Honeywell (USA), ETU St. Petersburg (RUS)
- nanoPack — Nano packaging technology for interconnect and heat dissipation
  - Thales (F), Budapest University of Technology (H), Chalmers University of Technology (S), ...

Reliability Riscs at Embedded Dies

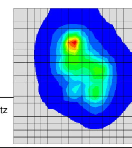


Thermal FE-Analysis: Heat Dissipation in a Radar-Based Adaptive Distance Control Unit



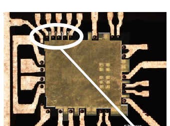


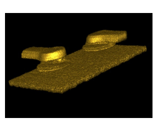
Optimised thermal resistance
- at DRO: $\Delta T/P < 13$ K/W ✔
- at VCO: $\Delta T/P = 17$ K/W ✔

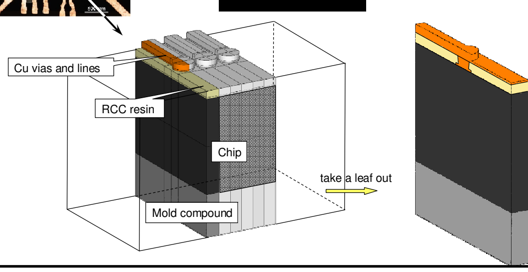


Can heat source treated as uniformly distributed?
- If not, > 40 % enlarged thermal resistance may occur!

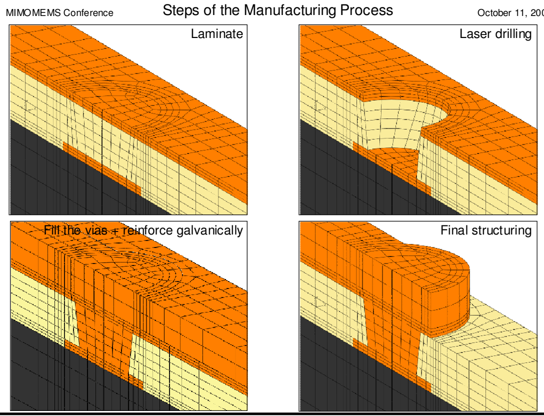
Vias at an RF Chip of the Radar Module (KRAFAS Project Demonstrator)



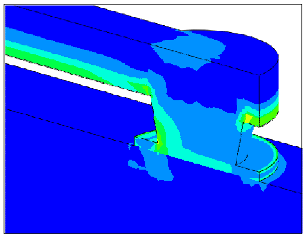


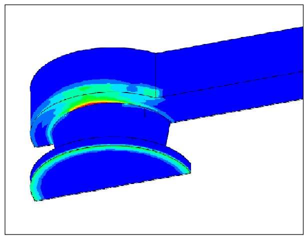


Steps of the Manufacturing Process



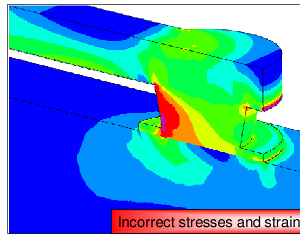
Stress and Plastic Strain after Manufacturing Process and First TC at -40 °C

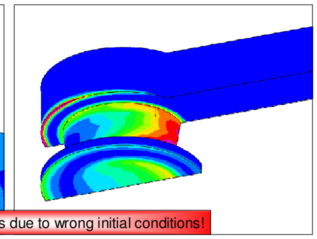




- v.Mises stresses
- Plastic strain

Cooling Down from 180 °C (Stress-Free) to -40 °C

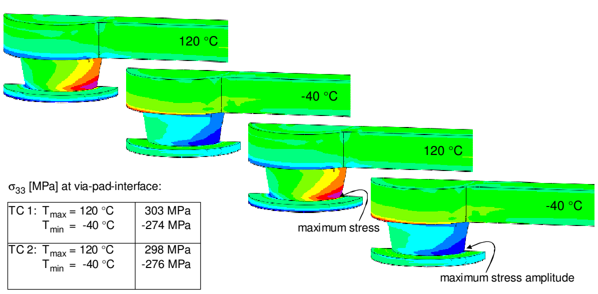




Incorrect stresses and strains due to wrong initial conditions!

- v.Mises stresses
- Plastic strain

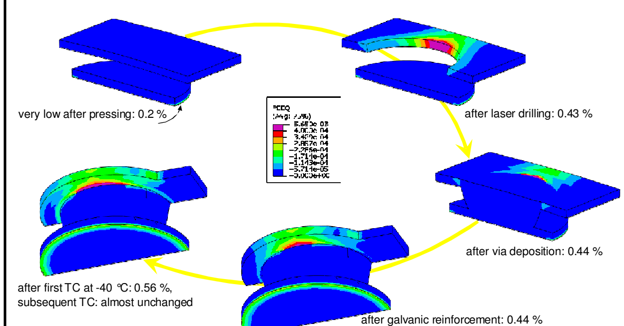
Peel Stress at a Cu-Via during Thermal Cycling



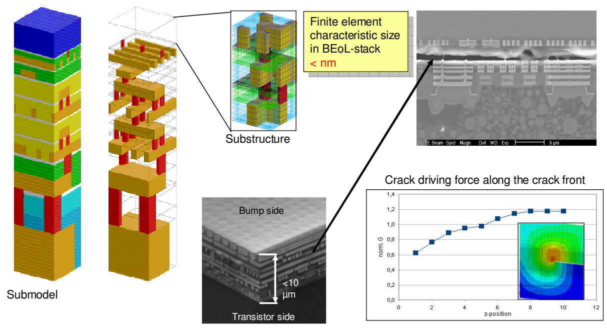
σ_{33} [MPa] at via-pad-interface:

TC 1: T_{max} = 120 °C T_{min} = -40 °C	303 MPa -274 MPa
TC 2: T_{max} = 120 °C T_{min} = -40 °C	298 MPa -276 MPa

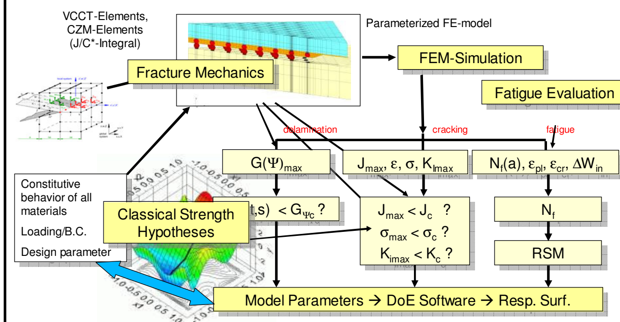
Plastic Deformation in the Cu-Structures at a Via



3D BEoL Stack FEA – Simulation of the Cracking/Delamination Behavior

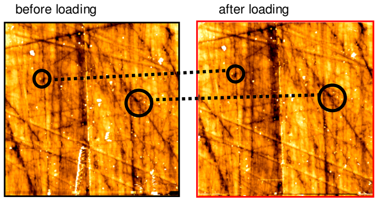


Solder Fatigue, Bulk Fracture, Interface Fracture – RSM/DoE



Digital Image Correlation:
Deformation **A**nalysis by means of **C**orrelation: **microDAC**® Principle

before loading after loading



Measurement data

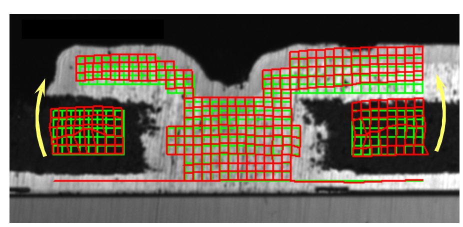
- In-plane displacement fields u_x and u_y
- Derived strain fields

$$\varepsilon_{xx} = \frac{\partial u_x}{\partial x}, \ \varepsilon_{yy} = \frac{\partial u_y}{\partial y}$$

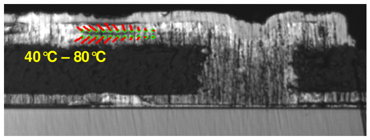
$$\varepsilon_{xy} = \tfrac{1}{2}\left(\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right)$$

- Tracking of local object pattern
- Independence of imaging method
- Images from microscopy: optical, REM, LSM, SAM, AFM, ...

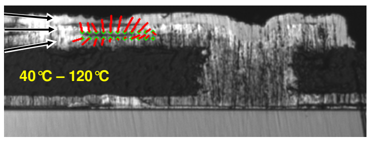
Intersection through a Cu Via - Heating from RT to 140 °C



Damage Recognition by Means of microDAC®



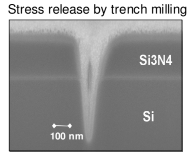
Galvanically reinforced Cu
Electroless deposited Cu
Cu of RCC



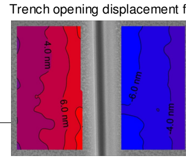
Scaling: 100x

fibDAC: Intrinsic Stress Determination in Thin Layers

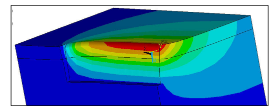
- Stress release by trench milling in FIB:



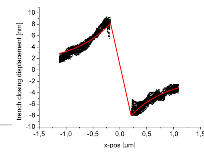
- Tensile stresses before trench milling
- Trench opening displacement field:



- ¼ FE model for trench milling:

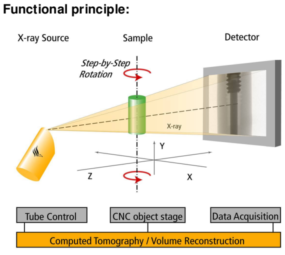


- Fitting computed to measured displacements: $\sigma_{max} \approx 2030$ MPa ± 3 MPa (fitting error)

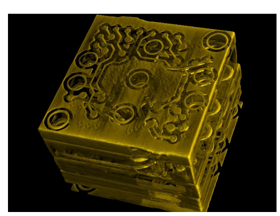


Nano-Focus Computer-Tomography System with 160 kV High Power X-Ray Tube (Phoenix-Xray Comp.)

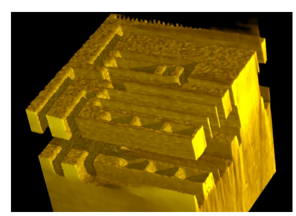
Functional principle:



Examples: Computer Tomography (nanotom, Phoenix Comp.)



3d autarkic micro system



MEMS detail

- Currently under development: MicroDAC combined with computer tomography

Summary

- Reliability aspects
  - Are relevant for any new electronic systems or MEMS
  - Cannot stand alone
  - Are always connected with real parts
- Micro Materials Center is well-prepared for upcoming European co-operations:
  - Experience for more than 15 years
  - Modern equipment for investigations in micro and nano range
- We would be pleased to contribute to new developments and projects!