Zuverlässigkeit, Sicherheit und Lebensdauer von Sensornetzwerken im Mikro-Nano-Übergangsbereich

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Institut
Zuverlässigkeit und
Mikrointegration

Integrationstechnologien
für
vernetzte autonome Mikrosysteme

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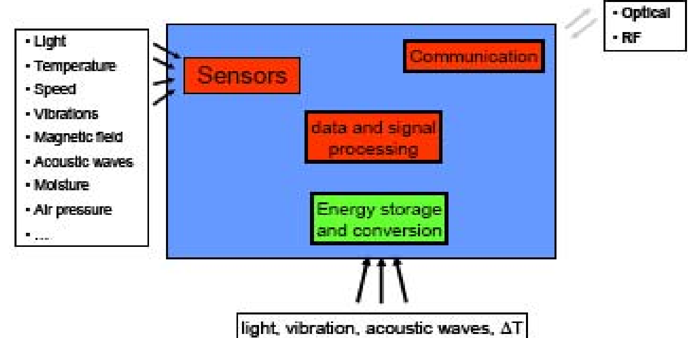
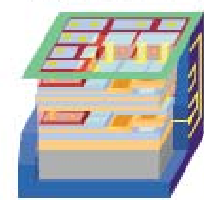
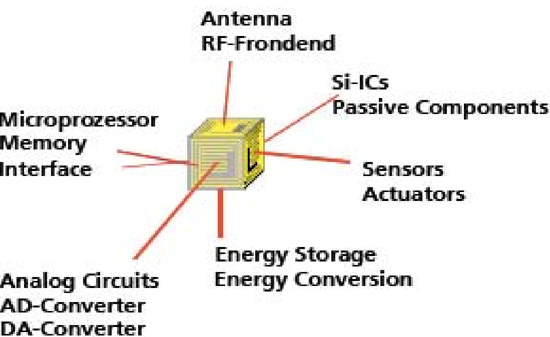
Self-sufficient Wireless Sensor Node

- Highly Miniaturized
- Receive, Process, Store and Send Data
- Integrated Sensors, Signal /Data Processing,
- Wireless Interface
- Power Conversion

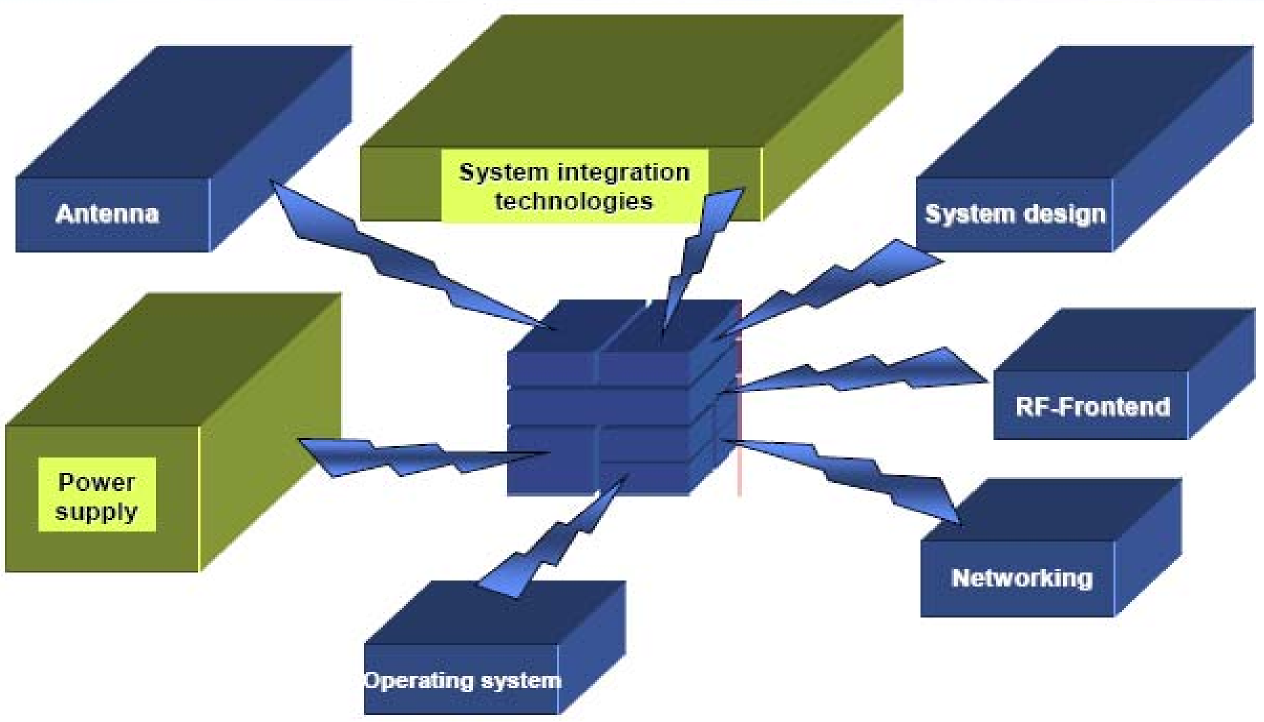


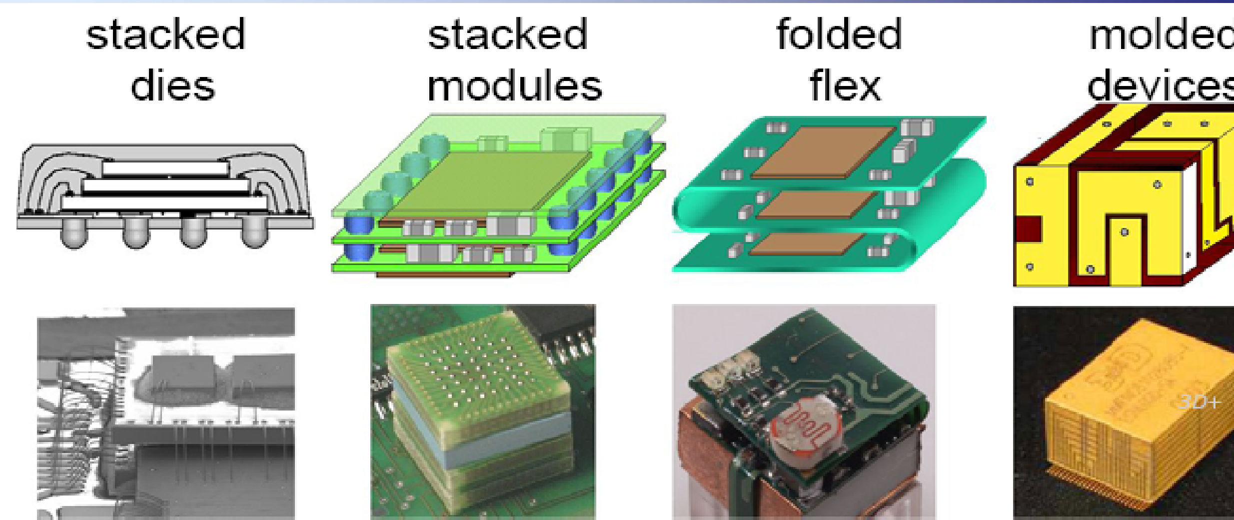
Vision: e-Grain





e grain – building blocks




Systembetrachtungen zur Miniaturisierung
Hetero System Integration – Technologies
stacked dies
stacked modules
folded flex
molded devices
3D+

Systembetrachtungen zur Miniaturisierung
Hetero System Integration – Technologies

stacked dies	stacked modules	folded flex	molded devices

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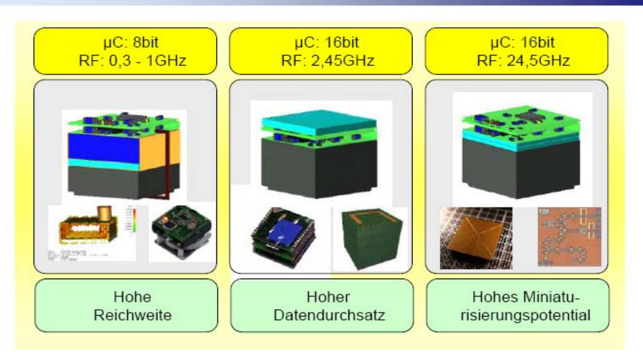
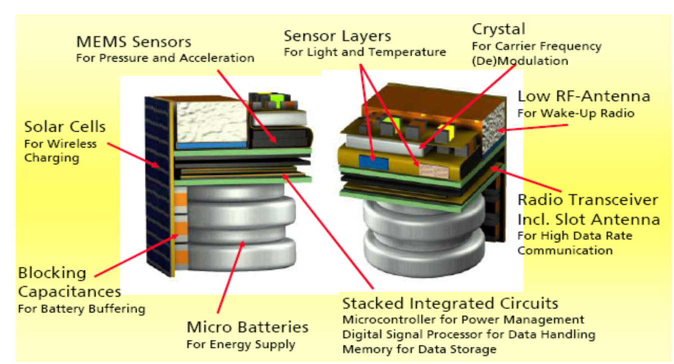


Flex Technologies for eGrains



eGrain-Roadmap

2002

2003

2004

2005

2006

2007

Standard-FR4
TQFP, TSOP
Kantenlänge
2 ... 3 cm
Volumen
8 ... 27 cm³

HDI-FR4
CSP, μBGA, COB, FC
Kantenlänge
0,8 ... 2 cm
Volumen
0,5 ... 8 cm³

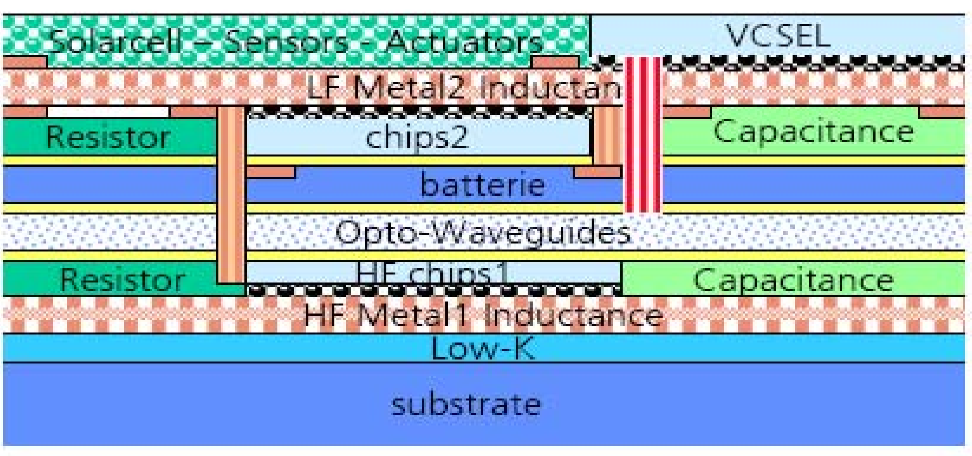
Flex
MCM-L
Kantenlänge
0,7 ... 1,5 cm
Volumen
0,3 ... 3 cm³

Flex
MCM-D
Kantenlänge
0,6 ... 1 cm
Volumen
0,2 ... 1 cm³

Chip Level
MCM-3D
Kantenlänge
0,5 ... 0,6 cm
Volumen
0,1 ... 0,2cm³

Wafer Level
MCM-3D
Kantenlänge
0,45 ... 0,5 cm
Volumen
0,09 ... 0,1 cm³

Multifunctional Organic Substrate Technology



Reel to Reel Processing

Hetero System Integration

Ir

Smart System Integration

More Moore

Katastrophenschutz

Potential Failure Mechanisms in SOP (System-on-Package) Microsystems

Change in Capacitance due to Stress/Strain

Solder Fatigue

Via Cracking

Interfacial Delamination

Dielectric Cracking

Board Warpage

Stress-induced Birefringence

FLASCH

RAM

µP

PD / TIA

CMOS / SOC

MEMS

DFB / TE

RF / IC

Embedded Opto

Capacitor

RF

Composite Substrate

Low CTE

High modulus

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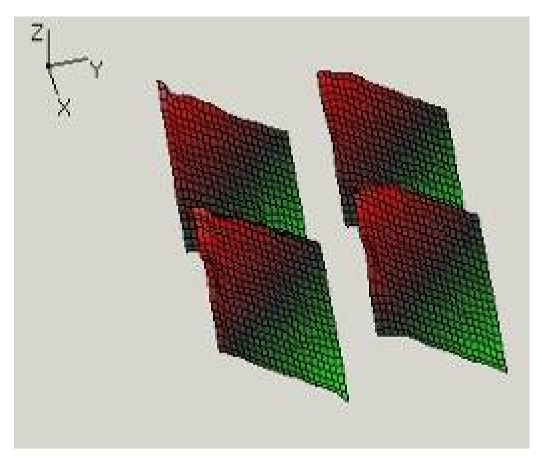
Reliability of electronic components

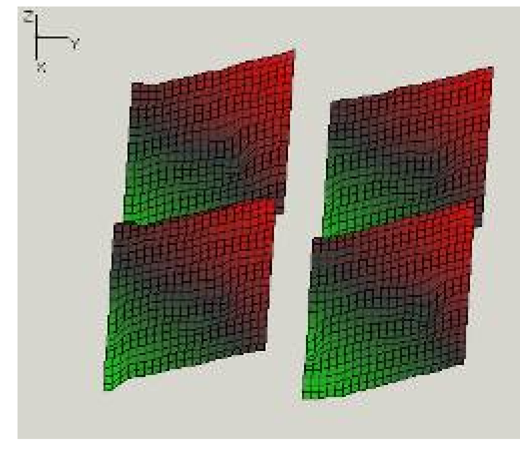
What is damage?

- Thermal properties
- Geometry
- Microstructural initial state
- Elastic Material properties
- Environment, e.g. humidity, oxidation
- Plasticity, creep (temperature dependent)
- Fracture
- Interfacial effects
- Microstructural changes due to fatigue
- Intermetallic phases
- Fatigue crack growth
- Electrical and thermal migration

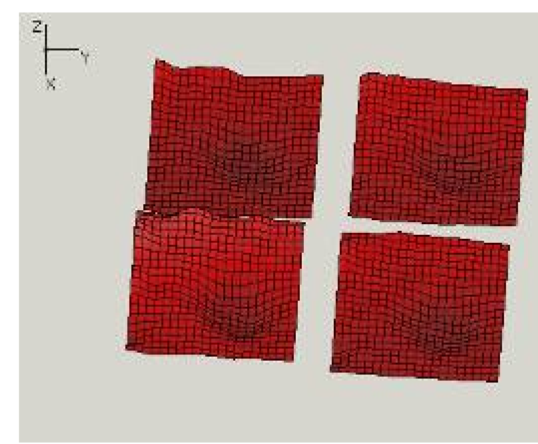
Messung



75 kHz

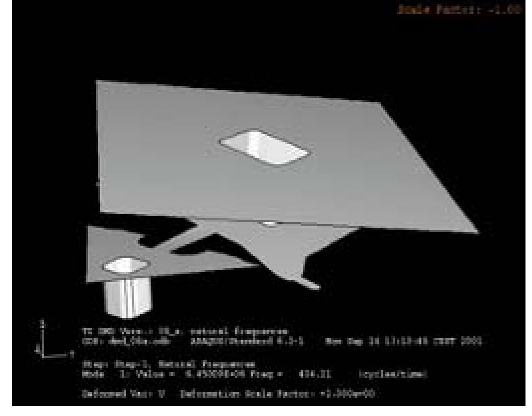


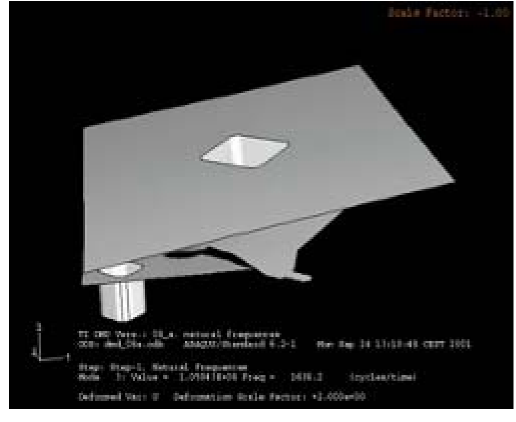
440 kHz

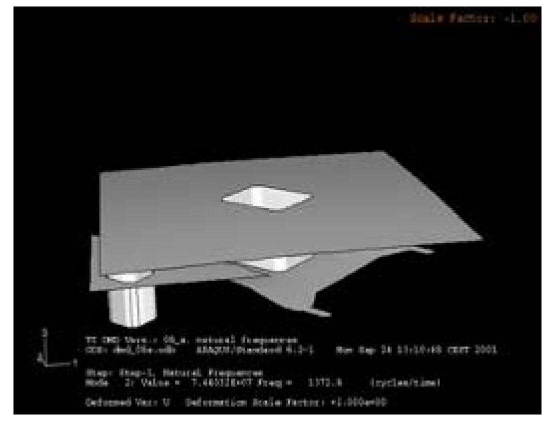


510 kHz

Berechnung







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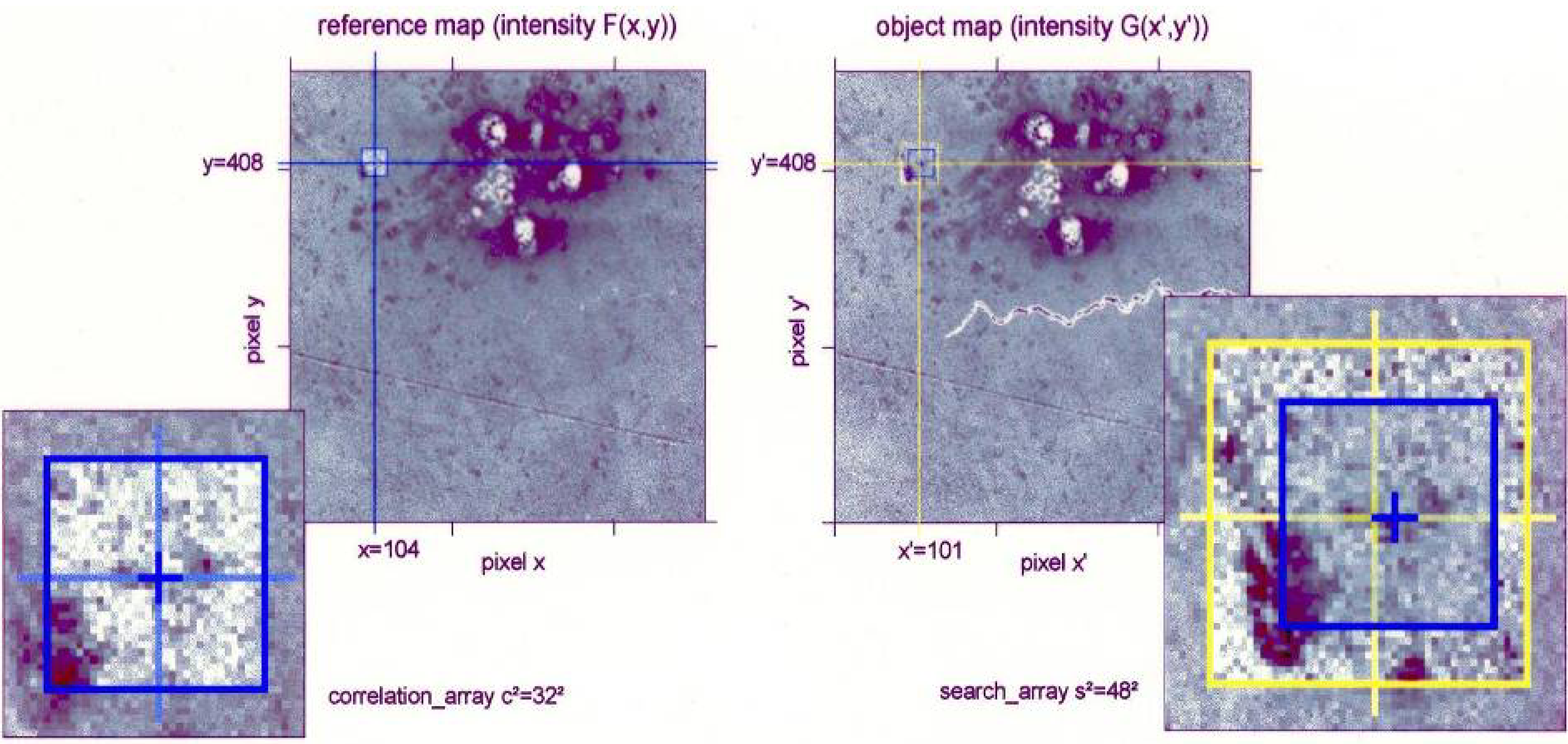
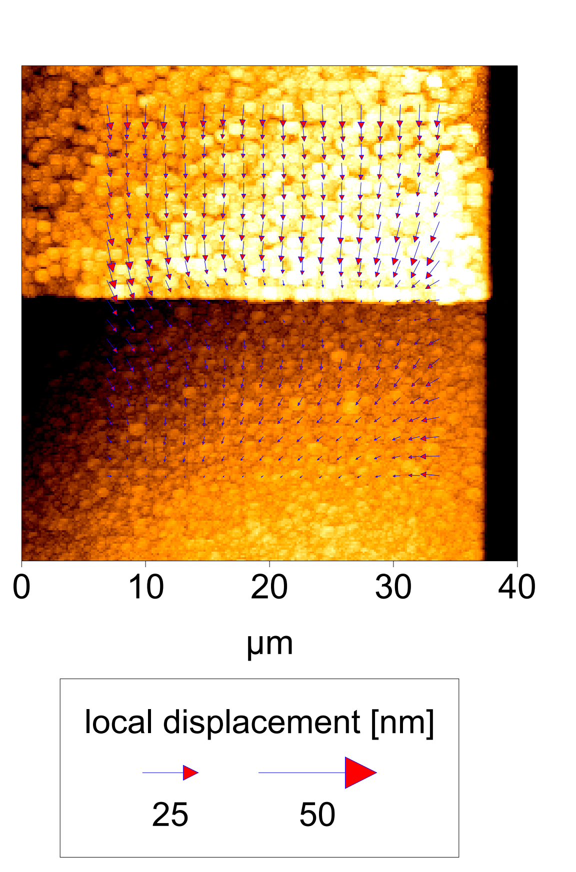


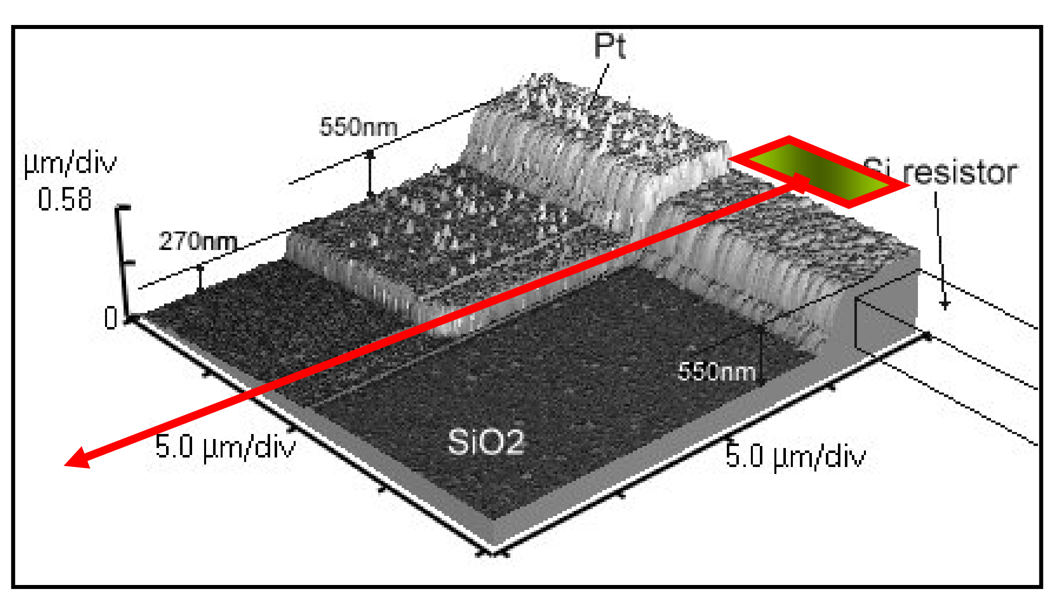
$$K(F,G) = S(F,G) \,/\, \mathrm{sqr}[S(F)^2 S(G)^2]$$

$$(ux,uy) = ([x'-x]+dx,[y'-y]+dy) \mid K(F,G)=\max$$

µDAC - SEM Deformation Analysis by Means of Correlation Analysis

3D Deformation Measurement on Sensor Structures by nanoDAC

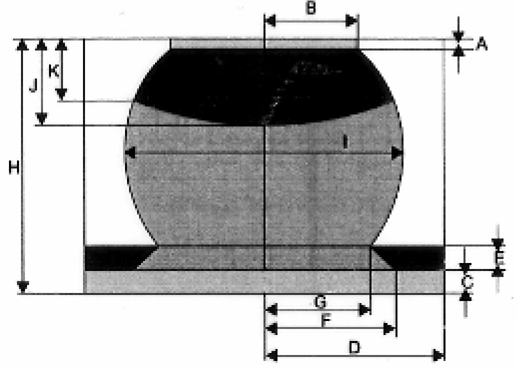




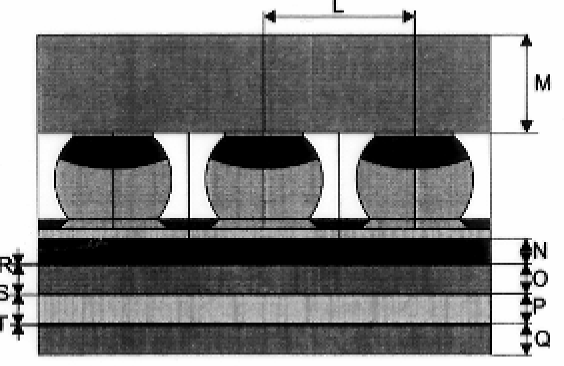
In-plane deformation field
- sensor heating under the AFM
- temperature gap: RT – 100°C

Parameterized FE-Model of a bump array with C4 bumps

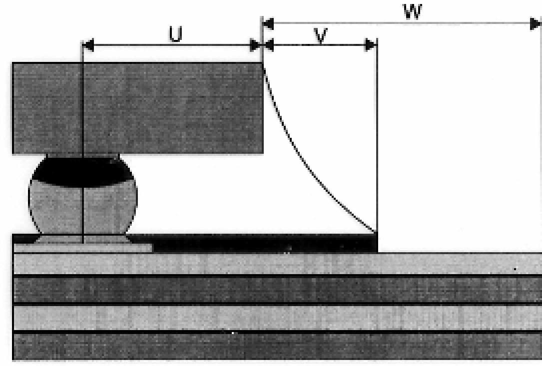
Parameters



A - height of the top pad
B - radius of the top pad
C - height of the bottom pad
D - radius of the bottom pad
E - height of the solder resist
F - radius of the upper solder resist opening
G - radius of the lower solder restist opening
H - standoff of the whole bump
I - largest bump radius
J - height of the hls bump at the center
K - height of the hls bump at the border



L - bump pitch
M - thickness of the die
N - Thickness of the 1st board layer
O - Thickness of the 2nd board layer
P - Thickness of the 3rd board layer
Q - Thickness of the 4th board layer
R - Thickness of the 1st copper layer
S - Thickness of the 2nd copper layer
T - Thickness of the 3rd copper layer



U - distance between the die edge and the center of the outer bump row
V - "width" of the underfill fillet
W - distance between the die edge and the board edge

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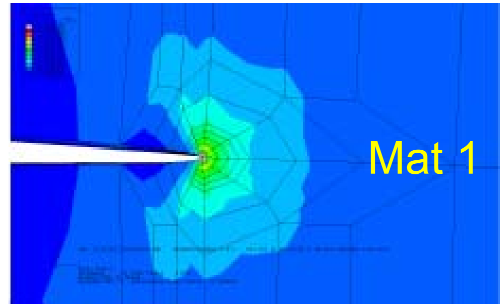
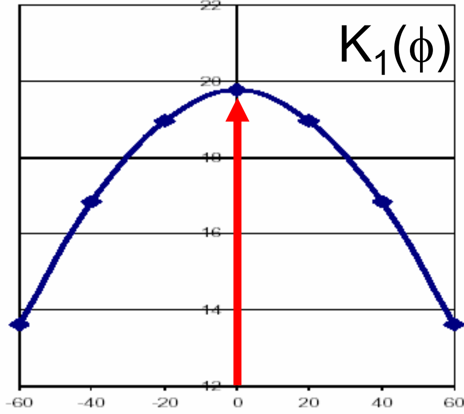
Bruchmechanik

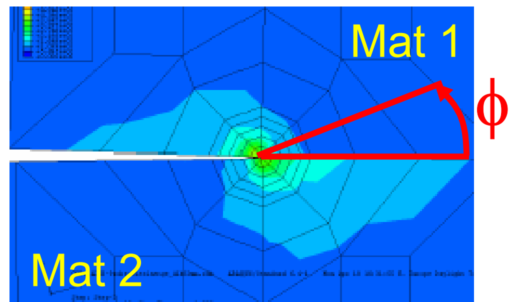
Mode Mix am Interface

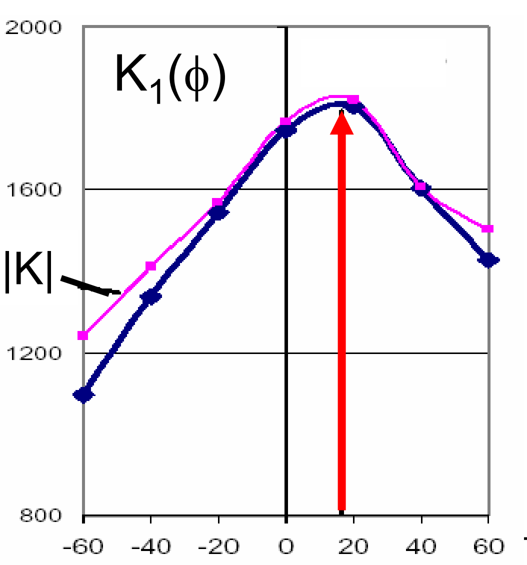
Riss im Bulk





Riss am Interface





→ Am Bi-Material Interface existiert immer ein Mode-Mix, d.h. Phasenwinkel $\phi \neq 0$, also nie eine reine Mode-I Belastung

- **Nanoreliability**
- **Microreliability**

Wissenschaftliche Ziele (I)

- **Lebensdauerkonzepte für miniaturisierte Komponenten und Systeme**

  - Langzeitlebensdauer (> 15 Jahre)
  - komplexe Belastungen (therm., mechanisch, elektrisch,...)
  - extreme Einsatzbedingungen
  - neue Werkstoffe in miniaturisierten Verbünden (z. B. Biomaterialien)
  - "nano"-Applikationen
  - Rißvermeidungsstrategien
  - Restlebensdauerbewertung
  - high reliability applications

- **Entwicklung, Aufbereitung und Einsatz von Simulationsmethoden - Design für Reliability**

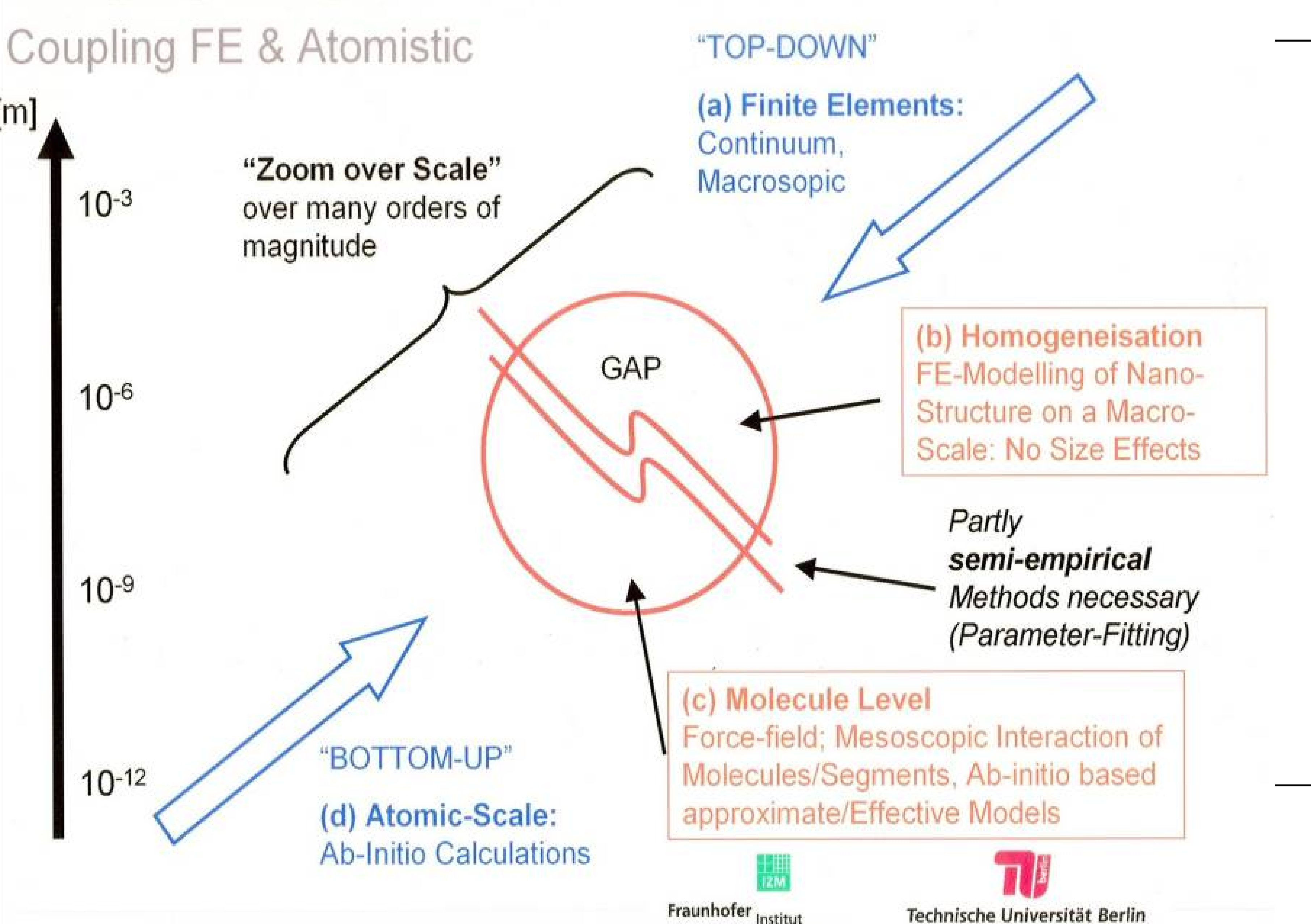
- **Schritt von der Komponentenzuverlässigkeit zur Systemzuverlässigkeit**

Zuverlässigkeitslücke

(Reliability Gap)

„Design for Reliability“

Bridging the gap between Micro and Nano



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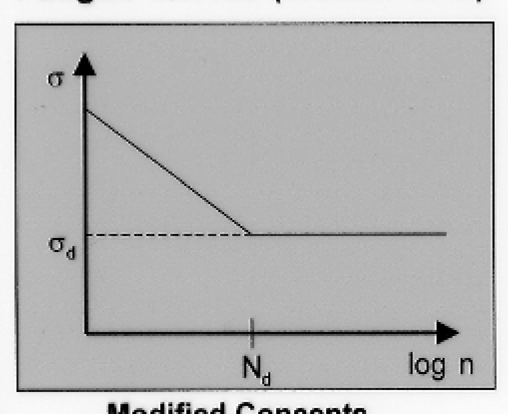
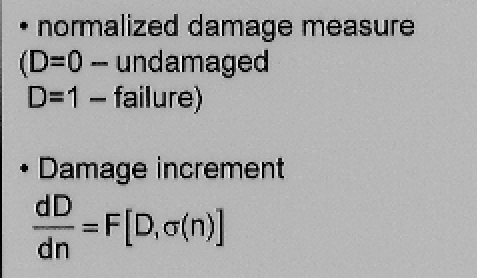
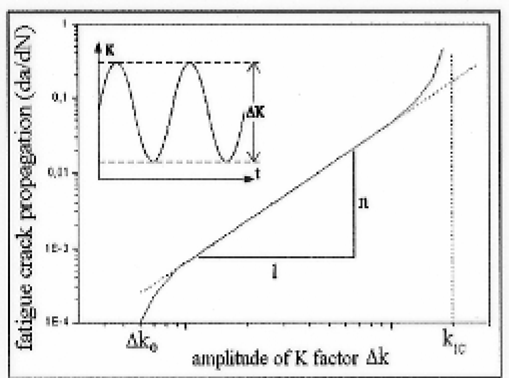
High Cycle Fatigue – Life Time Prognosis – Concepts

Fatigue Curves (Wöhler et al)	Kinetic Damage Equations	Crack Growth - Fatigue Curves





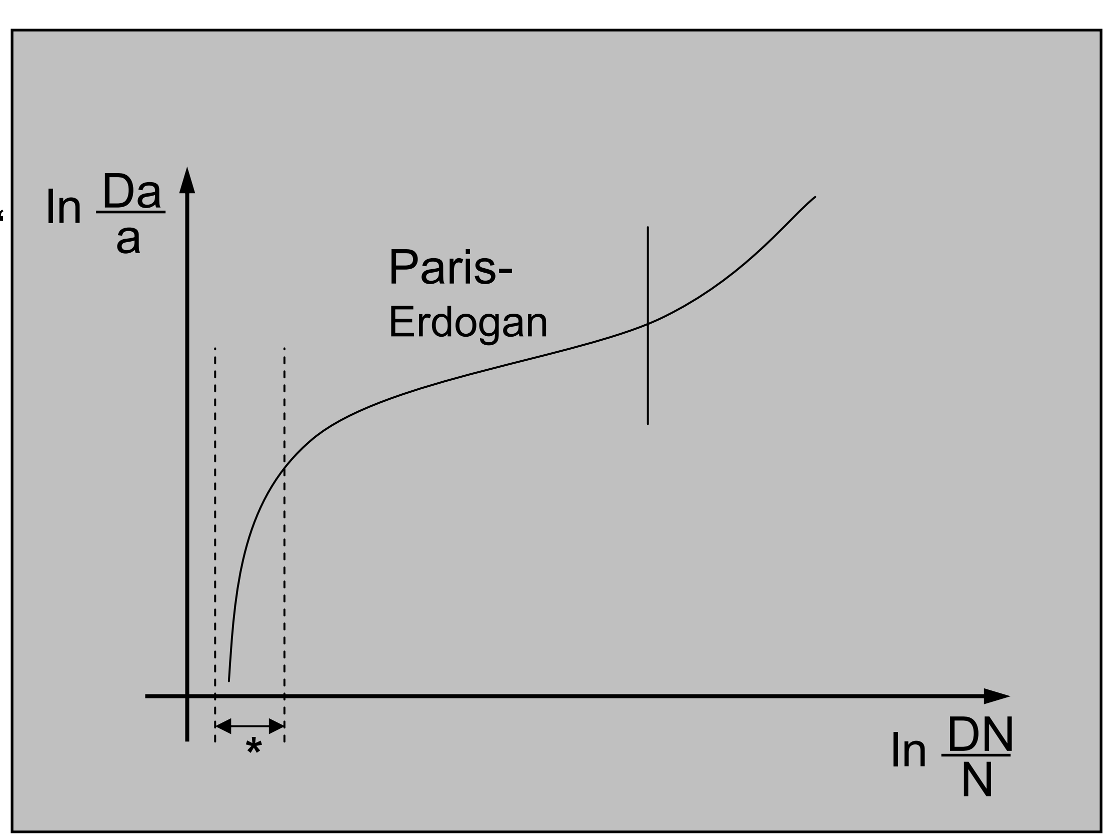


Modified Concepts

Reference Quantity:	Changes in Fatigue Curves dependent on:	Independent Damage Increments	Generalizied Damage Concepts:	Paris-Erdogan Concepts	Generalizied Concepts
• Strain • Stress or strain functions	• Damage Concept •	$\frac{dD}{dn} = \frac{1}{N(\sigma_i)}$	•e.g.: $\frac{dD}{dn} = F_1(D) \cdot F_2(\sigma(n))$	$\frac{da}{dn} = \alpha \cdot \Delta K^N$	• Energetic approach • Micro-mechanics • Formalized crack fatigue concept

Nanoreliability

„Theory of Defects“
„Lattice Theory“
„Modecular Modeling“
„Nanomaterials Simulation“



* „nano“ – short craks

Risse in Mikrosystemen in mechanischen und elektrischen Feldern

p

r

Θ

Riß

$$\sigma_{ij} = \frac{1}{\sqrt{r}} \left\{ \begin{array}{l} K_I \cdot f_{ij}^{I} \cdot (\Theta) + K_{II} \cdot f_{ij}^{II} \cdot (\Theta) \\ + K_{III} \cdot f_{ij}^{III} \cdot (\Theta) \\ + K_{IV} \cdot f_{ij}^{IV} \cdot (\Theta) \end{array} \right\}$$

K_I, K_{II}, K_{III}: klassische Spannungsintensitätsfaktoren der Bruchmechanik

K_{IV}: „elektrischer Beitrag“ zum mechanischen Spannungsfeld

European Center for Micro- and Nanoreliability

Áufgaben:

1. Bildung von *Eurolabs*
2. Schaffung eines *European Networks* der Eurolabs
   Executive Board, Scientific Advisory Board,
   Industrial Board,Board of Directors etc.
3. Awards, Expertisen
4. National Contact Points zur Zuverlässigkeitskompetenz
5. Konzeption, Initiierung und Koordinierung und von Projekten
   1. EU: IP,CRAFT,COST…
   2. International (z.B. USA-Deutschl….)
   3. National (BmbF, AIF,DFG,…)
   4. Regional (Land…)

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