



# SW Test Workshop

Semiconductor Wafer Test Workshop

June 7 - 10, 2015 | San Diego, California

## Experience in Applying Finite Element Analysis for Advanced Probe Card Design and Study



FEINMETALL

Contact technologies for electronics

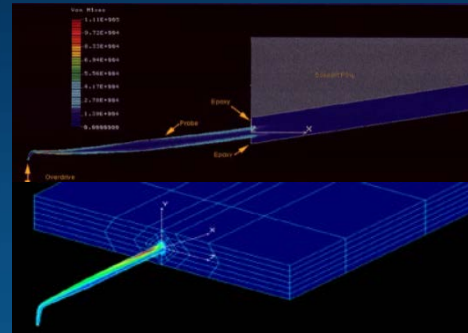
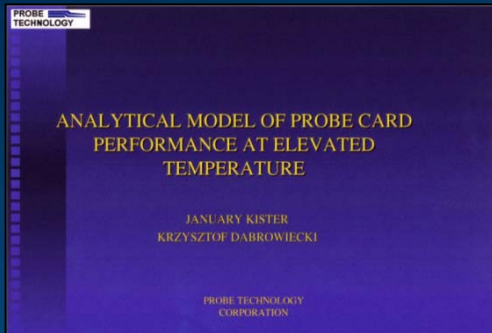
Krzysztof Dabrowiecki

Jörg Behr

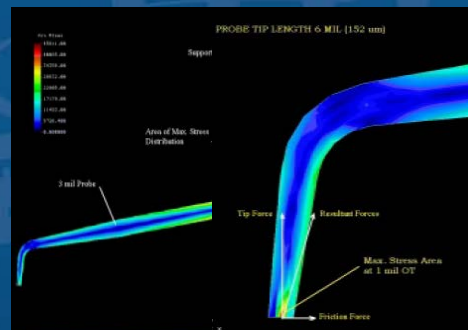
# Overview

- A little bit of history in applying finite element analysis for probe card design
- Trial and error versus FEM approach
- Example of recent FE design and studies
- Summary and conclusion
- Follow-on work

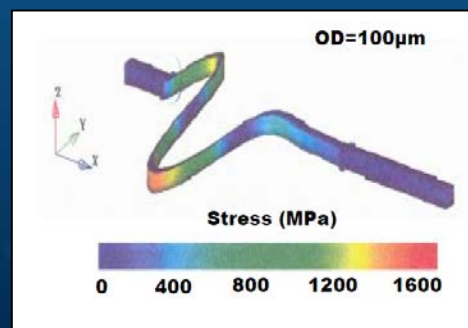
# A little bit of history of FE Modeling



**SWTest 1997:** First finite element parametric model for 4.5 mil diameter cantilever probe



**SWTest 1999:** Advanced FE probe model for 3mil cantilever probe



**SWTest 2000:** The finite element model of vertical spring silicon probe

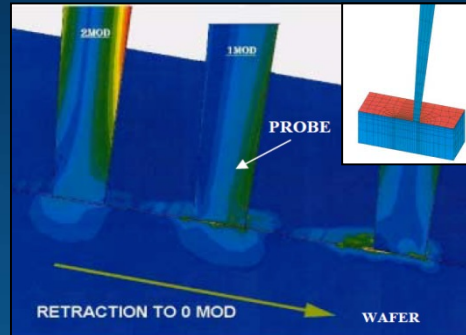
# A little bit of history... (cont.)

**CONTACT MECHANICS FOR THE CANTILEVER PROBE TIP**

Authors:  
January Kister      Krzysztof Dabrowiecki

SWTWS  
JUNE 2000

PROBE  
TECHNOLOGY



SWTest 2000: 3D modeling of mechanical contact between probe tip and bond pad

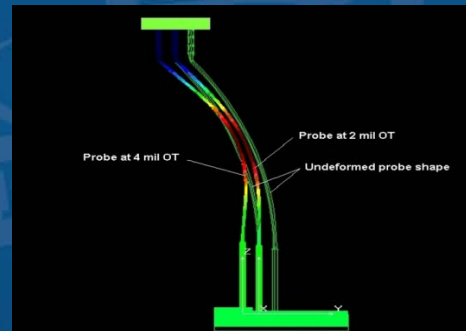
**2003 SOUTHWEST TEST WORKSHOP intel.**

**Vertical Probe Development for Copper Bump Test Challenges**

Bahadir Tunaboylu, PhD, Kulicke & Soffa Industries  
Ethan Caughey, Intel Corporation

June 2, 2003  
Joint Development and Collaboration Effort Between K&S and Intel

BTunaboyluECaughey      6/2/2003      1

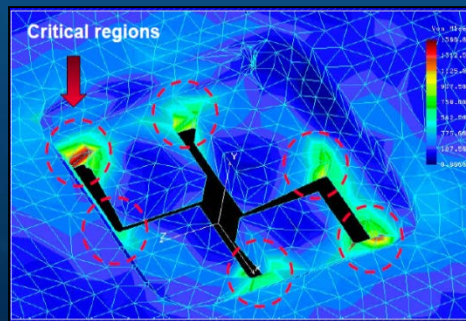



SWTest 2003: The FE model of 3D, parametric and non linear vertical, Cobra style probe

**Structural stability of shelf probe cards**

Krzysztof Dabrowiecki, Probe2000 Inc

Southwest Test Conference, San Diego, CA  
June 08, 2004



SWTest 2004: Structural stability of the ceramic shelf probe card.

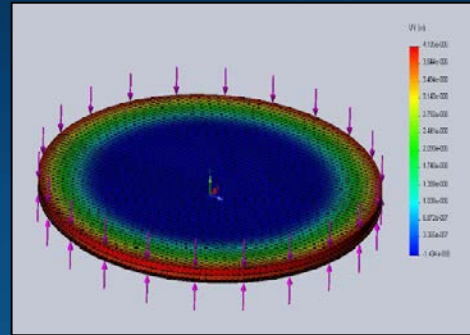


# A little bit of history... (cont.)

**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop  
June 7-10, 2009  
San Diego, CA

**How To Buckle Under Pressure**

**Scott Lindsey, Ph.D.**  
Co-Authors  
Chris Buckholtz  
Aehr Test Systems  
Simon Allgaier, Gunther Böhm  
Feinmetall GmbH

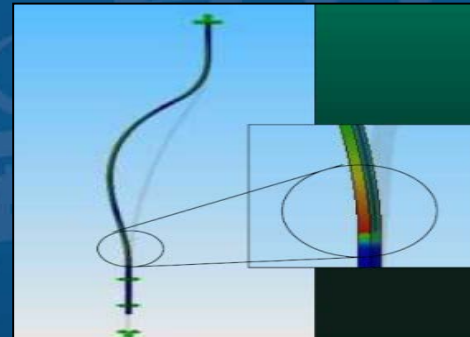



**SWTest 2009: The FE of single touch probe card model with very high force**

**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop  
June 7-10, 2009  
San Diego, CA

**Evaluation of Low Pressure MEMS Probes**

**Scott Clegg, Krzysztof Dabrowiecki**  
Probelogic  
**Shoichi Asanuma**  
TOTO  
**Darren James**  
Rudolph Technologies



**SWTest 2009: FE model of vertical low pressure MEMS probes.**

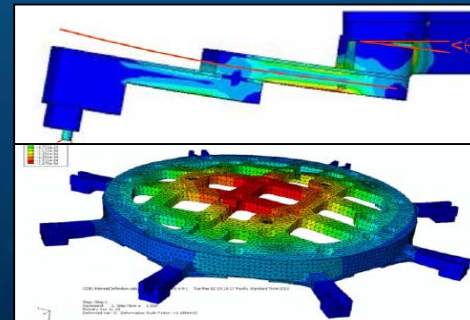
**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop

**Matt Losey**  
Vishwanath Dattala  
Michael Pirooz  
Lakshminathan Ramasubramanian  
Lucy Anagnostopoulos  
Touchdown Technologies

**Low-Force MEMS Probe Solution for Full Wafer Single Touch Test**

**TOUCHDOWN TECHNOLOGIES**  
a VERITY company

June 6 to 9, 2010  
San Diego, CA USA



**SWTest 2010: The FE of MEMS torque probe and full wafer, single touch probe card models**

# A little bit of history... (cont.)

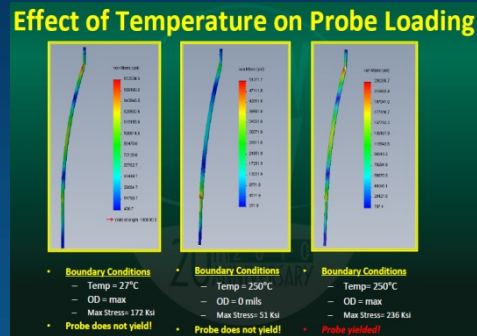
**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop

Rehan Kazmi, PhD  
Habib Kiliccihan  
Jeffrey Hicklin  
Bahadır Tunaboylu, PhD  
SV Probe, Inc.

**Measuring Current Carrying Capability (CCC) of Vertical Probes**



June 6 to 9, 2010  
San Diego, CA USA




**SWTest 2010: Thermo mechanical FEA of vertical probe model**

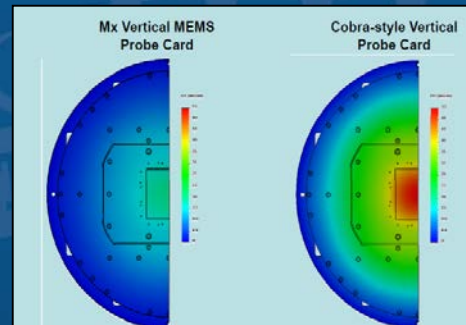
**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop

June 12 to 15, 2011  
San Diego, CA

**Evaluation of New Probe Technology on SnAg and Copper Bumps**



Alexander Wittig (GLOBALFOUNDRIES)  
Amy Leong (MicroProbe)  
Darko Hulic (Nikad)




**SWTest 2011: FE models of vertical probe cards Comparison of PCB deflection using MEMS and Cobra type probes**

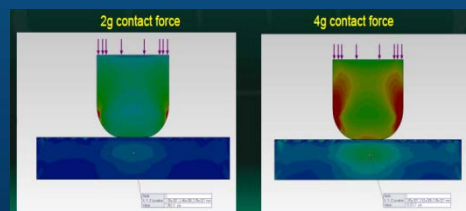
**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop

June 12 to 15, 2011  
San Diego, CA

**A Flexible Vertical MEMs Probe Card Technology for Pre-Bump and eWLP Applications**



Mike Slessor  
Rick Marshall  
(MicroProbe, Inc.)



**SWTest 2011: FE of low contact force MEMS probe for pre-bump applications**

# A little bit of history... (cont.)

**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop

**NXP** Founded by Philips

**Fraunhofer IWM**

Jan Martens  
NXP Semiconductors Germany

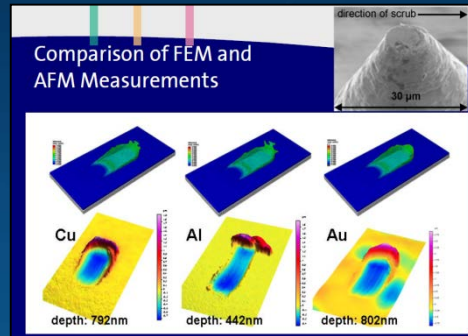
Dr. Joerg Seekamp  
Gunther Boehm  
FENMETALL

Marcel Mittag  
Fraunhofer IWM

Contact formation in wafer test probing  
Fritting, breakdown, pad damage and conduction

SWTW

June 12 to 15, 2011  
San Diego, CA USA



SWTest 2011: FE model of probe scrub formation on aluminum wafer

**Cu-Pillar Bump Probing: Utilizing a 50µm Pitch Fine Pitch Vertical Probe Card Technology**

Senthil Theppakuttai, Ph.D.  
SV Probe

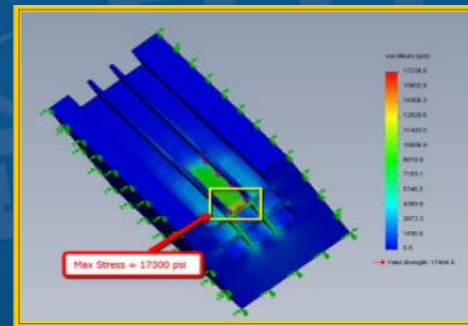
Todd Tsao  
ASE Global

sv probe An EpiStar Company

ASE GROUP

SWTW

**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop  
June 10 - 13, 2012 | San Diego, California



SWTest 2012: FE analysis of guide plates to optimize probe design

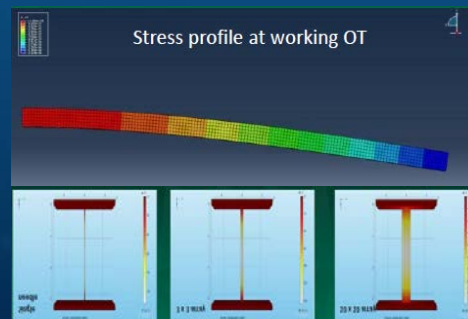
**TPEG™: a new vertical MEMS solution for high current, low pitch applications**

TECHNOPROBE  
MEMS Probing / MEMS Packaging

Raffaele Vallauri  
Technoprobe

SWTW

**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop  
June 10 - 13, 2012 | San Diego, California



SWTest 2012: FE buckling beam MEMS probe model. The multi-physics, thermo-electrical analysis for high current and low pitch applications

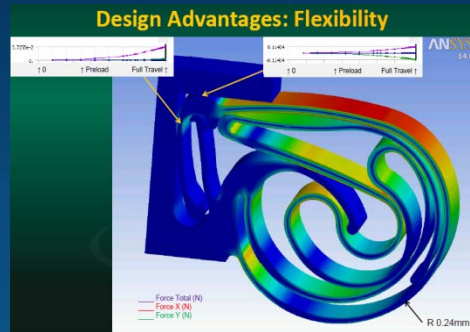


# A little bit of history... (cont.)

**LIGA and its Application to Electrical Interconnects**

**Rosenberger** Frank Schonig  
Rosenberger, R&D  
Jim Jaquette  
Rosenberger, Program Mgmt.

**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop  
June 10 - 13, 2012 | San Diego, California



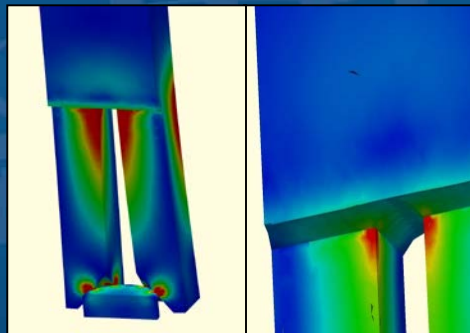
SWTest 2012: FE analysis of MEMS Monolithic Compliant Interconnects (MCI)

**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop  
June 9 - 12, 2013 | San Diego, California

**Very Small Pitch Micro Bump Array Probing**

Fraunhofer IZM FEINMETALL CascadeMicrotech TEAM NANOTEC imec

Gunther Böhm FEINMETALL Samuel Kalt Team Nanotech Dr. Armin Klumpp Fraunhofer-EMFT Erik Jan Marinissen IMEC Dr. Joerg Kiesewetter CASCADE Microtech Dr. Wolfgang Schäfer FEINMETALL



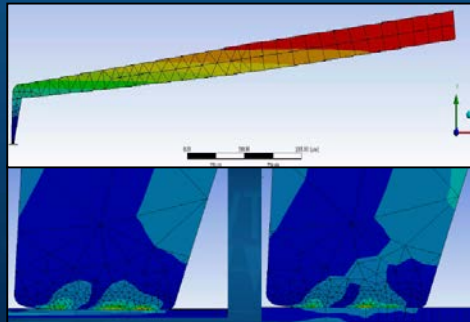
SWTest 2013: A unique and novel MEMS probe design. The finite element analysis of silicon probe with metalized crown tip

**IEEE SW Test Workshop**  
Semiconductor Wafer Test Workshop  
June 8 - 11, 2014 | San Diego, California

**Finite Element Modeling and Characterization of Cantilever Probe Tips Used in Wafer Test**

BYU IDAHO ON Semiconductor Levi W. Hill<sup>1,2</sup>  
Noelle L. Blaylock<sup>1</sup>  
Stevan Hunter PhD<sup>1,2</sup>

<sup>1</sup>Brigham Young University Idaho <sup>2</sup>ON Semiconductor  
This work supported by ON Semiconductor



SWTest 2014: FEM of the cantilever probe tip model in contact with thin and thick aluminum pads.

# A little bit of history... (cont.)

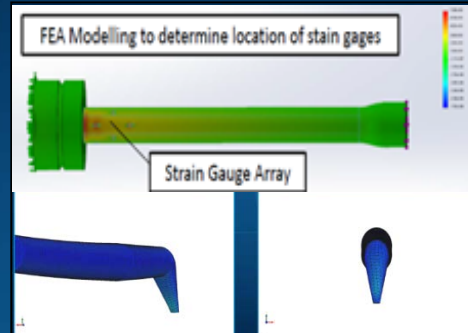
**SWTW** IEEE SW Test Workshop  
Semiconductor Wafer Test Workshop  
June 8 - 11, 2014 | San Diego, California

**Transverse Load Analysis For  
Semiconductor Applications**

**Presenters:** Soheil Khavandi

**Co-authors:** Parker Fellows  
Robert Hartley  
Jordan James  
Aaron Lomas

**Advisor:** Jerry Broz, Ph.D.



**SWTest 2014: FE model of transverse load cell and cantilever probe tips scrubbing an aluminum wafer**

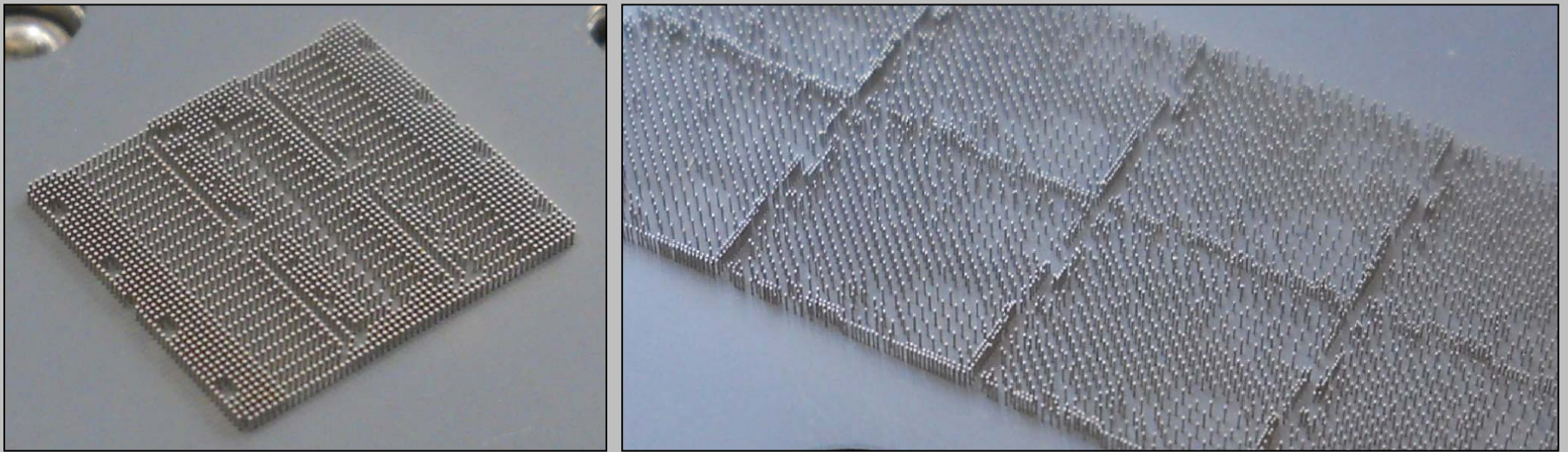
25TH ANNIVERSARY

***A pretty remarkable portfolio  
of FE analysis last 20 years!***

# How to Approach New Challenges?

- **Trial and Error Method**
- **Finite Element Method for composite materials and complex designs**
- **Combined two methods to verify a final design**

# Trial and Error Tests

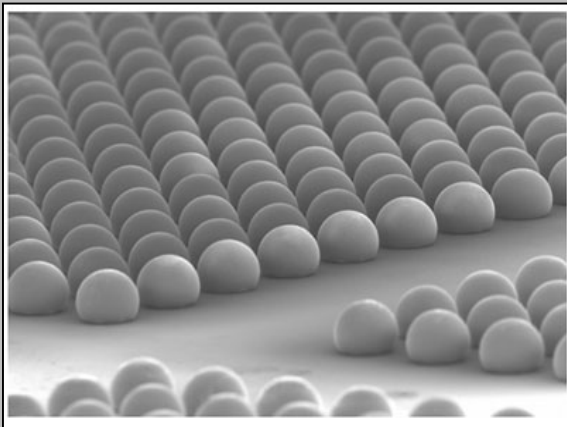
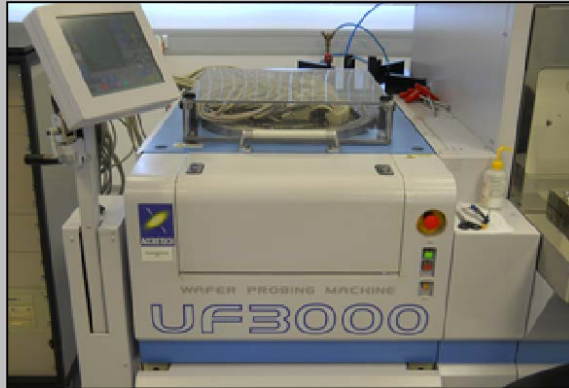


**A custom design and build of test probe head or probe card**

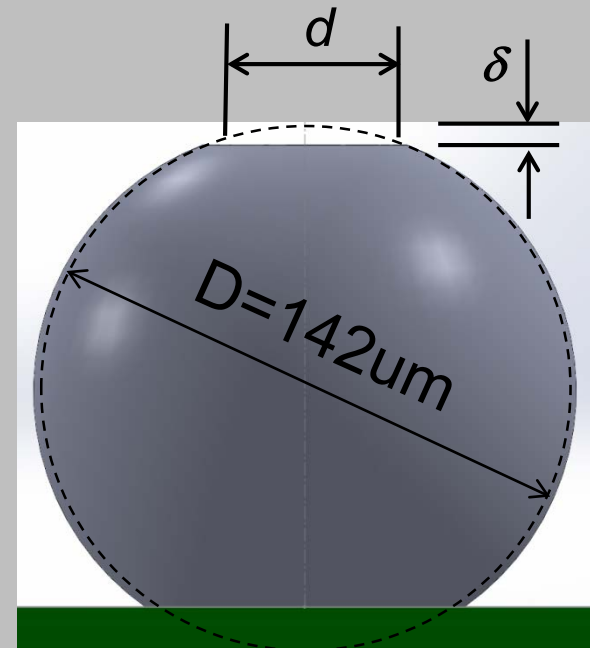


# Wafer Bump Deformation Test

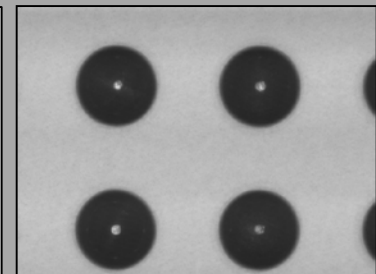
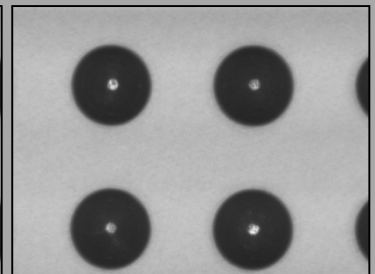
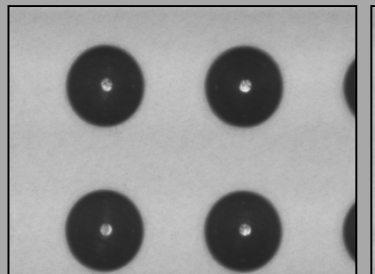
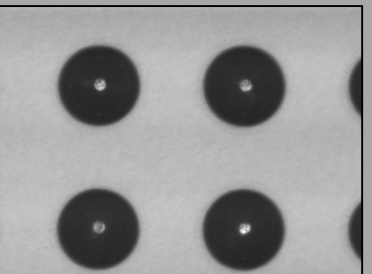
## Bump Wafer SAC305



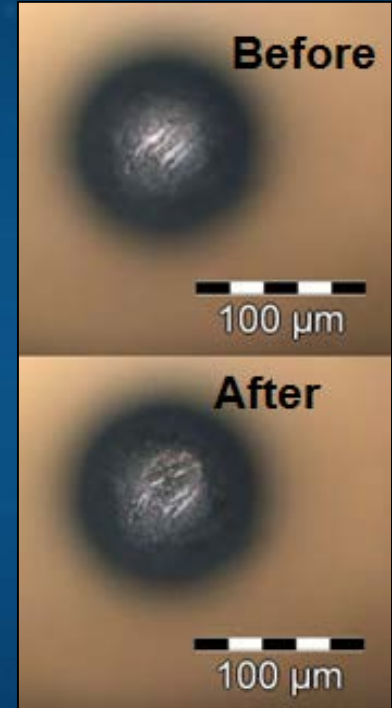
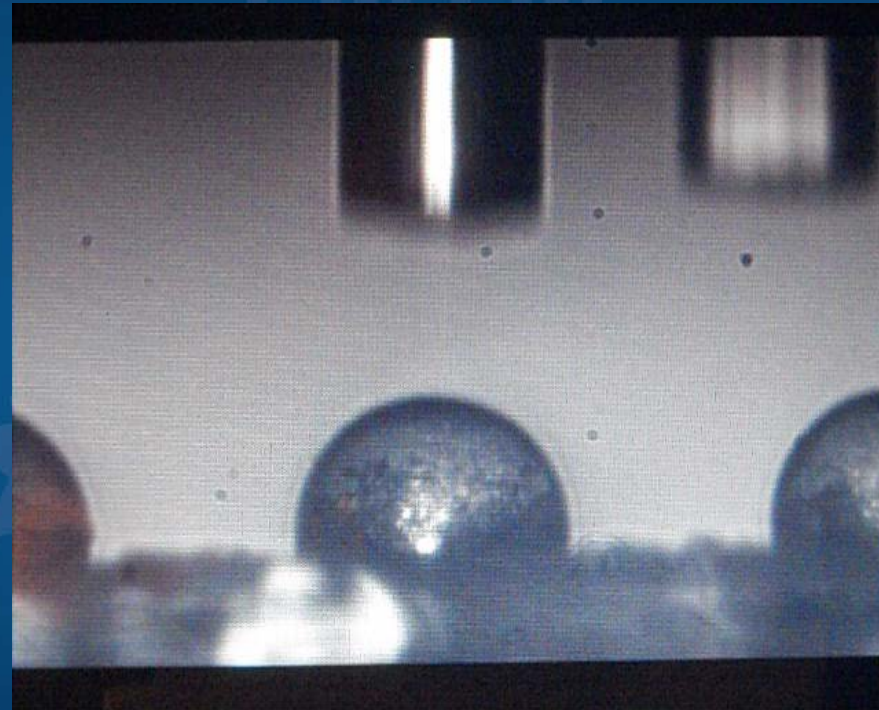
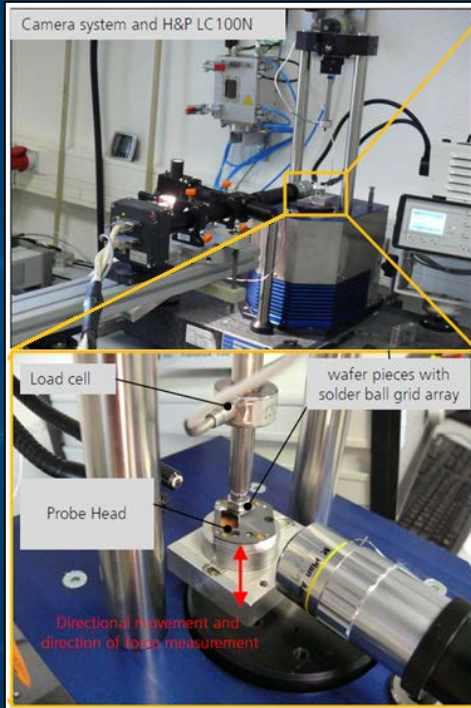
## Bump Deformation



# Wafer Bump Deformation Test at RT

Wafer Bump Image								
Over Drive (um)	25		50		75		100	
Scrub Diameter (um)	12,7		19,1		21,6		21,8	
Percent of Bump Def (%)	8,9		13		15		15,3	

# Study Using High Speed Camera



**Video capture of dynamic contact a probe with bump**

**Description: frame rate 500Hz; Over-travel 500 $\mu\text{m}$ ; Over-drive 100 $\mu\text{m}$**

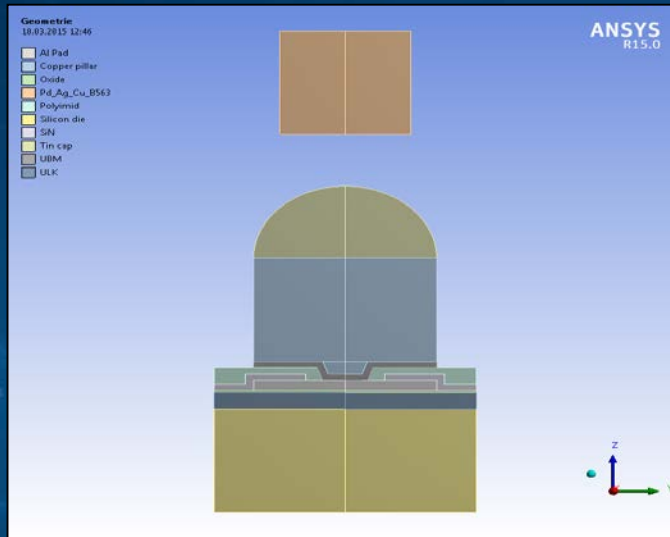


# But always is a question. Can we ...

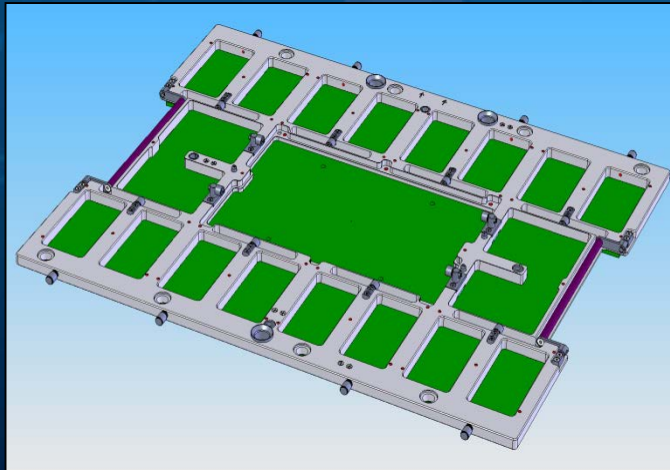
**.. develop a reliable, virtual method to predict a complex structure behavior for various load conditions?**

**... quickly and in advance predict a weakest link of material structure to avoid composite material damages or failures?**

# A Couple Examples of FE Studies

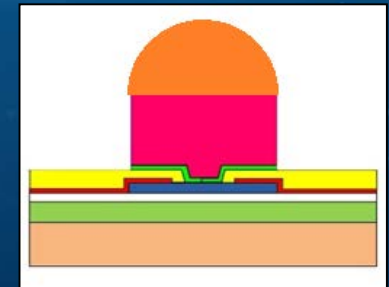
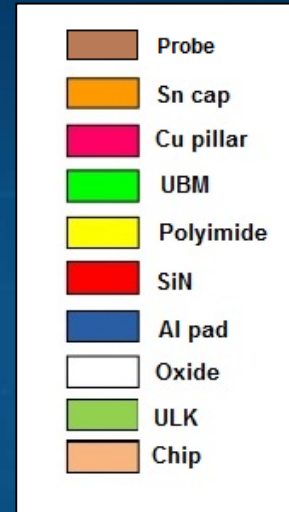
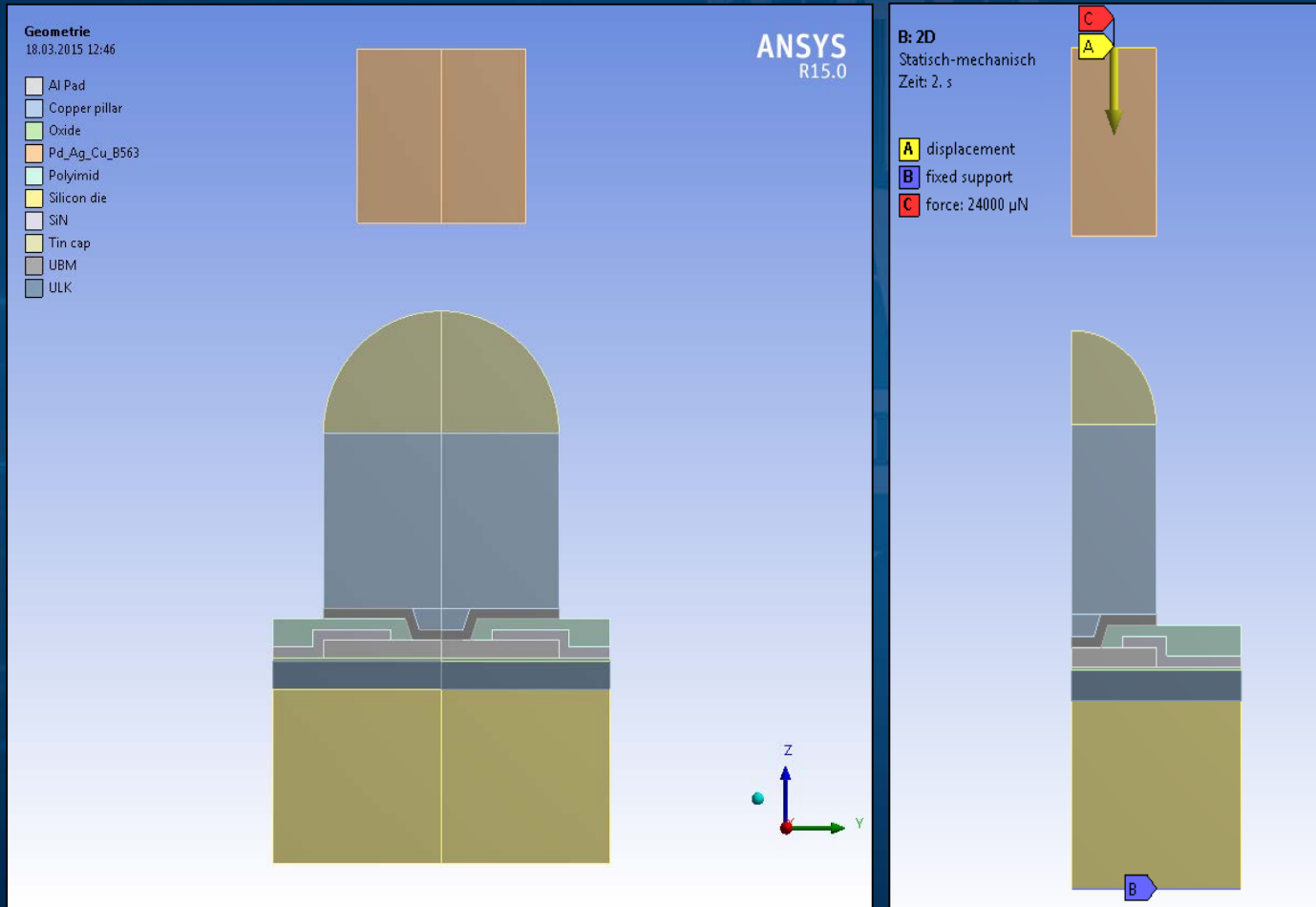


Cu Pillar bump model



V93k Direct Probe PCB model

# Cu Pillar FE Model



Bump Cross Section  
Source: NUU

# Model Material Properties

Items	Modulus of elasticity (E)	Poisson's ratio ( $\nu$ )	Thermal expansion (CTE, $\alpha$ )	Thermal conductivity ( $\kappa$ )	Yield strength (Re / Rp0.2)
	[GPa]		[ppm/C]	W/(m K)	MPa
Silicon die	131	0,28	2,8	150	UTS=7000
Copper pillar/ Copper pad	121	0,34	16,9	399	70
Tin Cap	48	0,35	22,3	55	24
Oxide	215	0,21	4,5	12	69
Al Pad	72	0,33	23,0	238	414
SiN	270	0,28	5,0	30	86
Polyimide	3,5	0,35	35,0	1,6	69
UMB	135	0,33	14,5	34	32
ULK	8	0,2	25,0	0,39	96

Source: NIST, IBM, STATS ChipPAC, Ansys, Japan Institute of Metals

# FE for 2D and 3D Models

## **Ansys elements:**

- 2D: PLANE183 (axisymmetric), CONTA172, TARGE169, SURF153
- 3D: SOLID186, CONTA174, TARGE170

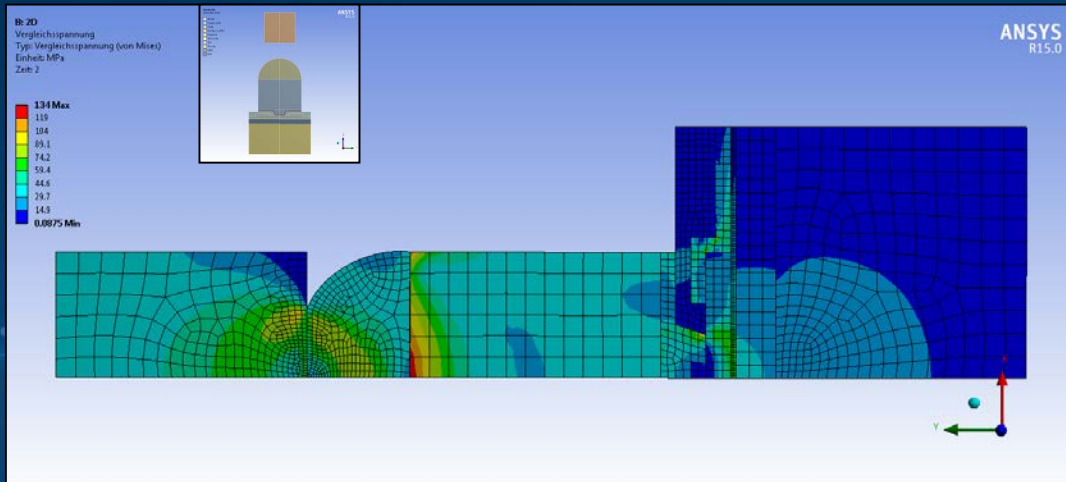
## **Elements and nodes created after model meshing**

- 2D: 2924 elements
- 3D: 20875 elements

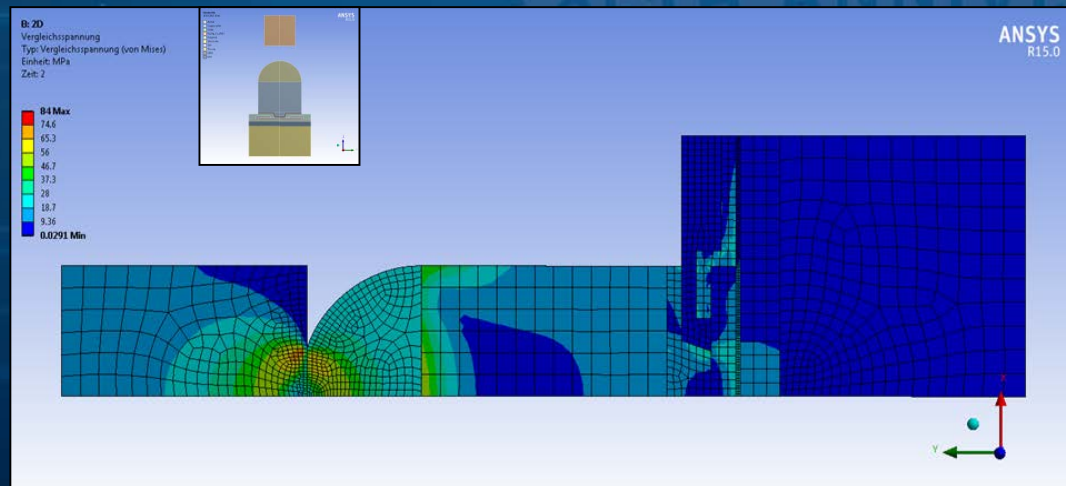
## **Elastic-plastic contact between probe and Cu pillar**

- 3D: Deformable-deformable contact, Augmented Lagrange method, initial friction coefficient 0.2, non-linear material model only for lead free cap (bi-linear)

# FE Model Stress Distribution

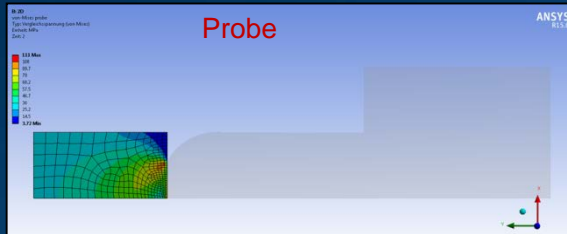


Contact force = 6.6 cN  
Max Stress= 134 MPa  
Deformed bump diameter – 26.6um

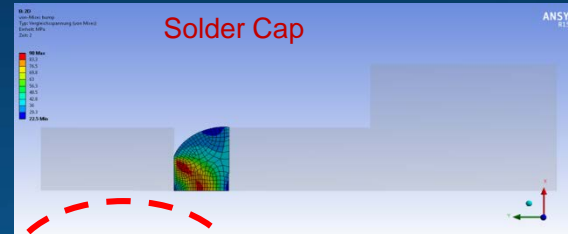


Contact force = 2.4 cN  
Max Stress= 84 MPa  
Deformed bump diameter – 18.2um

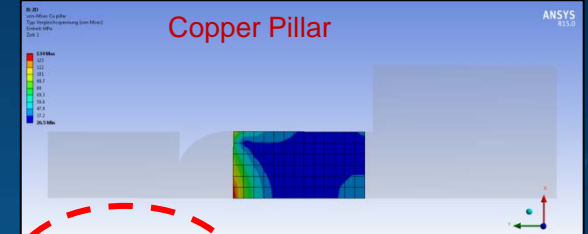
# Stress by Model Layers – CF 6.6cN



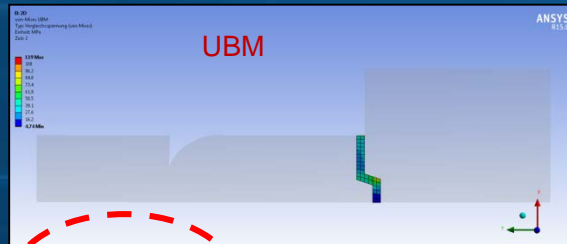
Max s=111 MPa  
Yield s=755 MPa



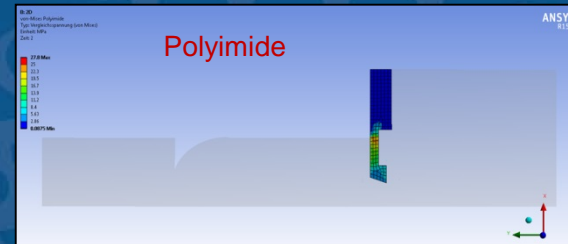
Max s=90 MPa  
Yield s=24 MPa



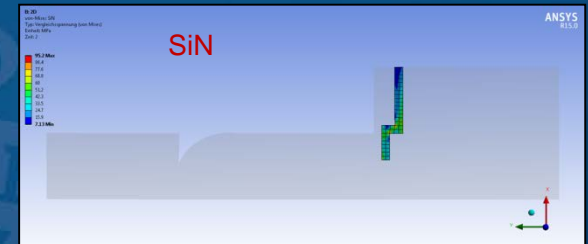
Max s=134 MPa  
Yield s=70 MPa



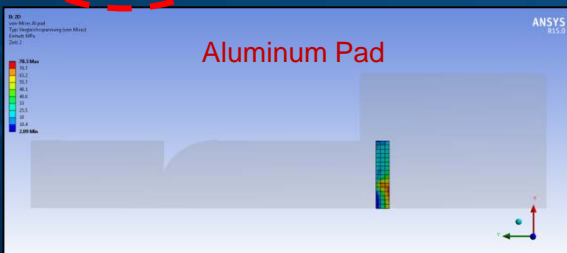
Max s=90 MPa  
Yield s=32 MPa



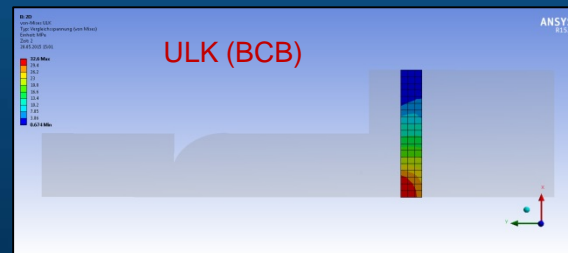
Max s=27 MPa  
Yield s=69 MPa



Max s=65 MPa  
Yield s=86 MPa



Max s=78 MPa  
Yield s=414 MPa



Max s=32 MPa  
Yield s=96 MPa

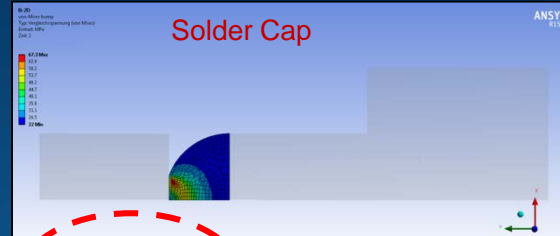


Max s=24 MPa  
UTS s=7000 MPa

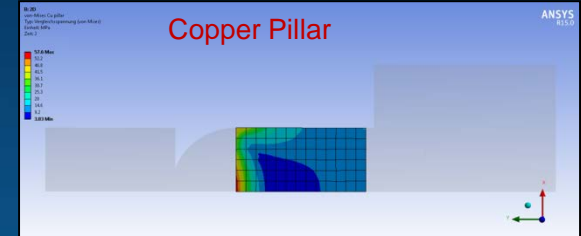
# Stress by Model Layers – CF 2.4cN



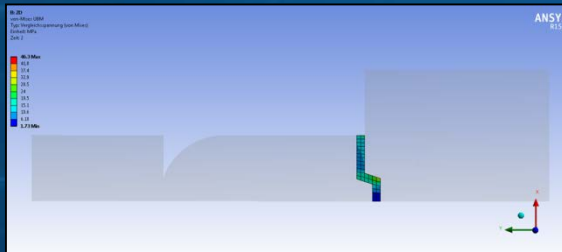
Max s=84 MPa  
Yield s=755 MPa



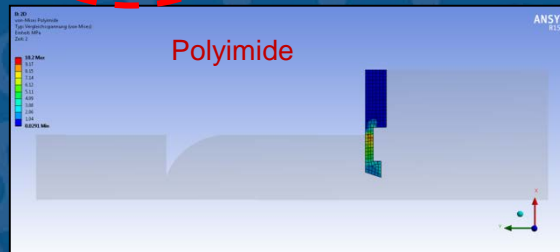
Max s=67.4 MPa  
Yield s=24 MPa



Max s=57 MPa  
Yield s=70 MPa



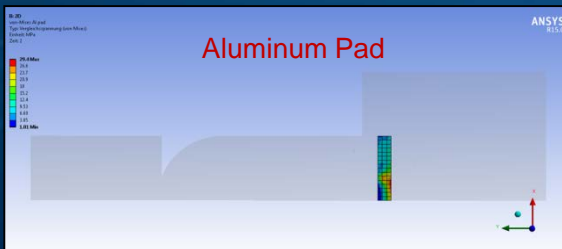
Max s=24 MPa  
Yield s=32 MPa



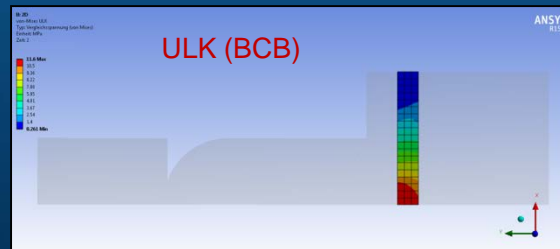
Max s=10 MPa  
Yield s=69 MPa



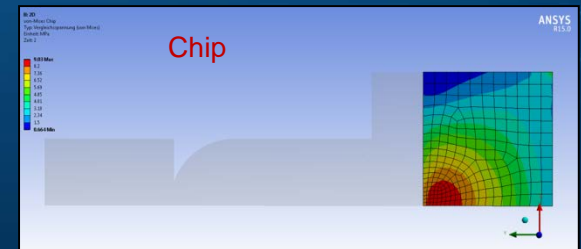
Max s=21 MPa  
Yield s=86 MPa



Max s=29 MPa  
Yield s=414 MPa



Max s=11.6 MPa  
Yield s=96 MPa

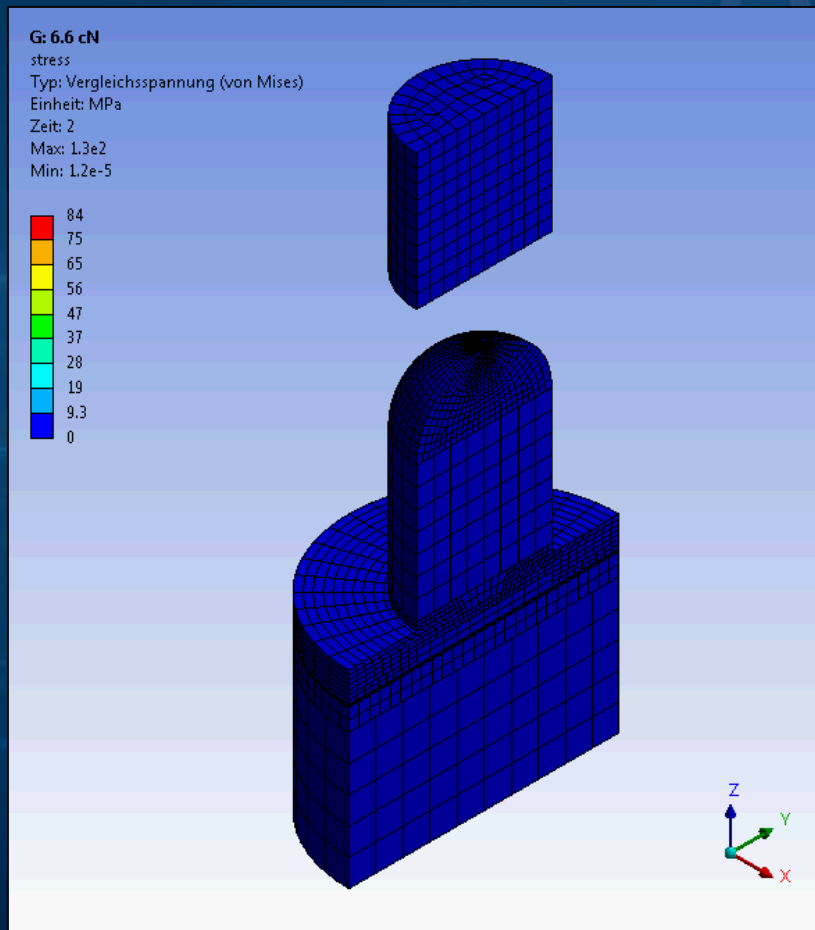


Max s=9 MPa  
UTS s=7000 MPa

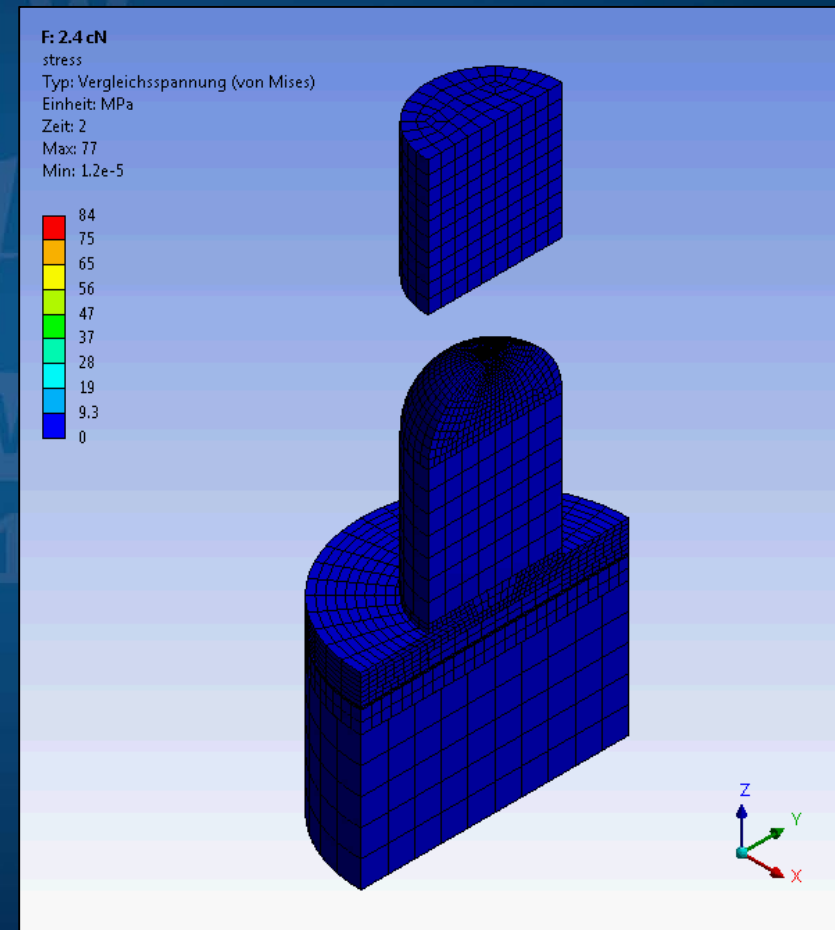


# FE Cu Pillar Models Simulation

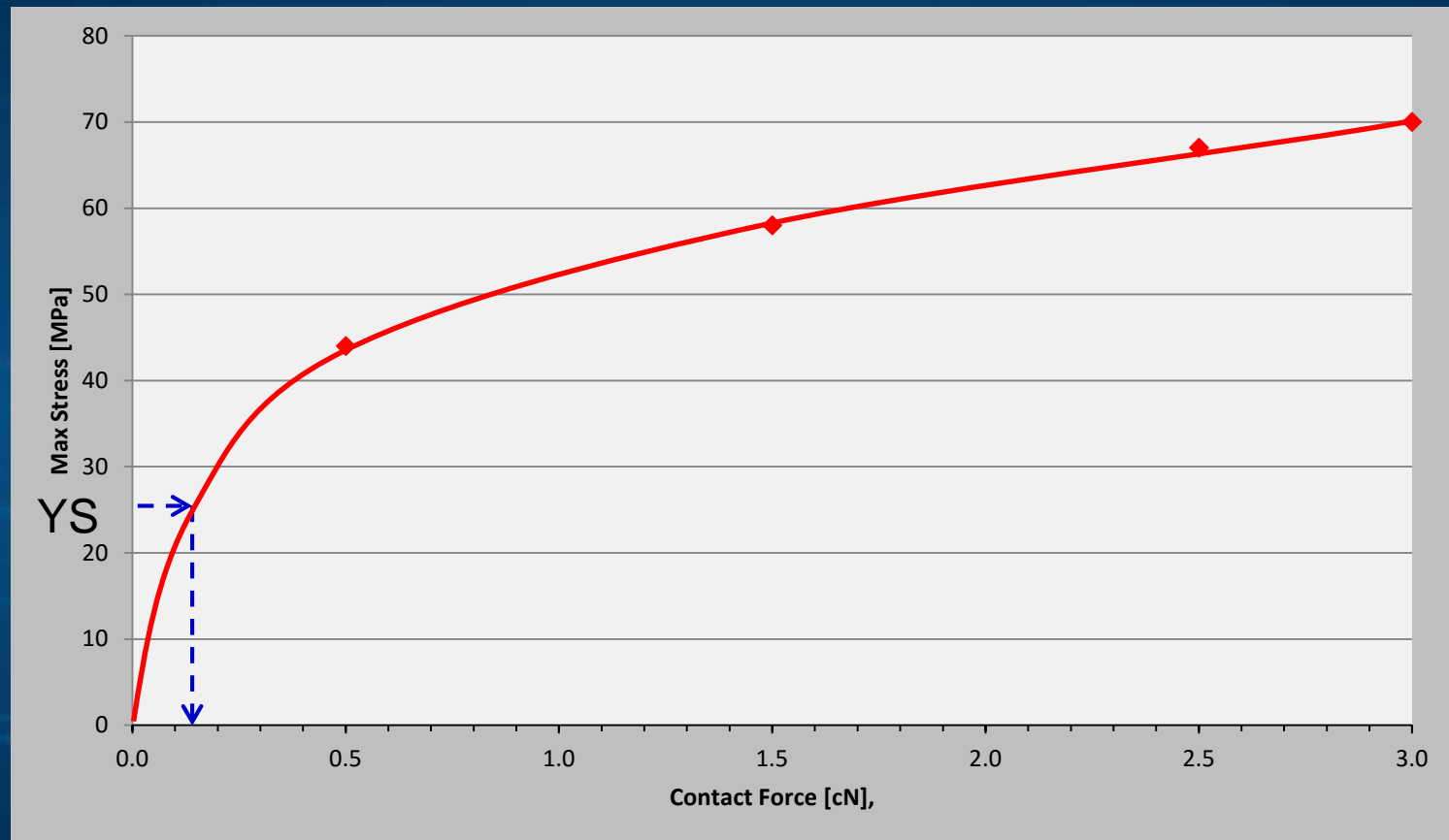
Probe force 6.6cN



Probe force 2.4cN

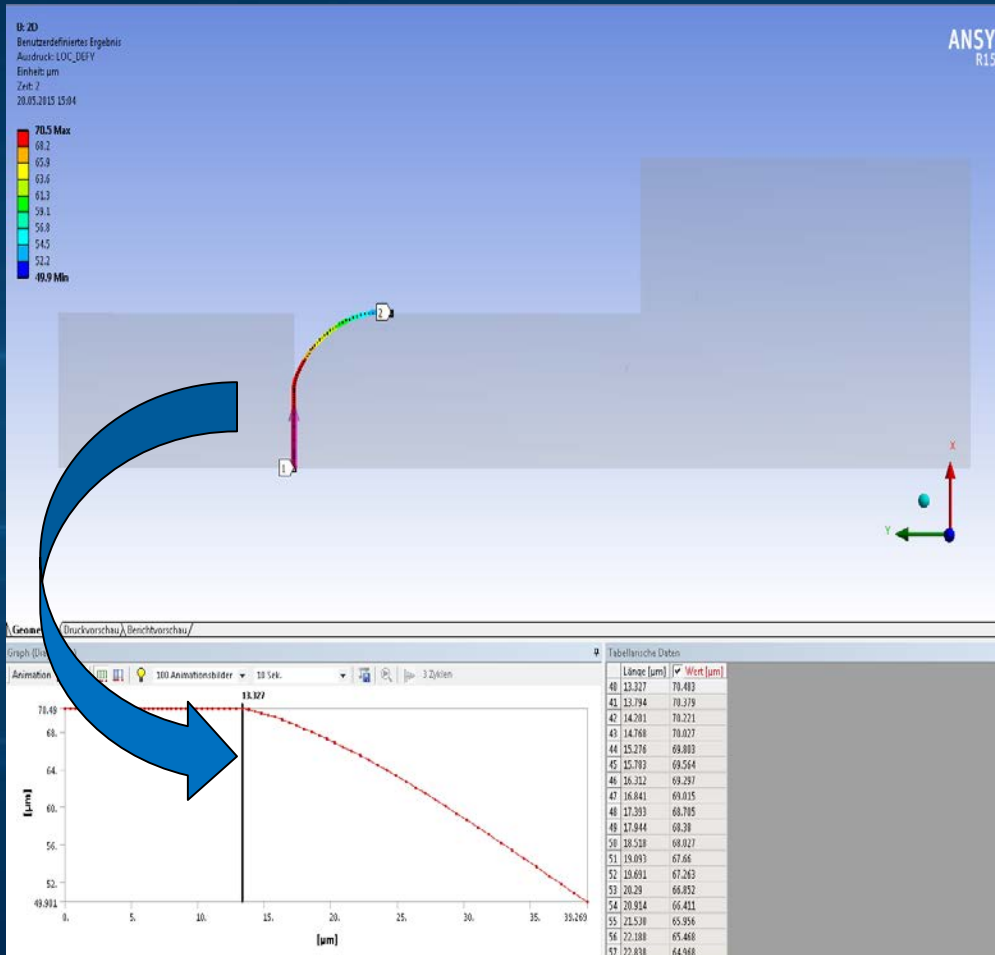


# Max Stress Vs. Contact Force

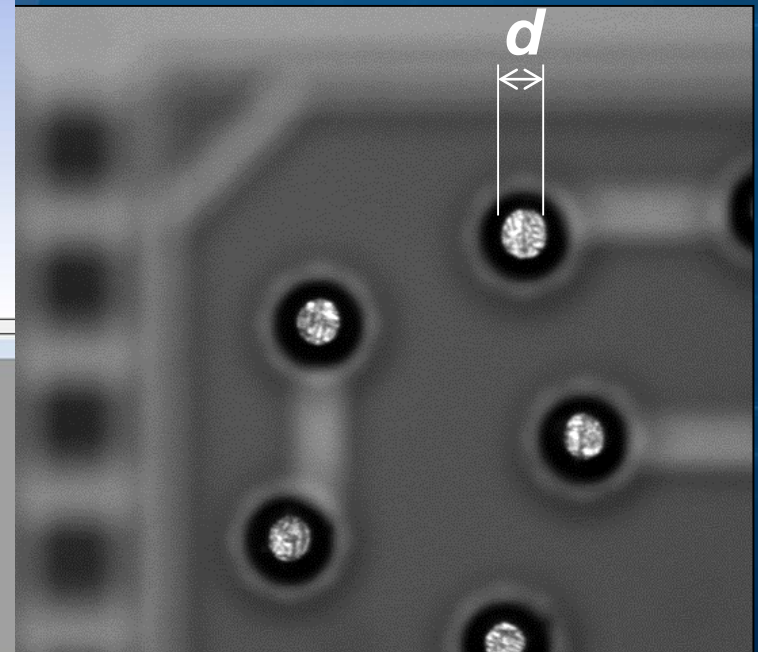


**FEA estimated less than 0.2 cN as min contact force of flat probe tip with hemisphere bump**

# FE Model Validation – CF=6.6cN

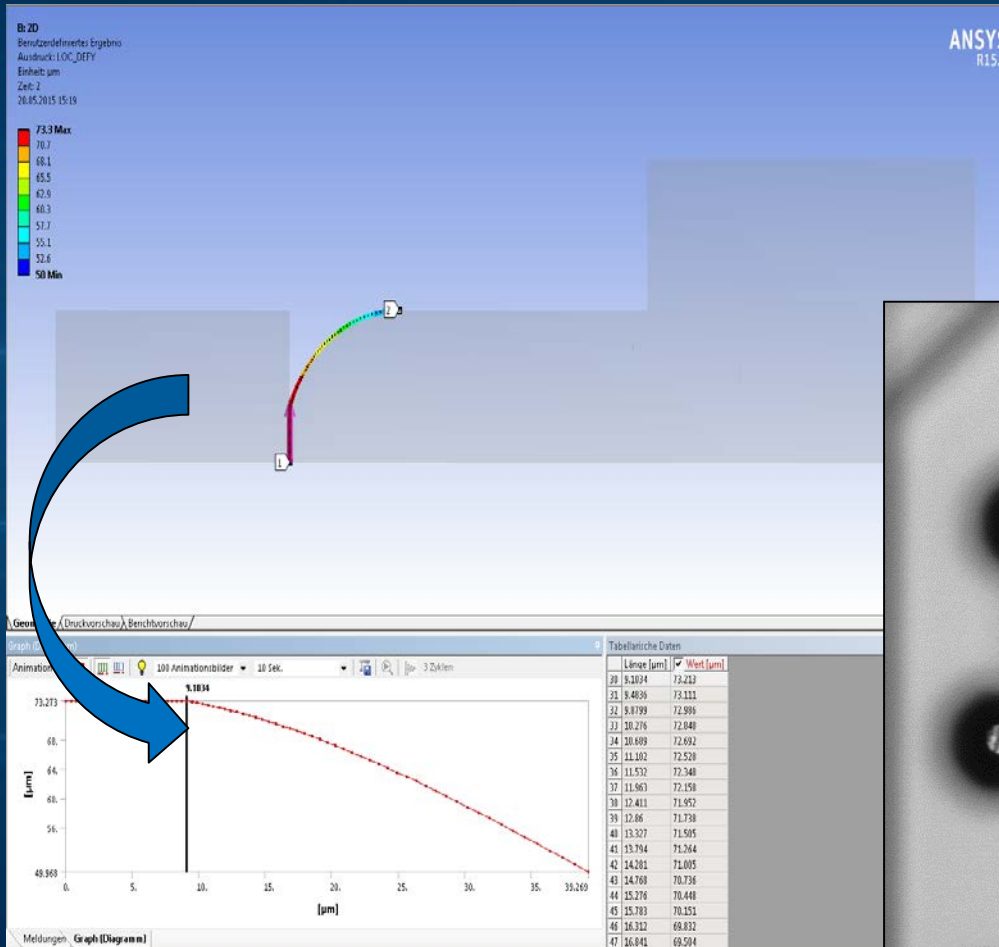


Production wafer test - deformed bump diameter  $d = 27.7\mu\text{m}$

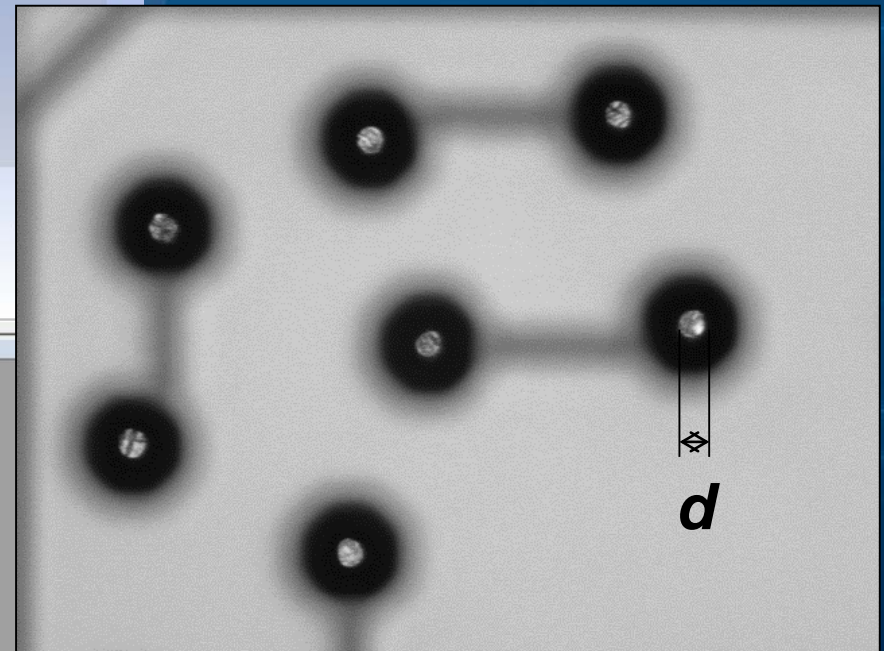


Advanced Model - FE deformed bump diameter  $d = 26.6\mu\text{m}$

# FE Model Validation – CF=2.4cN

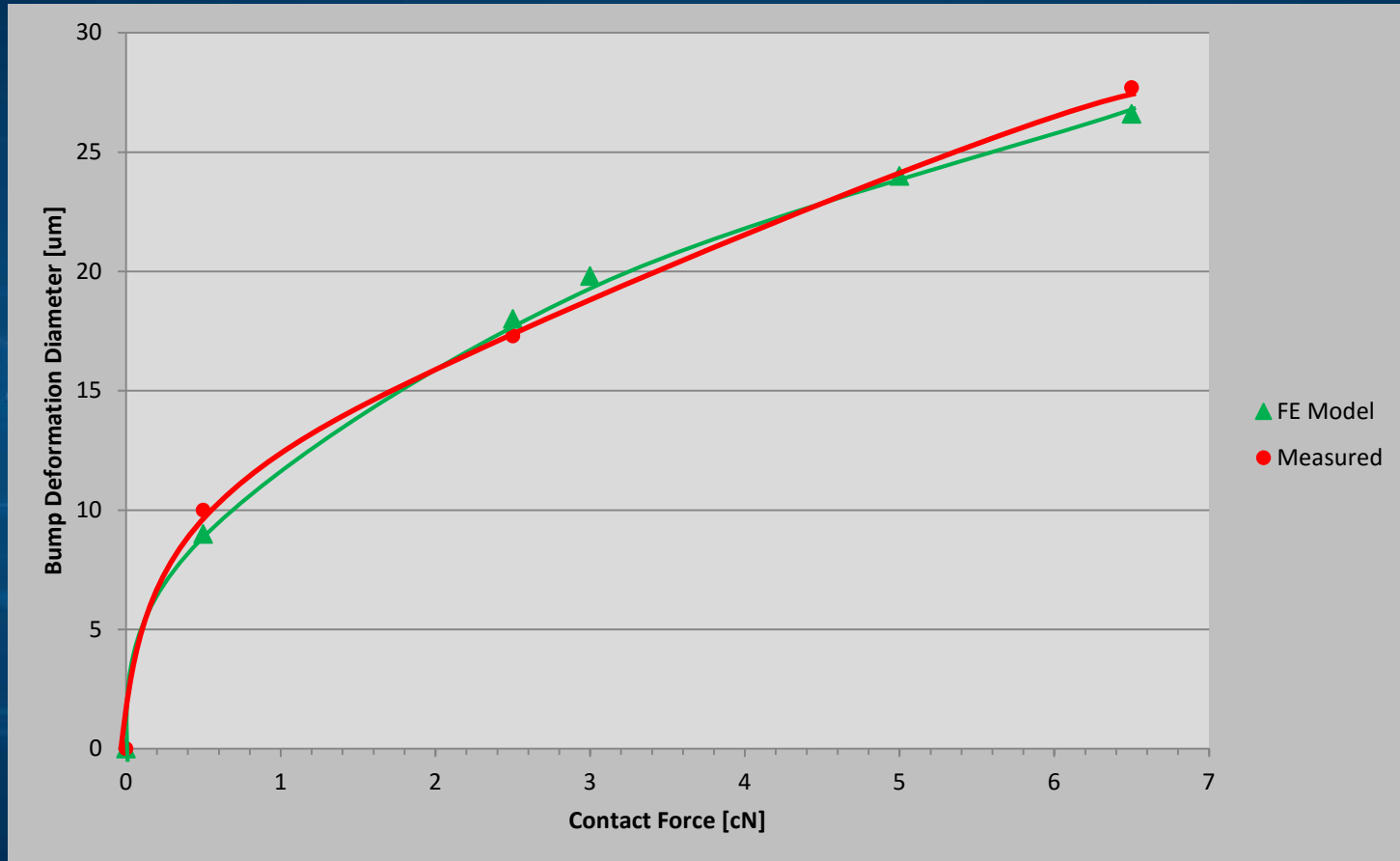


Production wafer test - deformed bump diameter  $d = 17.3\mu\text{m}$



Advanced Model - FE deformed bump diameter  $d = 18.2\mu\text{m}$

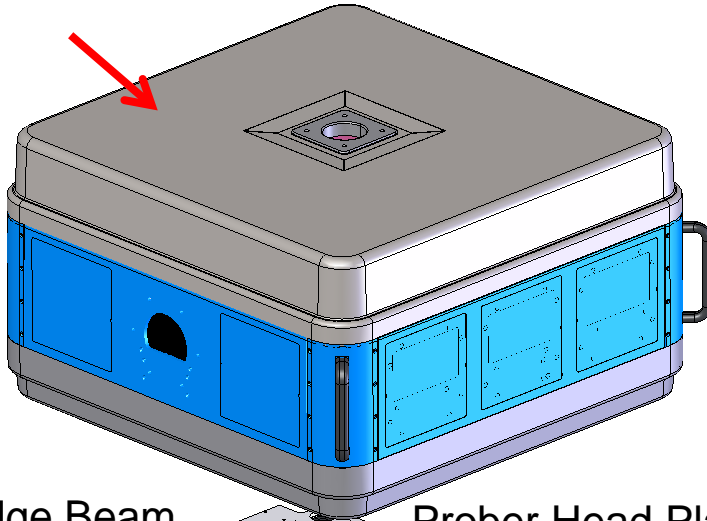
# FE Model Vs. Wafer Test Correlation



**FE Models showed a good correlation between calculated and measured deformed bump area with increasing contact force**

# V93000 Direct-Probe™ Test Solution

V93000 Test Head

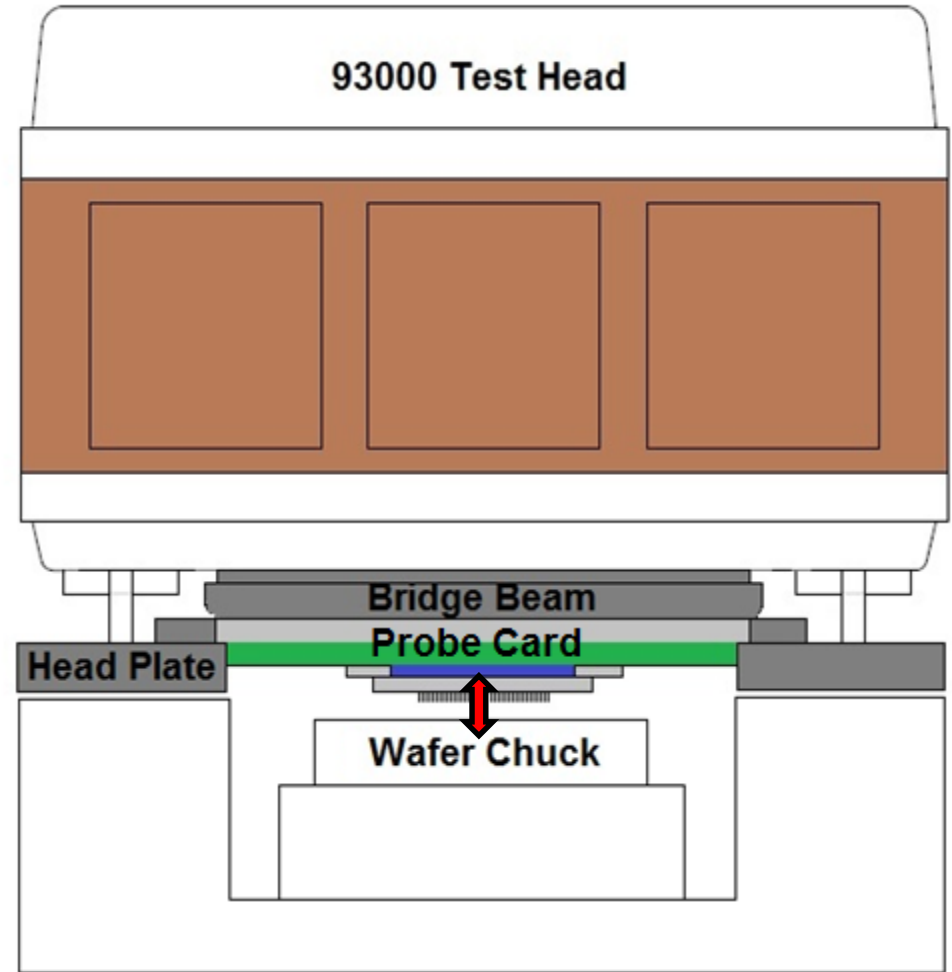


Bridge Beam

Prober Head Plate

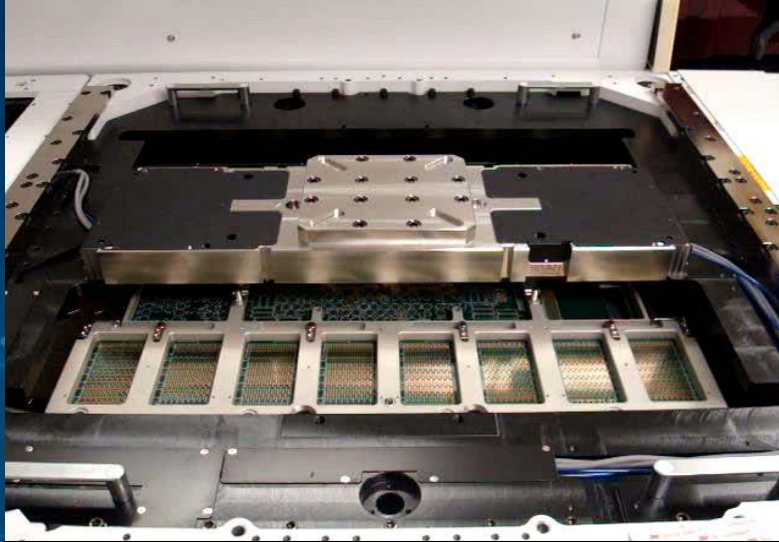
Probe Card

93000 Test Head



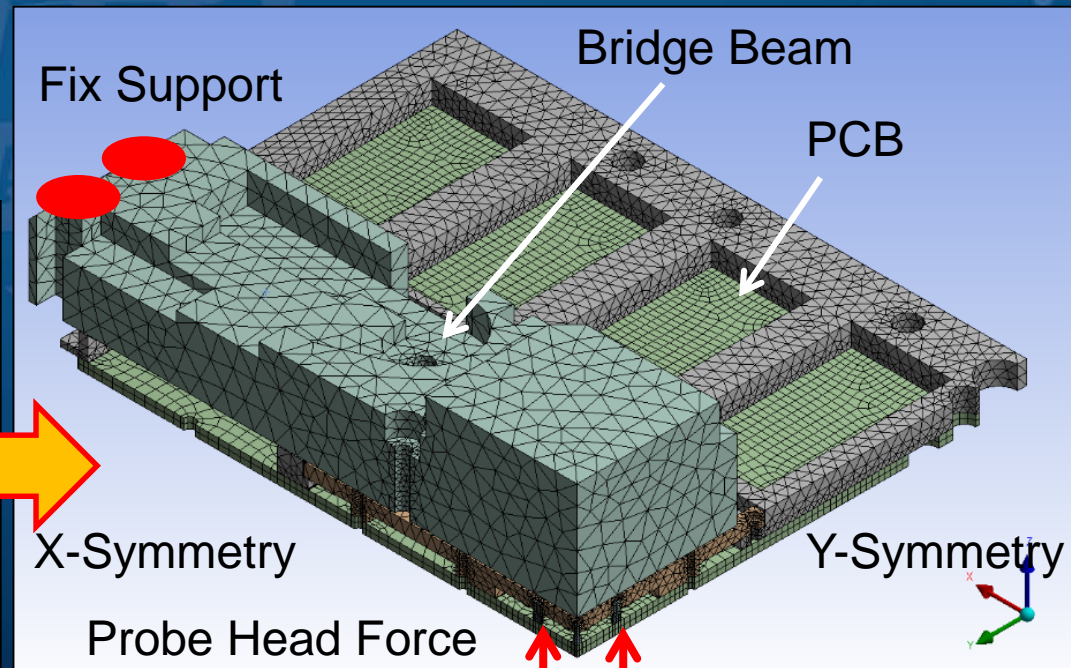
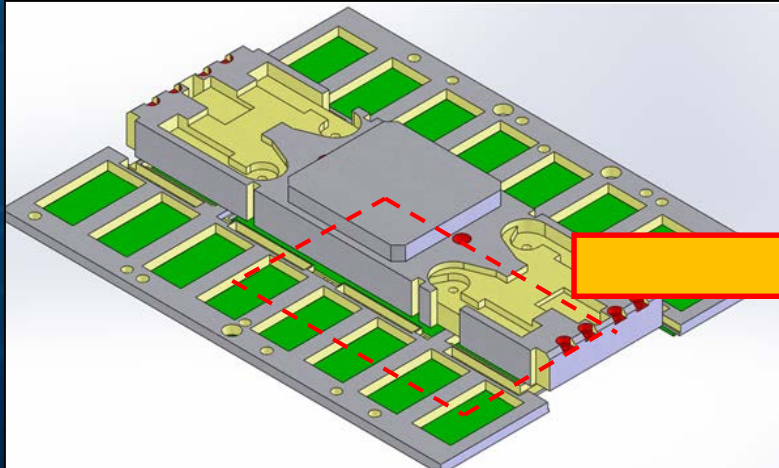
Source: Verigy / Advantest

# V93000 Direct-Probe™ FE Model



Full scale 3D model, size 550mm x 480mm

FE model (quarter) of V93000 DP PCB with stiffener inlay and bridge beam



Picture Source: Advantest

# PCB Properties and FE Parameters

- **PCB material:**

- Modulus of Elasticity - 25 GPa
- Poisson's Ratio – 0.18
- Yield Stress – 60 MPa

- **Used elements:**

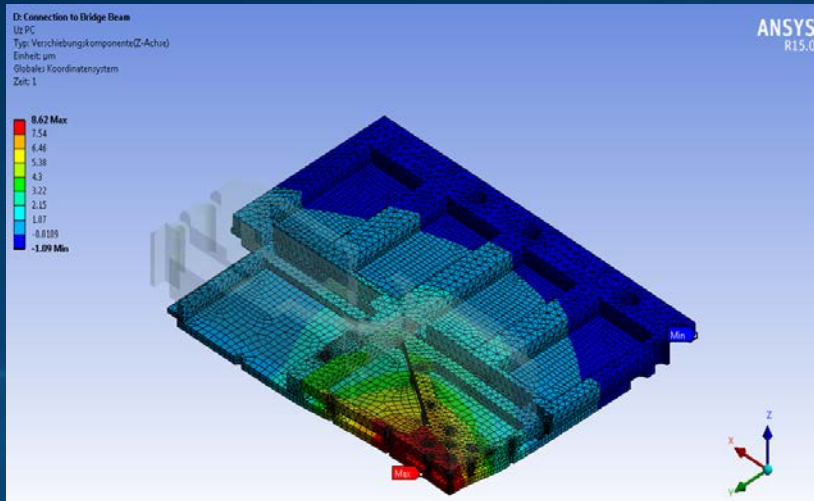
- 3D Model: 76962 elements of SOLID186 & SOLID187, 14800 elements of CONTA74 & TARGE70, 280 elements of SURF154, 480 spring elements

- **Boundary conditions:**

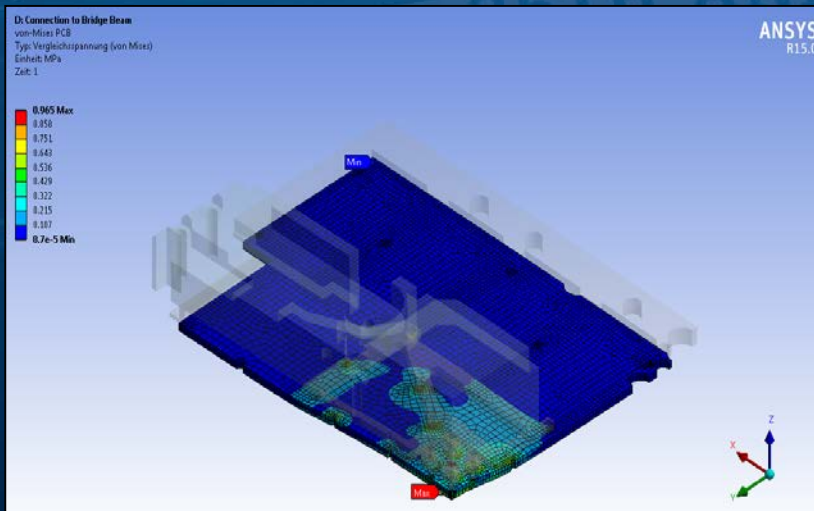
- Force: 624 N equivalent of 26000 probes
- Fixed support in screw holes of the bridge beam



# Stiffener Inlay and Bridge Beam

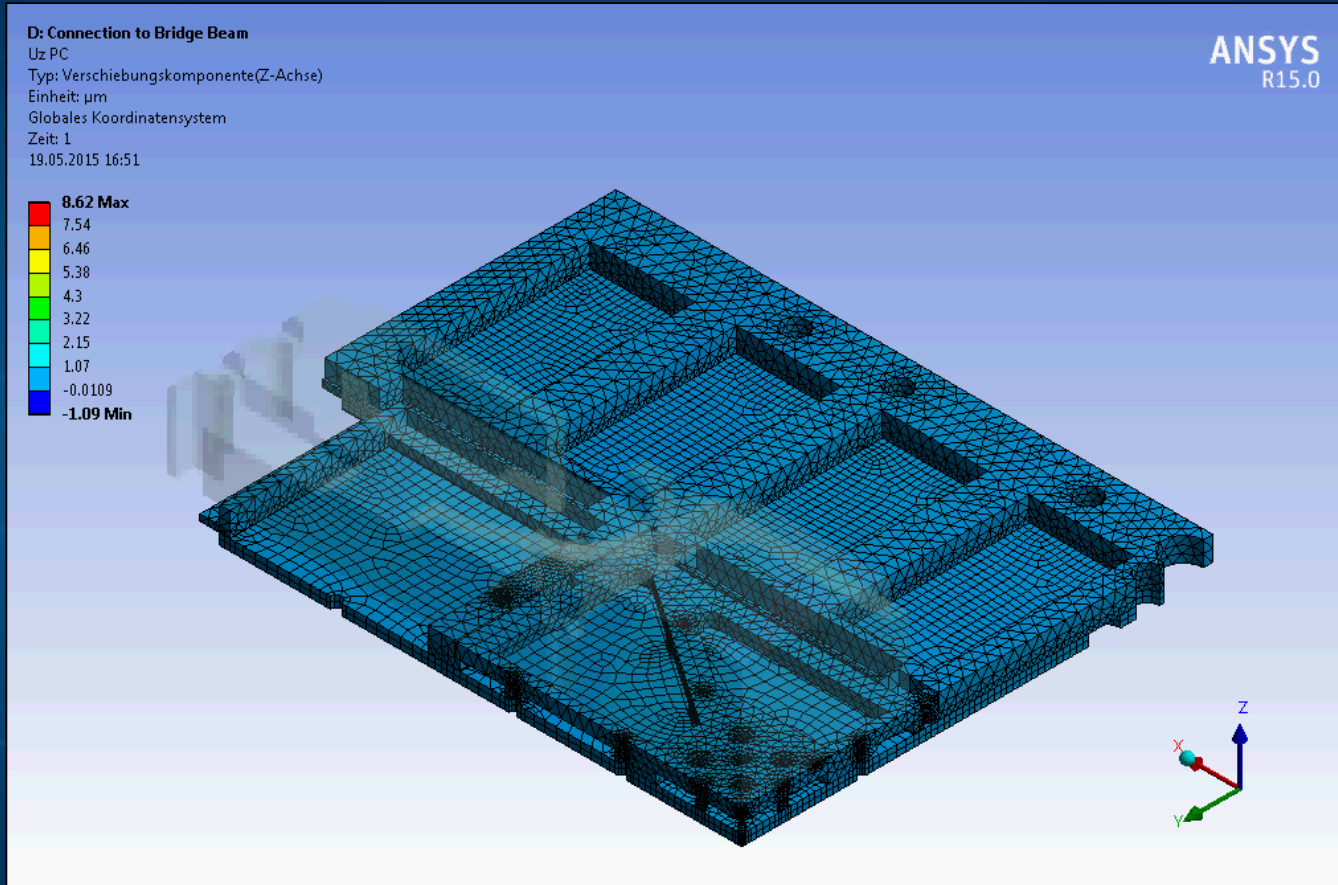


PCB maximum deflection supported by stiffener inlay connected with bridge beam: 8.6 um



PCB maximum von Mises stress: 0.9 MPa.

# Probe Card Deflection Simulation



**Simulation scale: x1100**

# Summary and Conclusion

The finite element modeling has become sufficiently mature to develop reliable insights into the mechanical integrity especially of composite materials and complex structures.

The graphical interpretation of the results and model simulations allow a better understanding of copper pillar structures as well as critical factors identifying the weakest parts of materials underneath of interconnectors or complex structure like 93000 Direct Probe™ solution

# Summary and Conclusion

The test results shown a good correlation between FE calculated bump deformation and measured scrub marks on the production wafers.

The calculated and used low probe contact force improved the wafer probing by eliminating cracks of UBM and Cu Pillar delamination

FEA calculations allow to improve the PCB stiffener design reducing a board deflection

# Follow-on Work

- It would be interesting to calculate the PCB deflection and performing verification tests for various temperature conditions from -50C to 150C
- And also to perform the PCB deflection study using the maximum pin count available for active area of 93000 Direct-Probe™

# Acknowledgments

We would like to thank colleagues at FEINMETALL for their help in preparation of this presentation. We are especially indebted to Lisa Schwarz, Uli Gauss, Jurgen Bauersfeld, Micha Frerichs and Gunther Böhm for his valuable comments.

## Thank you