SWTW 25TH ANNIVERSARY 2015

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

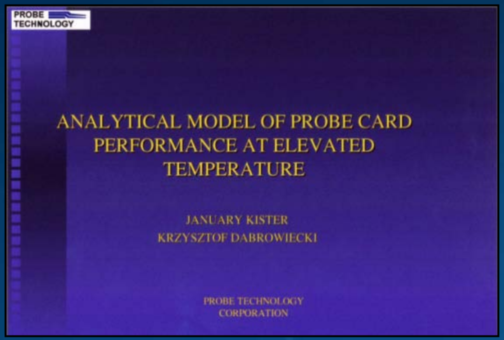
Krzysztof Dabrowiecki

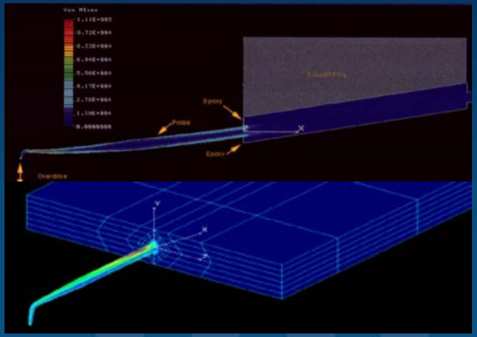
Jörg Behr

Overview

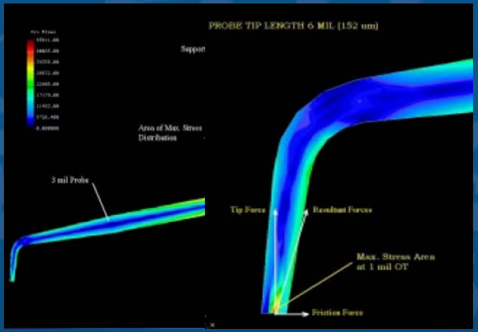
- A little bit of history in applying finite element analysis for probe card design
- Trial and error versus FEM approach
- Example of recent FE design and studies
- Summary and conclusion
- Follow-on work

A little bit of history of FE Modeling

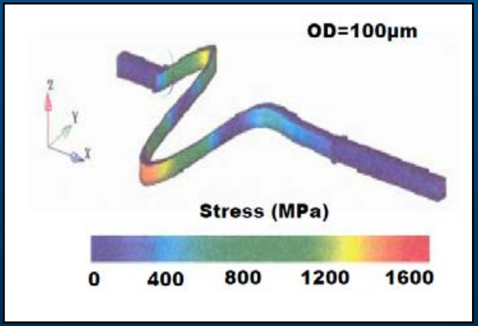




SWTest 1997: First finite element parametric model for 4.5 mil diameter cantilever probe

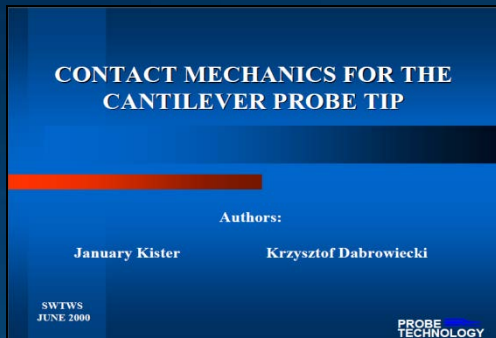


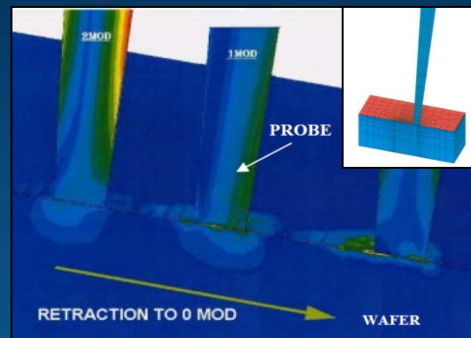
SWTest 1999: Advanced FE probe model for 3mil cantilever probe



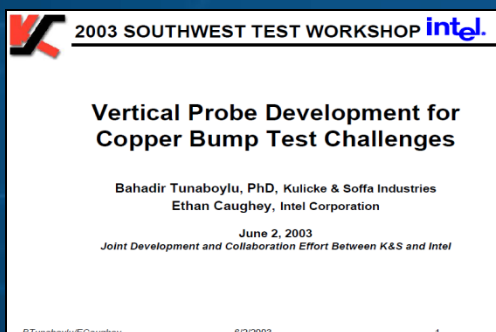
SWTest 2000: The finite element model of vertical spring silicon probe

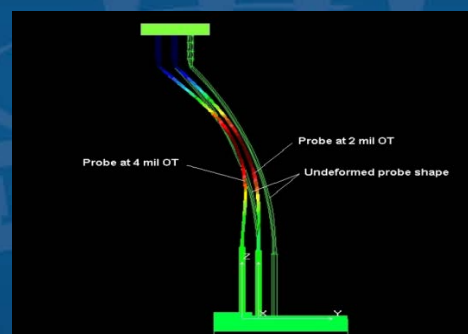
A little bit of history… (cont.)



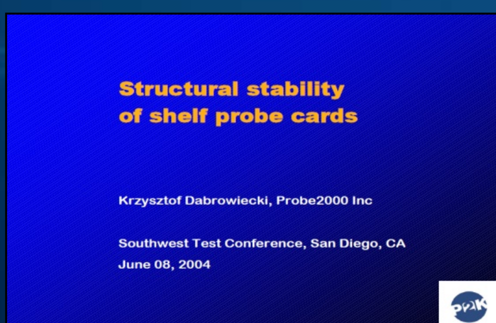


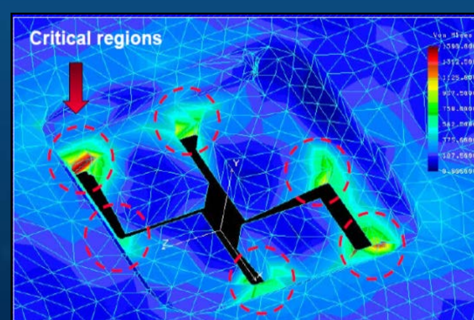
SWTest 2000: 3D modeling of mechanical contact between probe tip and bond pad





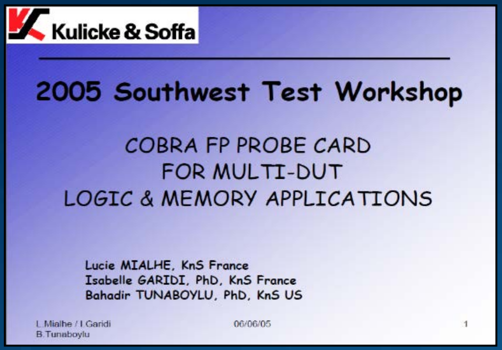
SWTest 2003: The FE model of 3D, parametric and non linear vertical, Cobra style probe

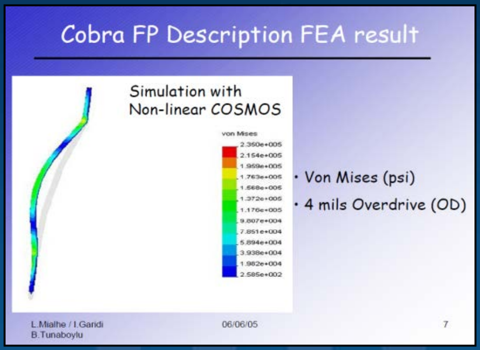




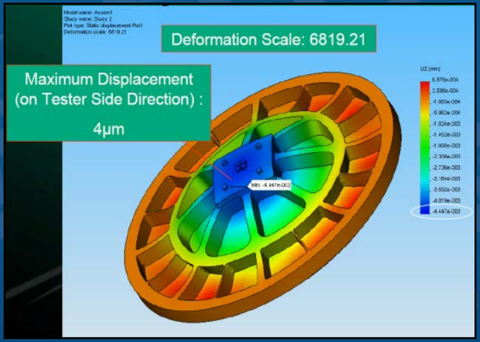
SWTest 2004: Structural stability of the ceramic shelf probe card.

A little bit of history… (cont.)

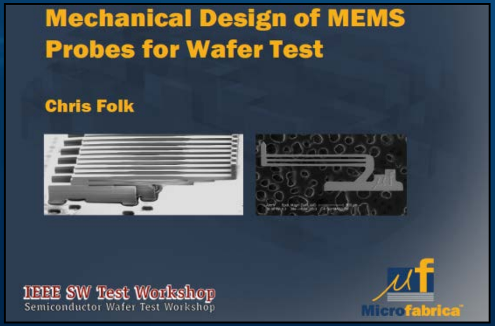


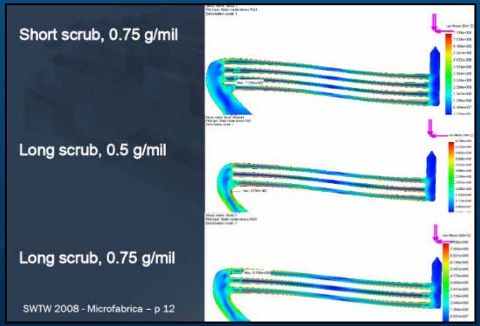


SWTest 2005: Model of fine pitch Cobra style probe for multi-DUT logic and memory applications.



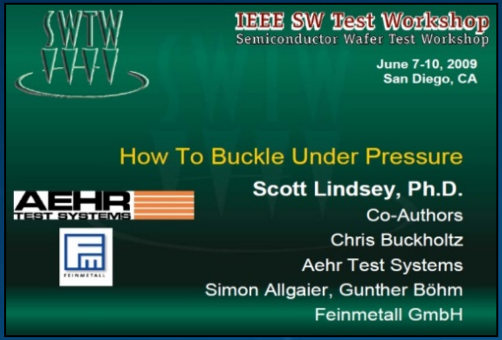
SWTest 2007: Structural stability of PCB with vertical high pin count

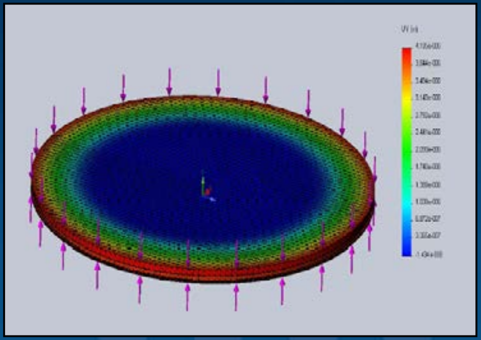




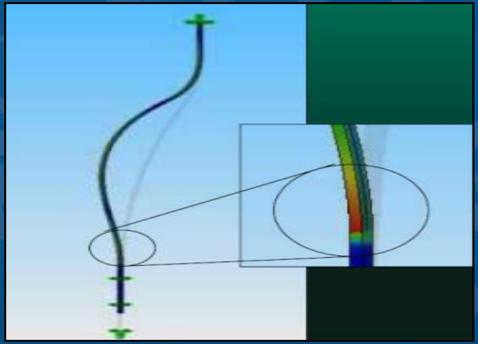
SWTest 2008: FE model of cantilever MEMS probes, built using EFAB process

A little bit of history… (cont.)

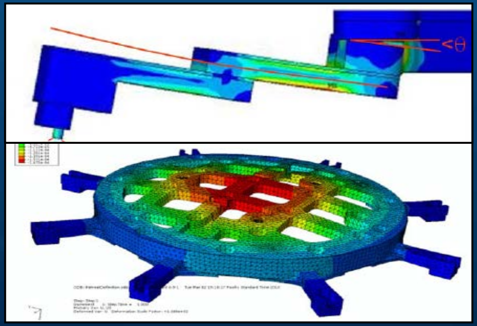




SWTest 2009: The FE of single touch probe card model with very high force

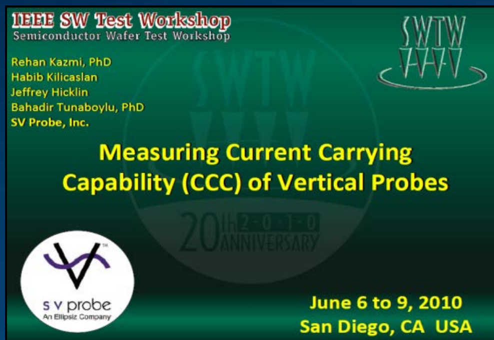


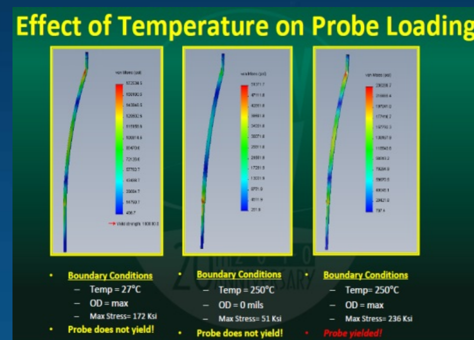
SWTest 2009: FE model of vertical low pressure MEMS probes.



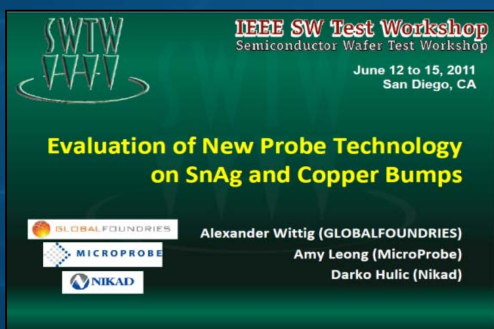
SWTest 2010: The FE of MEMS torque probe and full wafer, single touch probe card models

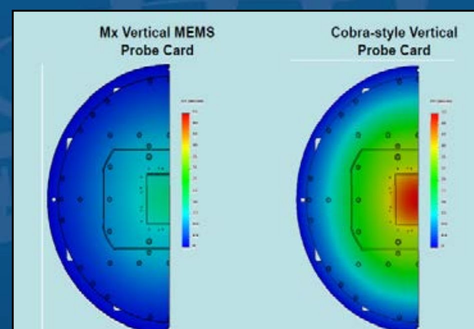
A little bit of history… (cont.)



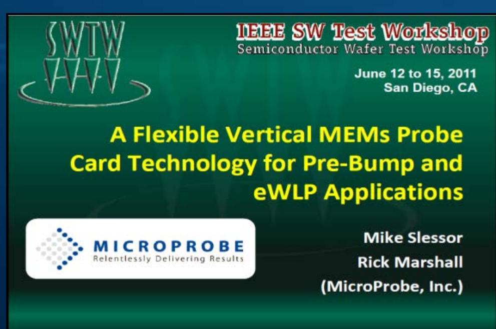


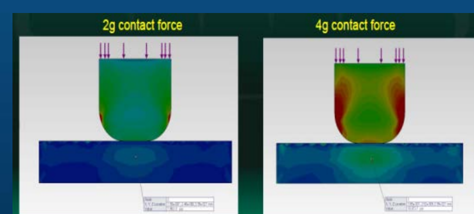
SWTest 2010: Thermo mechanical FEA of vertical probe model





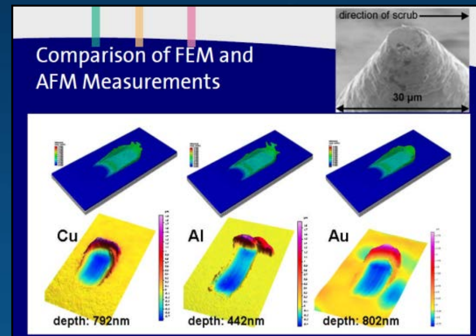
SWTest 2011: FE models of vertical probe cards Comparison of PCB deflection using MEMS and Cobra type probes



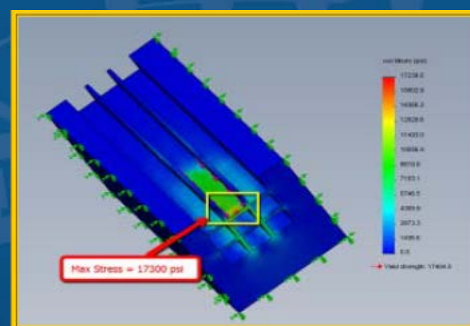


SWTest 2011: FE of low contact force MEMS probe for pre-bump applications

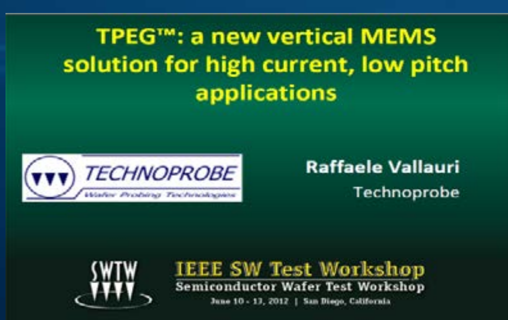
A little bit of history… (cont.)

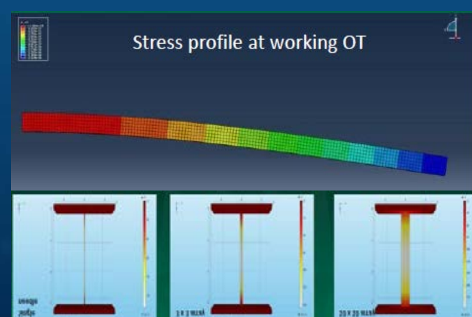


SWTest 2011: FE model of probe scrub formation on aluminum wafer



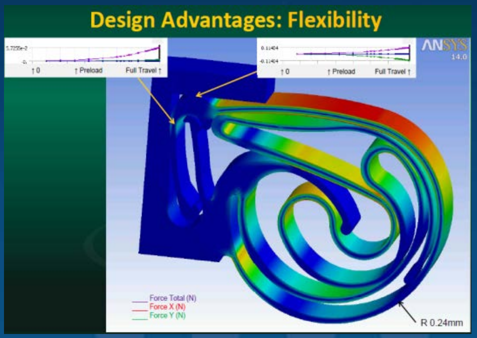
SWTest 2012: FE analysis of guide plates to optimize probe design



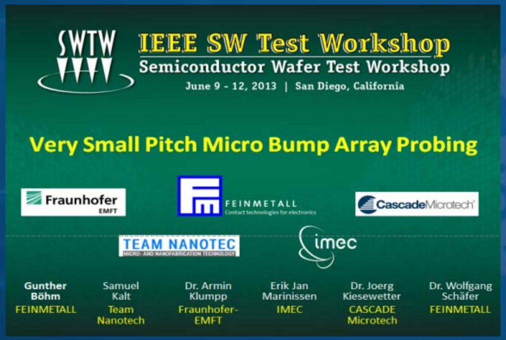


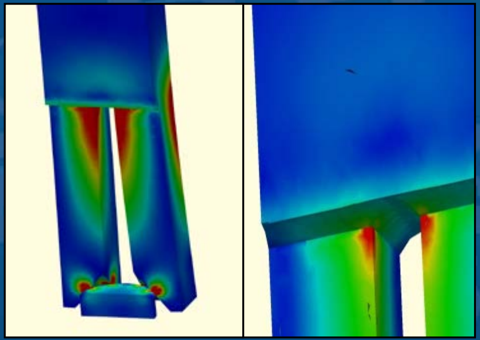
SWTest 2012: FE buckling beam MEMS probe model. The multi-physics, thermo-electrical analysis for high current and low pitch applications

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

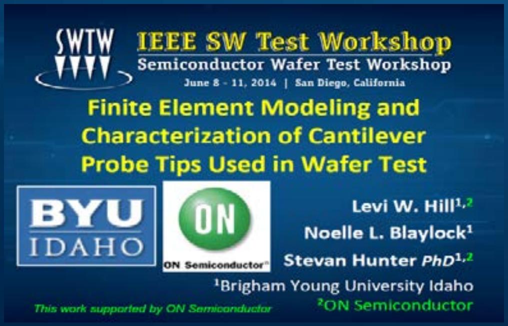


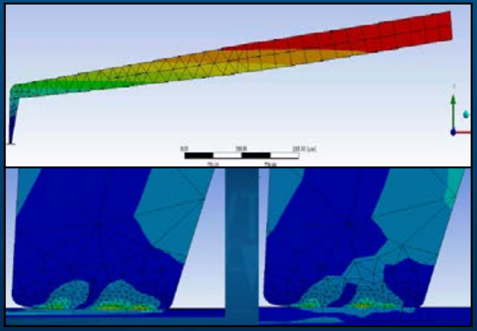
SWTest 2012: FE analysis of MEMS Monolithic Compliant Interconnects (MCI)





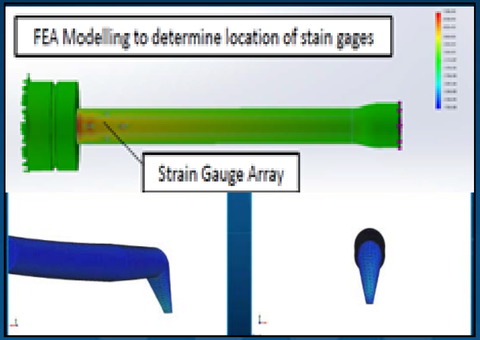
SWTest 2013: A unique and novel MEMS probe design. The finite element analysis of silicon probe with metalized crown tip





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

A little bit of history… (cont.)



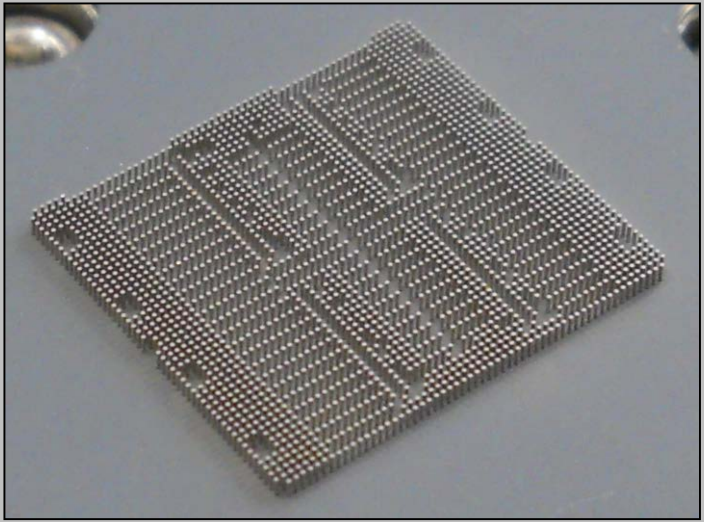
SWTest 2014: FE model of transverse load cell and cantilever probe tips scrubbing an aluminum wafer

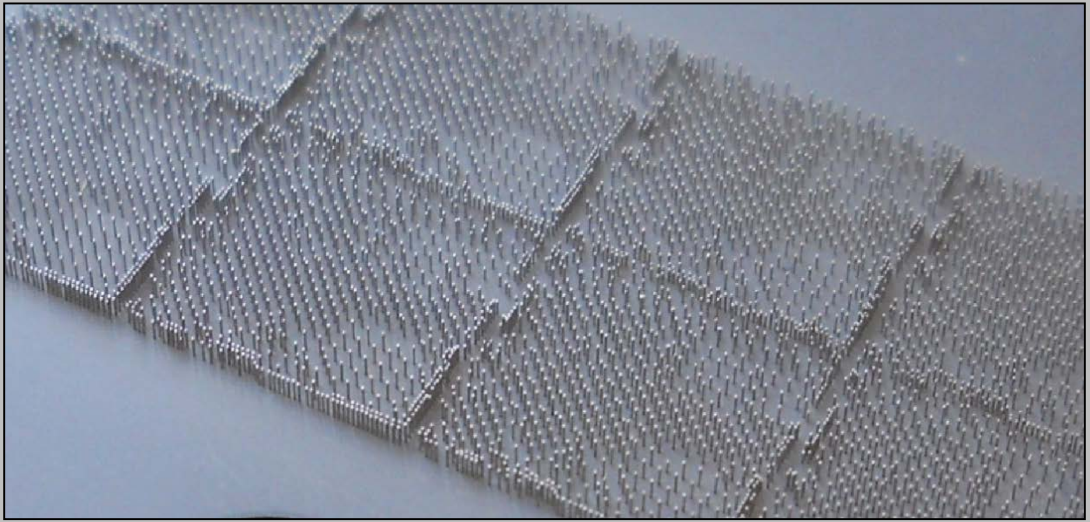
A pretty remarkable portfolio of FE analysis last 20 years!

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

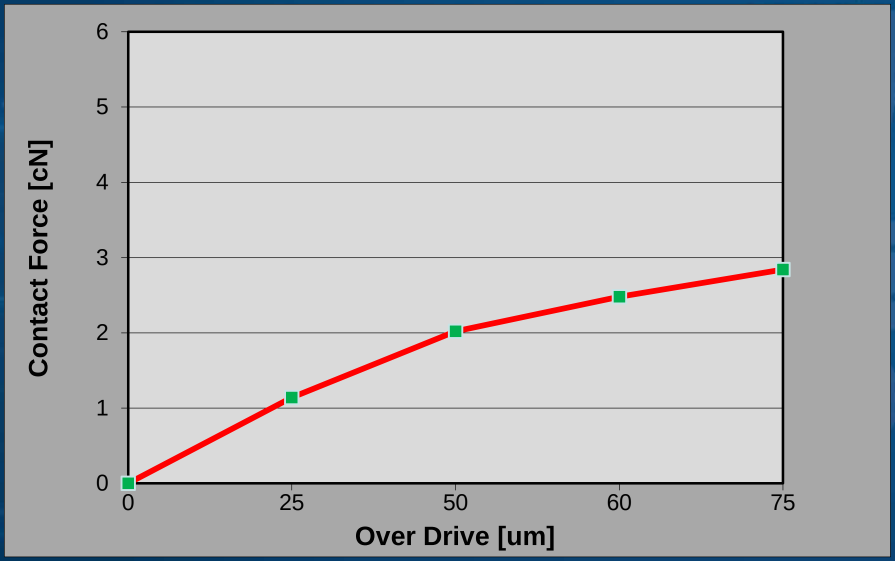




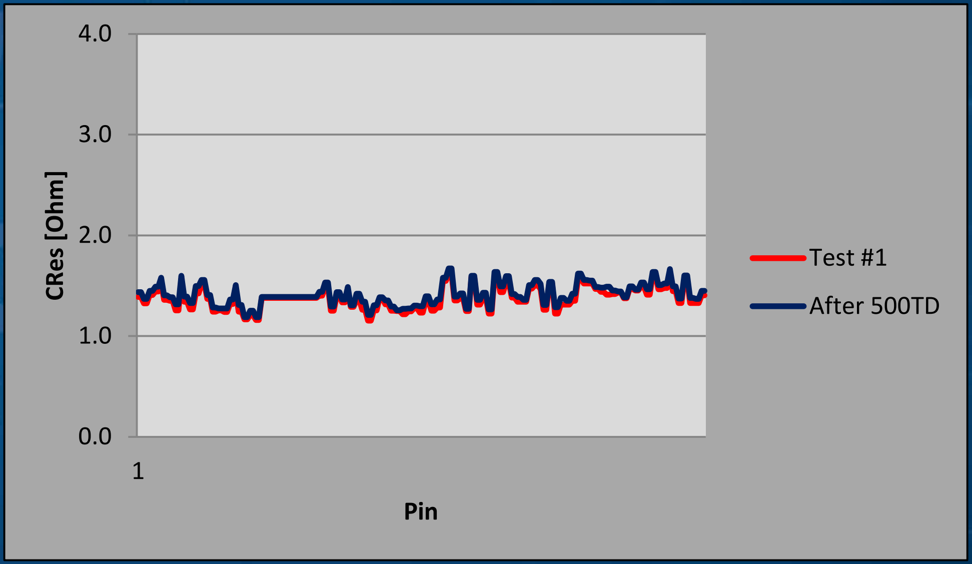
A custom design and build of test probe head or probe card

Initial Test Parameters

Probe Contact Force

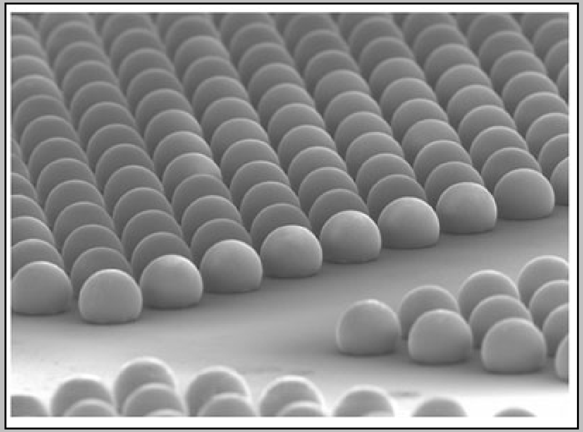


Path Resistance

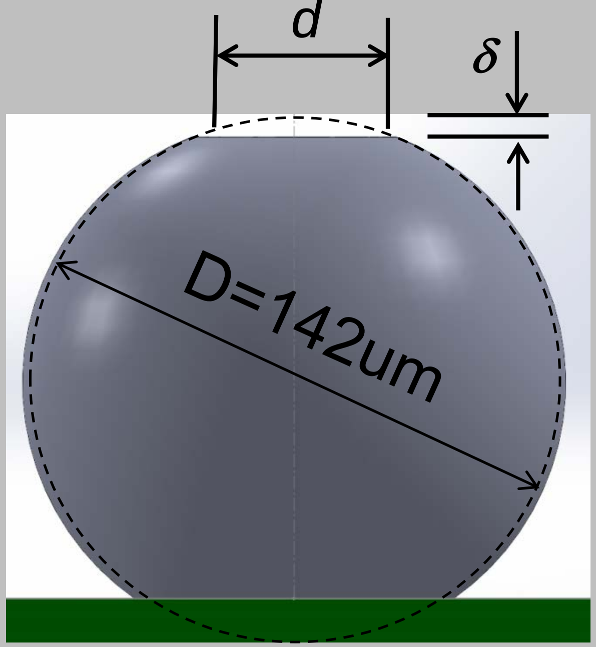


Wafer Bump Deformation Test

Bump Wafer SAC305

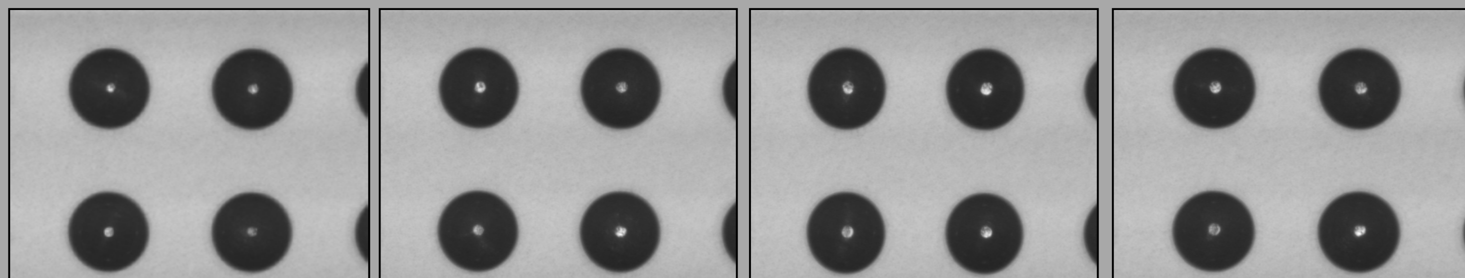


Bump Deformation



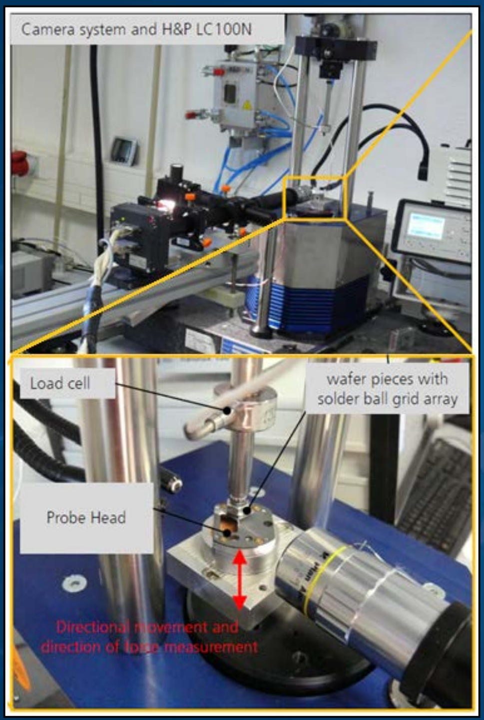
Wafer Bump Deformation Test at RT

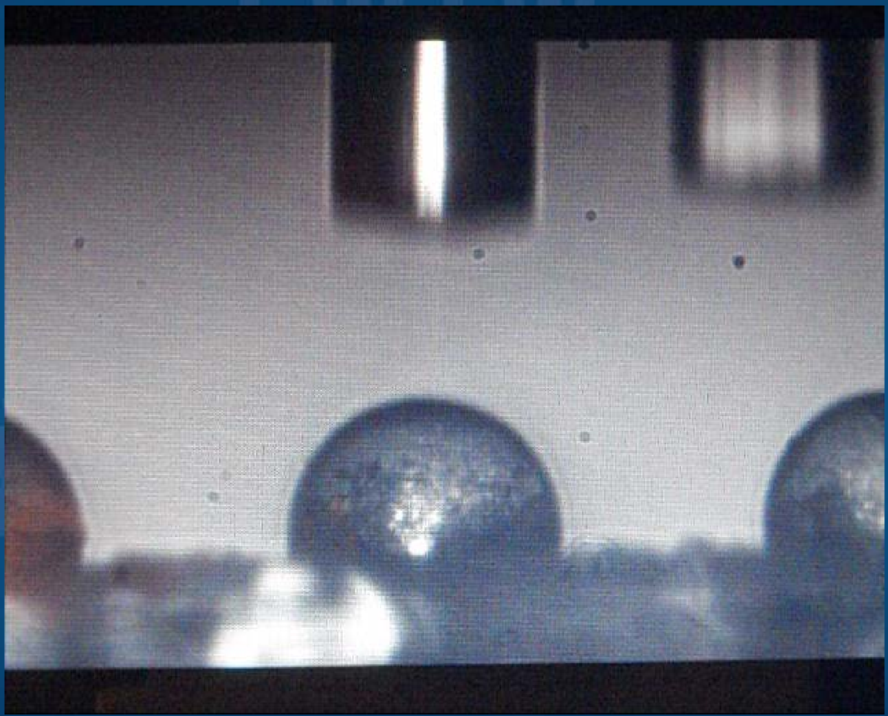
Wafer Bump Image



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

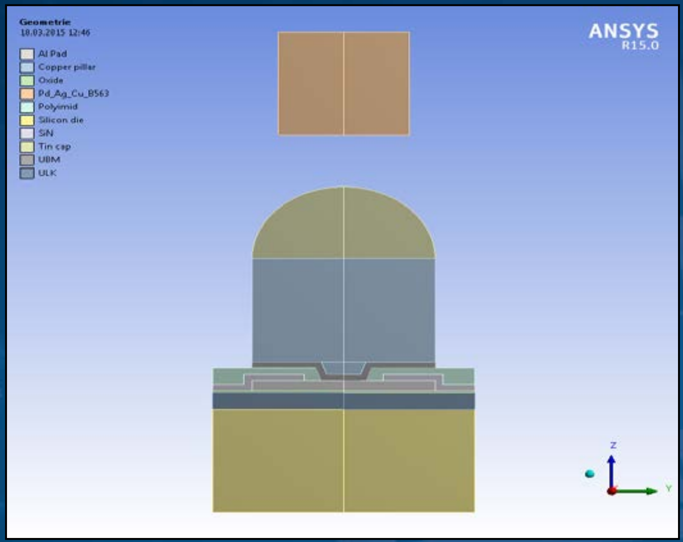
Description: frame rate 500Hz; Over-travel 500µm; Over-drive 100µm

But always is a question. Can we …

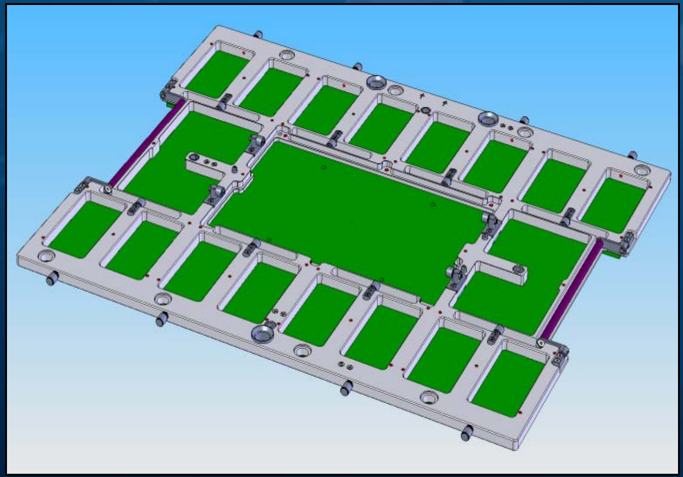
.. develop a reliable, virtual method to predict a complex structure behavior for various load conditions?

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

A Couple Examples of FE Studies

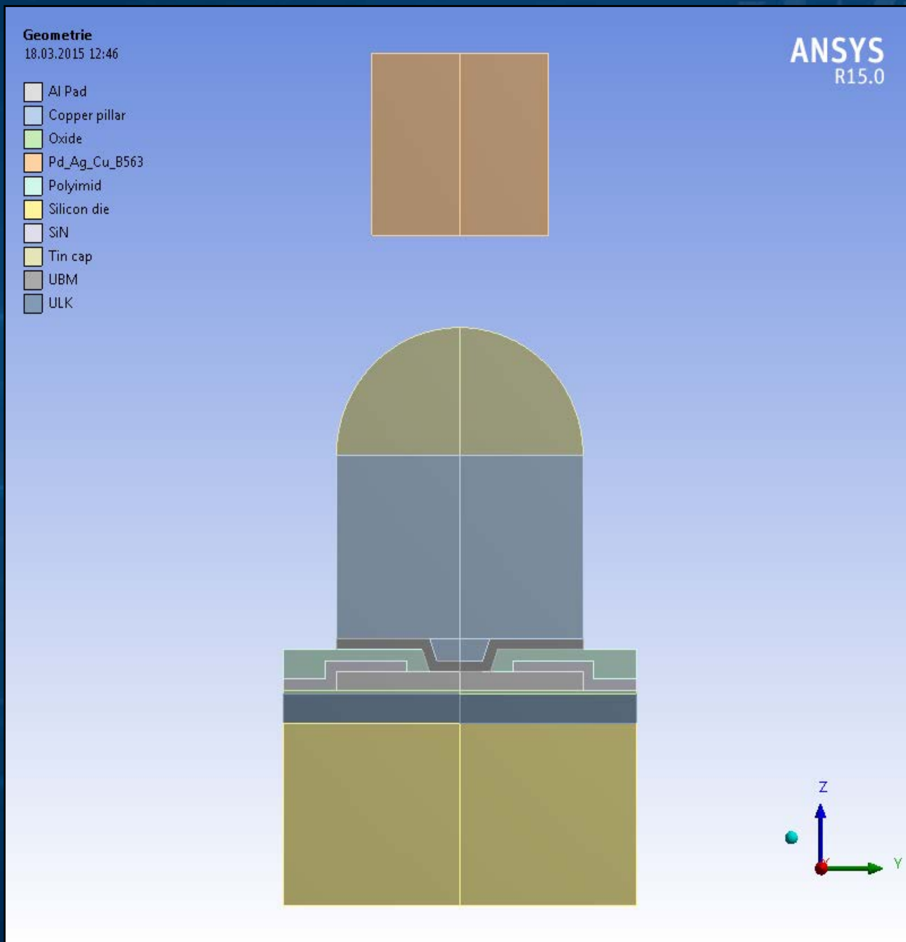


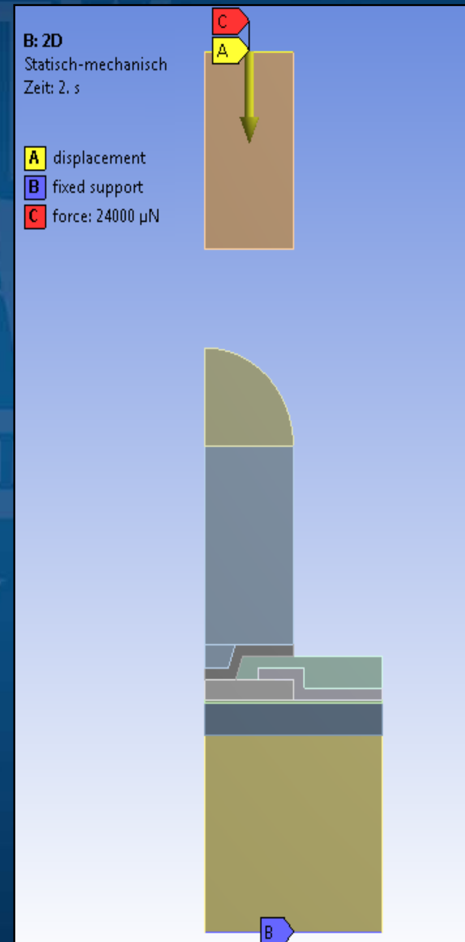
Cu Pillar bump model

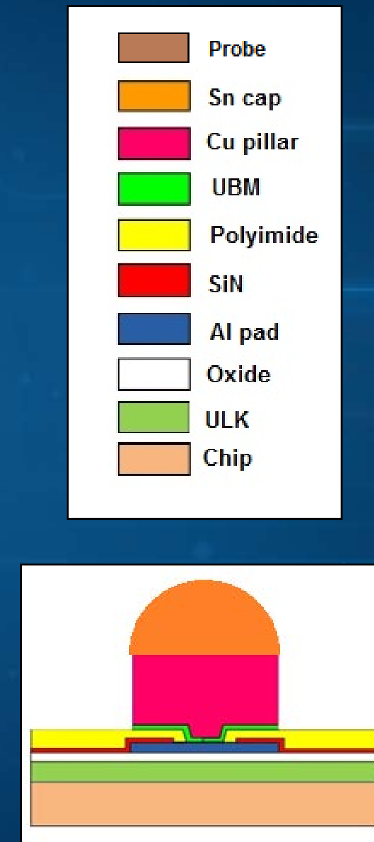


V93k Direct Probe PCB model

Cu Pillar FE Model







Bump Cross Section
Source: NUU

Model Material Properties

Items	Modulus of elasticity (E)	Poisson's ratio (v)	Thermal expansion (CTE, α)	Thermal conductivity (κ)	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

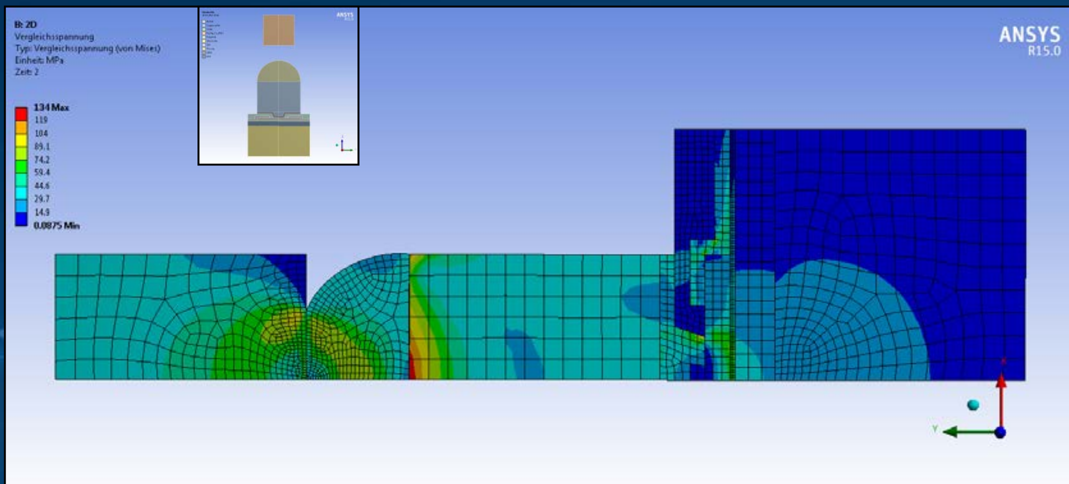
Elements and nodes created after model meshing

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

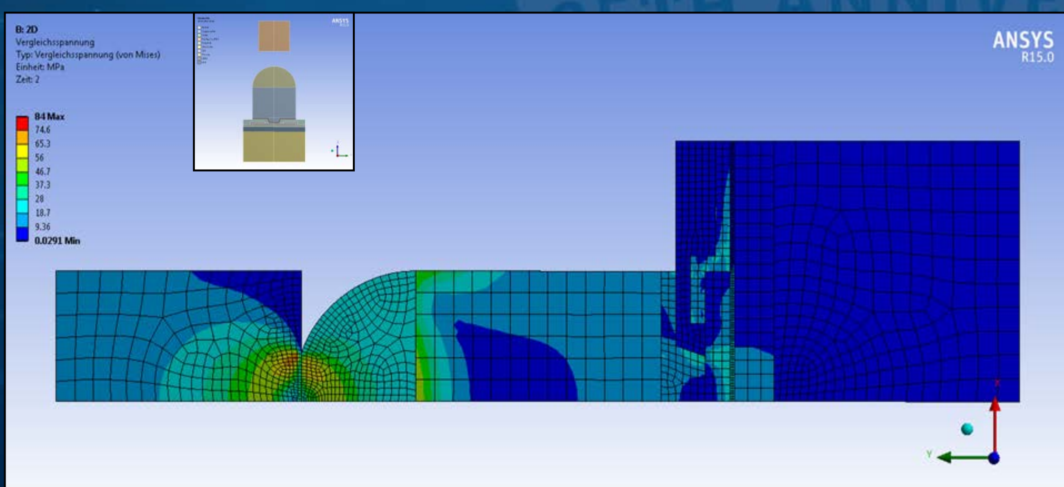
Elastic-plastic contact between probe and Cu pillar

- 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

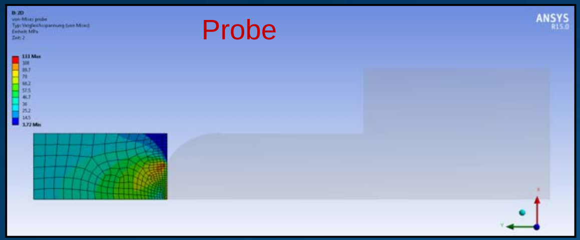


Contact force = 6.6 cN
Max Stress= 134 MPa
Deformed bump diameter – 26.6um

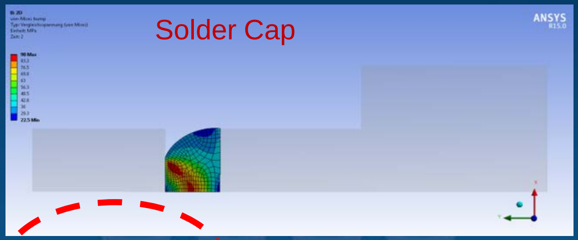


Contact force = 2.4 cN
Max Stress= 84 MPa
Deformed bump diameter – 18.2um

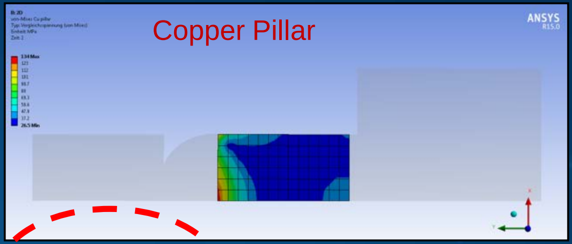
Stress by Model Layers – CF 6.6cN



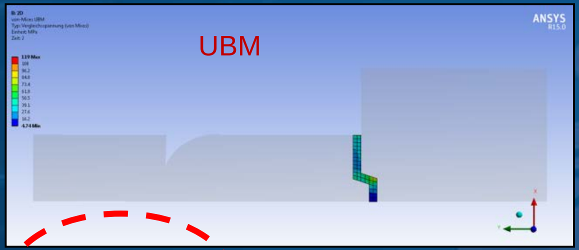
Max s=111 MPa
Yield s=755 MPa



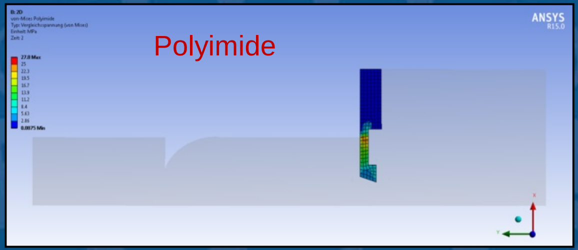
Max s=90 MPa
Yield s=24 MPa



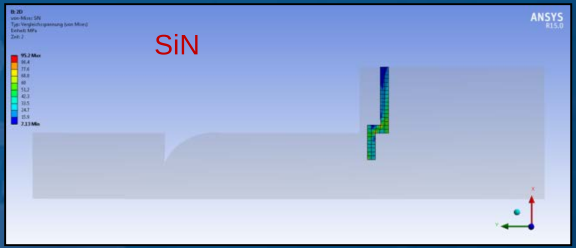
Max s=134 MPa
Yield s=70 MPa



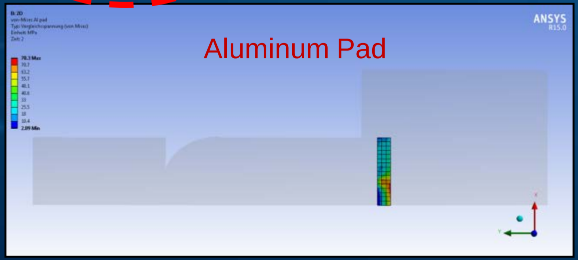
Max s=90 MPa
Yield s=32 MPa



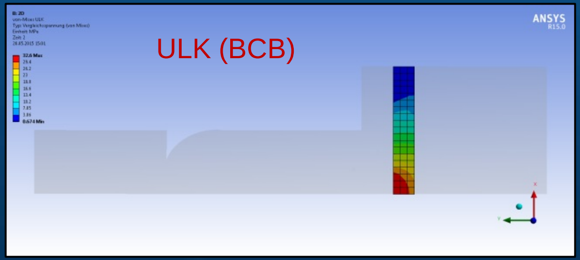
Max s=27 MPa
Yield s=69 MPa



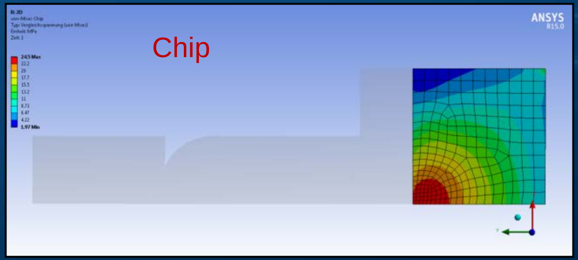
Max s=65 MPa
Yield s=86 MPa



Max s=78 MPa
Yield s=414 MPa

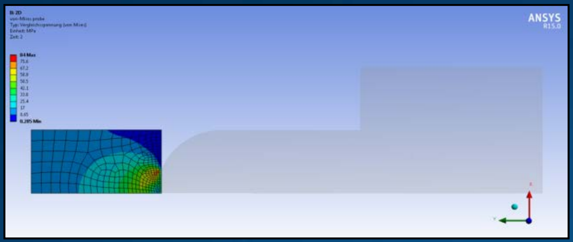


Max s=32 MPa
Yield s=96 MPa



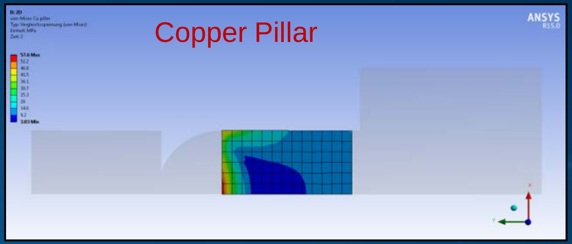
Max s=24 MPa
UTS s=7000 MPa

Stress by Model Layers – CF 2.4cN

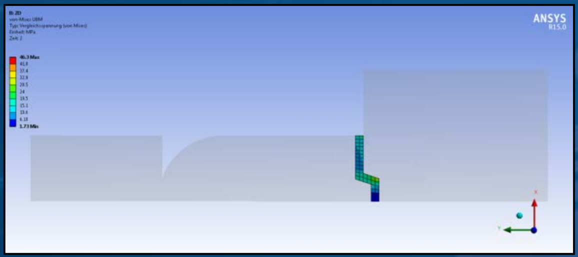


Max s=84 MPa
Yield s=755 MPa

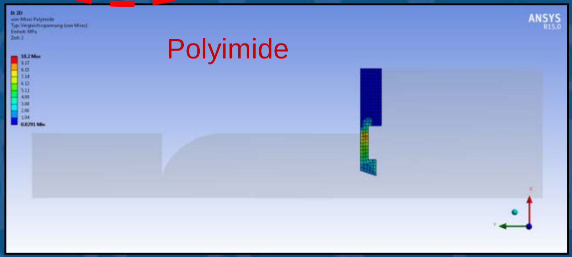
Max s=67.4 MPa
Yield s=24 MPa



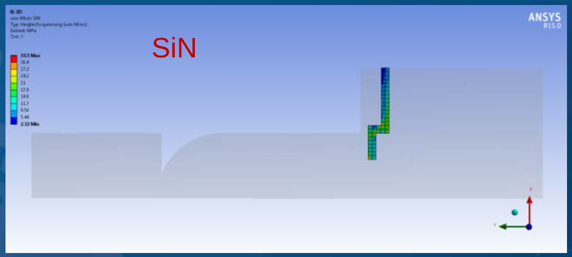
Max s=57 MPa
Yield s=70 MPa



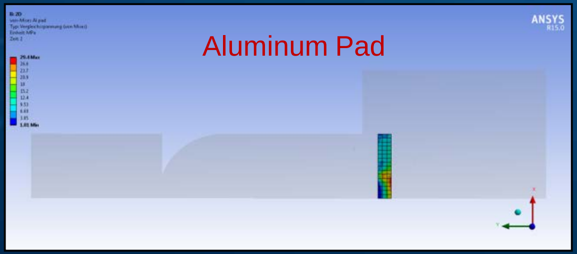
Max s=24 MPa
Yield s=32 MPa



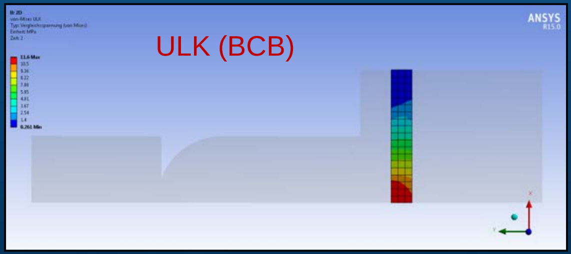
Max s=10 MPa
Yield s=69 MPa



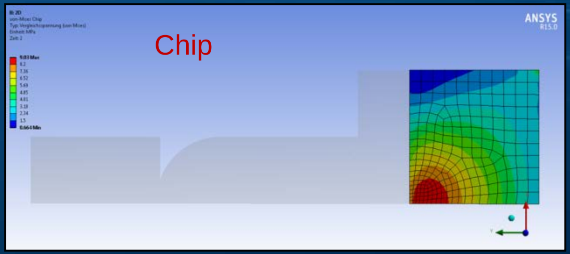
Max s=21 MPa
Yield s=86 MPa



Max s=29 MPa
Yield s=414 MPa



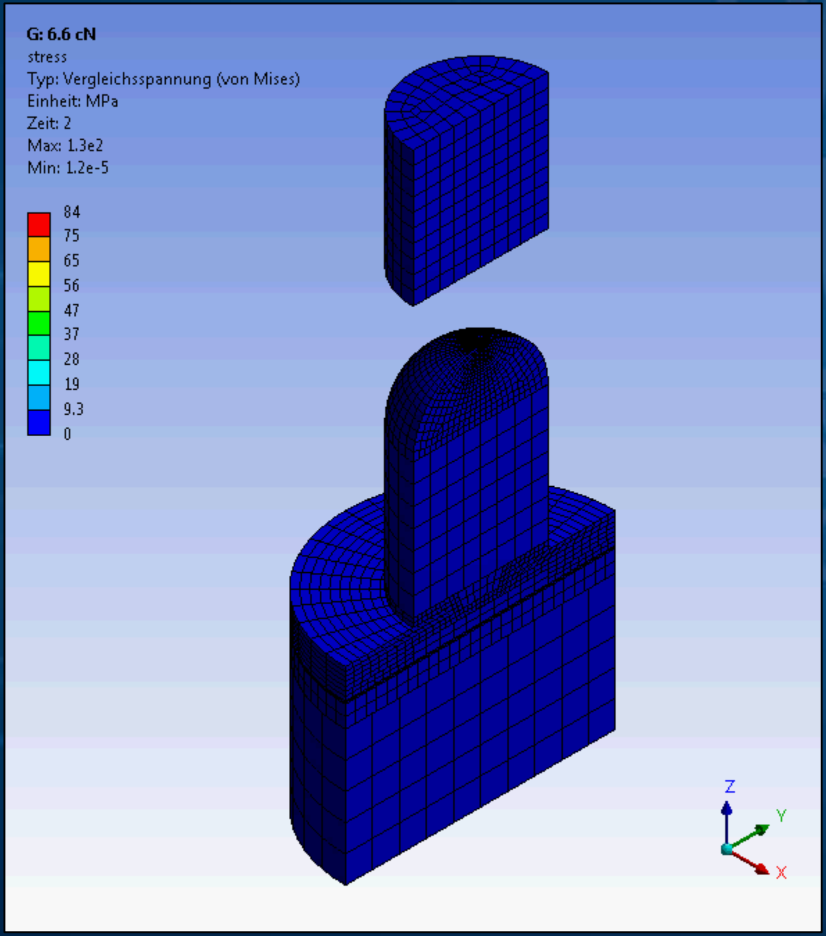
Max s=11.6 MPa
Yield s=96 MPa



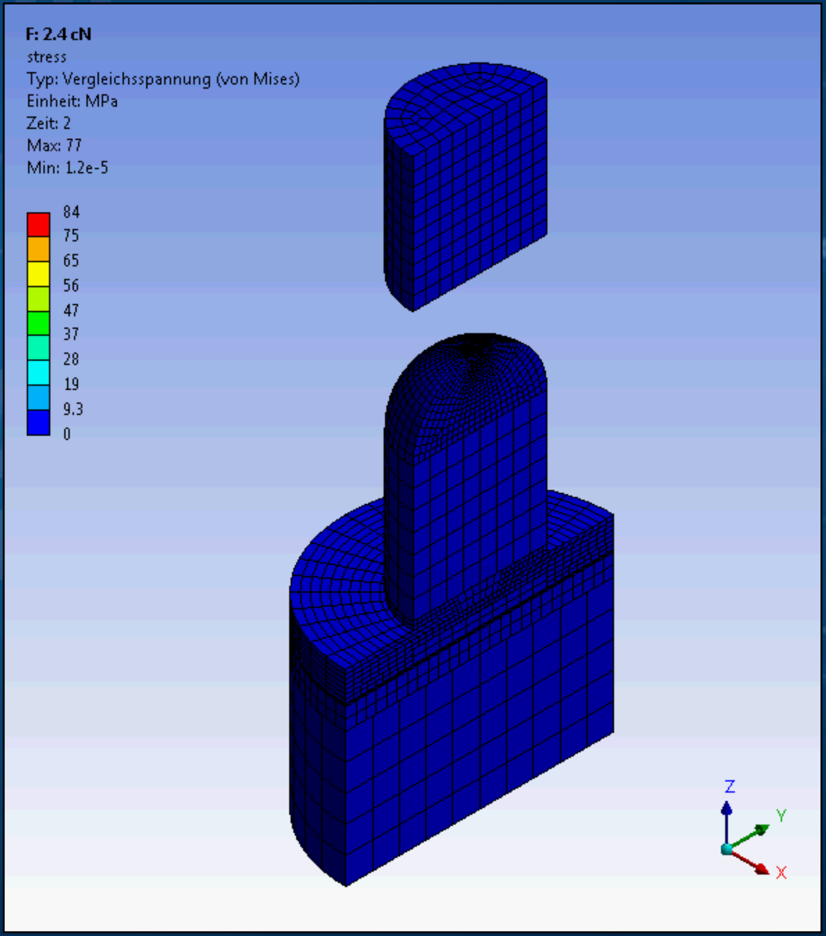
Max s=9 MPa
UTS s=7000 MPa

FE Cu Pillar Models Simulation

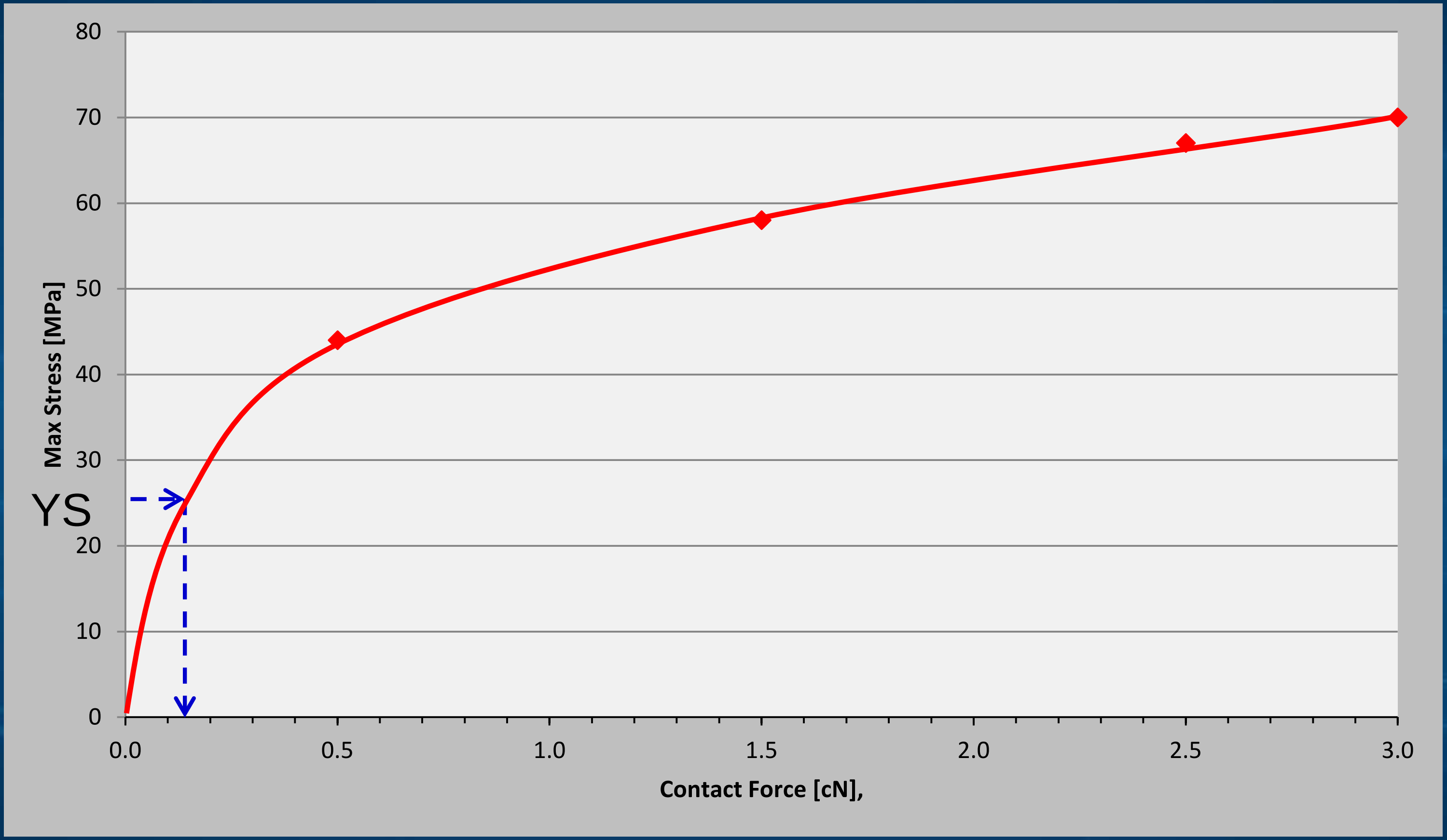
Probe force 6.6cN



Probe force 2.4cN

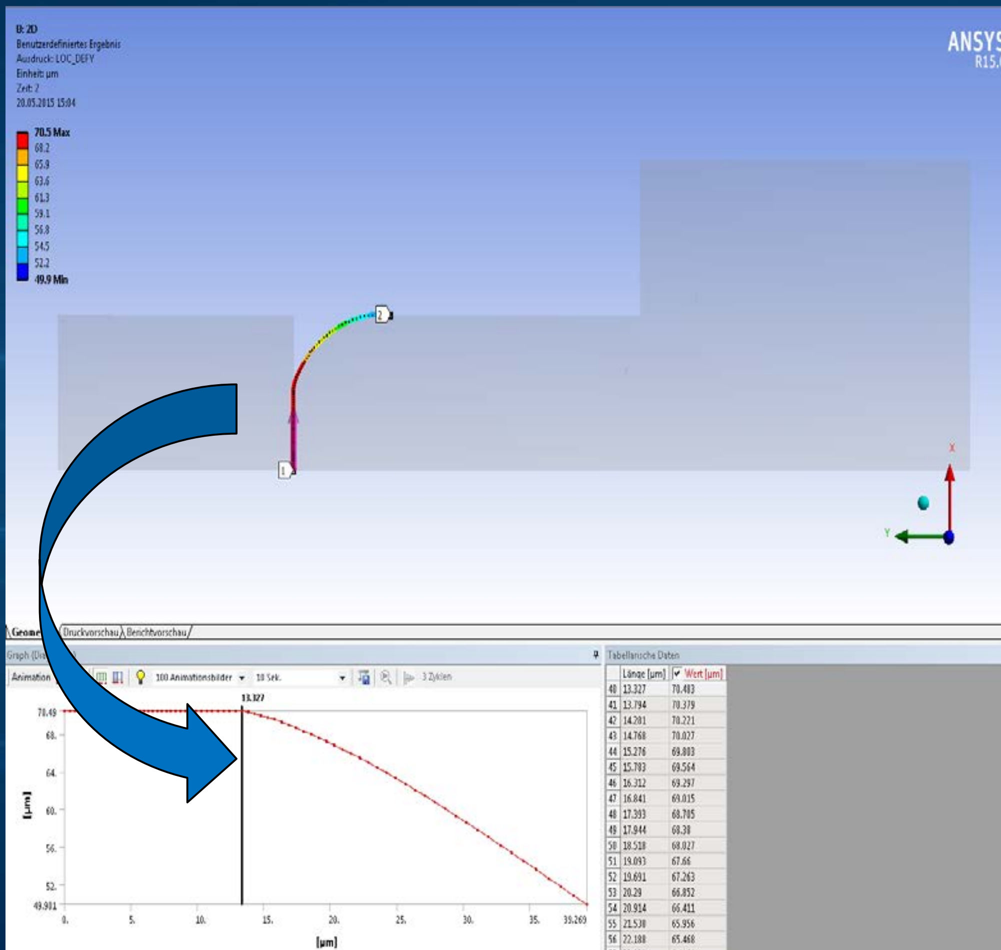


Max Stress Vs. Contact Force

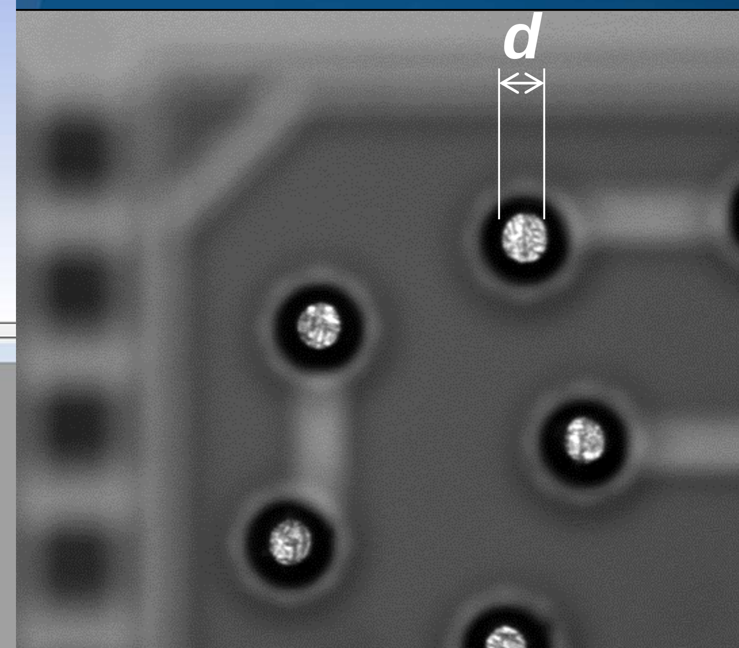


FEA estimated less than 0.2 cN as min contact force of flat probe tip with hemisphere bump

FE Model Validation – CF=6.6cN

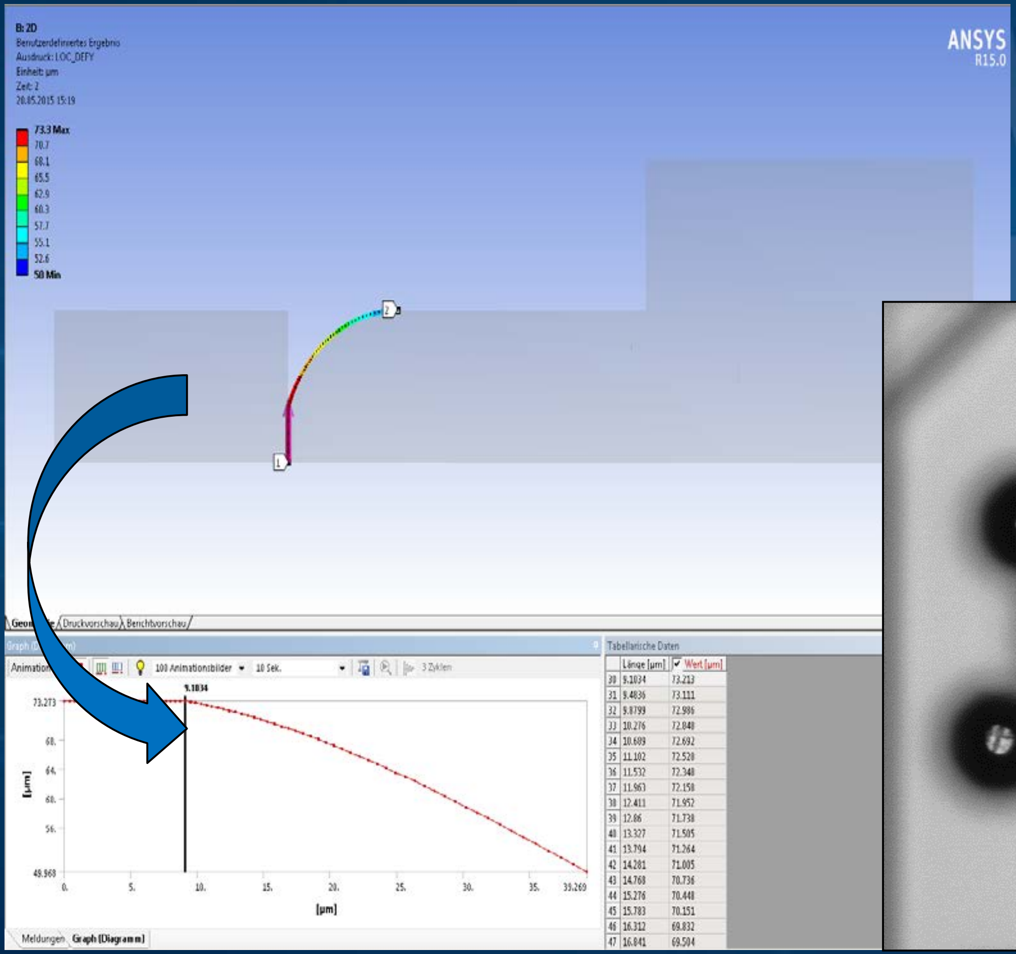


Production wafer test - deformed bump diameter *d* = 27.7um

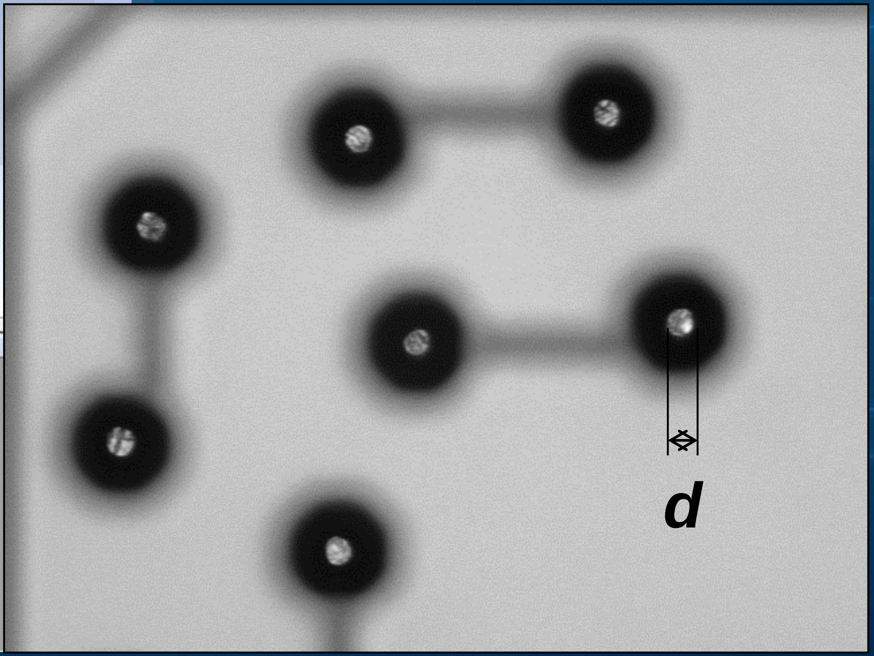


Advanced Model - FE deformed bump diameter *d* = 26.6um

FE Model Validation – CF=2.4cN

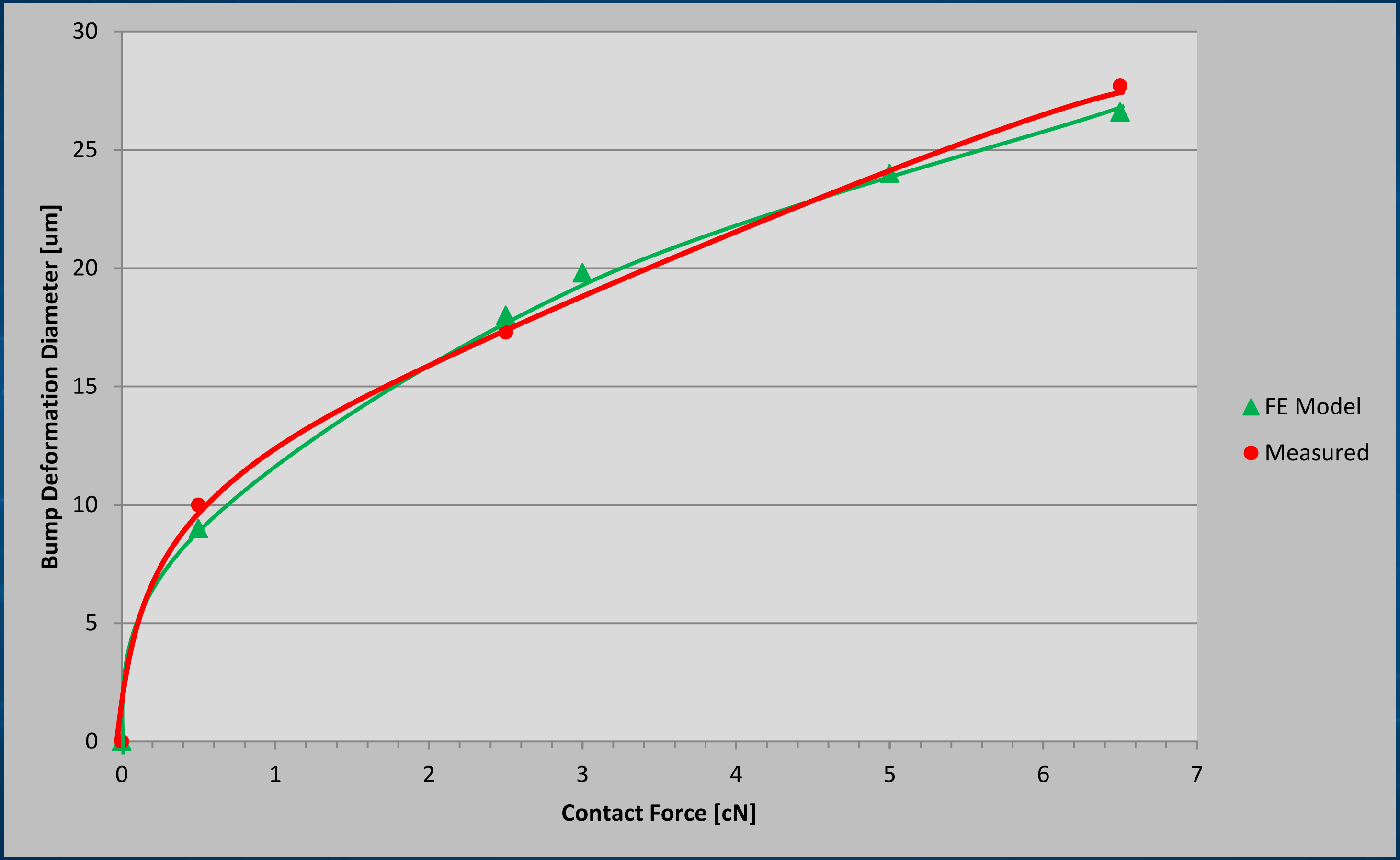


Production wafer test - deformed bump diameter *d* = 17.3um



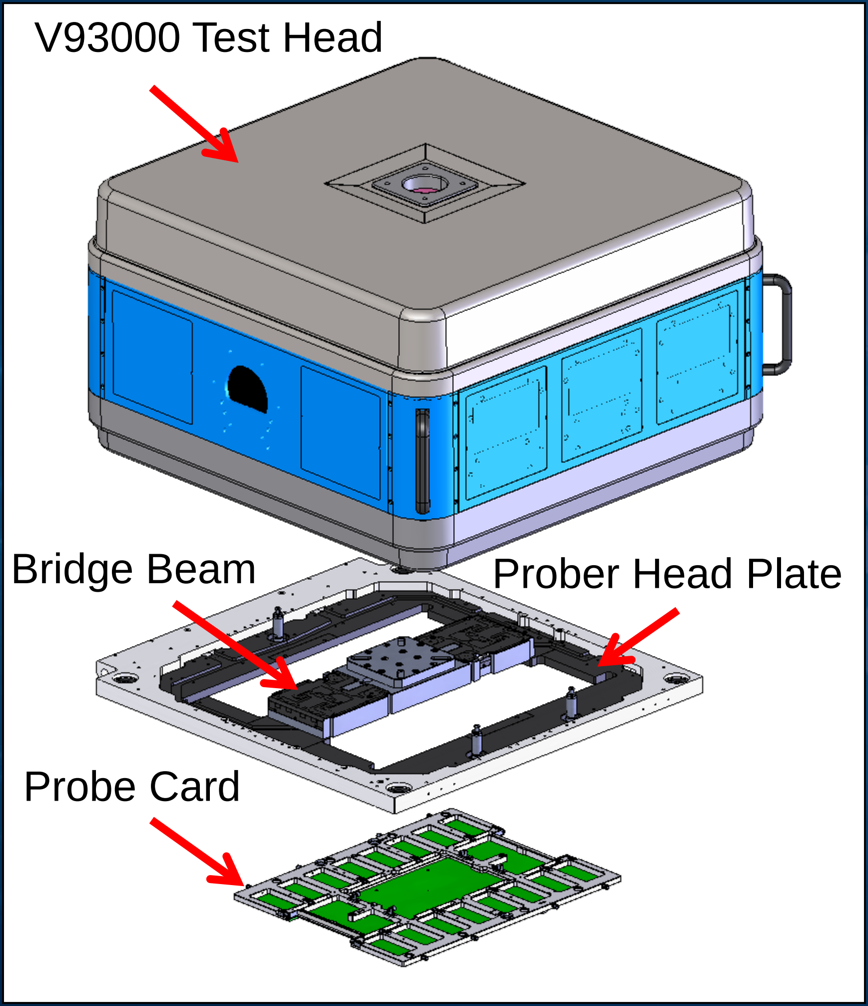
Advanced Model - FE deformed bump diameter *d* = 18.2um

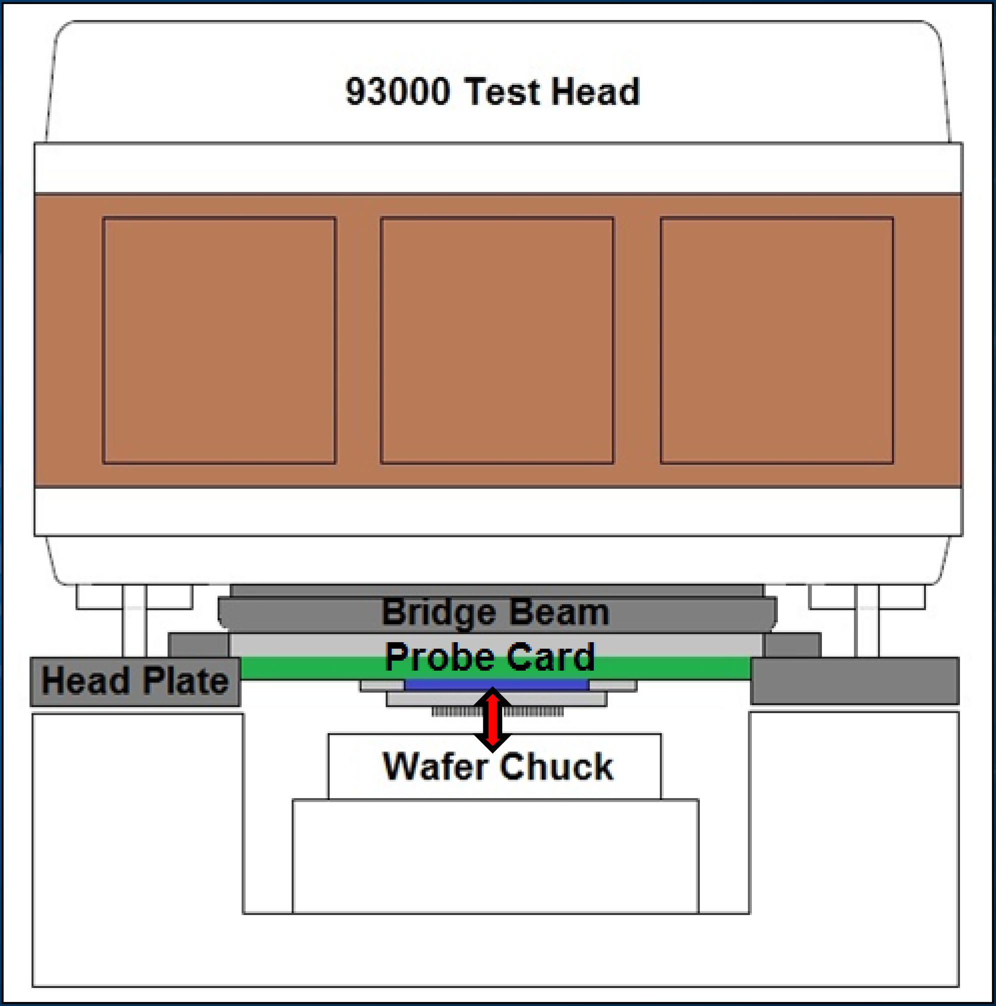
FE Model Vs. Wafer Test Correlation



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

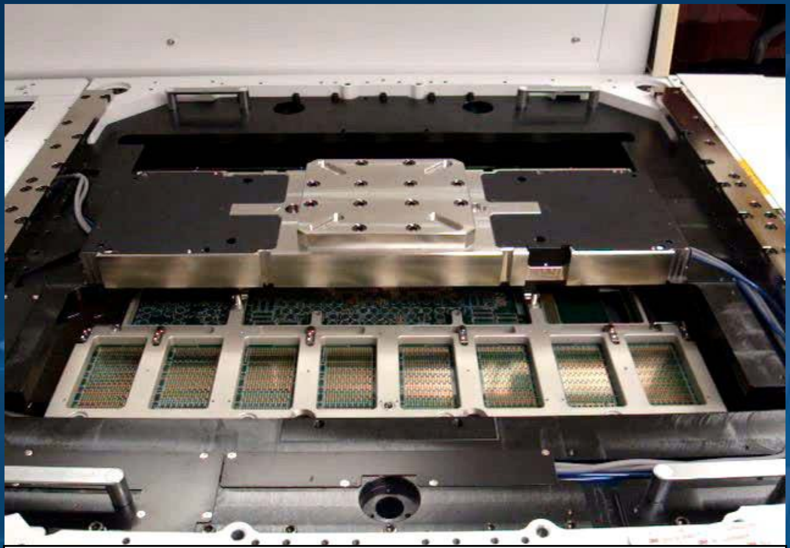
V93000 Direct-Probe™ Test Solution

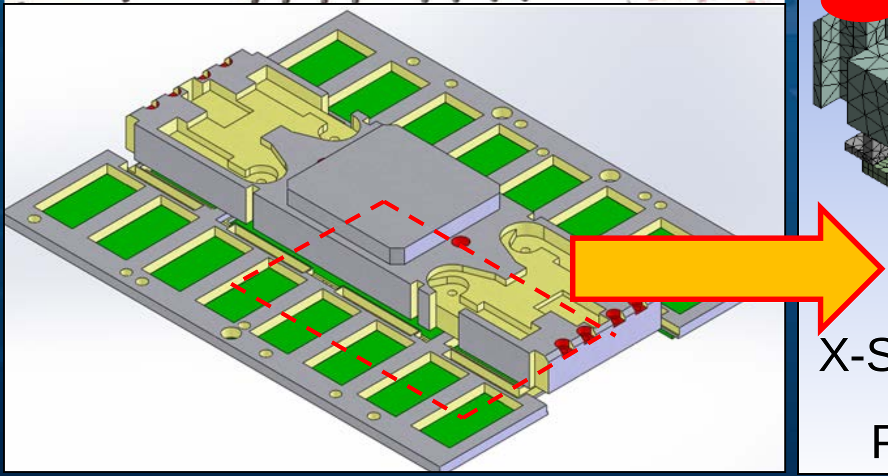




Source: Verigy /Advantest

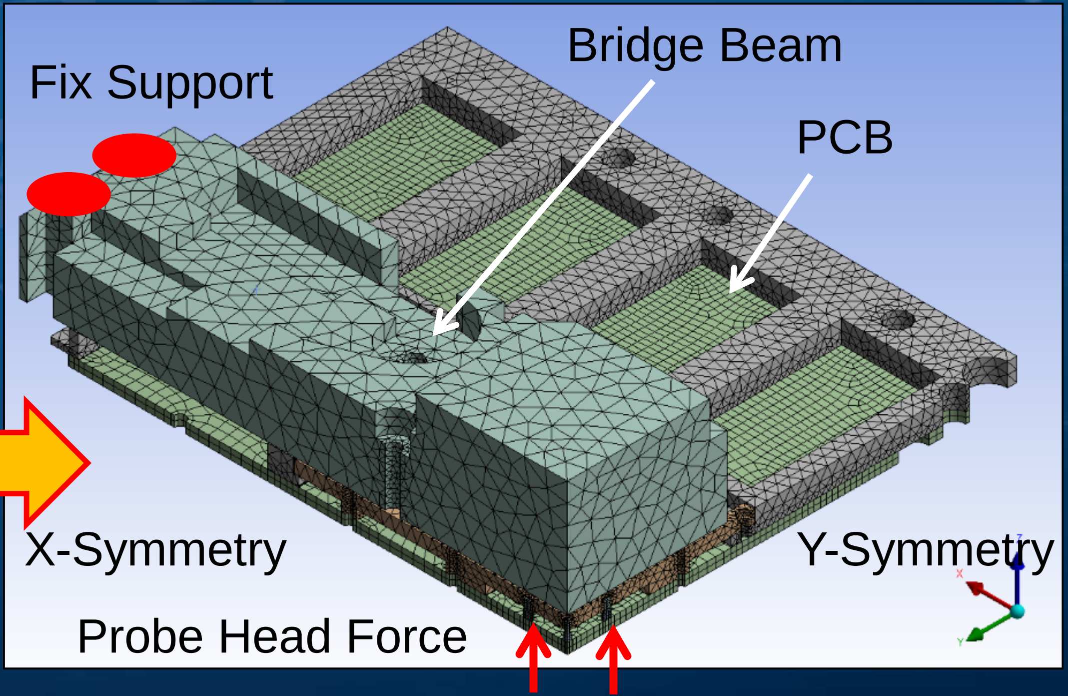
V93000 Direct-Probe™ FE Model





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

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

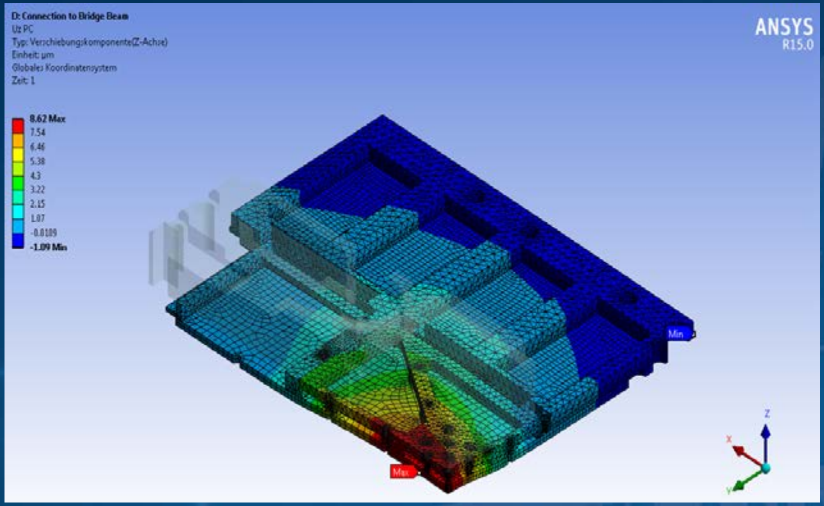


Picture Source: Advantest

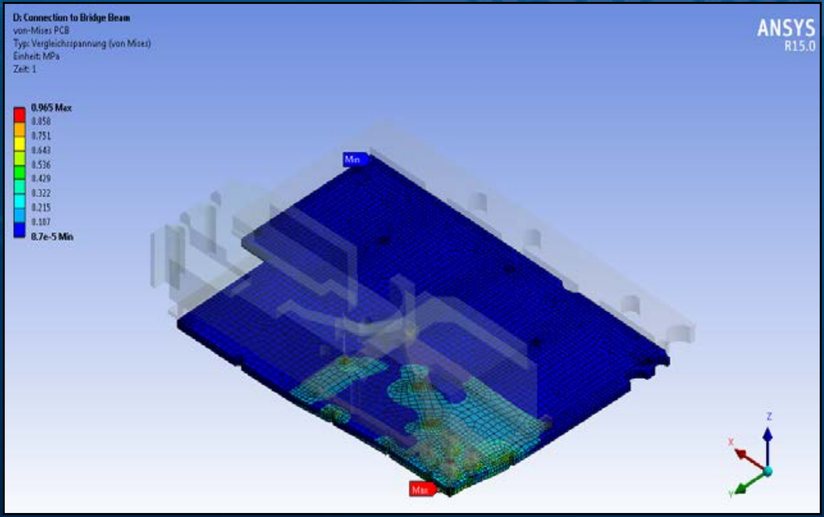
PCB Properties and FE Parameters

- **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

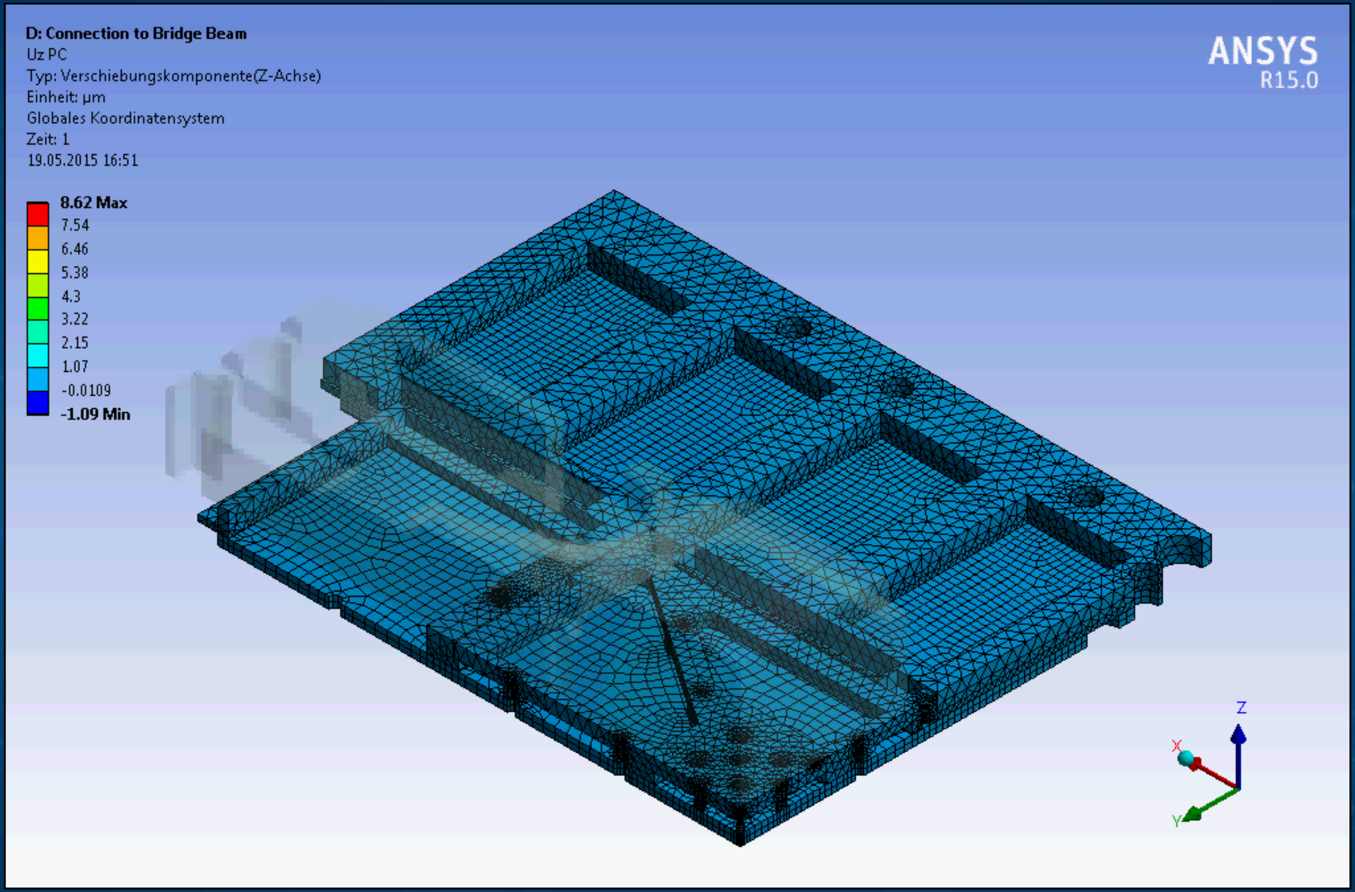


PCB maximum deflection supported by stiffener inlay connected with bridge beam: 8.6 um



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