SIMULATION OF THE PLASTIC DEFORMATION OF CONTACT PADS DURING MICROELECTRONIC TESTING

The 11th OpenFOAM® Workshop

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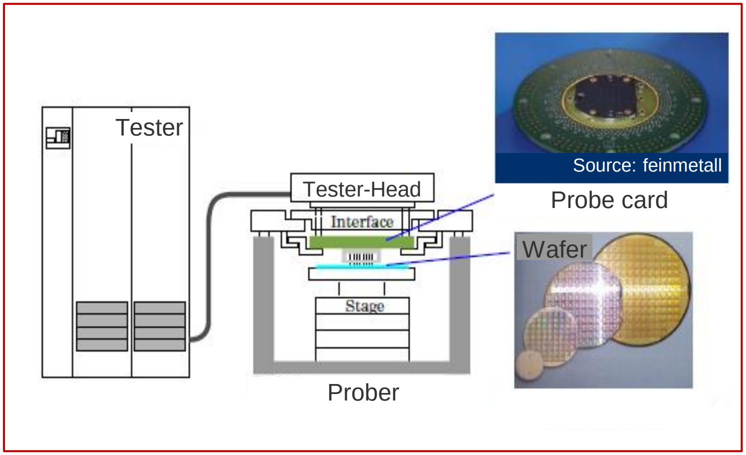
Agenda

- Content of the presentation

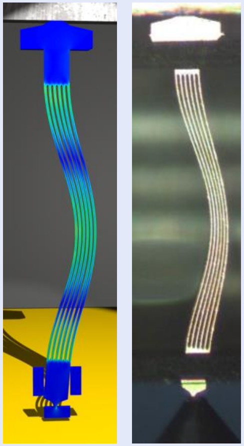
- Content of the Project
  - Goal of the project
  - Initial Situation
- Modelling
  - Background
  - Simulation Model
  - Experiment
  - Validation
- Future Prospect and Summarize
- Discussion and Questions



Project Content

- Goal of the project

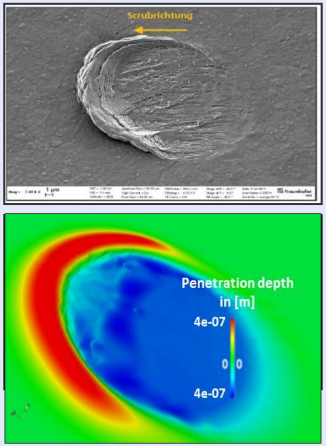
Contact element



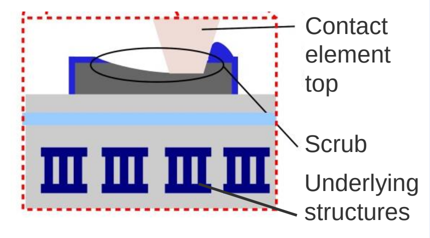
Motivation:

- New optimised total simulation of the contacting process in microchip testing
- Analyse of the impact on the pad fundament and the substructure during the contacting process

The scrub



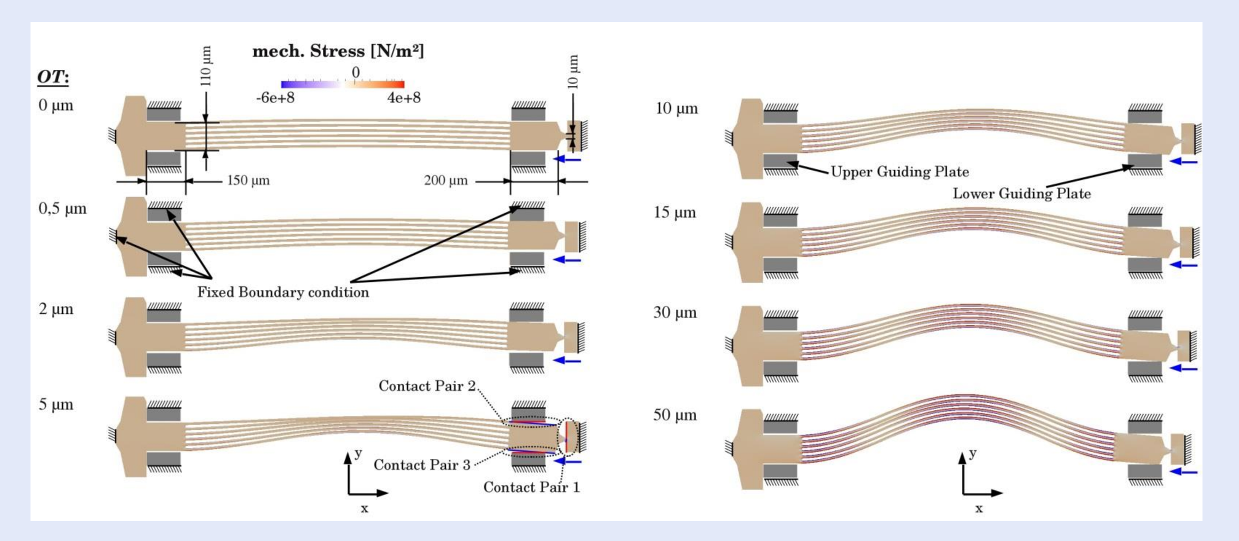
Effect analysis



→ **A total simulation of the contacting processs**

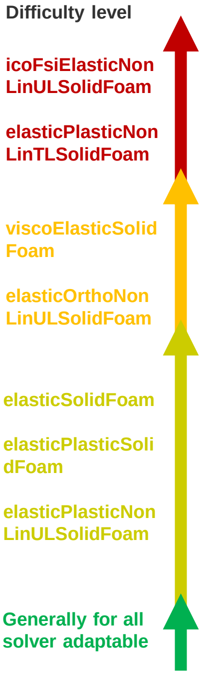
Project Content

- Initial Situation
  - **First part of the simulation:**
    - Mockup behaviour of the buckling
    - Dynamic numerical simulation of the buckling beam and integration of the friction model (elasticFrictionContactNonLinFoam)
    - Validation of the buckling beam



Modeling

- Background
  - **The solid mechanic solver can be subdivided into the following Governing equation:**



Difficulty level

icoFsiElasticNonLinULSolidFoam

elasticPlasticNonLinTLSolidFoam

viscoElasticSolidFoam

elasticOrthoNonLinULSolidFoam

elasticSolidFoam

elasticPlasticSolidFoam

elasticPlasticNonLinULSolidFoam

Generally for all solver adaptable

- Equilibrium condition:

$$\frac{\partial^2(\rho\mathbf{u})}{\partial t^2} - \nabla\cdot\boldsymbol{\sigma} = \mathbf{0}$$

- Rheology property:

$$\boldsymbol{\sigma} = 2\mu\boldsymbol{\varepsilon} + \lambda tr(\boldsymbol{\varepsilon})\mathbf{I}$$

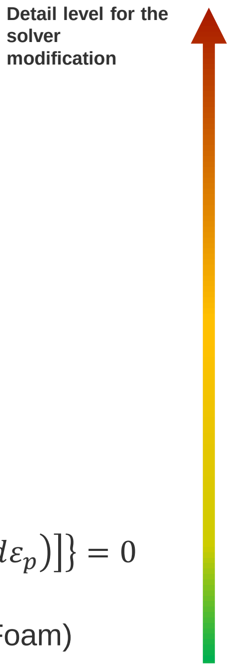
- Kinematic relation:

$$\boldsymbol{\varepsilon} = \frac{1}{2}[\nabla\mathbf{u} + (\nabla\mathbf{u})^T]$$

- Plasticity approaching model:

$$\nabla\cdot\{\mu\nabla(du) + \mu[\nabla(du)]^T + \lambda I tr[\nabla(du)] - [2\mu(d\varepsilon_p) + \lambda I tr(d\varepsilon_p)]\} = 0$$

- Friction and Boundary condition (elasticFrictionContactNonLinFoam)



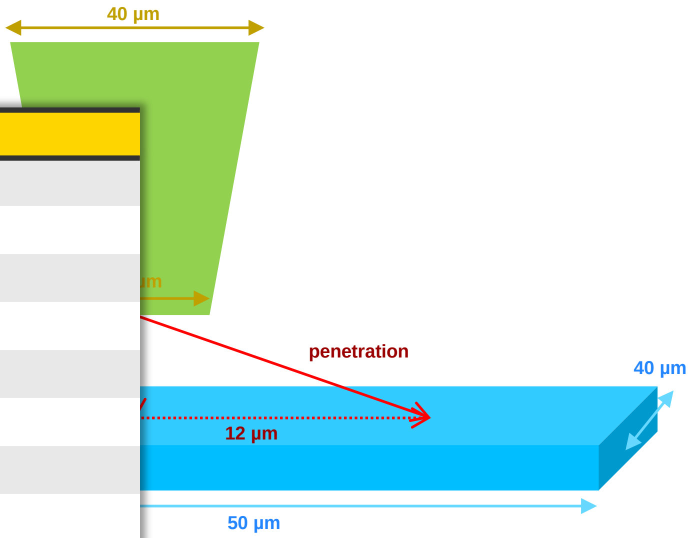
Detail level for the solver modification

Modeling

- Simulation concept

Trivar HC 1.6 Mil:

Simulation Parameter	Minimal Value
Tolerance (inner iteration)	≤ 1e-7
Toleranz (outer iteration)	≤ 1e-6
Relative tolerance	≤ 0,1
Simulation step	≤ 0,2 s
ncorrectors	≥ 25000
correctionFrequency	≤ 500
Minimum size of the finite volume	≤ 0.2e-6 m (scalable)
Velocity (computed from the CFL value)	≤ 0,5 um/s
Contact model	Standard Penalty
divSigmaExp	Surface
relaxationFactors	≤ 0,1

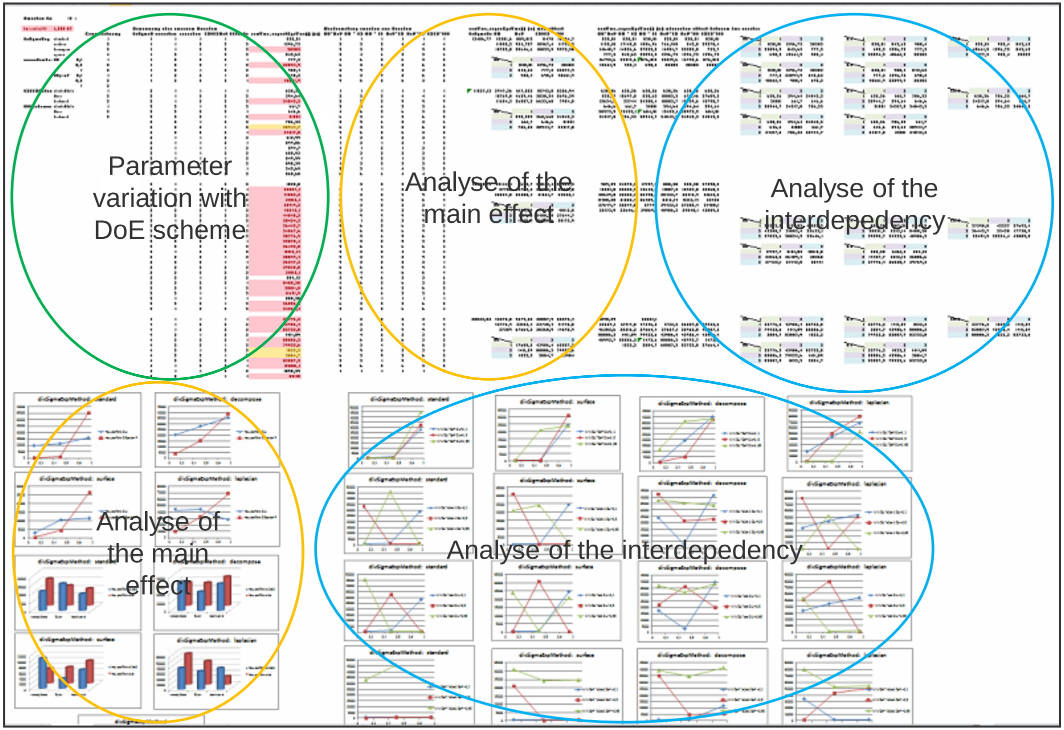


Aluminum Pad:

E Modul = 62 GPa
Yield strength = 187 MPa
Tensile strength = 218 MPa
Poisson‘s ration = 0.34

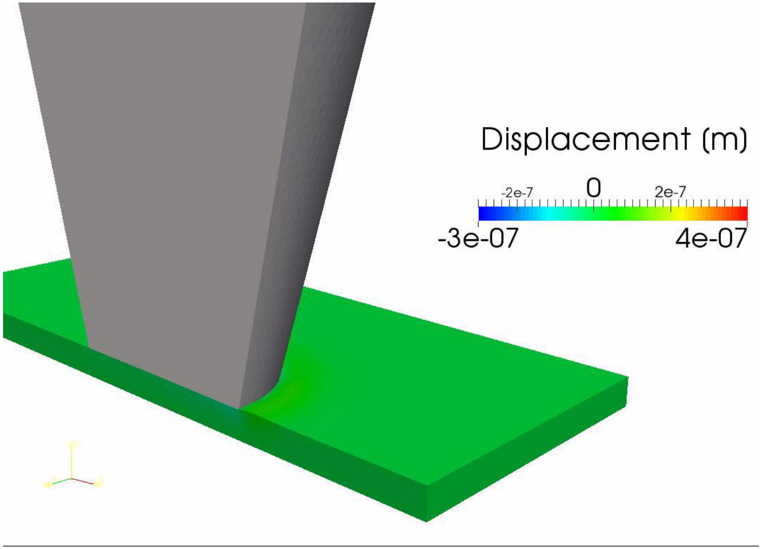
Modeling

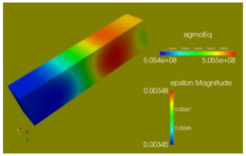
- Analyse of the simulation parameter with DoE



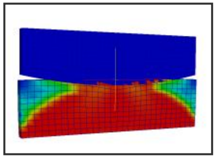
Modeling

- From the Simulation concept into the Mockup
  - **Contact element 1.6 Mil**

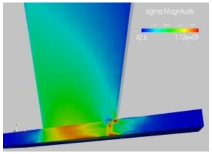




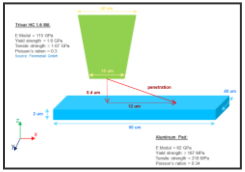
Boundary condition



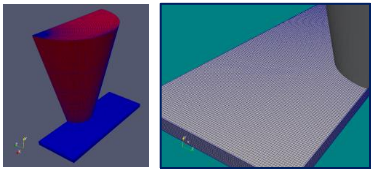
Contact detection



Friction



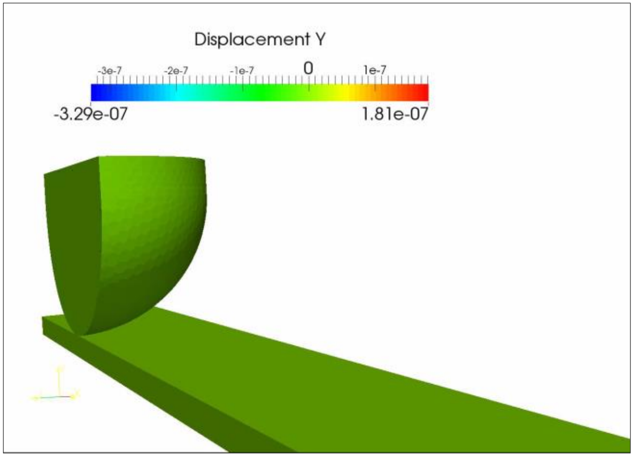
Simulation concept

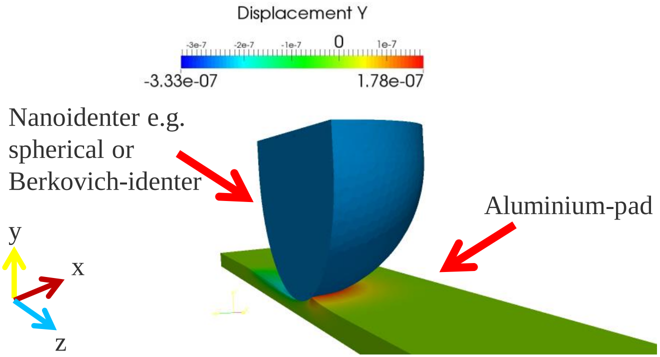


Geometrie and mesh generation

Modeling

- From the mockup into an adaptable simulation mockup





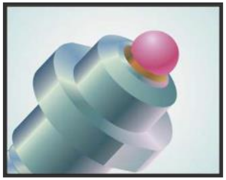
Nanoidenter e.g. spherical or Berkovich-identer

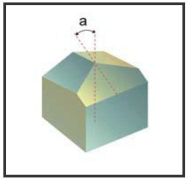
Aluminium-pad

- The simulation has now been adapted.
- The next step is to validate it.

Modeling

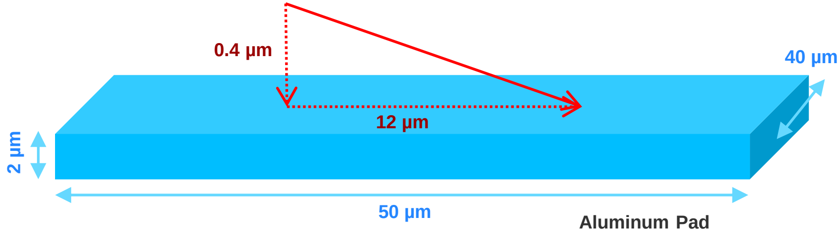
- Validation
  - **Validation with the nanoindentation**





Diamant:

E-Modul = 1050 GPa
Poisson‘s ratio = 0,1
Tensile strength = 750 Mpa
Density: 3,515 g/cm^3



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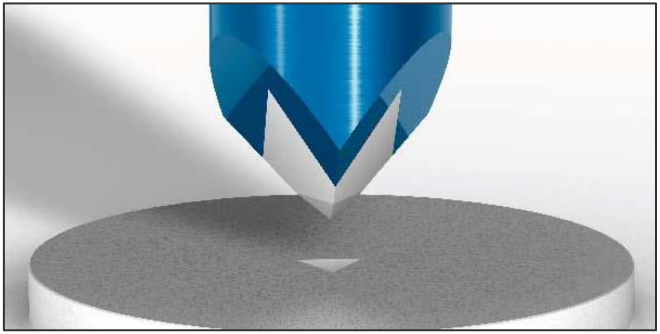


Source: Synton-MDP

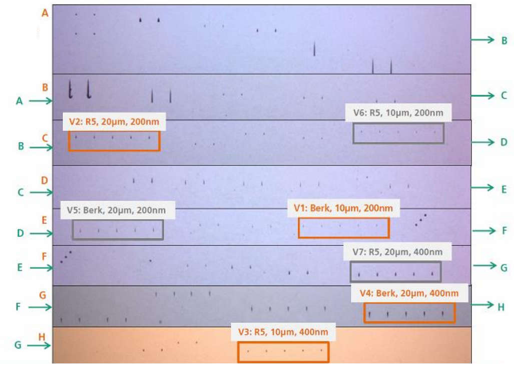
Goal of the validation:

- Penetration with Nanoindentation into the Aluminum layer on a Wafer
- Qualitative comparison of the surface pad between the simulation and the experiment
- Quantitative comparison of the force and penetration depth

Modeling

- Experiment
  - **Plan of the experiment with DoE**

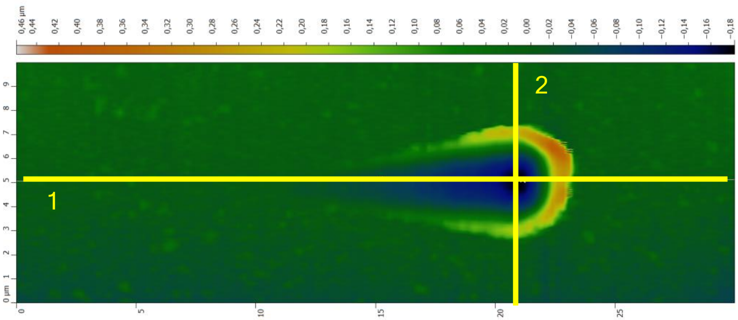
Evaluation:
- Penetration depth: AFM (Atomic Force Microscope)
- Comparison of force and penetration depth
- SEM (Scanning Electron Microscope)



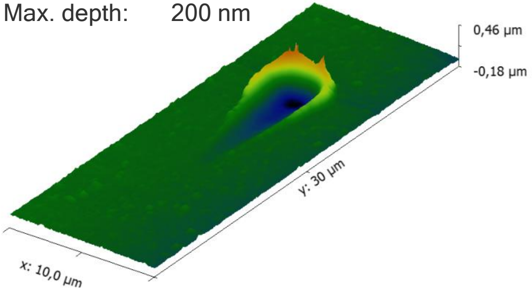
Number	Identer Geometry	Scratch length	Maximum force and penetration depth	Substrate
1	Berkovich-Indenter	10 µm	1,6mN, ca. 332nm (± 54nm)	Al on Si Wafer
2	Sphere-Indenter (5 µm Radius)	20 µm	8,0mN, ca. 179nm (± 10nm)	Al on Si Wafer
3	Sphere-Indenter (5 µm Radius)	10 µm	8,0mN, ca. 417nm (± 16nm)	Al on Si Wafer
4	Berkovich-Indenter	20 µm	7,2mN, ca. 597nm (± 10nm)	Al on Si Wafer
Addition:				
5	Berkovich-Indenter	20 µm	2,0mN, ca. 193nm (± 24nm)	Al on Si Wafer
6	Sphere-Indenter (5 µm Radius)	10 µm	6,0mN, 272nm (± 12nm)	Al on Si Wafer
7	Sphere-Indenter (5 µm Radius)	20 µm	15,0mN, 551nm (± 77nm)	Al on Si Wafer

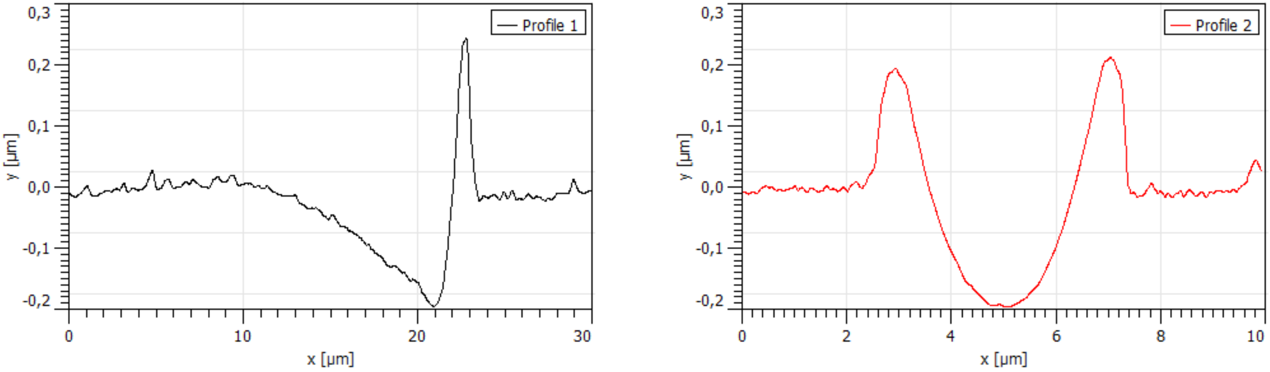
Modeling

- Experiment result
  - **Evaluation of the penetration depth with AFM**



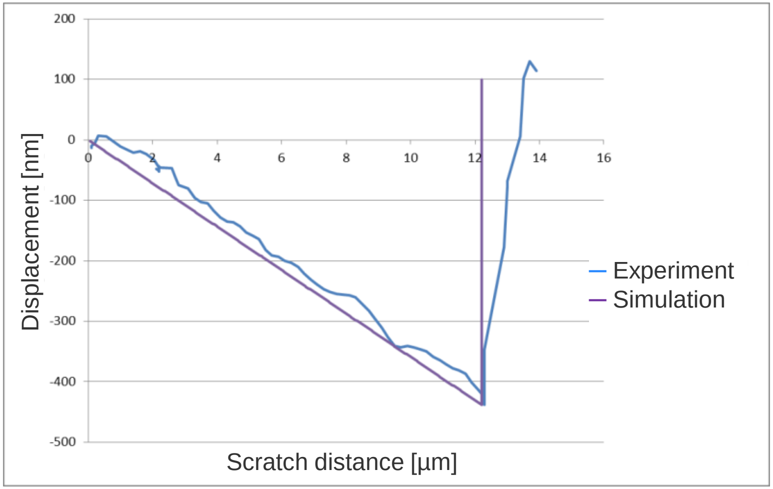
→ Identer: Spherical
→ Scratch length: 10 µm
→ Max. depth: 200 nm

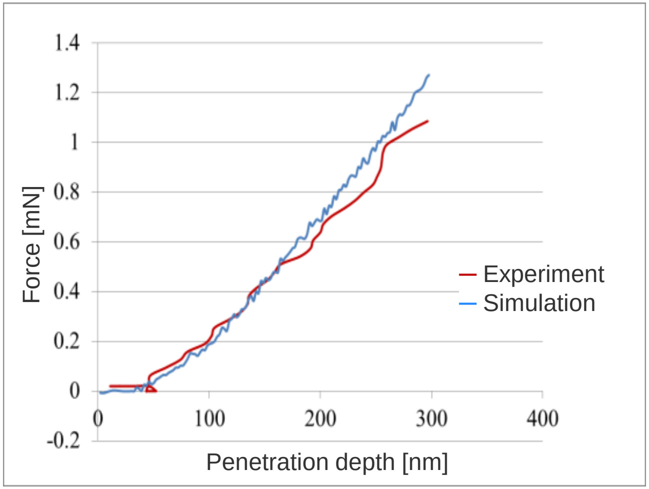




Modeling

- Validation
  - Comparison of the indentation movement and comparison of the displacement and force on the x- and z- axis





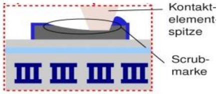
Berkovich-Identer: 12 µm scratch length
and about 440 nm penetration depth

Summarize

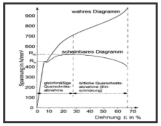
- Actual result
  - The implementation of the plastic deformed pad model was carried out
  - The experiment to validate the simulation has been done
  - The validation results show a very good consistency of the simulation up to certain penetration depth
  - The concept idea for the validation with a nanoindentation should be proven according to the real test in microchip testing
  - The coupling between the contact element solver (buckling) and the plastic deformed pad is still currently being processed
  - For more precise modeling, the use of dynamic mesh or crack solver is been considered

Future Prospect

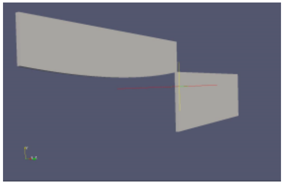
Simulation coupling



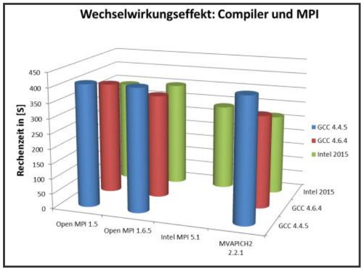
Compression curves



Silicon crack

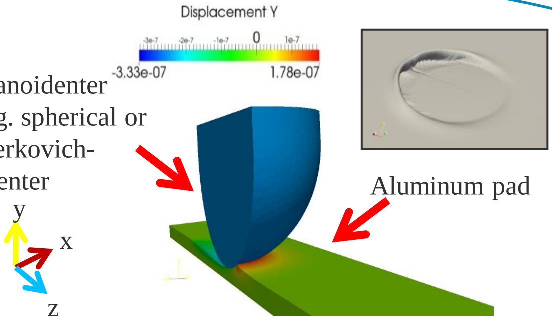


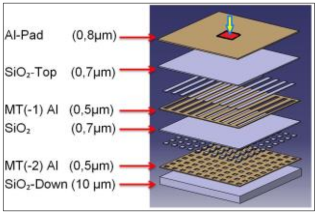
Multi layer simulation

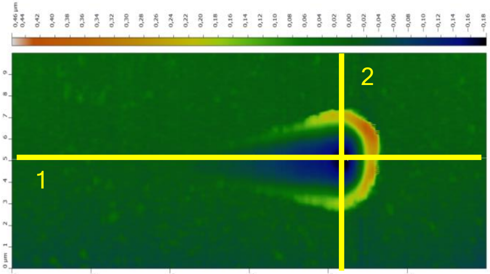


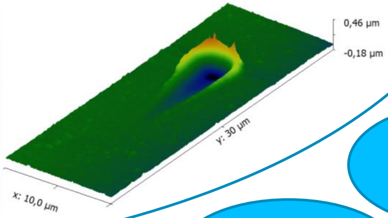
Nanoidenter e.g. spherical or Berkovich-identer

Aluminum pad









Test with a real chip from the market

Test with a real chip

Test with a real chip without the substructure

Thank you for your attention! Questions?

Bundesministerium für Wirtschaft und Energie
ZIM Zentrales Innovationsprogramm Mittelstand

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FEINMETALL Contact Technologies