MICRO-TRANSFER-PRINTING AND POTENTIAL PROCESS OPTIMIZATIONS BY FEA

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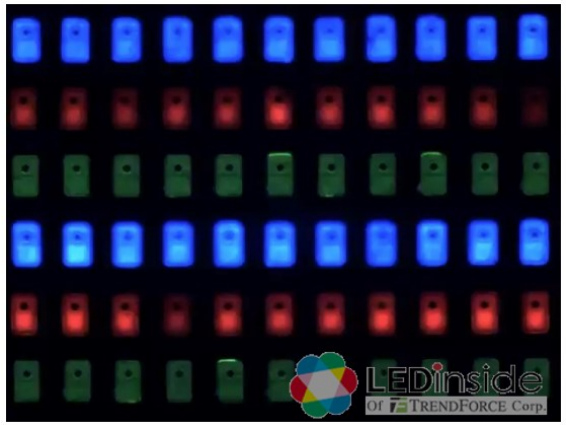
AGENDA

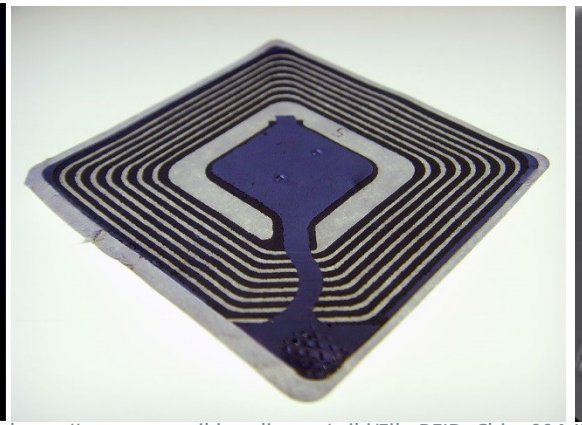
- Introduction
  - Motivation
  - MICROPRINCE-Project
  - Micro-Transfer-Printing
- Mechanical Characterization
  - Viscoelastic Properties
  - Adhesion Measurements
- Finite-Element-Analysis
  - Numerical Validation
  - µTP-Process Simulation
- Summary
- Outlook

Introduction
Motivation

https://www.osram.com/am/light-for/led-lighting/led-interior-lighting-ledambient/index.jsp

- Rising demand on electronic components
  - µLEDs, MEMS, RFID chips, printed photonics
- Advanced packaging technologies required
  - for handling of thin, fragile and small devices
  - Combining components of various materials
  - Components from wafers with different diameter (2”, 3”, 4”…)





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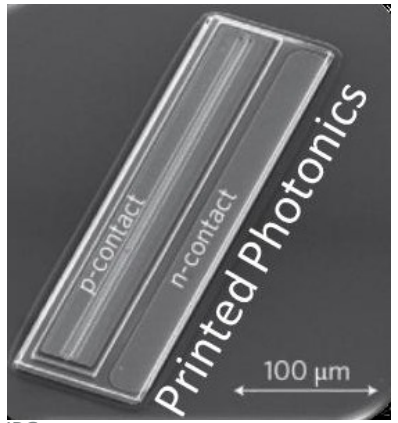

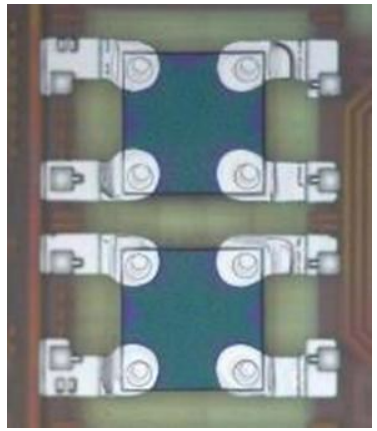

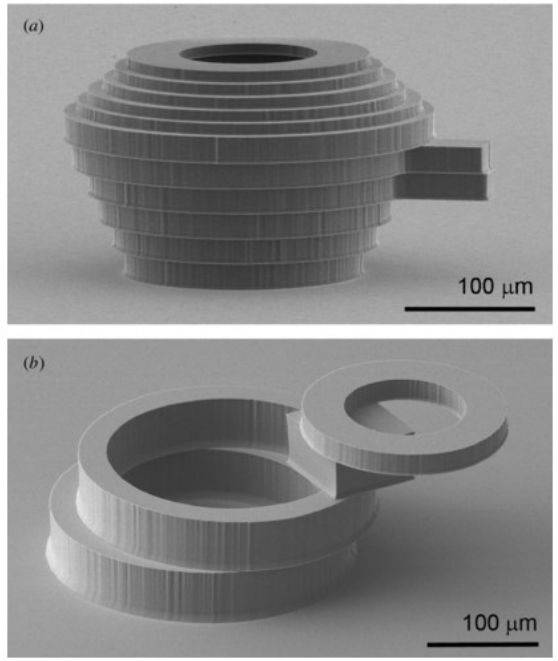

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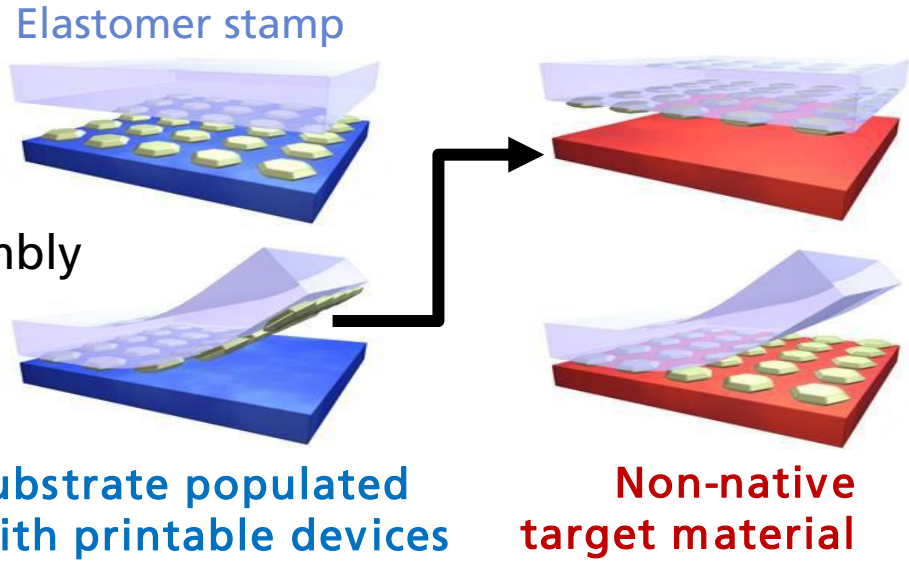
Introduction
Motivation



- Micro-Transfer-Printing (µTP) versatile technology for micro-assembly (pick and place)

- Parallel transfer of microscale functional components from a native substrate to a non-native target material via an elastomer stamp

➔ MICROPRINCE project

creating the worldwide first open access **pilot line for heterogeneous integration** of smart systems by **micro- transfer-printing (µTP)** in a semiconductor foundry manufacturing environment

Introduction
MICROPRINCE-Project

1) Transfer of the µTP from **research to an industrial environment**
2) **Creation, installation and demonstration of a µTP pilot line** in a semiconductor foundry manufacturing environment
3) Demonstration on **defined target applications**
(Hall plates for current sensors; filter for optical sensors; µLEDs for car ambient lighting; LEDs, sensors and modulators for Si-photonics applications)
4) Development of µTP as platform technology including **design rules** and their implementation in **Process Design Kits (PDK)**

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MICROPRINCE-Project

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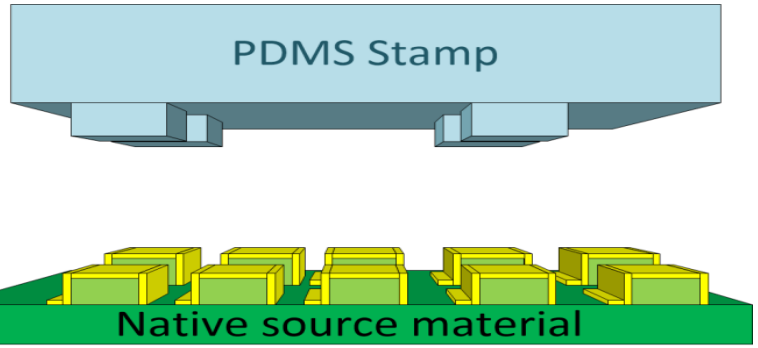
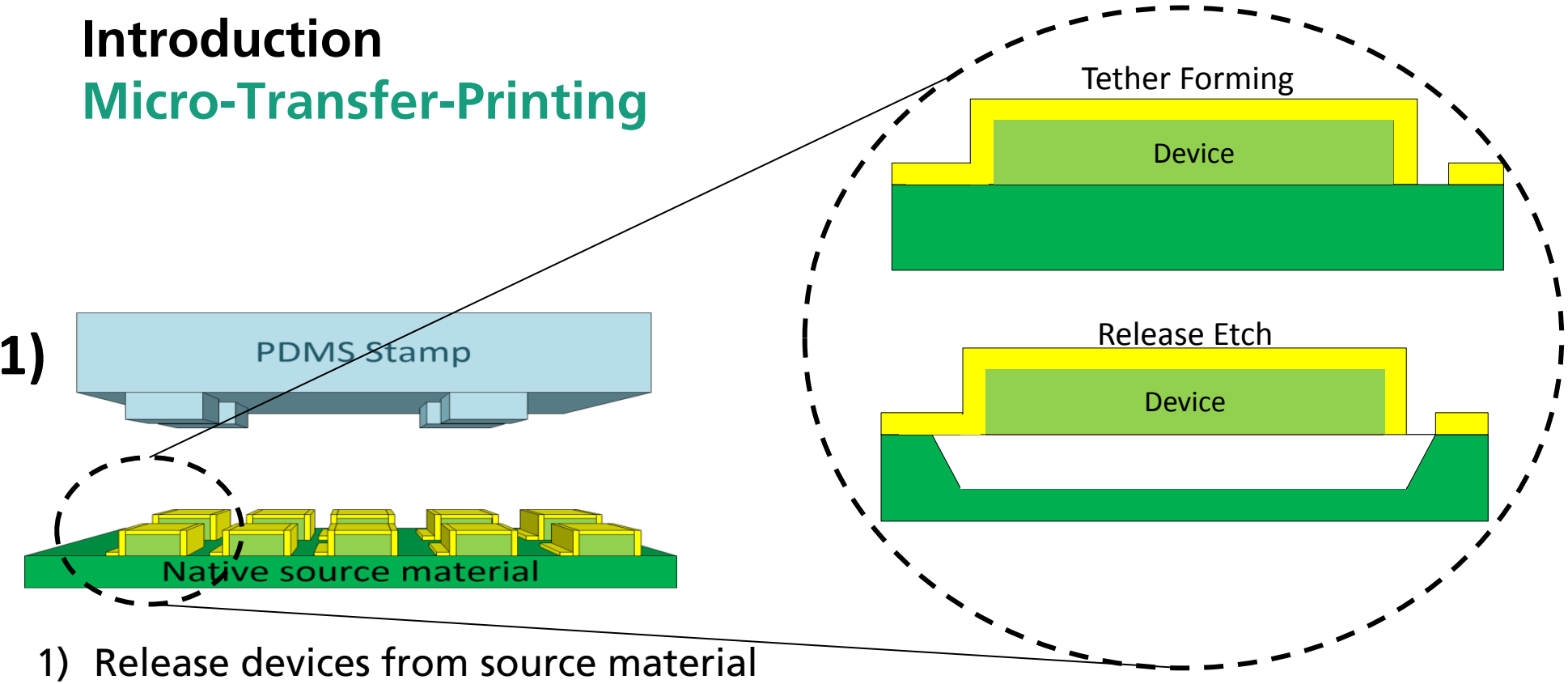
Introduction
Micro-Transfer-Printing

1)

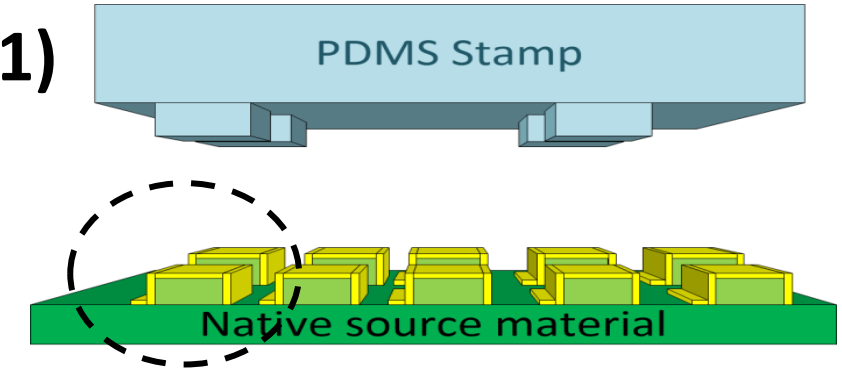


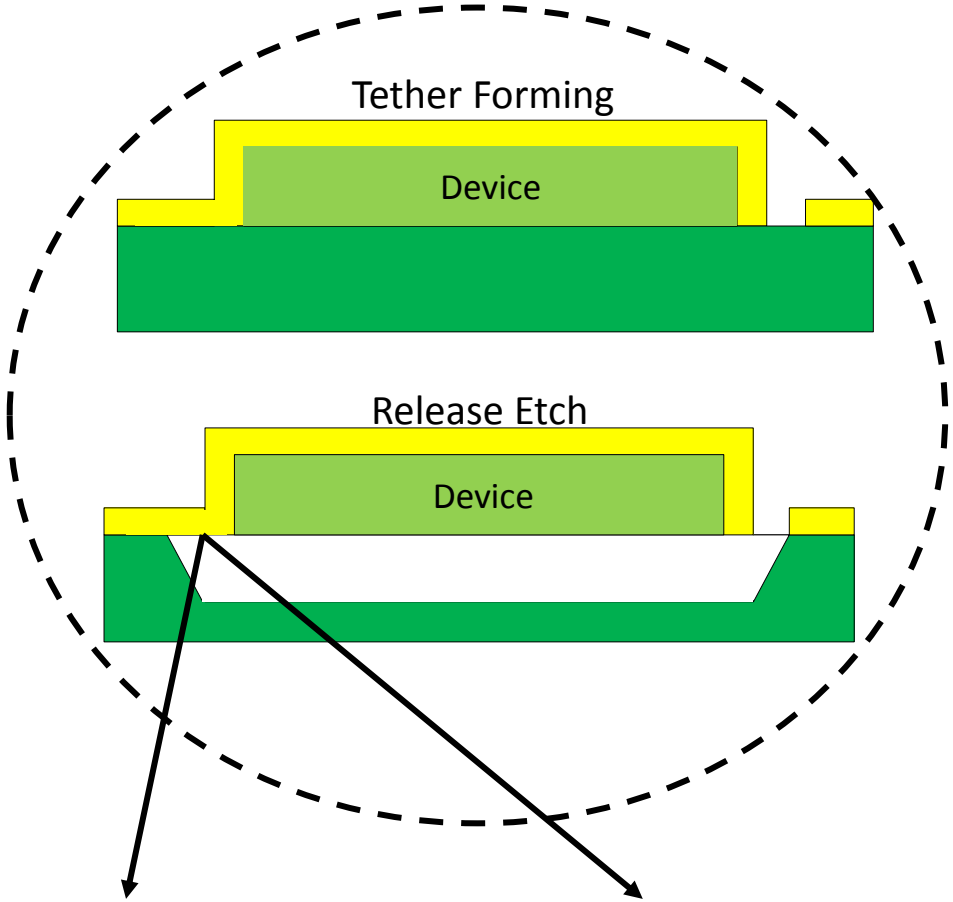
Introduction
Micro-Transfer-Printing

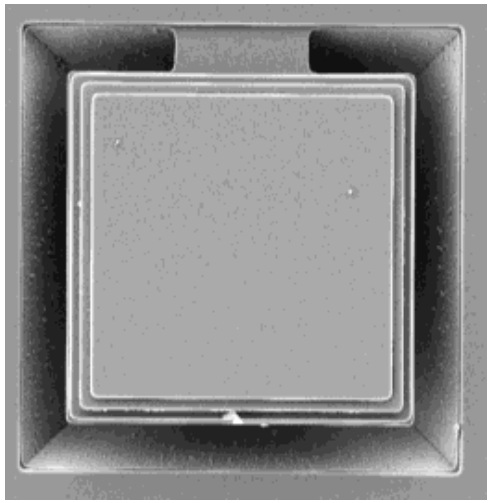


1) Release devices from source material

Introduction
Micro-Transfer-Printing

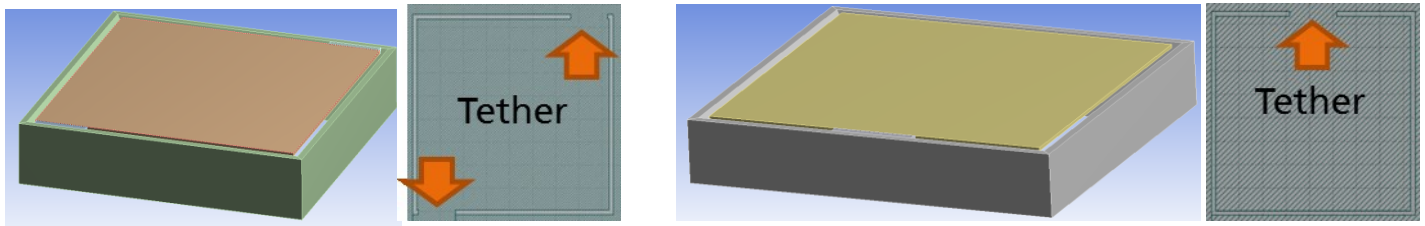






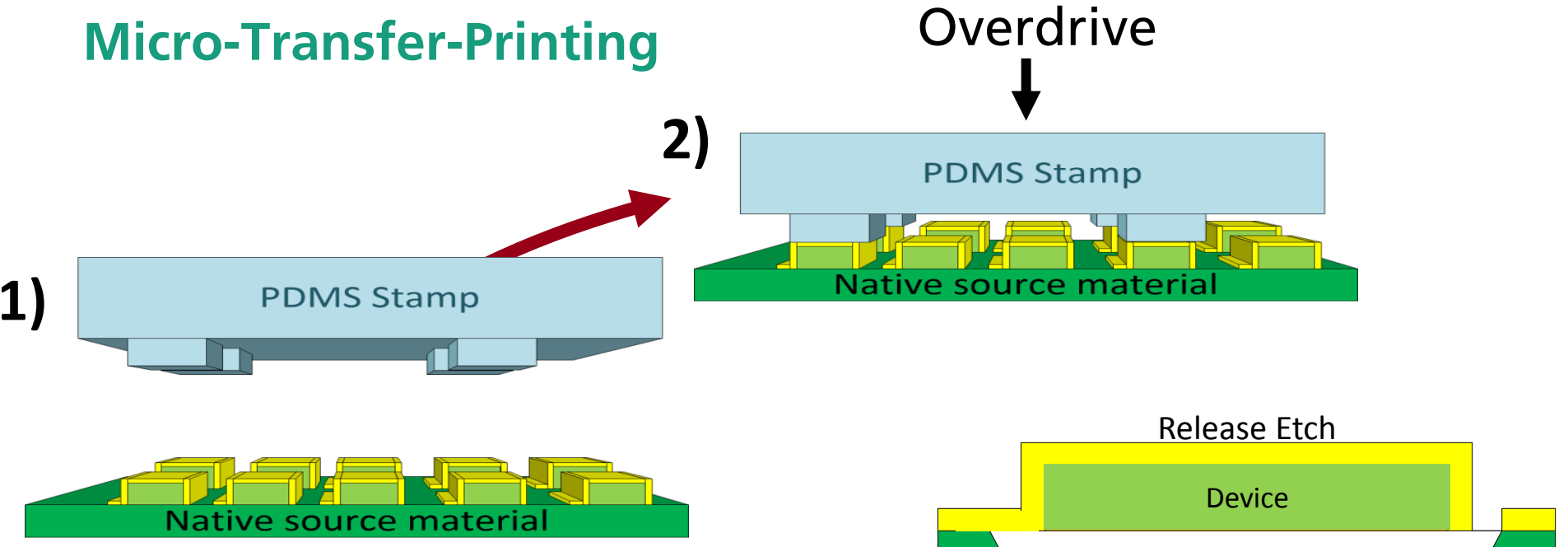
Top view of device held by tether (SEM)

1) Release devices from source material



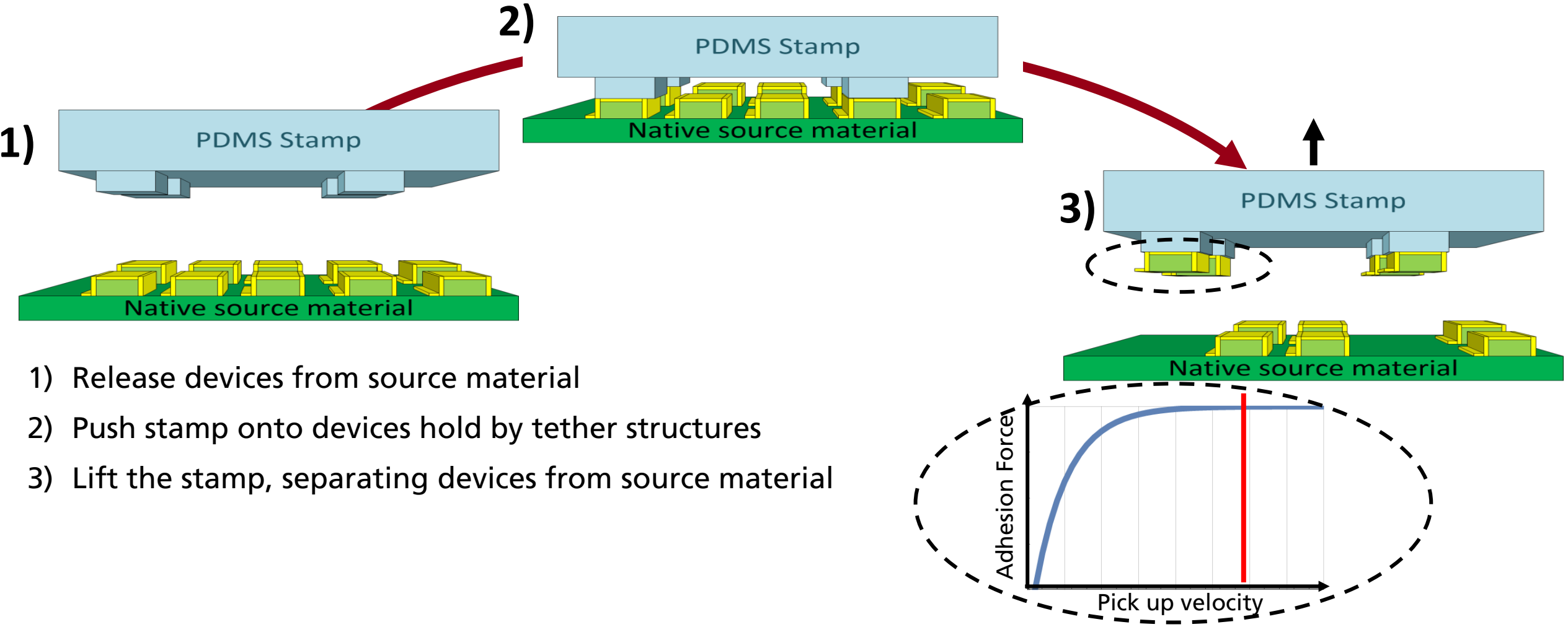
Different potential tether designs

Introduction
Micro-Transfer-Printing



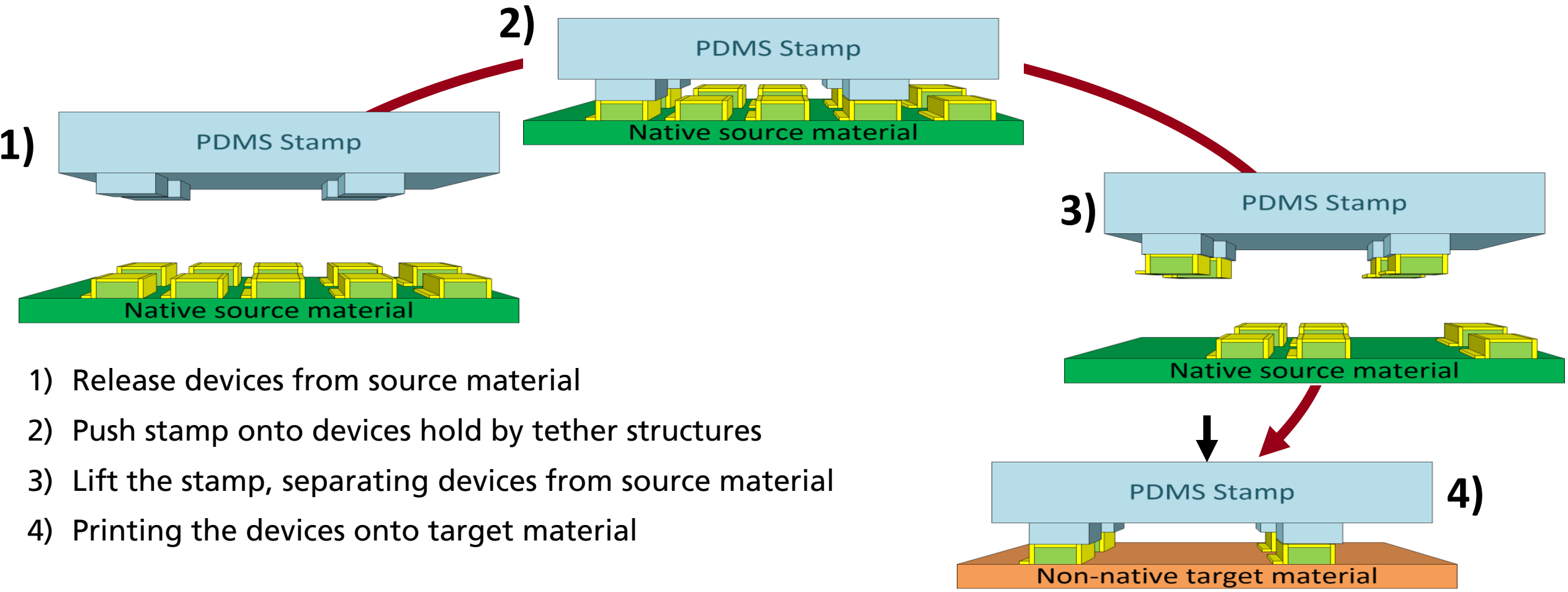
1) Release devices from source material
2) Pushing stamp onto devices hold by tether structures

Introduction
Micro-Transfer-Printing



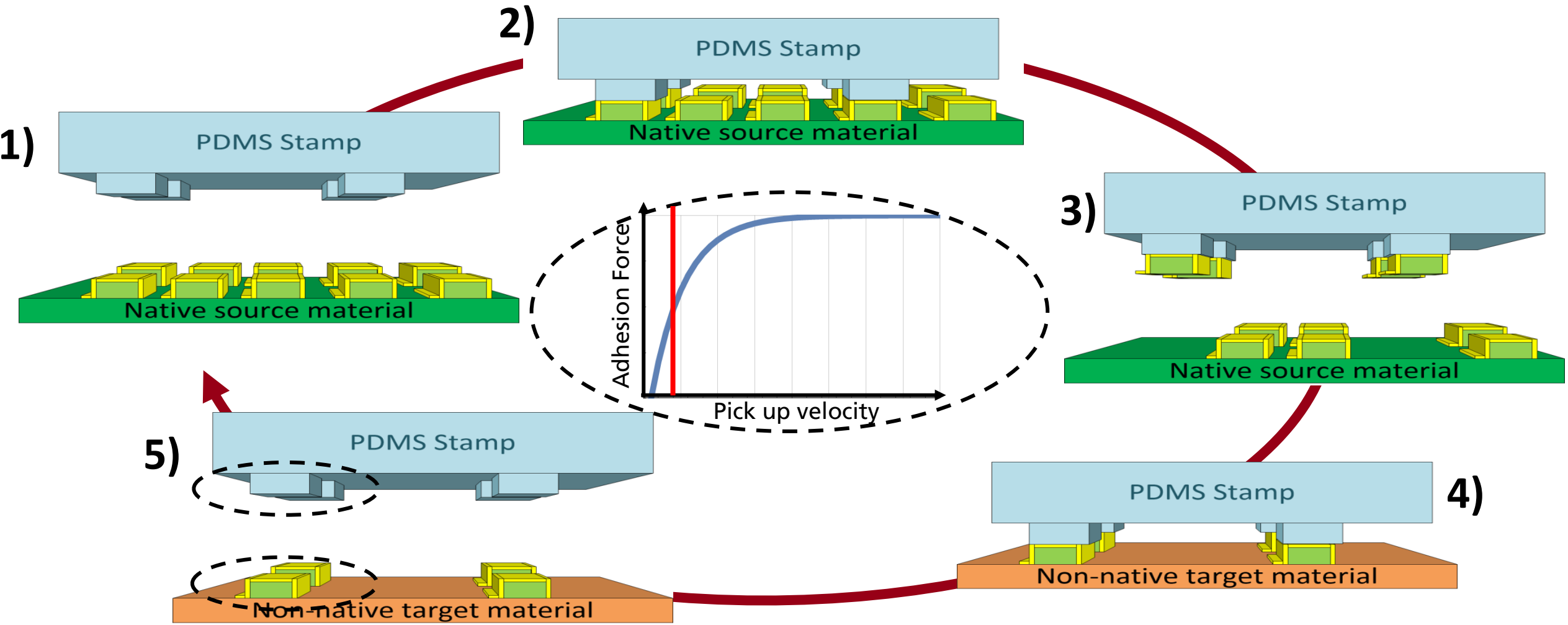
1) Release devices from source material
2) Push stamp onto devices hold by tether structures
3) Lift the stamp, separating devices from source material

Introduction
Micro-Transfer-Printing



1) Release devices from source material
2) Push stamp onto devices hold by tether structures
3) Lift the stamp, separating devices from source material
4) Printing the devices onto target material

Introduction
Micro-Transfer-Printing



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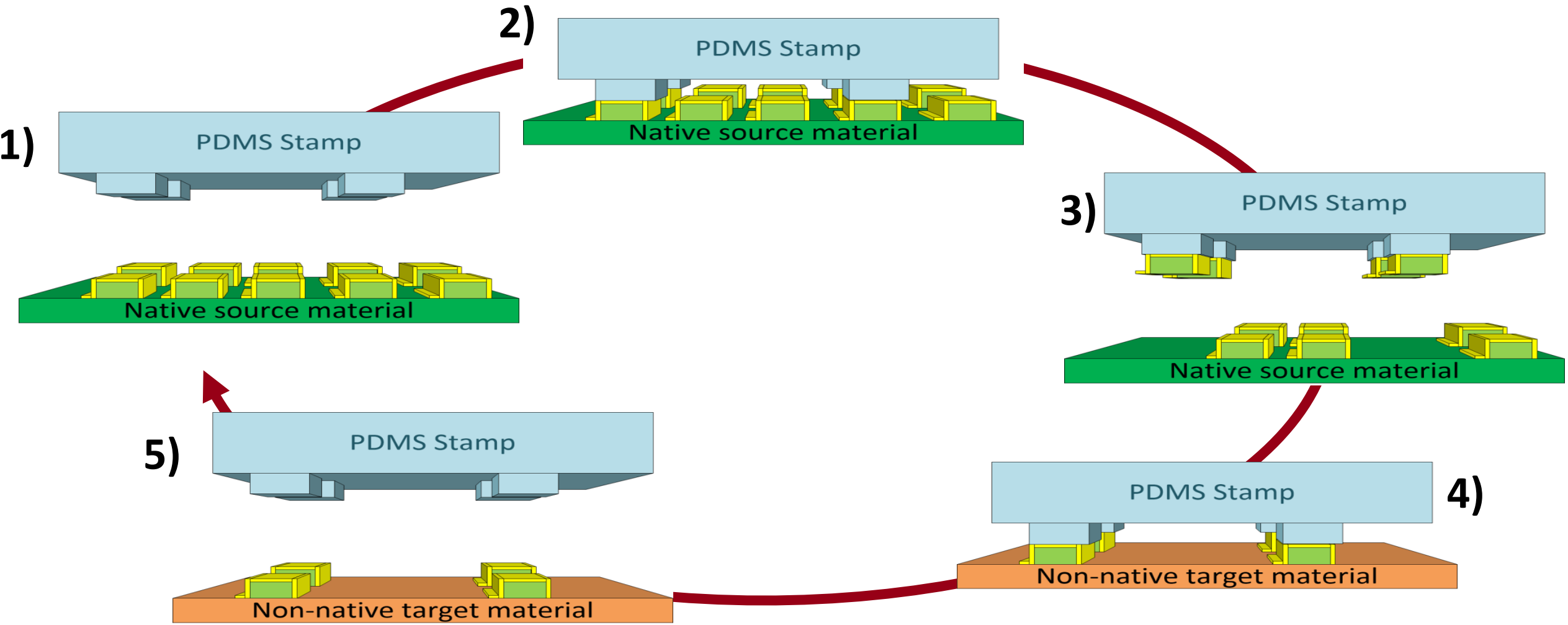

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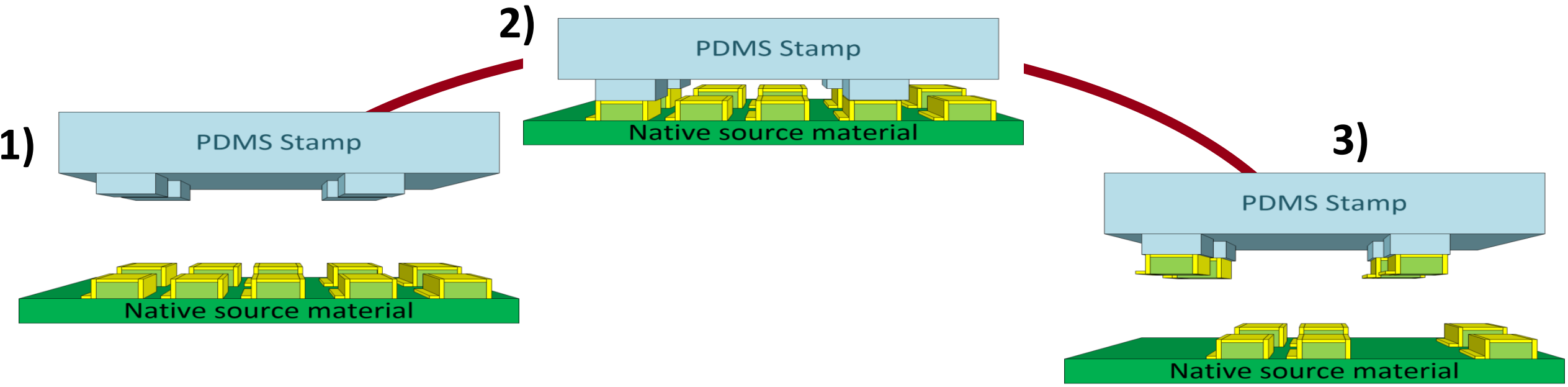
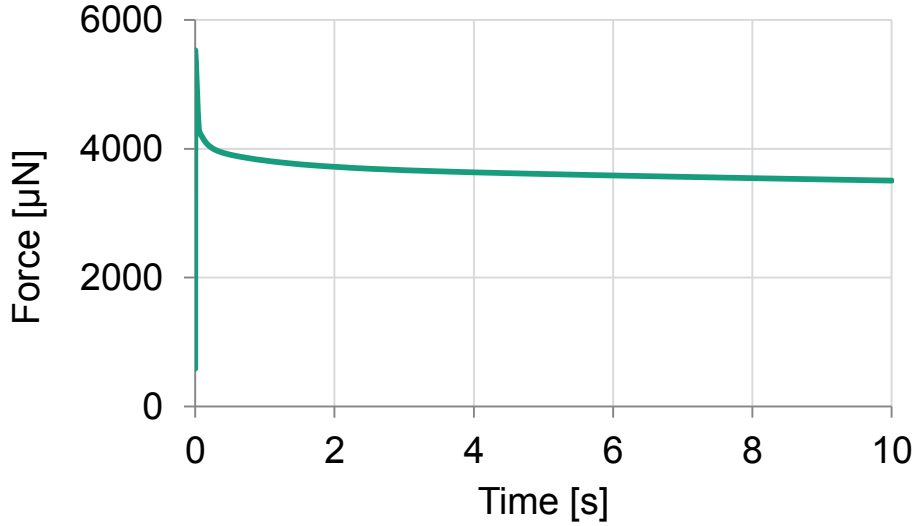
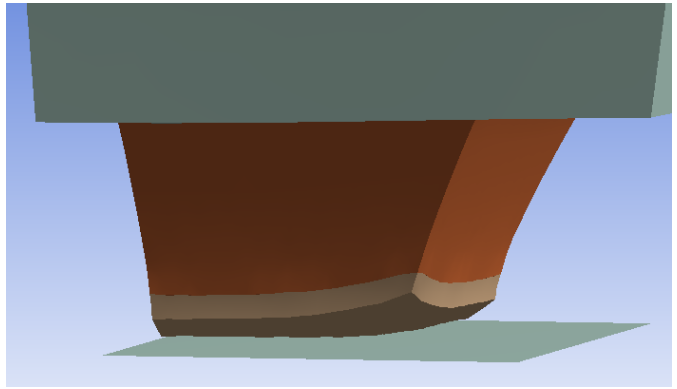


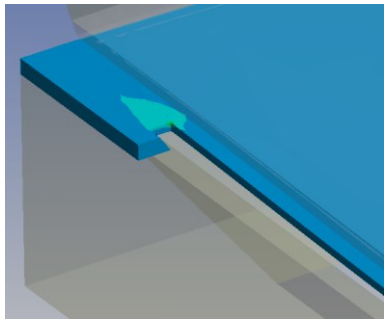
Simulation is dealing with the pick up stage

Micro-Transfer-Printing
Challenges and Goals for µTP-Simulation

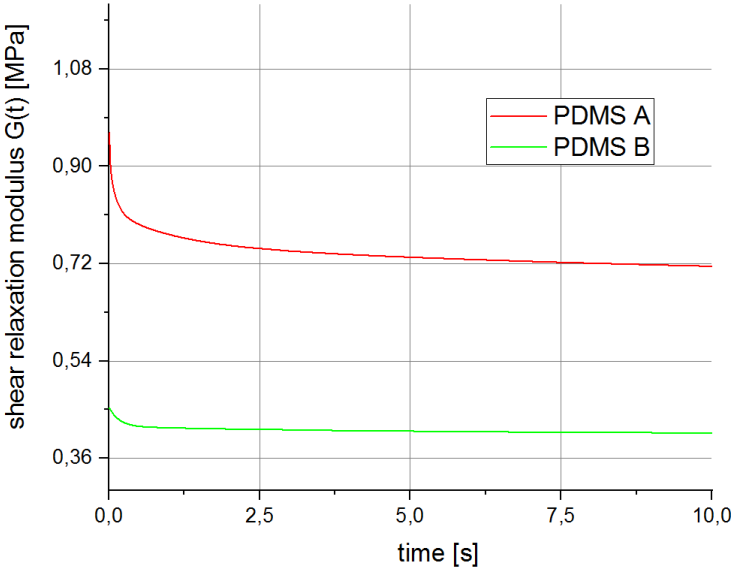


- PDMS stamp material behaviour
  - Viscoelasticity
- Adhesion of the stamp on chiplet surface
  - Rate dependent
- Stress of tether structure



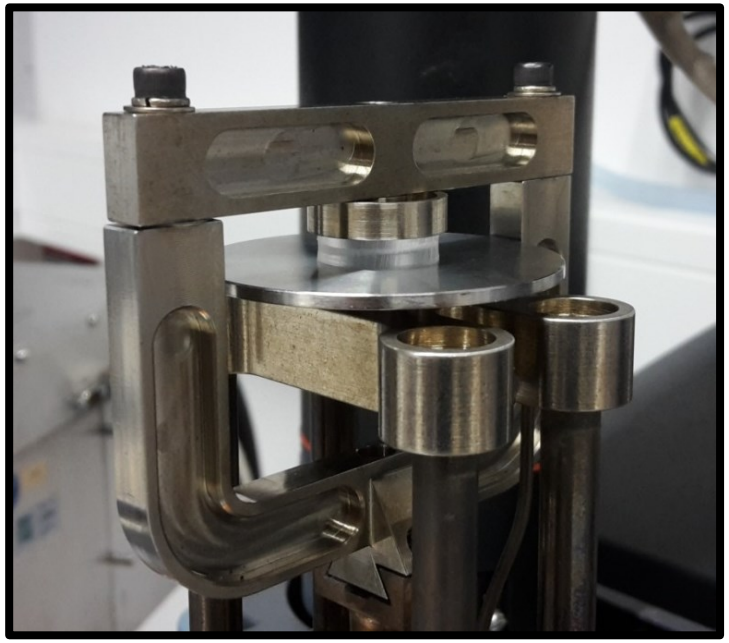


Mechanical characterization
Viscoelastic properties



- Elastomer stamp material shows highly nonlinear behavior (viscoelasticity
  - Wide range of material data in literature
  - Depending on manufacturing conditions and the way of loading

- Performing dynamic sweep measurements in compression mode
  - DMA TA Q800
  - Cylindrical PDMS specimen (d=13mm, t=3.1mm)
  - Temperature range of -50…150°C, frequency range of 1...55 Hz (TTS)



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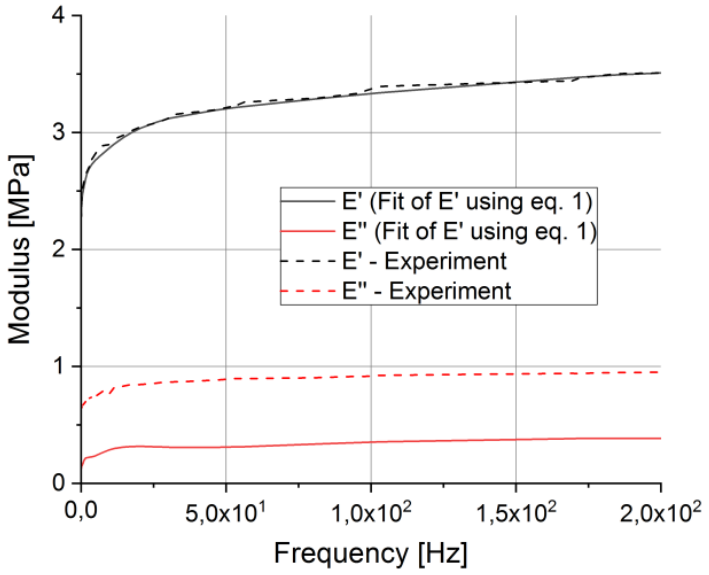


Generalized Maxwell model [1]

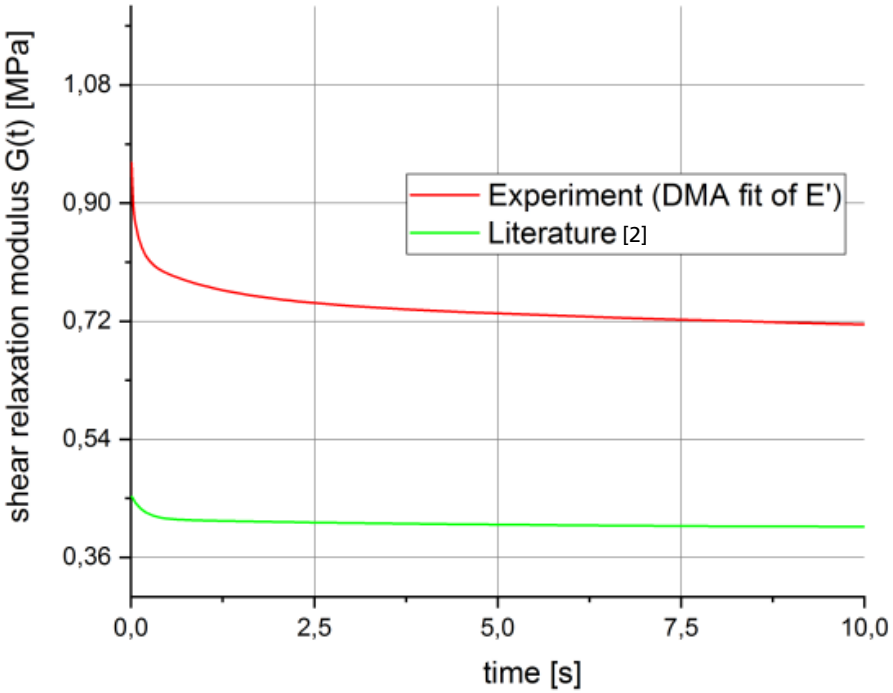
$$E' = \sum_{i=1}^{Z} \frac{E_i \omega^2 {\tau_i}^2}{1 + \omega^2 {\tau_i}^2} \quad (1)$$

$$E'' = \sum_{i=1}^{Z} \frac{E_i \omega \tau_i}{1 + \omega^2 {\tau_i}^2} \quad (2)$$

$$\omega = 2 \cdot \pi \cdot f$$

$$E(t) = 2 \cdot G(t) \cdot (1 + \nu) = \sum_{i=1}^{Z} E_i \cdot e^{-t/\tau_i} \quad (3)$$

E′ – storage modulus
E″ – loss modulus
ν=0.49



- TTS data fit by equation (1)

➔ Time dependent shear relaxation modulus for viscoelastic data in ANSYS (Prony fit)

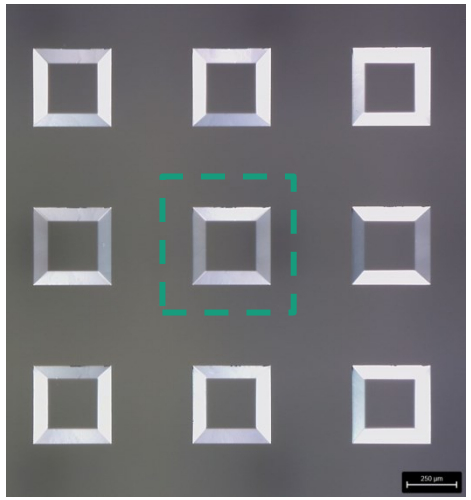
[1] M. T. Shaw,W. J. MacKnight, "Introduction to Polymer Viscoelasticity", Third Edition, John Wiley & Sons, Inc., 2005

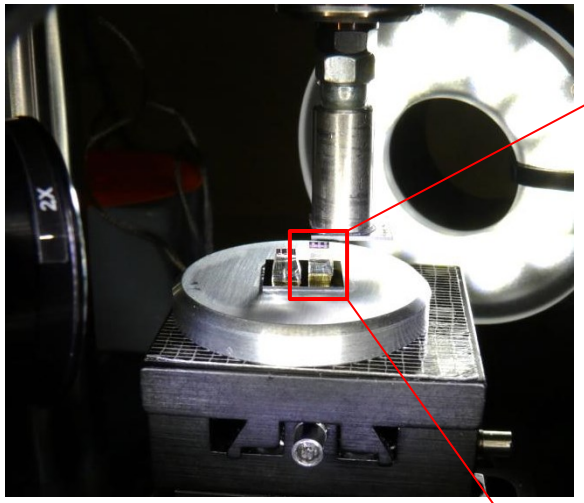
[2] I-Kuan, Kuang-Shun Ou, et al.,: "Viscoelastic Characterization and Modeling of Polymer Transducers for Biology Application", Journal of Microelectromechanical Systems, Vol. 18, No. 5, October 2009

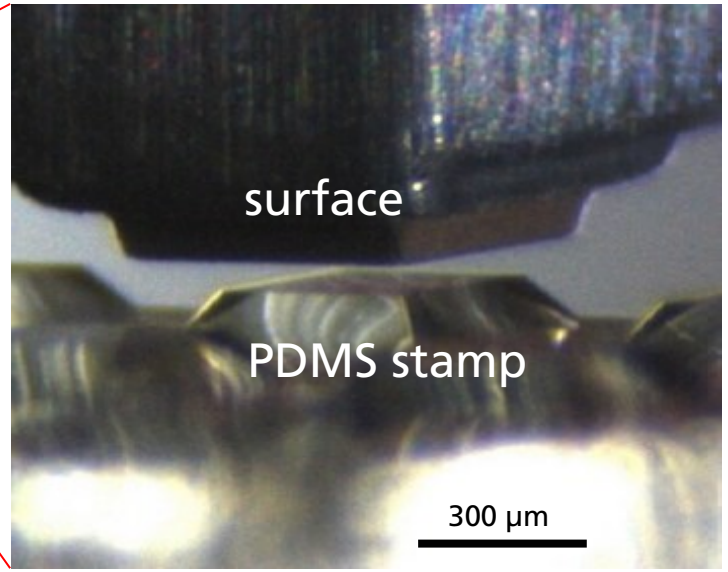
Fraunhofer IMWS

Mechanical characterization
Adhesion measurements

- Single PDMS-post on Si_3N_4 surface

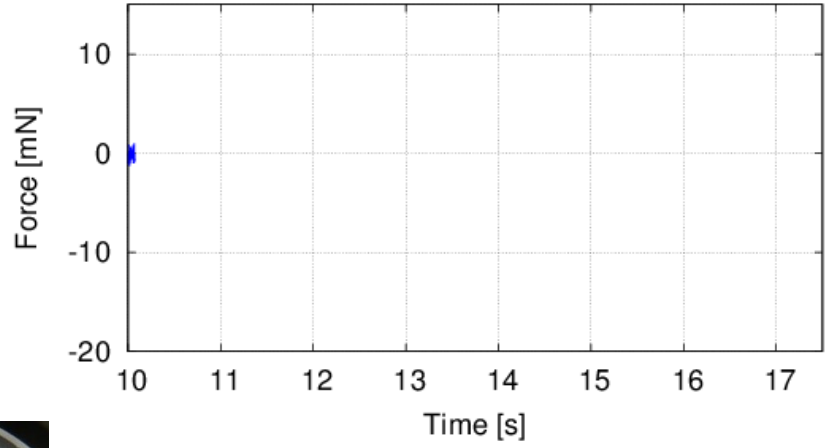




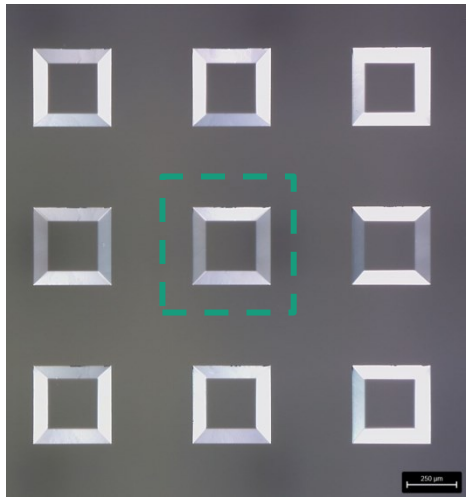


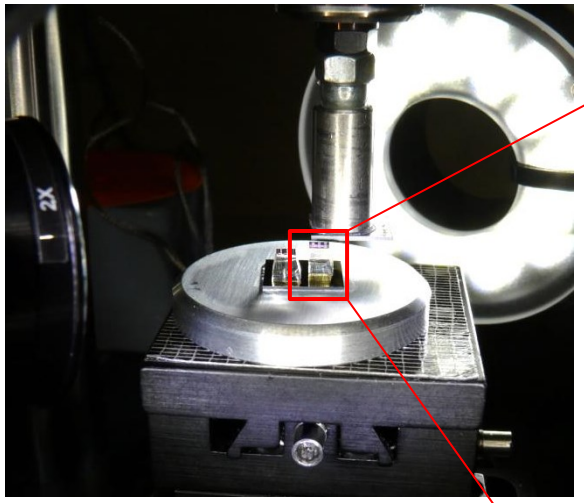
- Pick-up velocities of 1…132 mm/s
- Overdrive force 11mN
- 5 single posts of a PDMS array were tested

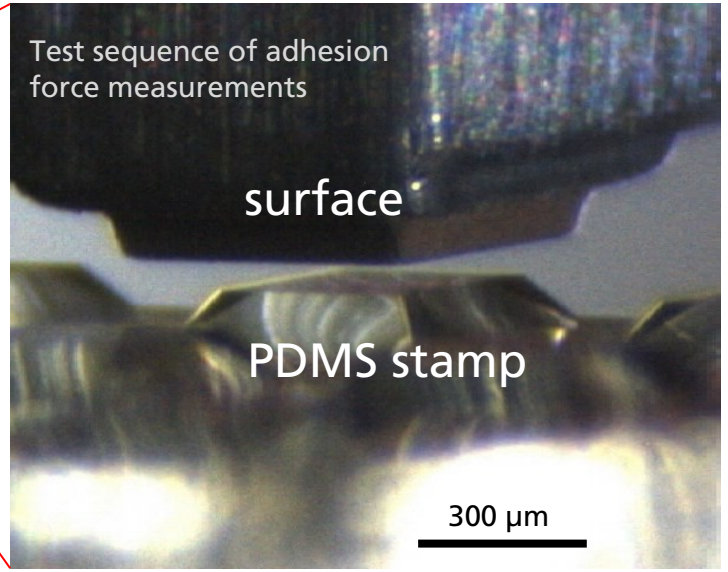
Mechanical characterization
Adhesion measurements



- Single PDMS-post on Si_3N_4 surface







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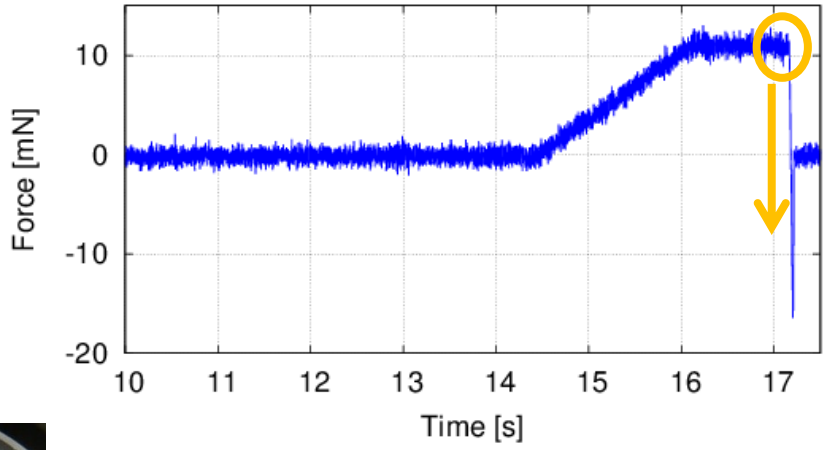
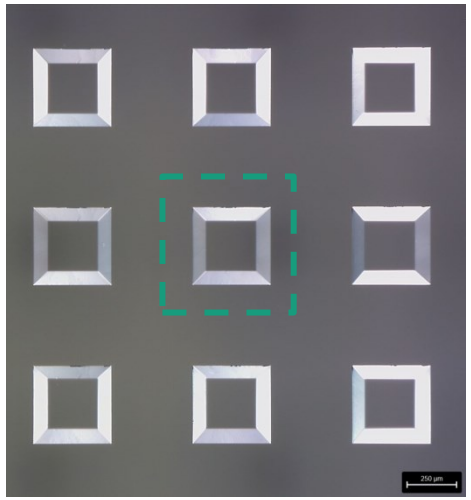
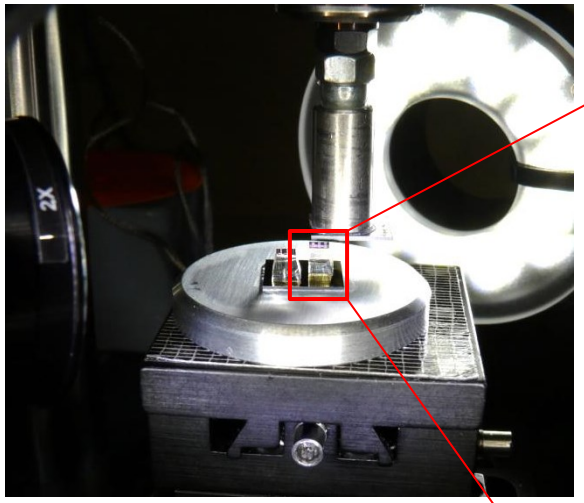
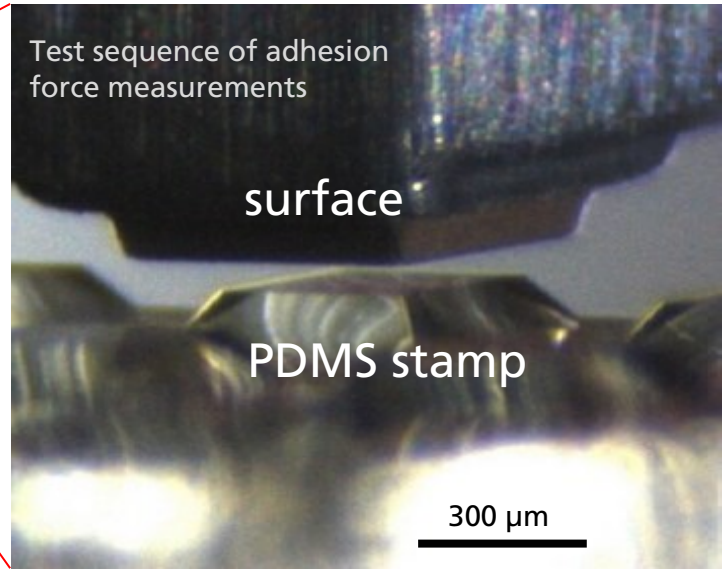


- Single PDMS-post on Si_3N_4 surface







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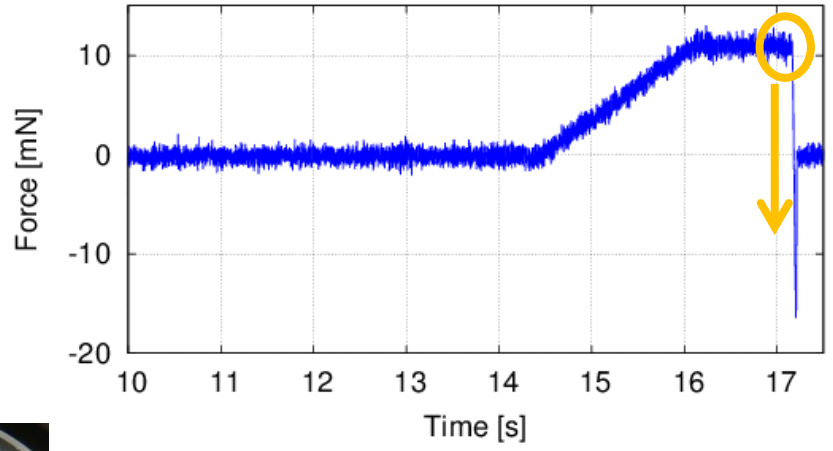

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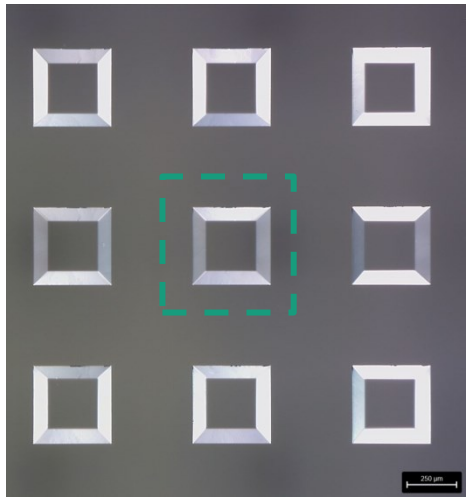

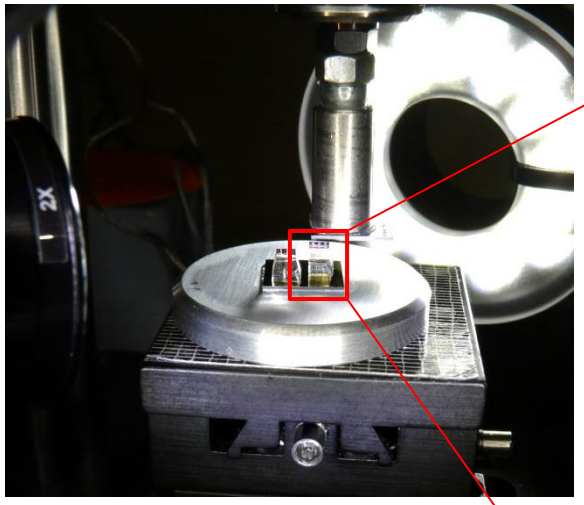

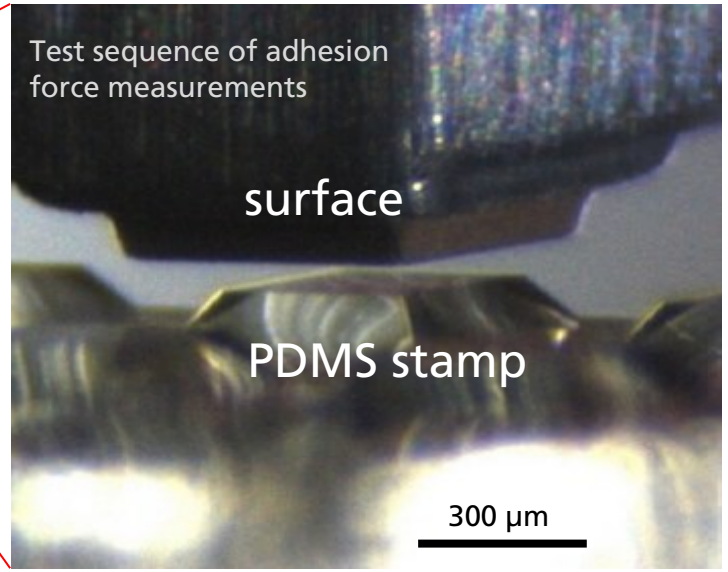

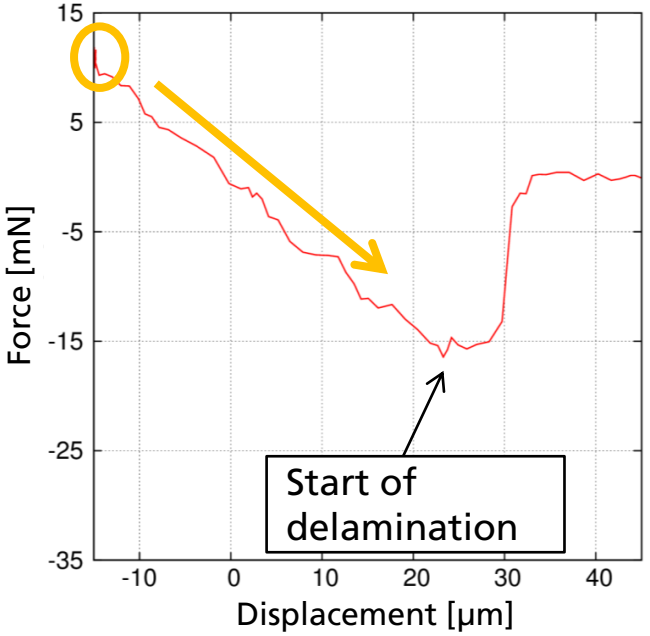

- Pick-up velocities of 1…132 mm/s
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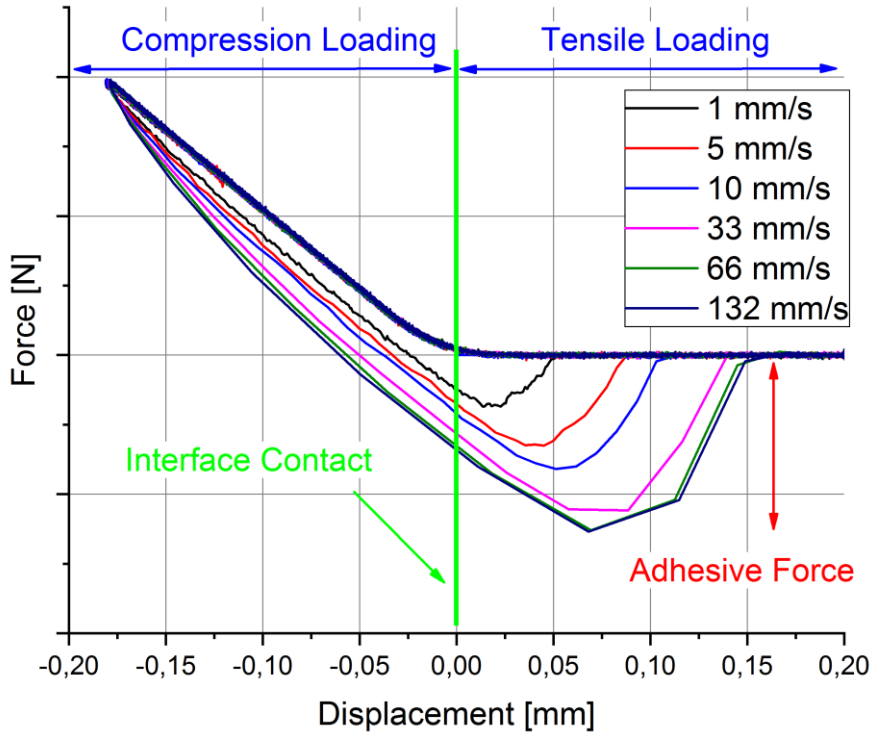
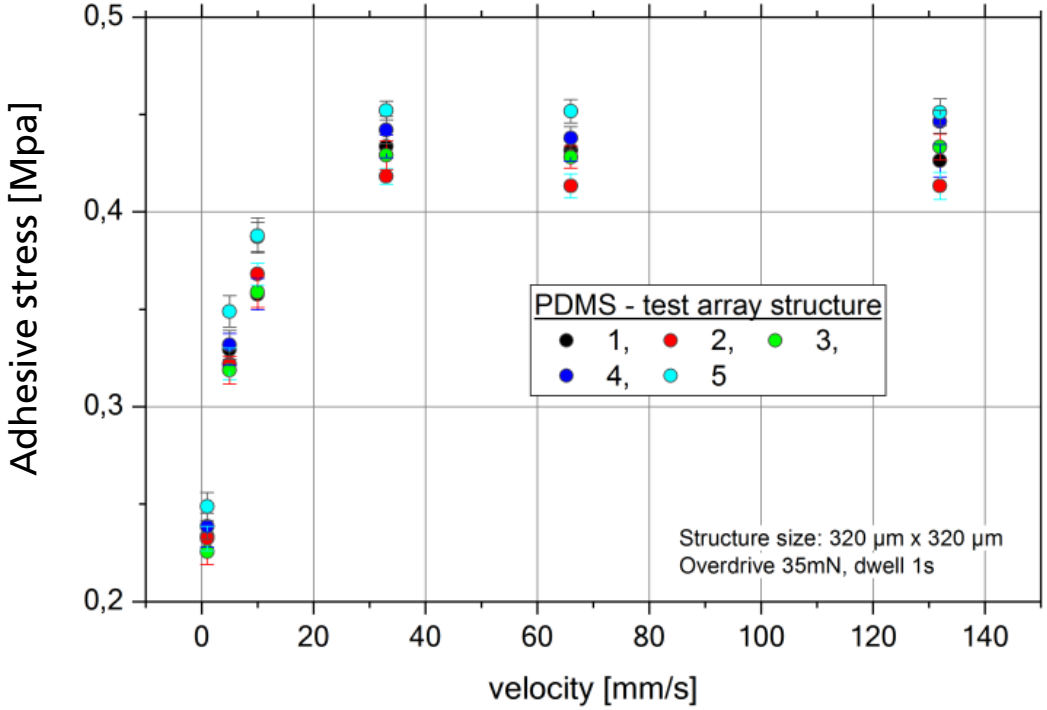
Mechanical characterization
Adhesion measurements

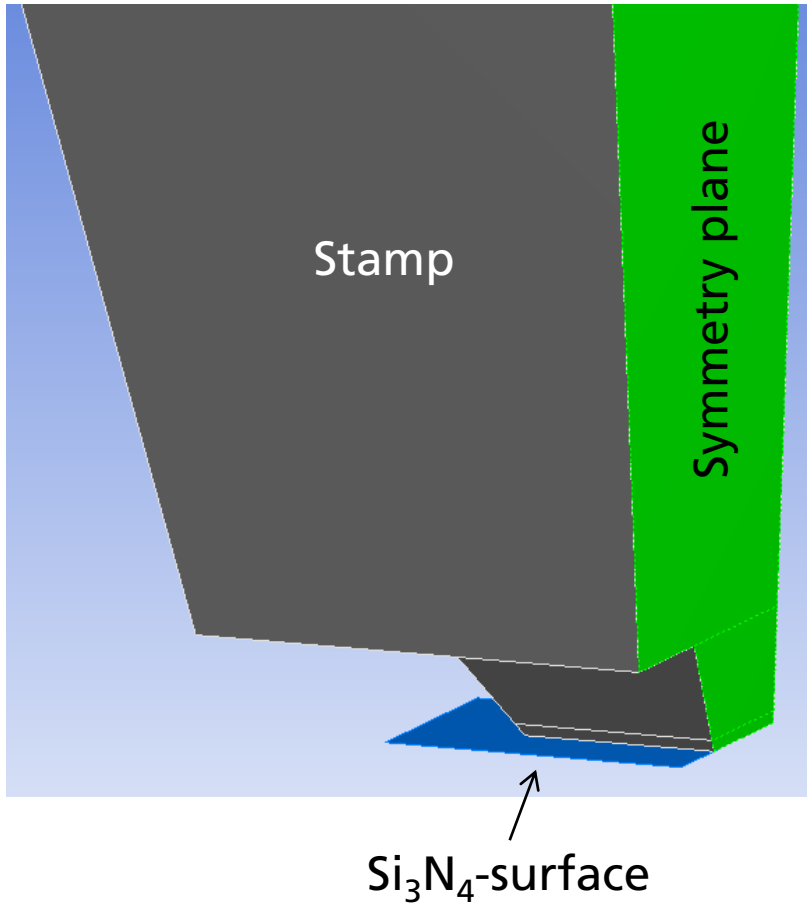




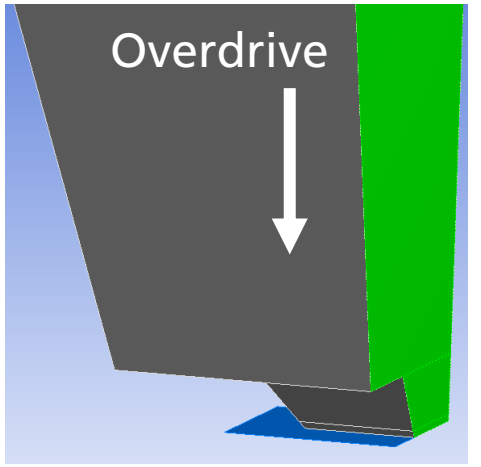
- Adhesion force and displacement strongly dependent on pick-up velocity
- Low scattering of different posts
- Maximum adhesion stresses using velocities greater 33mm/s

Finite-element-analysis
Numerical Validation
Model Setup

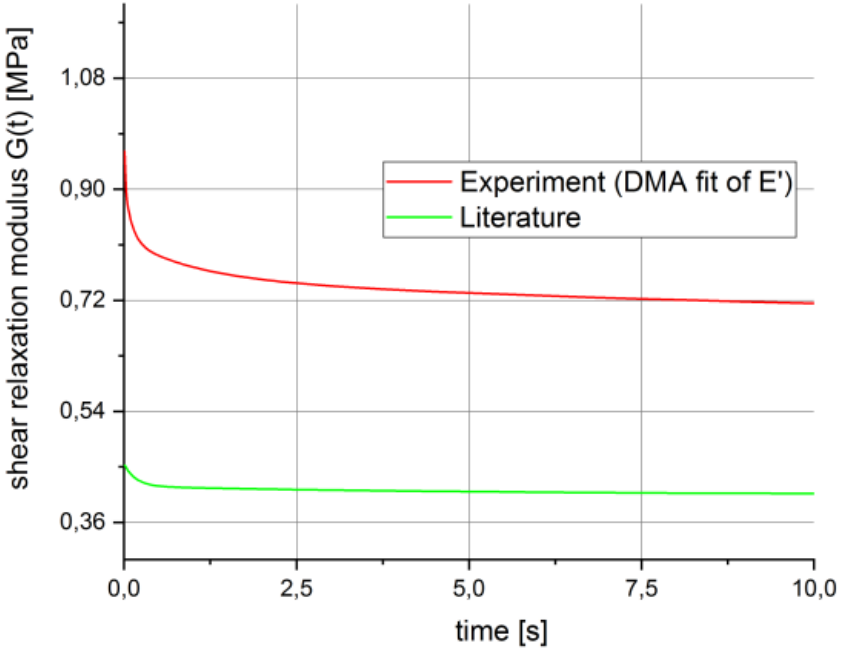
- Single post of a stamp array, using Quarter symmetry
- PDMS stamp → viscoelastic material model
- Si_3N_4-surface → rigid target



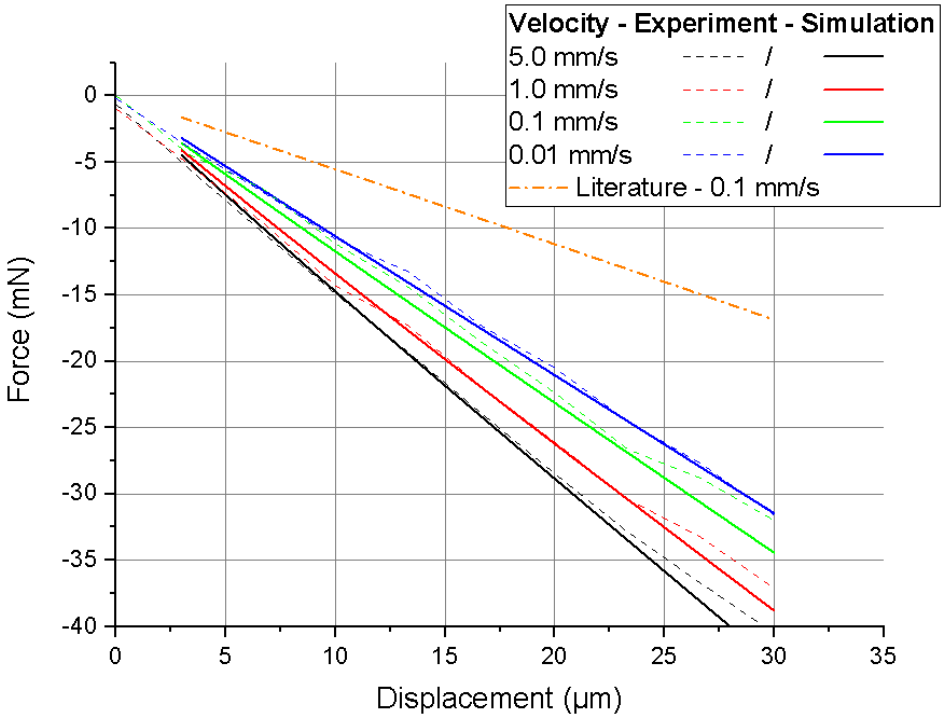
Finite-element-analysis
Numerical Validation
Viscoelasticity



- Viscoelasticity using prony series in ANSYS from experimental (DMA) relaxation fit
- Overdrive with different velocities

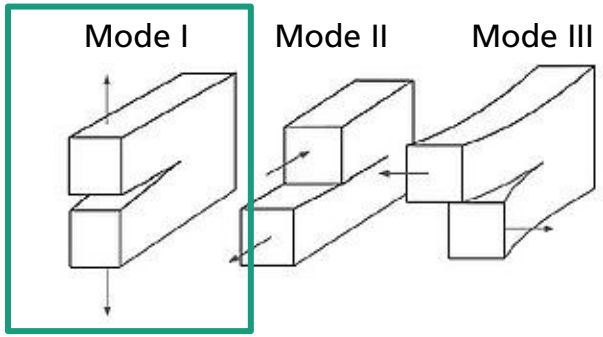


Time dependent shear relaxation of PDMS

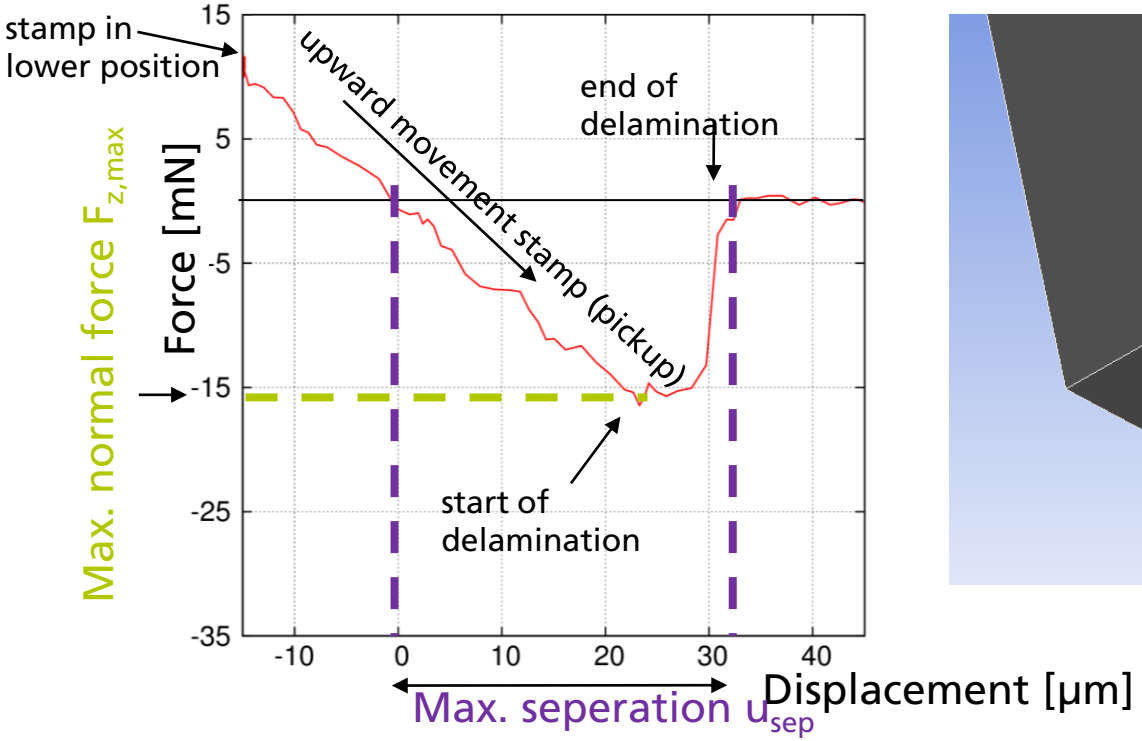


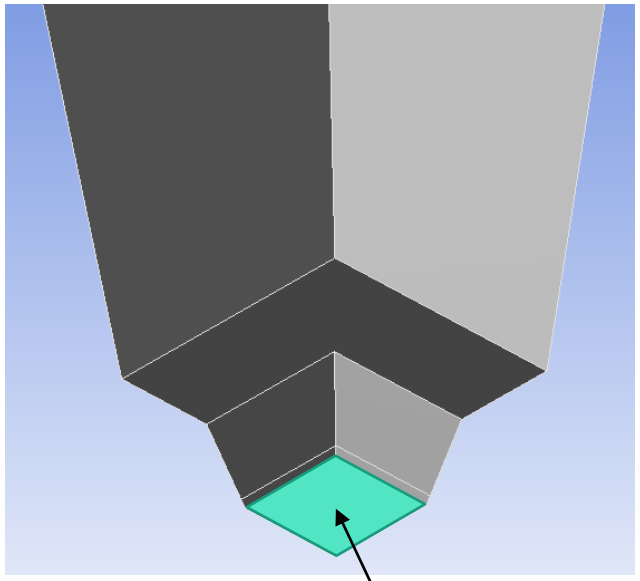
FEA in comparison to the experiment
during compression loading

Finite-element-analysis
Numerical Validation
Adhesion



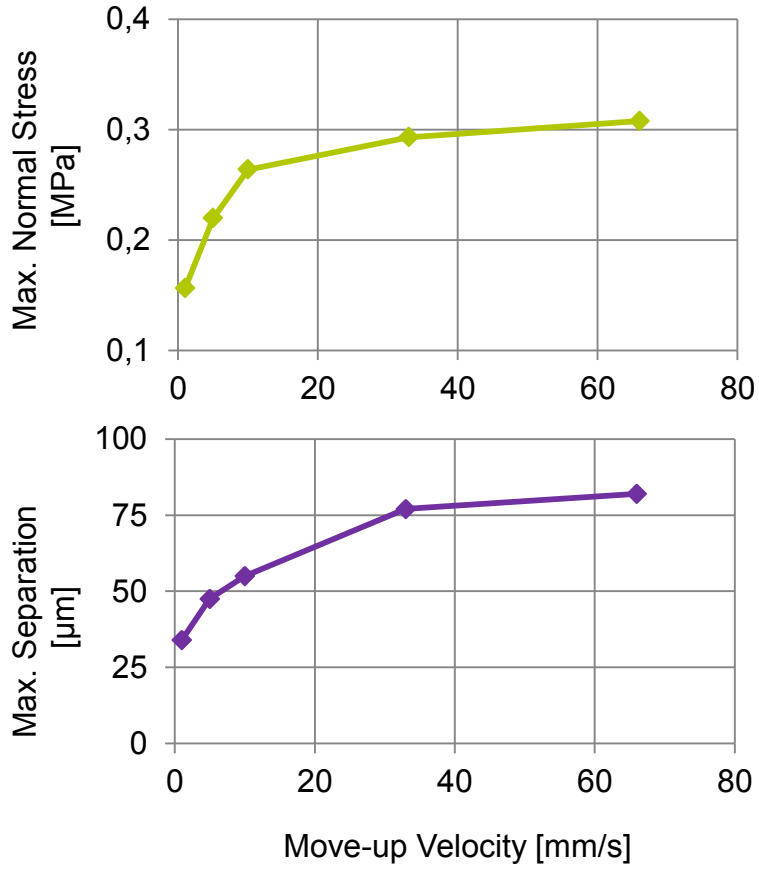
- Cohesive zone modeling (CZM) for adhesion (Mode I)
- How to determine the CZM-parameters from experiment





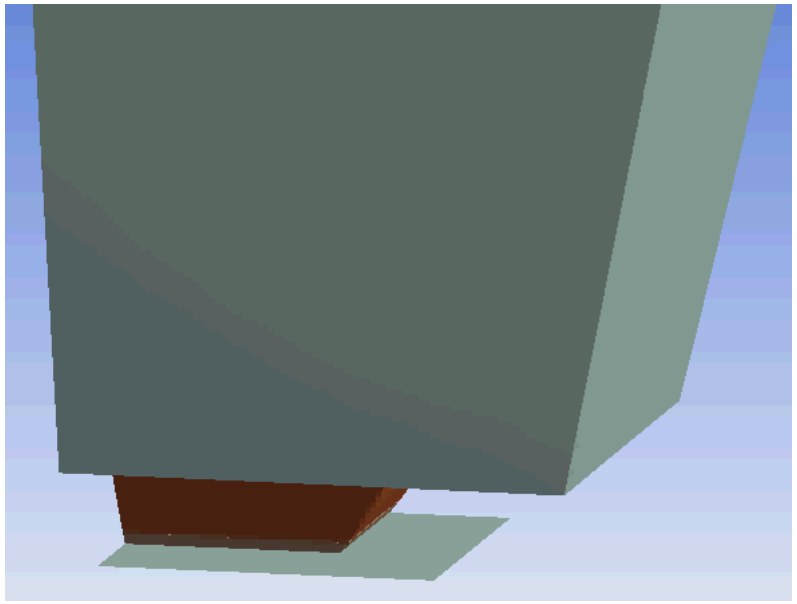
Stamp area for calculation of contact stress

Resulting CZM-parameters

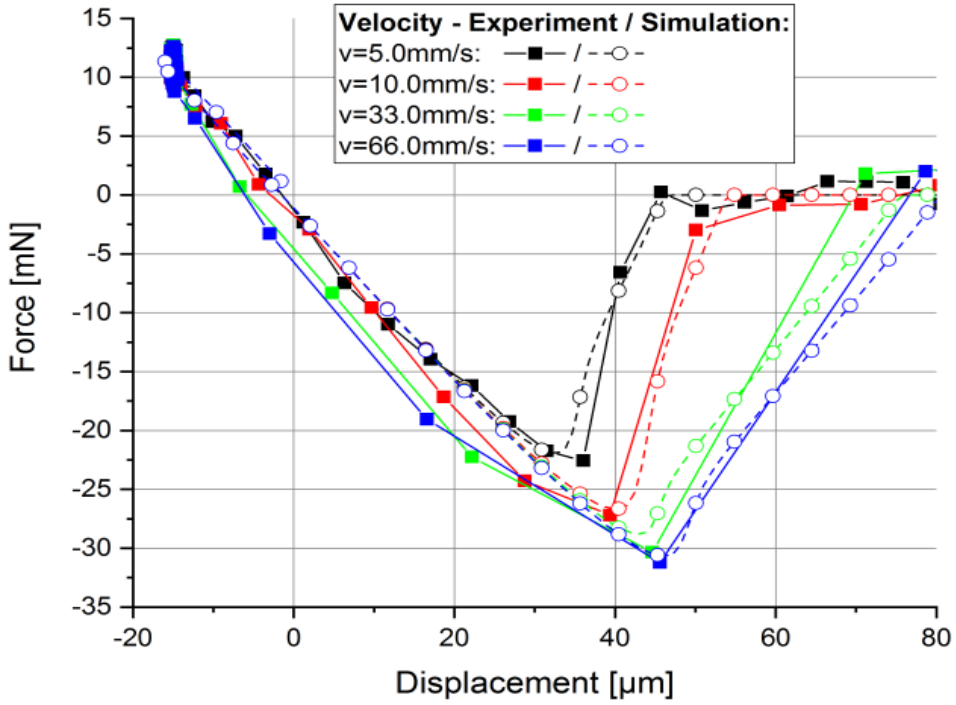


Finite-element-analysis
Numerical Validation
Adhesion

- Overdrive speed 0.1mm/s
- Dwell time 1s
- Varying pick-up velocities



(Slow motion and scaled displacement)

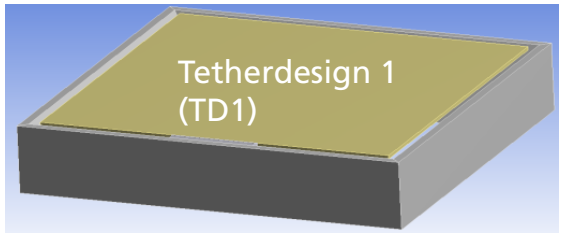


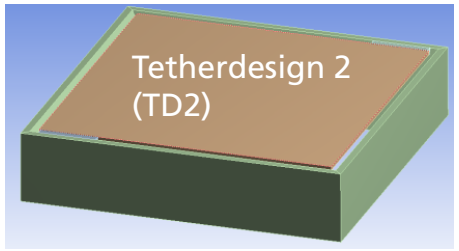
Adhesion & delamination modeling using CZM

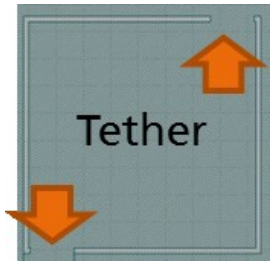
➔ Reaction of the stamp in order to adhesion can be modelled well for different velocities

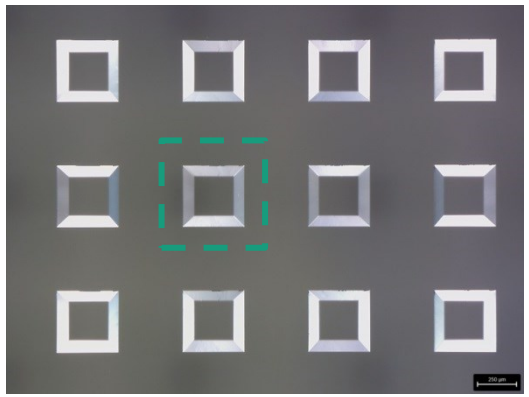
Finite-element-analysis
µTP-Process Simulation
Model Setup

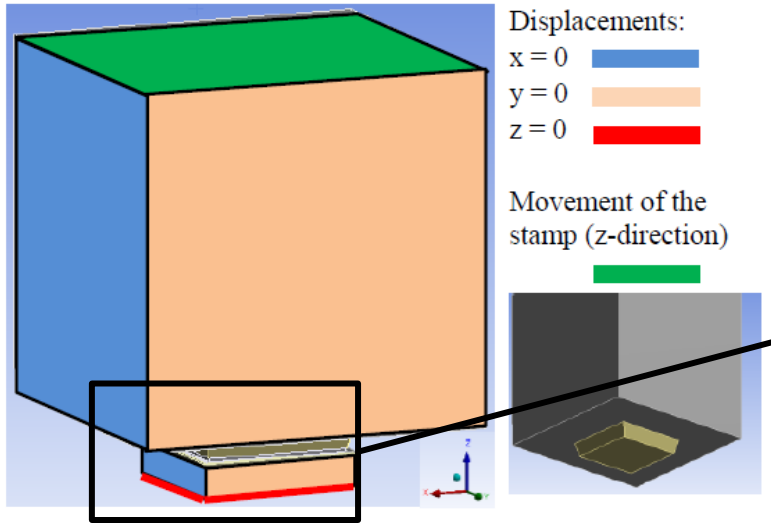
- Single post out of stamp array
- PDMS stamp → viscoelastic material model
- Si_3N_4-structure → linear elastic



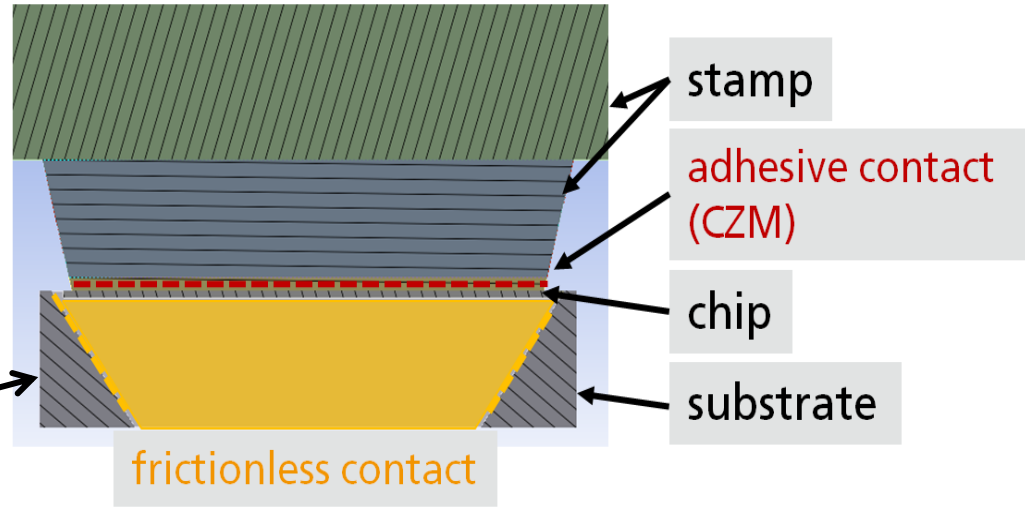








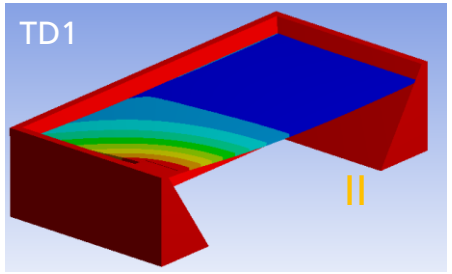
Cross section of the FEA model



Finite-element-analysis

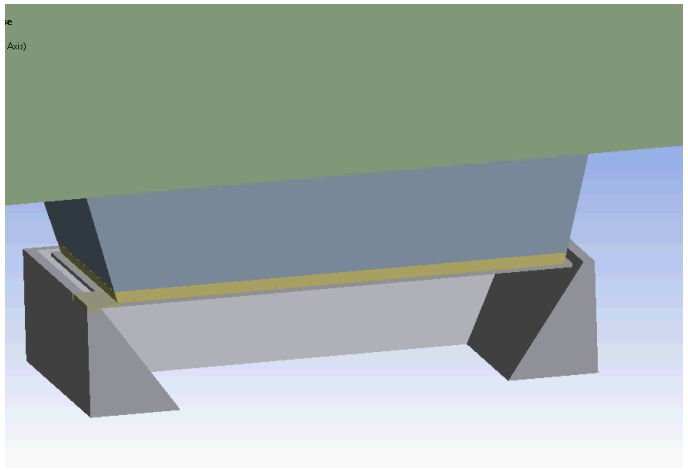
µTP-Process Simulation

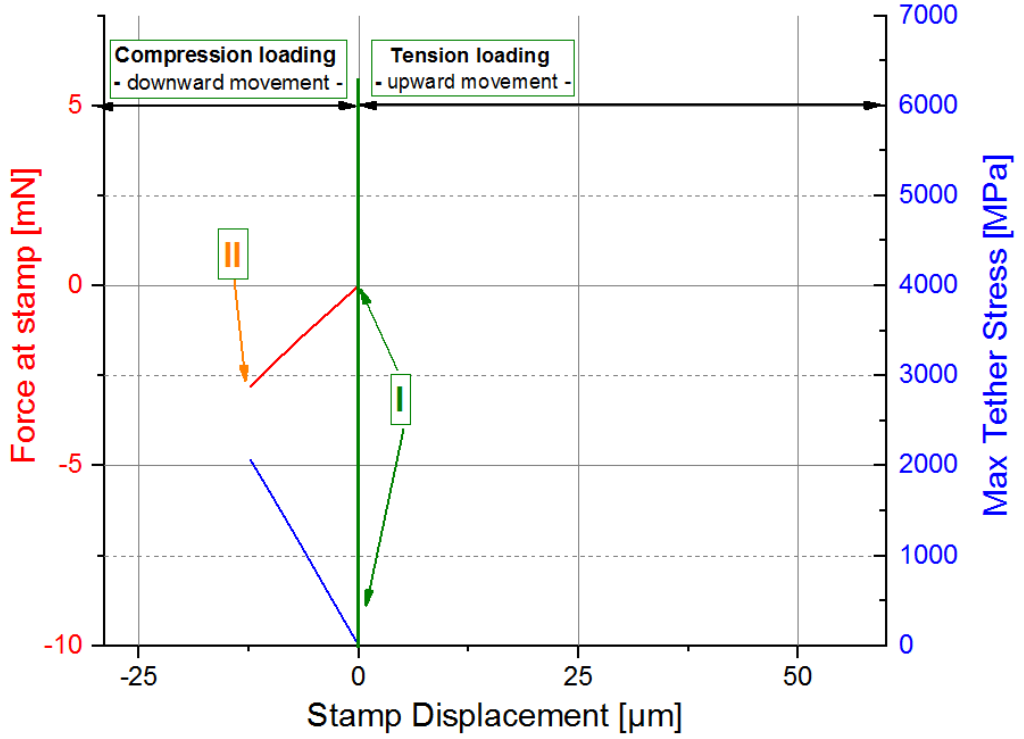
Kinematic behavior during µTP (device pick-up)



I – Contact chiplet/PDMS

II – Chiplet contacts remaining source material





Fraunhofer IMWS

Finite-element-analysis

µTP-Process Simulation

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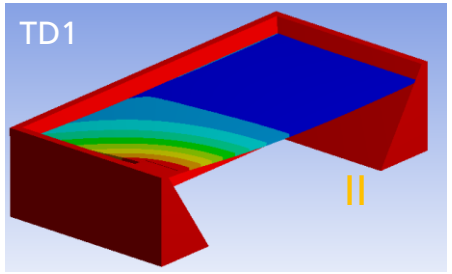

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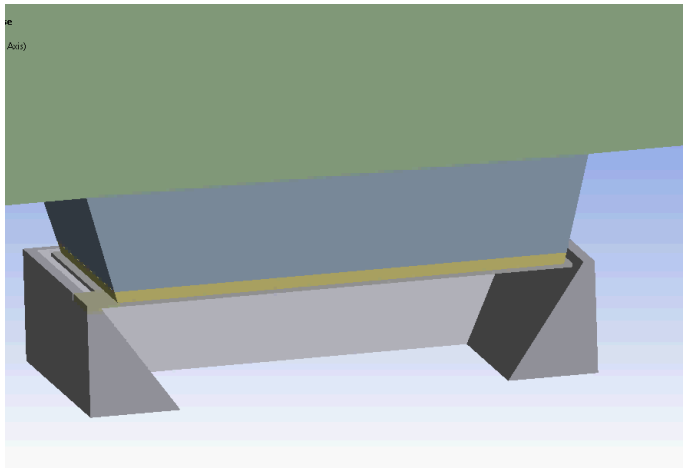

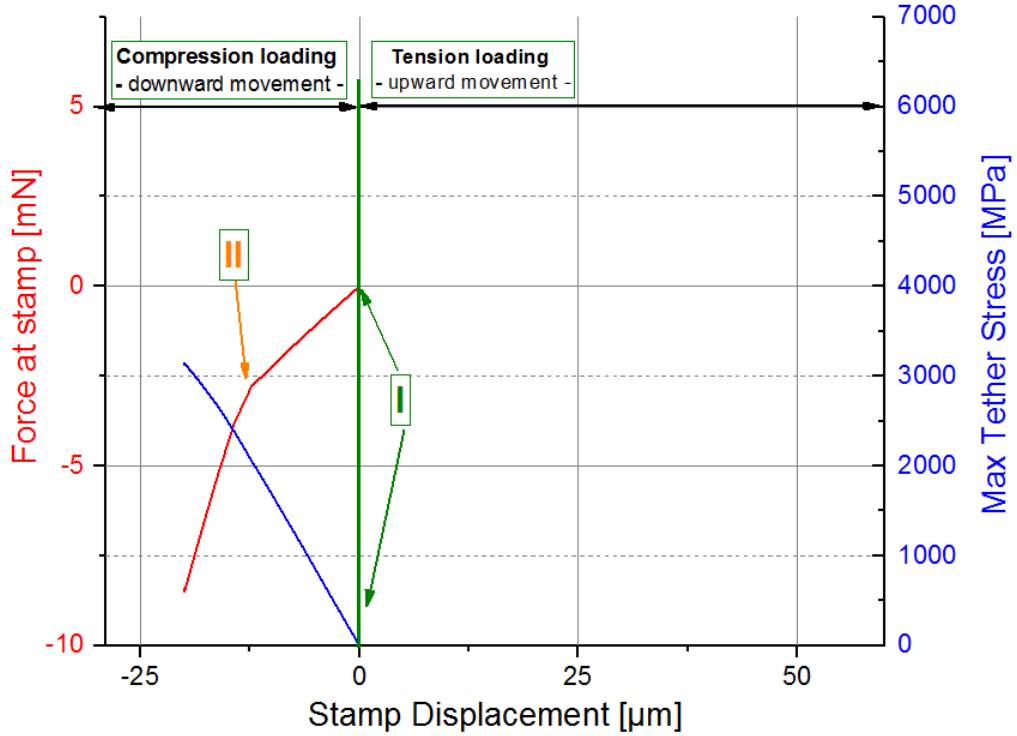

Fraunhofer IMWS

Finite-element-analysis

µTP-Process Simulation

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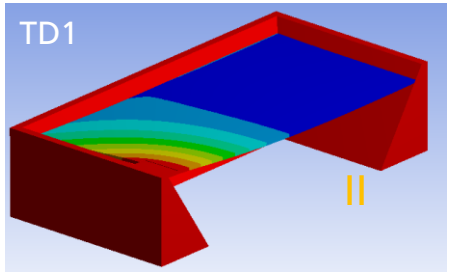

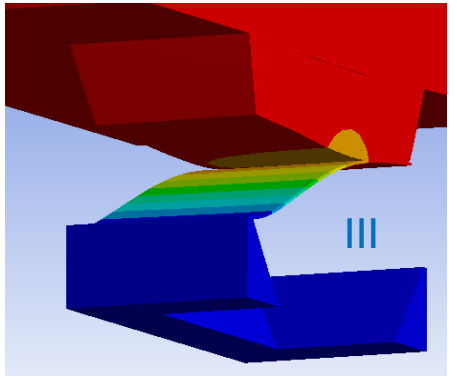

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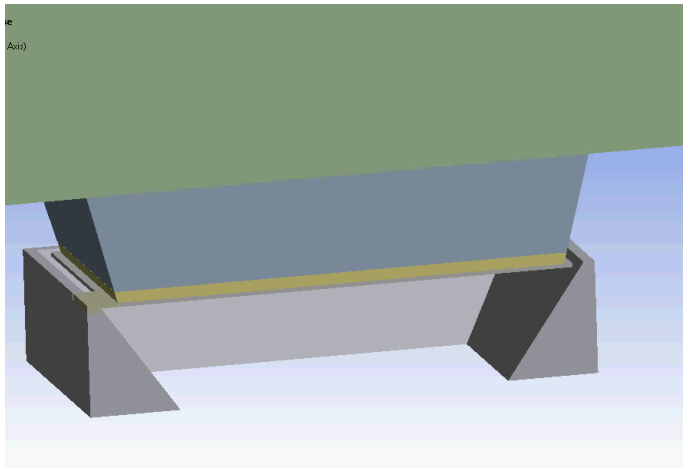
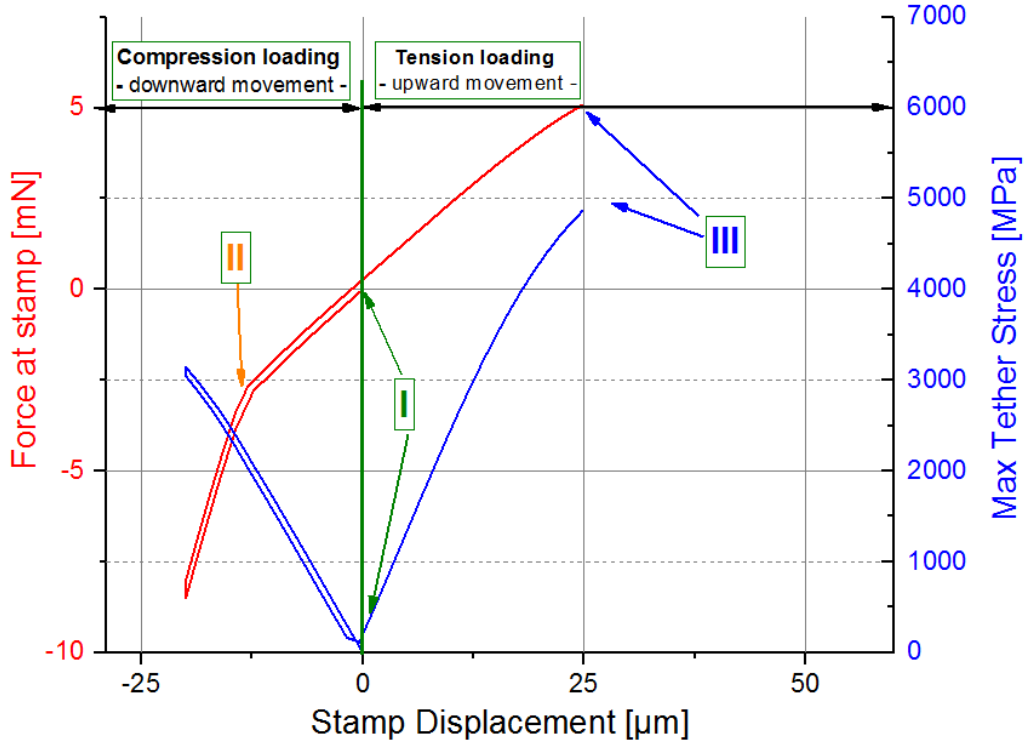
III – Starting stamp delamination



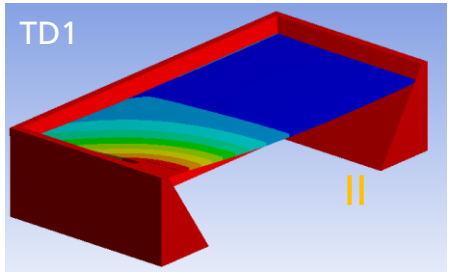


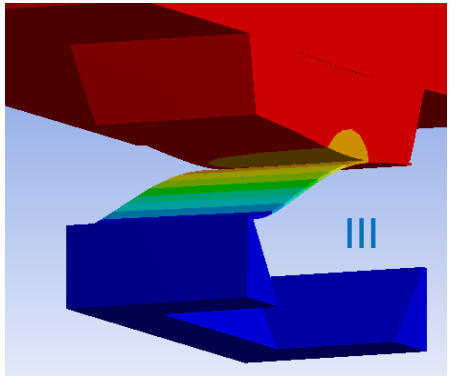
Fraunhofer IMWS

Finite-element-analysis

µTP-Process Simulation

Kinematic behavior during µTP (device pick-up)





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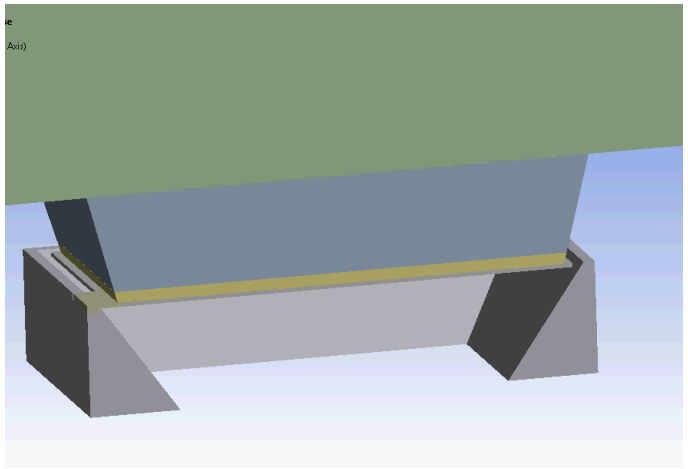

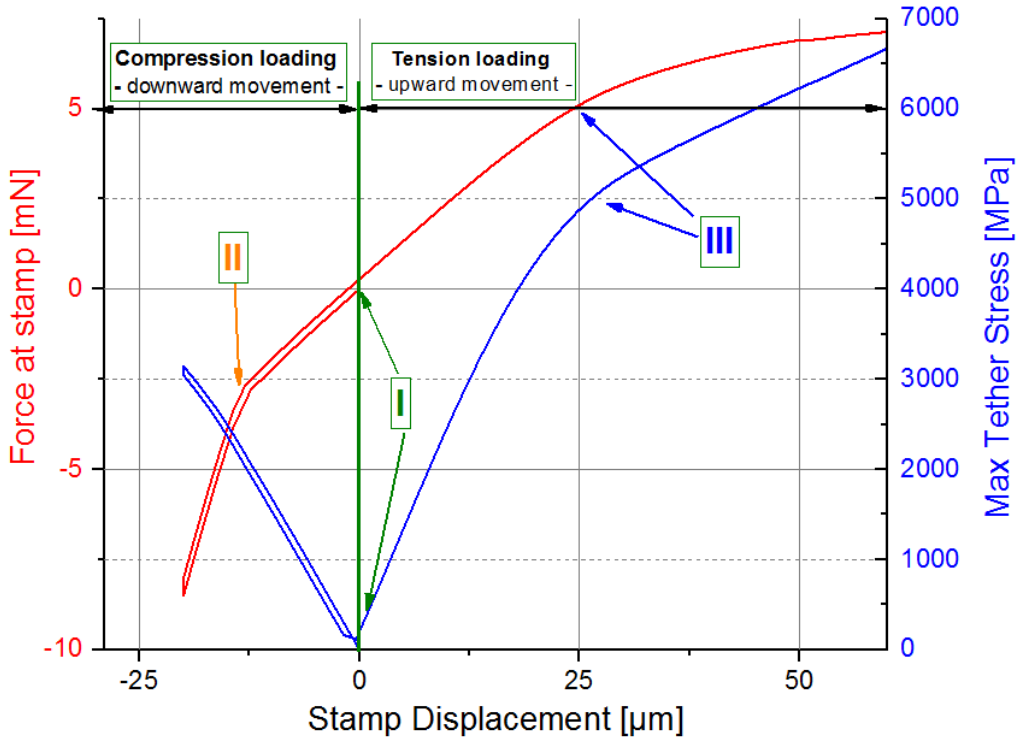

Fraunhofer IMWS

Finite-element-analysis

µTP-Process Simulation

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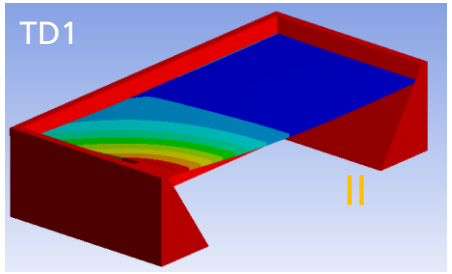

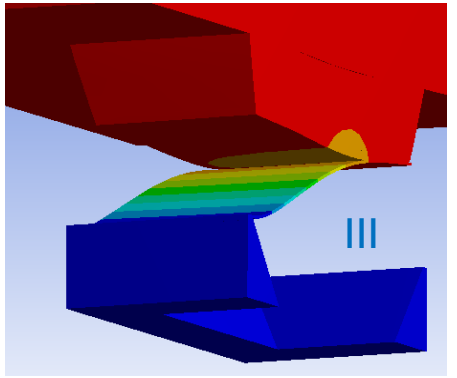

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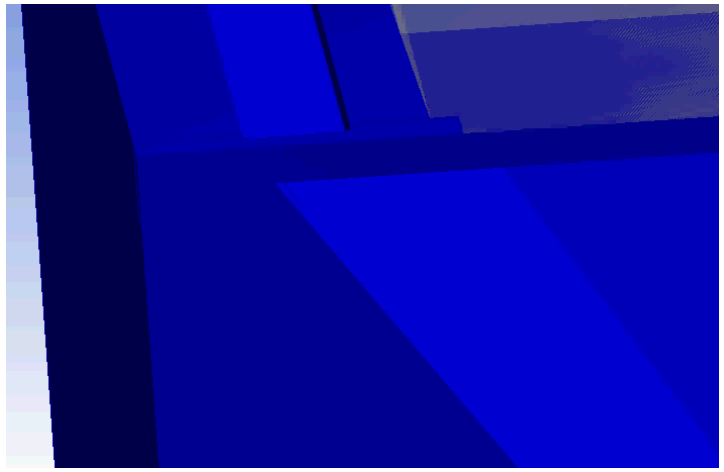
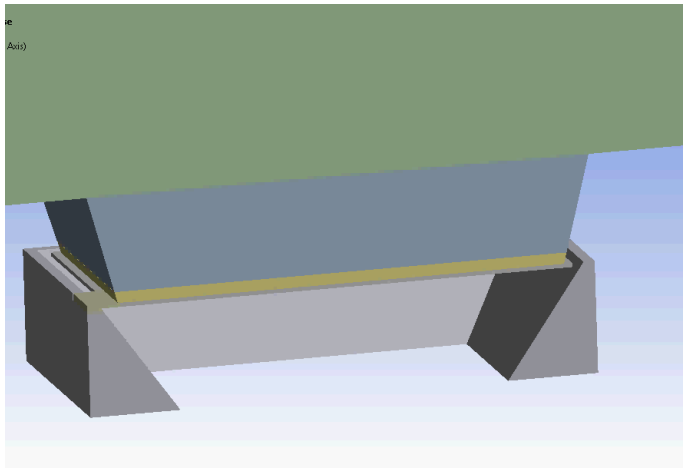
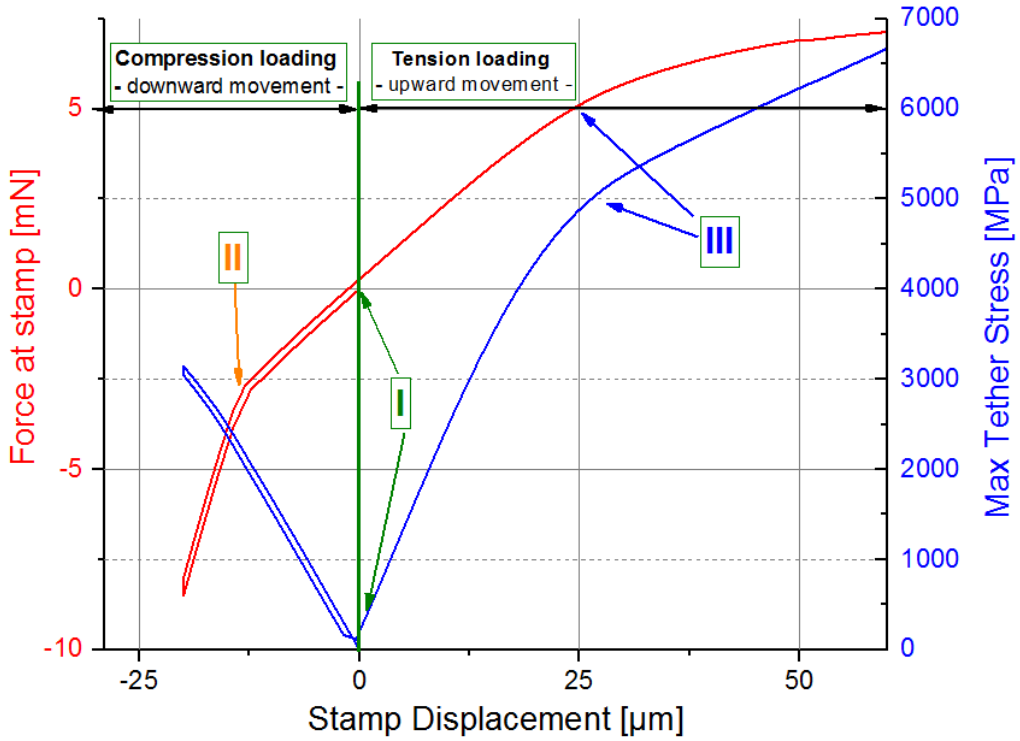




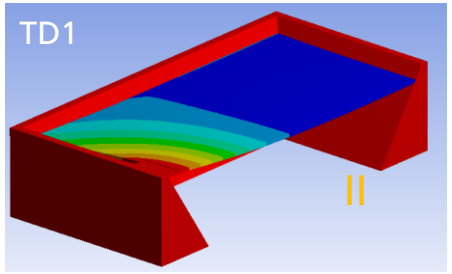


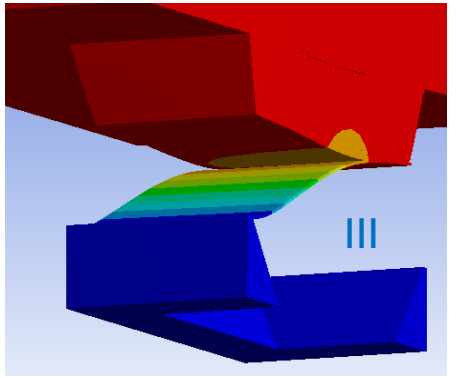
Fraunhofer IMWS

Finite-element-analysis

µTP-Process Simulation

Kinematic behavior during µTP (device pick-up)





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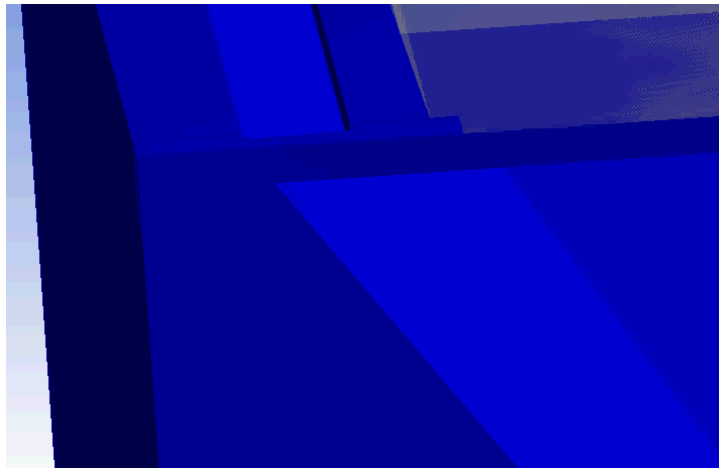
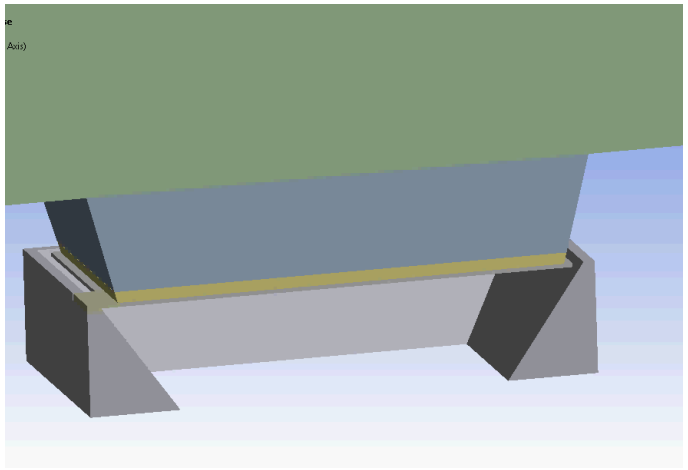
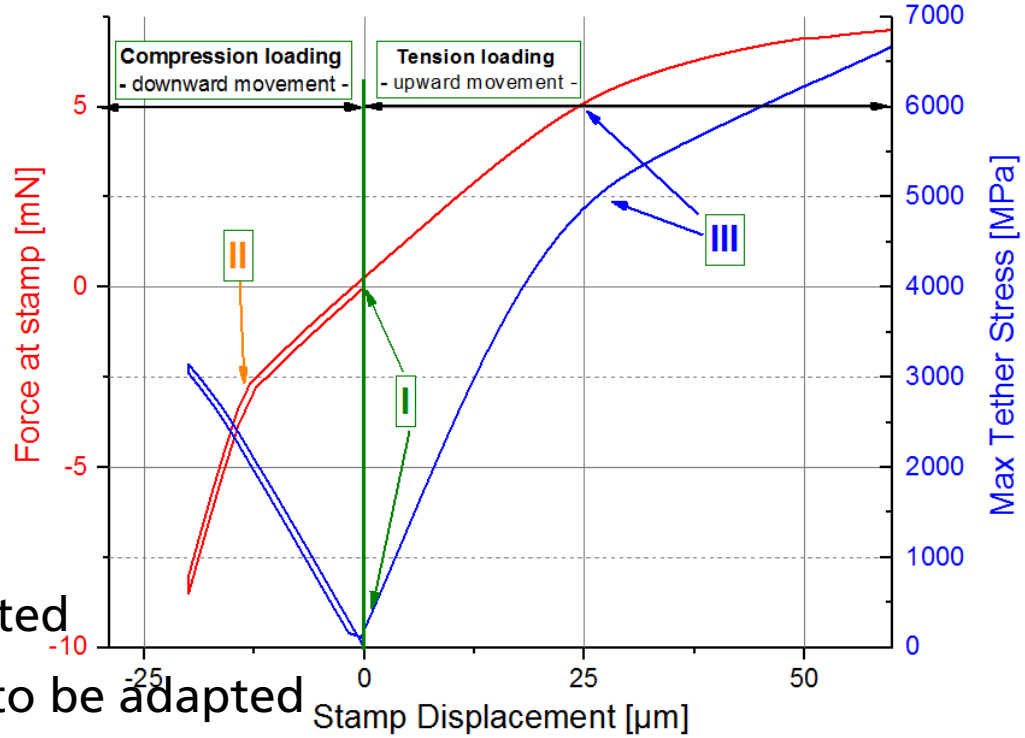






- Critical fracture stress values for Si_3N_4 of 400-500MPa[1] expected

→ Model assuming a sharp notch, radius and FEA mesh needs to be adapted

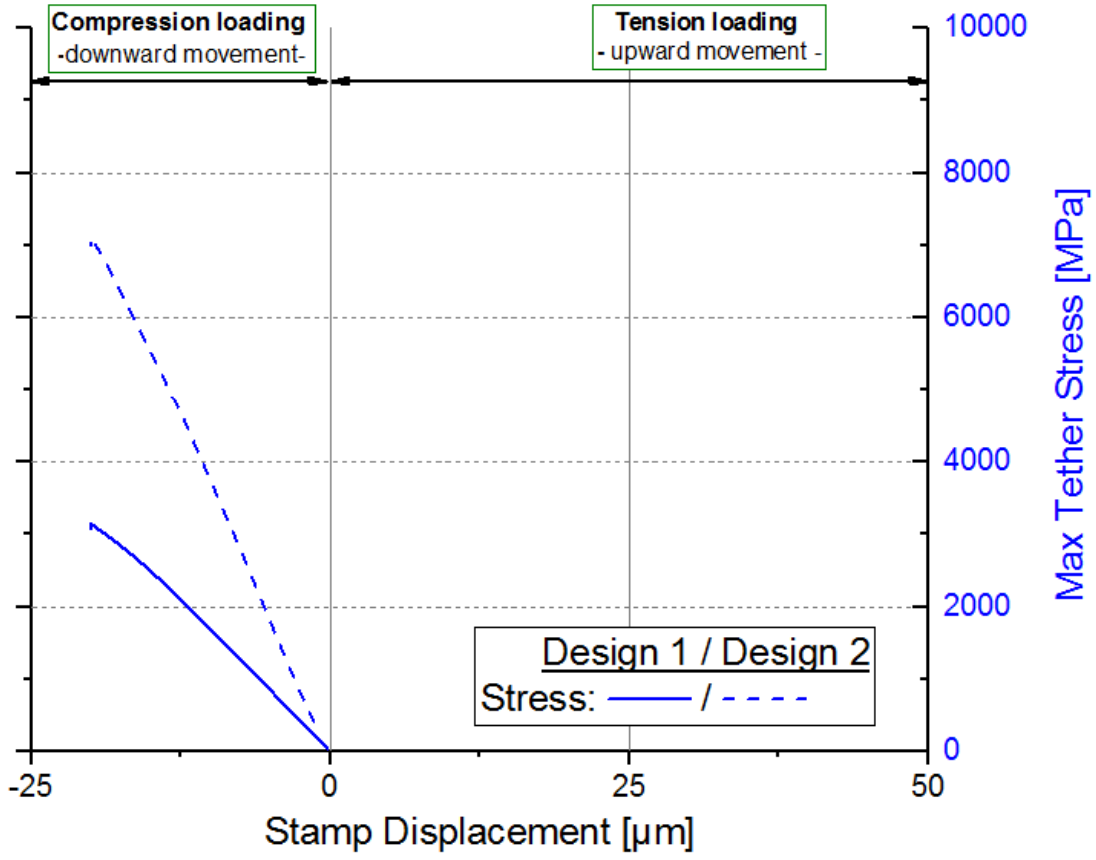
[1] G. F. Cardinale, R. W. Tustison, "Fracture strength and biaxial modulus of of plasma silicon nitride films", 126-130; Thin Solid Films, 207 (1992)

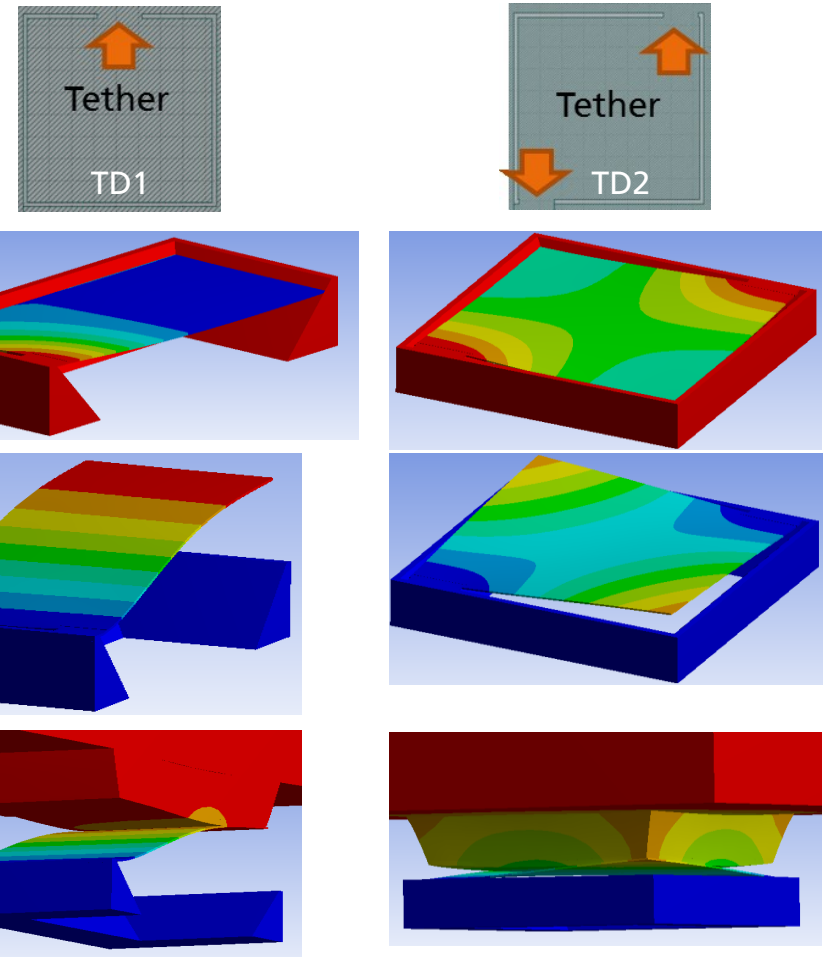
Fraunhofer IMWS

Finite-element-analysis

µTP-Process Simulation

Two different tether designs



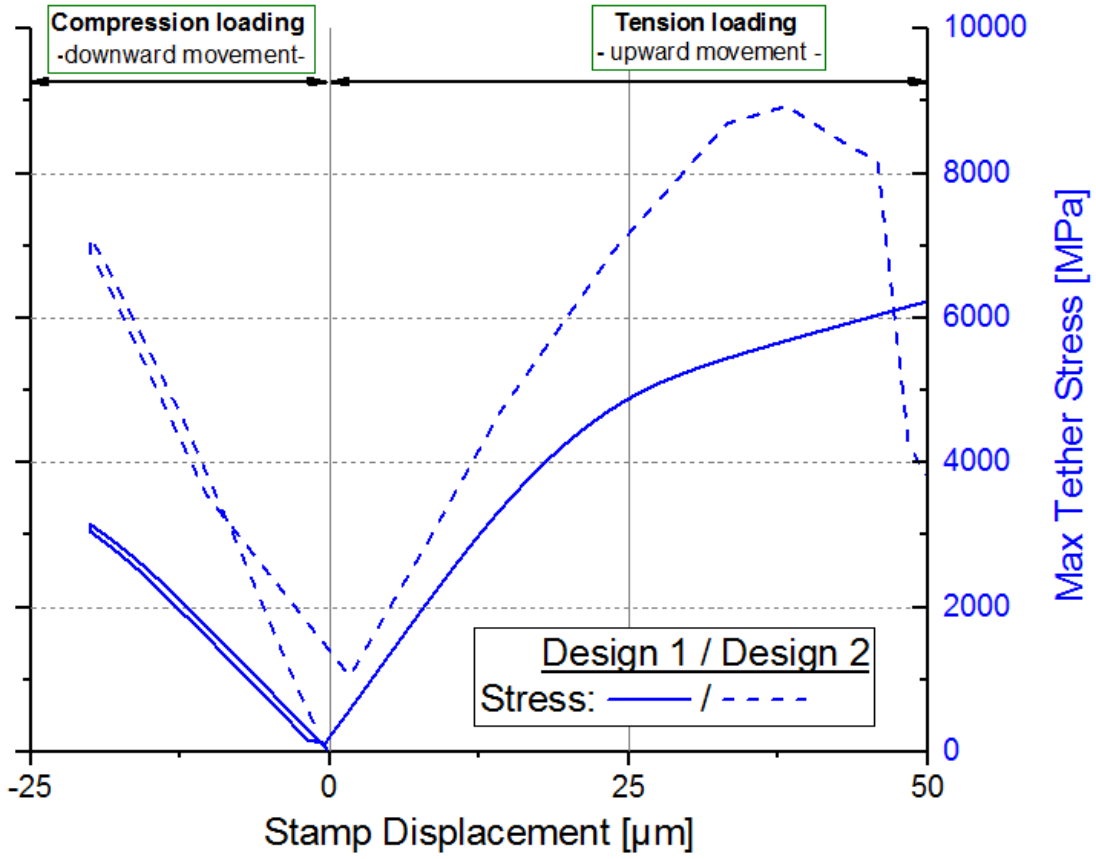


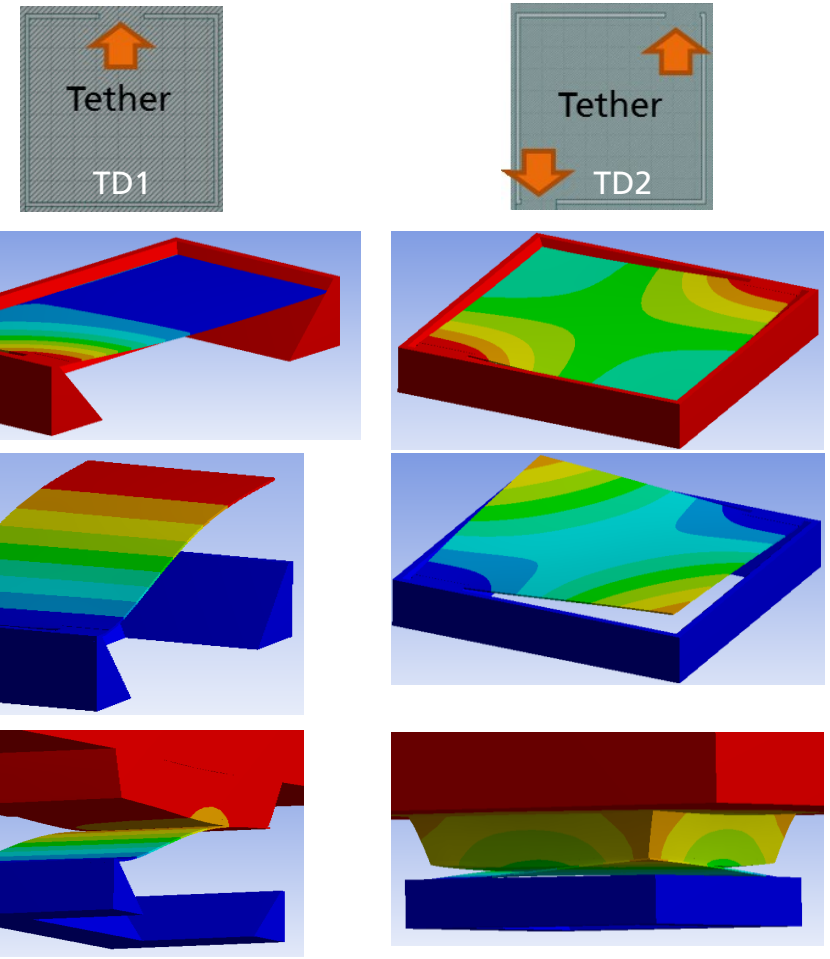
Fraunhofer IMWS

Finite-element-analysis

µTP-Process Simulation

Two different tether designs





- TD2 stiffer than TD1
- TD2 increased tether stress at same stamp displacement

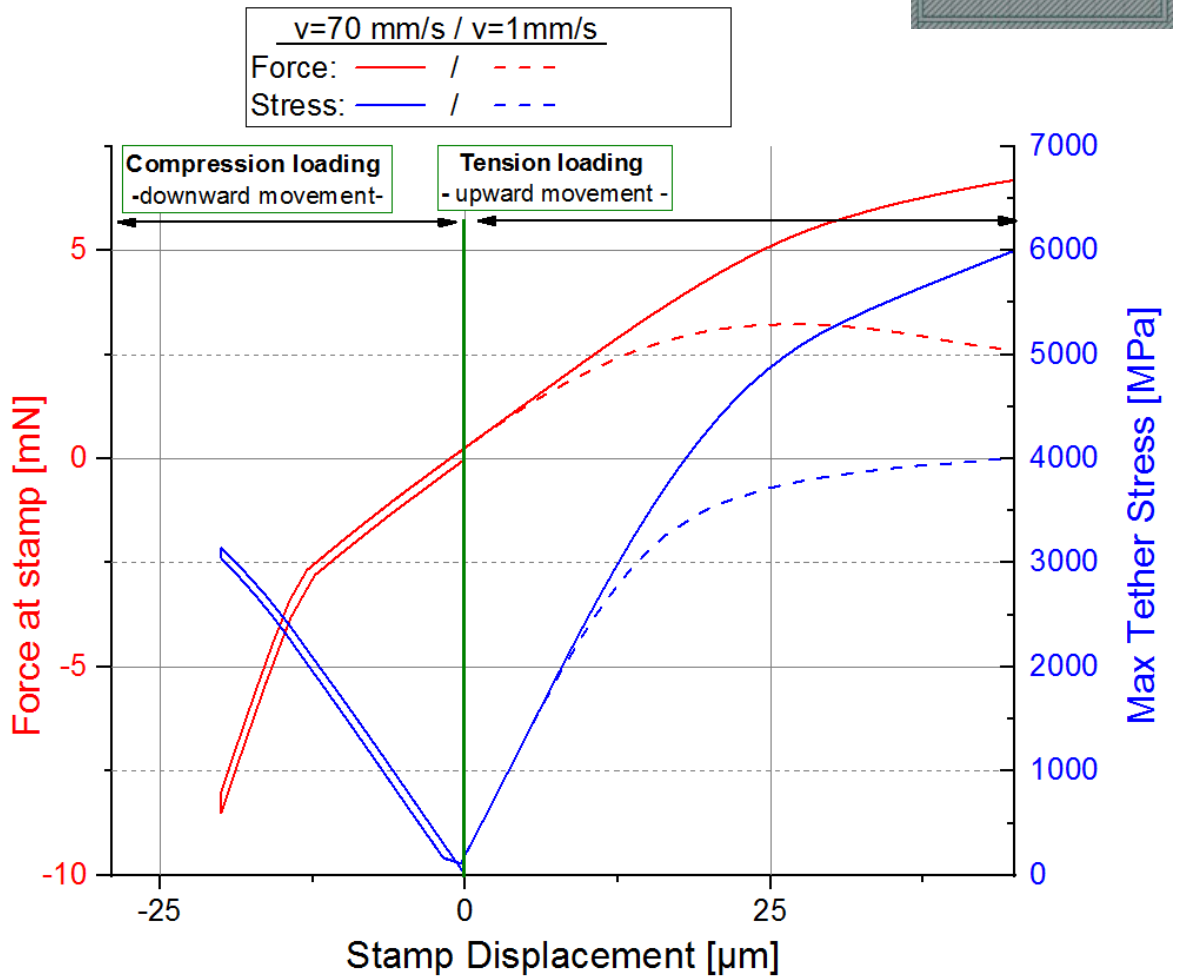
→ Different tether designs can be analyzed

Finite-element-analysis

µTP-Process Simulation

Case study: less pick up speed (TD1)

- Delamination occurs at less stamp displacement and a lower forces
- Less tether stress
- Risk of a failing pick up if tether does not break during downward movement

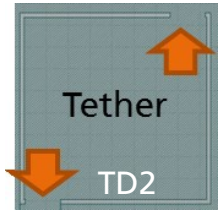


Fraunhofer IMWS

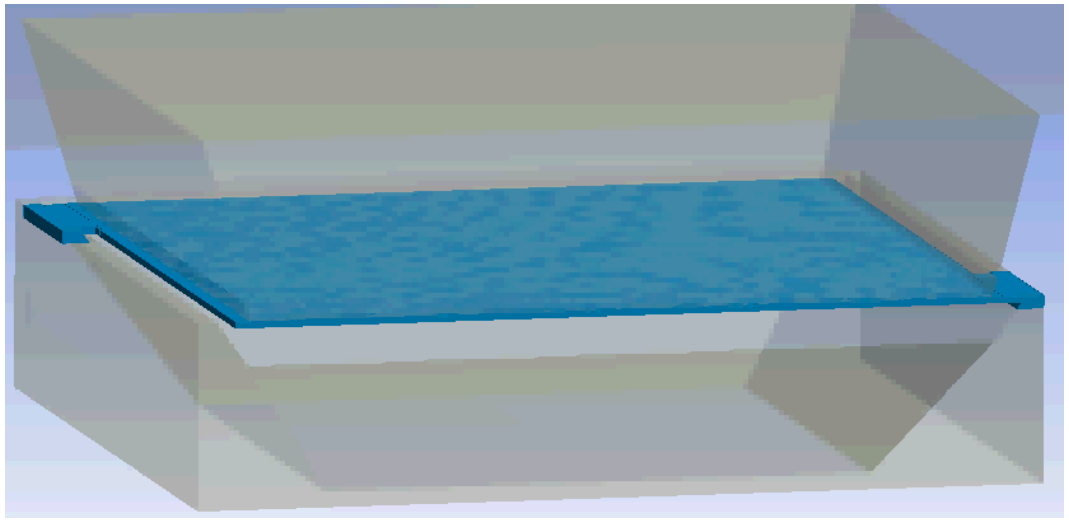
Finite-element-analysis

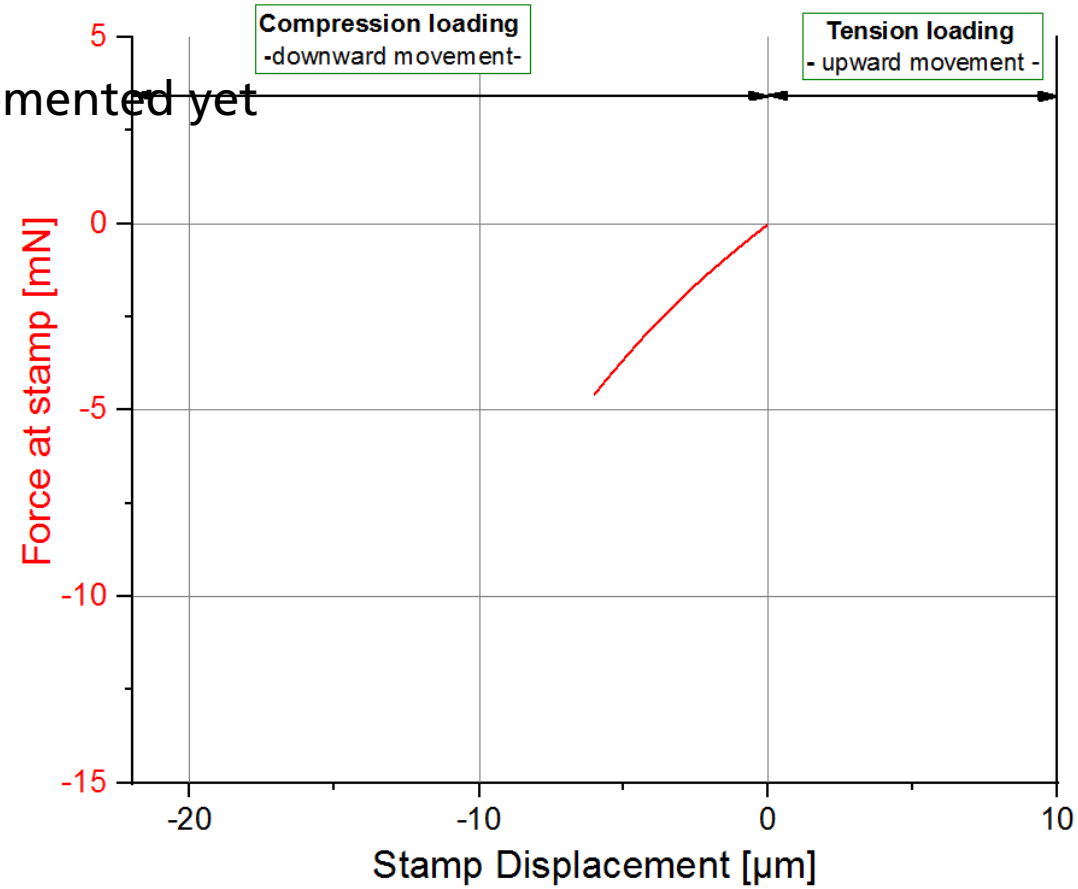
µTP-Process Simulation

Kinematic behavior of TD2 with breaking tethers



- No fracture mechanical models for tether breakage implemented yet





Finite-element-analysis

µTP-Process Simulation

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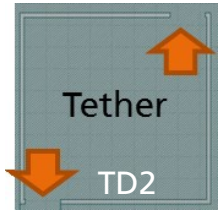

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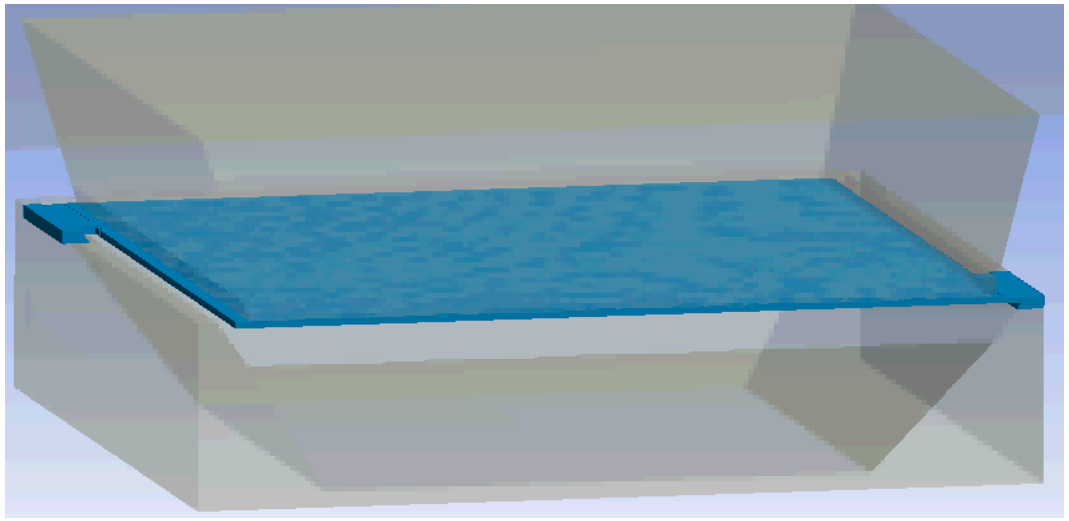
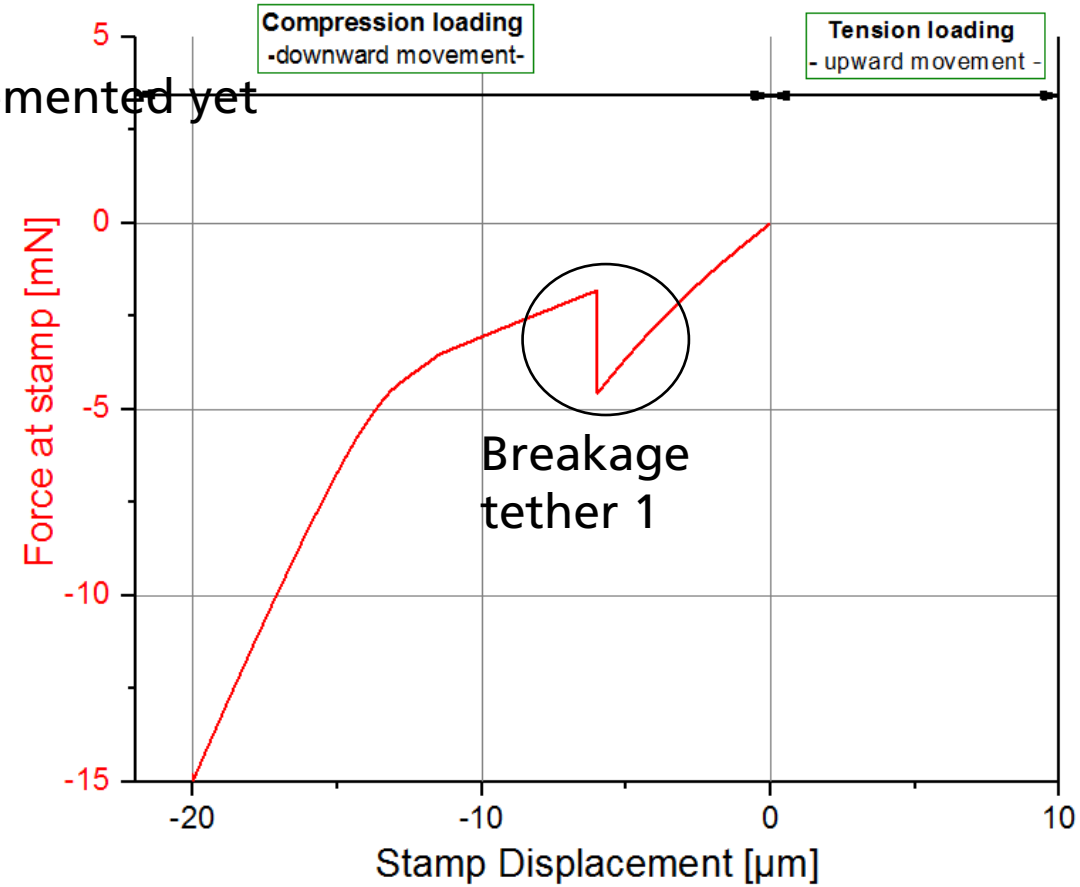


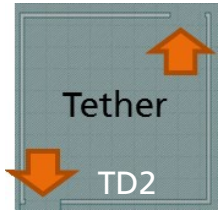


- Tether breakage leads to immediate stamp force and tether stress reduction

Finite-element-analysis

µTP-Process Simulation

Kinematic behavior of TD2 with breaking tethers



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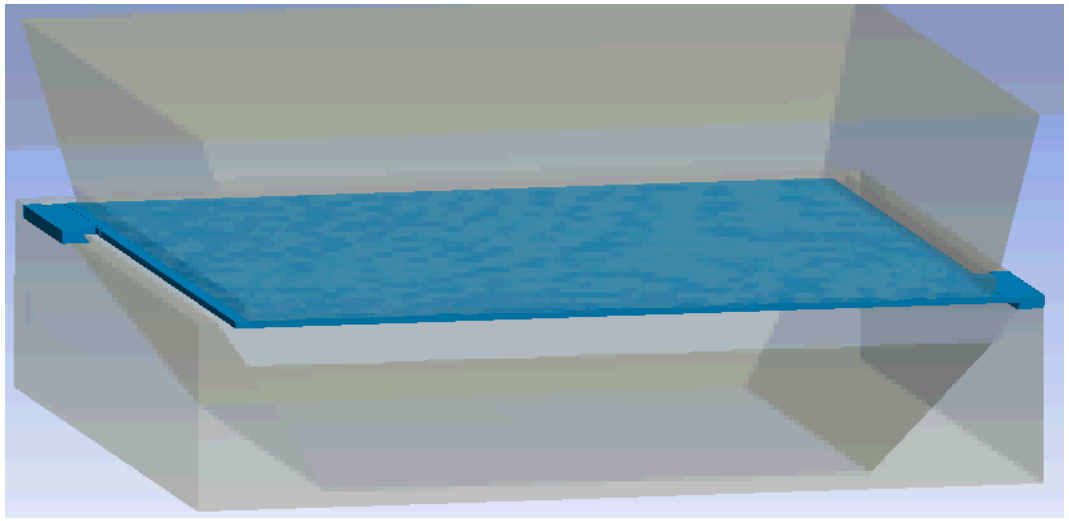
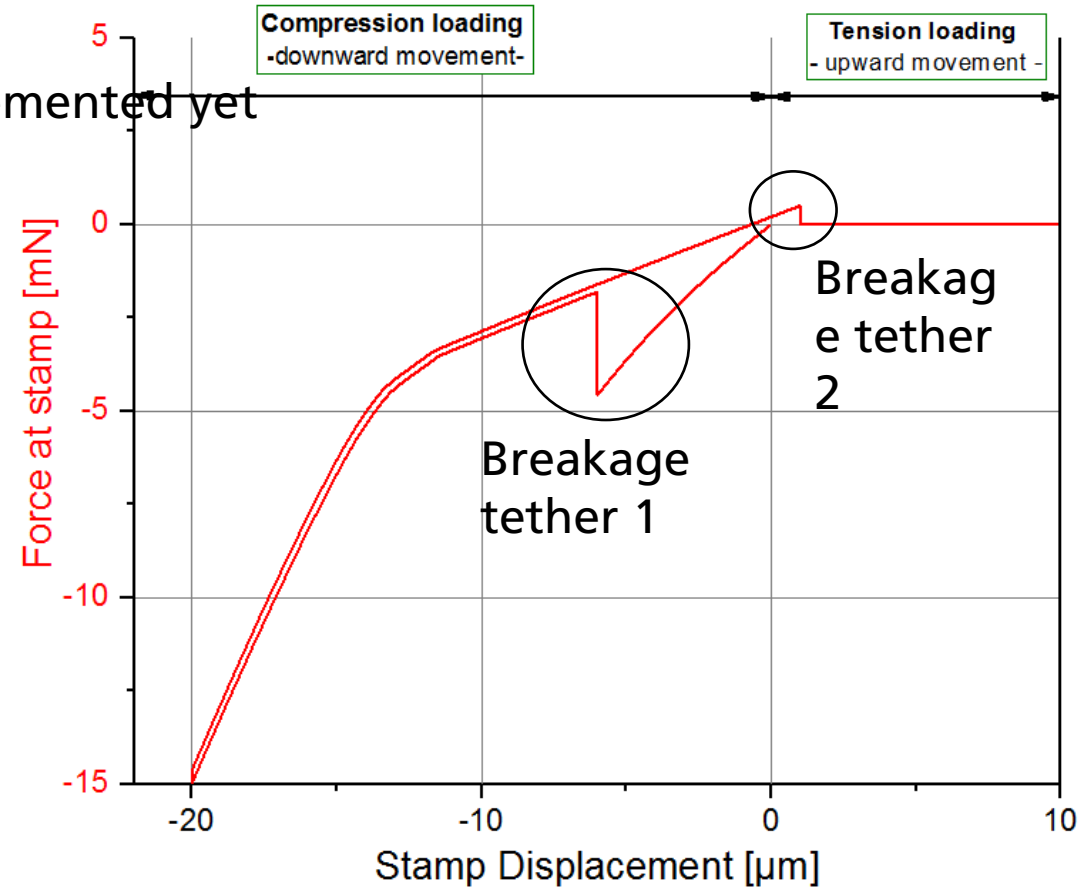


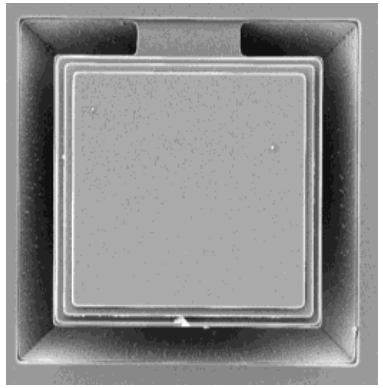


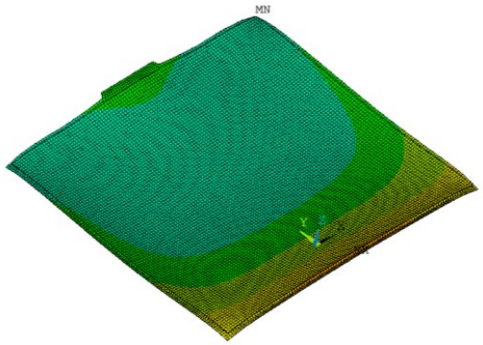
- Tether breakage leads to immediate stamp force and tether stress reduction

Summary

- FEA of µTP inside the „MICROPRINCE“-project for analyzing process reliability
- Mechanical characterization
  - Viscoelastic properties of PDMS by DMA
  - Velocity dependent adhesion measurements on single post stamps
- Process simulation
  - Interaction of stamp and released device regarding stamp and tether stress
  - Tether design and process parameter optimization possible
  - Evaluation of the impact of stamp material

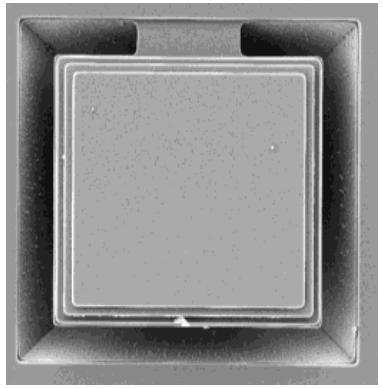
Outlook

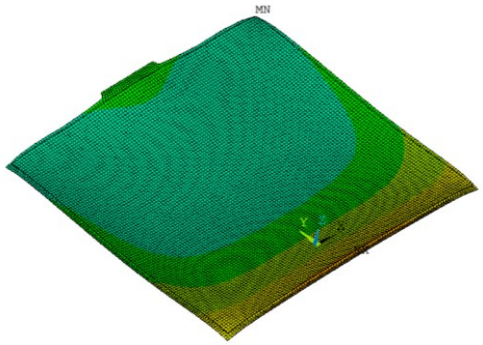




- µTP-process evaluation by single post stamp experiments
- Considering different device designs including intrinsic stresses due to processing
- Evaluation of fracture stress values by nano-indentation experiments
- Including fracture mechanical approaches for tether breakage

Outlook





- µTP-process evaluation by single post stamp experiments
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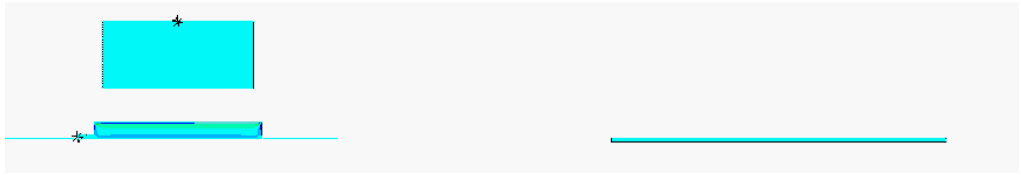
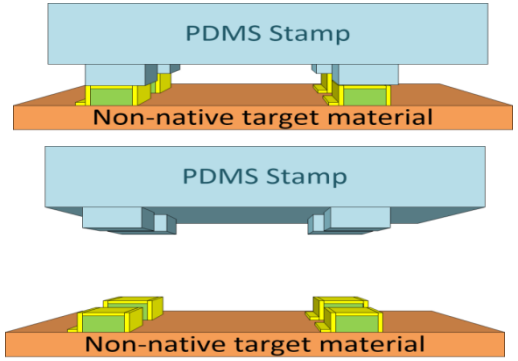
- Model extension to further µTP process steps





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