Electroadhesive structures on flexible polymer substrates for gripping applications

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Fraunhofer ISC

Fraunhofer Institute for Silicate Research ISC at a glance

Using chemical methods to make functional materials sustainable

Locations

Fraunhofer ISC …

- Chemical material design and hybrid materials
- 4 locations (2x Würzburg, 1x Bronnbach/Wertheim, 1x Bayreuth)
- Around 400 employees
- Around € 30 million budget/year

"Bridging the innovation gap", from laboratory to pilot scale

… in the Fraunhofer focus areas

- Bioeconomy
- Healthcare/Biomed
- Nutrition
- Chemical industry
- Artificial Intelligence
- Energy storage and efficient usage
- Process engineering, pilot lines
- Resources, climate, and water
- Hydrogen technologies

Focus materials developmetn, e. g. for

… ENERGY

- Greater efficiency in heating processes and energy conversion
- Safe and powerful energy storage systems

… CLIMATE | RESOURCES

- Efficient use of renewables
- Smart resources for less CO_2 emissions
- Green hydrogen - production, transportation, storage

… BIOMEDICINE

- Regenerative therapies
- Tissue-based modeling
- Stem cell processing
- 3R - alternative test systems

… ADAPTIVE SYSTEMS

- Sensors | Actuators
- Fluid materials
- Materials | Processes for Microelectronics and Microoptics

…DIGITALIZATION

- Laboratory and process automation
- Materials Data Space
- Smart Textiles

…BIOECONOMY

- Bio-based | biocompatible | biodegradable materials

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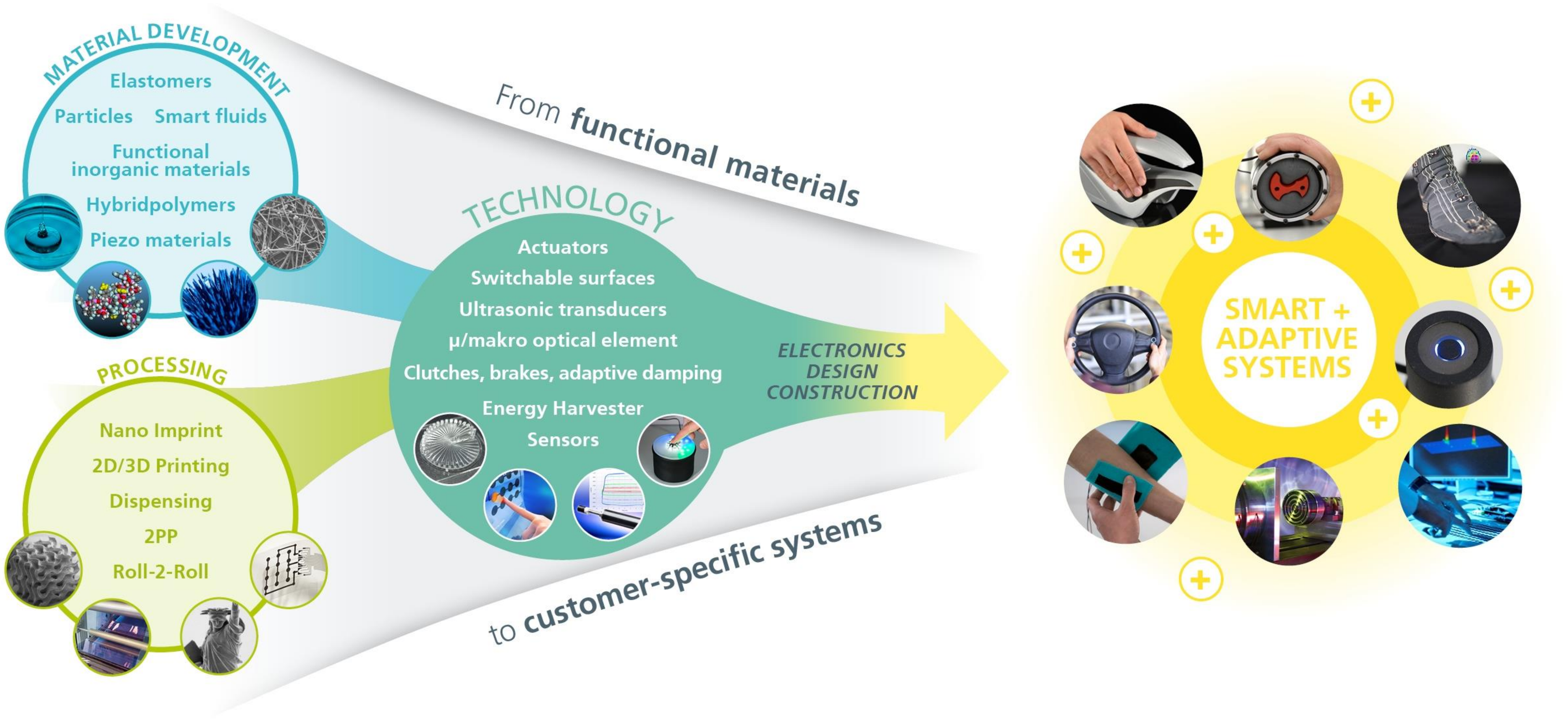
Center Smart Materials and adaptative Systems



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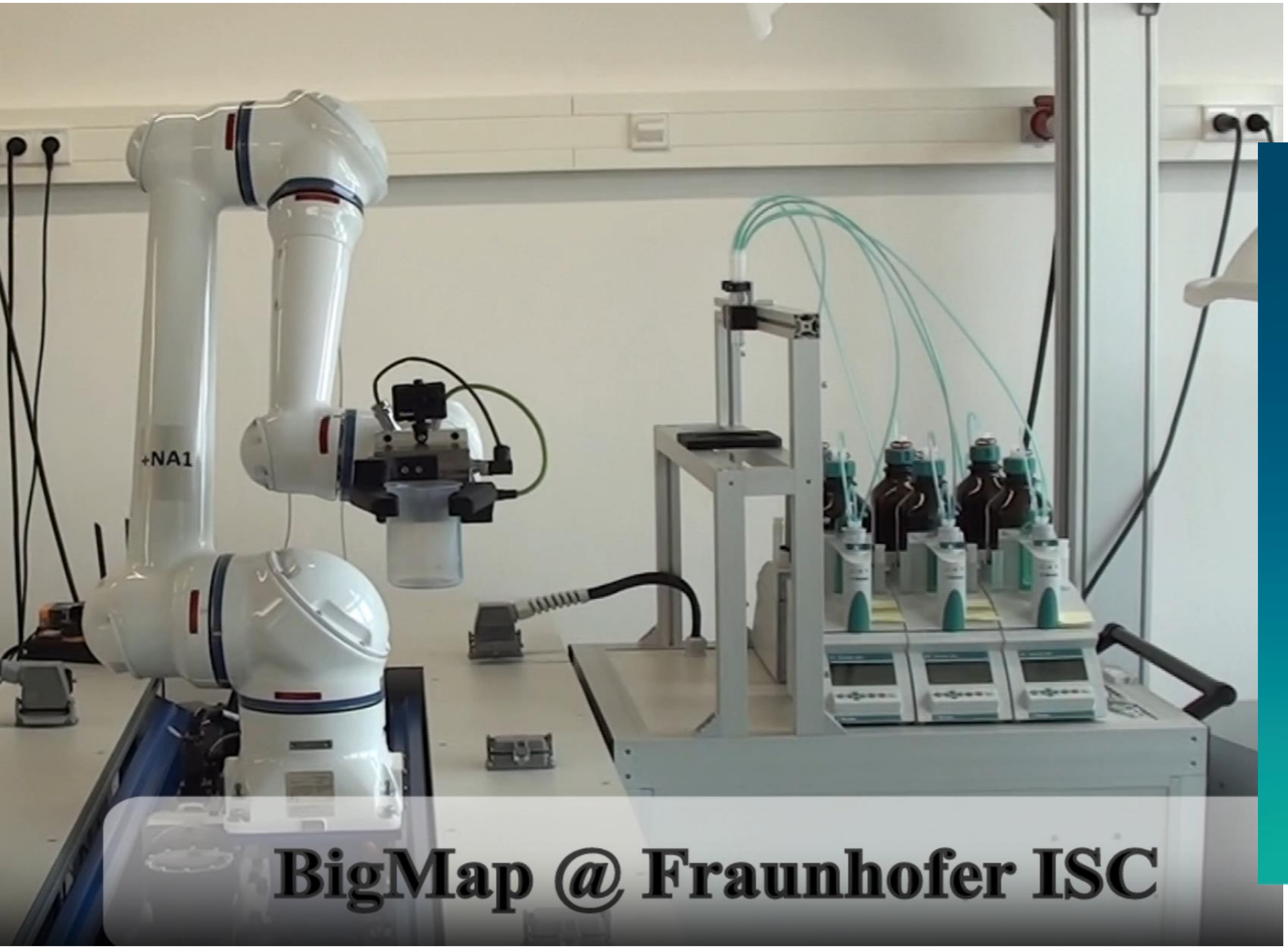
Machine learning and AI for accelerated materials development

„invent a new way how to invent" – e. g. BiG-MAP



Accelerating material development

- Laboratory automation for material synthesis and development
- Modular and multifunctional robot system
- Framework as a physical interface in the digitalized material development of the future
- Machine learning algorithms coupled with physical models and data for remote-controlled syntheses

Co-funded by the European Union

Renewable resources for high-tech applications

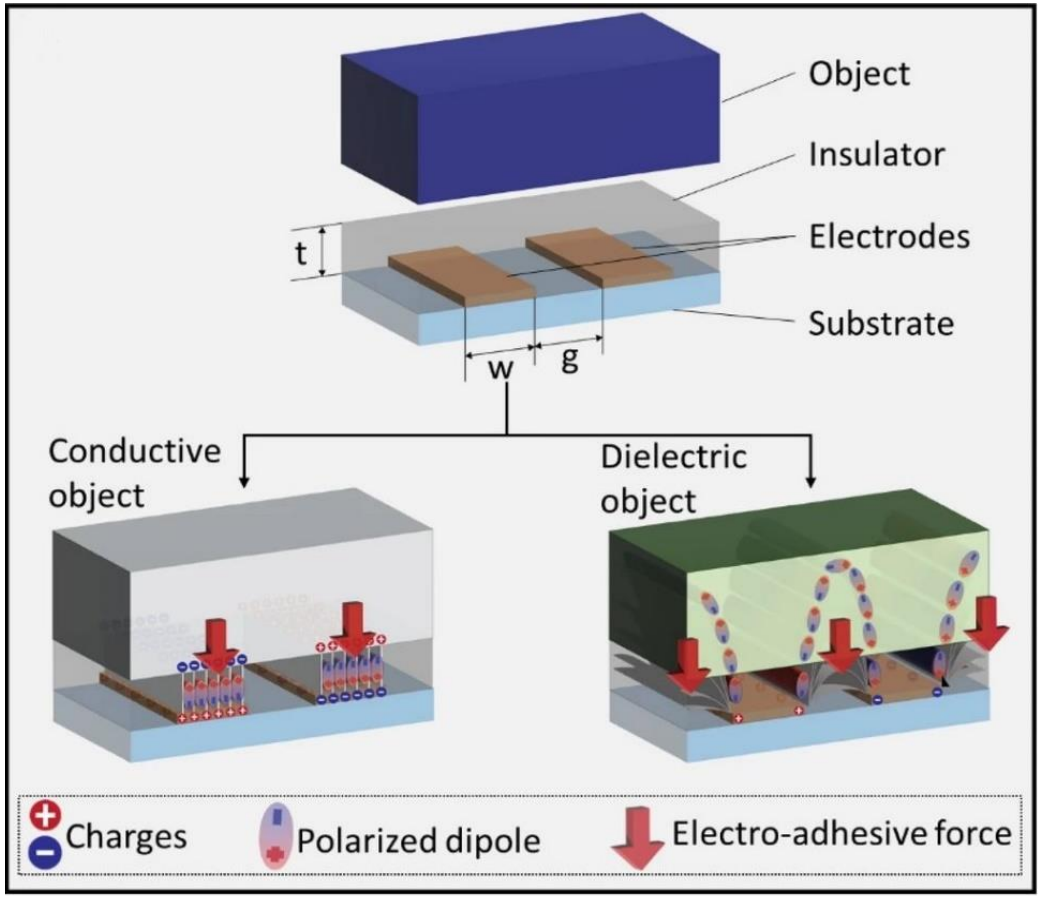
e. g. CircEl-Paper – recyclable electronics on paper

Alternative approaches for the production of printed electronics to increase recyclability and environmental friendliness

- Paper as a substrate material for multilayer printed circuit boards
- Material and process innovations for higher integration density during printing
- Validation of recyclability

Co-funded by the European Union

Electroadhesion – a brief introduction



Electroadhesive force F_e described by Hwang et al:

$$F_e = \frac{1}{2}\varepsilon\varepsilon_0 A\left(\frac{V}{d}\right)^2$$

ε: relative permittivity of the dielectric
ε_0: permittivity of the vacuum
A: electrode surface area
V: voltage difference
d: distance between the electrodes

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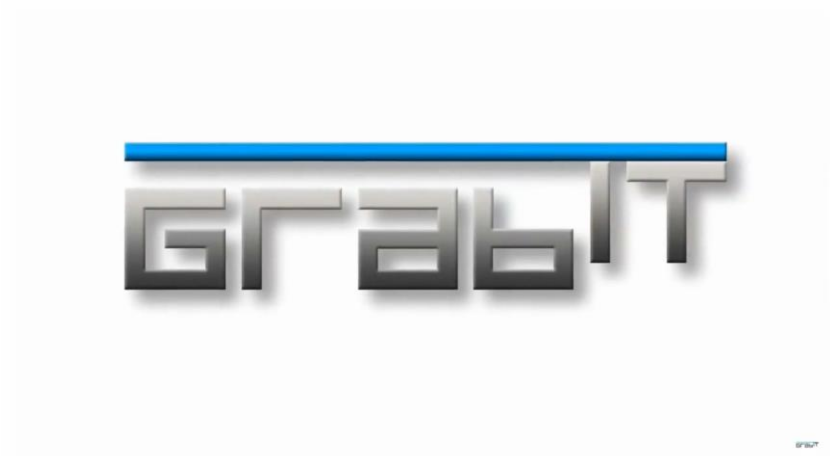
Source:www.grabitinc.com

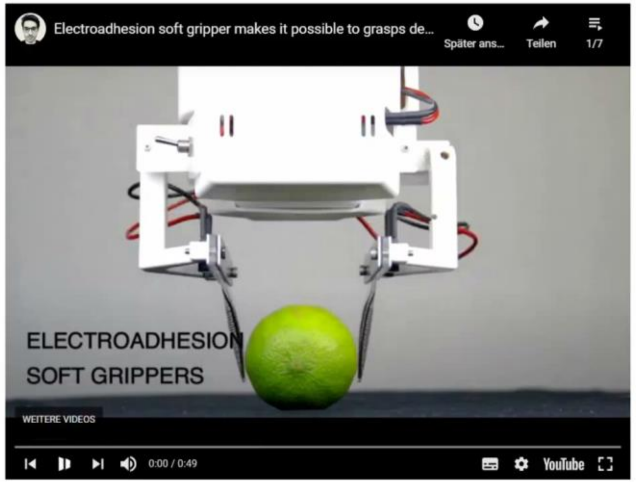
Electroadhesion – state of the art



- Elecroadhesion is a quite old and known effect
- First applications for gripping with electroadhesion where published by GrabIT 10 years ago
- Interdigital structures on PCB´s and non flexible polymer substrates

  Co-funded by the European Union

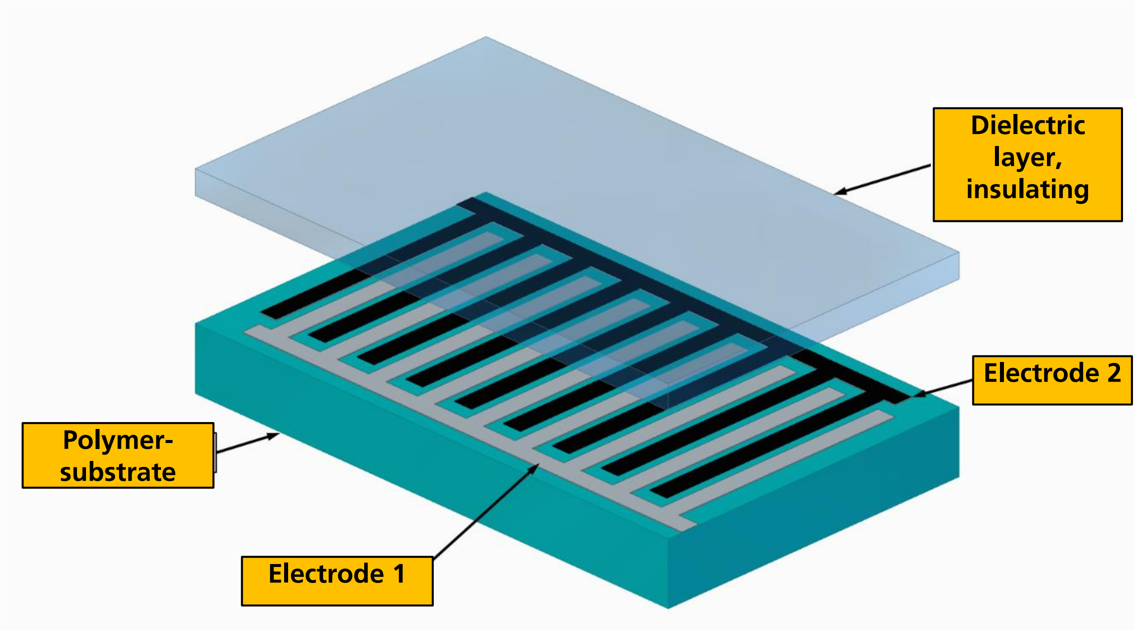
Electroadhesion – state of the art

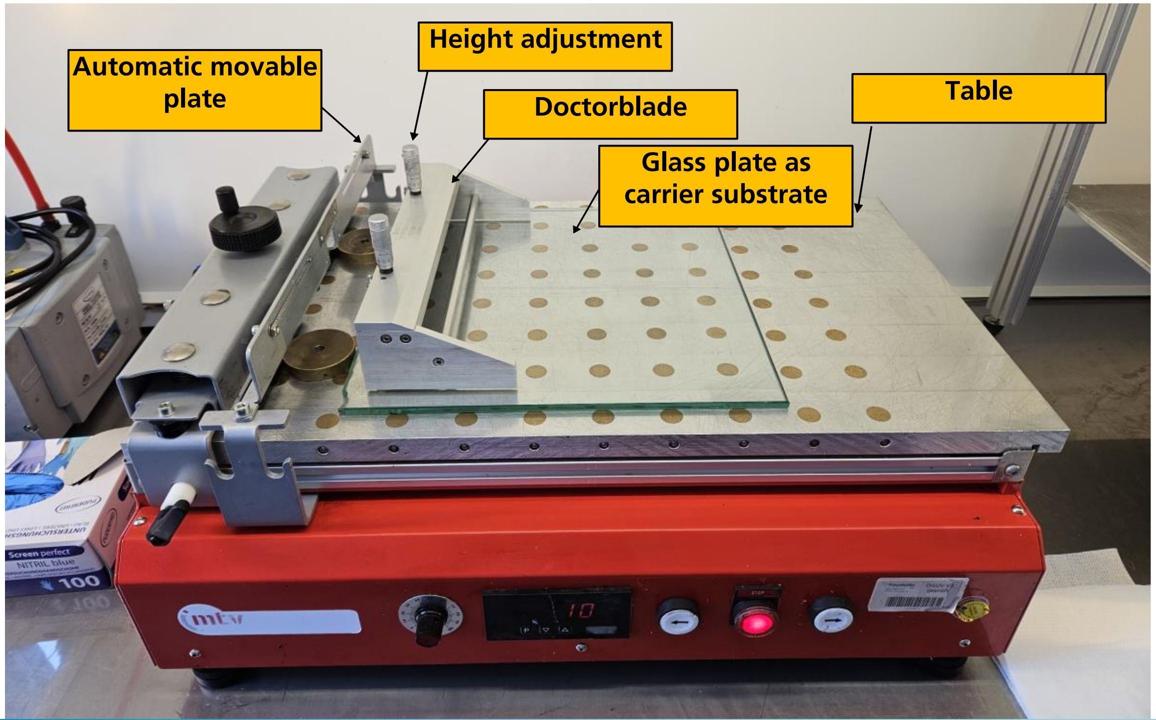


- Omnigrasp as spinoff of EPFL introduced flexible patches for grasping
- Interdigital structures on elastic polymers (PDMS) or flexible Polymers (PI and PET) are used
- PDMS material provides sticky surfaces which could be problematic for lighter goods
- State-of-the-art motor grippers are used for size adjustment and peel-off effect

  Co-funded by the European Union

Electroadhesion – fabrication by doctorblading



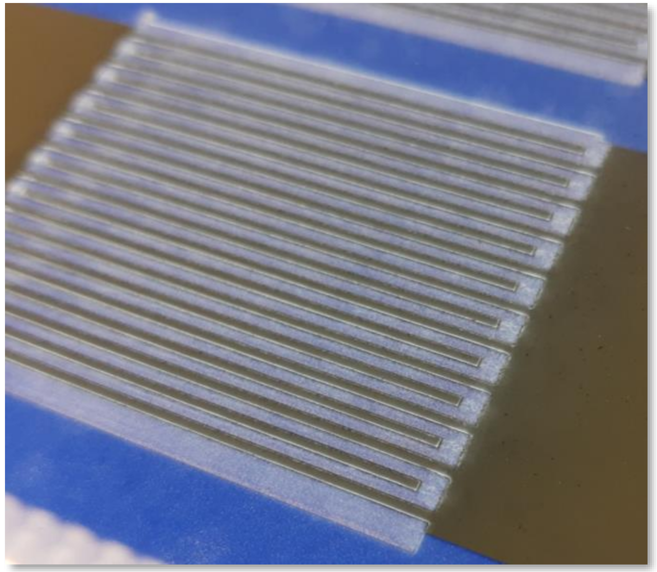


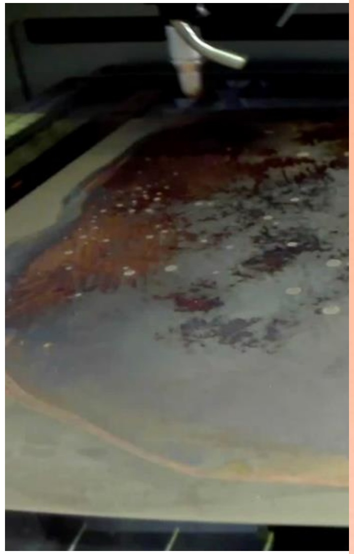
- Electroadhesive structures are produced by a bottom up, layer-by-layer doctorblading approach
- PDMS material is used as Polymer Substrate and Dielectric top insulation
- Carbon Black blended in PDMS binder is used as electrode layer
- The structure remains on the glass plate carrier until everything is finished.

Electroadhesion – fabrication

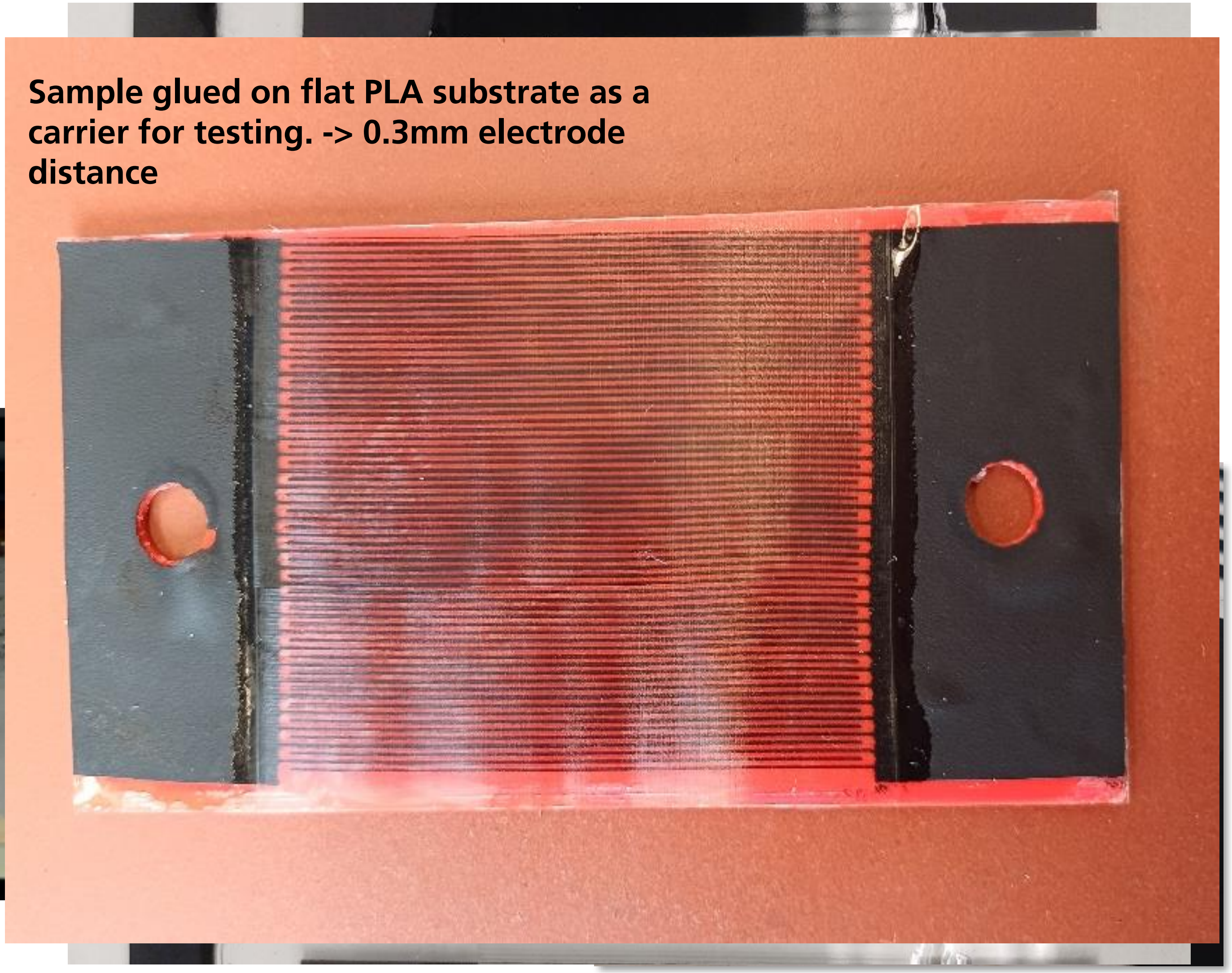
Laserablation:

- CO2 – Laser
- Full area coated carbon electrode
- Ablation of variable interdig. structures





Silicone sample after Laserablation and before cleaning

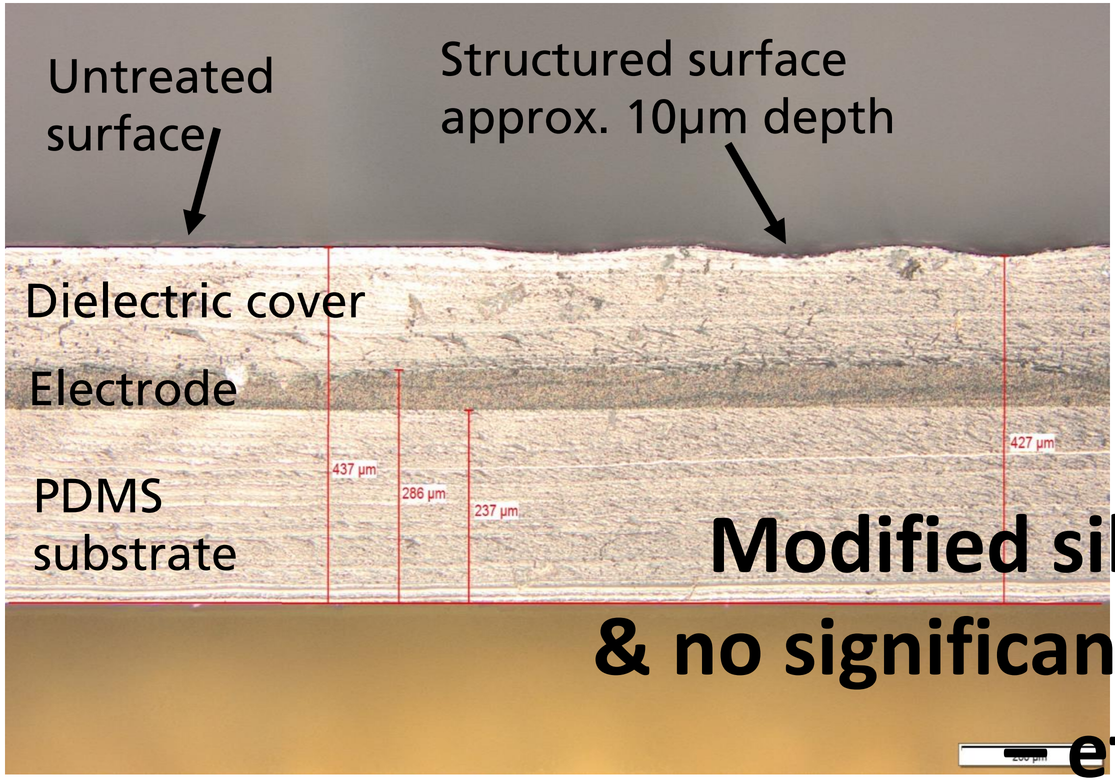


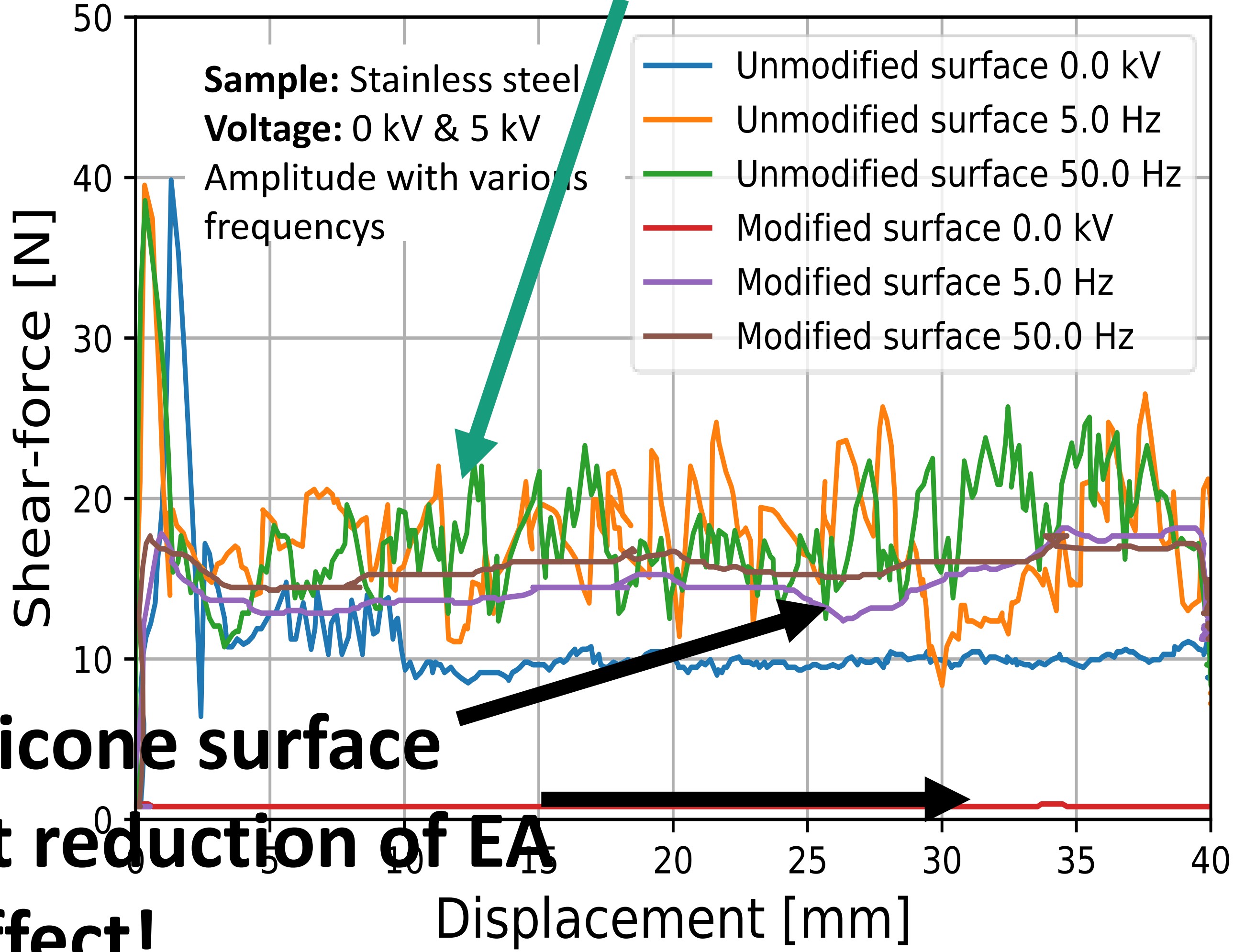
Sample glued on flat PLA substrate as a carrier for testing. -> 0.3mm electrode distance

Electroadhesion – fabrication

Unmodified with sticky silicone surface

Reduction of stick slip effect:

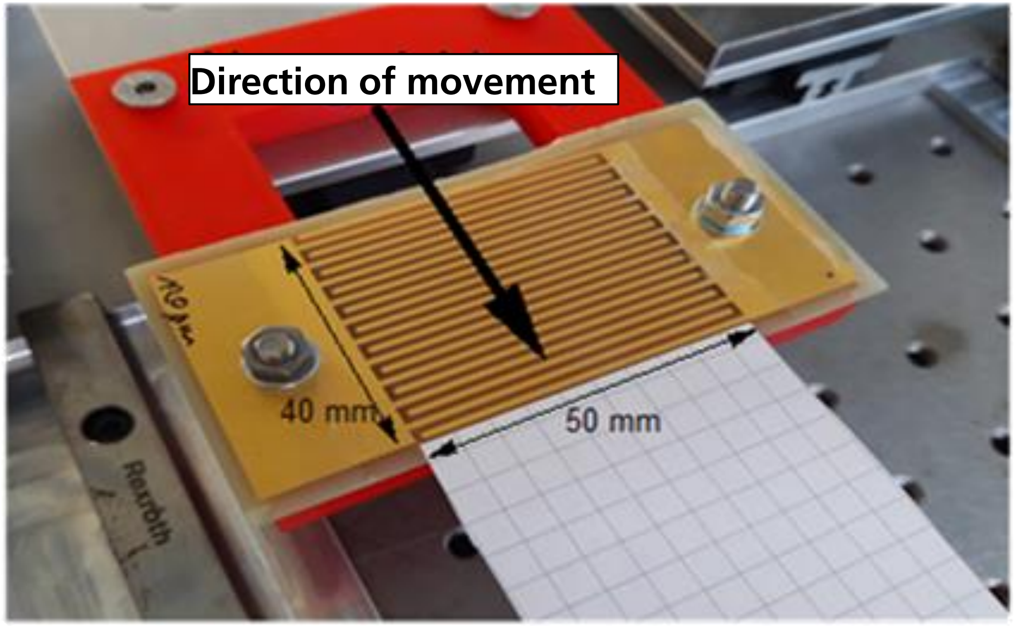


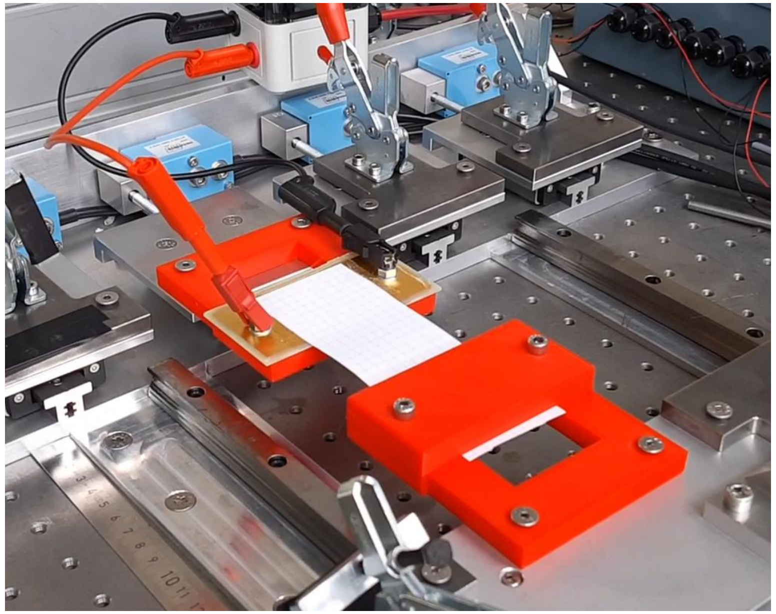


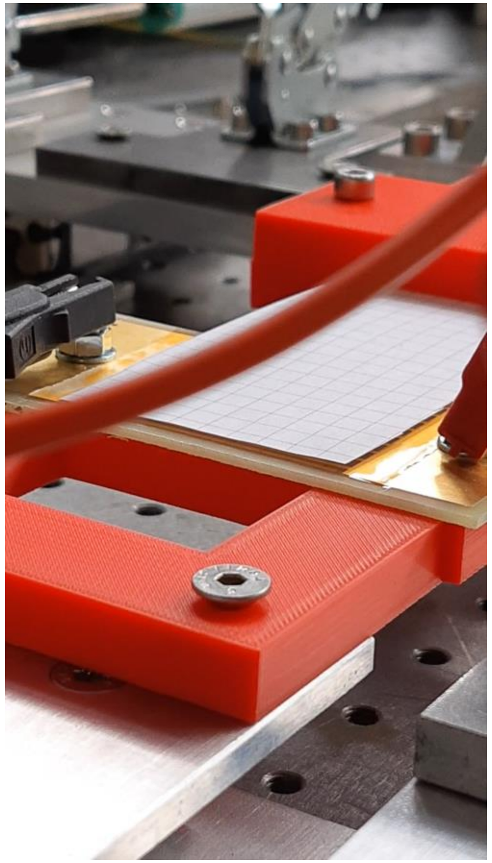
Modified silicone surface & no significant reduction of EA effect!

 07.07.2025 - public - Fraunhofer ISC

Electroadhesion – Characterisation method



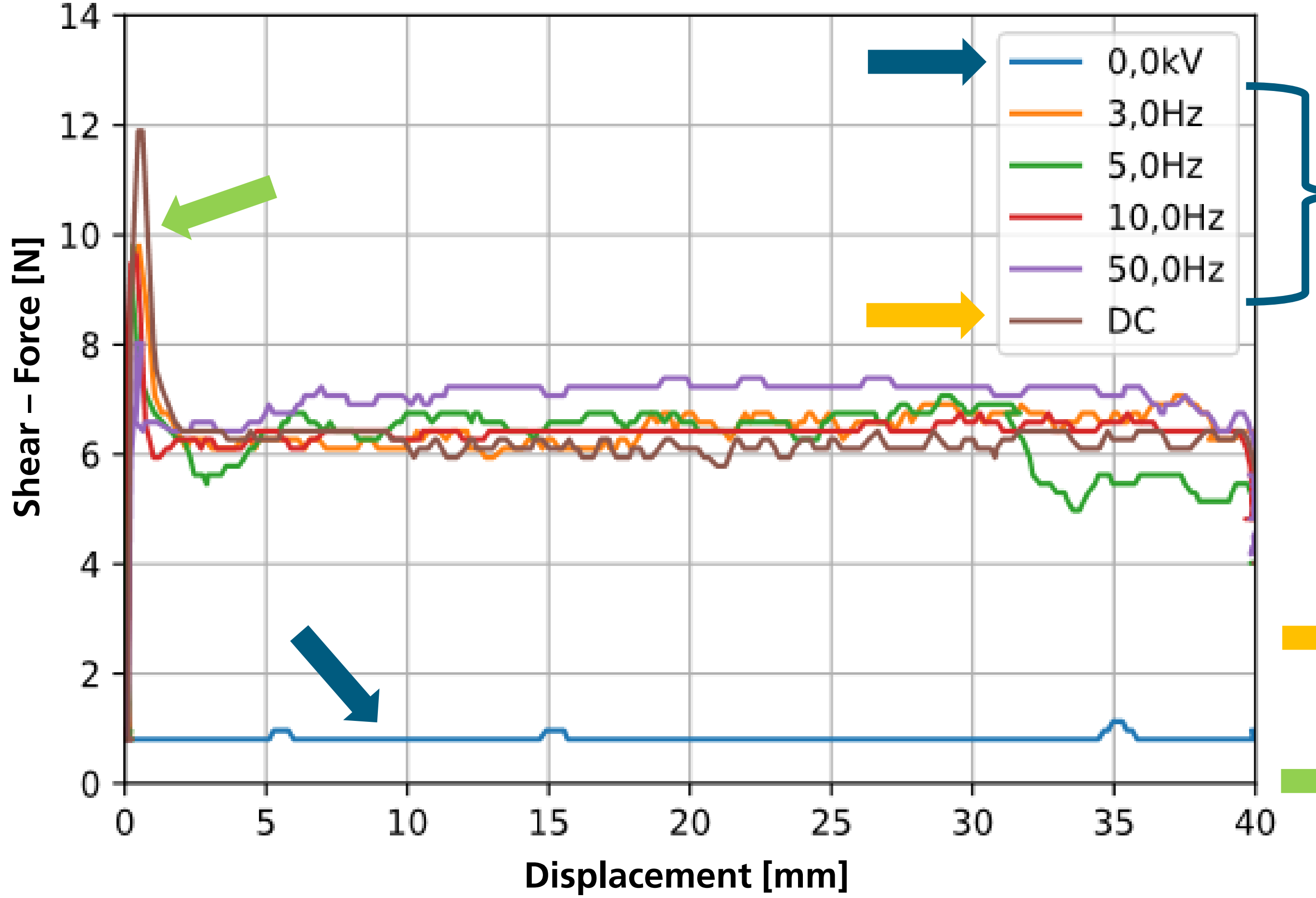




- Measurement of shear force on test samples with 40 x 50 mm size.
- Forced movement with a speed of minimum 3.6 mm/s. Variation possible
- Measurement with constant electroadhesive area or gradual reduction

Electroadhesion – Results

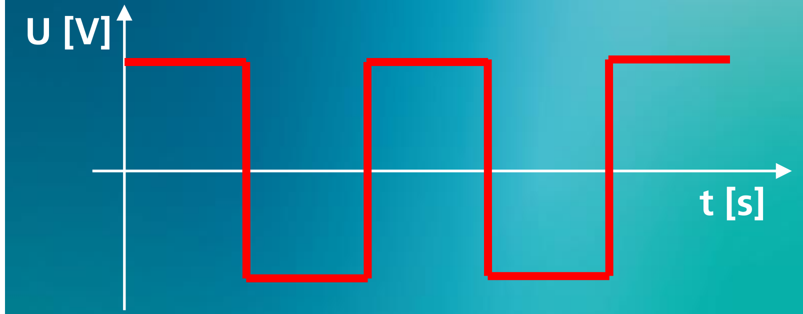
PDMS; 0.3mm electrode distance; 5kV amplitude; PET sample



Measurement @ 0kV as reference to test the stick slip effect

Measurement @ 3, 4 and 5 kV

rectangular frequencies to test the influence of surface polarization

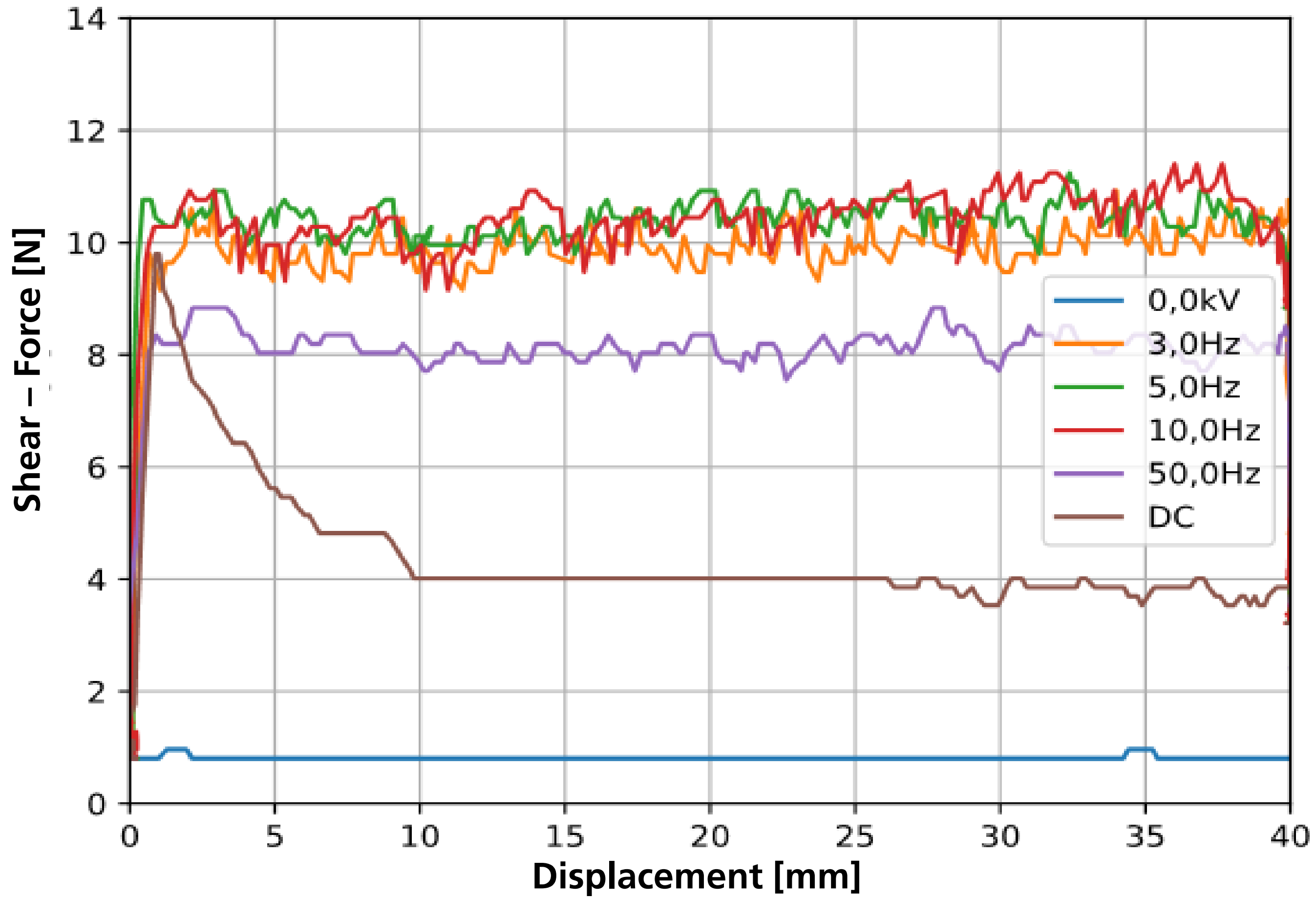


Measurement @ 3, 4 and 5 kV; DC in comparison to AC

Force peaks when the sample starts its movement

Electroadhesion – Results

PDMS; 0.3mm electrode distance; 5kV amplitude; Paper sample



- Higher shear force compared to PET
- DC applied voltage leads to a rapid shear force decrease
- Voltage frequencies between 3 and 10 Hz leads to optimal results

-> Force highly dependent on humidity

(comparison Paper > PET > PP investigated)

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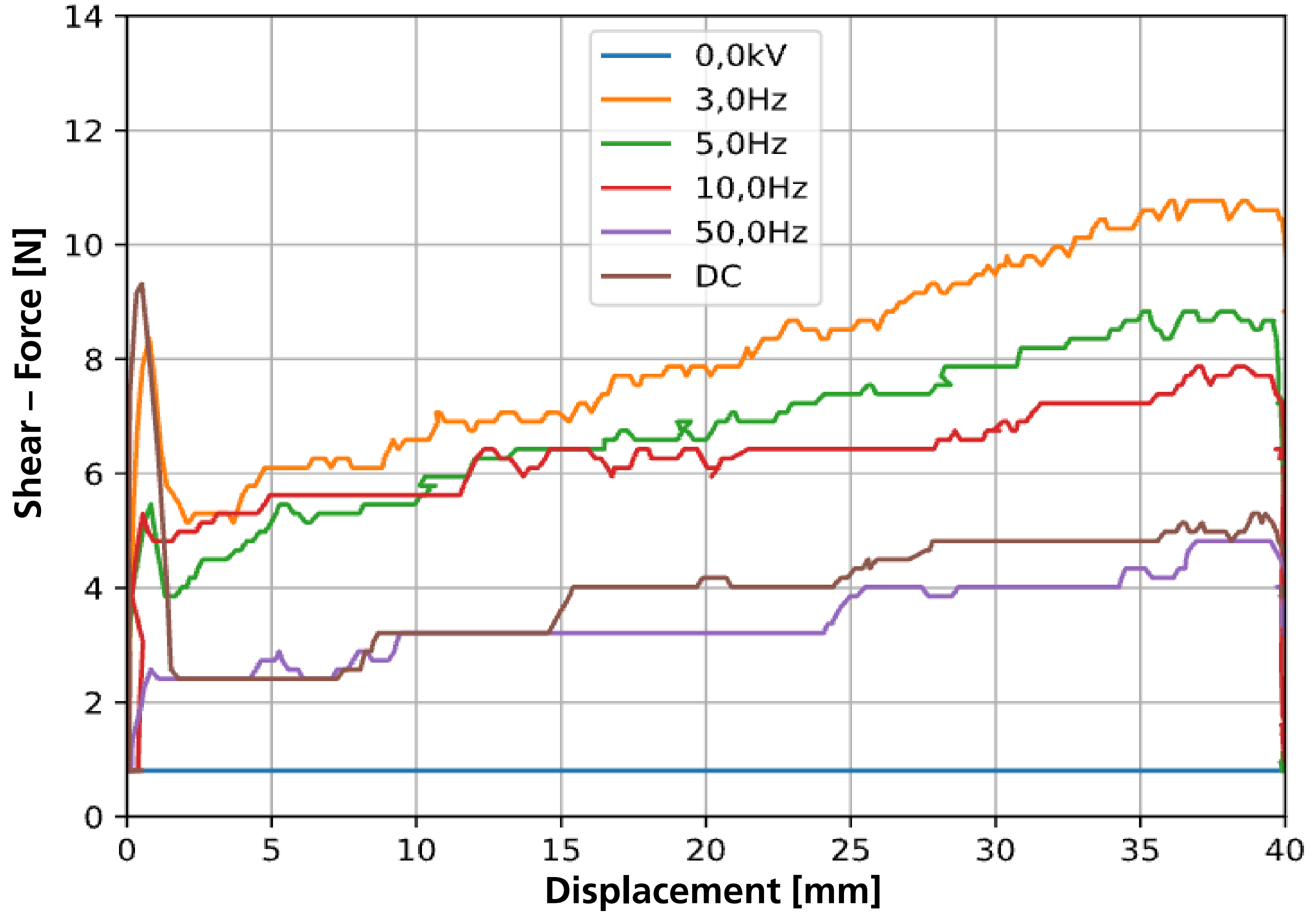
Electroadhesion – Results

PDMS; 0.3mm electrode distance; 3kV amplitude; PP sample



- Shear force comparable to PET but high influence of applied voltage form!
- High shear – force peak at measurement start.
- Shear force decreases with increased frequency.
- DC measurement and 50 Hz AC lead to similar outcome

-> Measurement dependency on humidity!

-> polarity of sample has influence on the shear force

(comparison Paper > PET > PP investigated)

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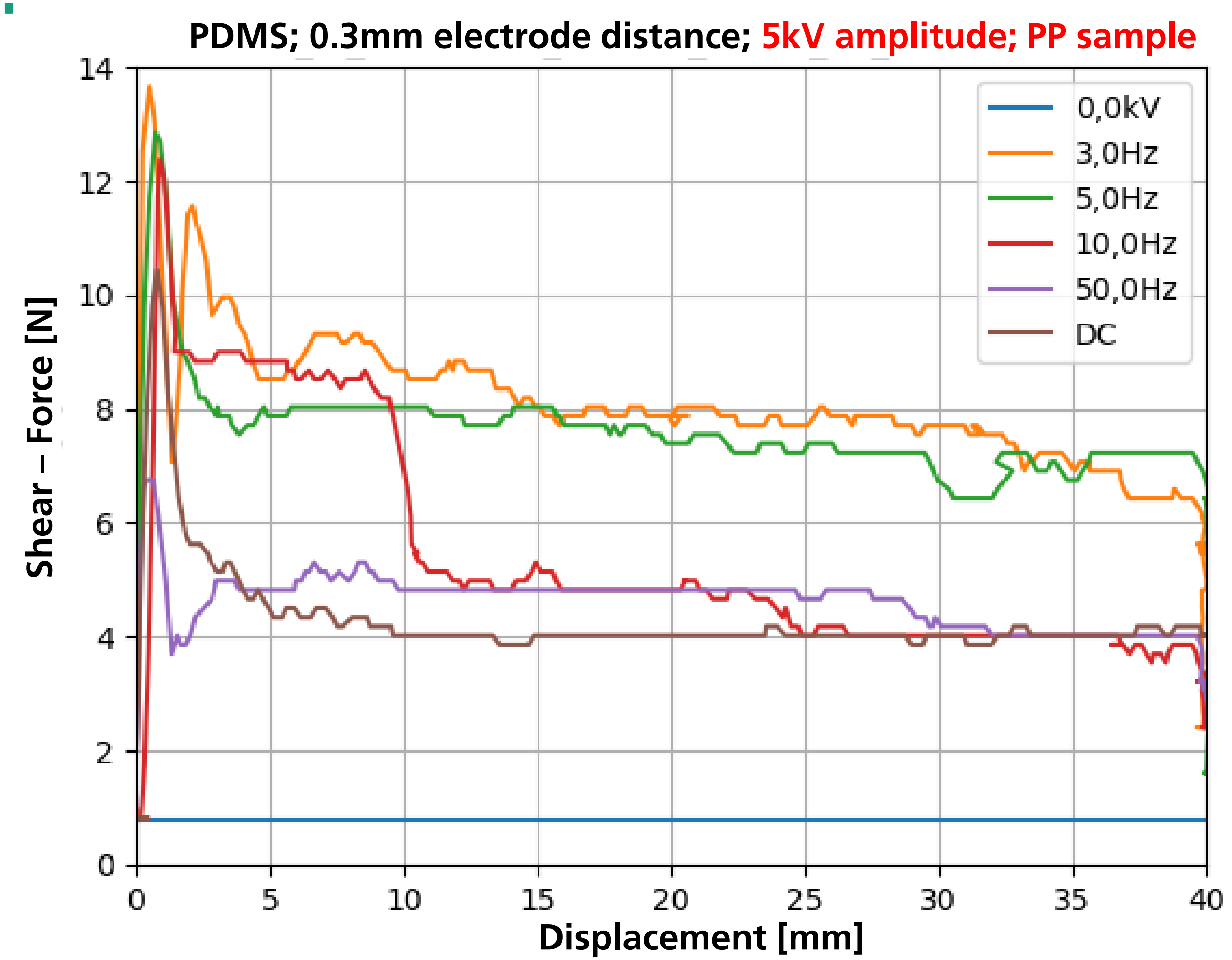
Electroadhesion – Results



-> High peak forces at the beginning of the measurement

-> Force highly dependent on humidity

-> Saturation effect?

-> The polarity of the polymer has an influence on the shear force

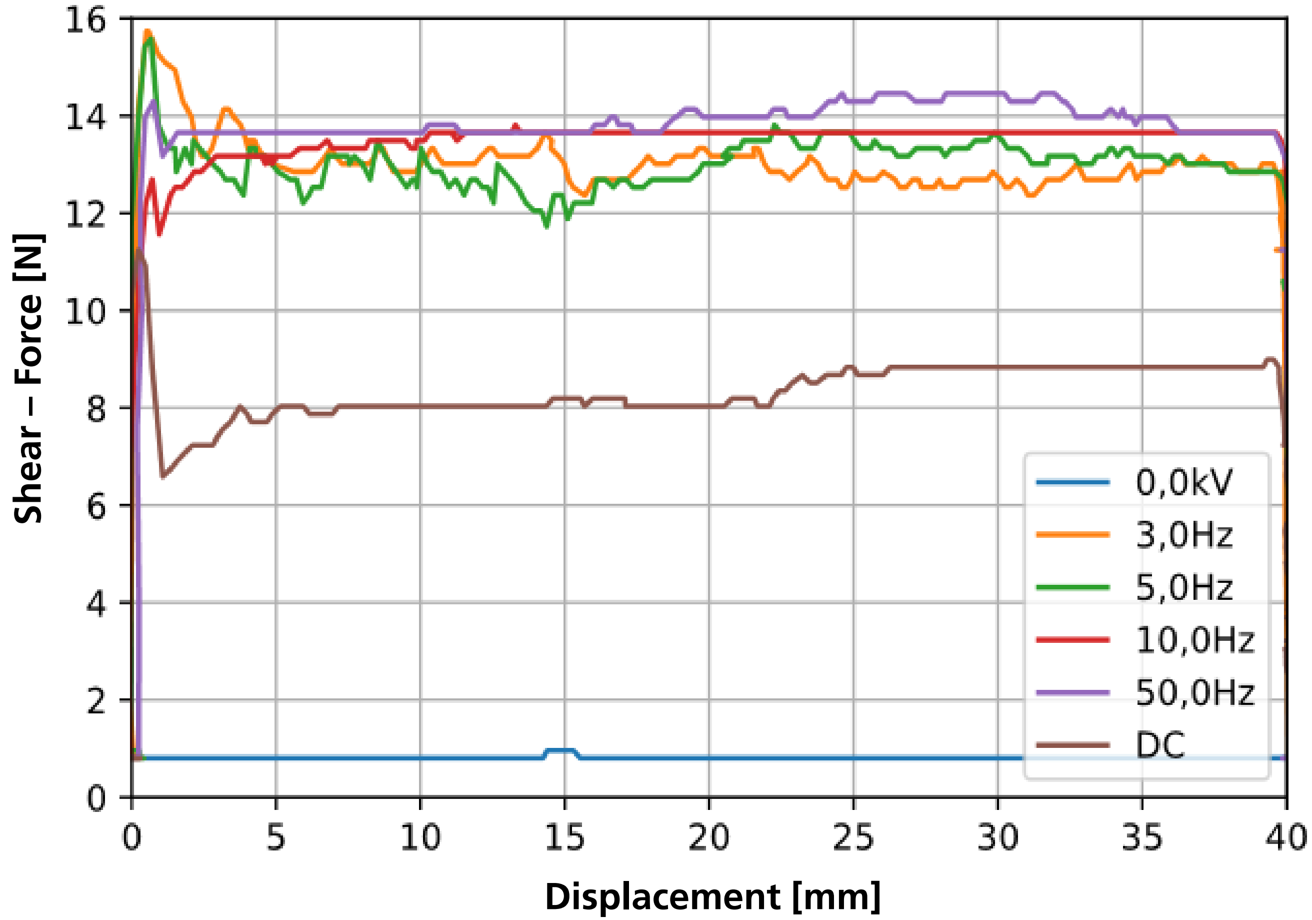
(comparison Paper > PET > PP investigated)

Results suggests low amplitude of gripping forces for low polarity

BUT…

Electroadhesion – Results

PDMS; 0.3mm electrode distance; 5kV amplitude; PI sample



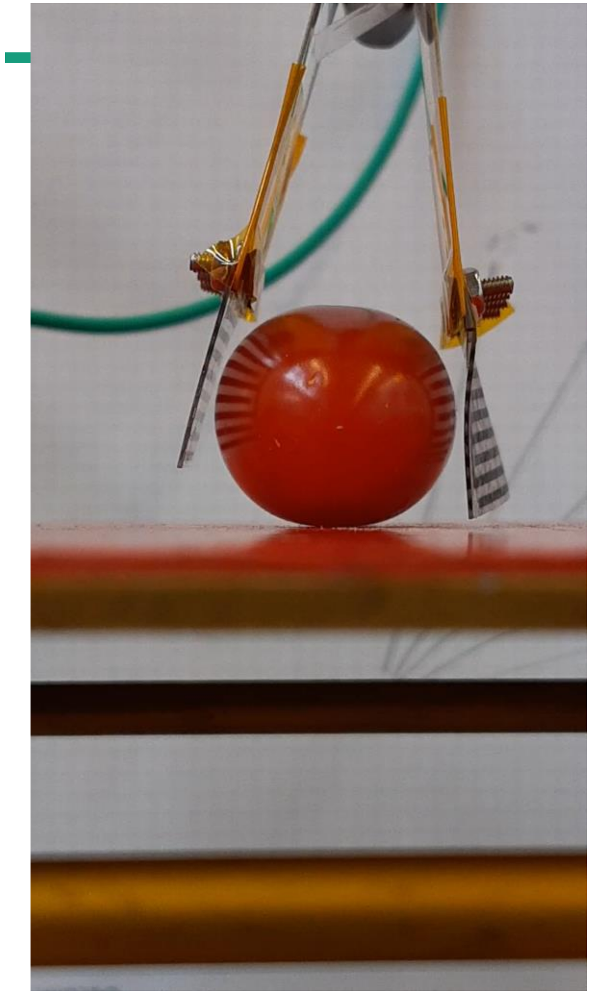
- Highest shear - force compare to PET, PP and paper
- High shear – force peak at the beginning of the measurement
- DC measurement are on a lower shear force level.

-> Measurement dependency on humidity! Here 40 rel% humidity

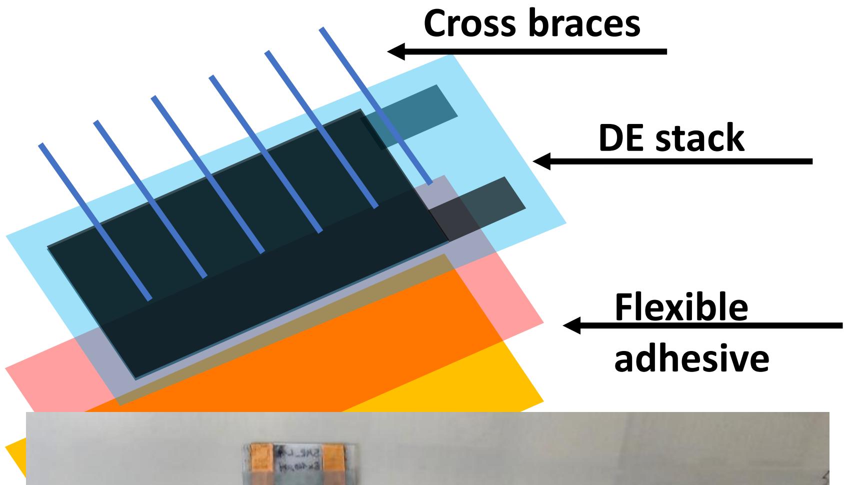
-> polarity of sample has influence on shear – force

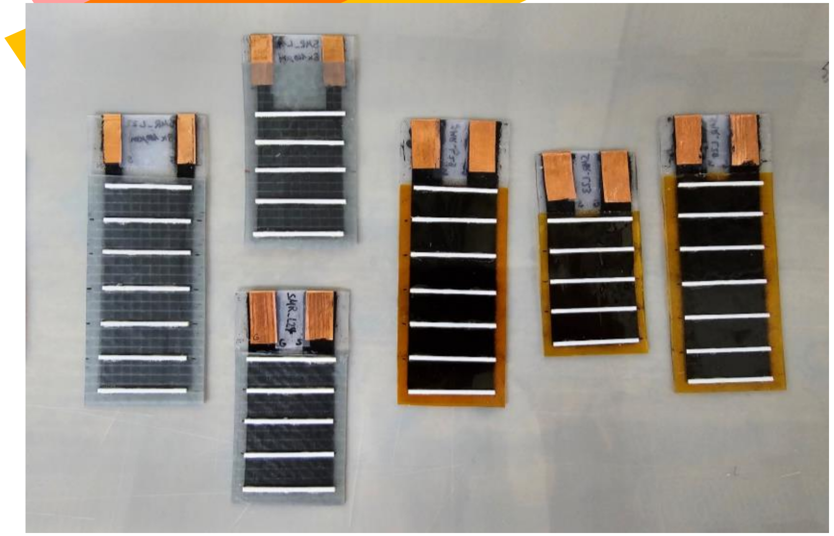
(comparison PI > Paper > PET > PP investigated)

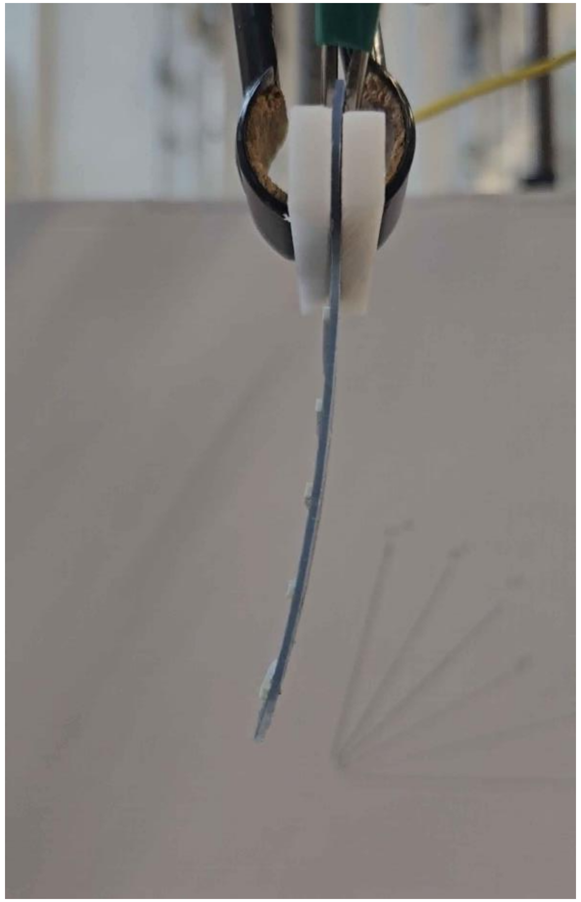
Electroadhesion – Electroadhesive applications



Electroadhesion – Electroadhesive gripping -> the Future with Unimorph DEA







Electroadhesion – Summary

- High gripping strengths possible on various types of organic surfaces! Depending on the applied electric field strength and form.
- Laser structuring of dielectric top layer reduces the stick slip effect without major influence of electroadhesion effect.
- Variable polymer substrates tested, different electroadhesive behaviors for a given set of parameters, BUT become comparable by parameter modulation.

SCIENTIFIC MAIN CONCLUSION:

- Electroadhesion is profundly related to the capacity to polarize the surface of the gripper surface and of the surface to be grasped.
- Effectively demonstrated as highly modulable to the amplitude of the surface polarity / dipole relaxation time.
- Target: similar forces reacheable for all surface type with basic parameter modulation.

OUTLOOK

- Combination of Unimorph DEA bending actuator with Electroadhesion for highly adjustable gripping in soft robotic.
- Establishment of additive processing for electroadhesive sample production.

