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DTU

Simulation of Topology Optimized Electrothermal Microgrippers

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- The COMSOL Model
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  - Mesh Settings
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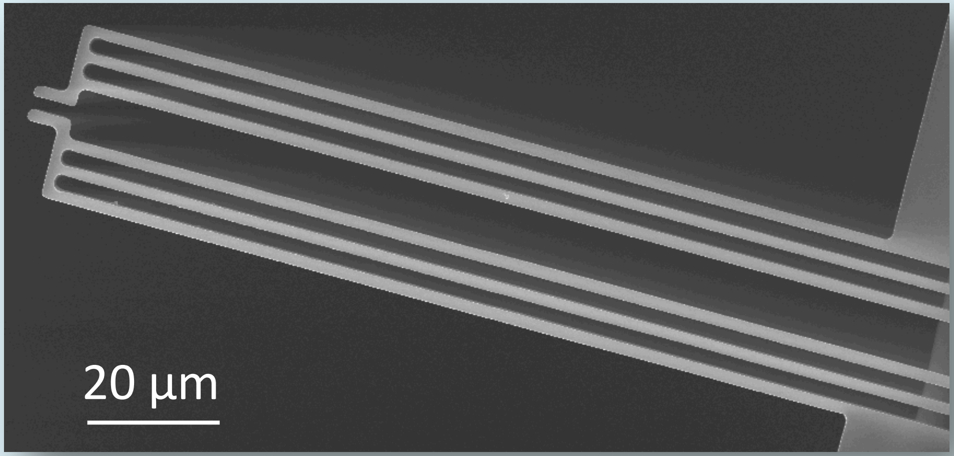
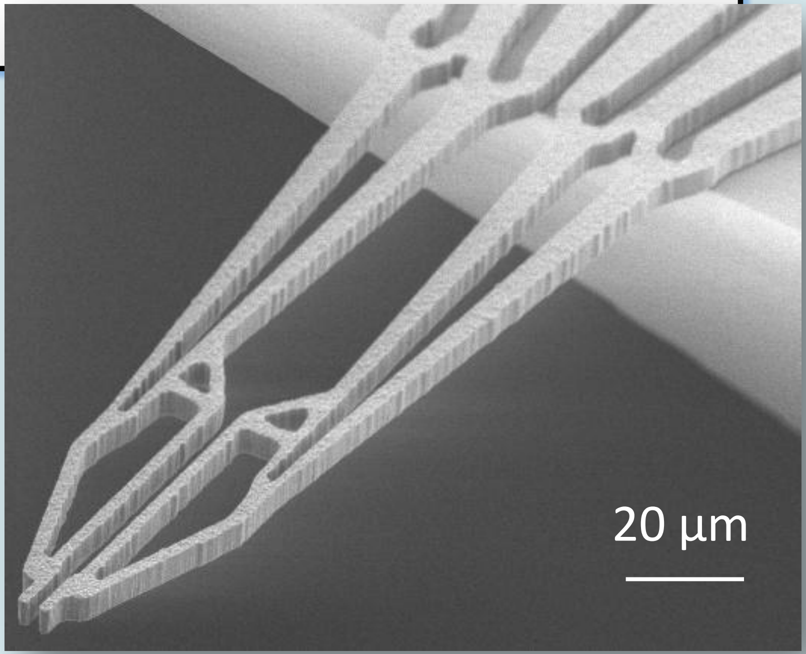
- Results & Discussion

Electrothermal Microgrippers

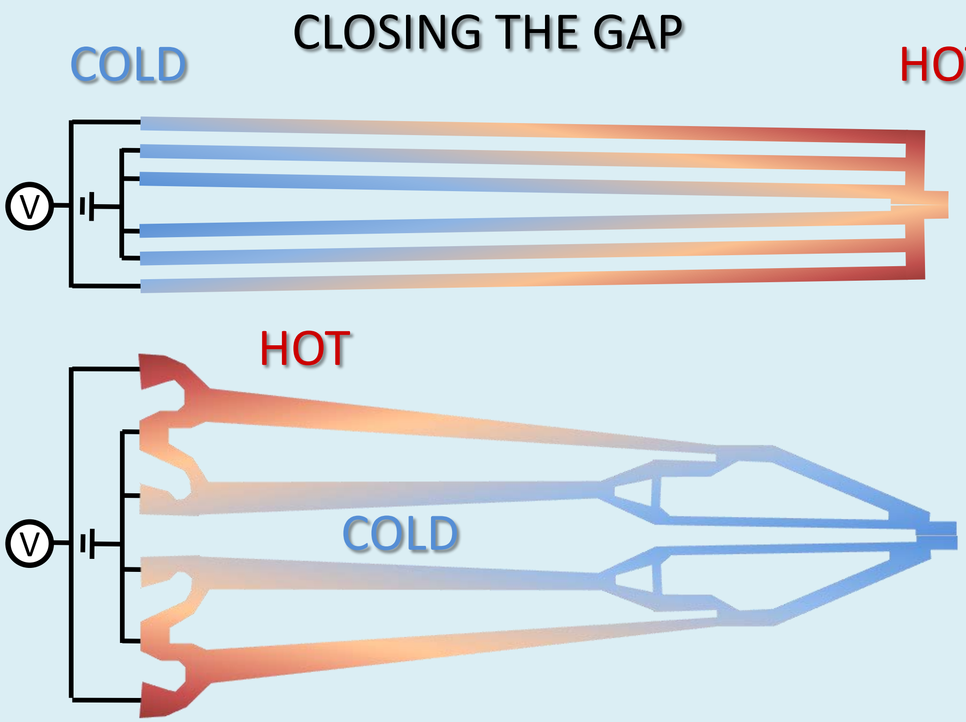
- Conventional Three-Beam Design
  - ☑ Compact & flexible design, easy to operate
  - ☒ Not strong enough
- Topology Optimized Design
  - ☑ Flexible design, easy to operate
  - ☑ Much higher force at the same size!





Operation Principle

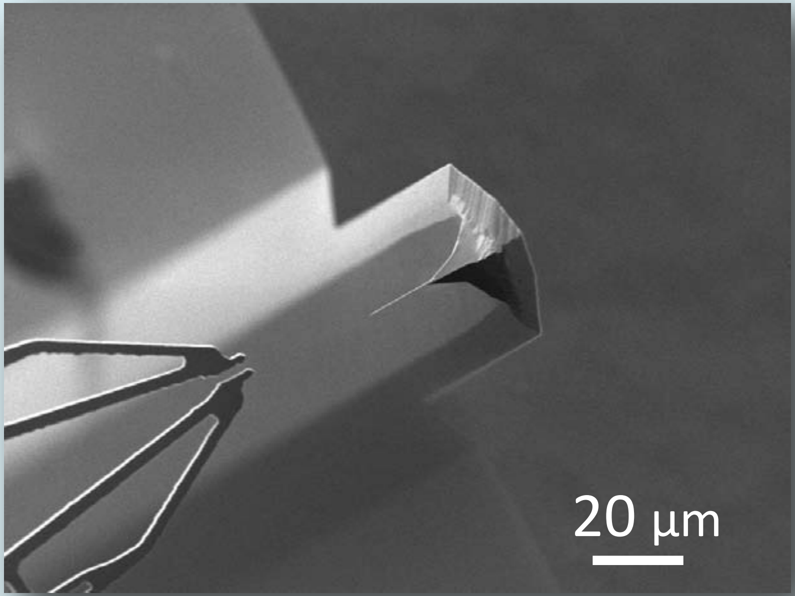
- Same for both three-beam and topology optimized designs
- Based on resistive heating
- Open & close

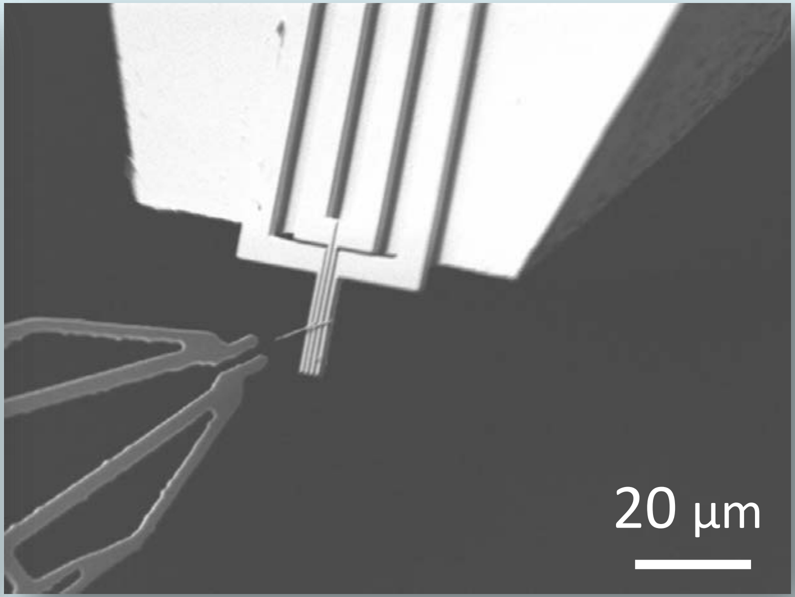


Nanomanipulation & Assembly

- Basic nanomanipulation of carbon nanotubes/nanowires
  - On TEM grids for structural analysis
  - On electrodes for electrical characterization
- Assembly of nano-devices
  - CNT/NanoBIT-enhanced AFM super-tips

Collaboration with V.Eichhorn





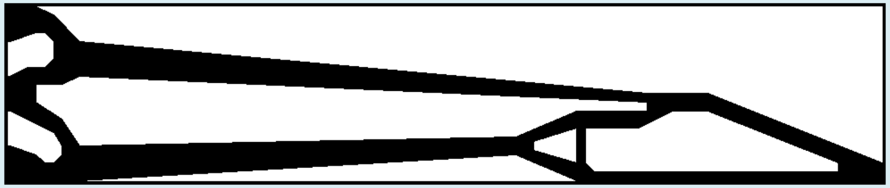
Motivation

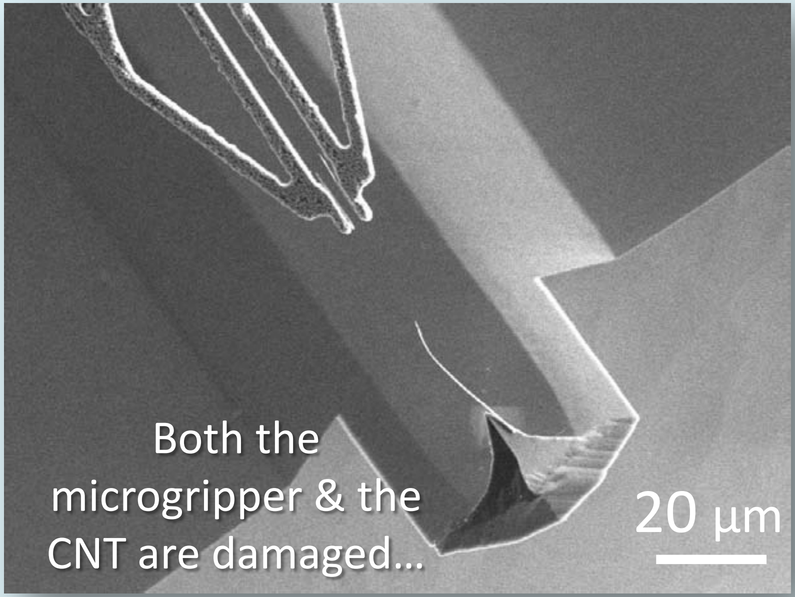
It is important to estimate…

- The influence of design variations
  - During image processing after topology optimization
  - During various microfabrication steps
- The operation temperature and the temperature at the end-effectors
- The effect of the microgripper interface

Grey-scale output from the optimization algorithm…

Improved binary image…

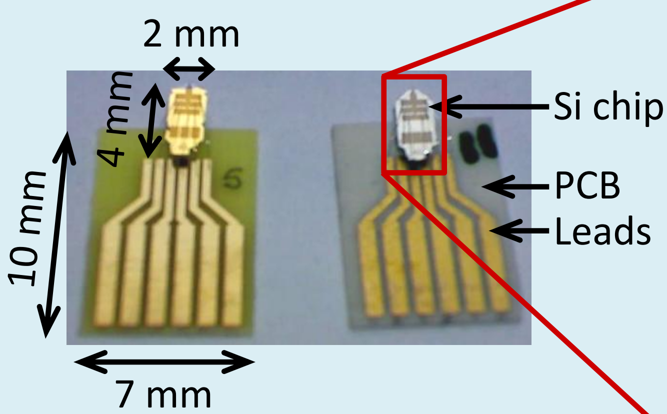


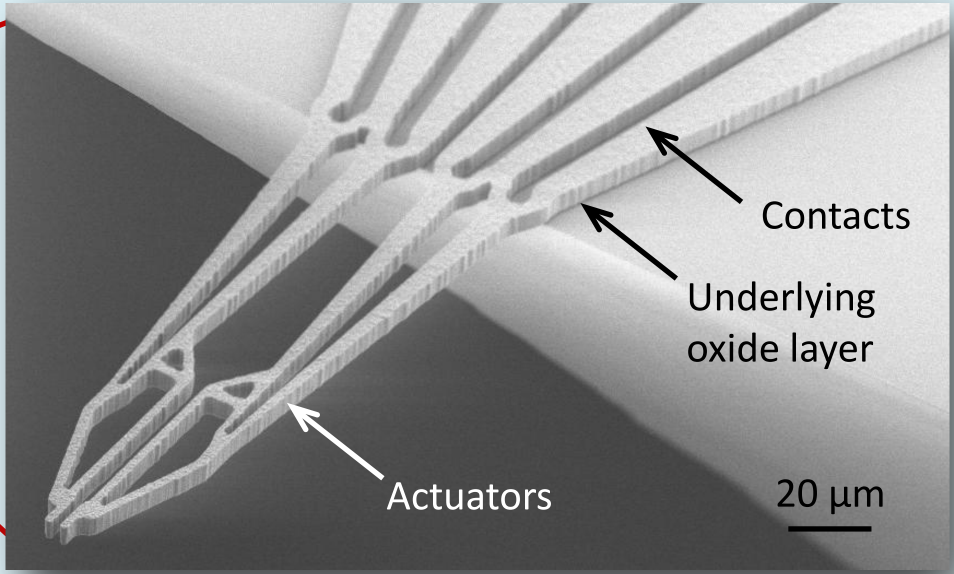


The Microgripper Interface

It is important to estimate…

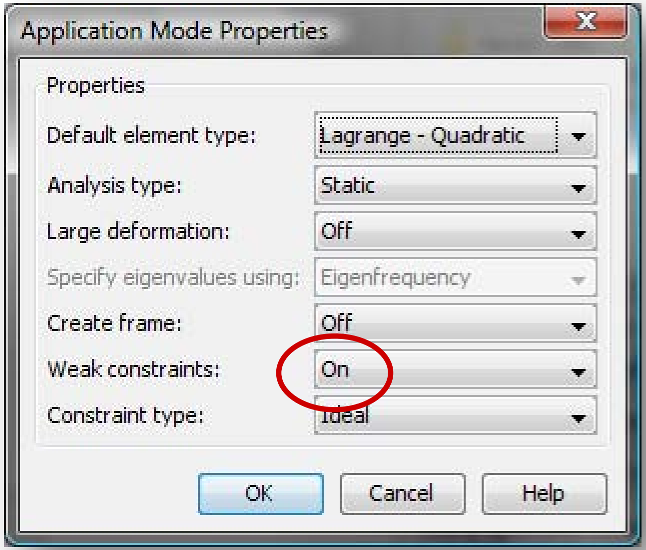
- The influence of design variations
  - During image processing after topology optimization
  - During various microfabrication steps
- The operation temperature and the temperature at the end-effectors
- The effect of the microgripper interface





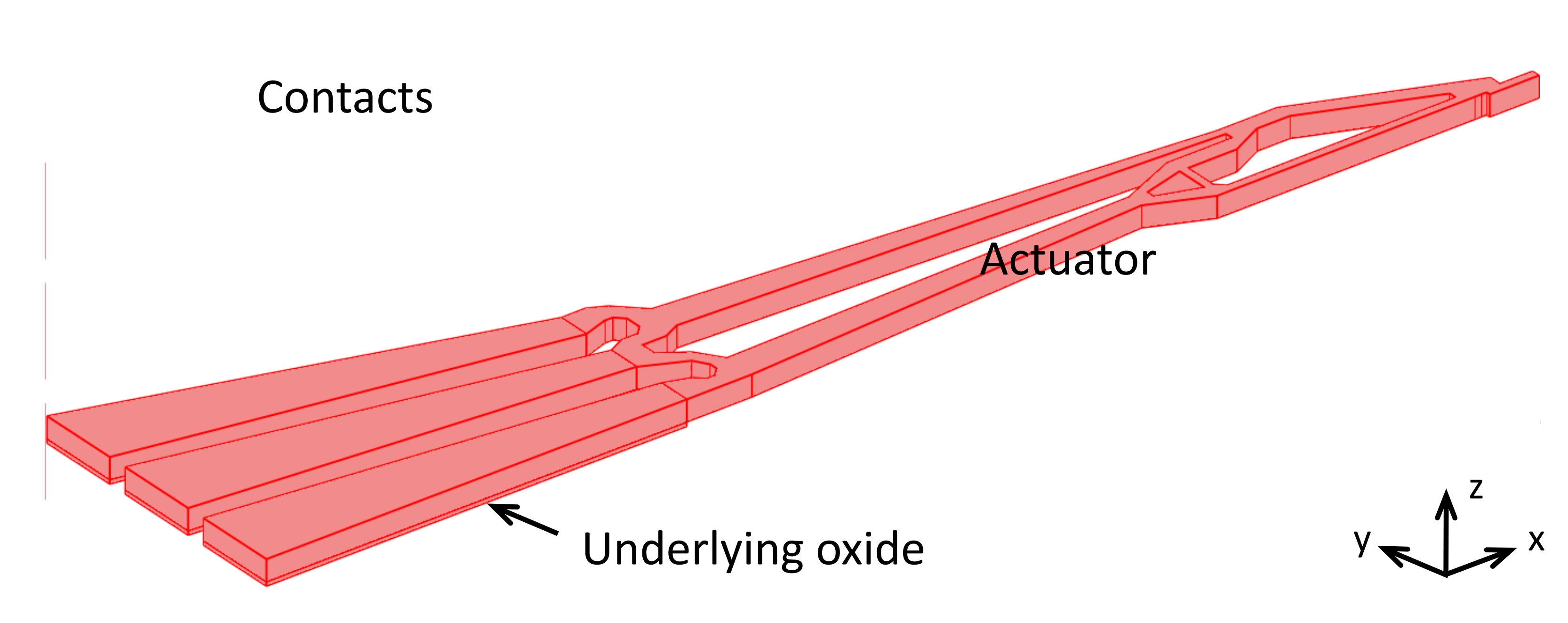
The COMSOL Model

- 3D Model
- Three application modes
  - Conductive Media (dc)
  - Heat Transfer by Conduction (ht)
  - Solid, Stress Strain (smsld) → Weak constraints on!



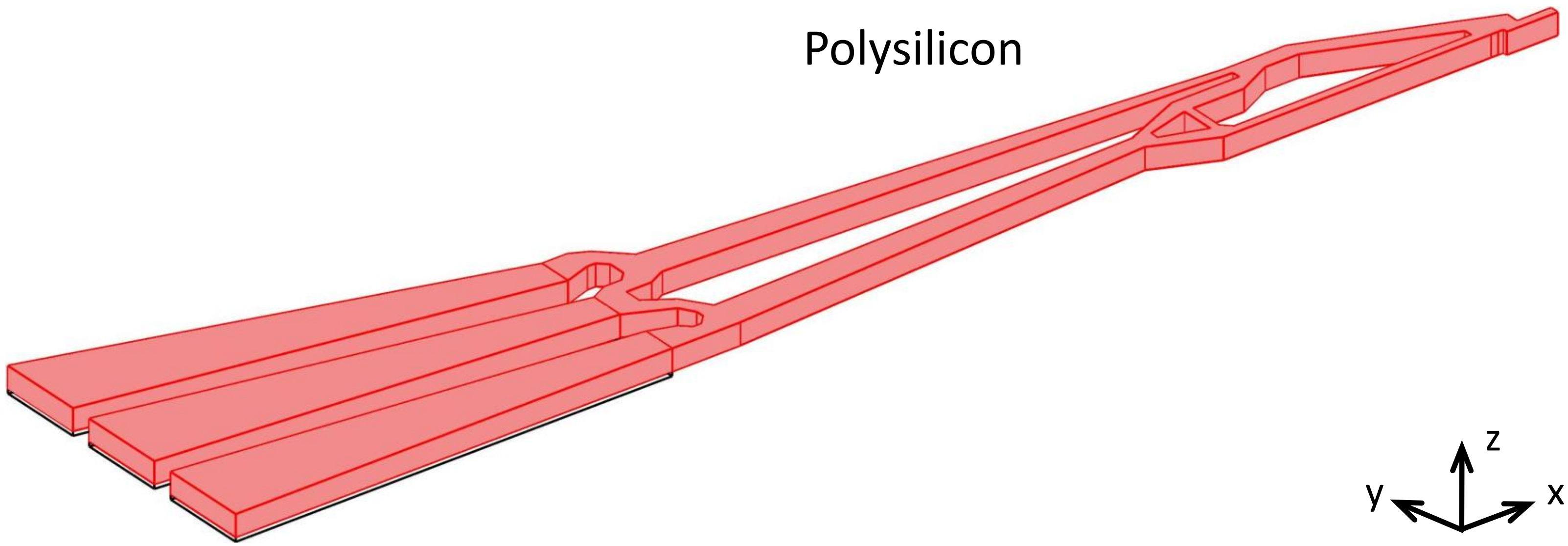
Geometry Settings

- 2D CAD drawing from a DXF file
- 3D model by extruding the geometry along the z-axis
  - Contact leads
  - 1 µm-thick oxide underneath



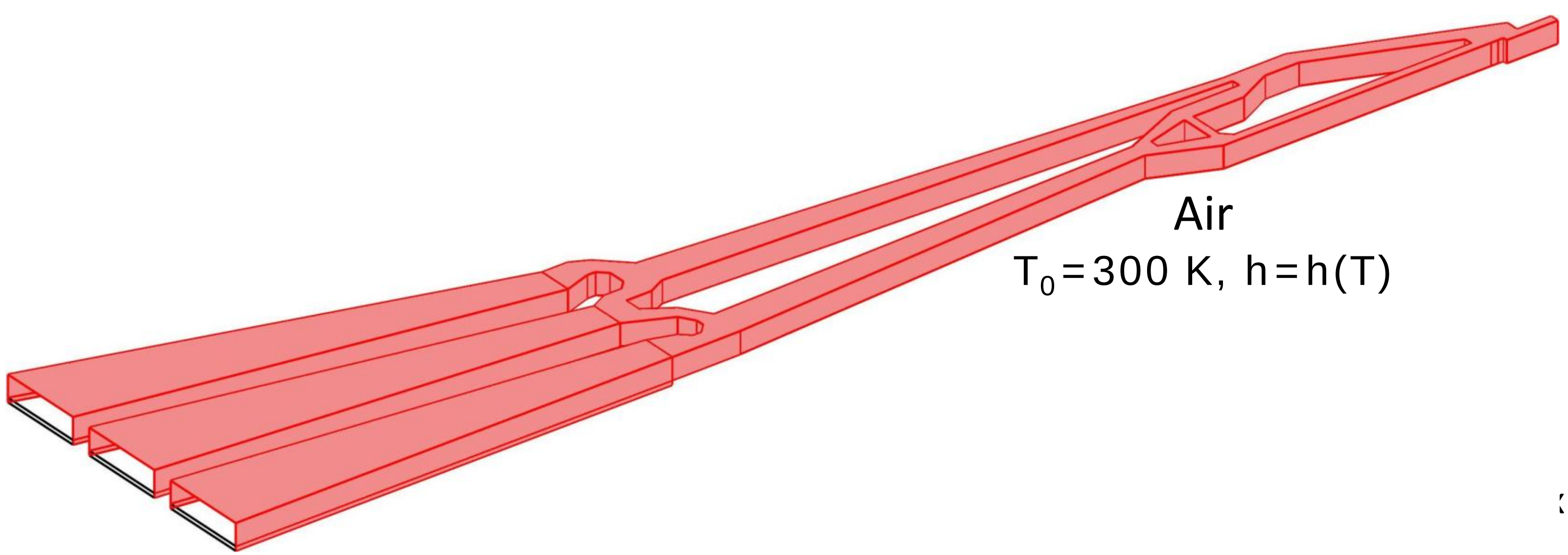
Subdomain Settings

- Silicon dioxide & polysilicon from the MEMS materials library
- For polysilicon, α = α(T), σ = σ(T) and k = k(T) (Geisberger 2003)
- For all subdomains
  - Resistive heating
  - Thermal expansion



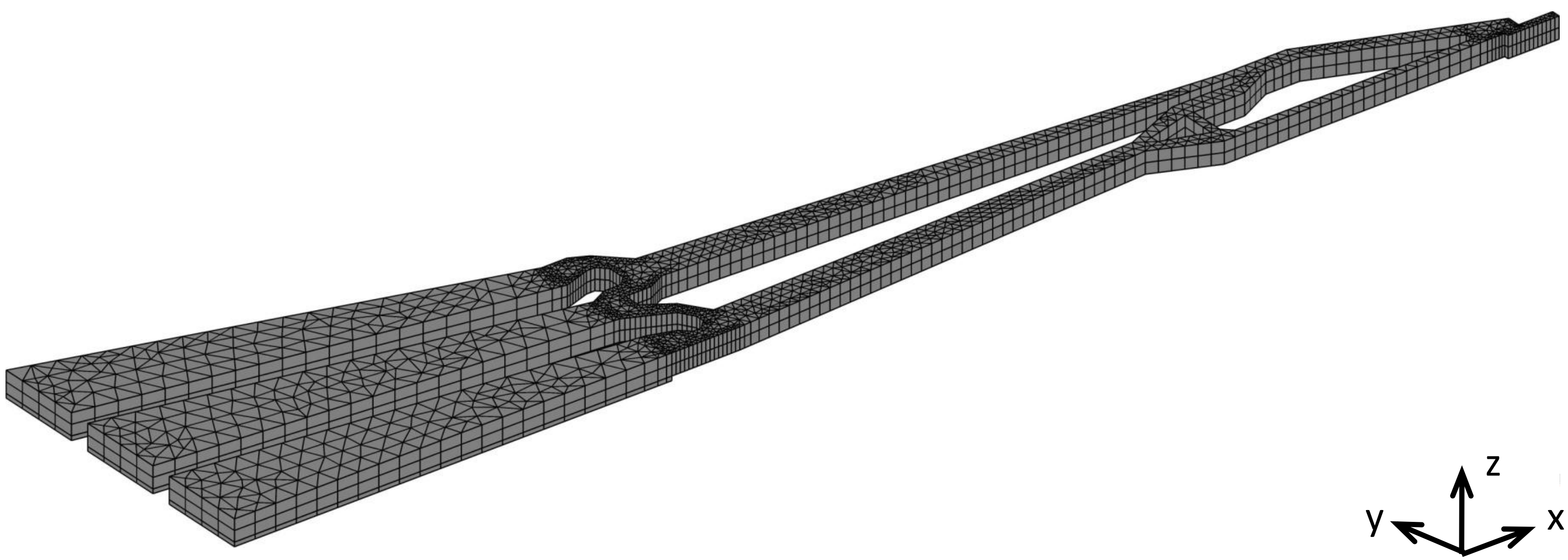
Boundary Settings

- Electrical domain
- Thermal domain
  - Fixed temperature underneath the oxide
  - Air convection, with h= h(T) (Geisberger2003)
- Mechanical Domain



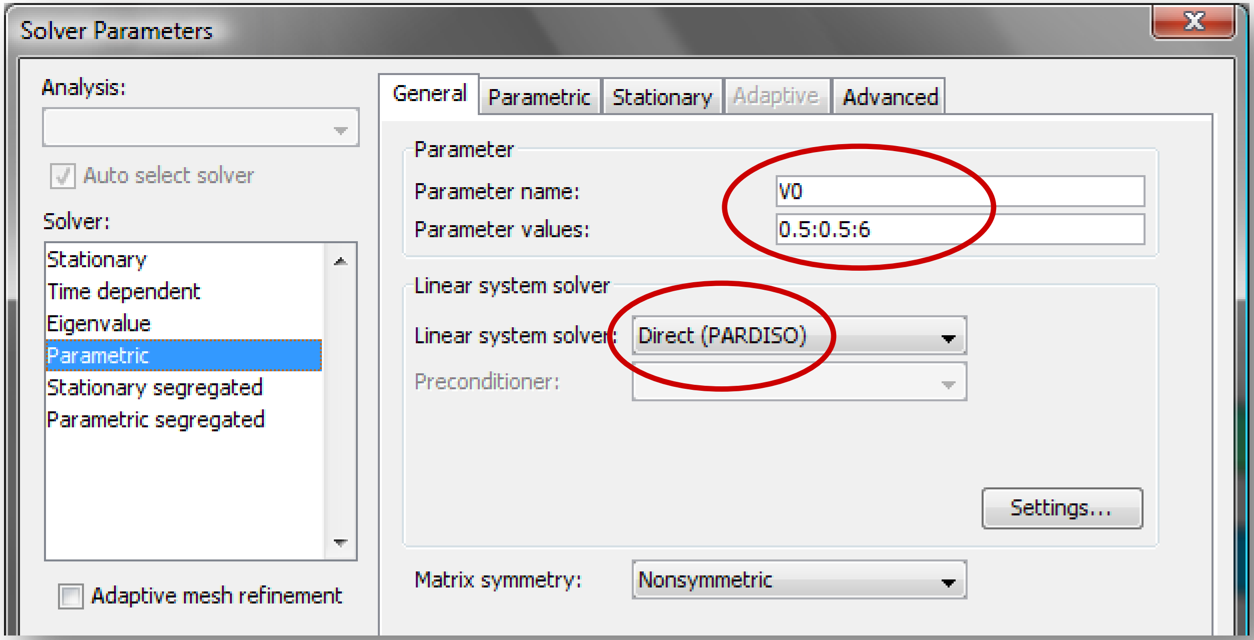
Mesh Settings

- Variable mesh density
  1. Meshing the critical edges
  2. Meshing the upper boundaries
  3. Sweeping through all subdomains (multiple layers)



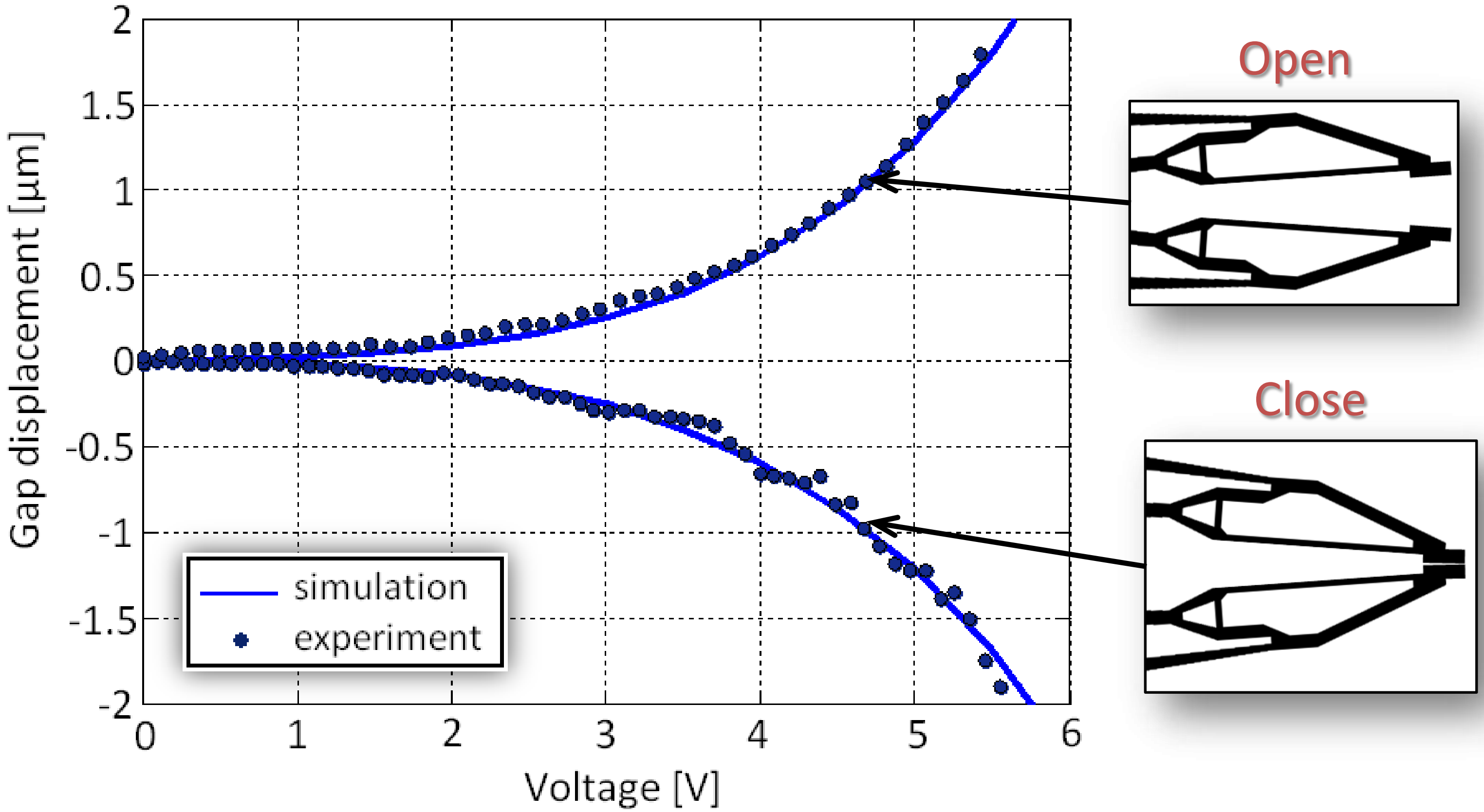
Solver Settings

- Simulation of the actuation behavior
  - Parametric solver with default settings



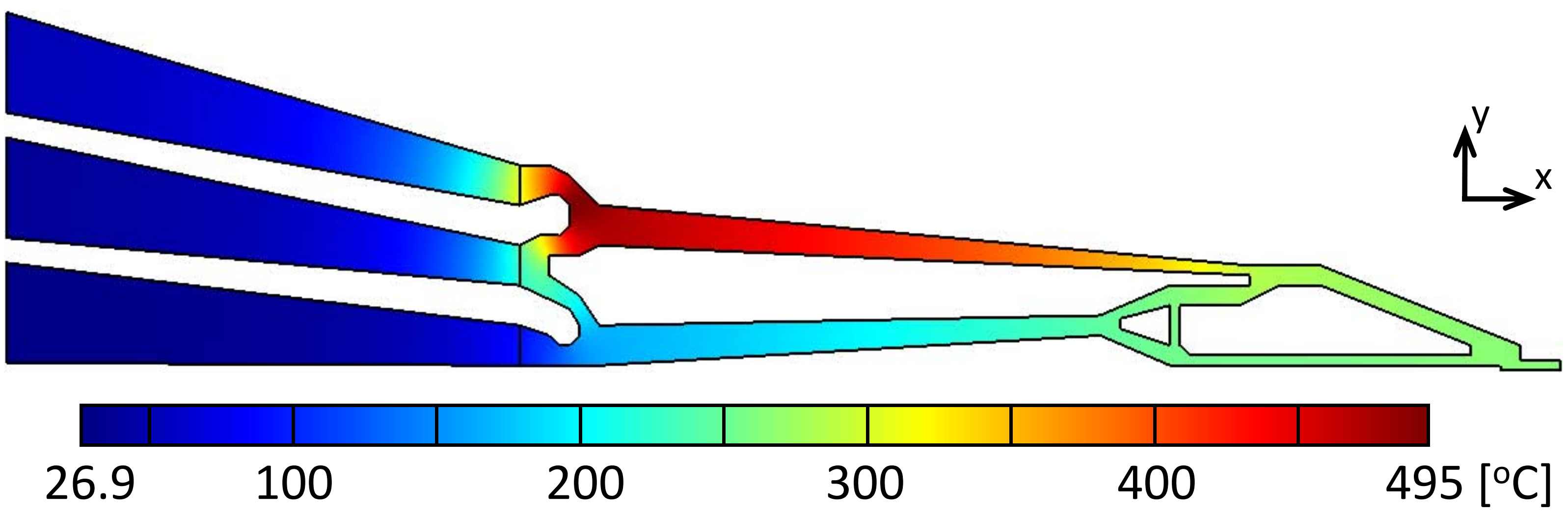
Displacement Results vs. Experiments

- Actuation under an optical microscope at room temperature
- Simultaneous filtering and image processing



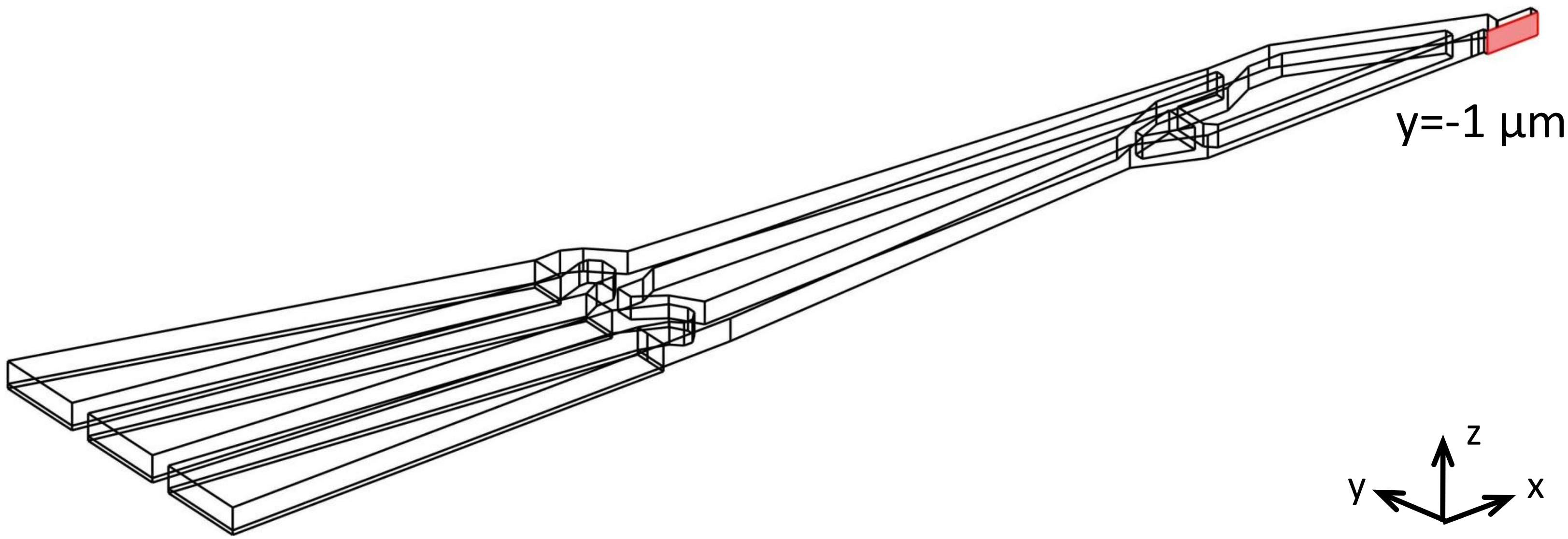
Temperature Results

- Temperature distribution within the actuator
  - Gap fully closed → 1 µm-displacement, V_0 = 5.6 V
- Ongoing Raman measurements agree with the profile!



Finding the In-plane Stiffness

- Settings:
  - Prescribed displacement at the end-effector boundary
  - Solving only for the mechanical domain
  - Integrating the force over the boundary



Stiffness Results

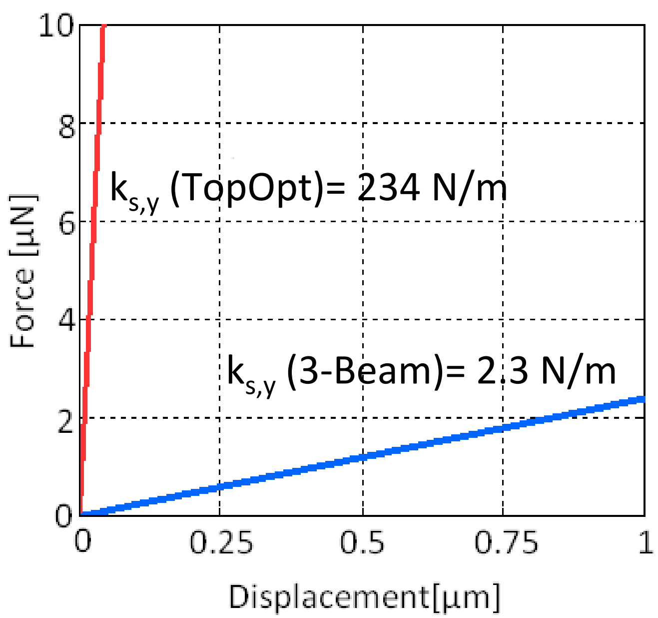
› Results:

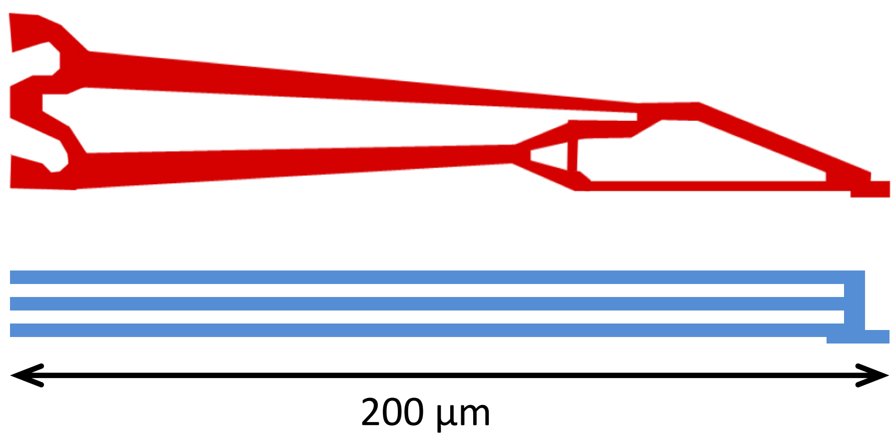
– Conventional design: $k_{s,y}$ = 2.3 N/m

(Agrees well with force measurements…)

– Optimized design: $k_{s,y}$ = 234 N/m

☑ ~10^2 times improvement at the same size!





Acknowledgements

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  - NANOHAND
  - NANORAC
- COMSOL A/S (Denmark):
  - Lars Gregersen
  - Thure Ralfs

NanoHand

NANORAC

THANK YOU FOR YOUR ATTENTION

QUESTIONS & COMMENTS?

Material Properties (I)

Temperature, T [K]	Thermal Conductivity, k [W/(m·K)]	CTE, α [K^{-1}]
300	65.00	2.5×10^{-6}
400	53.75	3.1×10^{-6}
500	46.54	3.5×10^{-6}
600	40.00	3.8×10^{-6}
700	35.00	4.1×10^{-6}
800	32.08	4.3×10^{-6}

Electrical Conductivity, $\sigma = 1/\rho = \beta_{1+} \beta_{2.} T^{\beta 3}$	
Coefficient	Value
β_1	2.6×10^{-3}
β_2	8.16×10^{-9}
β_3	1.946

Material Properties (II)

Temperature [K]	Heat Transfer Coefficient, h [W/(m²·K)]
300	1101.7
400	1214.3
500	1381.0
600	1520.7
700	1660.3
800	1799.9