A Gecko-Inspired Chip-Integrated Reversible Adhesive

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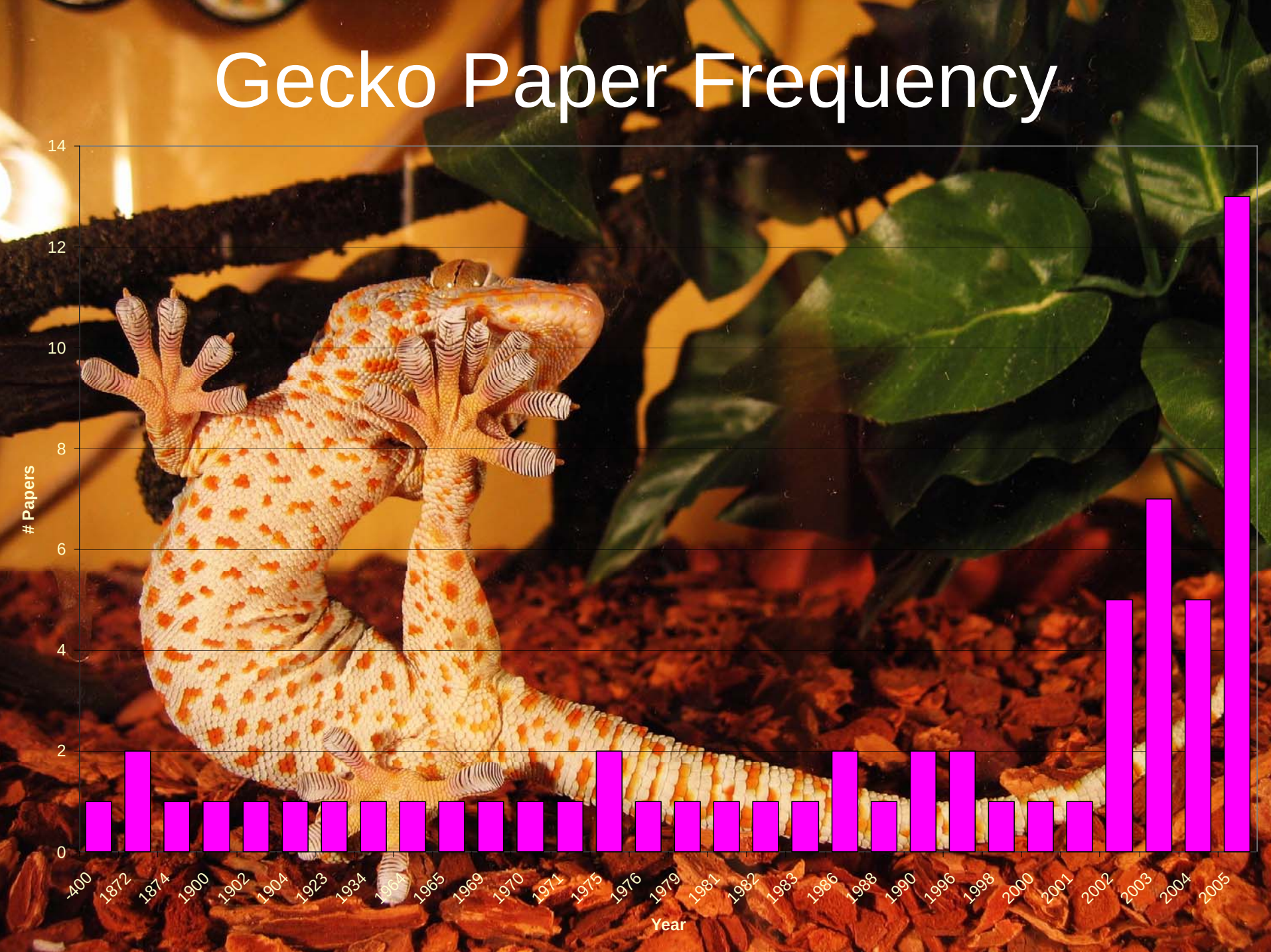
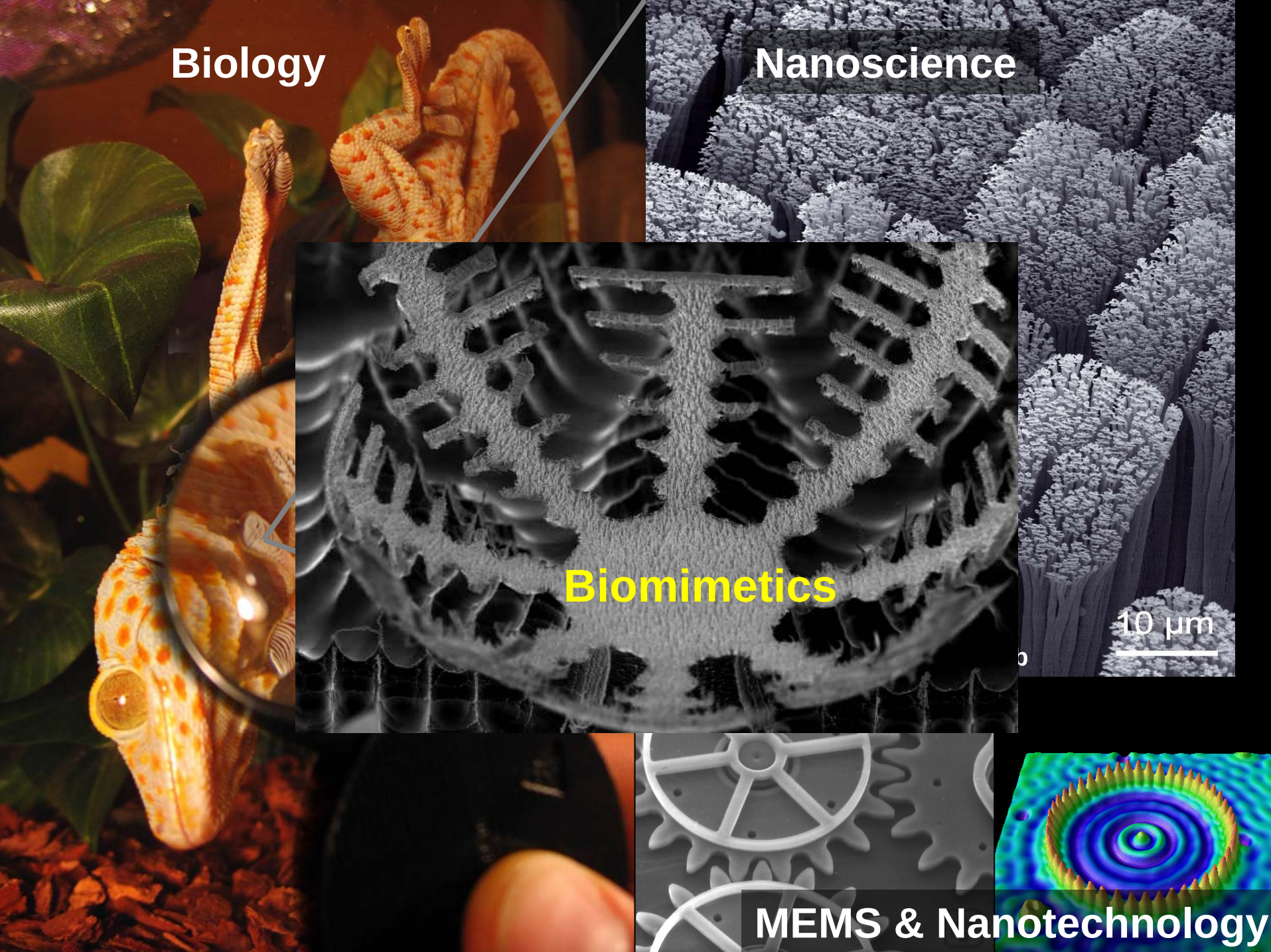
Outline

- **Introduction & Motivation**
- Gecko Adhesion Mechanism
- Integrated Micro/Nanostructures
  - -adhesion testing
- Adhesion Control
  - -adhesion testing

Gecko Paper Frequency



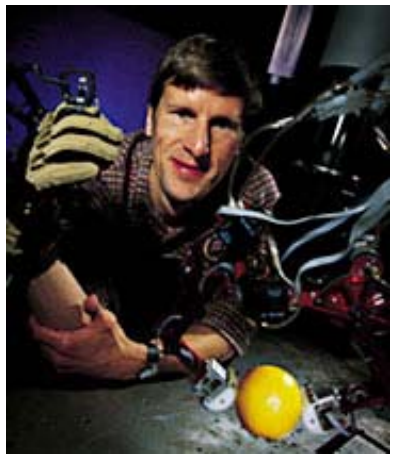

Biology
Nanoscience
Biomimetics
10 µm
MEMS & Nanotechnology

Stanford Report, March 12, 2003

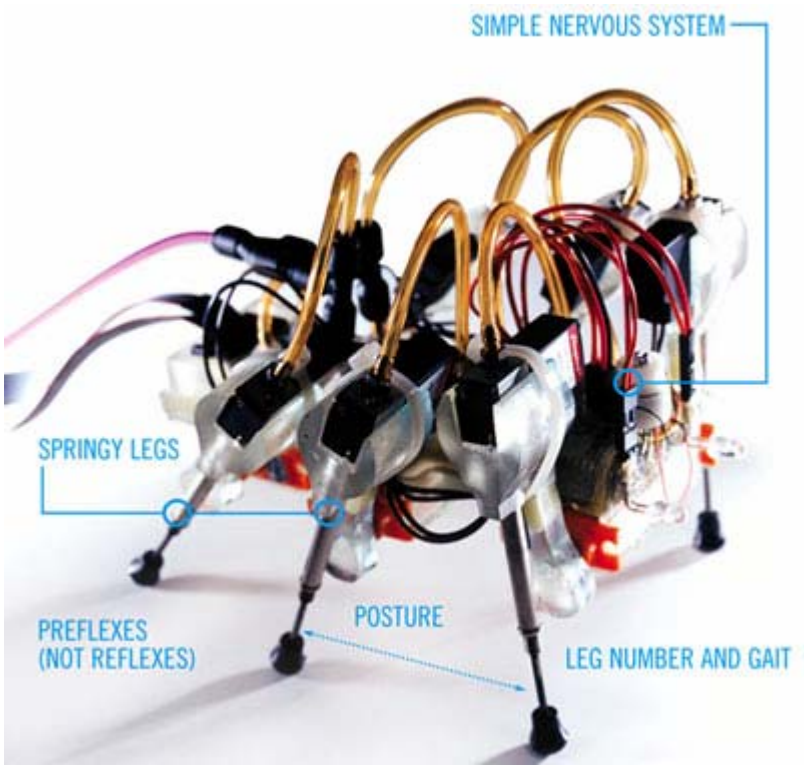
Mimicking cockroaches' 'mechanical intelligence'

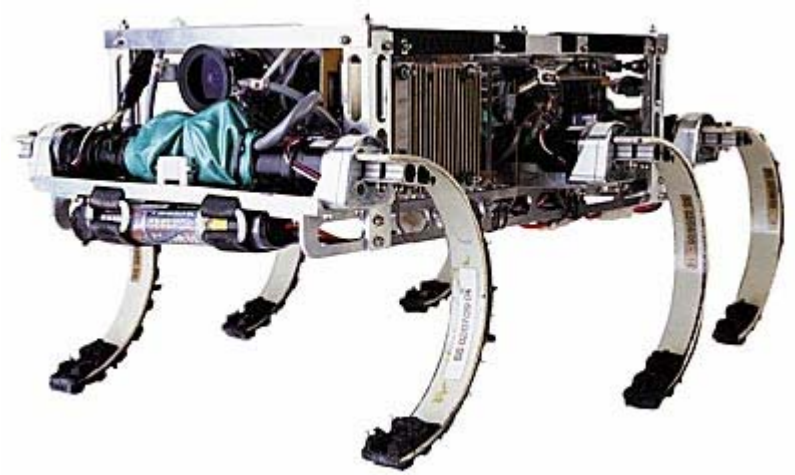
Development of legged robots could help in navigating disaster sites, other dangerous and difficult-to-reach places

BY BRONWYN BARNETT



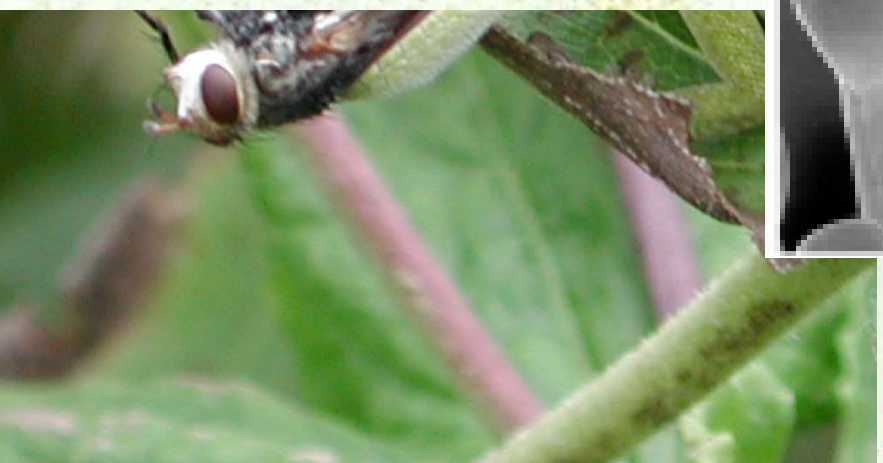
Mark Cutkosky

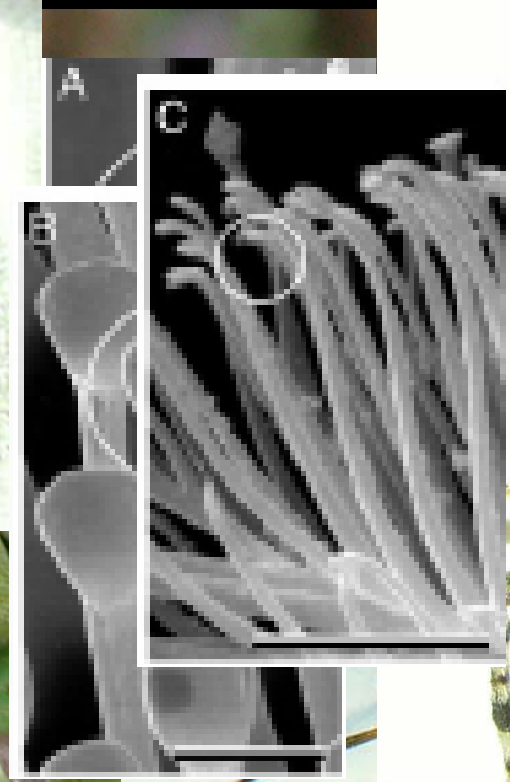




“Fine hair” adhesive motif

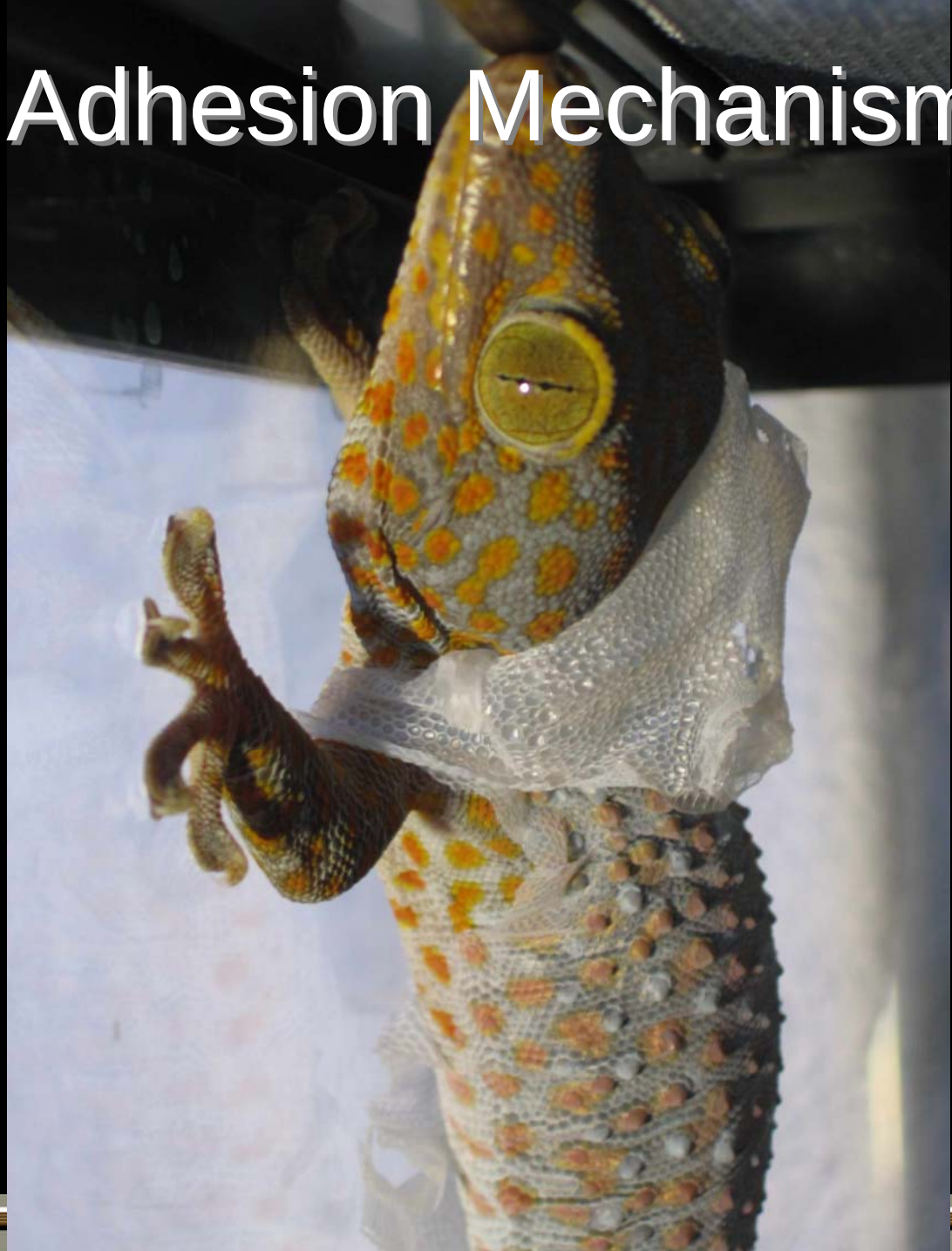
- Also found in other lizards and insects
  - e.g. anoles, crickets, beetles, flies, spiders.





University of Neb
Department of Er

Adhesion Mechanism



van der Waals

Short range London Dispersion Force

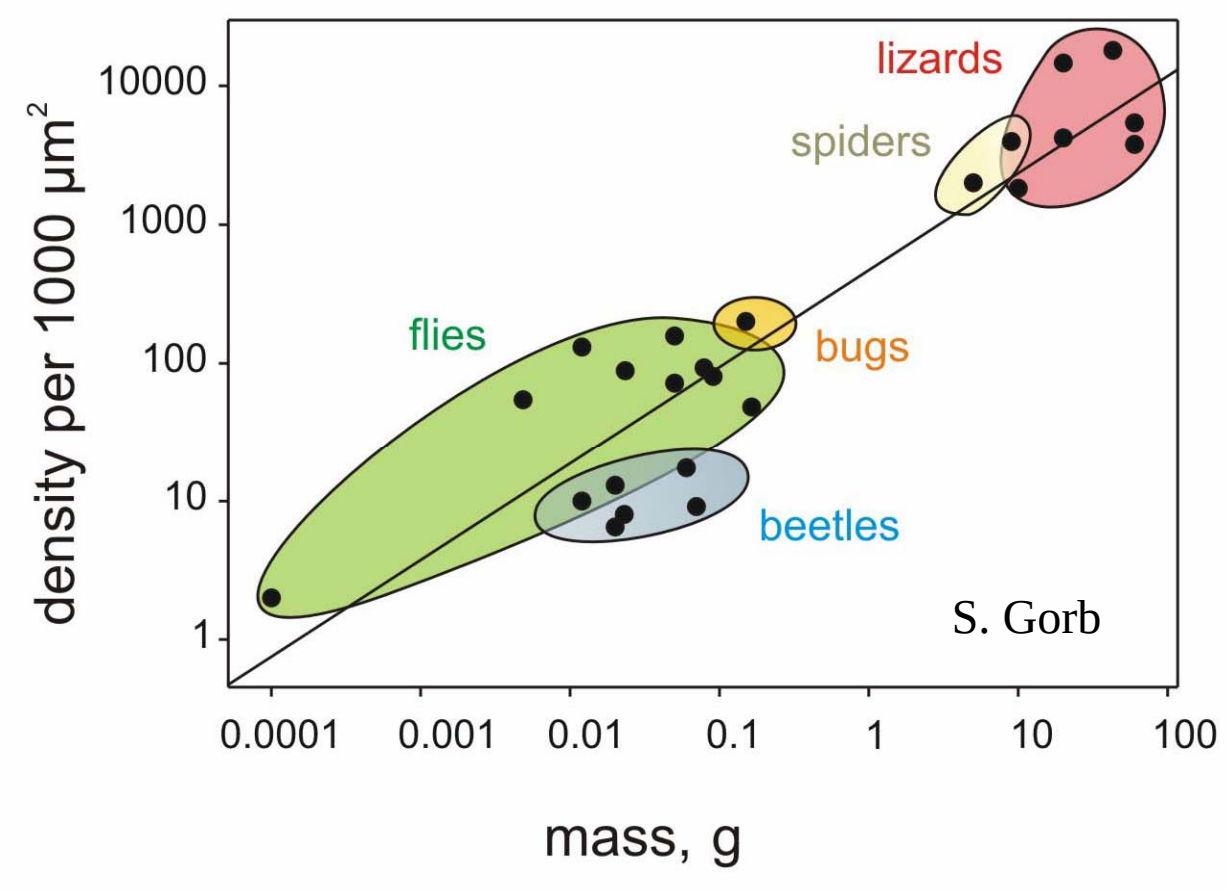
$$F = \mathbf{n}\, H\, R / 6D^2$$

H = Hamaker Constant (surface property)

R = Radius

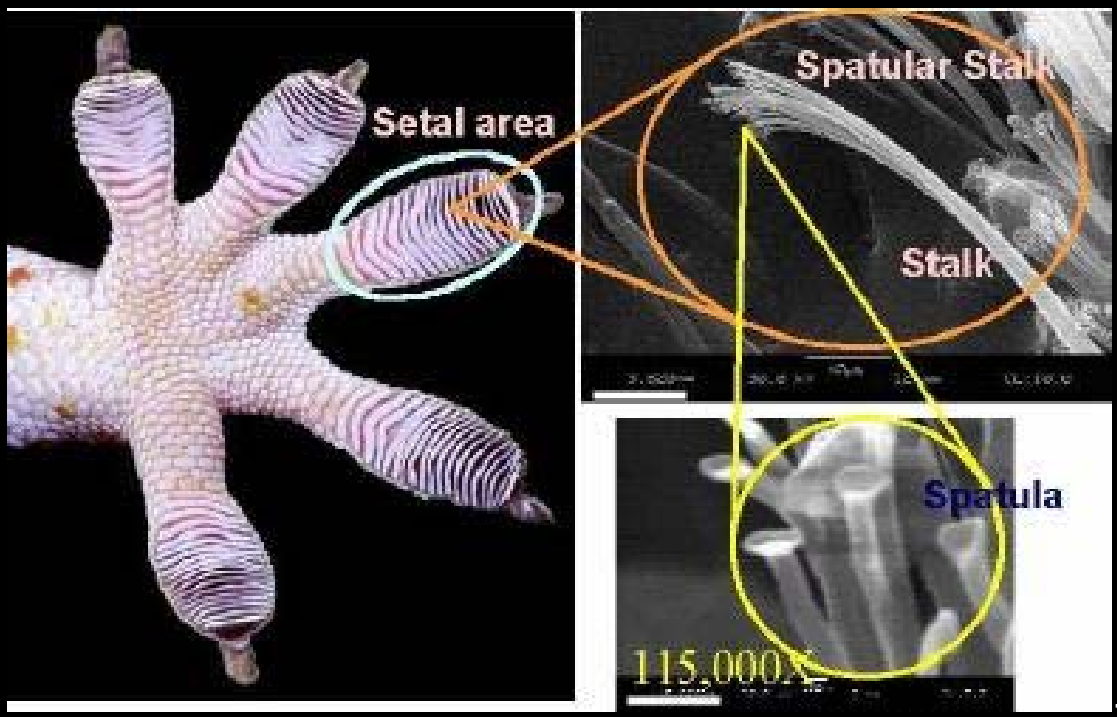
D = Cut-Off Distance (variable)

n = Number of Contacts

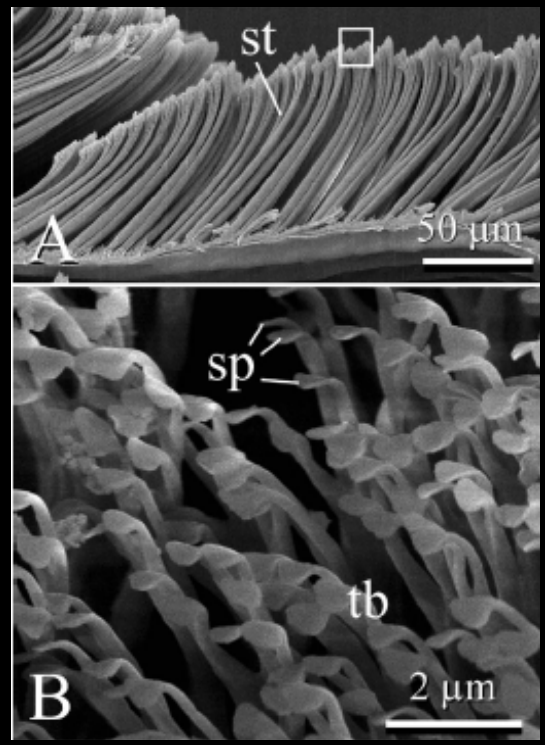


Arzt, Gorb, Spolenak PNAS 2003

Multi-scale conformal structure



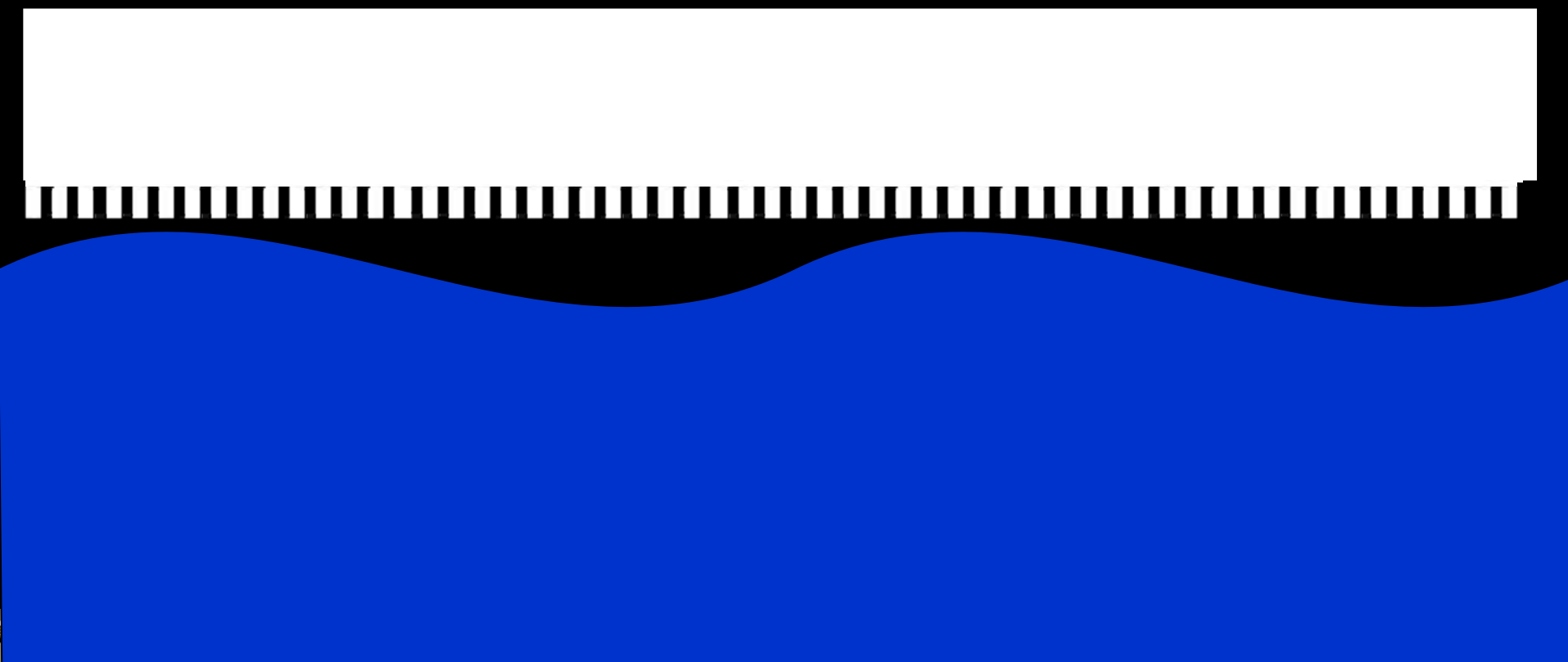
Autumn, K., *et al.*, PNAS, **99**(19): p. 12252-12256 (2002).



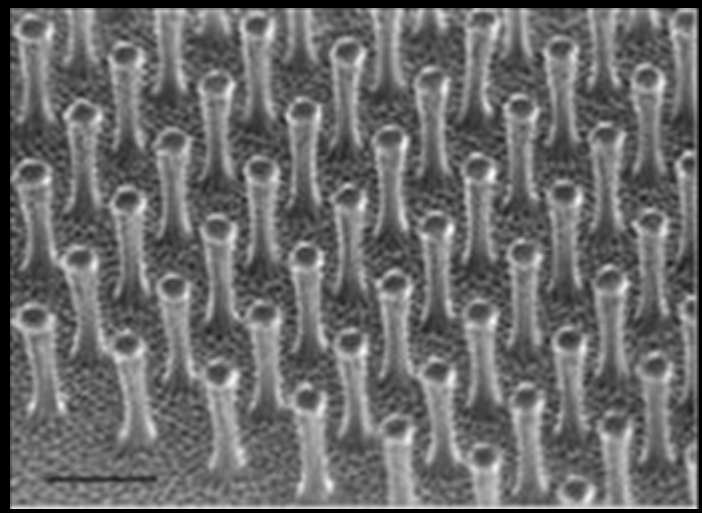
This hierarchical construction makes the lizard adhesive system elastically very soft on all relevant length scales (from mm to nm).

Persson and Gorb, J. Chem. Phys. (2003).

Controllable Conformance

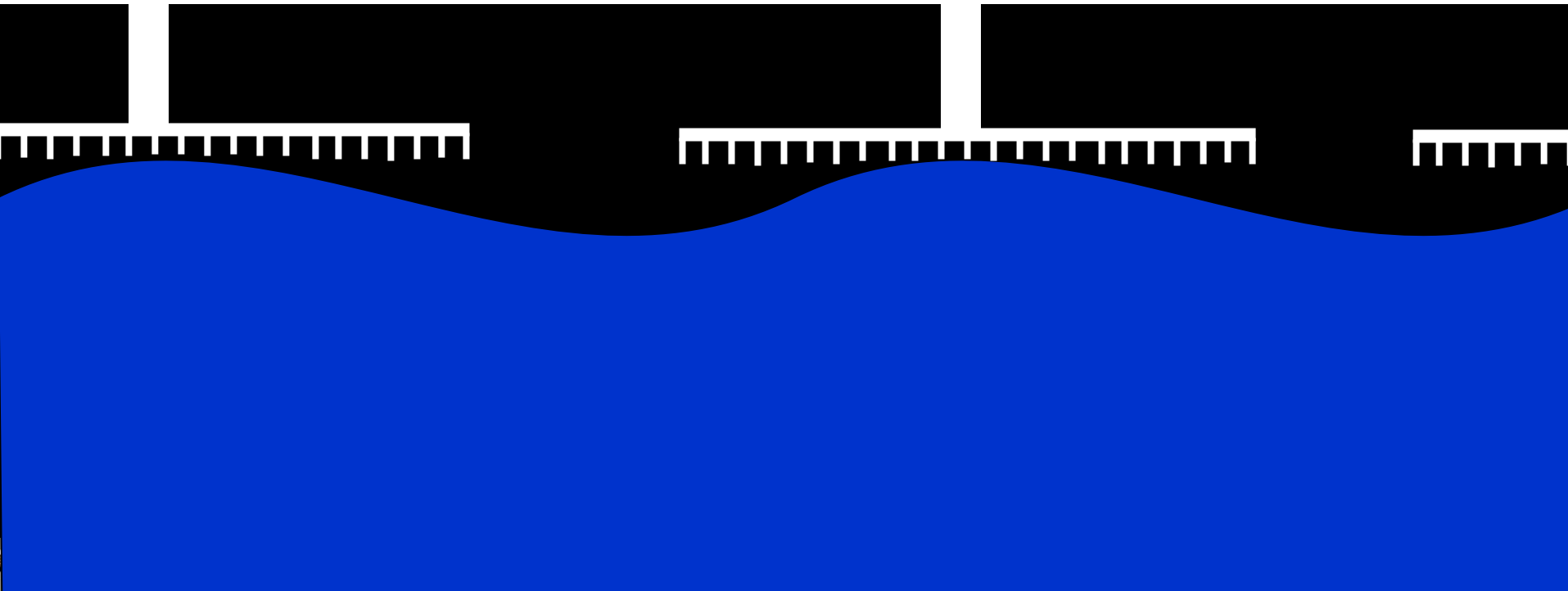


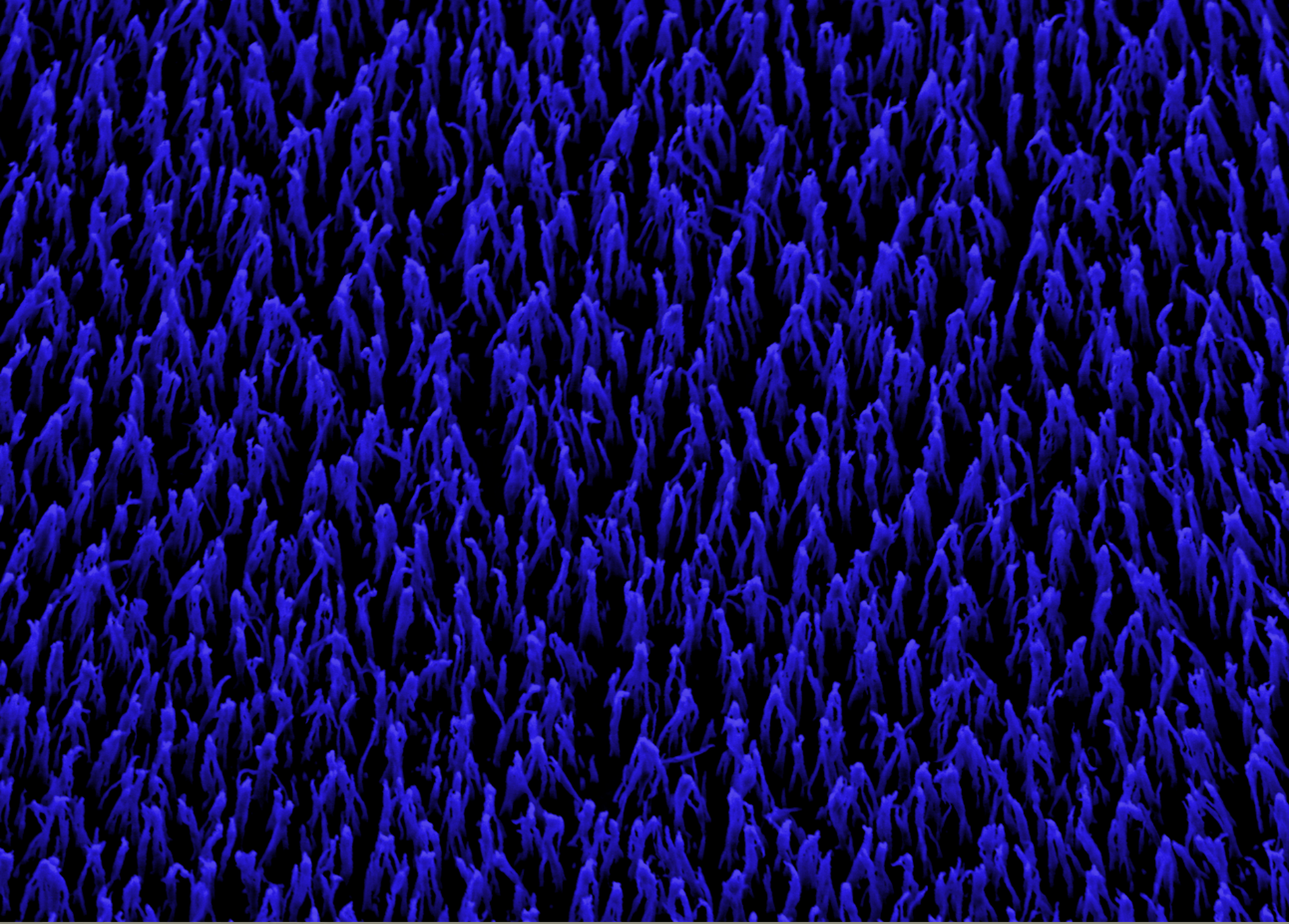
"The use of a soft rather than solid base has dramatically (by nearly 1,000 times) improved gecko tape to support the weight of a suitably light familiar object
(a toy in Fig. 4)."



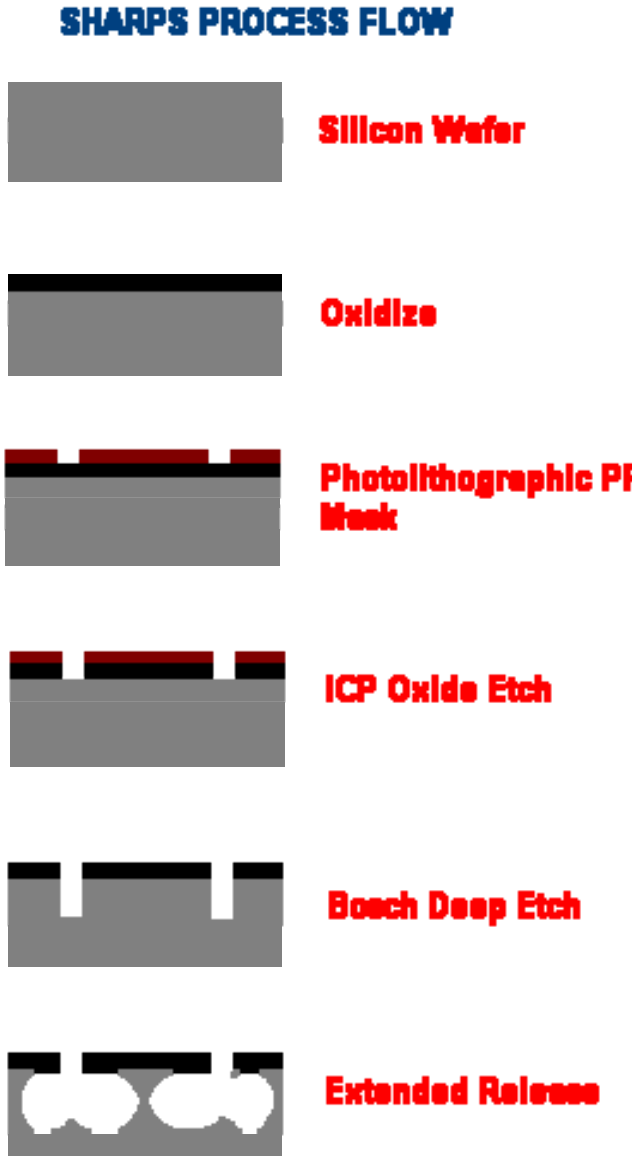
Geim, A. K., Dubonos, S. V., Grigorieva, I. V., Novoselov, K. S. & Zhukov, A. A. *Nature Materials* **2**, 461-463 (2003).

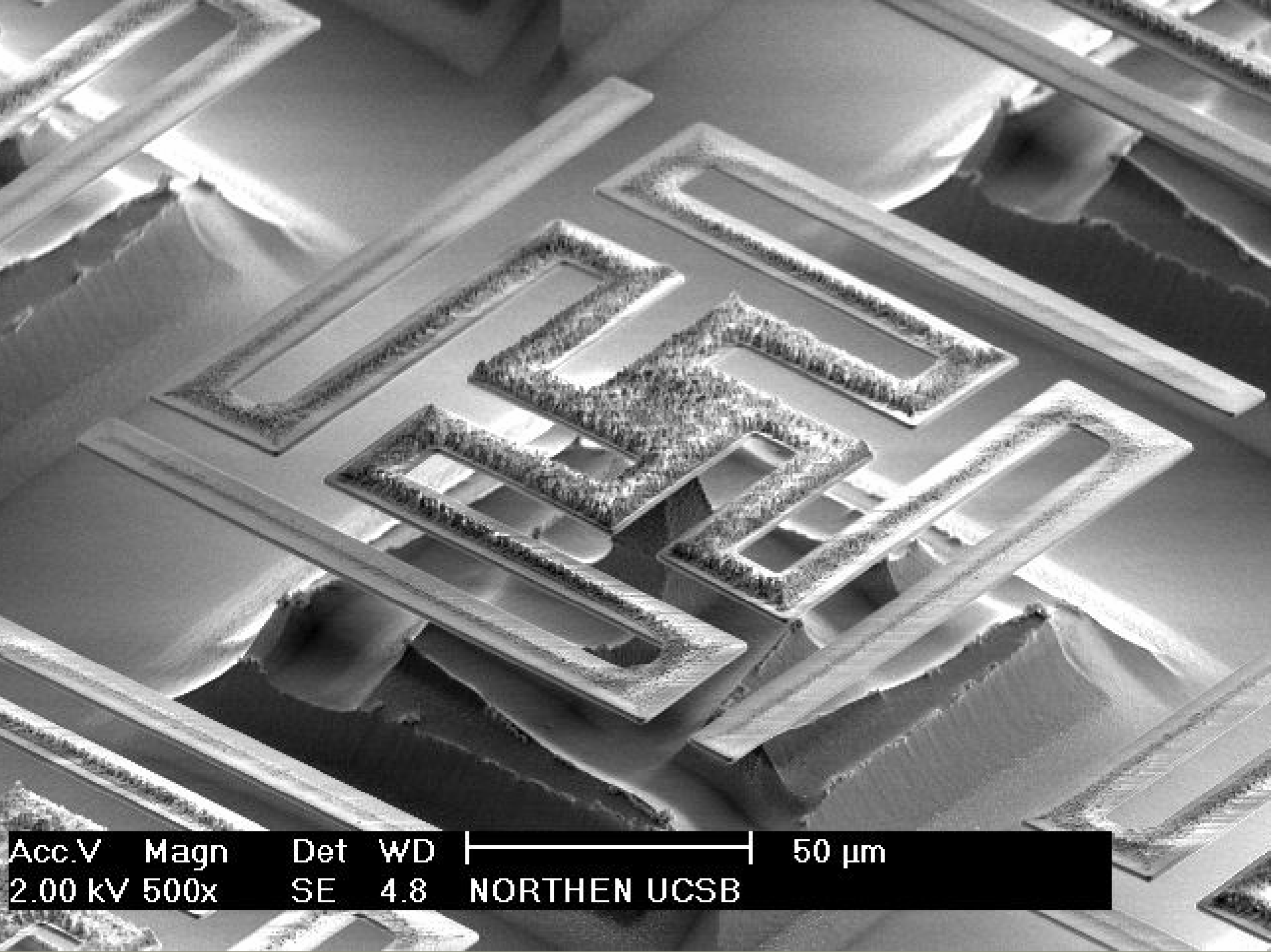
Controllable Conformance

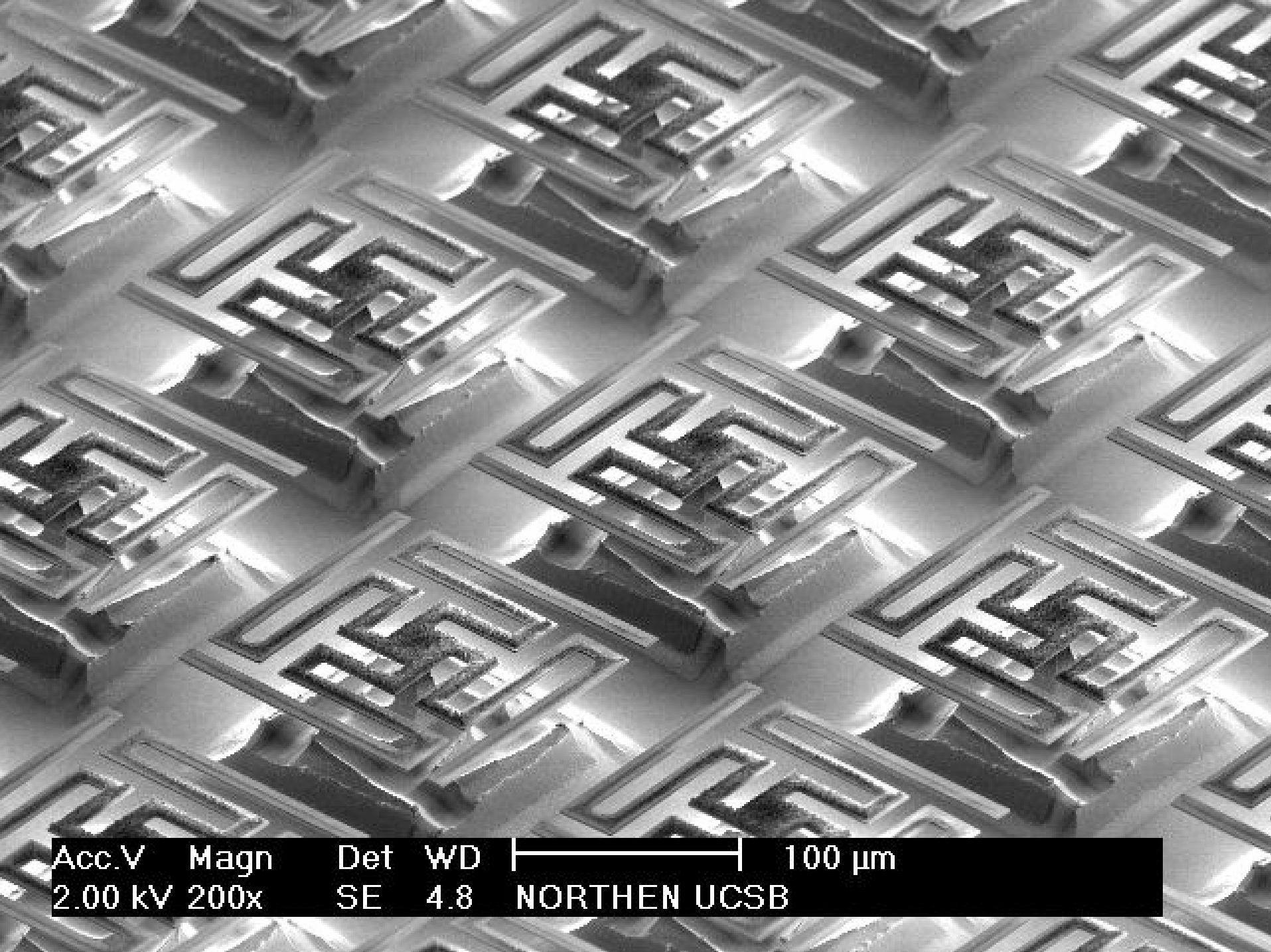


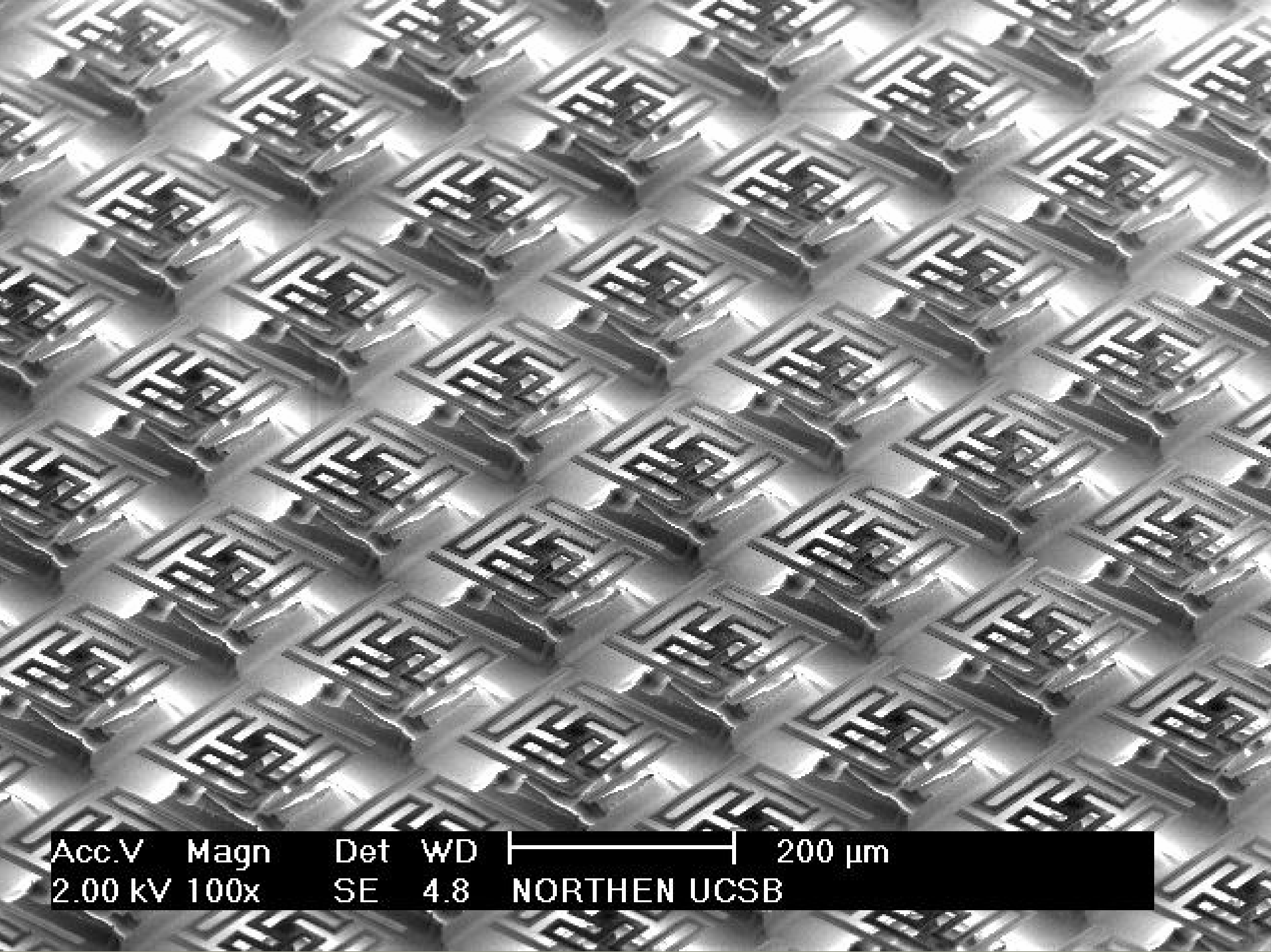


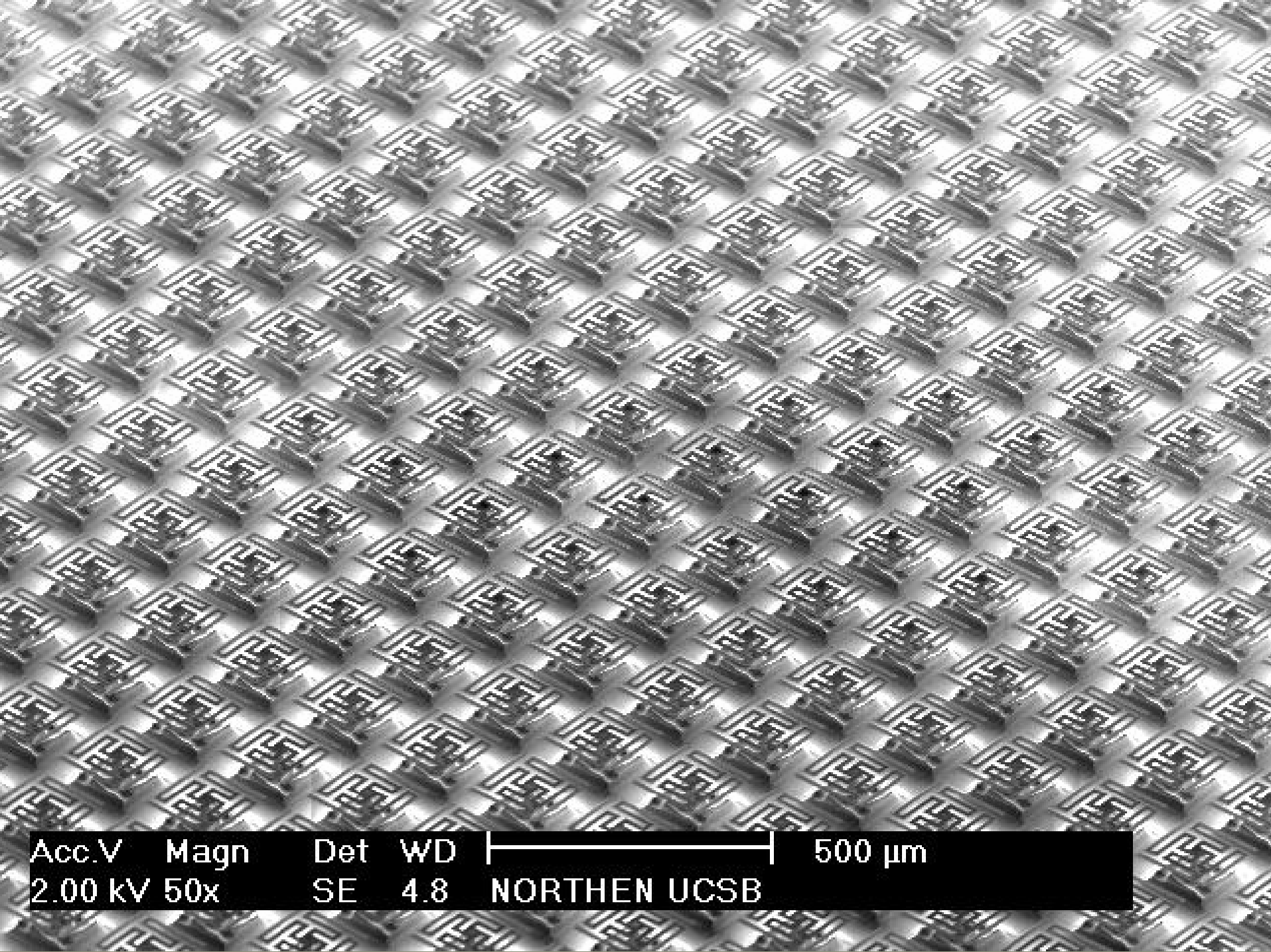
Fabrication

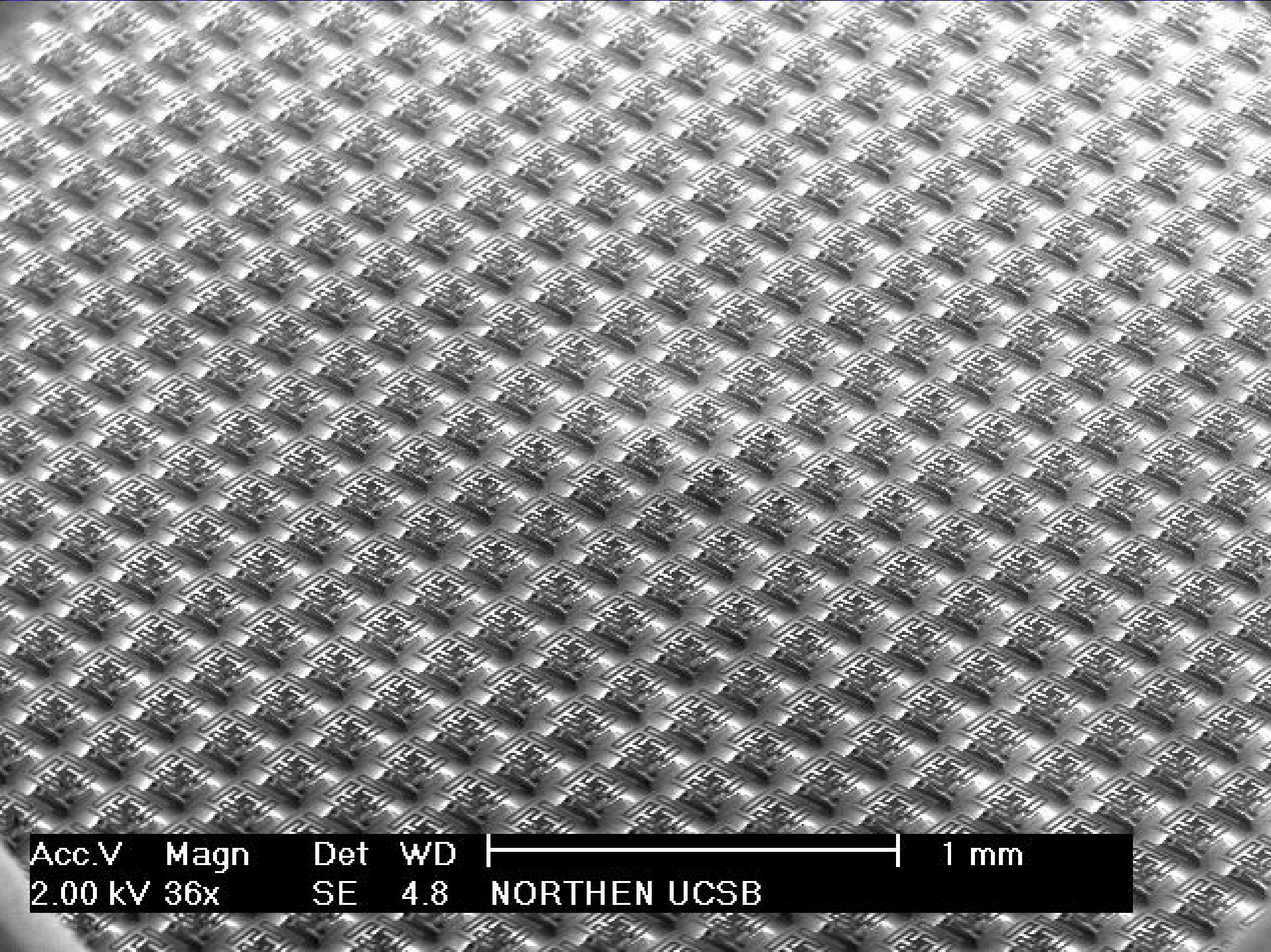



Acc.V Magn Det WD 50 µm
2.00 kV 500x SE 4.8 NORTHEN UCSB

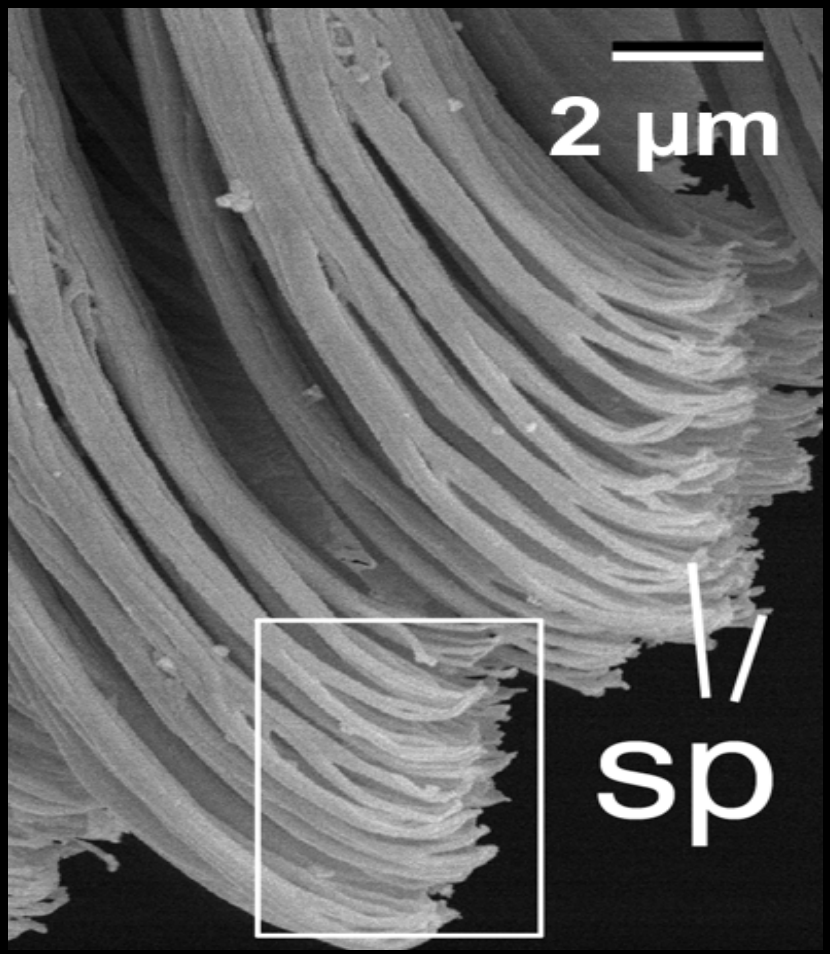

Acc.V Magn Det WD 100 µm
2.00 kV 200x SE 4.8 NORTHEN UCSB


Acc.V Magn Det WD 200 µm
2.00 kV 100x SE 4.8 NORTHEN UCSB


Acc.V Magn Det WD 500 µm
2.00 kV 50x SE 4.8 NORTHEN UCSB


Acc.V Magn Det WD 1 mm
2.00 kV 36x SE 4.8 NORTHEN UCSB

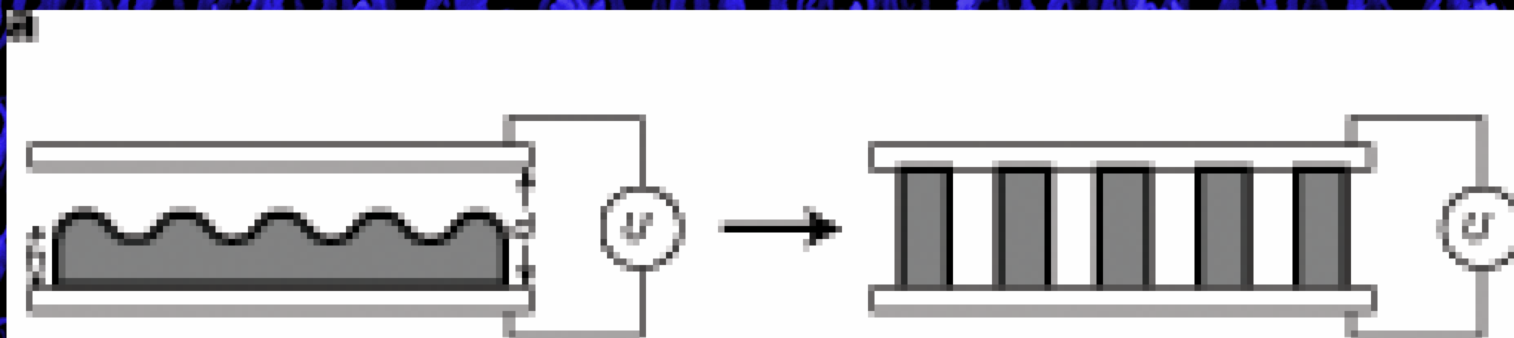
Nanorod Properties



Courtesy Edward Arzt (S. Gorb)

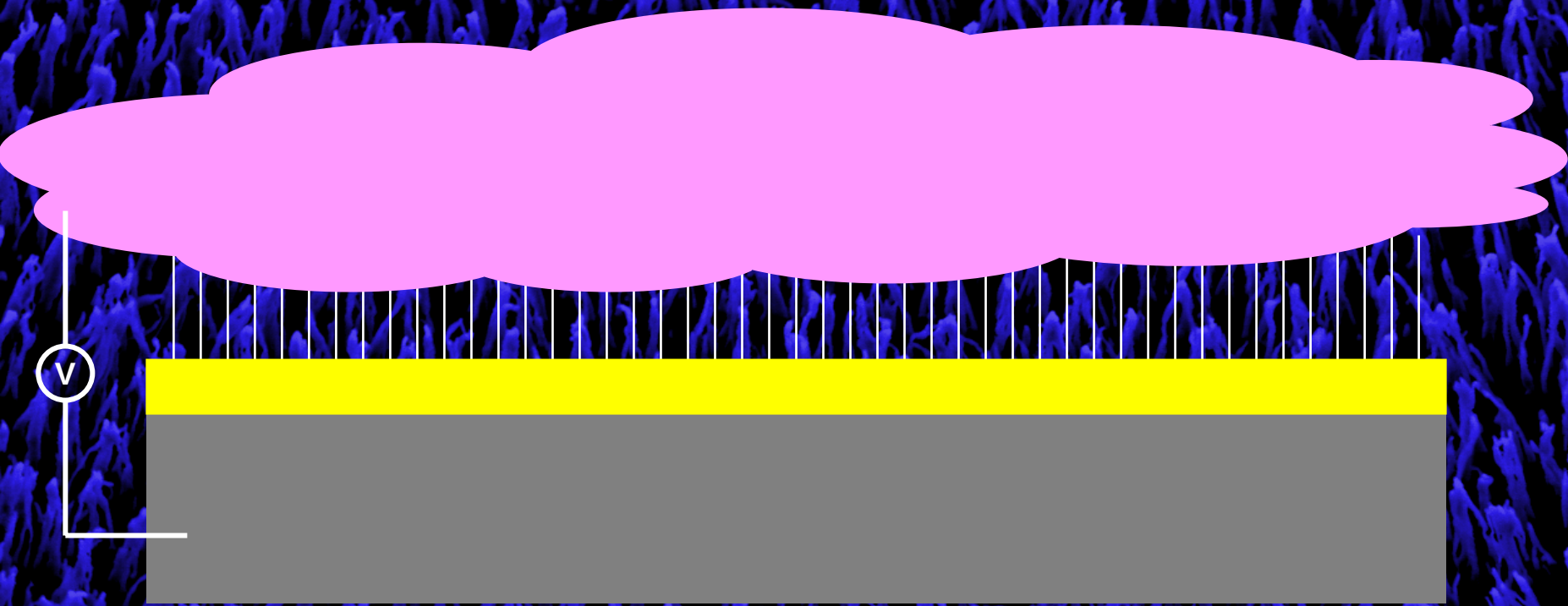
- Diameter ~ 200 nm
- Length ~ 4 µm
- Beta Keratin
- Modulus ~ 1-15 GPa
- High Density
- No Condensation
- Ultra-Hydrophobic, Contact Angle ~170°

Growing Nanorods

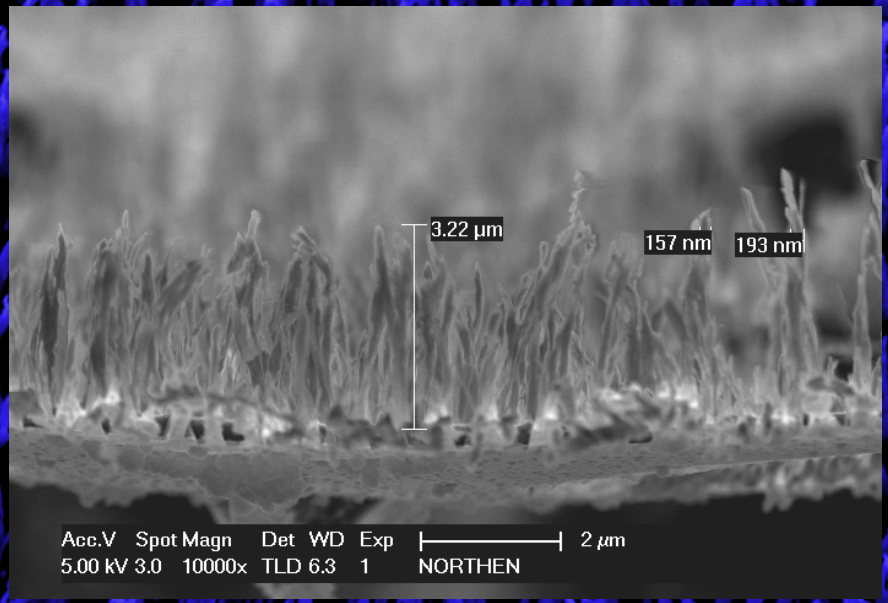


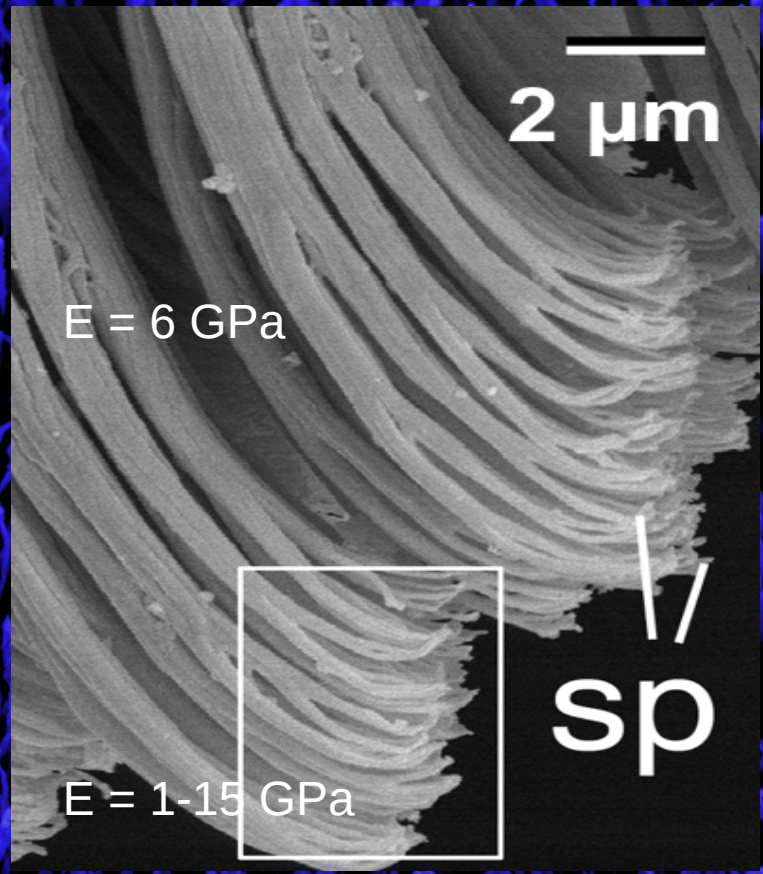
(E. Schäffer, Thurn-Albrecht, T., Russell, T. P., Steiner, U., Nature 403, 874 (2000))

Nanowire Synthesis



‘Organorods’





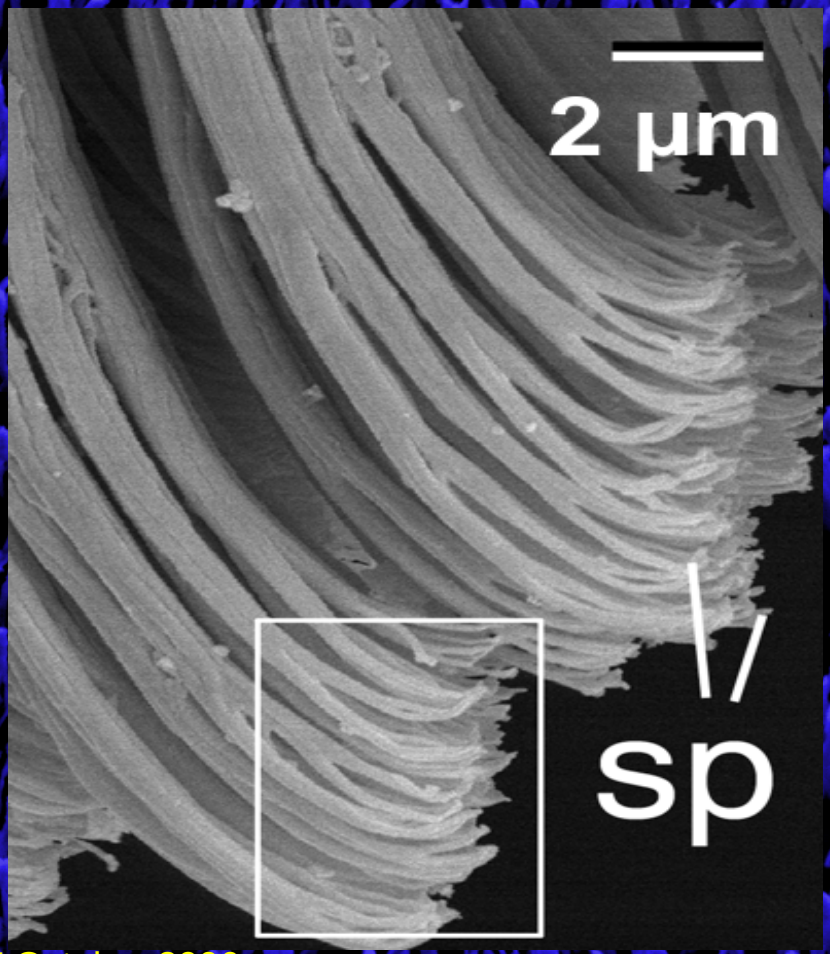
Courtesy Edward Arzt (S. Gorb)

Gecko

UCSB

Turner and Northen

Nanorod Properties



- Diameter ~ 200 nm
- Length ~ 4 µm
- Beta Keratin
- Modulus ~ 1-15 GPa
- High Density
- No Condensation
- Ultra-Hydrophobic, Contact Angle ~170°

Courtesy Edward Arzt (S. Gorb)

Turner and Northen

UCSB

ICB

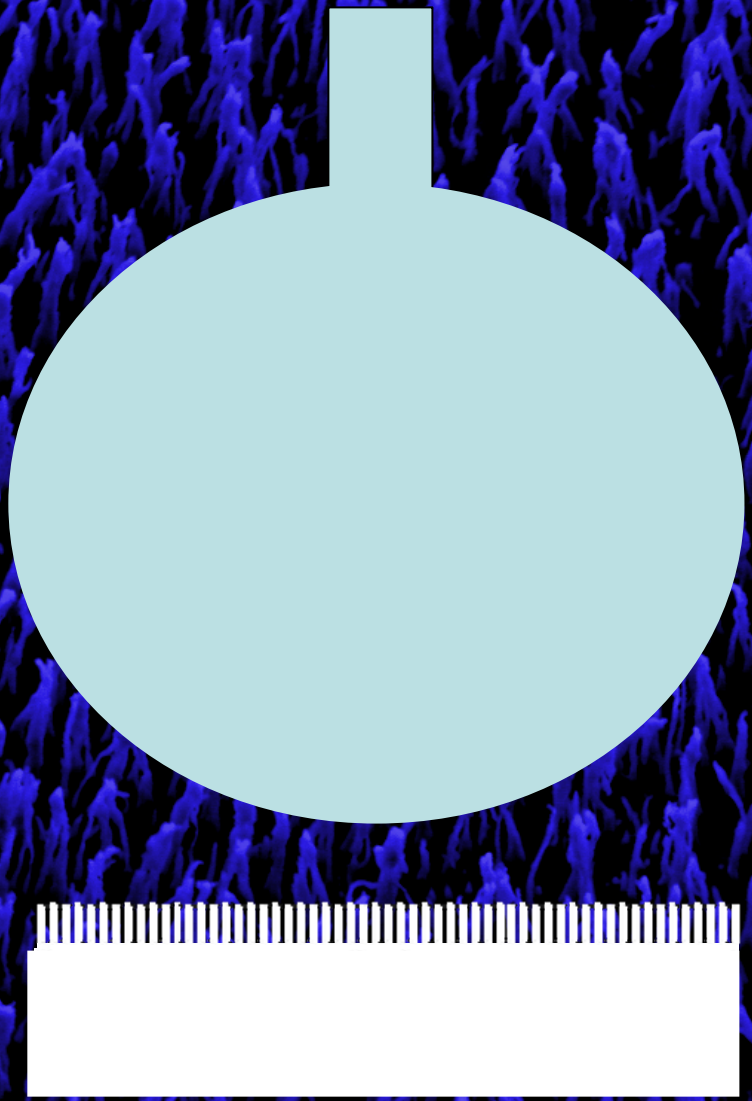
Contact Angle

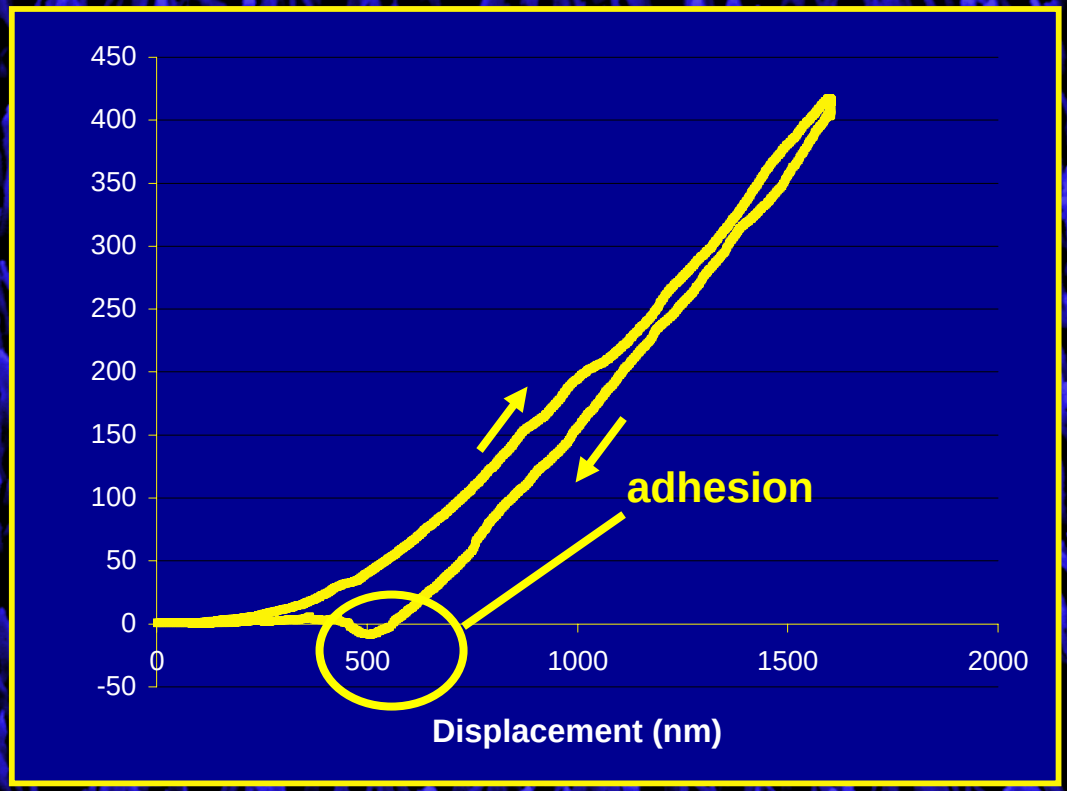
Hydrophilic → 42.5°

-OR-

Highly Hydrophobic → 145°

Adhesion Testing

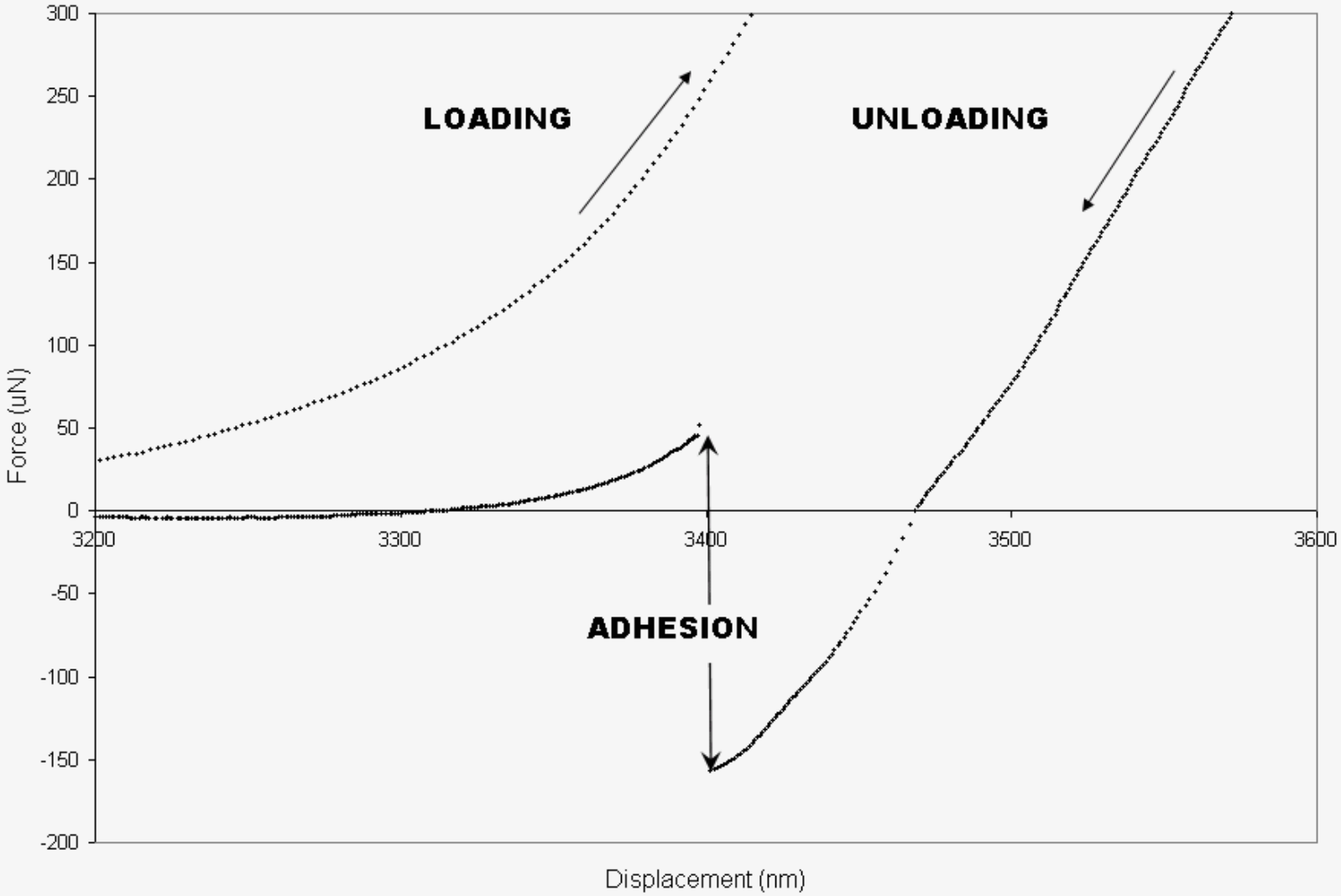




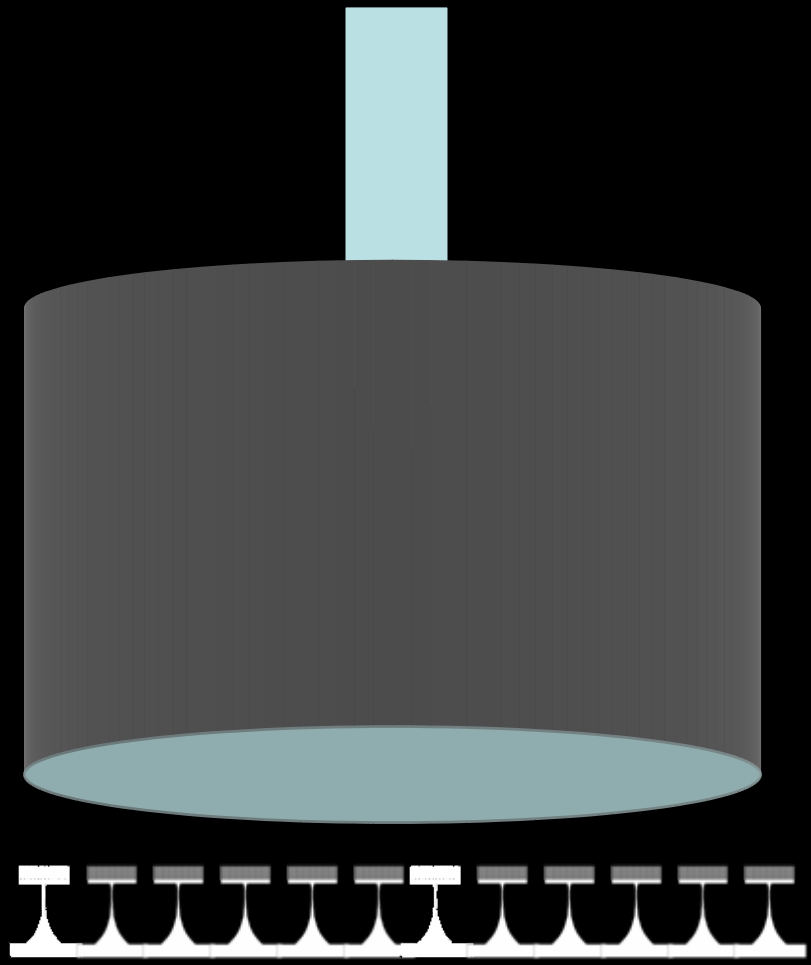
Northen, M. T., Turner, K.L. (2005). "Meso-scale adhesion testing of integrated micro- and nano-scale structures." Sensors and Actuators A **(In Press).**

Turner and Northen

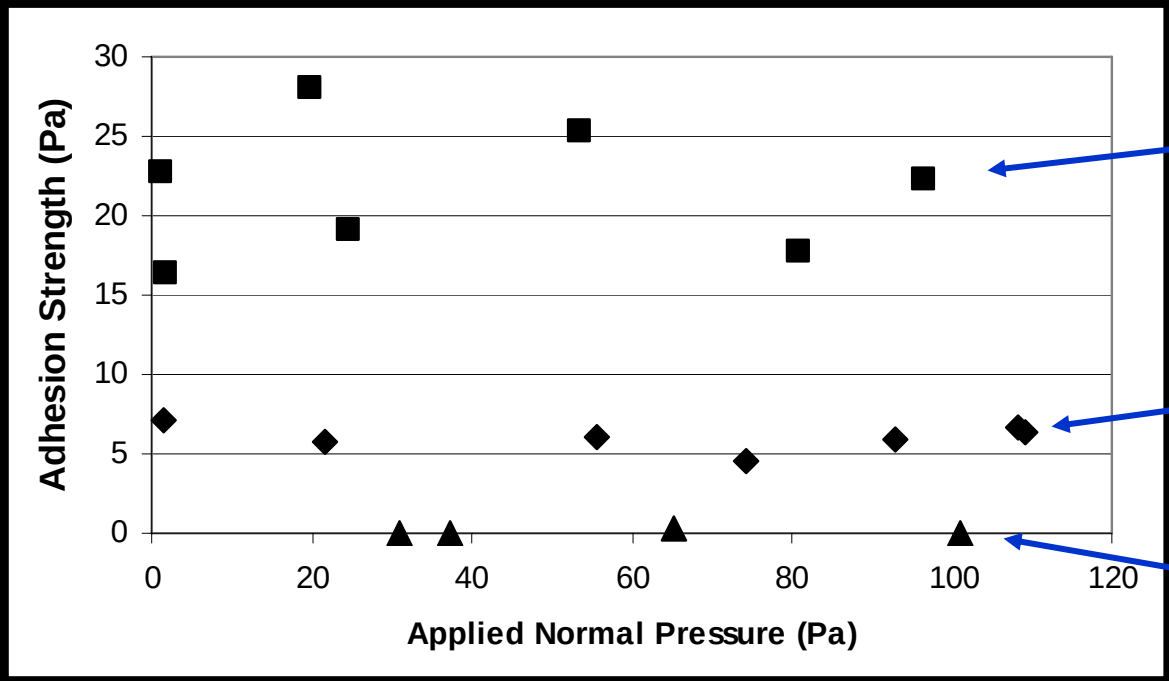
UCSB

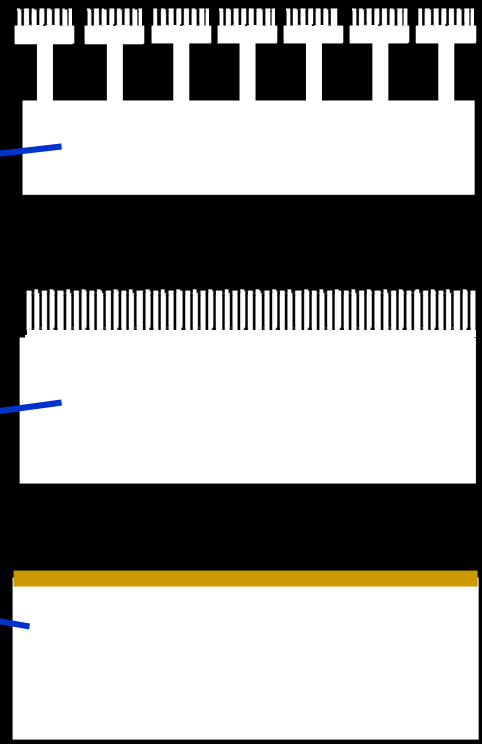

LOADING
UNLOADING
ADHESION
Force (uN)
Displacement (nm)
300
250
200
150
100
50
0
-50
-100
-150
-200
3200
3300
3400
3500
3600

Adhesion Testing

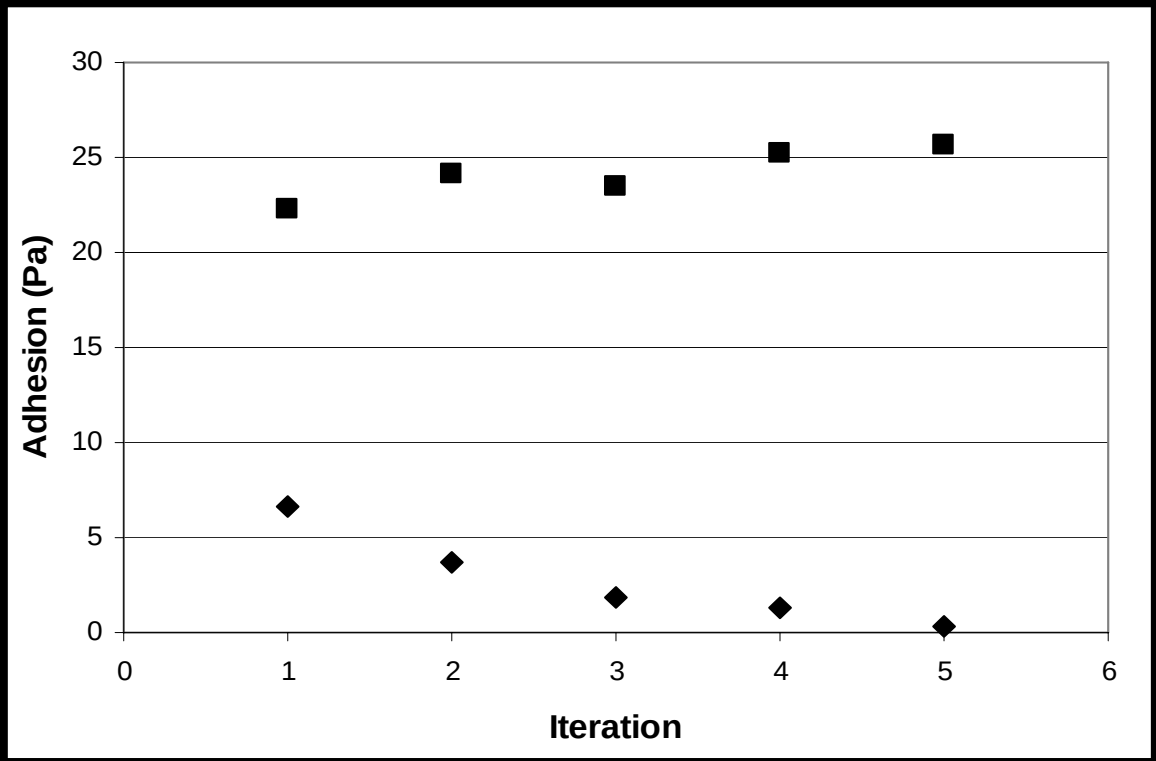


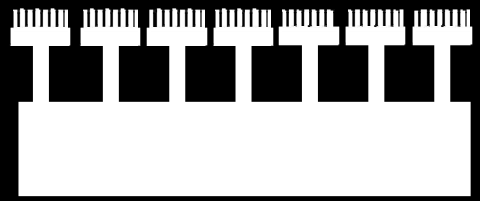
Adhesion Comparison



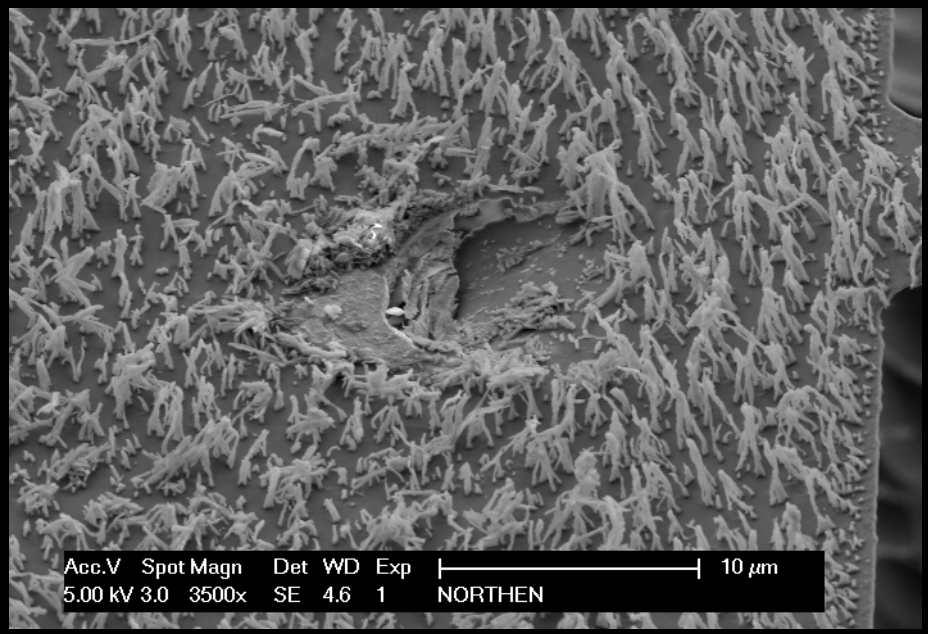


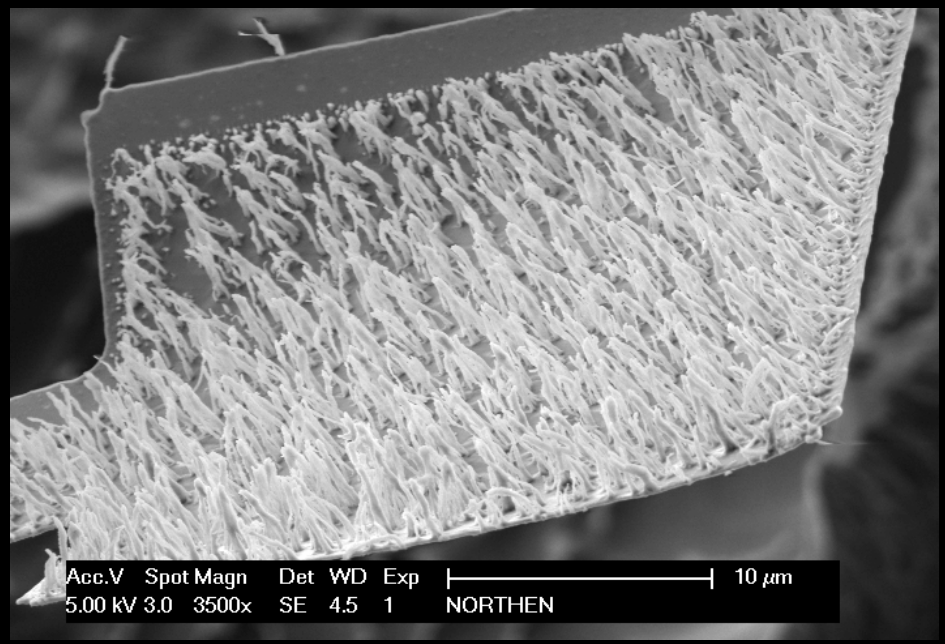
Durability Comparison





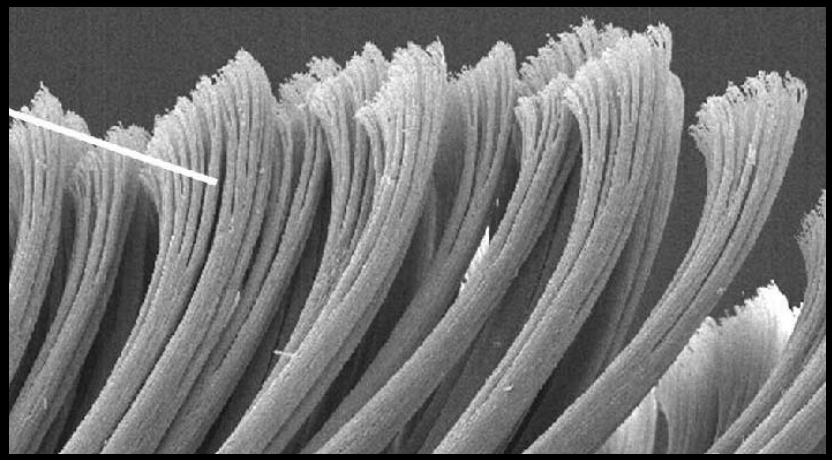
Solid vs. Flexible



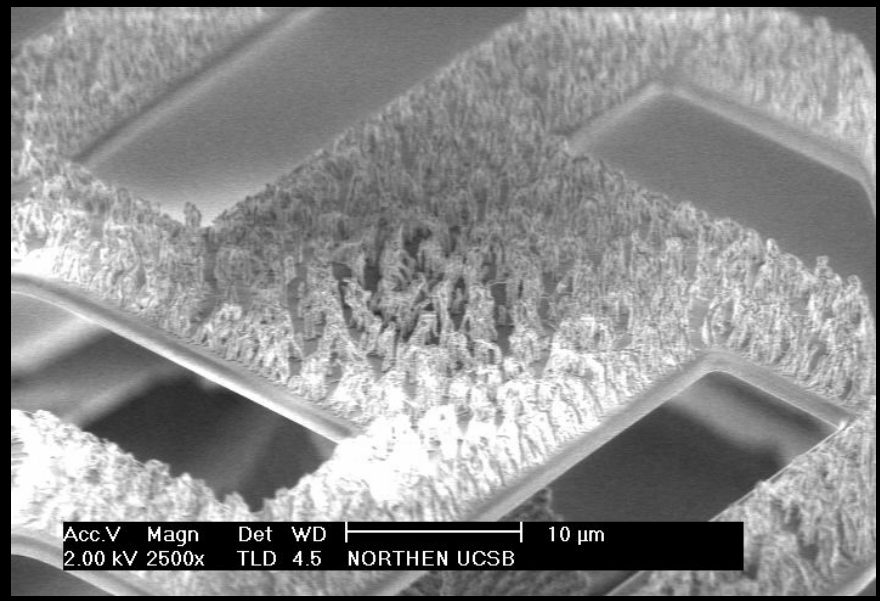


Damage vs. No Damage

Mimicked?



Coutesy Eduard Arzt (S. Gorb)



Gecko > 300 Pa (Adhesion)

90 kPa (Frictional Adhesion)

Synthetic < 30 Pa (Adhesion)

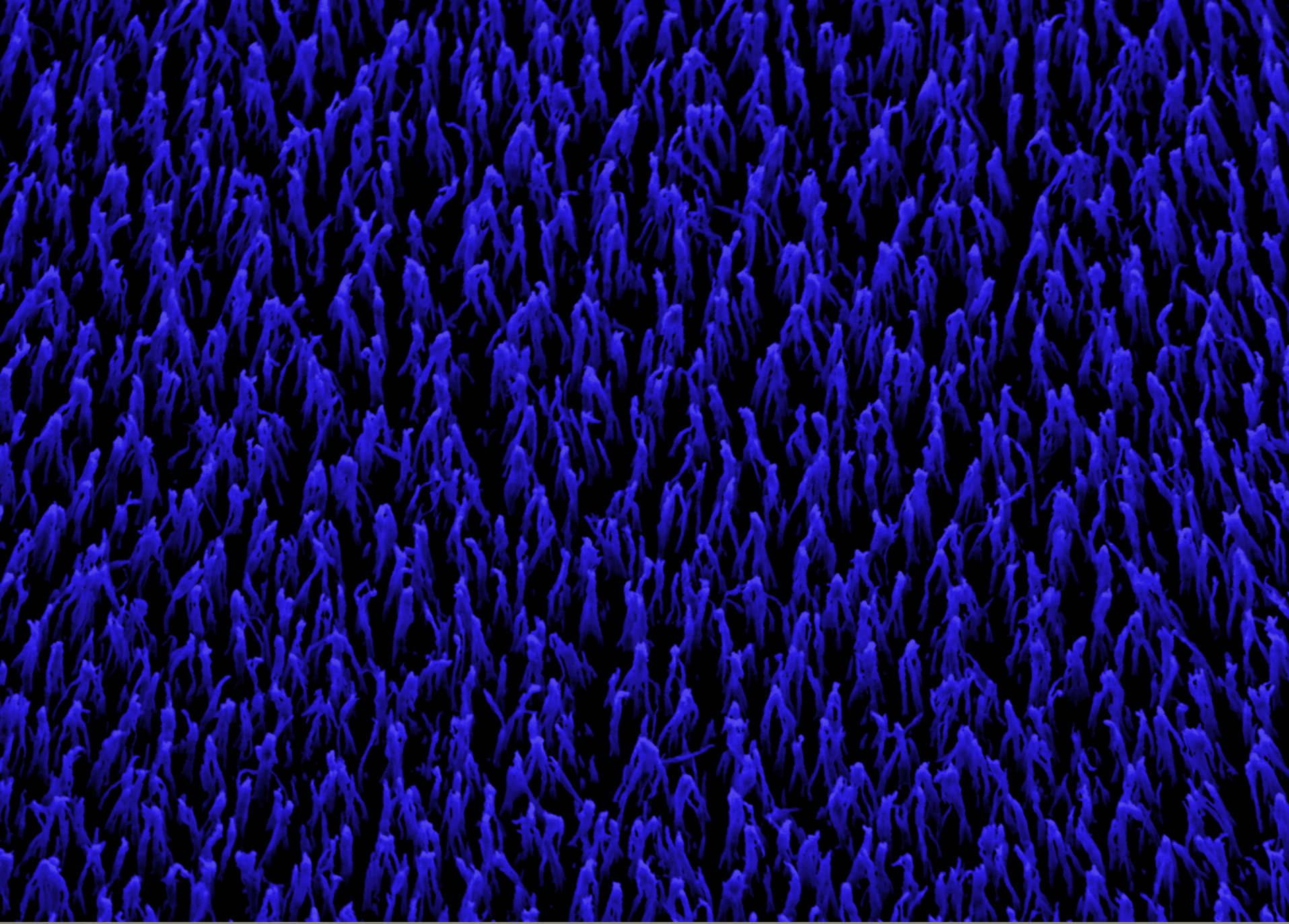
$\mu' = F_{adhesion} / F_{preload}$

Geim et. al → $\mu' = 0.06$

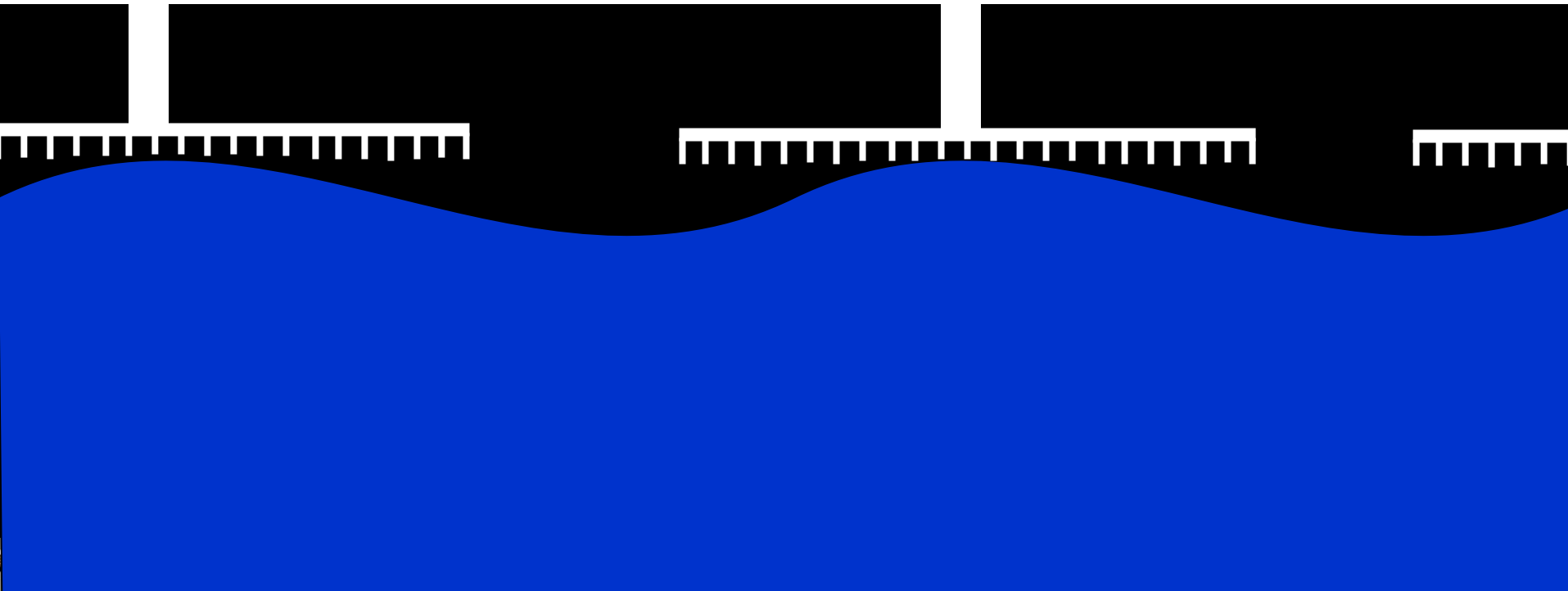
Northen & Turner → $\mu' = 0.125$

Gecko → $\mu' = 8\text{-}15$

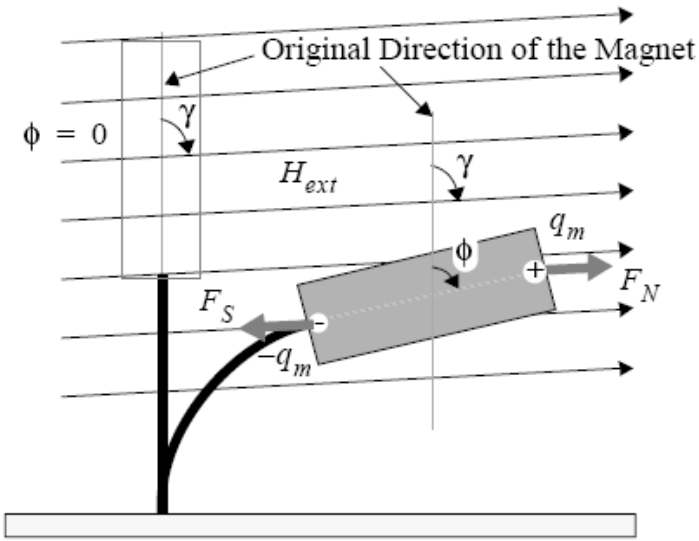
Adhesion Control



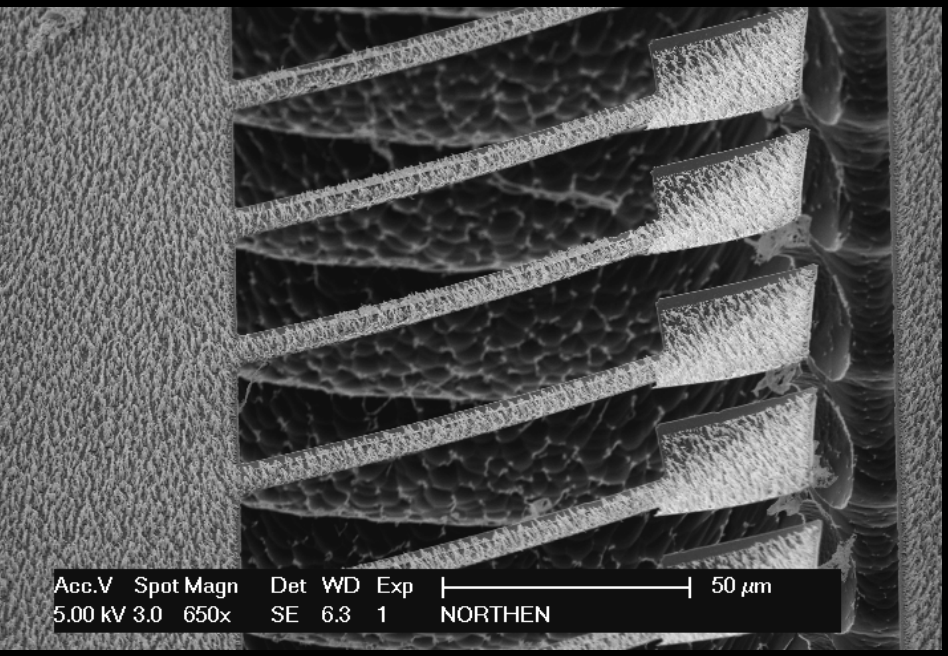
Controllable Conformance



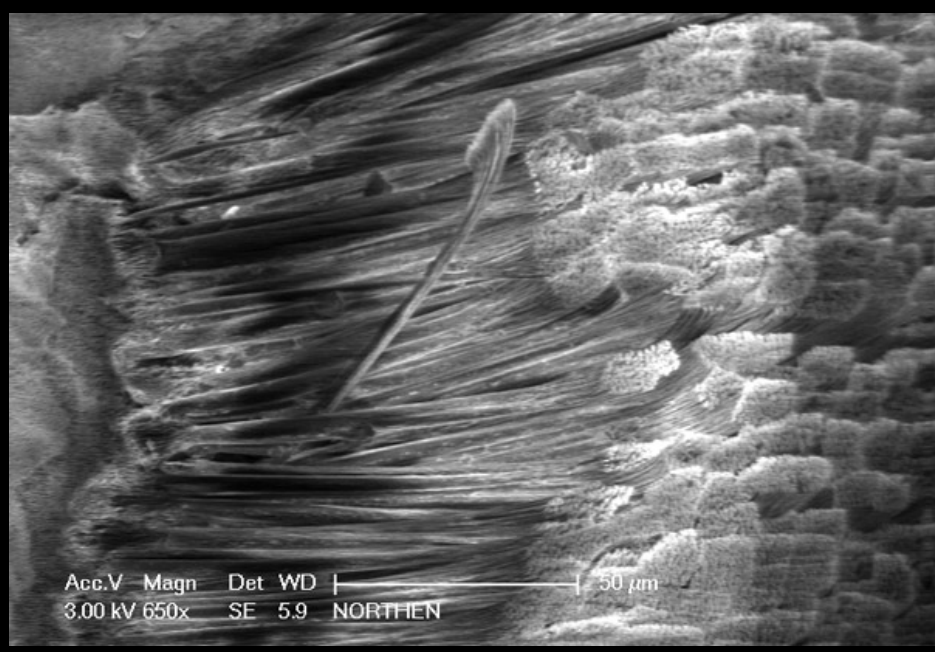
Ferromagnet in a magnetic field



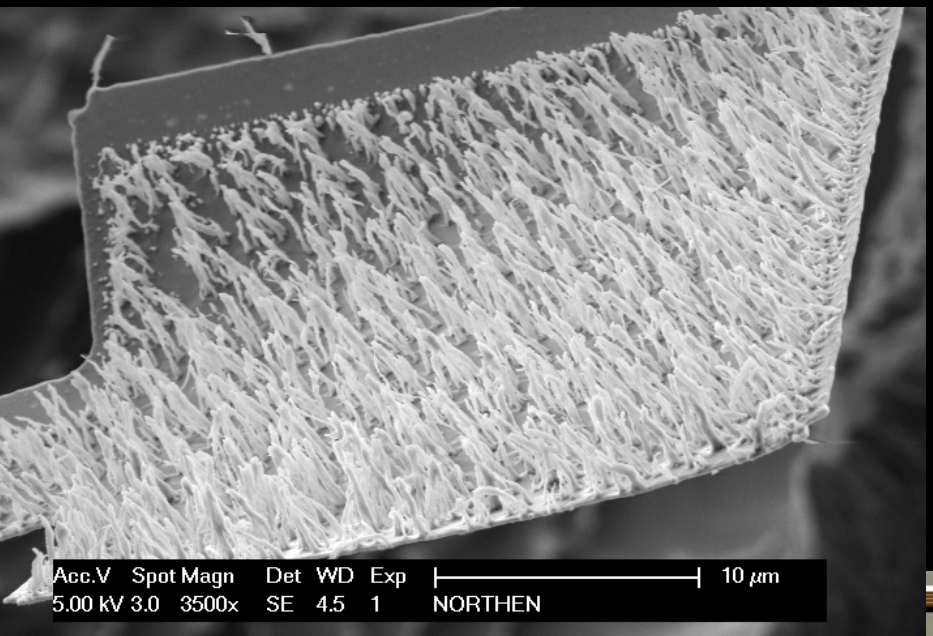
J. W. JUDY ET AL.: MAGNETIC MICROACTUATION OF POLYSILICON FLEXURE STRUCTURES.

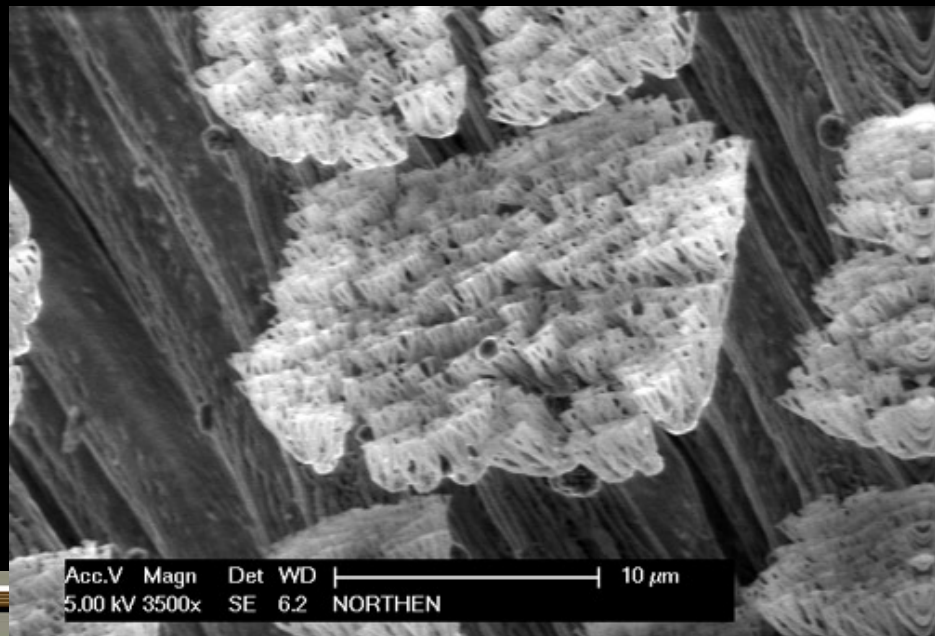


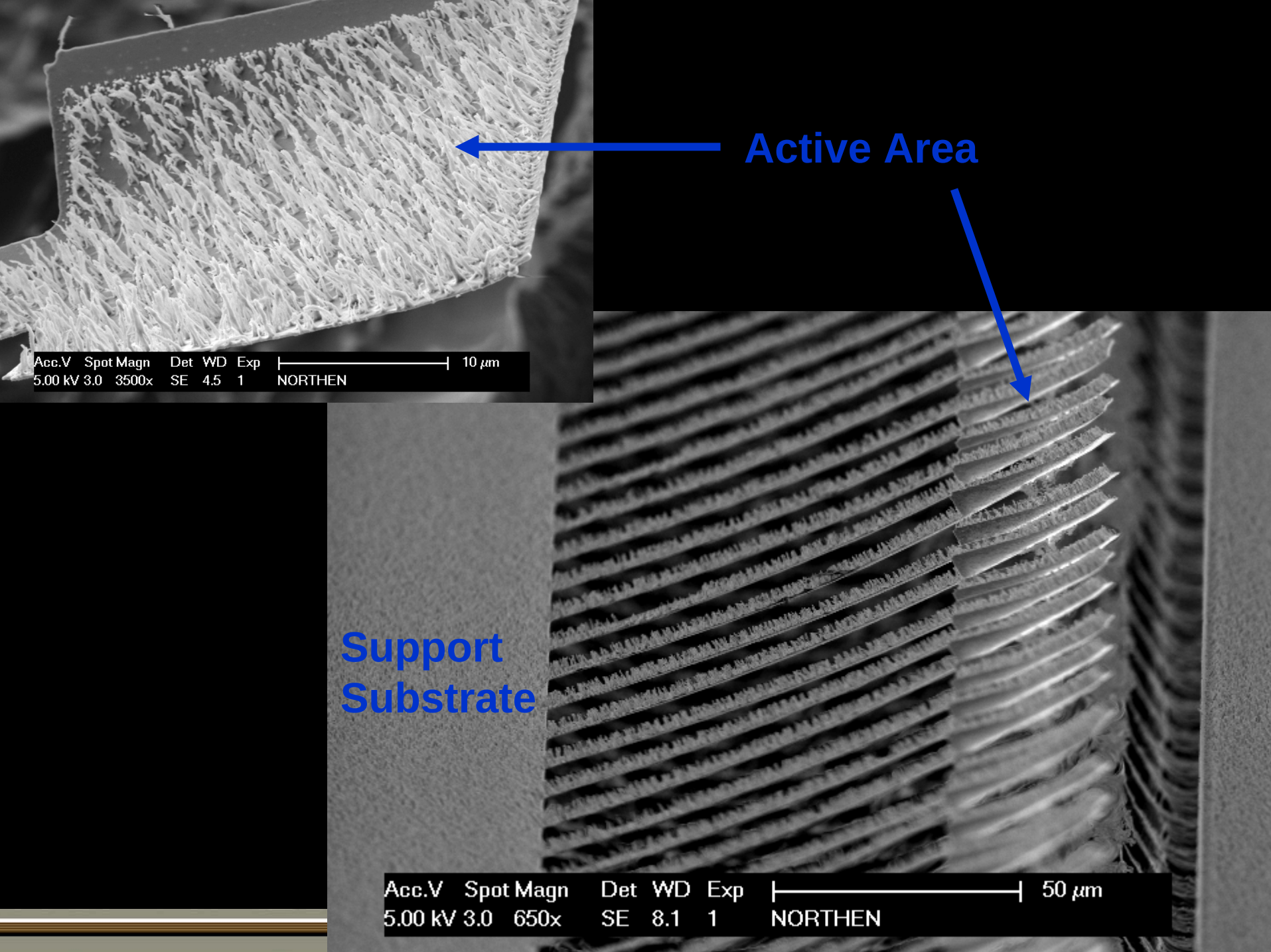
Michael-Fabricated

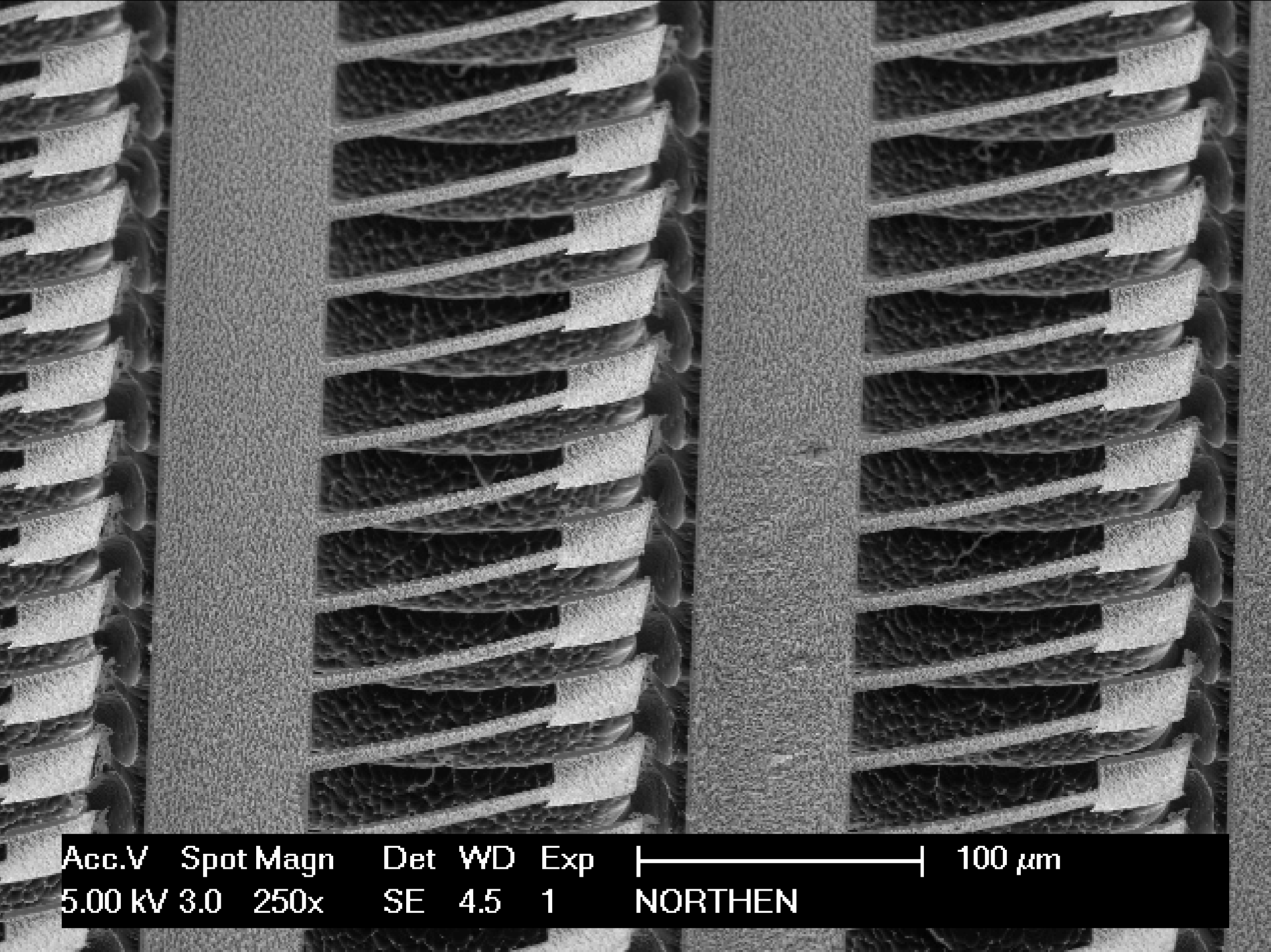


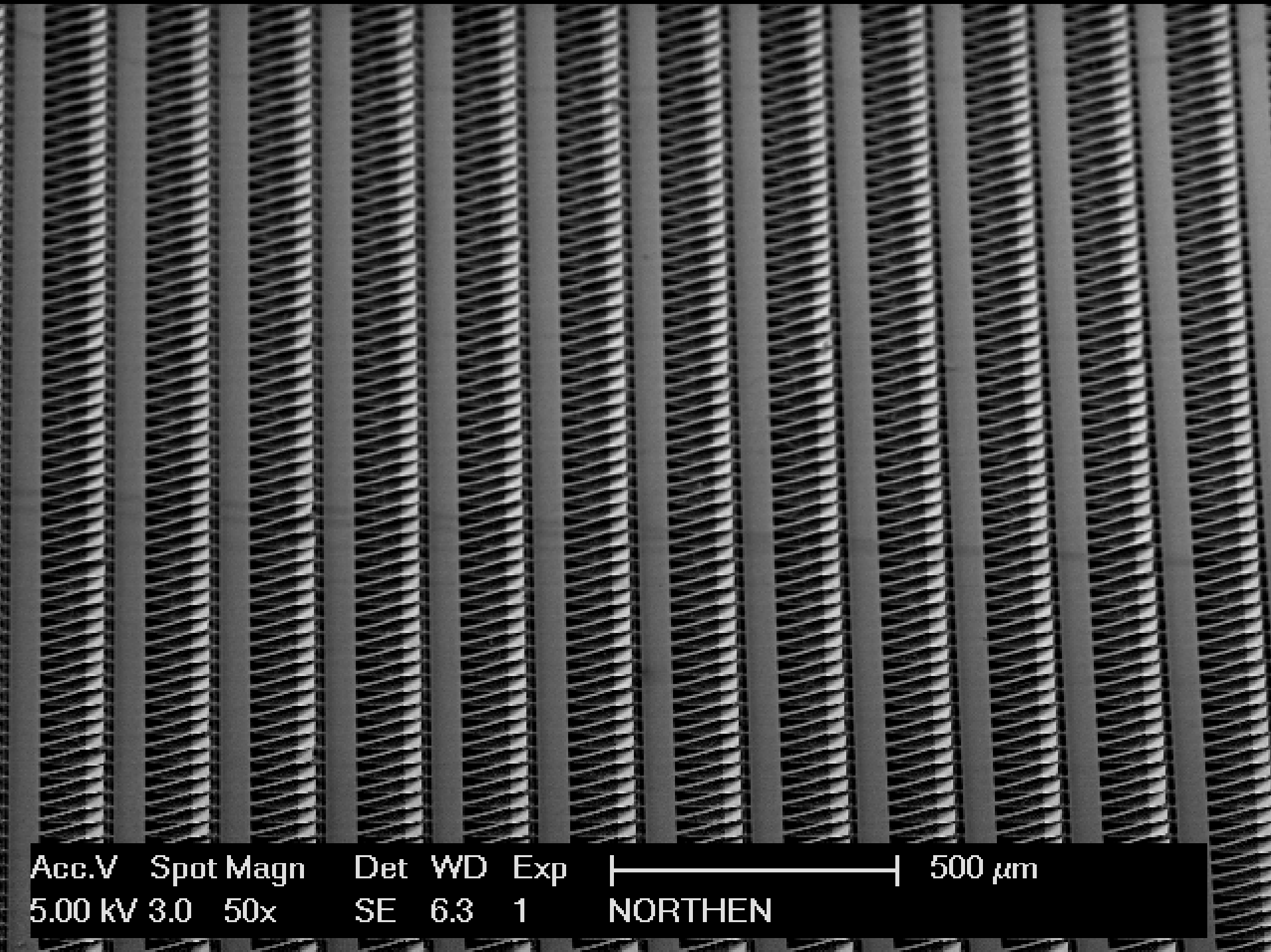
Gecko-Fabricated

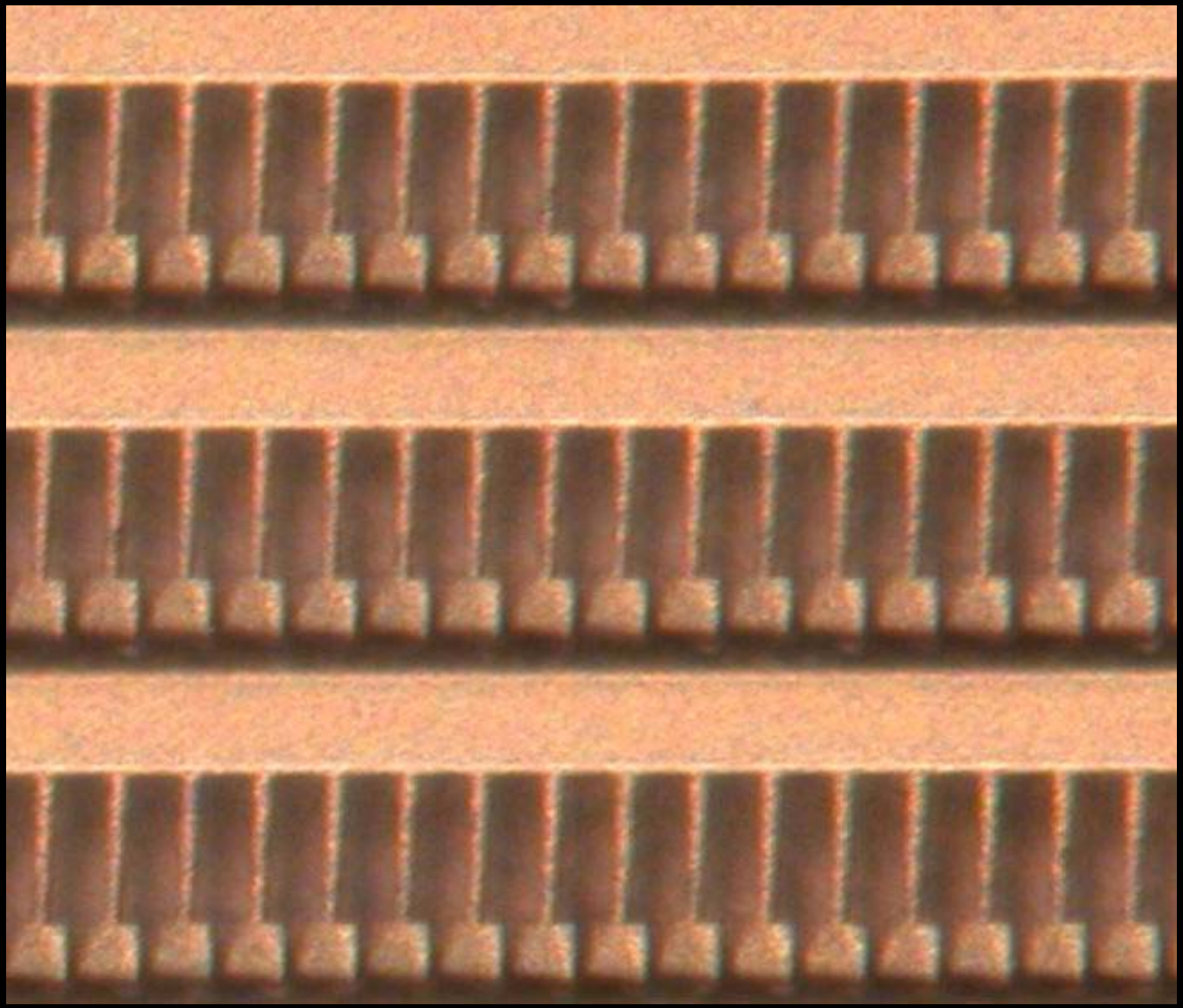


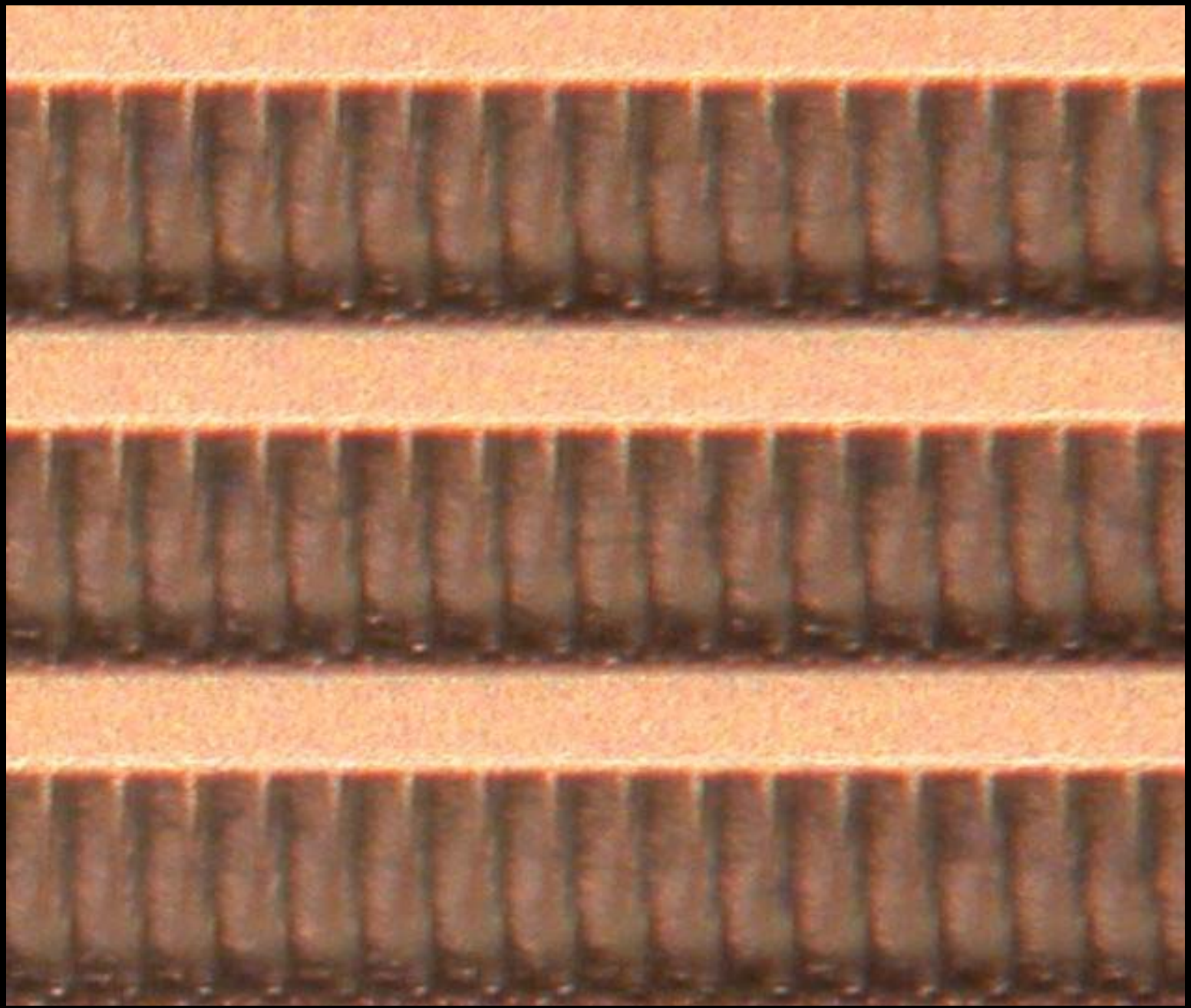


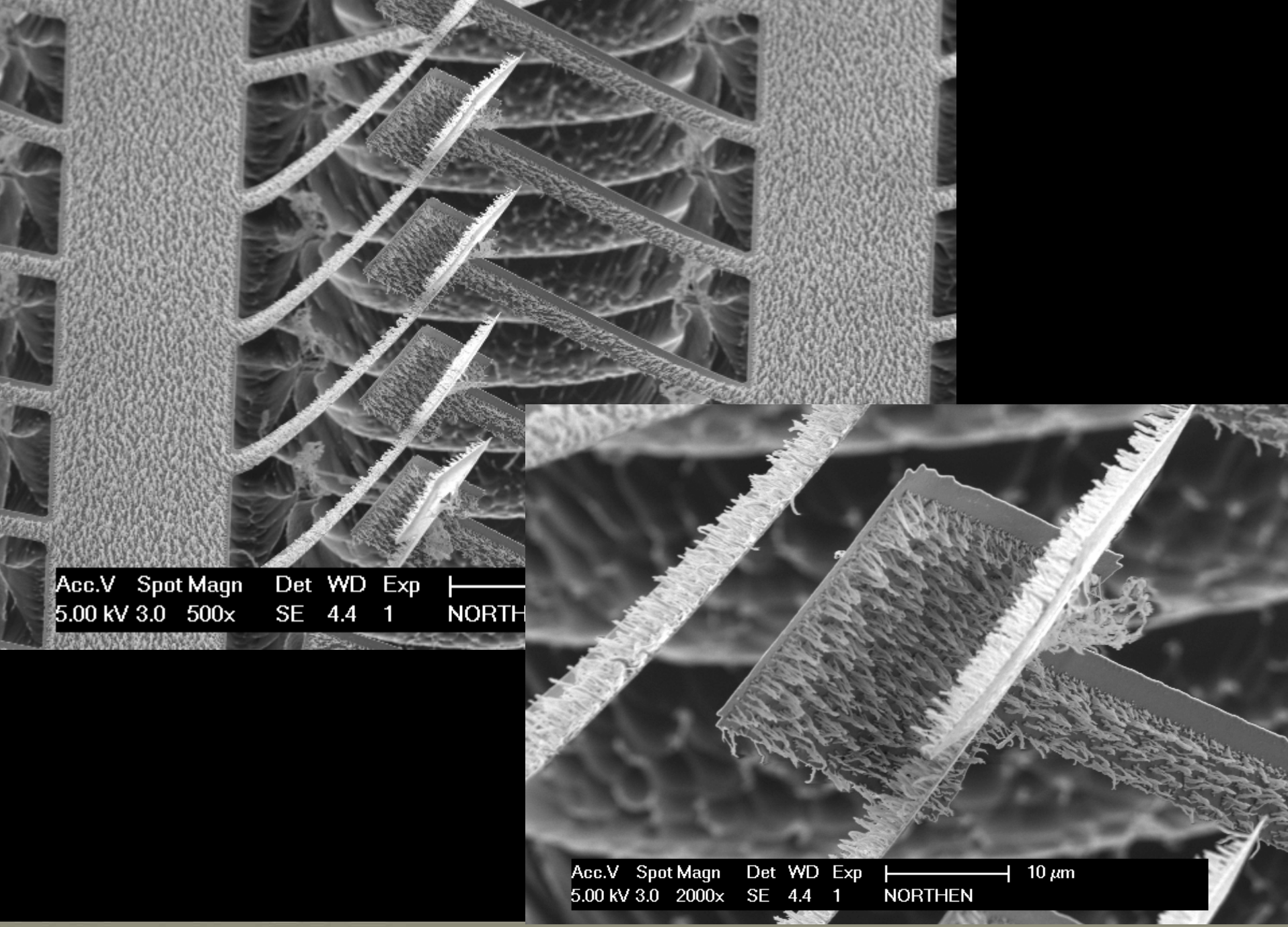

Active Area
Support Substrate
Acc.V Spot Magn Det WD Exp 10 µm
5.00 kV 3.0 3500x SE 4.5 1 NORTHEN
Acc.V Spot Magn Det WD Exp 50 µm
5.00 kV 3.0 650x SE 8.1 1 NORTHEN


Acc.V Spot Magn Det WD Exp 100 µm
5.00 kV 3.0 250x SE 4.5 1 NORTHEN

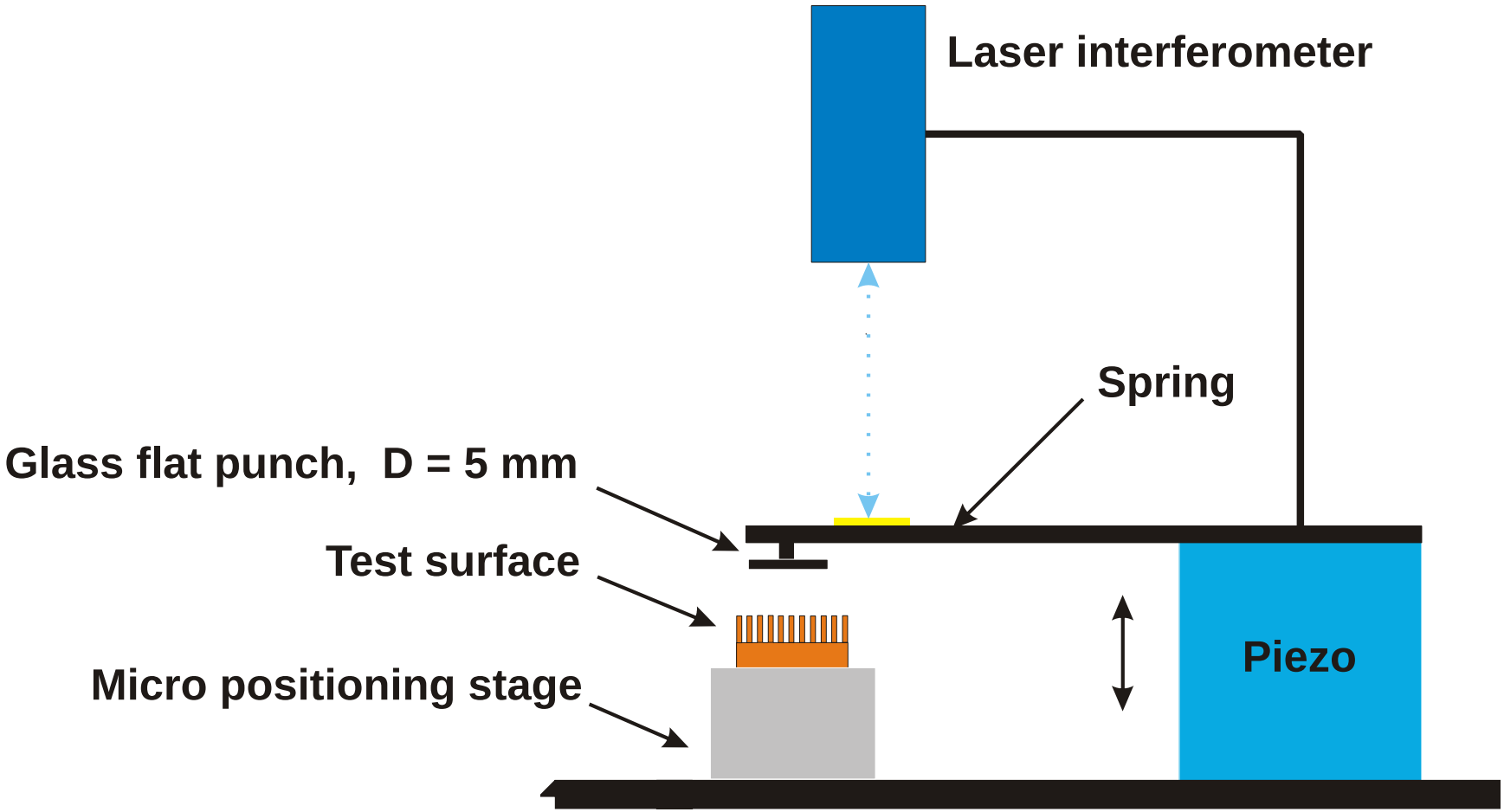

Acc.V Spot Magn Det WD Exp
500 µm
5.00 kV 3.0 50x SE 6.3 1 NORTHEN



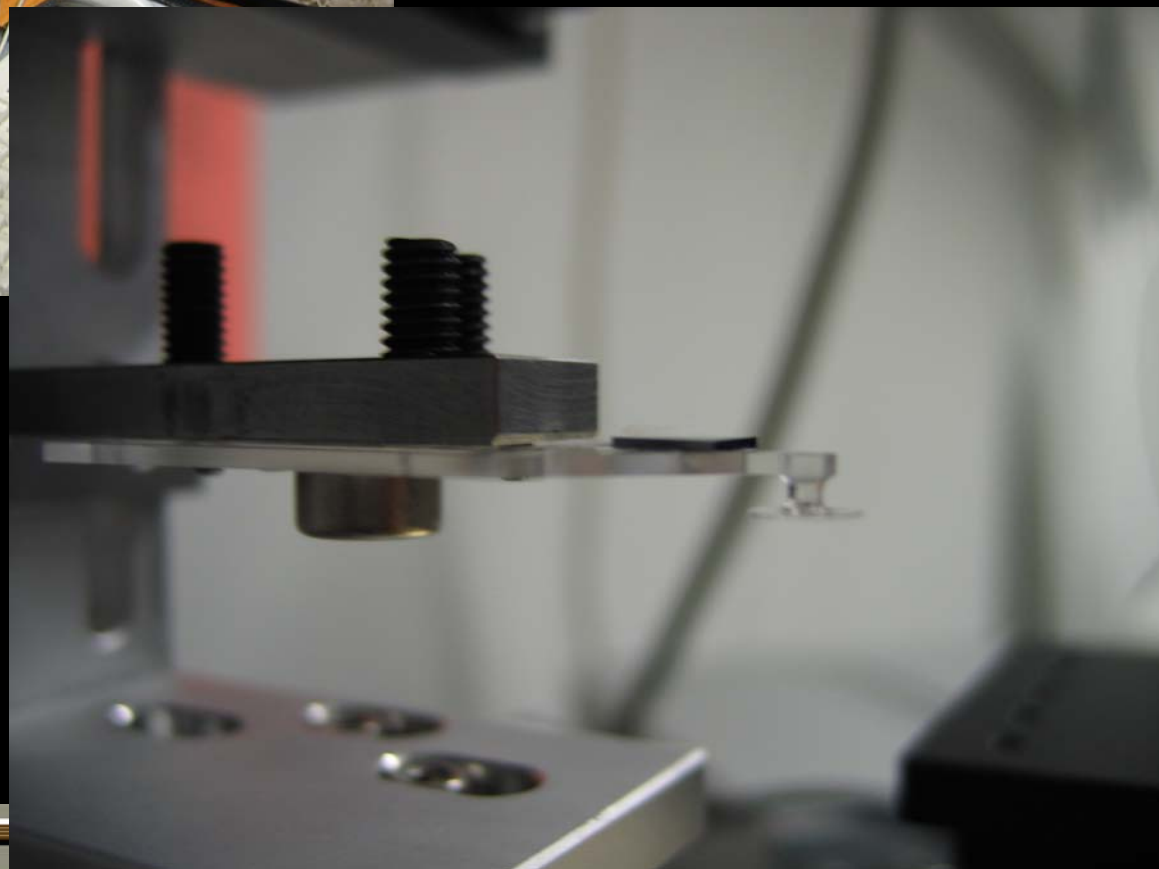


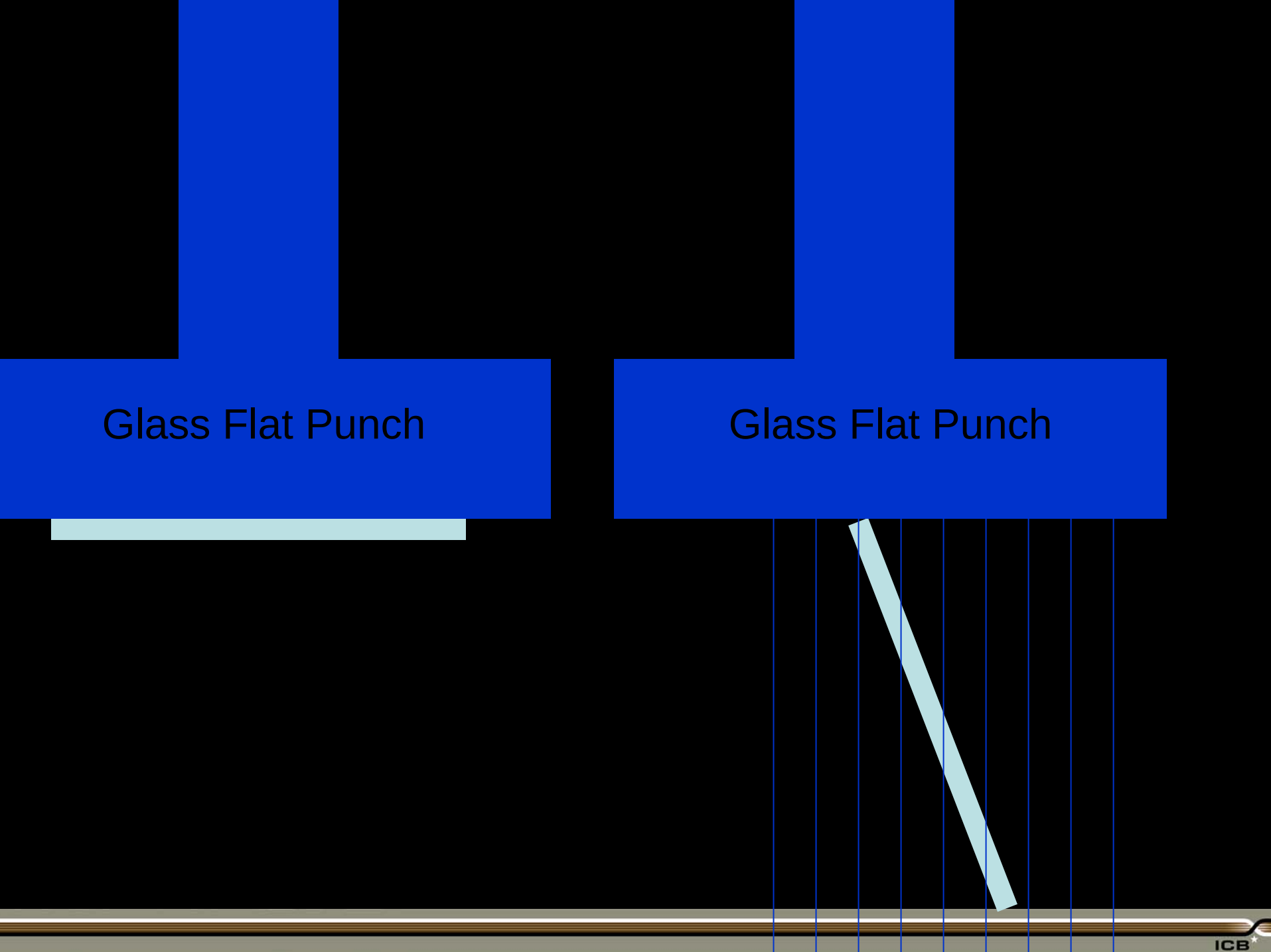

Acc.V Spot Magn Det WD Exp
5.00 kV 3.0 500x SE 4.4 1 NORTH
Acc.V Spot Magn Det WD Exp 10 μm
5.00 kV 3.0 2000x SE 4.4 1 NORTHEN

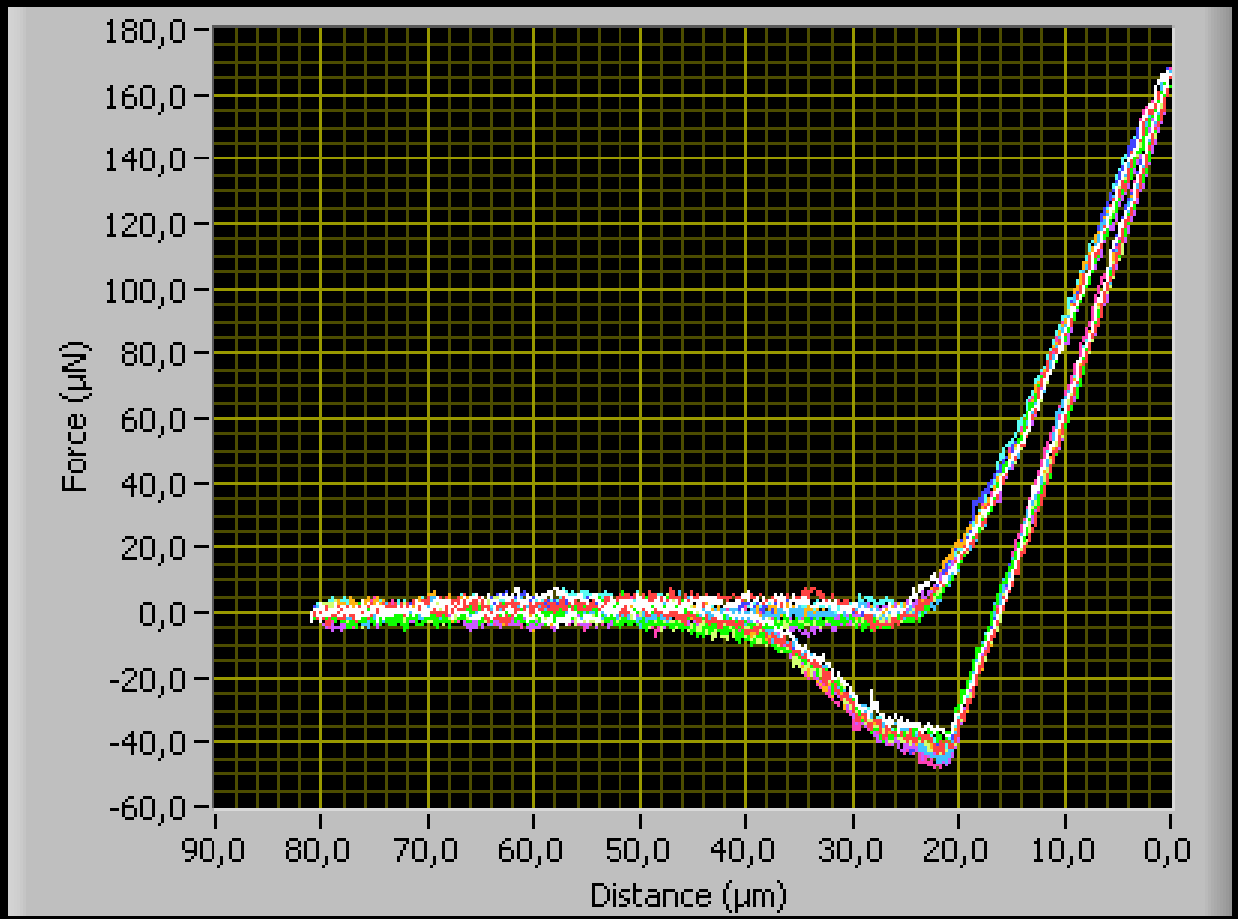
Basalt II Adhesion Tester

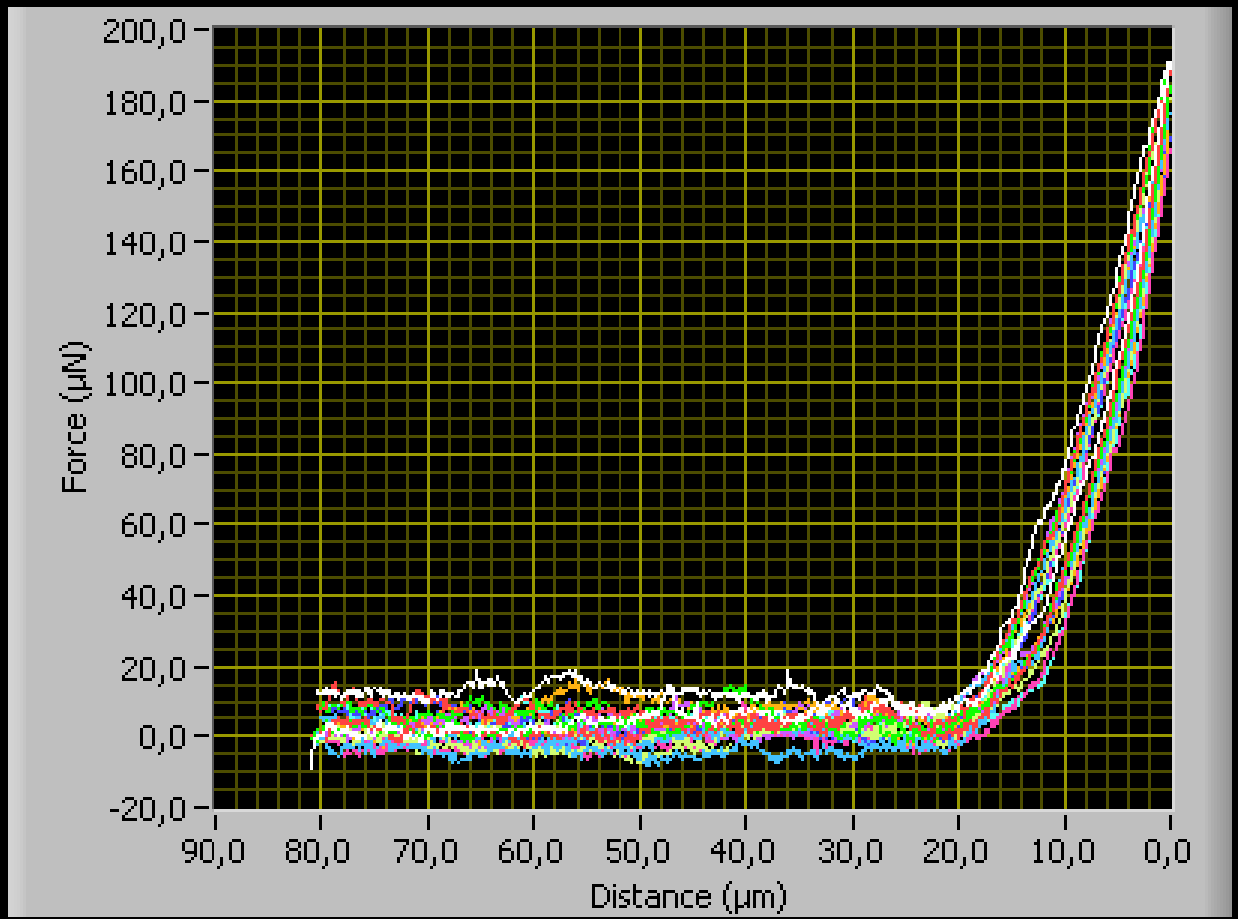


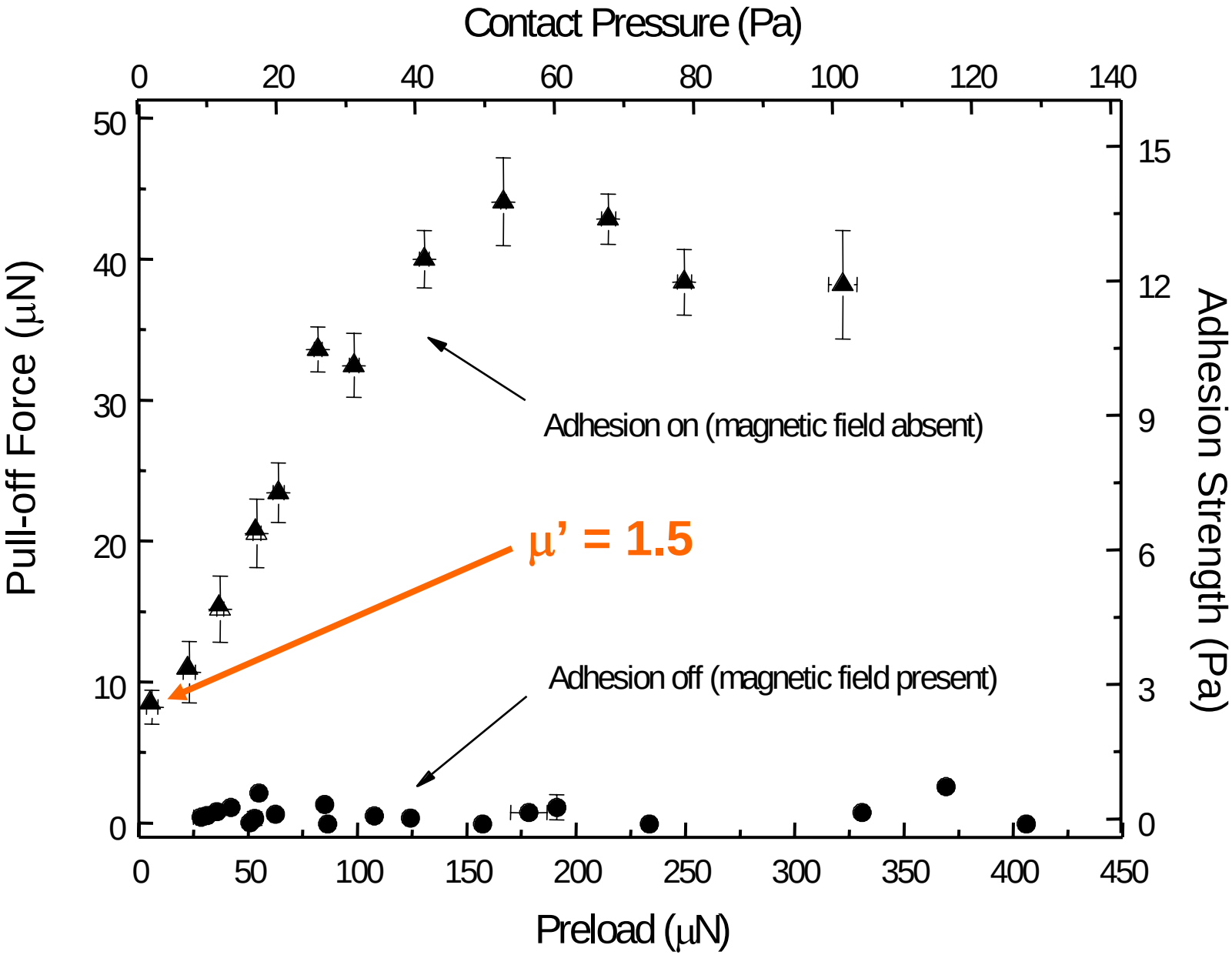
Basalt II Adhesion Tester



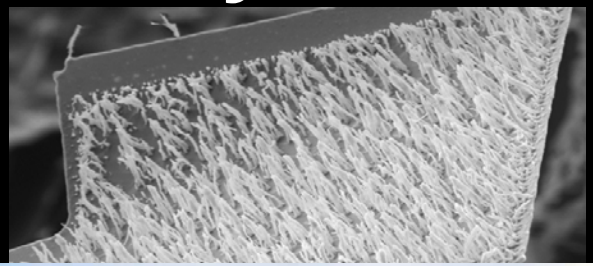

Glass Flat Punch
Glass Flat Punch

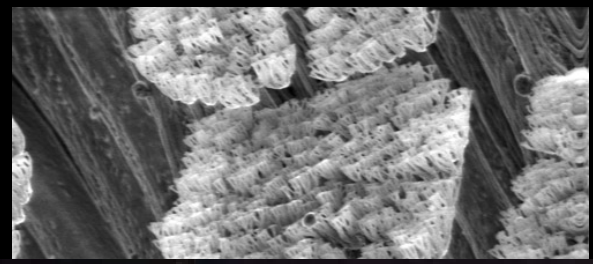

180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
-20,0
-40,0
-60,0
Force (µN)
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
Distance (µm)

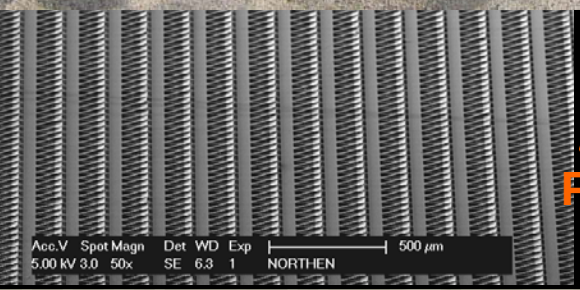

200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
-20,0
Force (µN)
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
Distance (µm)


Contact Pressure (Pa)
0
20
40
60
80
100
120
140
Pull-off Force (μN)
Adhesion Strength (Pa)
50
40
30
20
10
0
15
12
9
6
3
0
Adhesion on (magnetic field absent)
μ' = 1.5
Adhesion off (magnetic field present)
0
50
100
150
200
250
300
350
400
450
Preload (μN)

Synthetic vs. Gecko

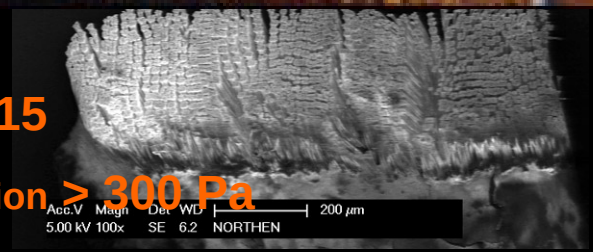






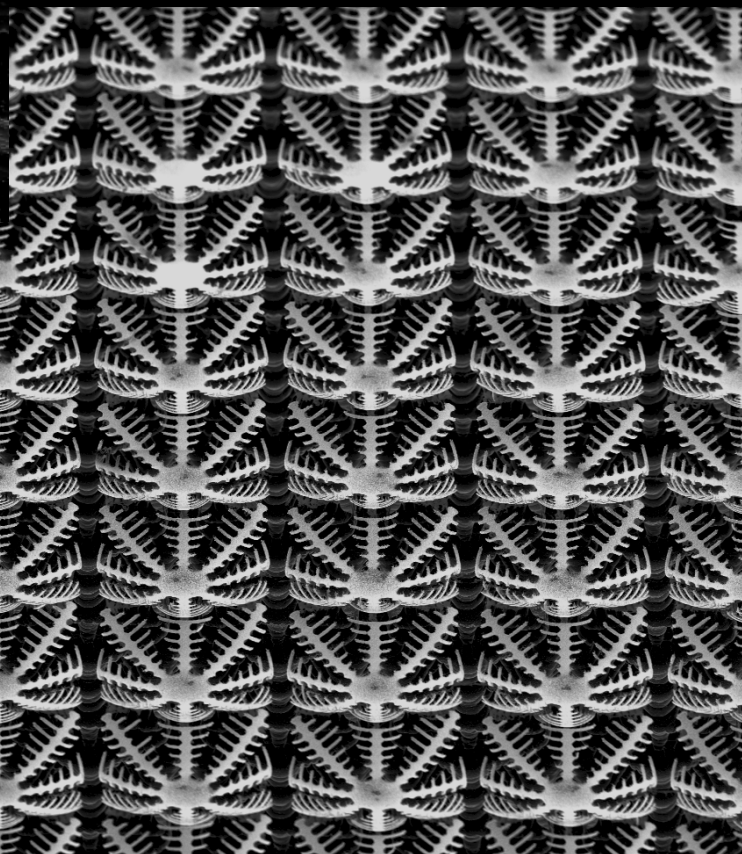
μ' = 1.5

Fadhesion < 15 Pa



μ' = 8-15

Fadhesion > 300 Pa



The future:

Frictional Adhesion (more bio-inspiration)

Increased Packing Density

Integrated Magnetic Fields

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'Dude' →

For More Information:

www.engr.ucsb.edu/~tmems