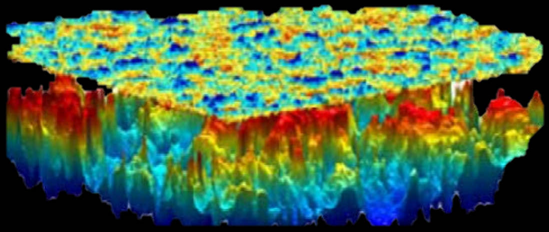
UNIVERSITY OF TWENTE.

MODELLING AND MEASURING ADHESION AND FRICTION IN A IN TRIBOLOGICAL CONTACT



SURFACES, INTERFACES & COATINGS WORKSHOP

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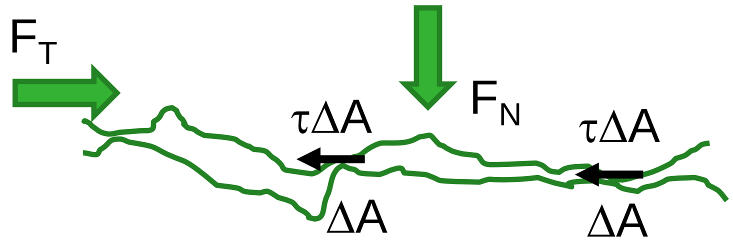
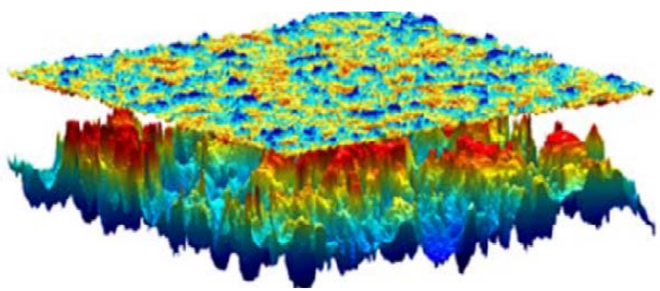




Van der Waals forces + Meniscus forces

Elastic deformation

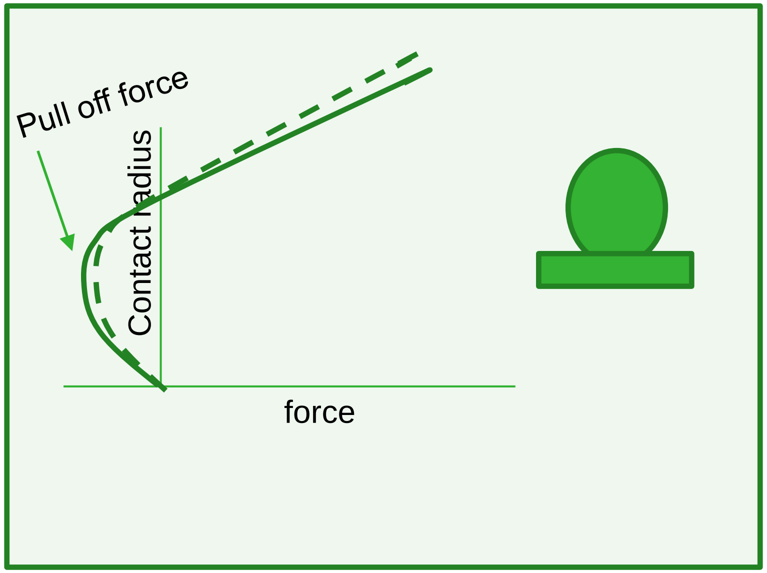
Larger ΔA

Relatively smooth

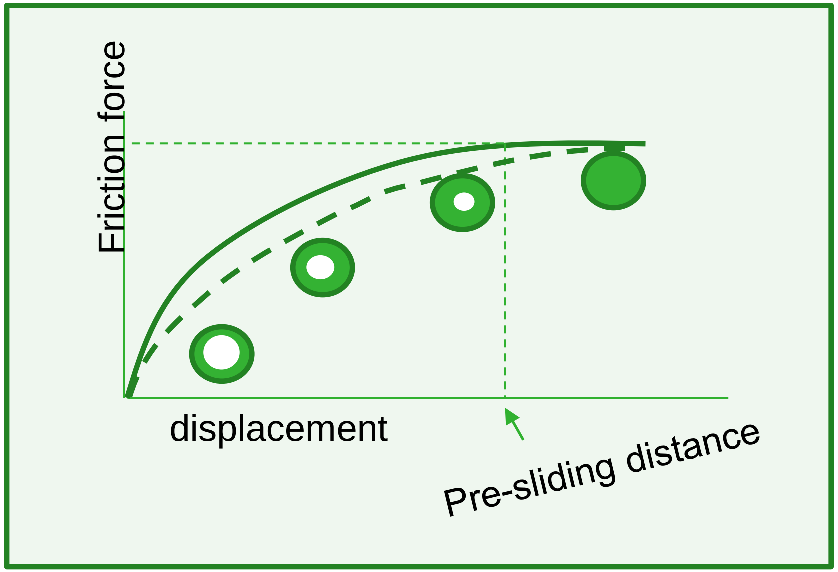
(Pre) sliding

Basic concepts

Adhesive contact

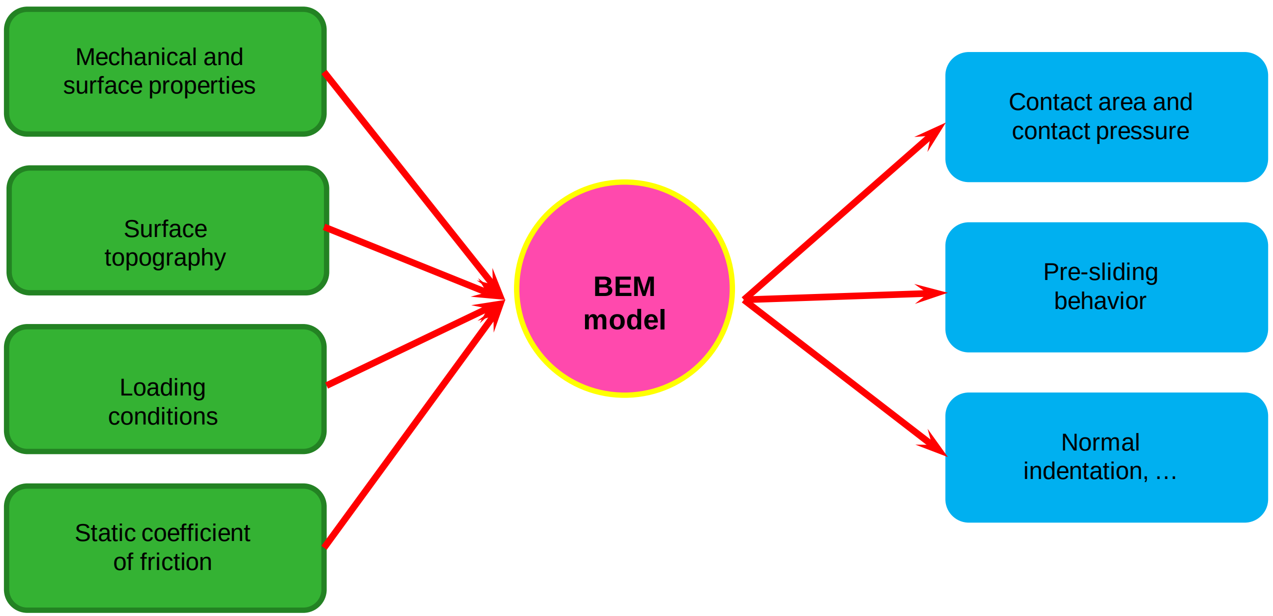


Pre-sliding



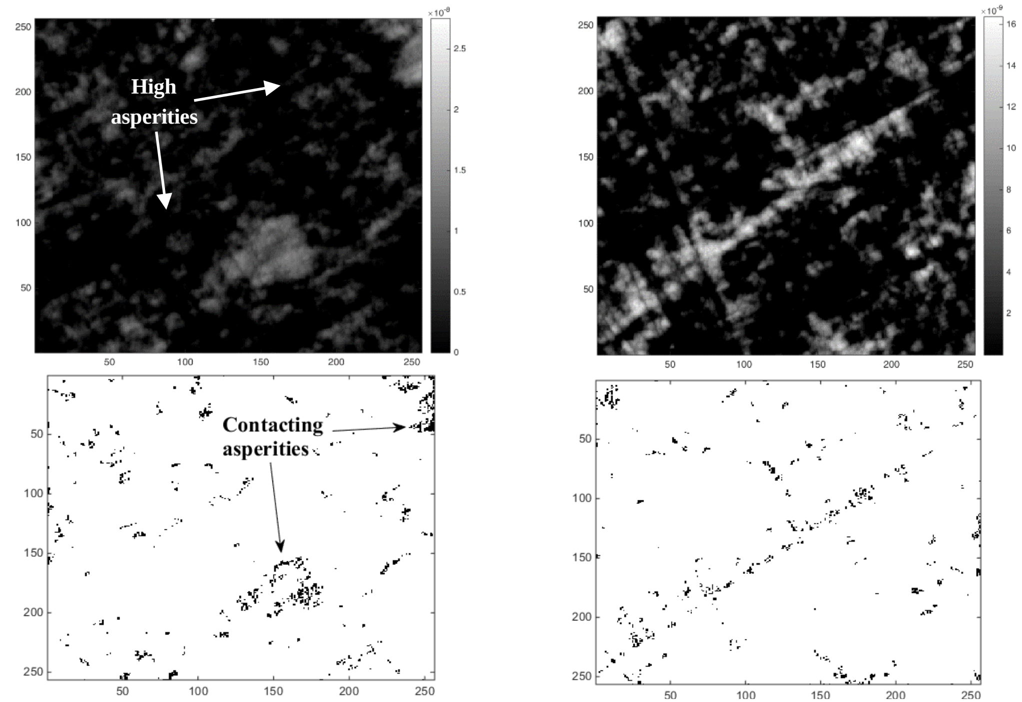
Modelling + Experimental validation

Developed Boundary Element Model (BEM) model



Contact at a rough interface

- 10*10 um AFM measurement



Can be calculated fast (minutes) with order 10^6 datapoints
Also subsurface stresses, coated surfaces etc.

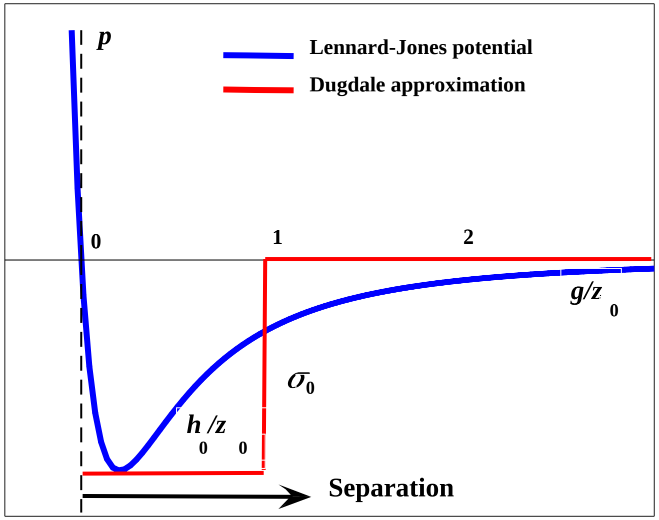
ADHESIVE CONTACT
VAN DER WAALS INTERACTION

The role of van der Waals forces

$$p_{vdW} = \frac{8\Delta\gamma}{3z_0}\left(\left(\frac{z_0}{g+z_0}\right)^9 - \left(\frac{z_0}{g+z_0}\right)^3\right)$$

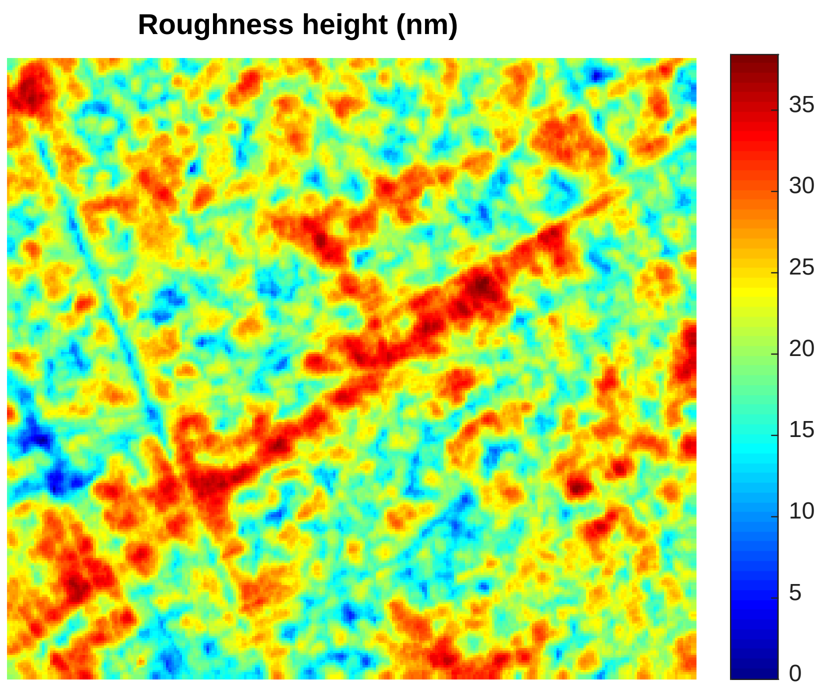
$$\sigma_0 = \frac{16\Delta\gamma}{9\sqrt{3}z_0}$$

$$h_0 = \frac{\Delta\gamma}{\sigma_0} \approx 0.97z_0$$

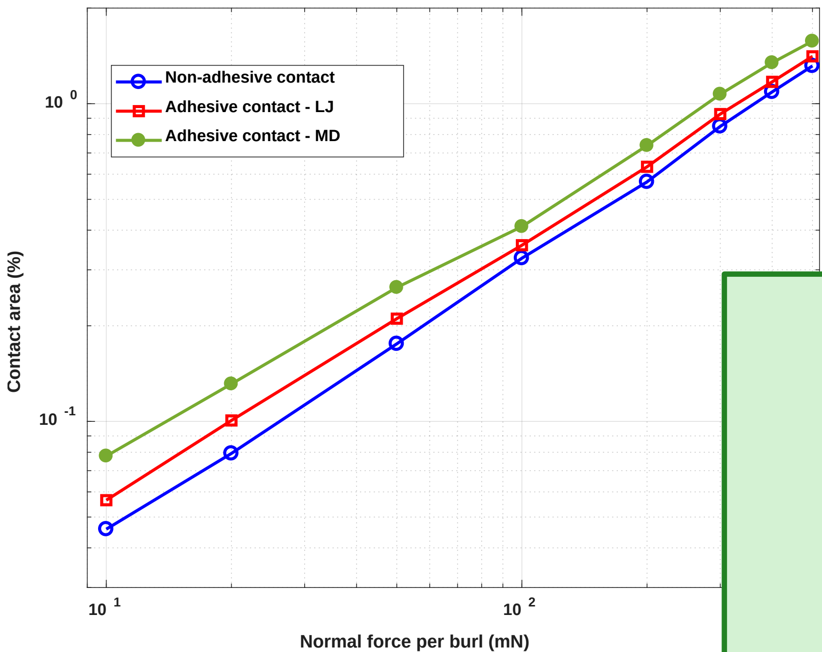


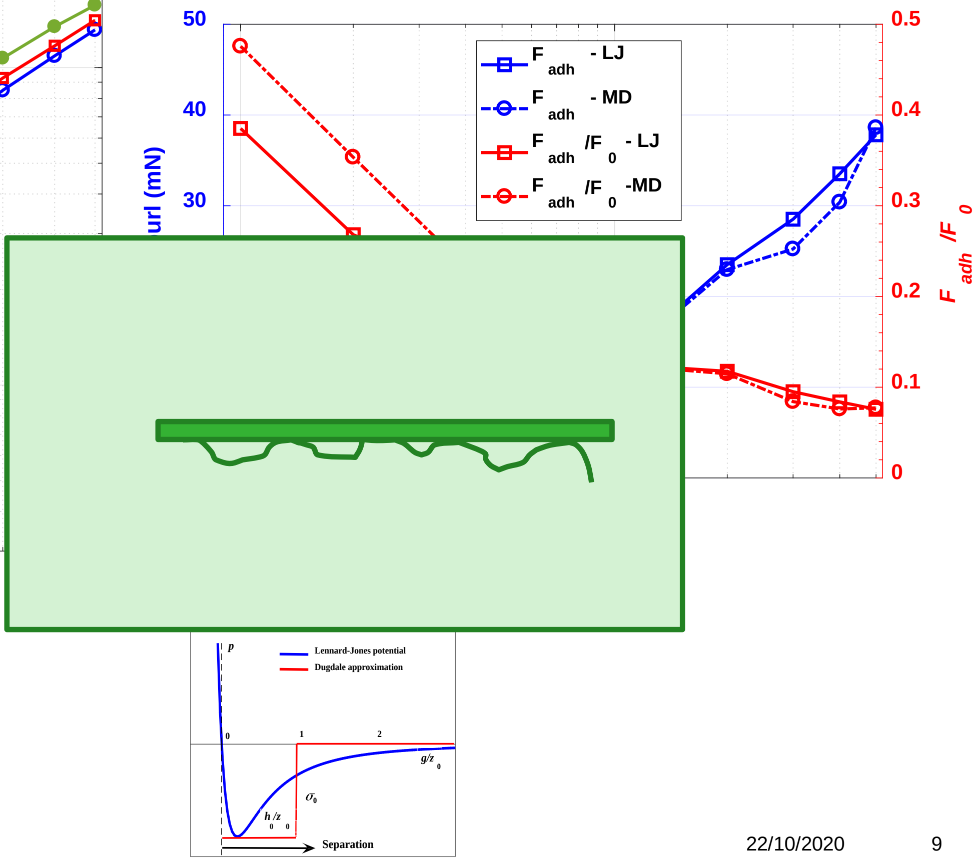
The role of van der Waals forces

- AFM measurement 10x10 μm, 256x256 points
- Contact between a smooth silicon wafer and glass coated by CrN
- Work of adhesion = 60 mJ/m^2

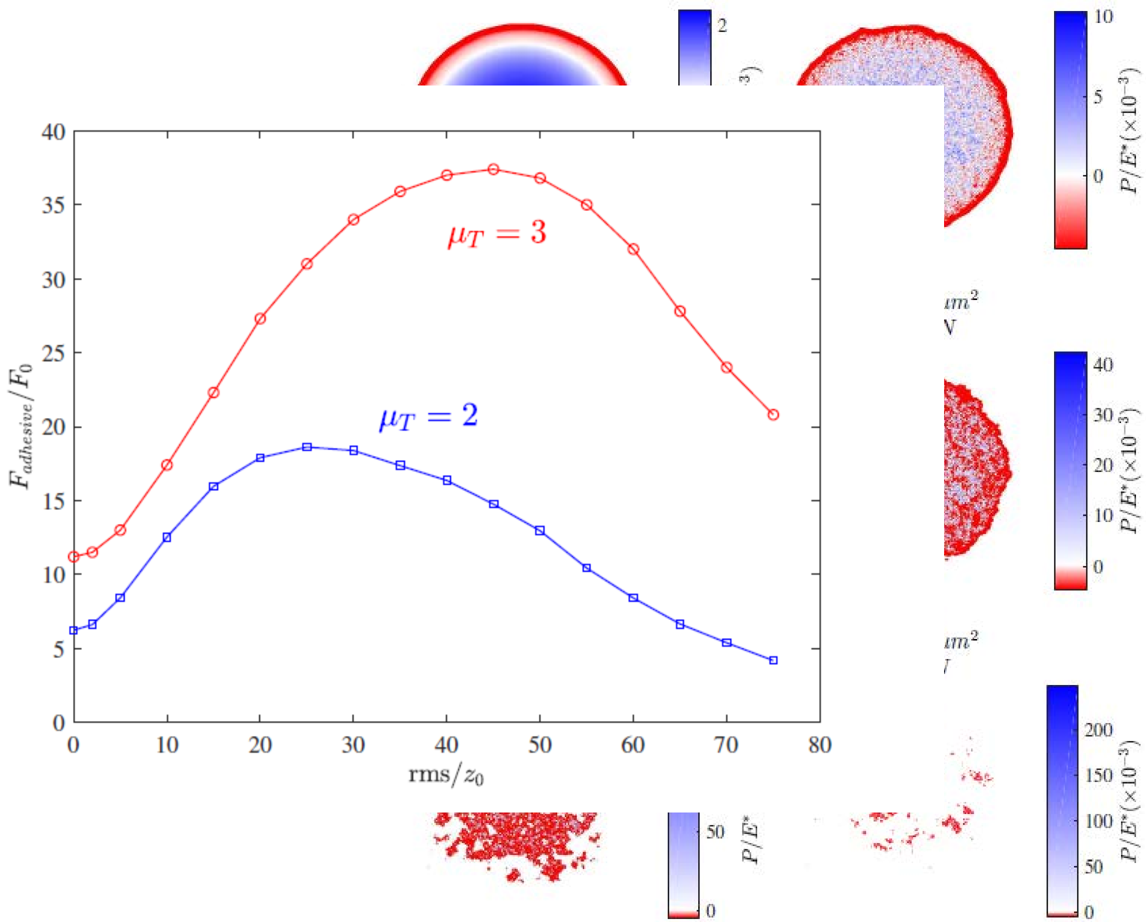


The role of van der Waals forces





Adhesion in rough contacts

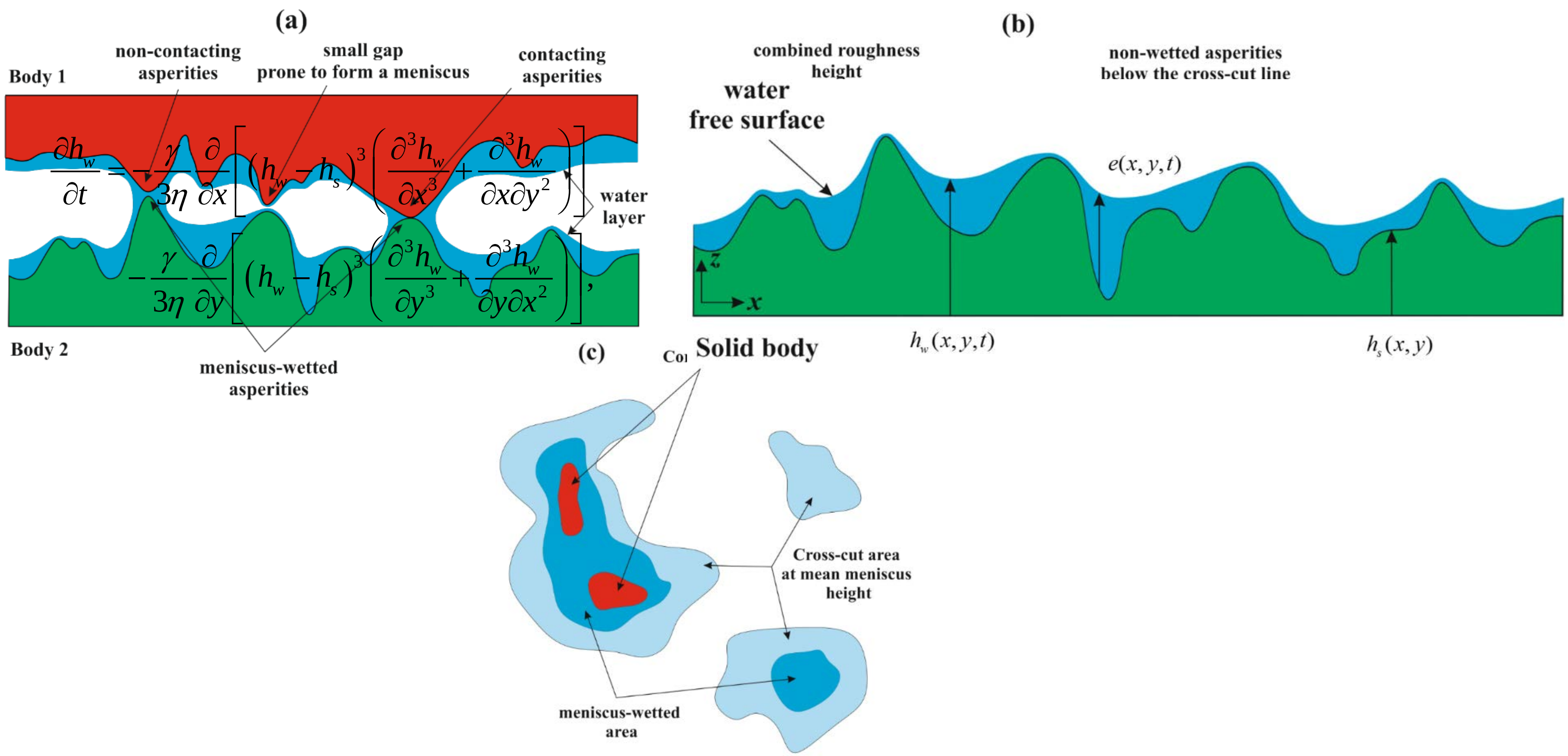


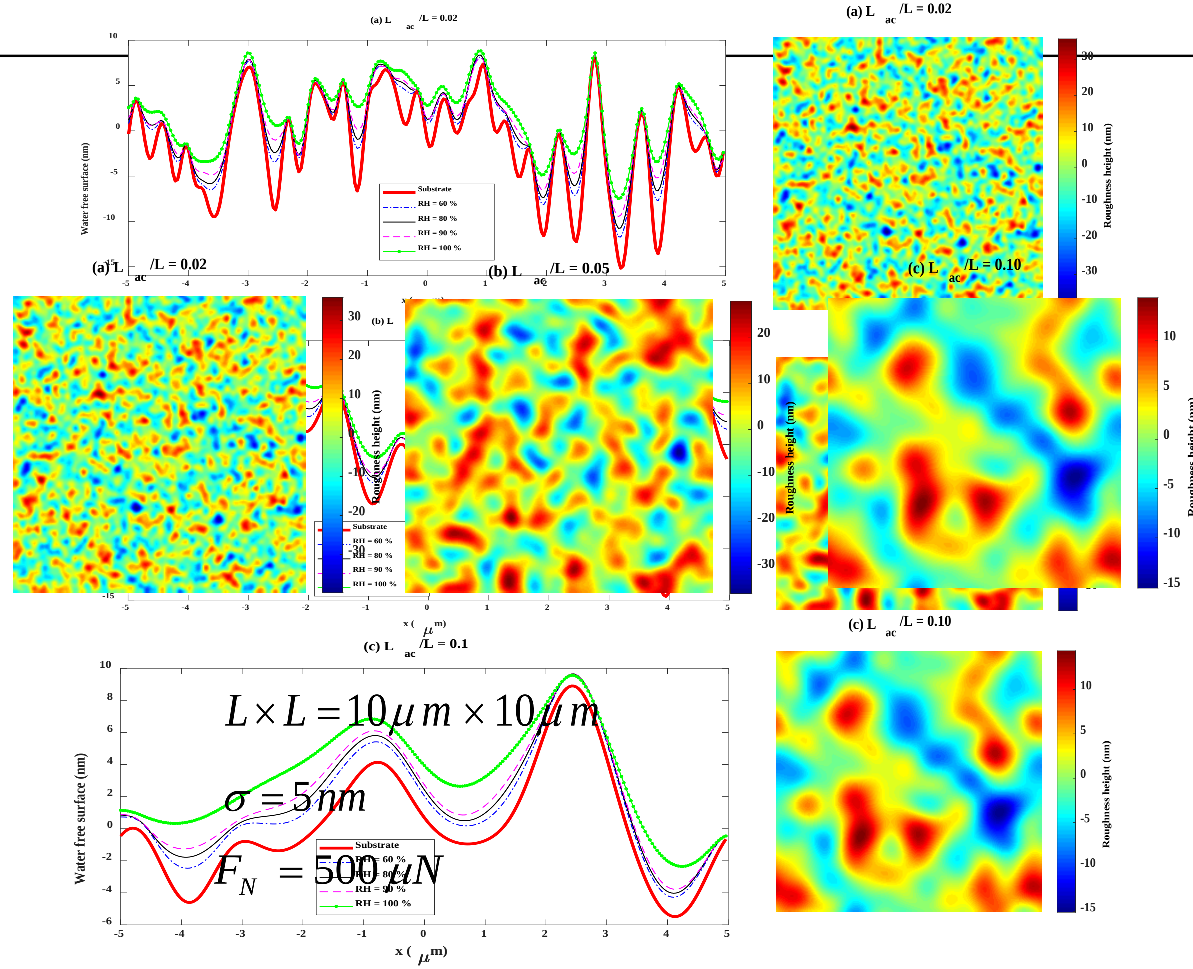
(e) $rms/z_0 = 50$
$A_{Adhesive} = 0.381\mu m^2$
$F_{Adhesive} = 130\mu N$

(f) $rms/z_0 = 100$
$A_{Adhesive} = 0.039\mu m^2$
$F_{Adhesive} = 13.5\mu N$

ADHESIVE CONTACT
MENISCUS FORCES

Capillary model for a rough contact



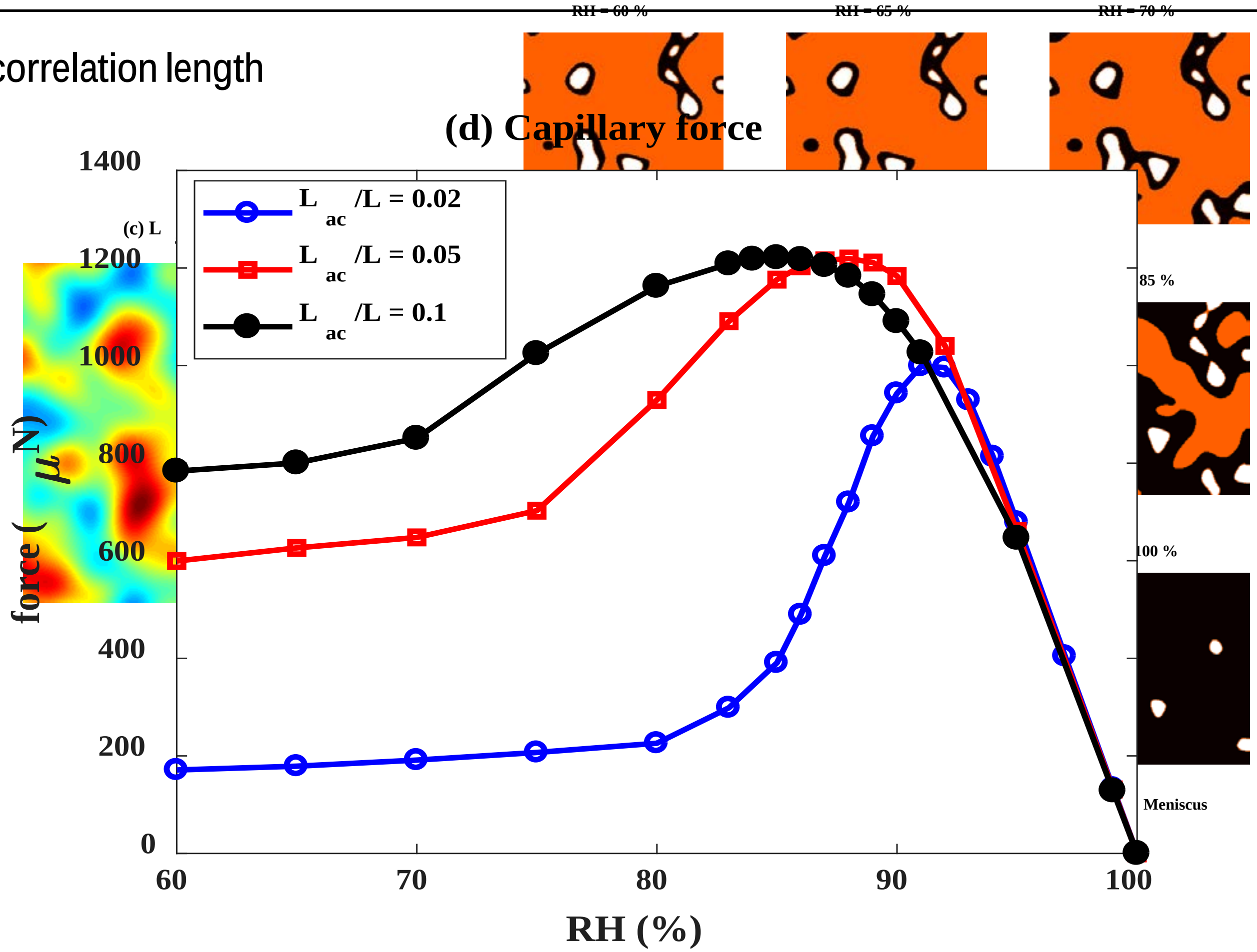


$$L \times L = 10\,\mu m \times 10\,\mu m$$

$$\sigma = 5nm$$

$$F_N = 500\,\mu N$$

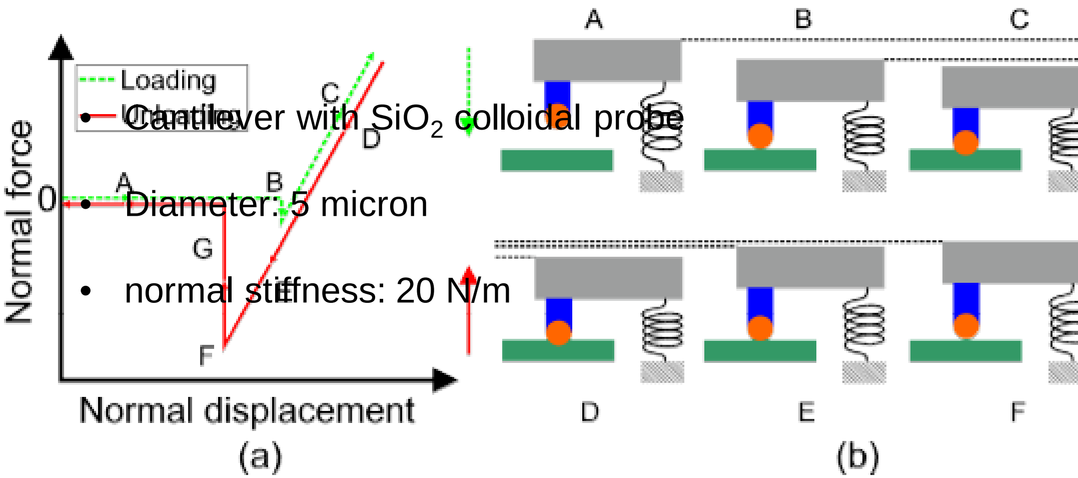
Long auto-correlation length

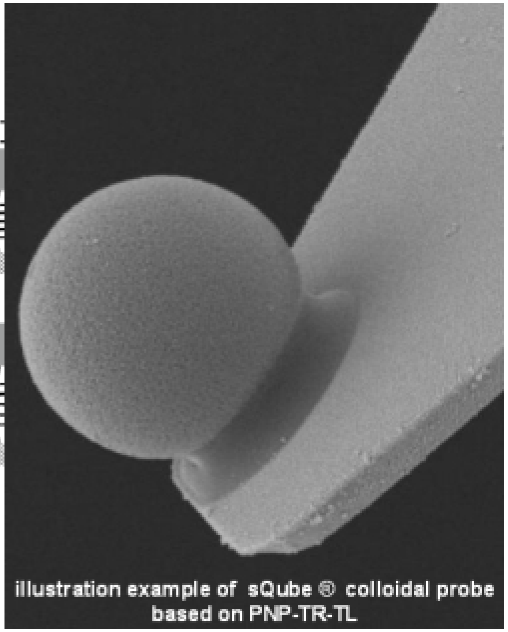


Experimental validation on the AFM

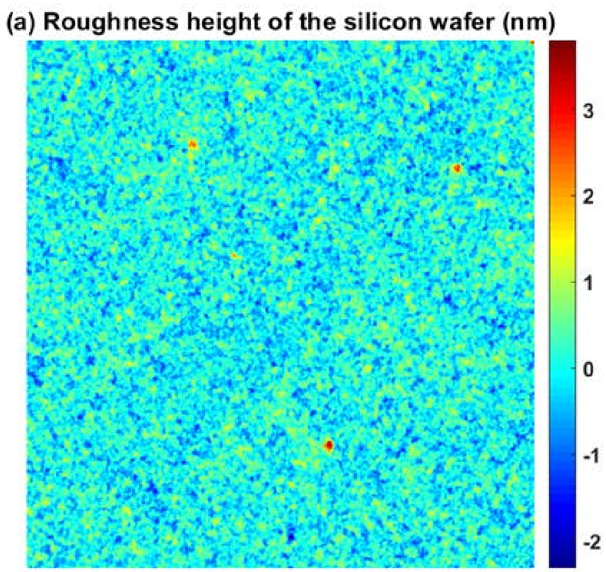
Pull-off force measurement on an AFM

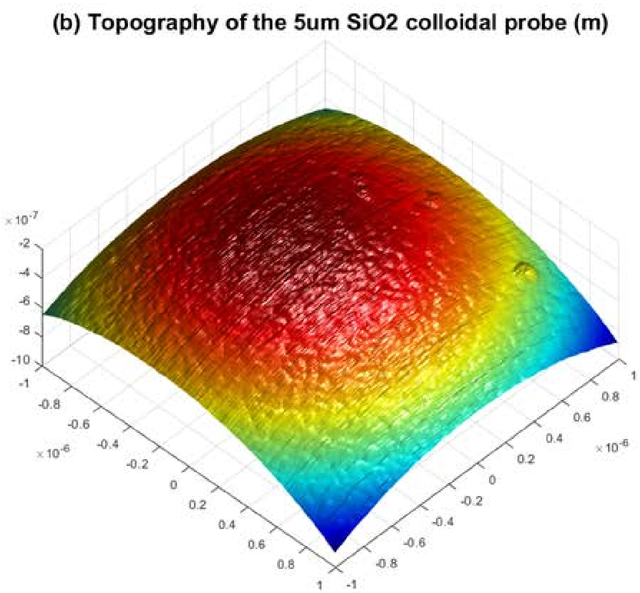
- Cantilever with SiO_2 colloidal probe
- Diameter: 5 micron
- normal stiffness: 20 N/m



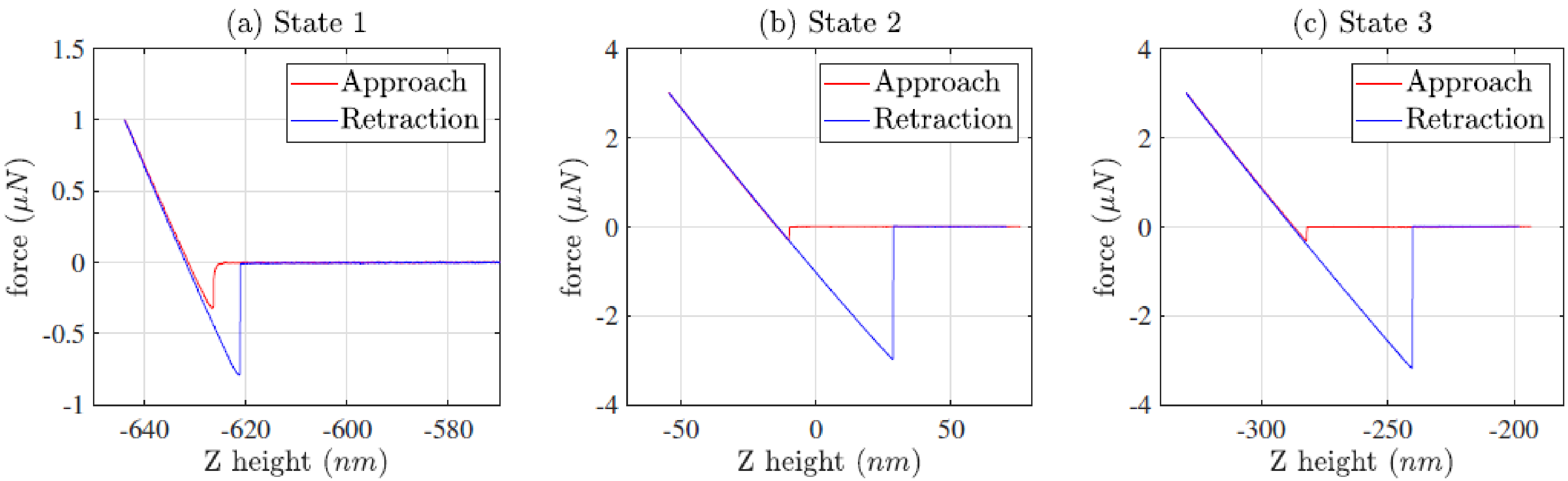


SiO2 ball and silicon wafer surface roughness



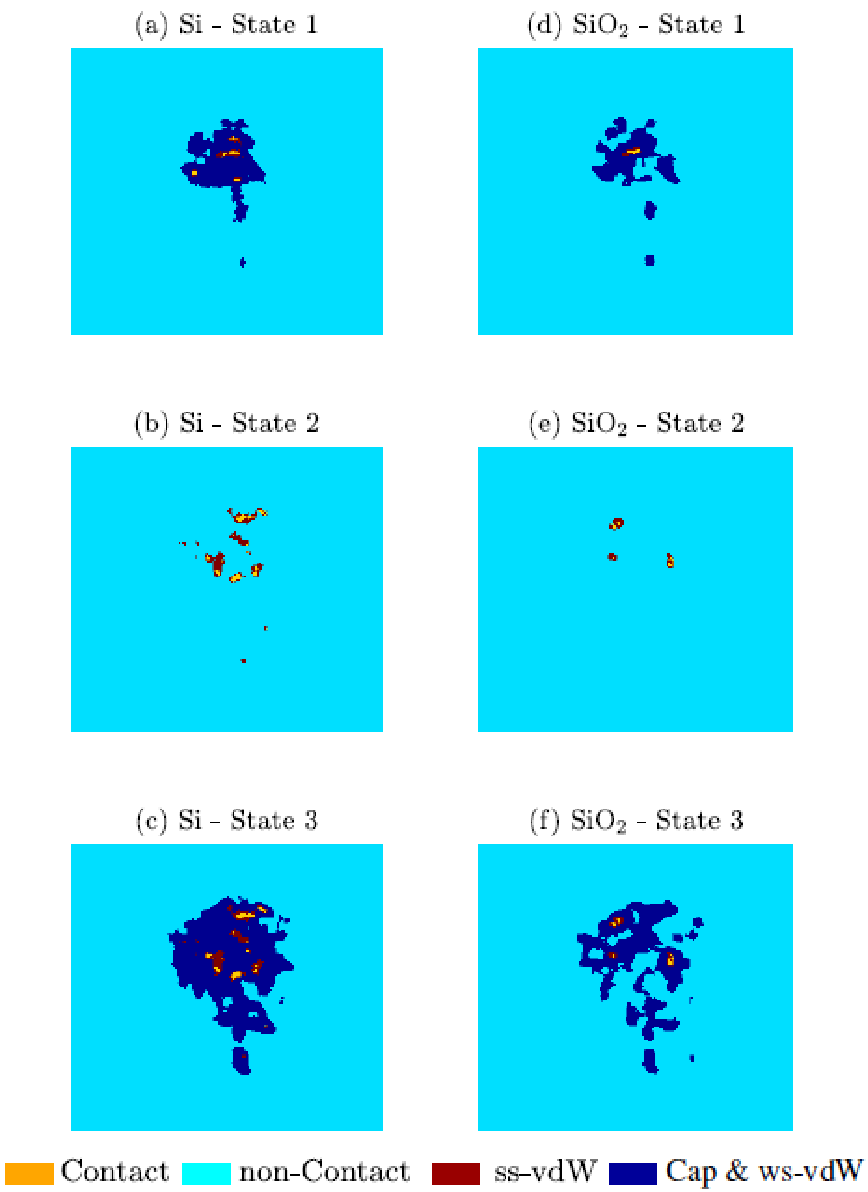


Measured adhesion curves



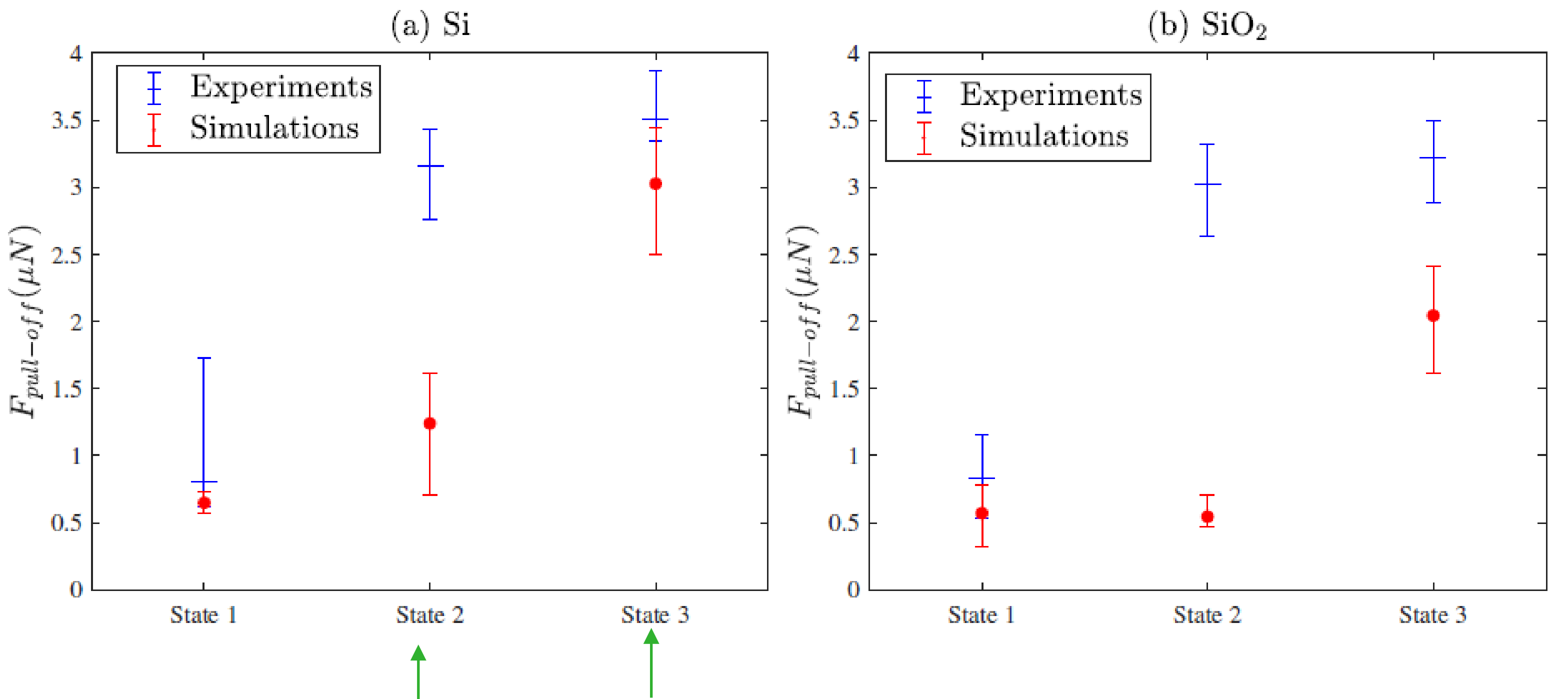
ambient → vacuum → Vacuum chamber opened

Results



(a) Si - State 1
(d) SiO_2 - State 1
(b) Si - State 2
(e) SiO_2 - State 2
(c) Si - State 3
(f) SiO_2 - State 3
Contact
non-Contact
ss-vdW
Cap & ws-vdW

Calculations versus experiments

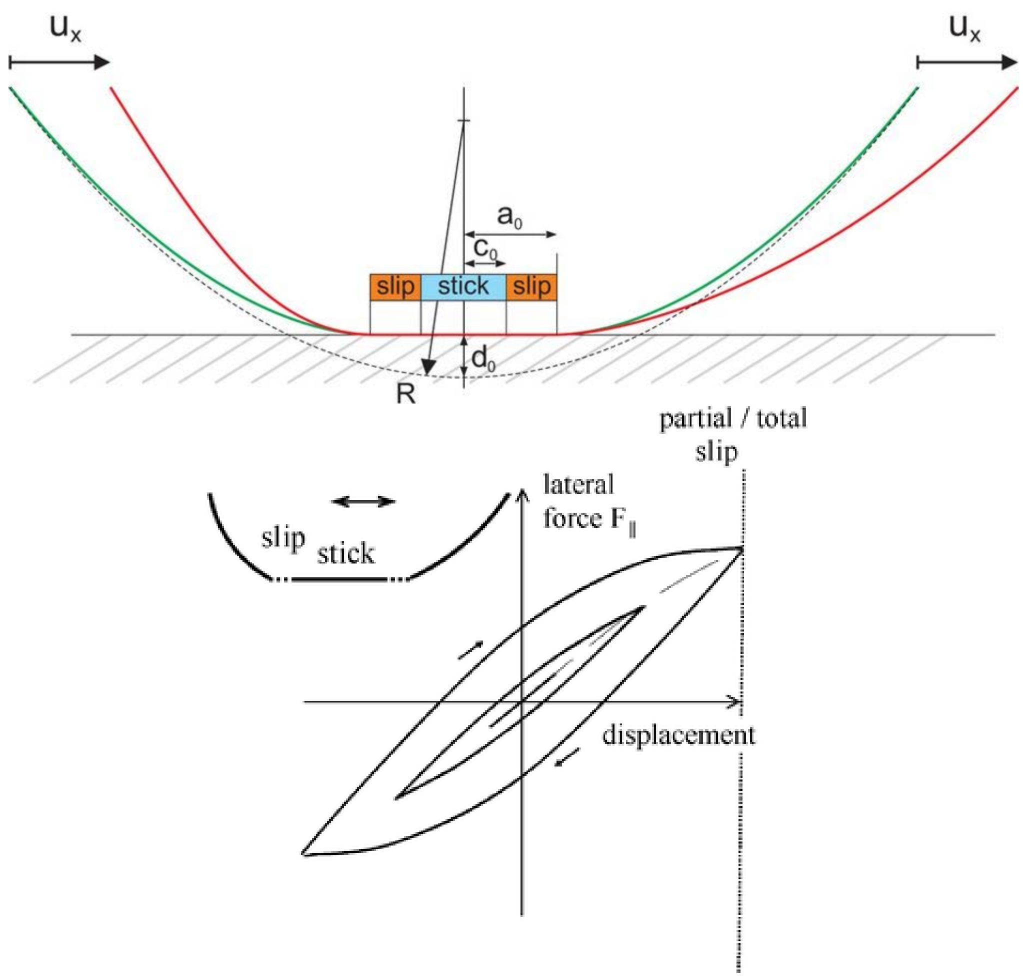


Surface has been cleaned
Topography changes

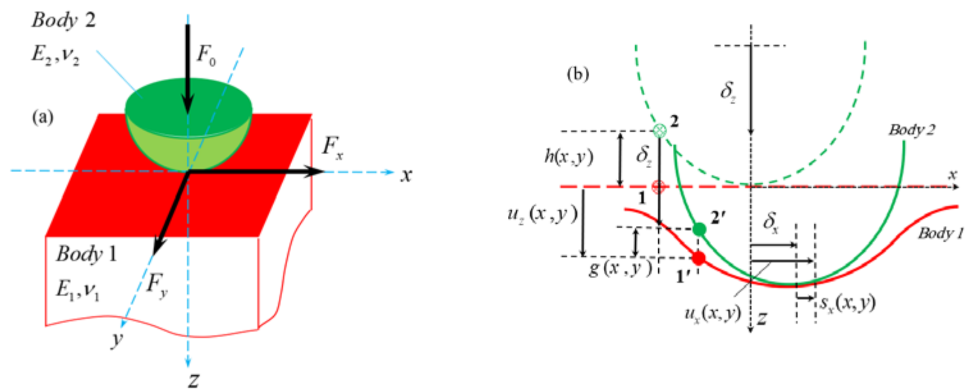
Assuming no water layers
Topography changes

PARTIAL SLIP

PARTIAL SLIP



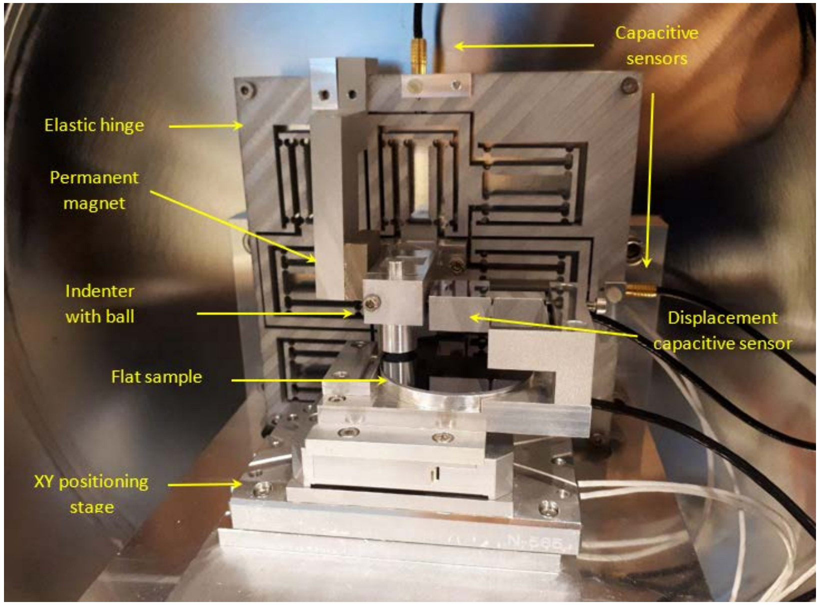
Partial slip model

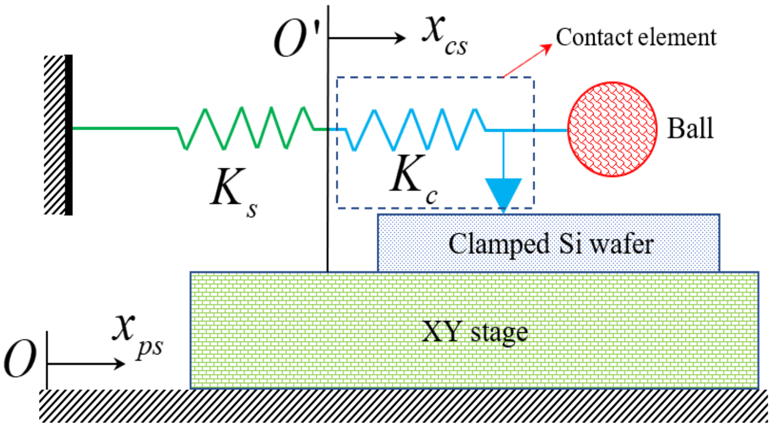


$$\Delta s_m(x,y,t) = s_m(x,y,t) - s_m(x,y,t-\Delta t), m = x, y$$

$$\begin{cases} A_{st} = \left\{(x,y) \in A_c \middle| \sqrt{q_x(x,y)^2 + q_y(x,y)^2} < \mu_f p(x,y), \sqrt{\Delta s_x(x,y)^2 + \Delta s_y(x,y)^2} = 0\right\} \\ A_{st} = \left\{(x,y) \in A_c \middle| \sqrt{q_x(x,y)^2 + q_y(x,y)^2} = \mu_f p(x,y), \sqrt{\Delta s_x(x,y)^2 + \Delta s_y(x,y)^2} \neq 0\right\} \end{cases}$$

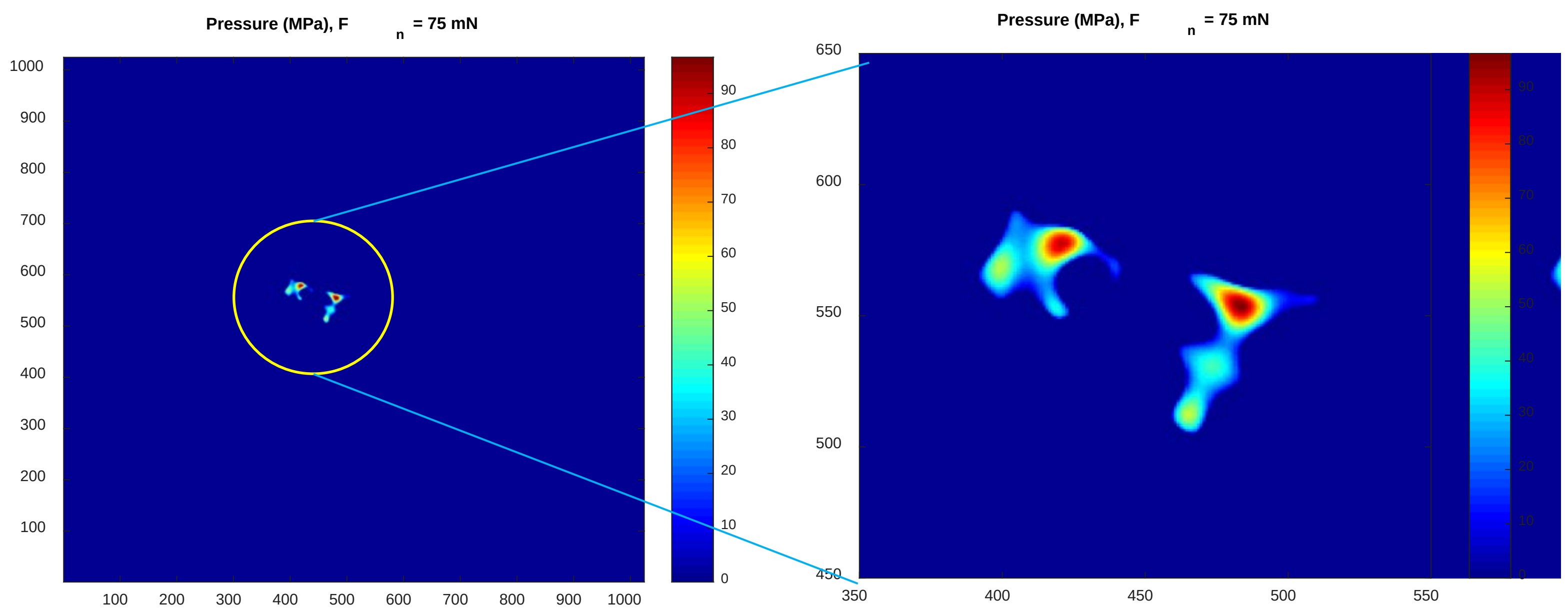
Friction measurements



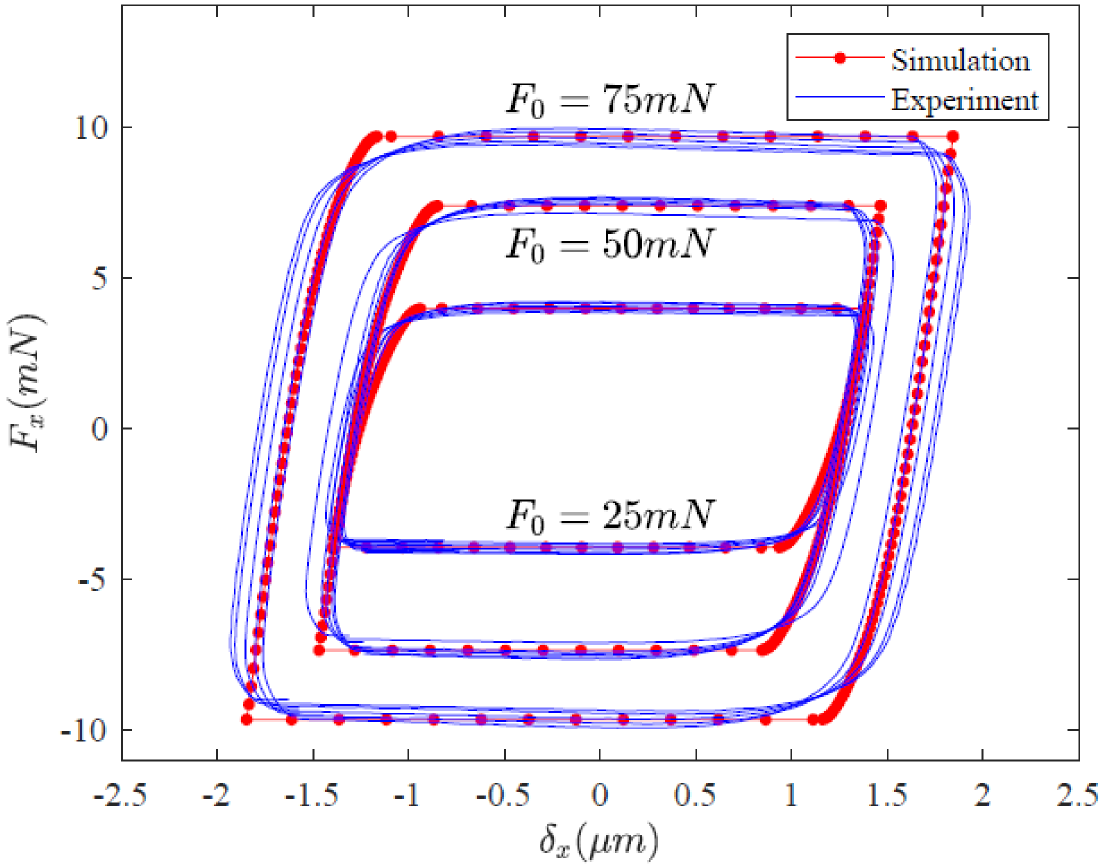


Measurements and calculations

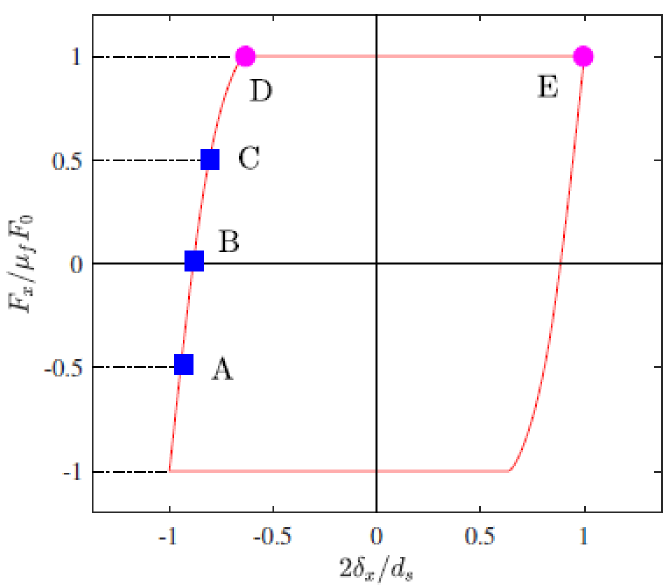
Ball topography HDPE Ball

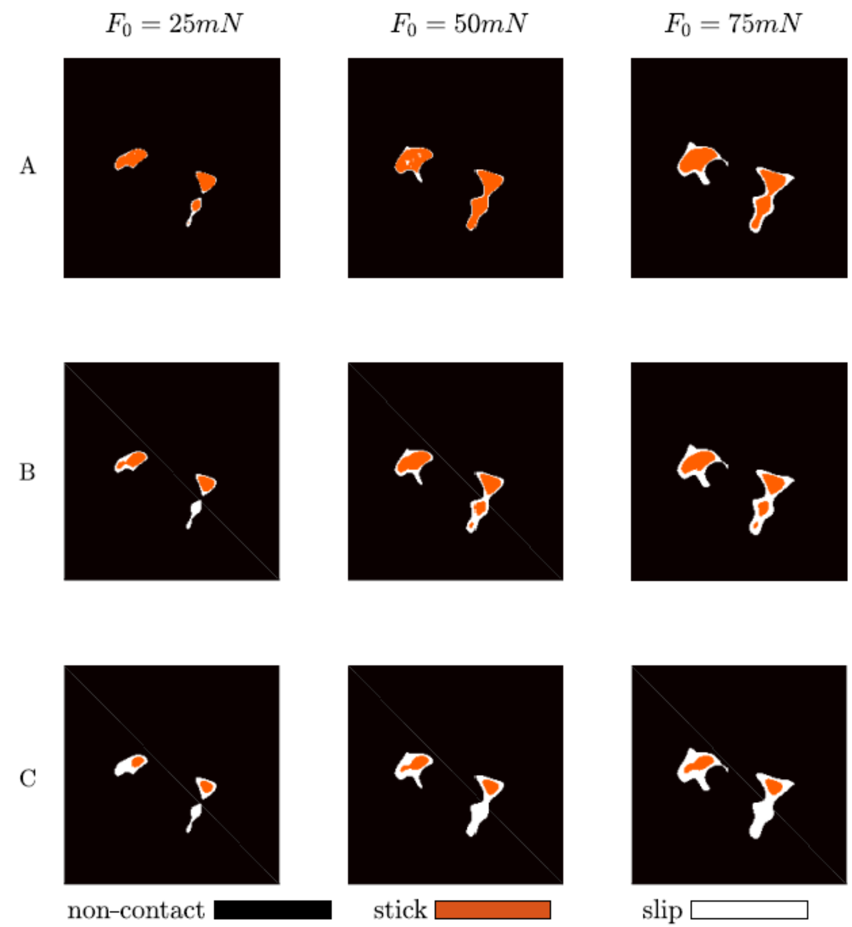


Measurements and calculations

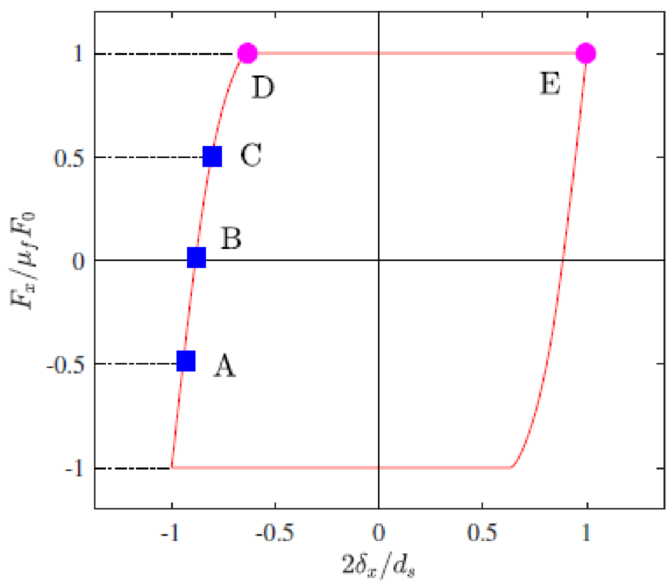


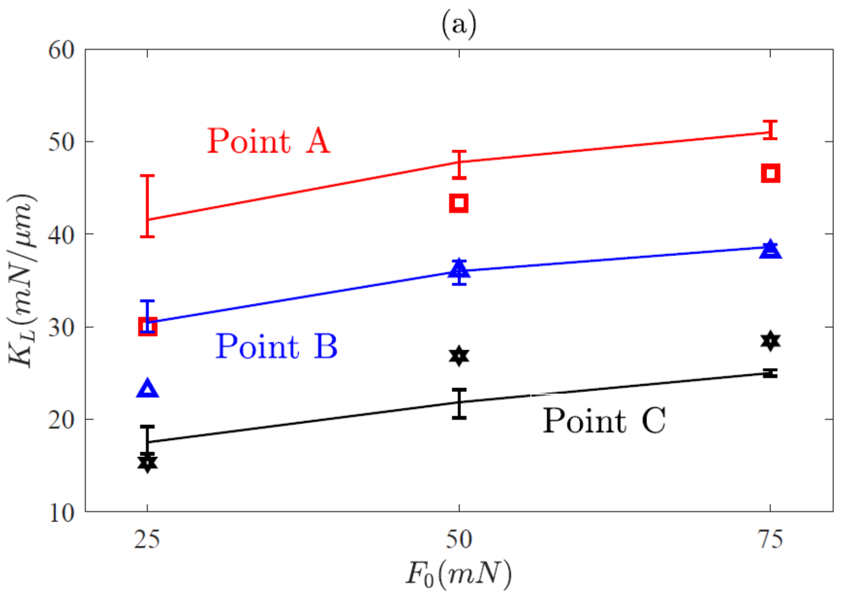
Calculations





Measurements and calculations





HDPE ball - wafer

Conclusions

- Pre sliding, adhesion as well as meniscus formation
  - Have been modelled for rough contacts and compared with measurements
  - Small roughness details matter!