Nanotubes and Nanotribology

Joël Chevrier
Université Joseph Fourier
LEPES CNRS
ESRF
Grenoble France

Collaborators:

ESRF: S.Decossas, C. Guillemot, I. Snigireva, F.Comin, C.Alandi, G. Poignant

LEPES: L. Patrone

Samples:

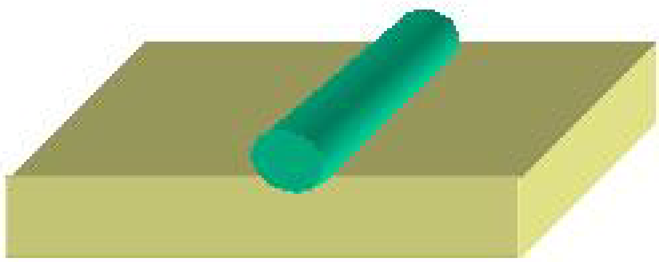
Nanotubes: AM Bonnot LEPES

Ge nanodots on silicon: A Barski CEA

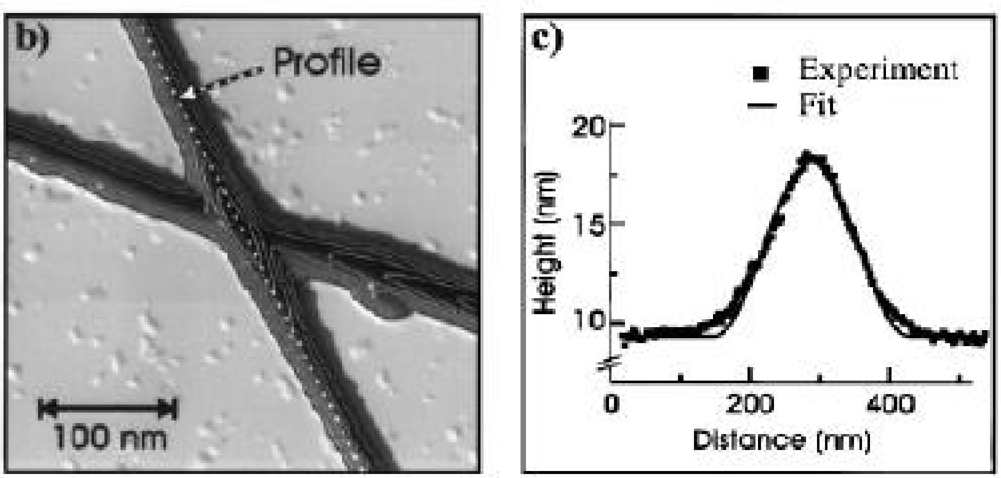
Part 1: overview

Examples

Interaction of Carbon Nanotubes with Surfaces:



Nanotube is in full contact all along !!!

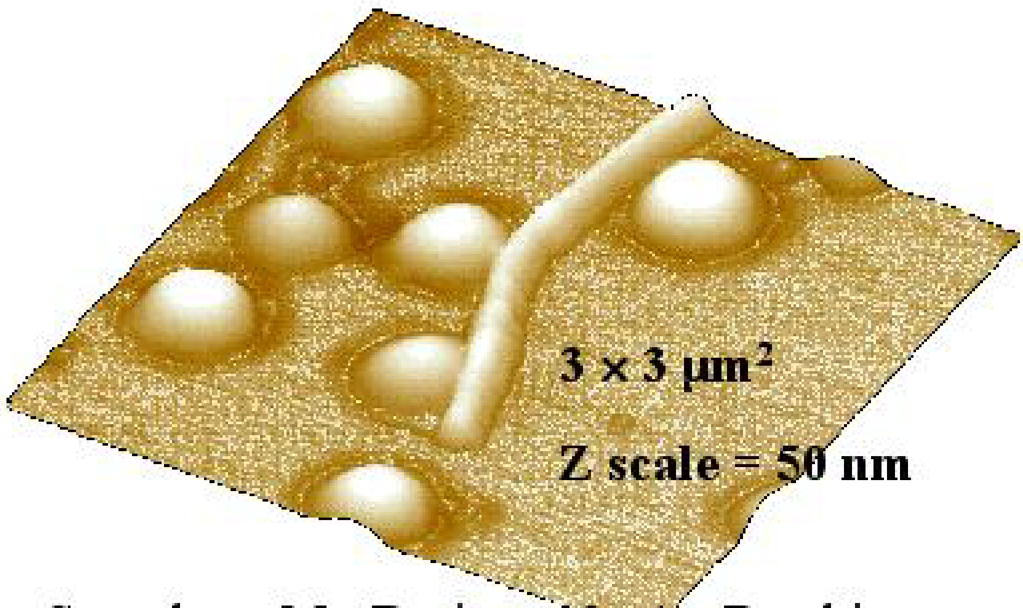


PHYSICAL REVIEW B VOLUME 58, NUMBER 20 15 NOVEMBER 1998-II

Deformation of carbon nanotubes by surface van der Waals forces

Tobias Hertel, Robert E. Walkup, and Phaedon Avouris*
IBM Research Division, Thomas J. Watson Research Center, Yorktown Heights, New York 10598
(Received 12 February 1998; revised manuscript received 7 May 1998)

Interaction of Nanotubes with Nanoobjects on Surfaces

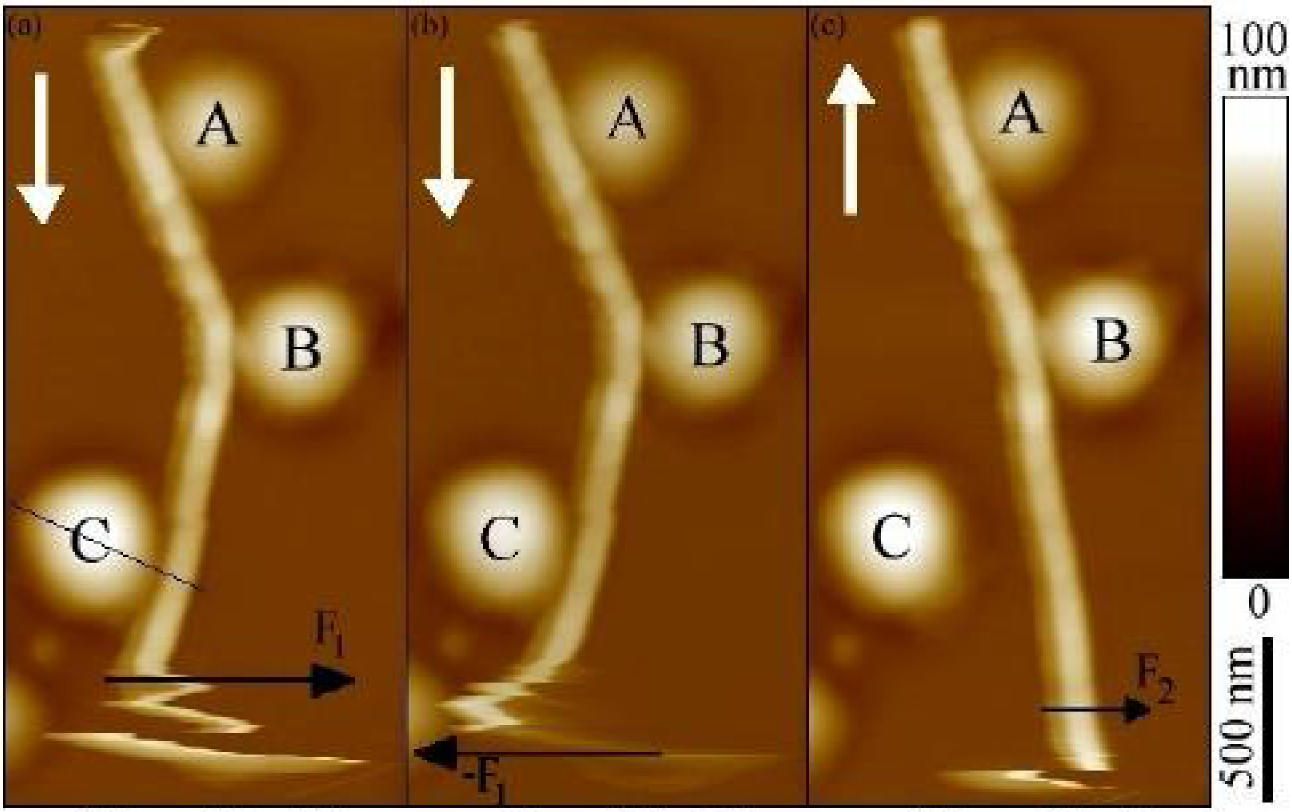


Sample : M. Derivaz & A. Barski (DRFMC/CEA)

Ge dots grown by MBE on oxidized Silicon

Strong effect:
Pinning of nanotubes by nanoobjects in both directions

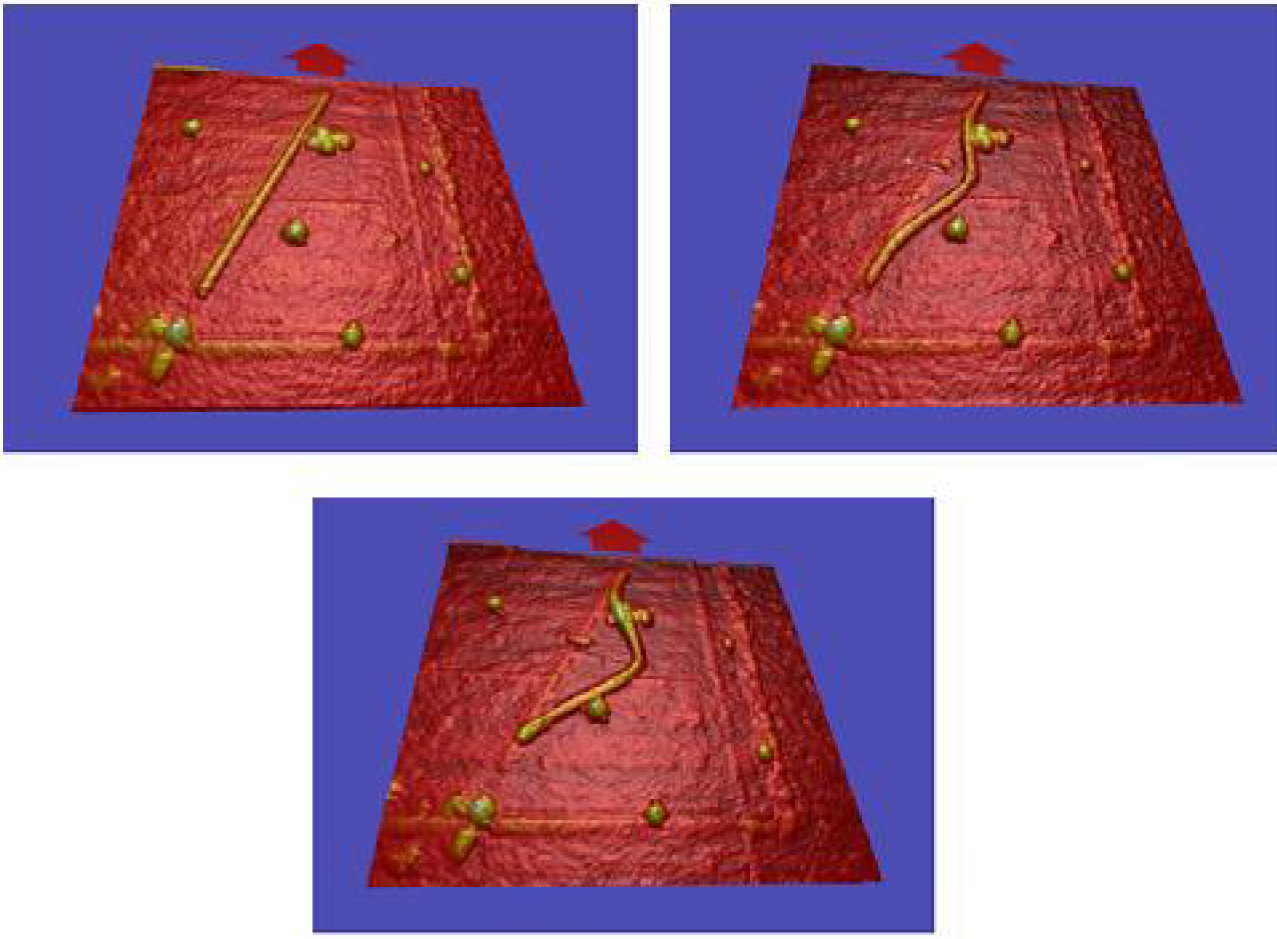
Open question:
nanotubes on dense layer of nanoobjects ?



F_N = 50 nN F_N = 50 nN F_N = 35 nN

-Nanotubes on silicon flat surfaces
are easily displaced
By an AFM tip
(contact mode)

-They are pinned on nanoobjects



Nanomanipulator project:
University of Chapell Hill
http://www.cs.unc.edu/Research/nano/index.html

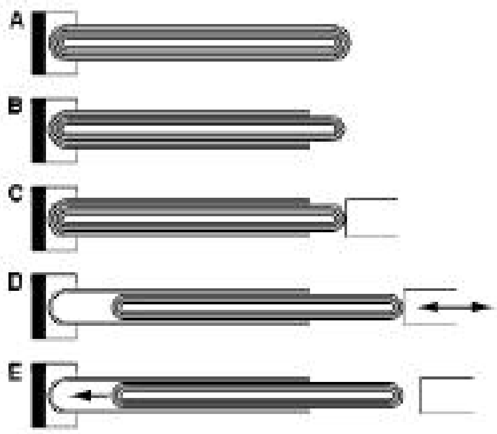
A carbon multiwall nanotube is manipulated amongst codeposited 20nm gold colloidal particles The particles remain fixed on the substrate, acting as constraints to the moving nanotube. The sequence proceeds from top-left to top-right, bottom-left to bottom-right. The tube bends as it is slid through the colloids, until it slips free from the center colloid The tube is then unstable to imaging until it relaxes to hit a colloid on the far right.

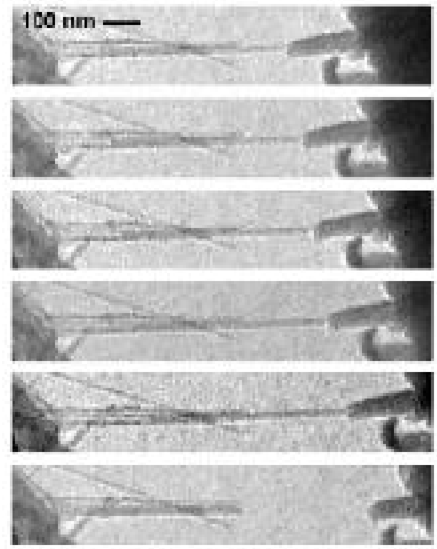
Interaction of Nanotubes with Nanotubes

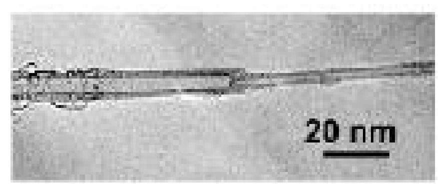
REPORTS

Low-Friction Nanoscale Linear Bearing Realized from Multiwall Carbon Nanotubes

John Cumings and A. Zettl*







Department of Physics, University of California, Berkeley, CA 94720, USA, and Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA.

*To whom correspondence should be addressed. E-mail: azettl@physics.berkeley.edu

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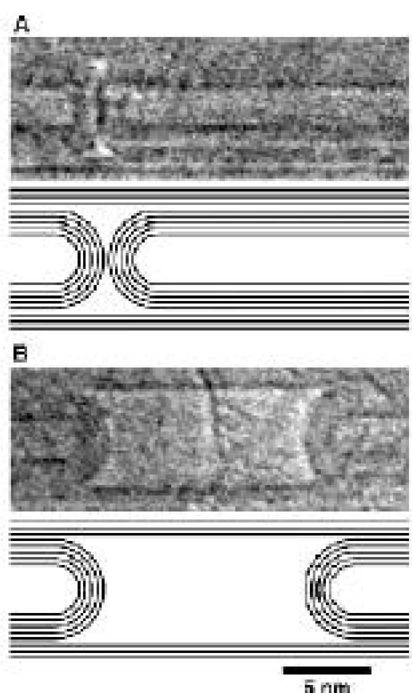


Key words for nanotribology and nanotubes

-Adhesion:
-Friction:

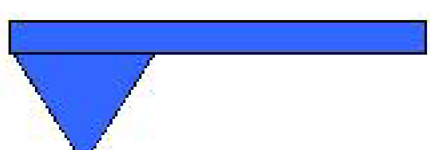
Origin/strength/mechanism

-Nanotube/surface

-Nanotube/nanotube

-Nanotube/nanoobject

-Nanotube/ AFM tip



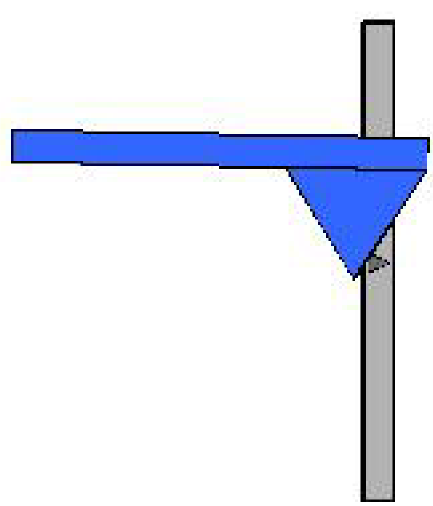
CARBON NANOTUBES

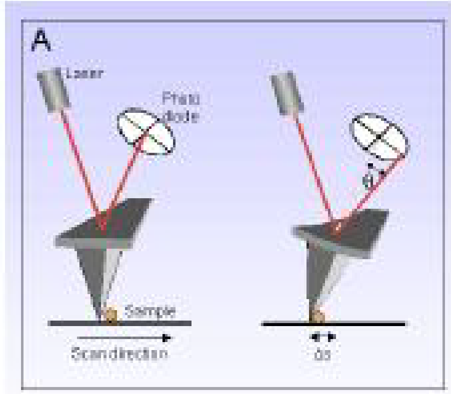
-Adhesion/friction
versus Mechanical deformation

-Length of carbon nanotubes/

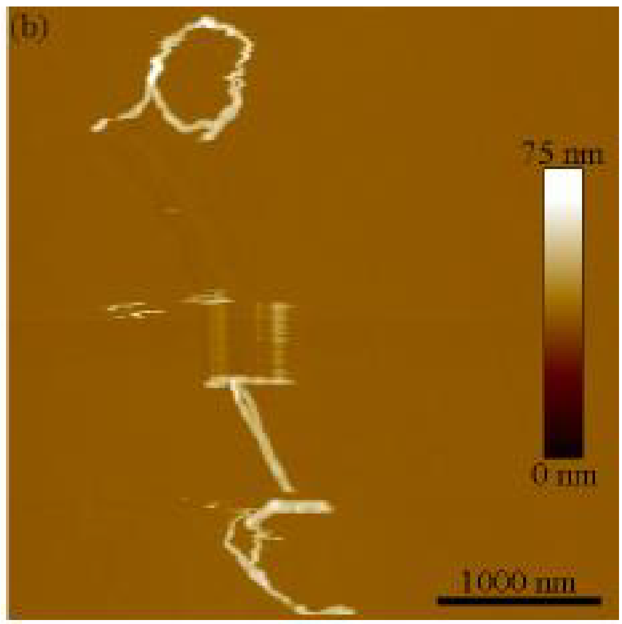
-Friction and/or adhesion/

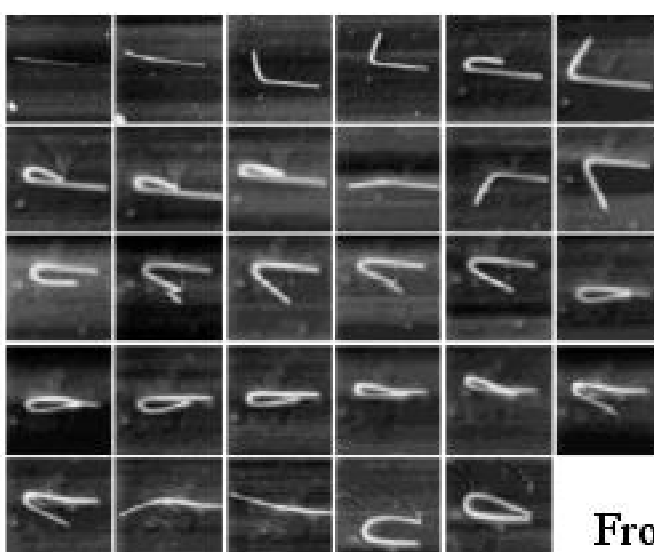
-Rigidity
(elastic constant like Young modulus)
See lectures of Ruoff and Yakobson





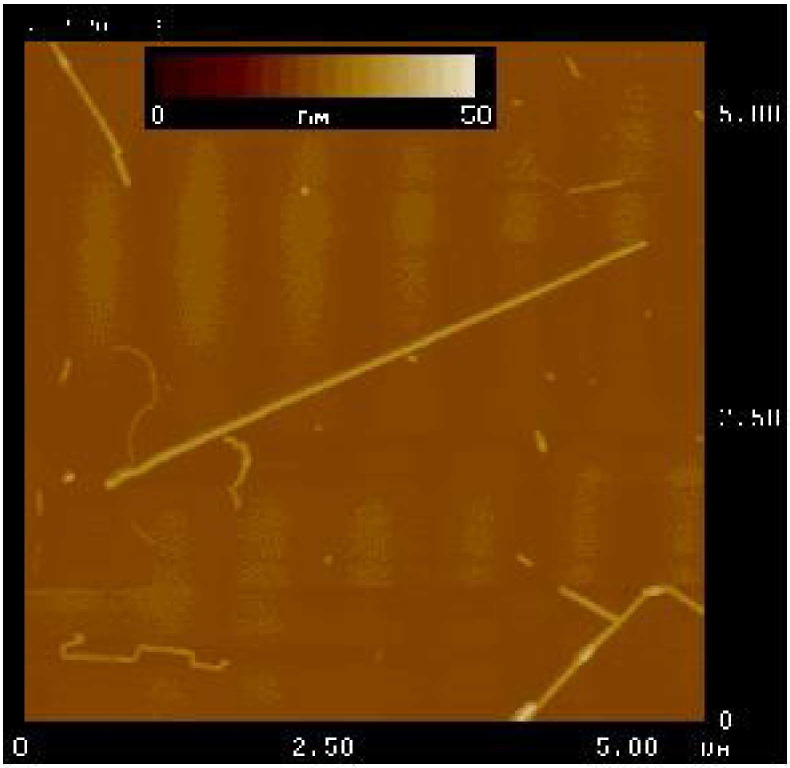
S. Decossas
PhDThesis





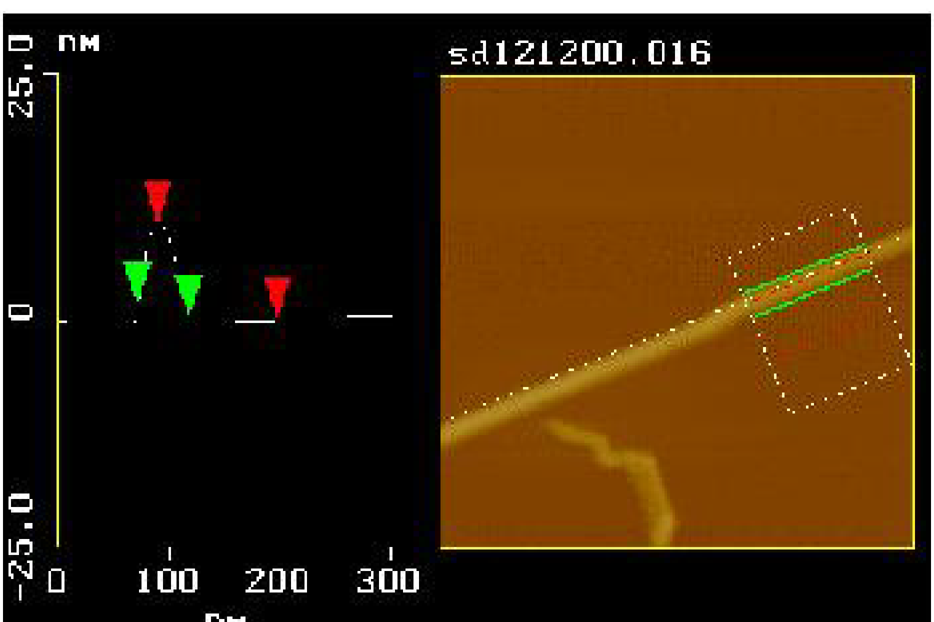
From Chapell Hill

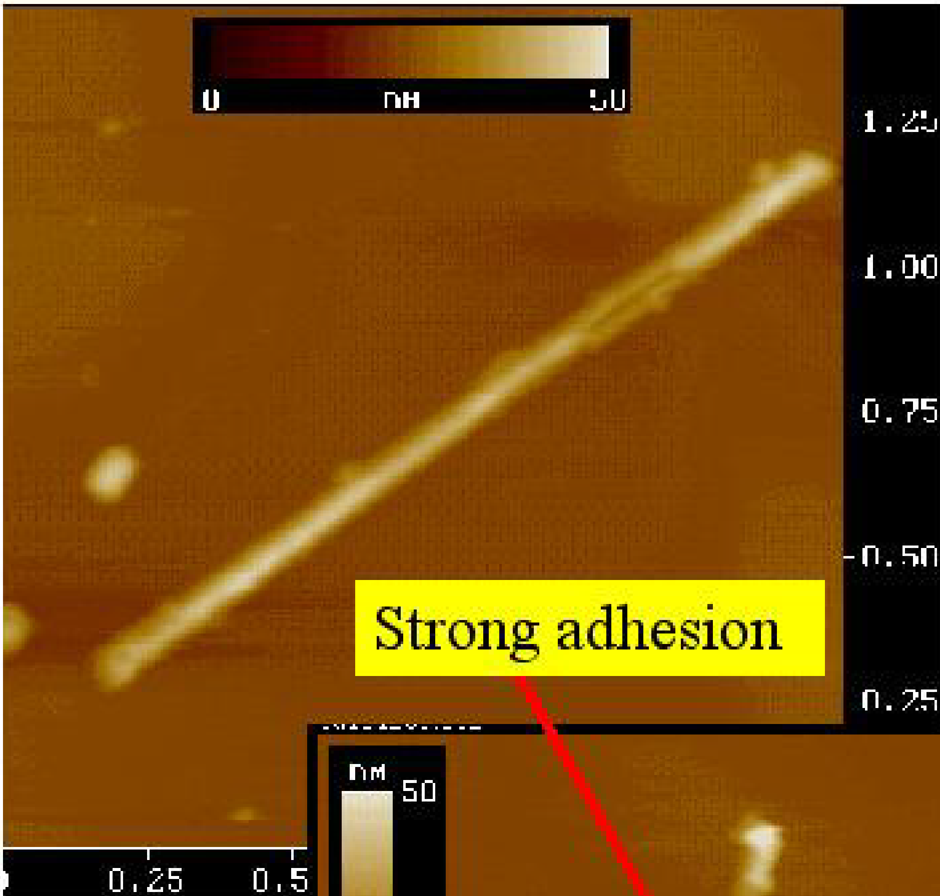
Falvo et al.,University of north California

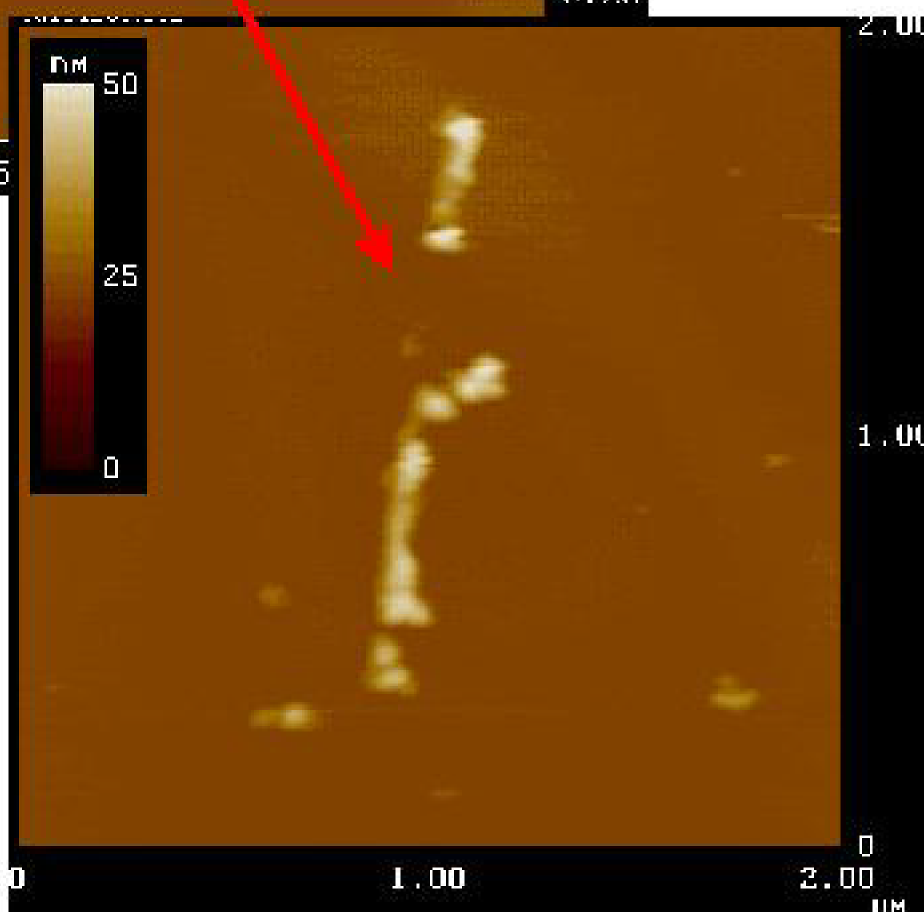


Surfaces:
Mica or silicon

Tunicier: clavelina lepadiformis
Sample from CERMAV Grenoble (UJF)
Dense molecules (no hole inside) made of N, H, O
With many OH at the surface



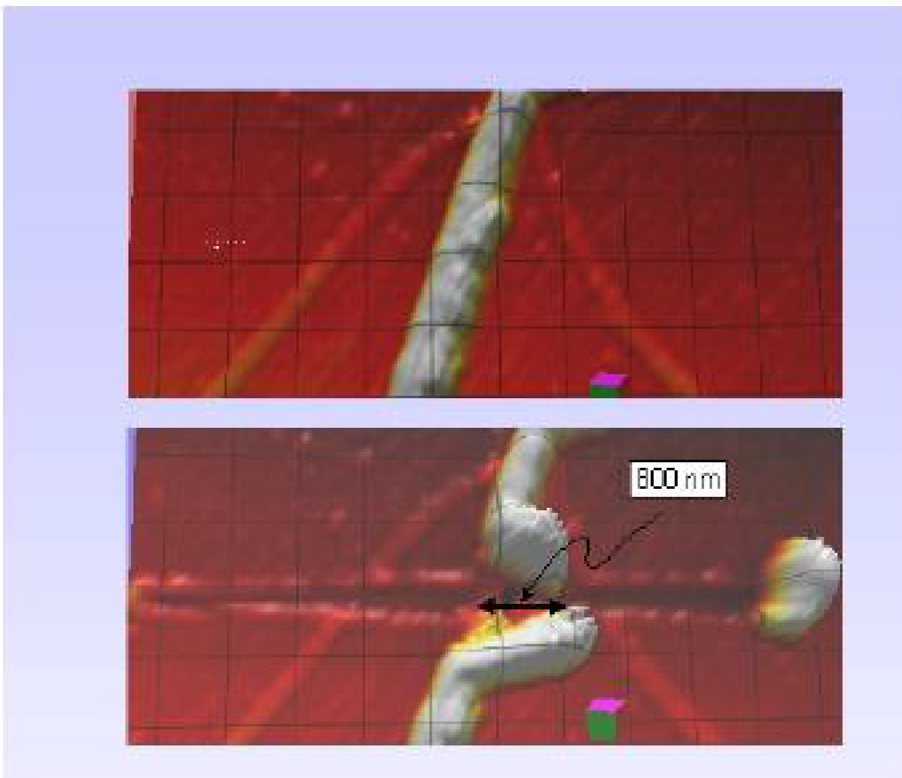


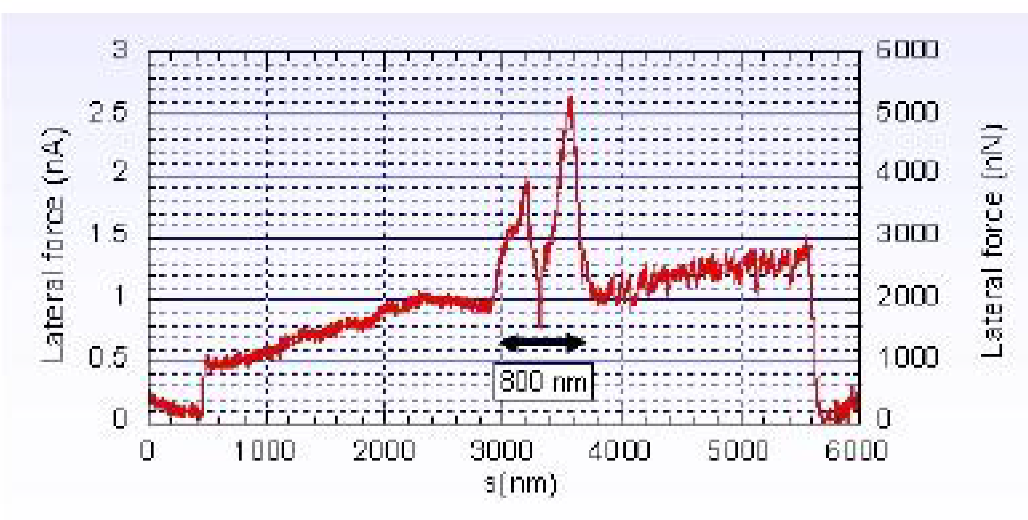


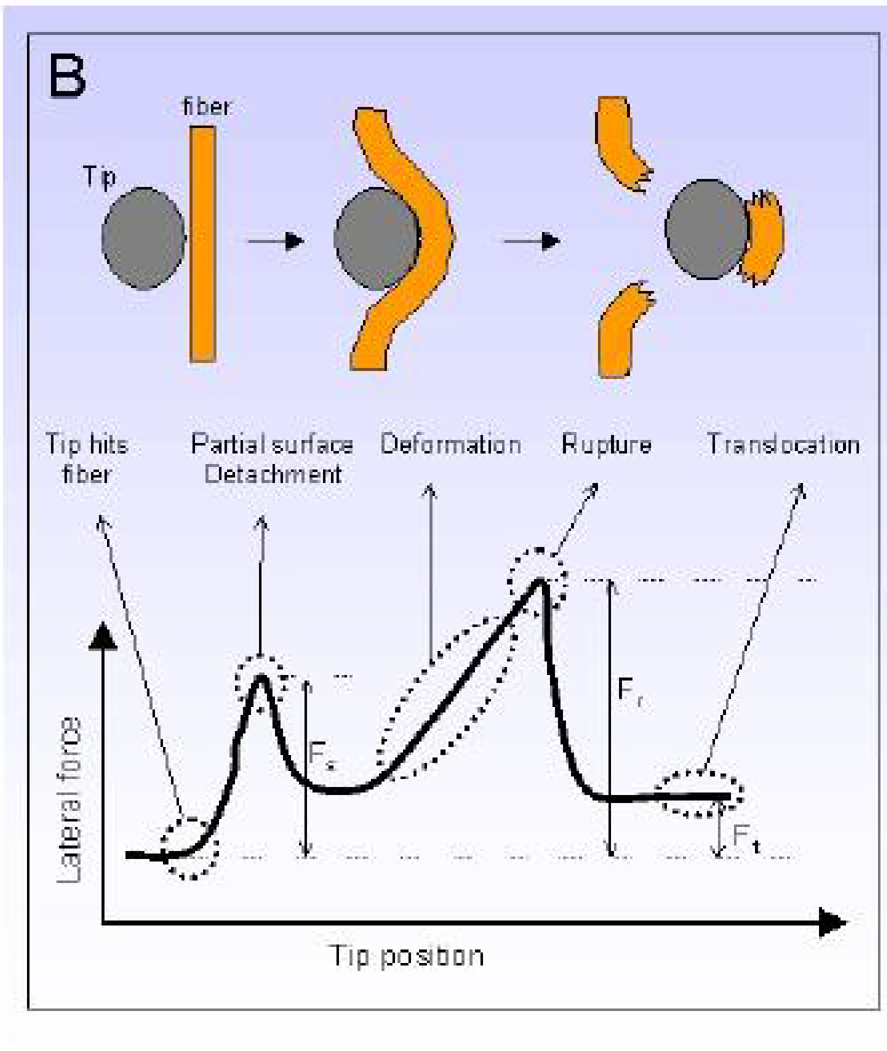
AFM contact:
No displacement
Instead:
Nanoobject
destruction

CONTROLLED MANIPULATION OF INDIVIDUAL FIBRIN FIBERS

Martin Guthold, J. Mullin, S. Lord, D. Erie, R. Superfine, R. Taylor, University of North Carolina, Chapel Hill, NC 27599






B
fiber
Tip
Tip hits fiber
Partial surface Detachment
Deformation
Rupture
Translocation
Fs
Fr
Ft
Lateral force
Tip position

Carbon nanotubes
with combined AFM studies of:

-large deformation

-weak adhesion on surfaces

-friction studies:

-nanotubes on the surface

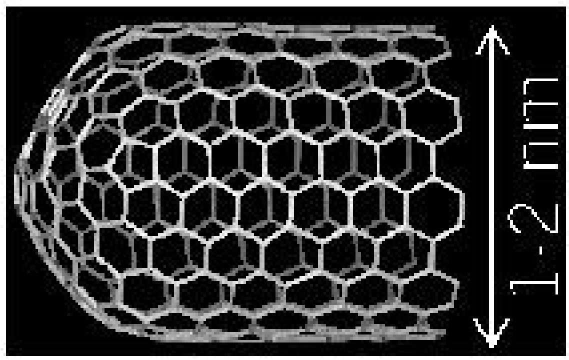
-AFM tip on the nanotube

-nanotubes and nanoobjects

Some characteristics of the nanotubes

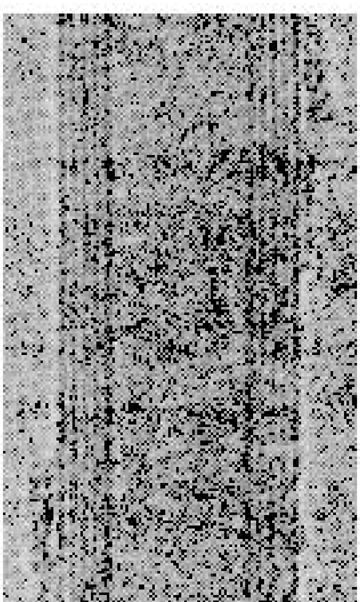
For nanotribology

Single wall nanotube (SWNT)



Multi wall nanotubes (MWNT):

Several sheets of carbones



- *diameter : from 0.4 nm up to 50 nm*
- *lenght : from 100 nm to 10 μm*

Physical properties:

- metallic or semiconductor
- large Young modulus
- Large deformation, no fatigue

Some key points:

-no or weak chemical interaction with surfaces *(iono-covalent bonding, strong polar interaction)*

-no or weak chemical interaction between carbon sheets (see Zettl et al)

This distinction is clearly reminiscent of the traditional difference in surface science:

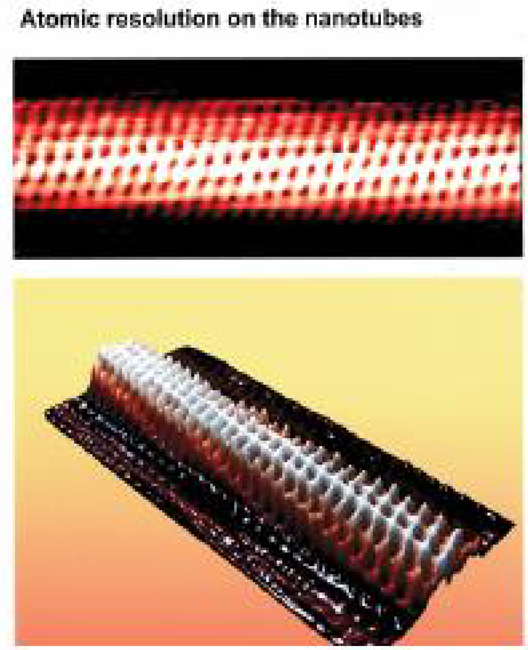
-physisorption
-chemisorption

-perfect 1D system

-model system for other studies of nanotribology:

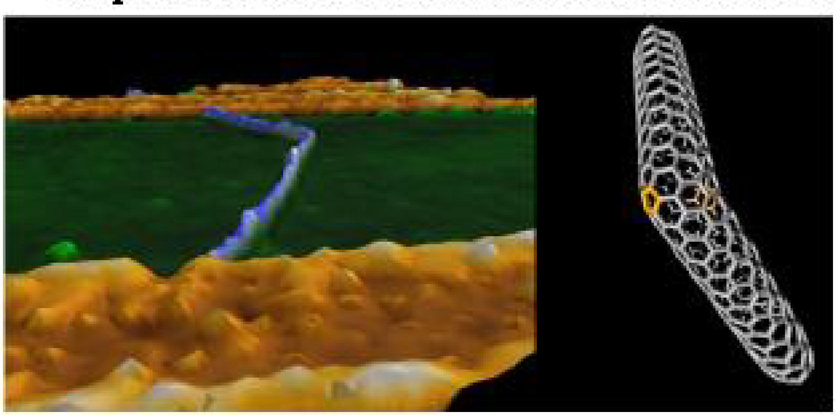
- -tunicier
- -fibrin
- -DNA
- -….

At the frontier: description of the structure



Atomic structure:
-chirality
-bond deformation
-defects
-electronic properties
-commensurability (friction)

http://www.mb.tn.tudelft.nl/nanotubes.html



Cees Dekker,
Delft Univ of Tech

Continuum:
-friction
-rolling/sliding
(on amorphous structure ?)

From http://www.physics.unc.edu/~falvo/Gallery/Gallery.html

Part 2: NANOTRIBOLOGY by ATOMIC FORCE MICROSCOPY on CARBON NANOTUBES

S. Decossaset al., Europhys. Lett. 53 (6), 742 (2001)

- Interaction between an AFM tip and ananotube carpet :

  Experiments and numerical simulations

Nanotube carpets grown by HFCVD (A.M. Bonnot)

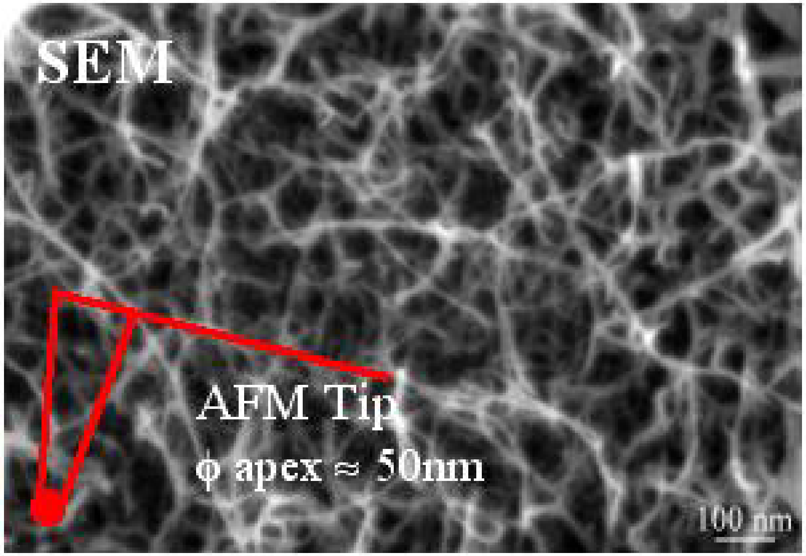
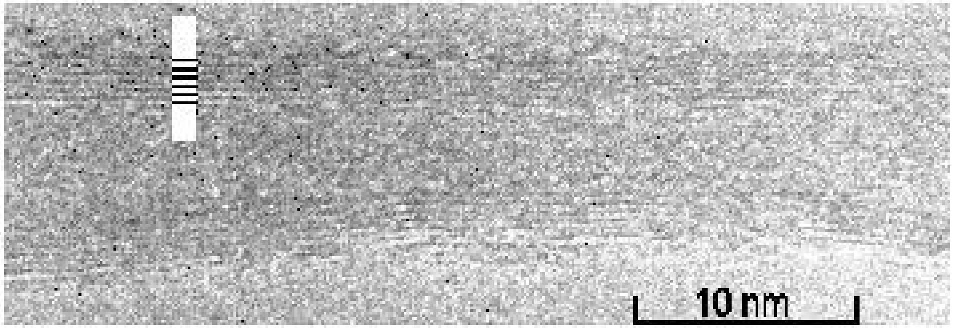
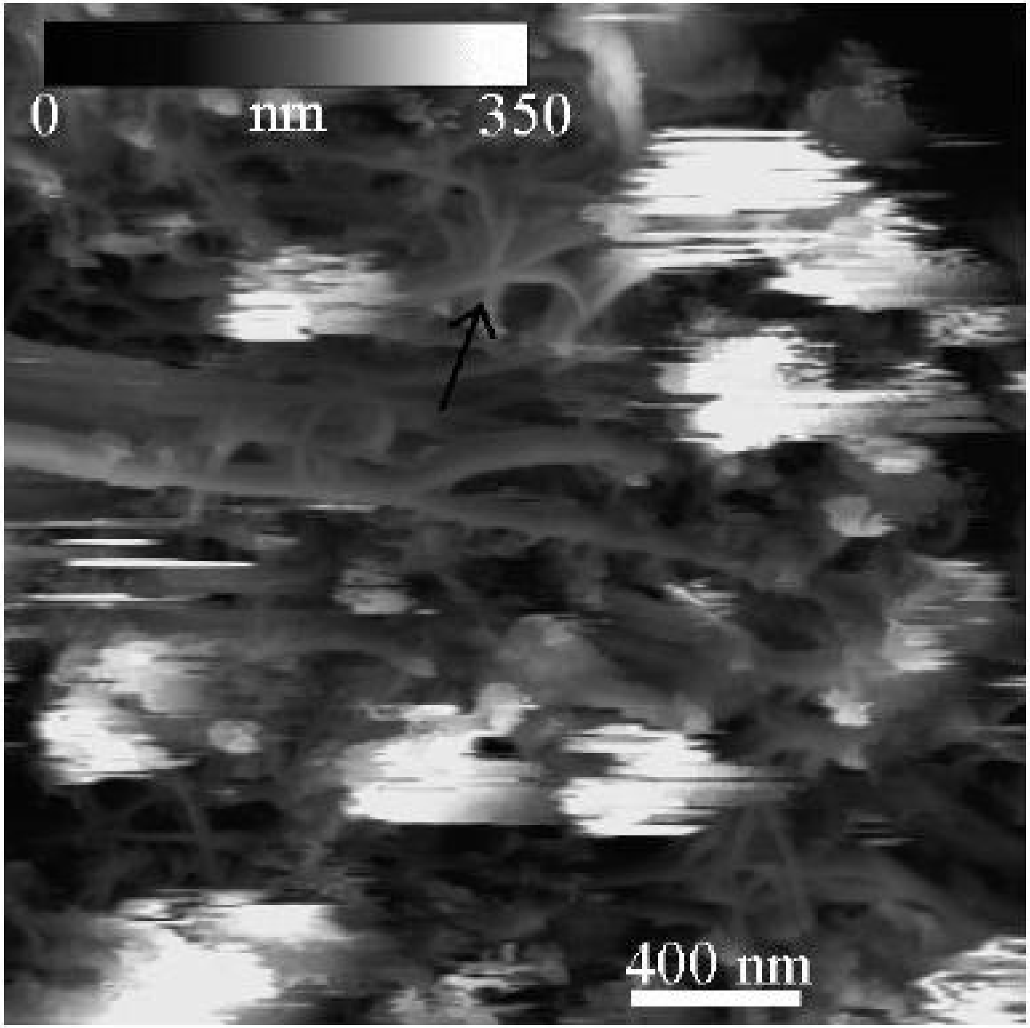
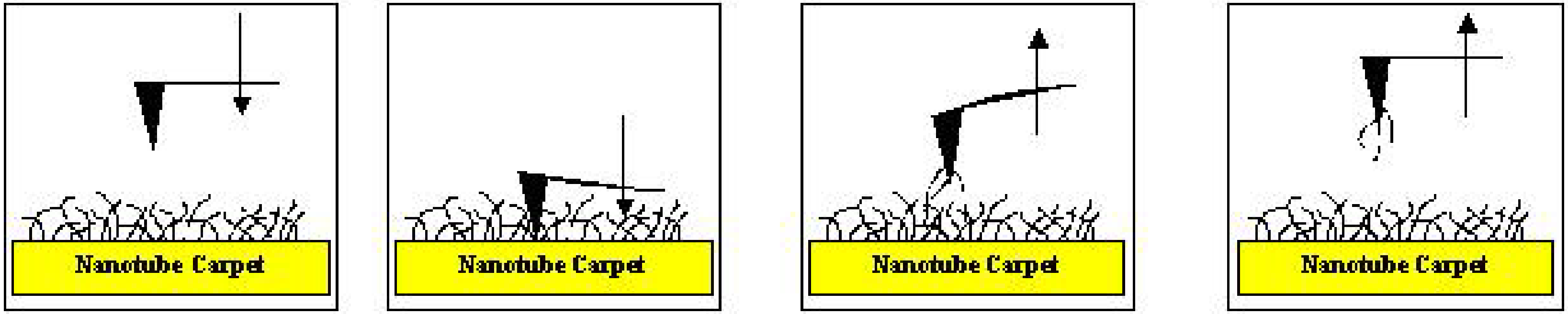


Image L. PONTONNIER, Cristallographie, CNRS Grenoble

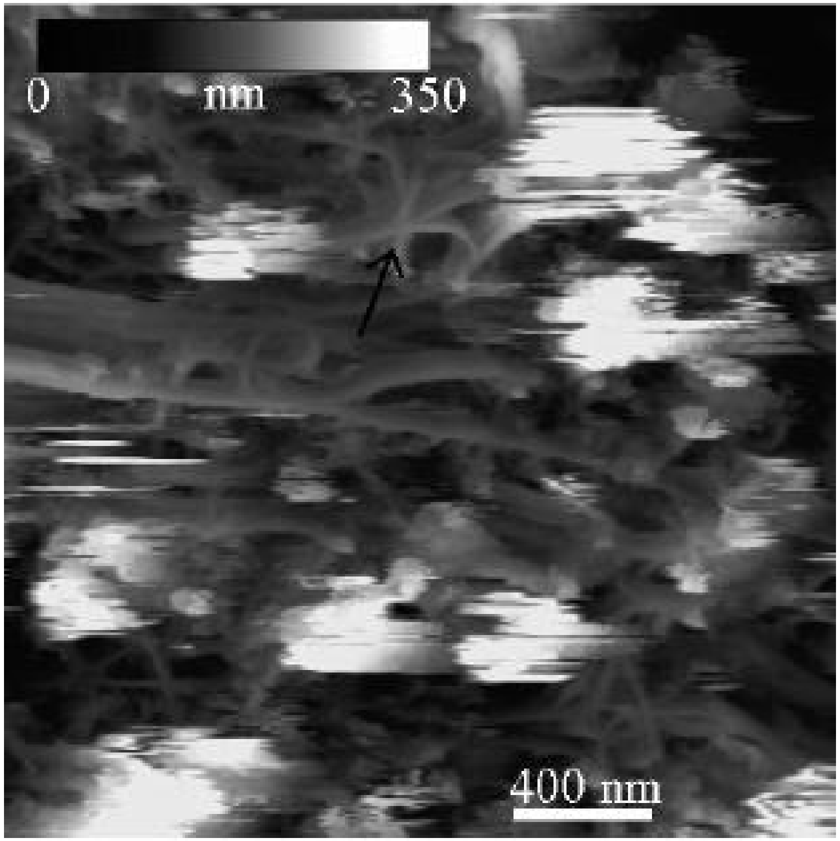


- Entangled nanotubes (length : 100nm to few μm)
- Multi-walled carbon nanotubes (φ ≈ 25nm) with well defined atomic structure
- Discrete medium for an AFM tip

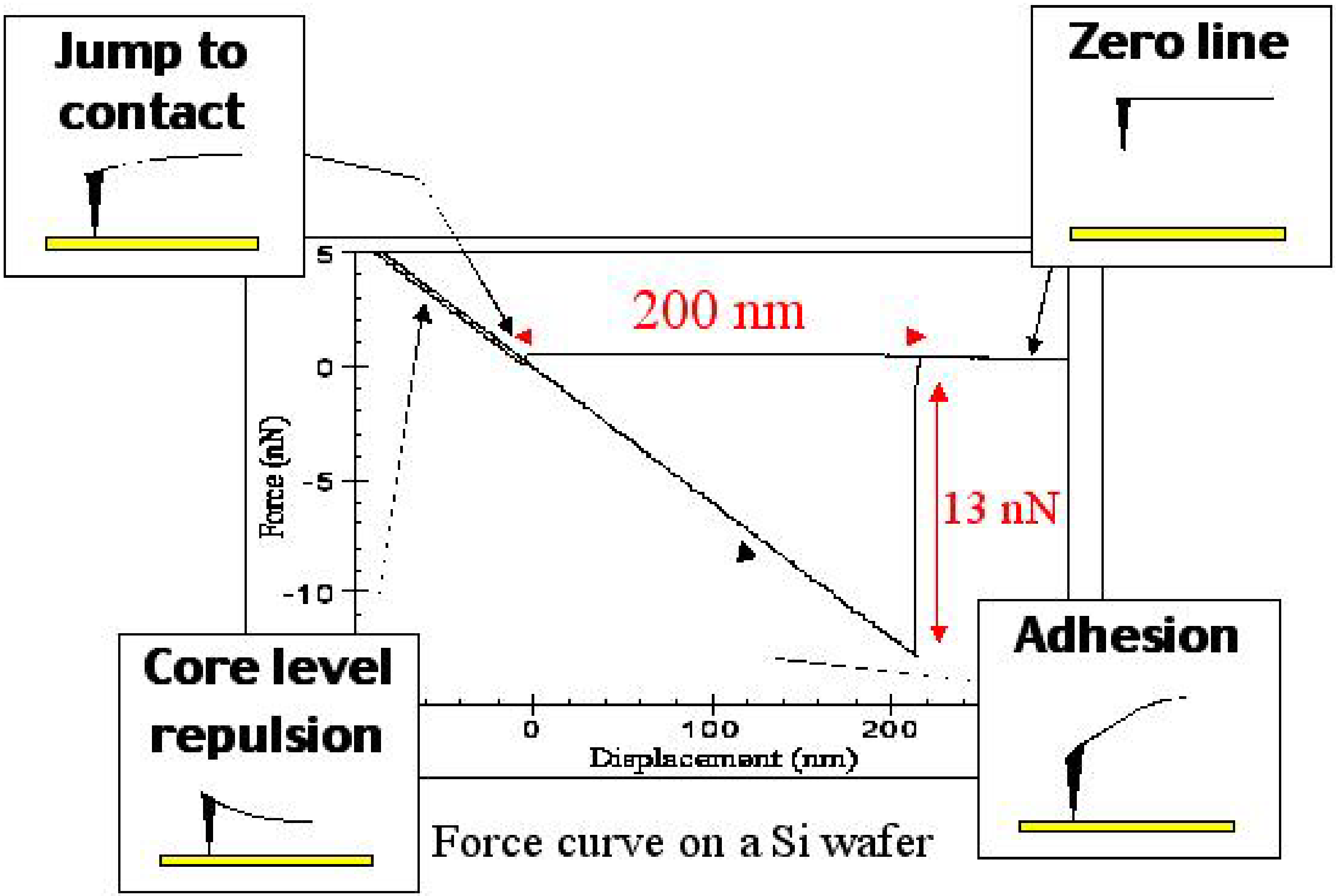

0
nm
350
400 nm



AFM: Force curve measurements

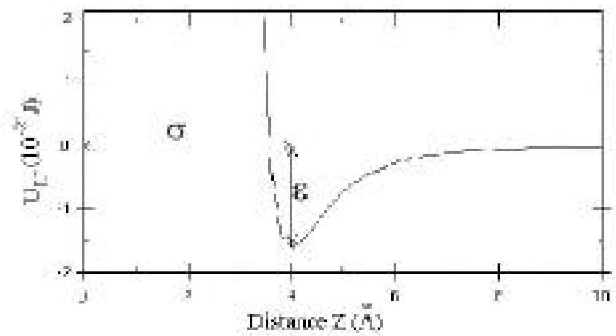


Force curve measurement by AFM



Force curve on a Si wafer

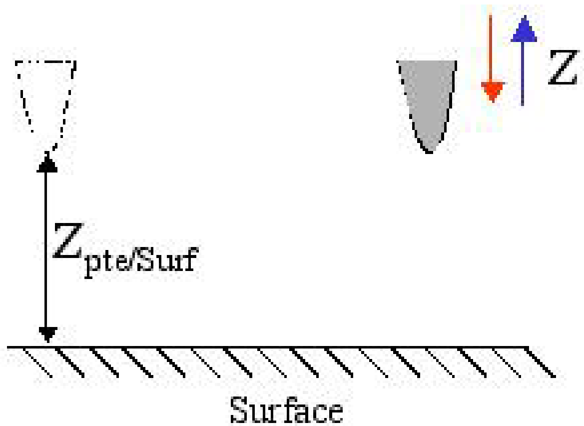
(air, tip spring constant = 0.06 $N.m^{-1}$)

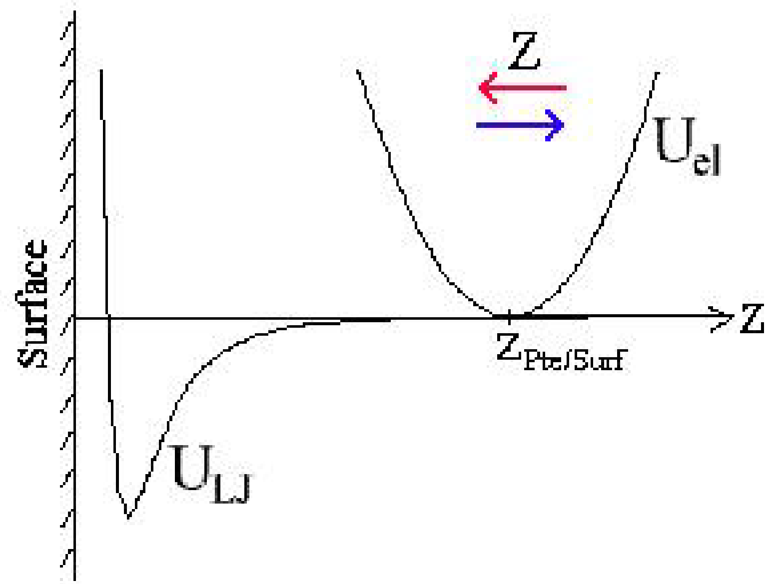


$$U_{LJ} = \frac{\epsilon}{(n-m)}\left(\frac{m\sigma^n}{Z^n} - \frac{n\sigma^m}{Z^m}\right)$$

Fig. 1.7 – Potentiel de Lennard Jones ($\sigma = 4$ Å, $\epsilon = 10$ meV, n = 12, m = 6).

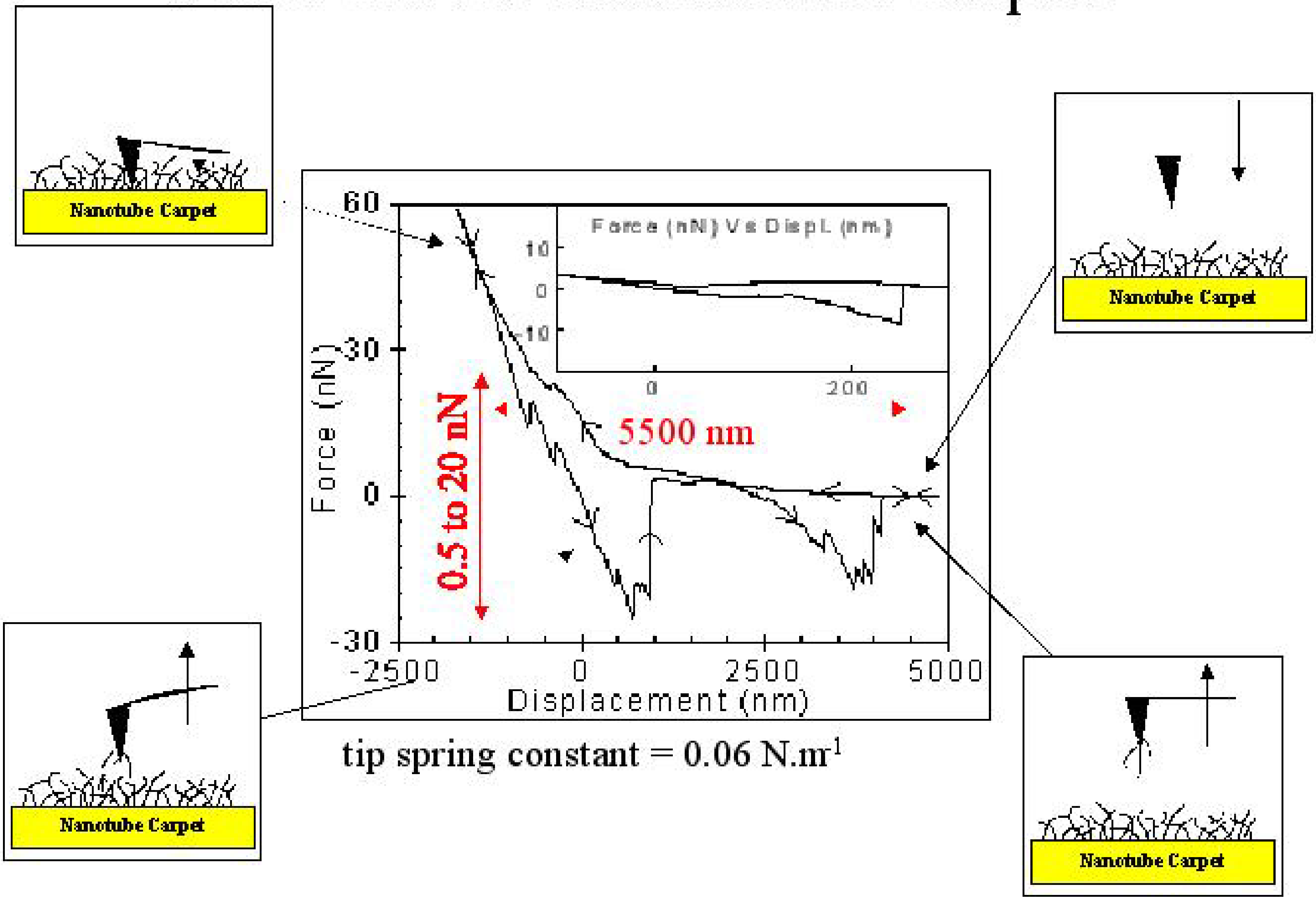
AFM tip stable position





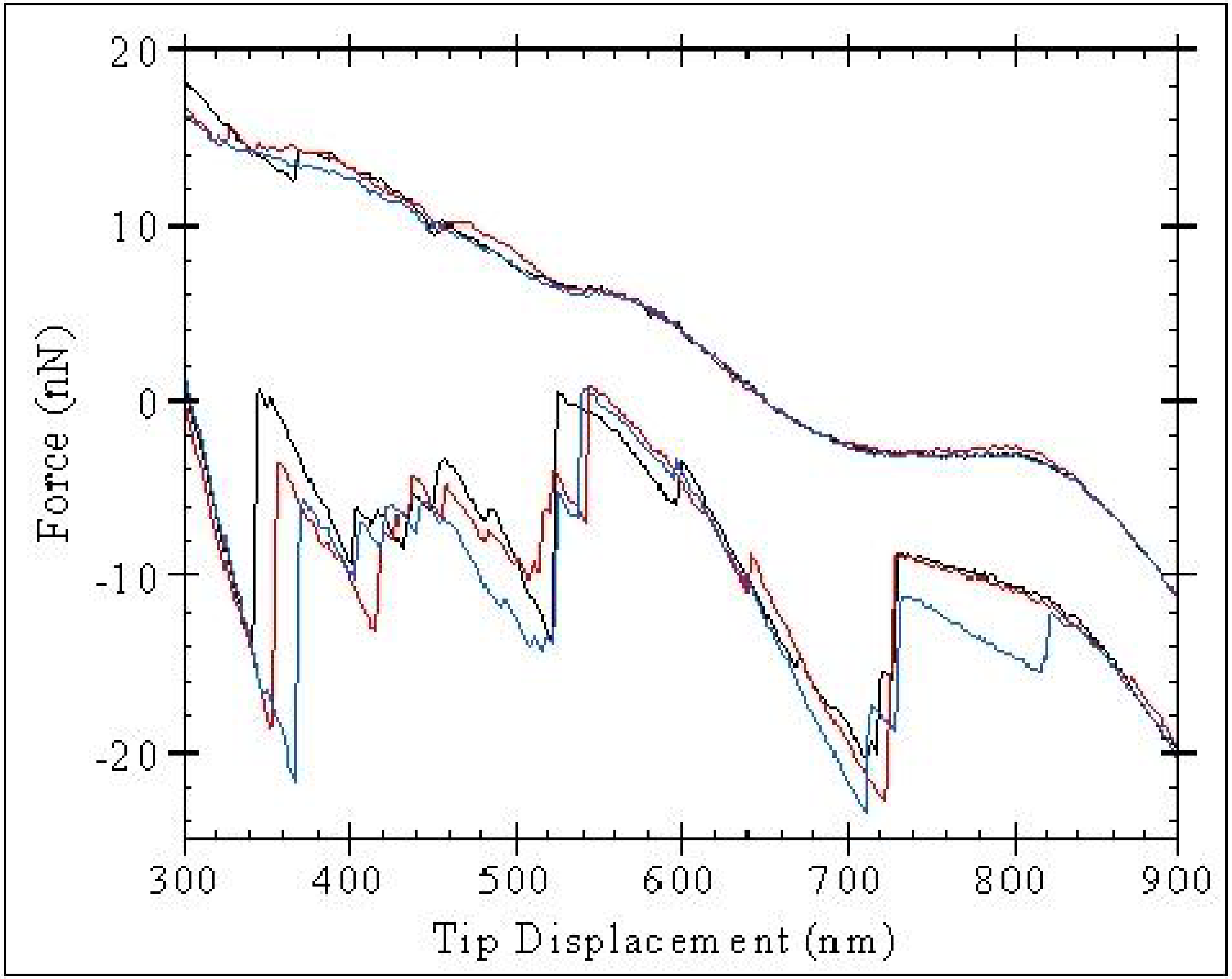
(1-4)

Force curves on nanotube carpets



tip spring constant = 0.06 N.m[1]

Reproducibility of force curves on nanotube carpets



Tip spring constant = 0.58 N.m^{1}

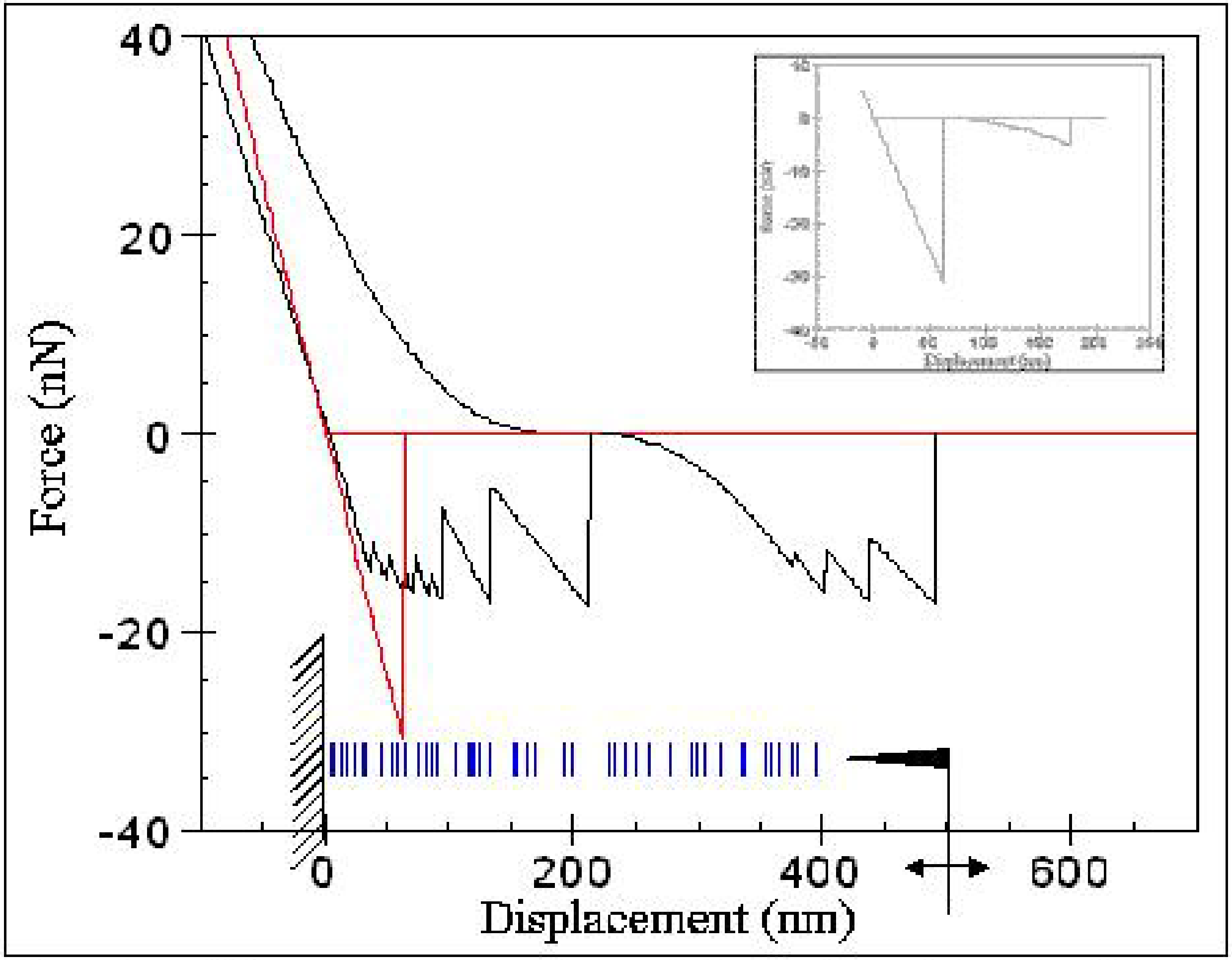
Force curves on nanotube carpet: numerical simulation

Analysis of the mechanical stability: CNT carpet indented by the tip

- Point like tip of spring constant k_{tip}
- Tip wafer interaction : 12-3 Lennard Jones potential
- Tip nanotube interaction = Long range attractive (Vander Waals like)
- Schematic description of the nanotube carpet
  - Nanotube wafer distance randomly chosen
  - Nanotube length and diameter randomly chosen
  - Nanotube can be elongated (Young modulus E)
  - Nanotube can be bent (spring constant k_{CNT})
- No nanotube-nanotube nor nanotube-wafer interaction

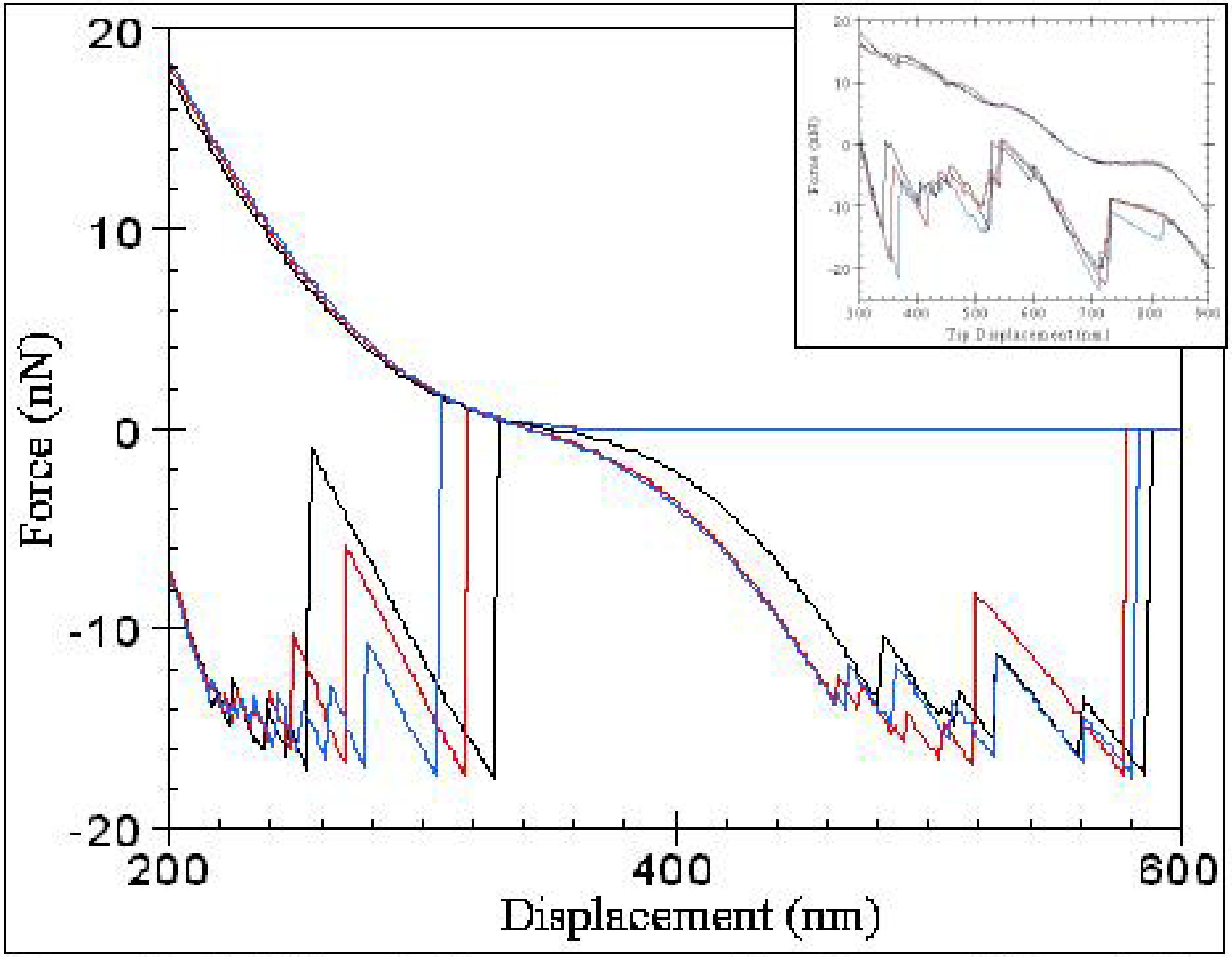
S. Decossas et al., Europhys. Lett. **53** (6), 742 (2001)

Force curves on nanotube carpet: numerical simulation



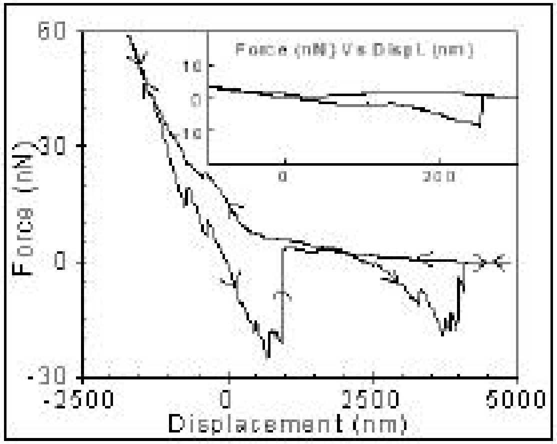
Simulated force curves with a 50nanotube distribution

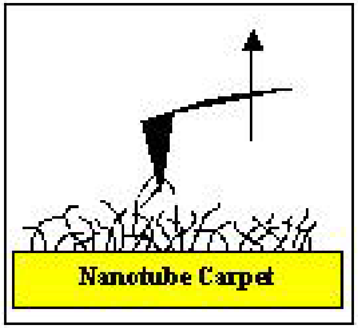
Force curves on nanotube carpet: numerical simulation

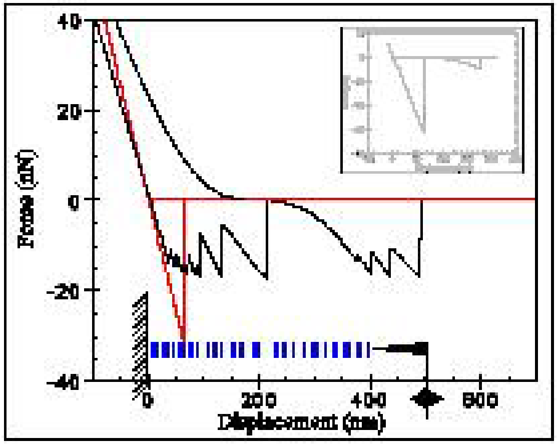


Reproducibility of force curves for three different 50 nanotube distributions

Conclusion on the second part: tribology on a nanotube carpet





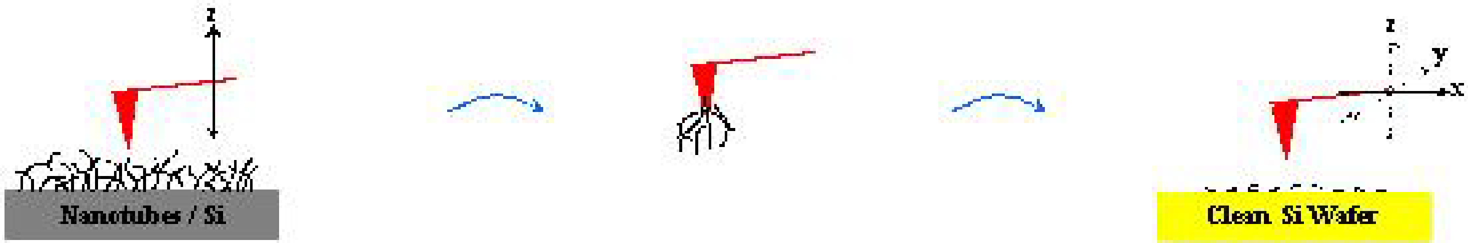


Here tip moved at constant speed! ⟶ Force variation

Constant force ⟶ carpet rheology:

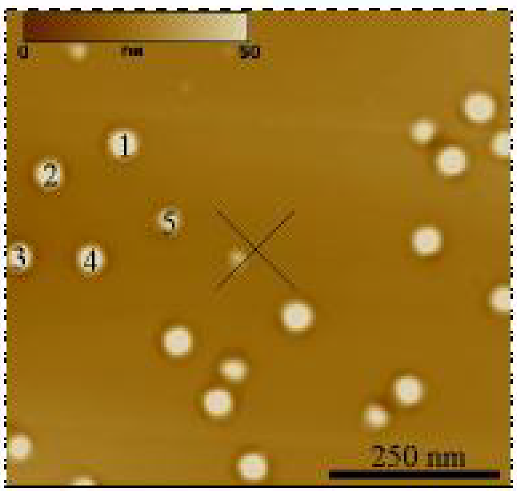
time variation of deformation

Transport and absolute positioning of nanotubes

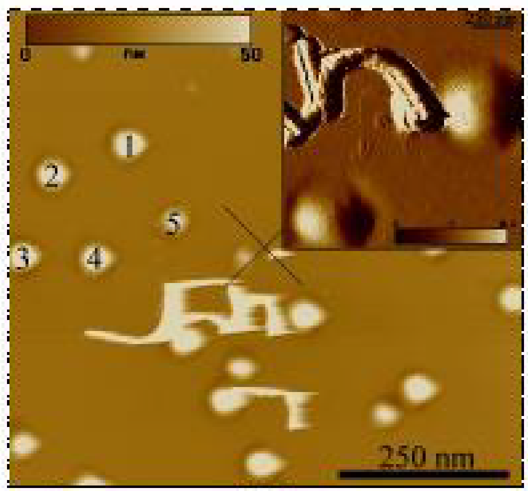


1 / Force curves on nanotube carpet

2 / Images on Si wafer after nanotube deposition



Before Deposition
Contact mode



After Deposition
Tapping mode

Deposition method

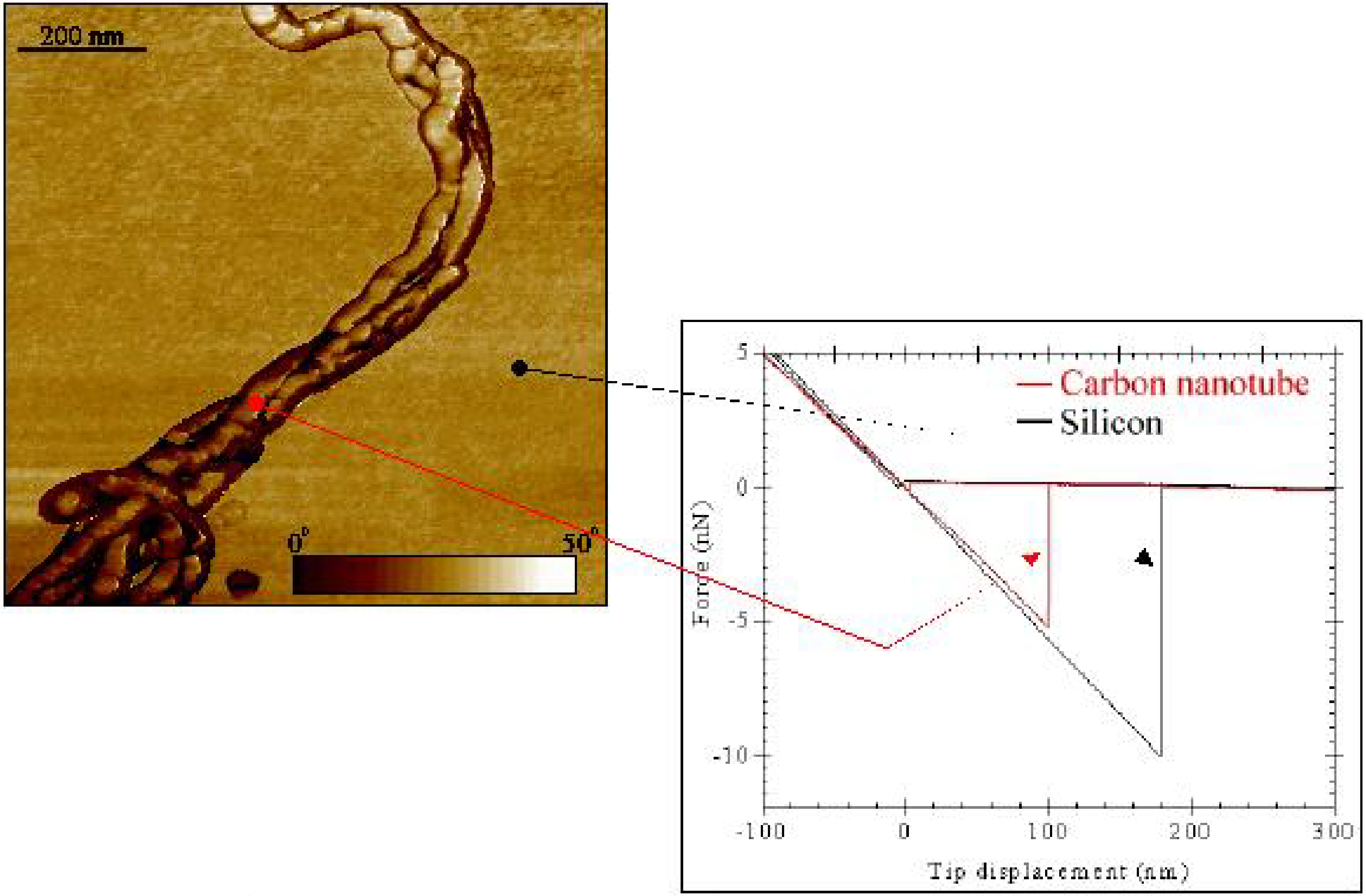
- precision ≈ 500 nm
- No wet chemistry
- limited number ofnanotube

Change of the Tip possible

- All the AFM modes
- Work with a clean tip

S. Decossas et al., In preparation

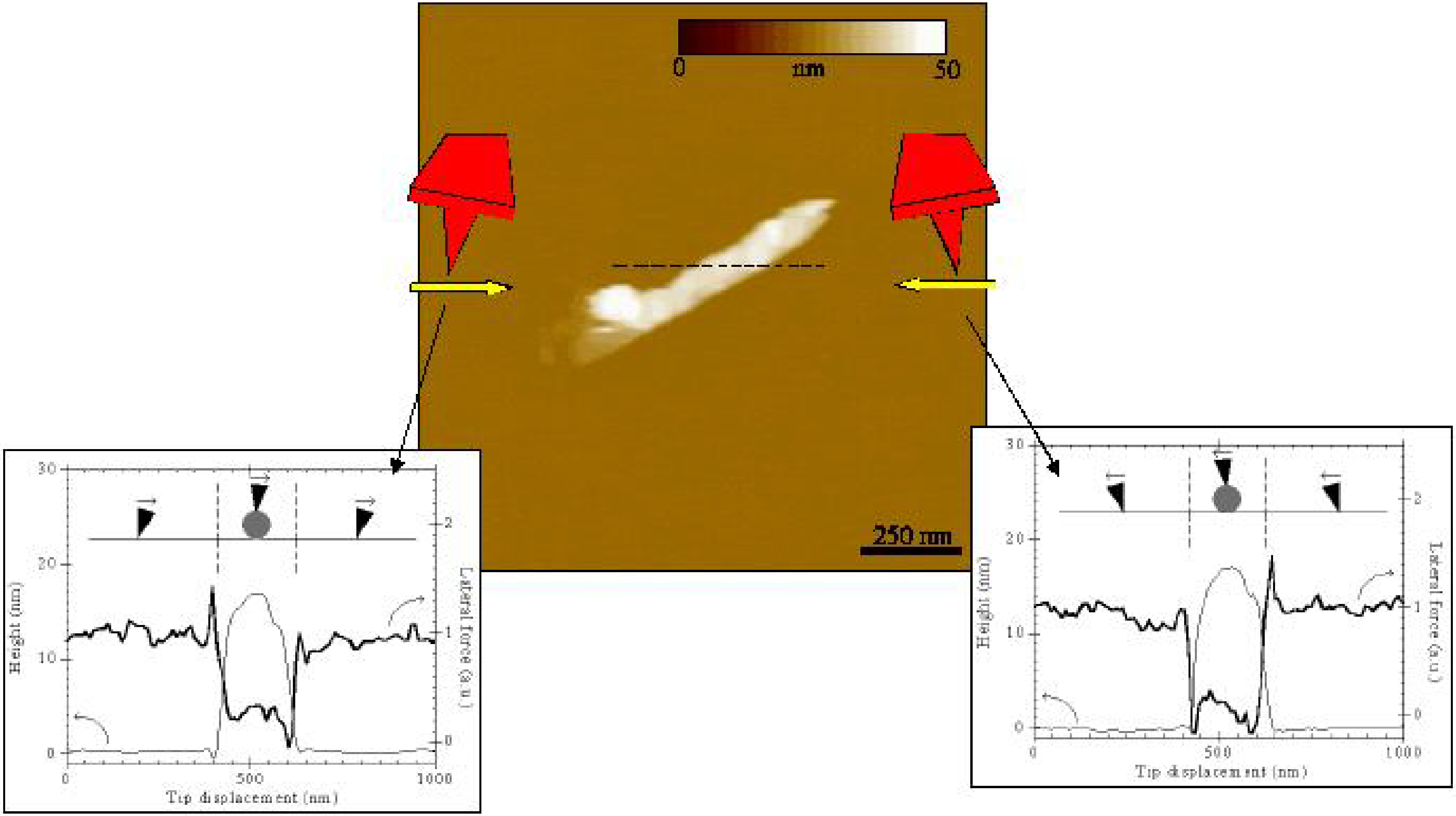
Adhesion measurement on isolated nanotubes



Whatever is the atmosphere (air or dry N_2):

$$\textbf{Adhesion}_{\textbf{Silicon}} \approx 2 \times \textbf{Adhesion}_{\textbf{nanotube}}$$

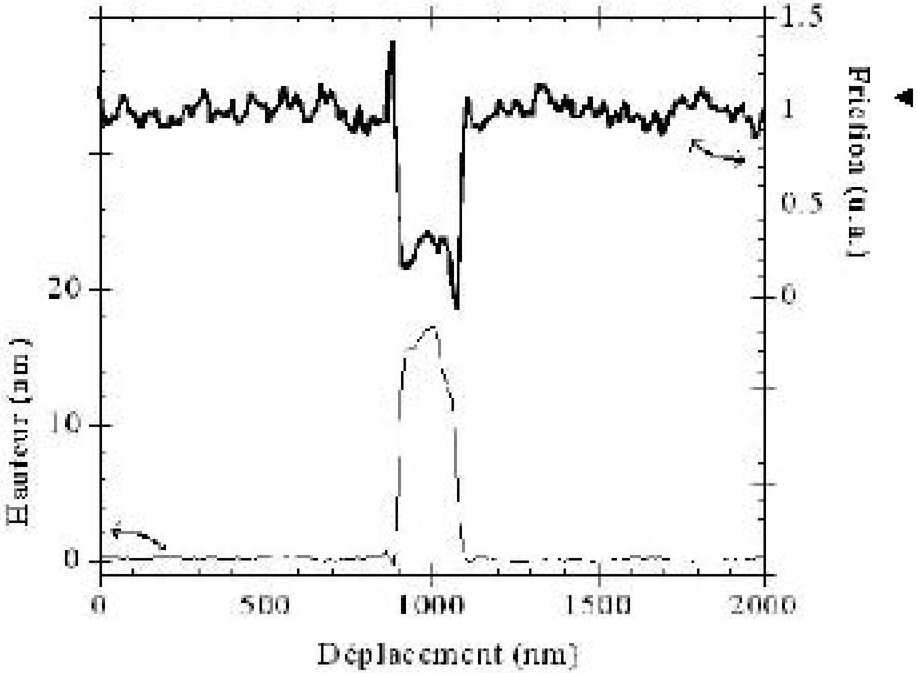
Friction measurement on isolated nanotube



Whatever is the atmosphere (air or dry N_2):

$$\mathbf{Friction_{Silicon} \approx 5 \times Friction_{nanotube}}$$

Friction
on carbon nanotubes



Friction on tuniciers