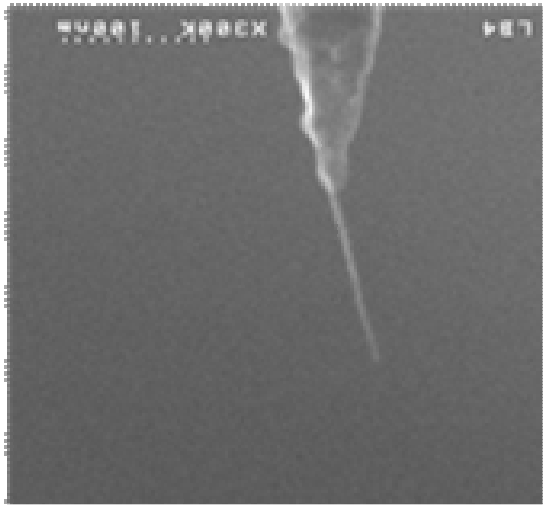
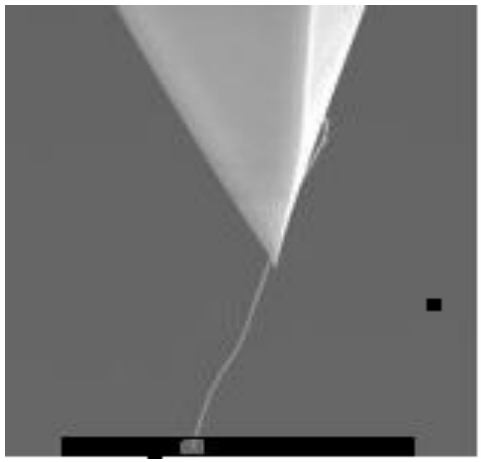
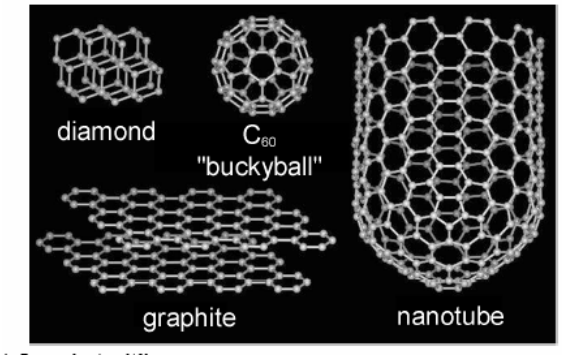
Julien Buchoux, Sophie Marsaudon,
Rodolphe Boisgard, Jean-Pierre Aimé,
CNRS-Université Bordeaux I.

Carbon nanotube a Versatile AFM Tip







- CNT: Why? for doing What?

- CNT as AFM-tip: a simple mechanical nanosystem ?

- **How does a CNT touch a surface?**

Carbon nanotube as **AFM Tip**

Why CNT ?

- Well defined geometry at the nanoscale .
-Good Mechanical properties: no wear, Robust
- Chemically inert, very stable against molecular pollution
- Soft

What for?

-Metrology: More accurate AFM Image, almost no tip dilation.

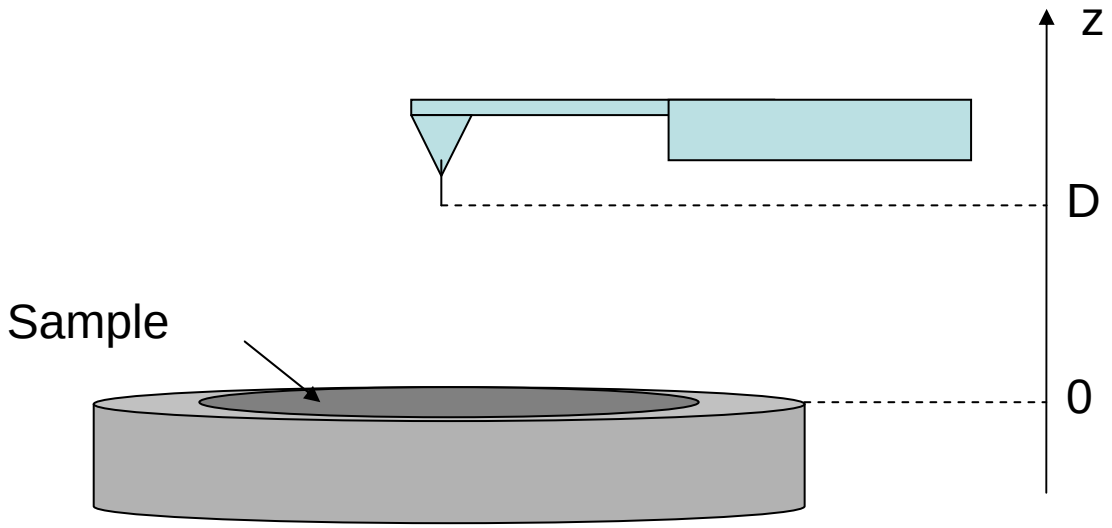
- Stable Tip sample interaction even on complex systems: relevent images are expected
- soft tip allowing to image proteins at work without damage?!

Carbon nanotube as **AFM tip: Work on began more than 10 years ago, still not widely used, nor is a large scale product**

WHY?

CNT AFM tip: a simple mechanical system?

Frequency Modulation mode and thermal noise studies: Carbon Nanotube Stiffness k_{NT}



- Frequency shift $\Delta\nu = \nu - \nu_0$
- Dissipation

$$\frac{\Delta\nu}{\nu_0} \approx \frac{k_{NT}}{k_{cantilever}}$$

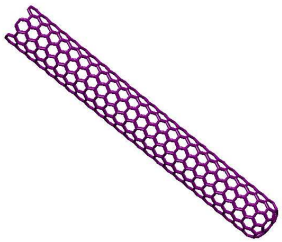
SWNT vs MWNT

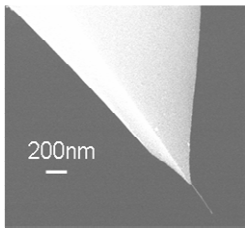
$$\frac{\Delta\nu}{\nu_0} \approx \frac{k_{NT}}{k_{cantilever}}$$

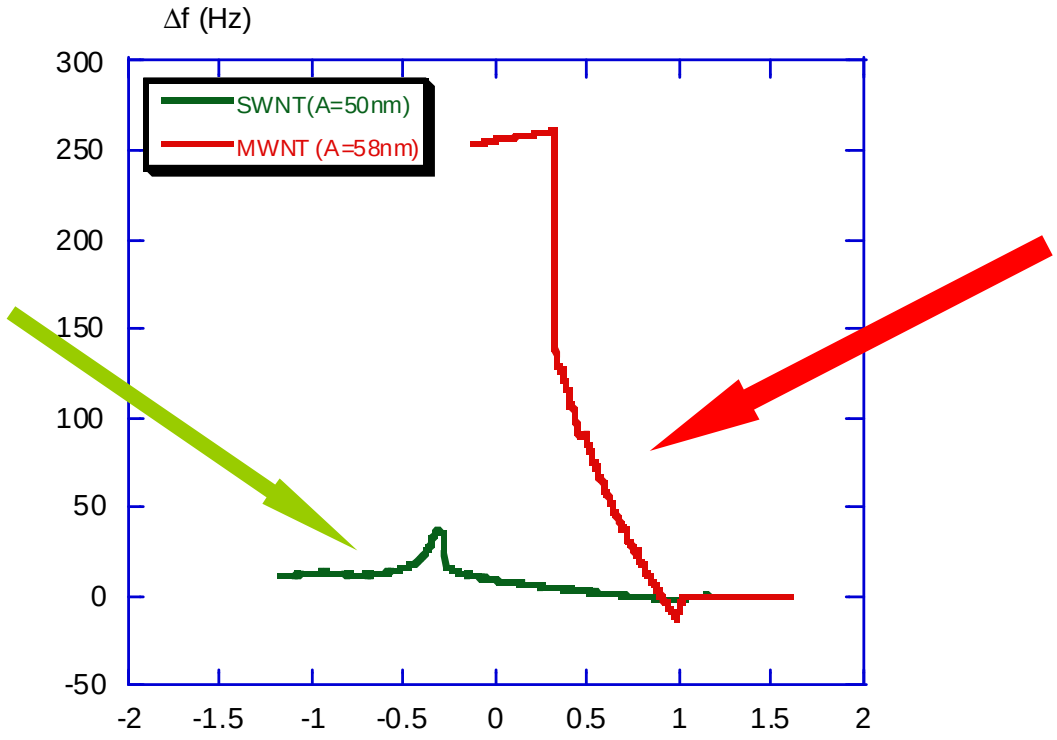
$\Delta\nu$

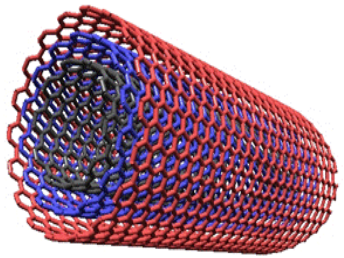
MWNT : typ. **200 Hz**

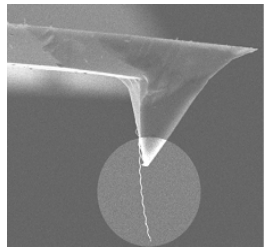
SWNT : typ. **10 Hz**







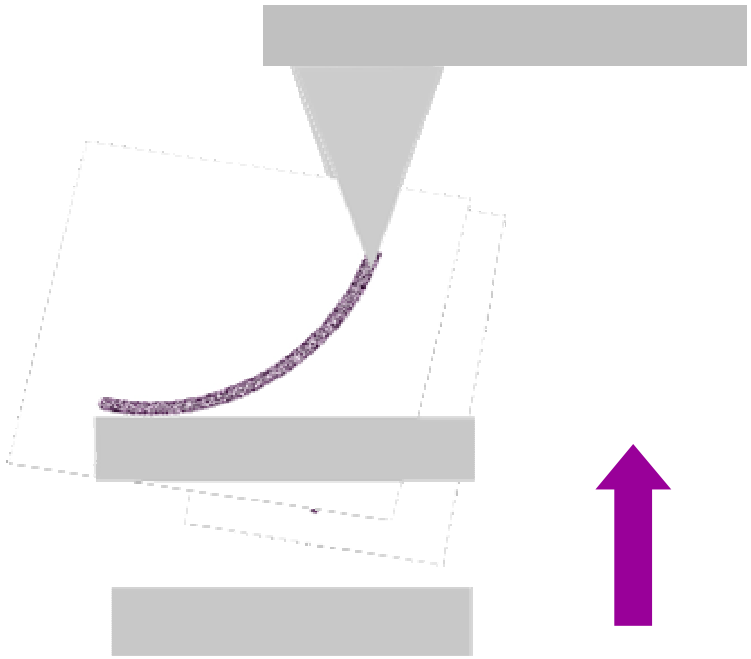


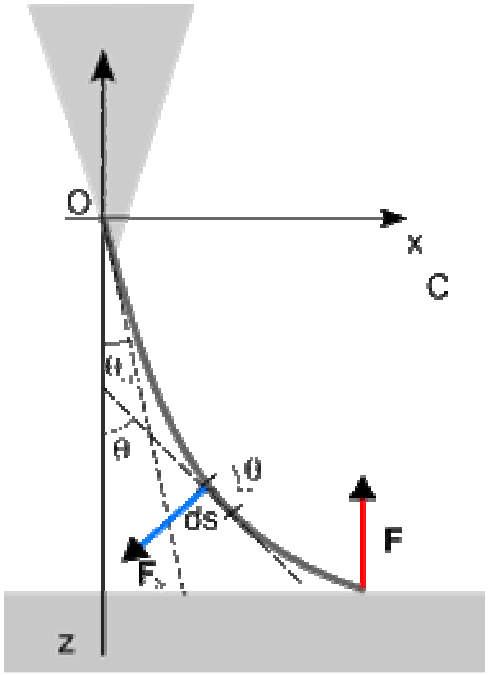


D. Dietzel, et al *Physical Review B* 72, 035445 (2005), *Nanotechnology* (2005) 16, pS73-S78,

C. Bernard et al Nanotechnology19, 35709-35718 (2008). S. Marsaudon et al , "Applied Scanning Probe". (Springer-2008).

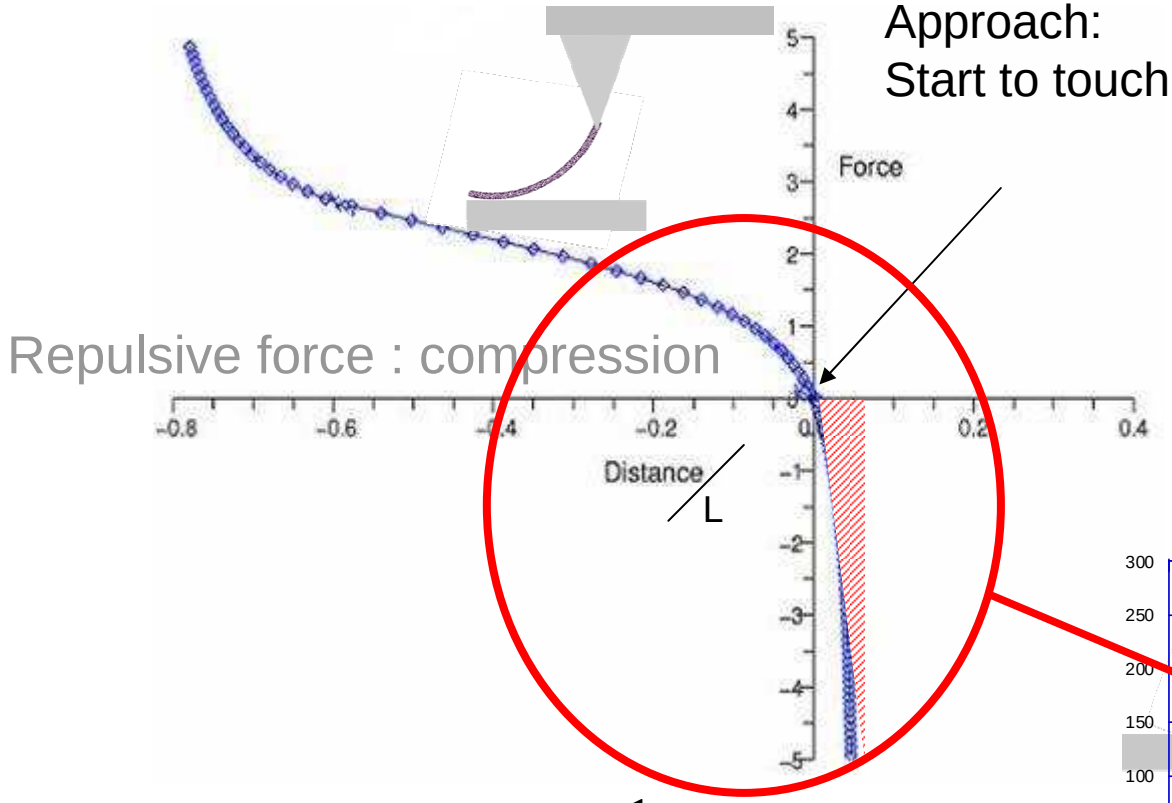
CNT AFM nanoprobe: a simple mechanical system?

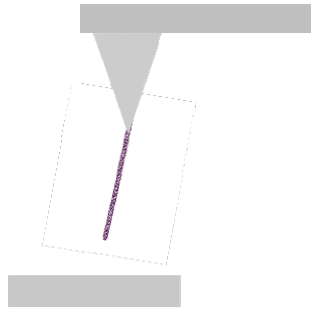


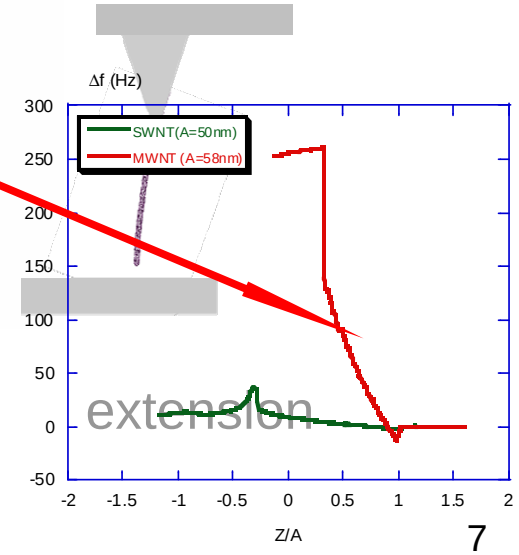


AFM Dynamical mode: Nanotube mechanical cycle

Modl for AFM experiments

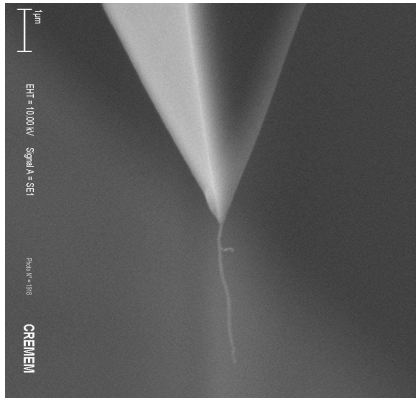


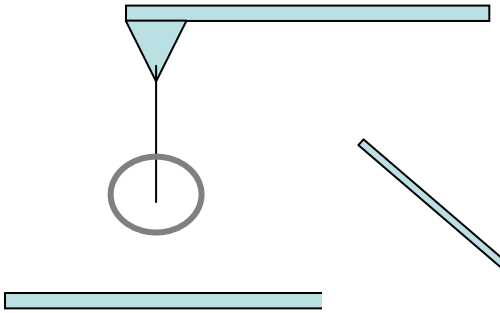


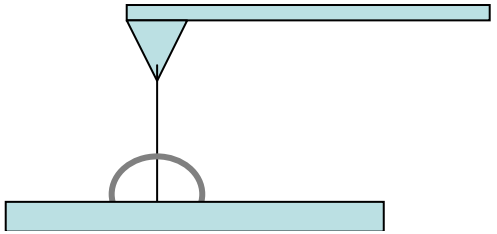


Cycle area: $\left\langle E_{diss} \right\rangle_T \approx \frac{1}{2} k_{adh} \Delta^2 = cste$

Thermal Noise



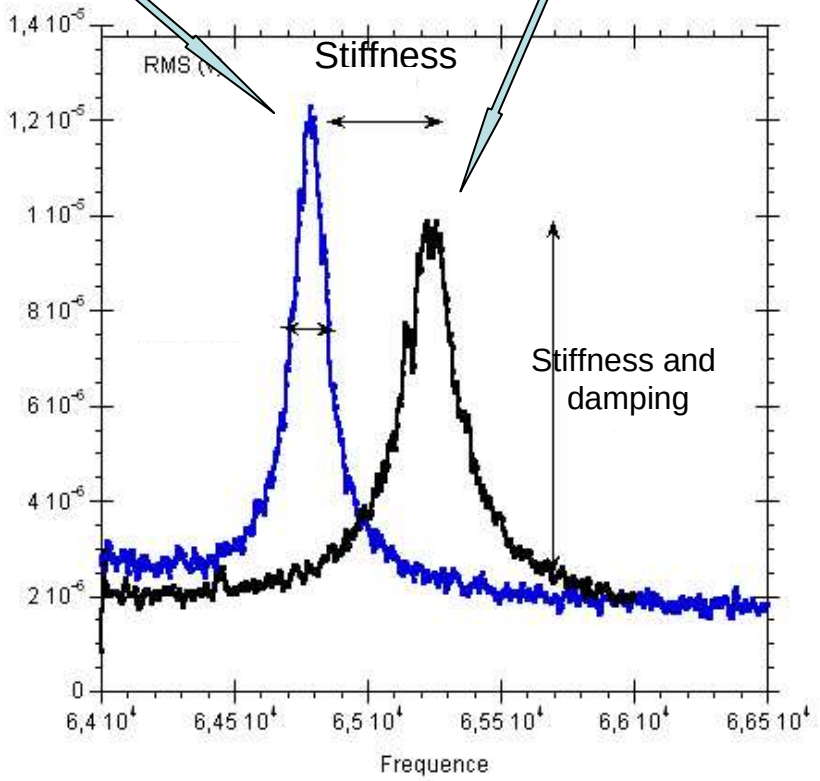




$$< X_\omega^2 >= \frac{4k_B T \gamma_0}{m^2 \left[\omega^2 - \omega_0^2\right]^2 + \gamma_0^2 \omega^2}$$

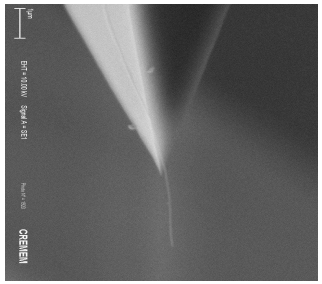
$$\gamma_0 \simeq \rho \frac{\pi}{4} W^2 L \omega \left[3.8 \frac{\delta}{W} + 2.7 \left[\frac{\delta}{W}\right]^2\right]$$

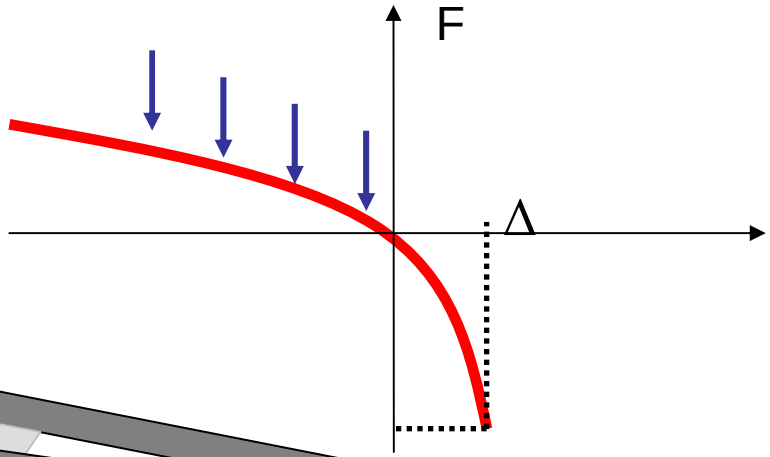
Moderate vacuum P=5-10 mbar

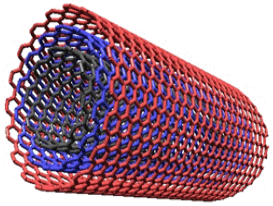


YESS F

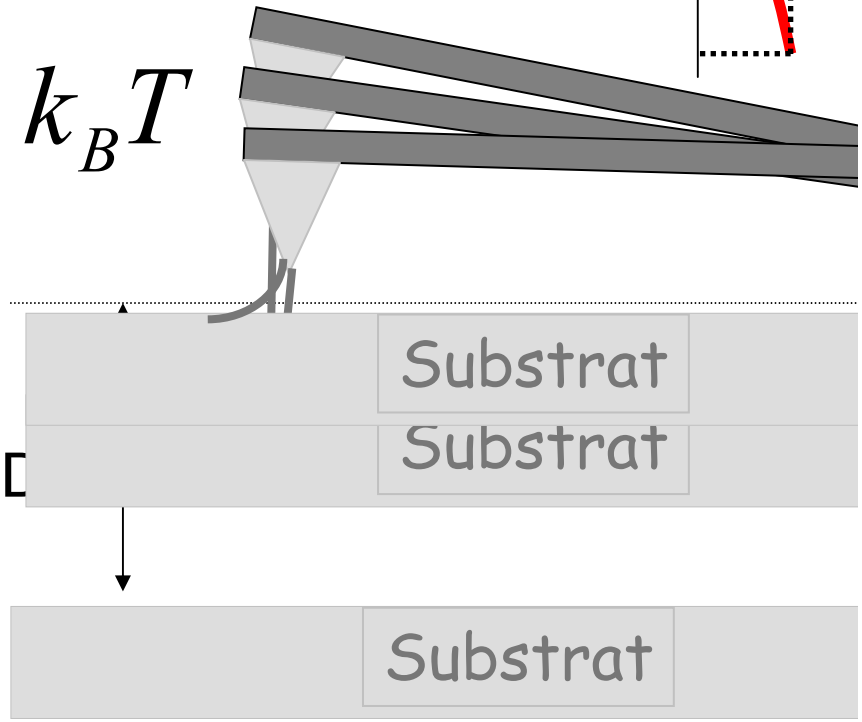
MWNT Thermal Noise Forcing







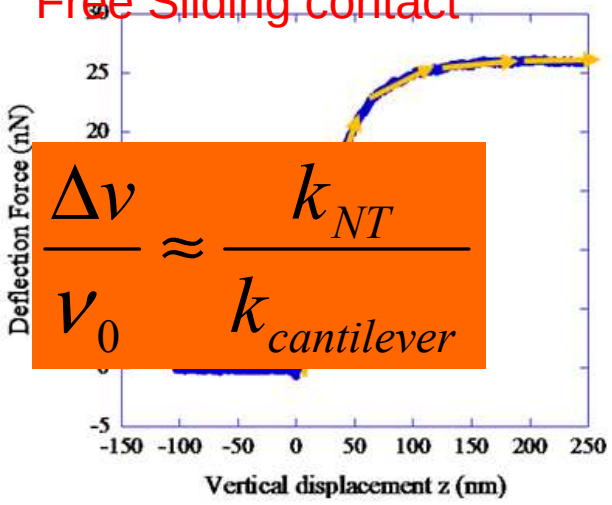
$k_B T$



Free sliding versus pinned CNT contact

Force curve

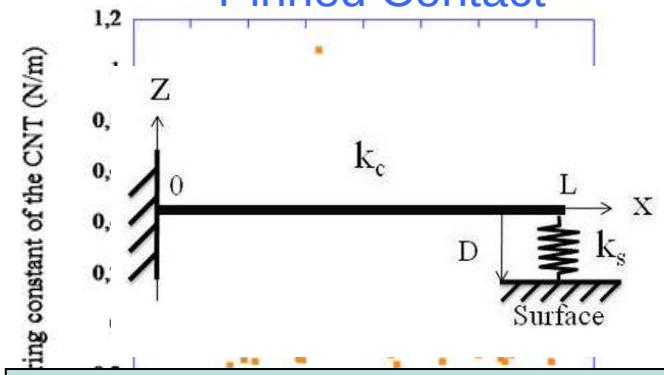
Free Sliding contact



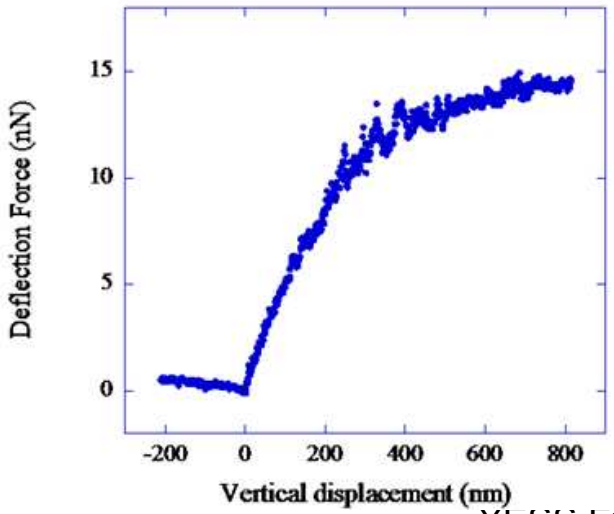
$$\frac{\Delta\nu}{\nu_0} \approx \frac{k_{NT}}{k_{cantilever}}$$

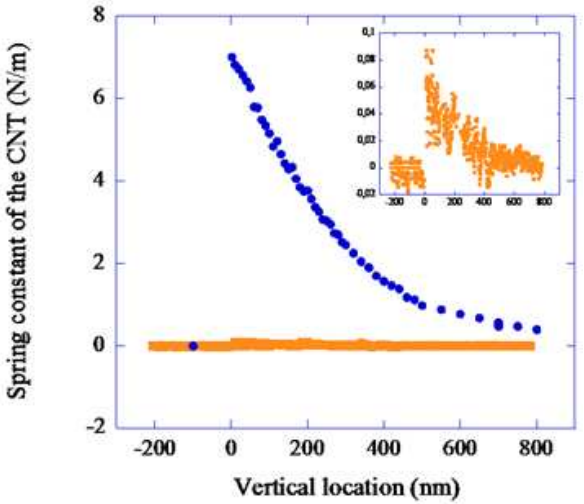
Spring constants

Pinned Contact



$$\frac{k_s}{k_l} = \frac{(k_n L)^3\left(1+\cos(k_n l)\cosh(k_n l)\right)}{3\left(\sinh(k_n l)\cos(k_n l)-\sin(k_n l)\cosh(k_n l)\right)}$$



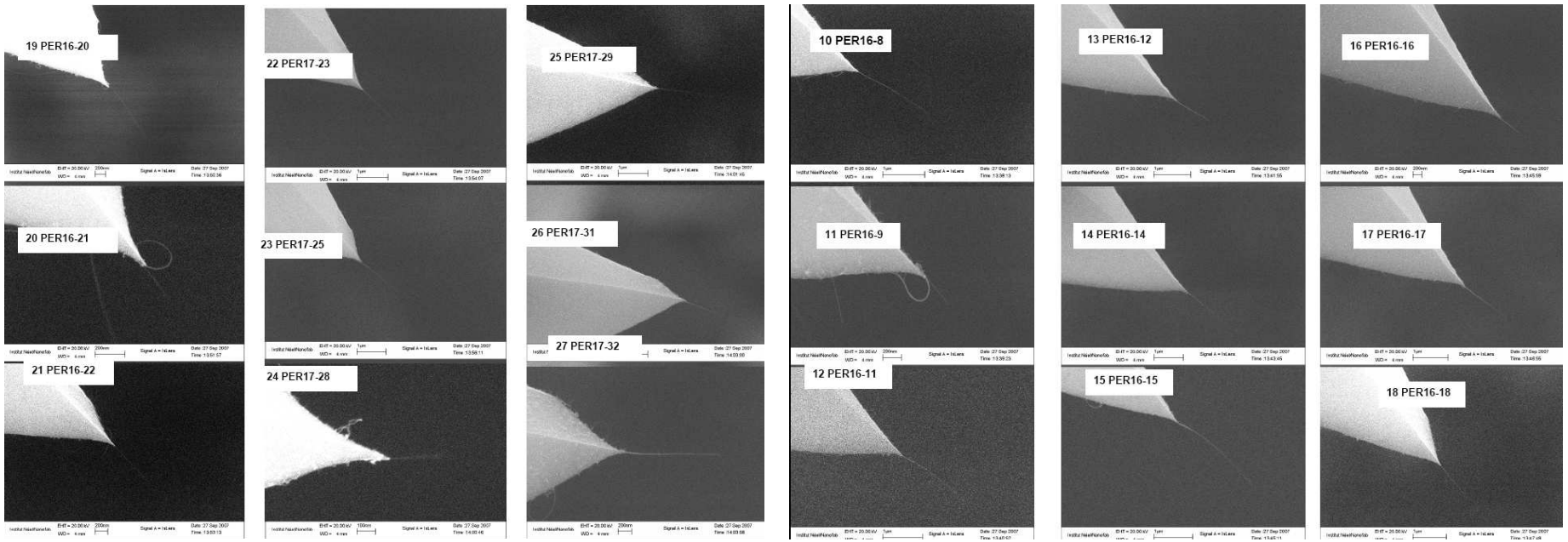


SWNT

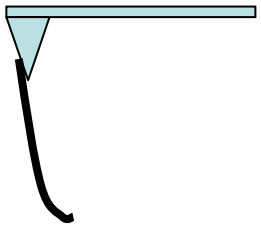
Anne-Marie Bonnot (retired)

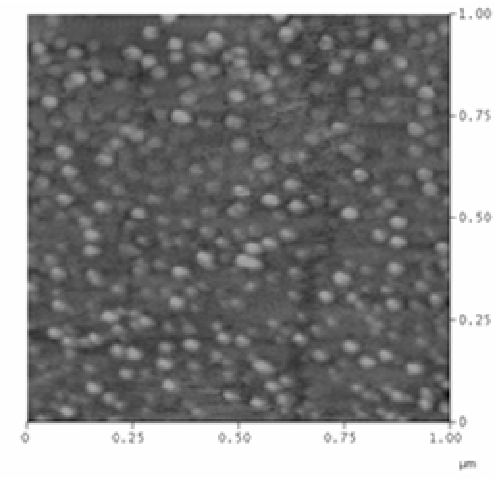
Institut Louis Néel Grenoble

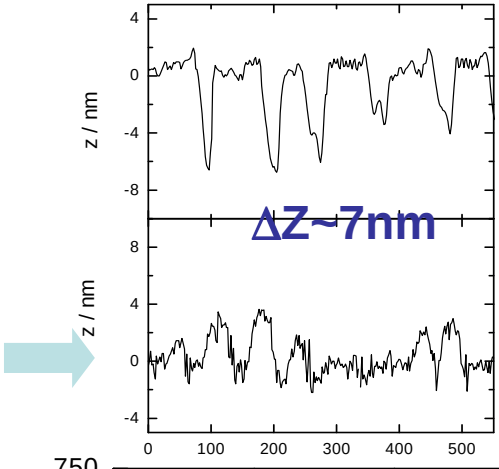
(SWNT reactor now in CBMN Bordeaux I)

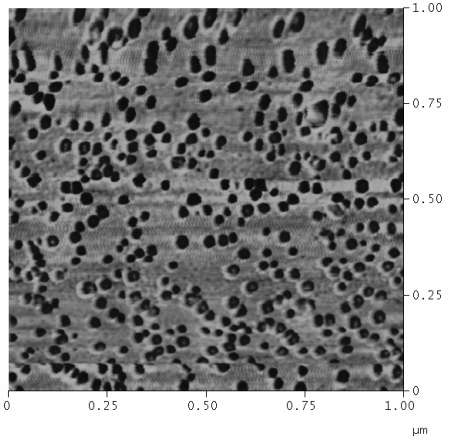


Softer: More rich behaviour, Contact Fluctuations happen

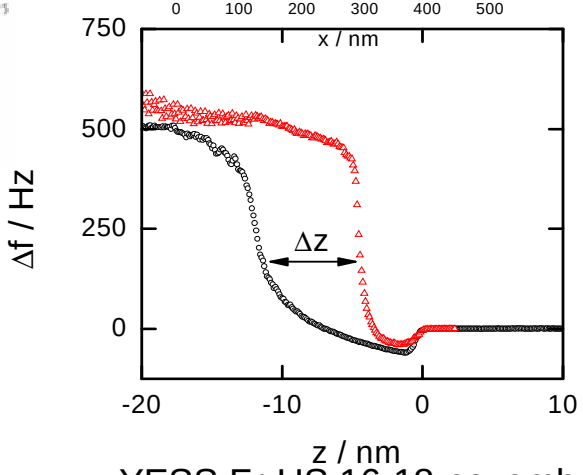




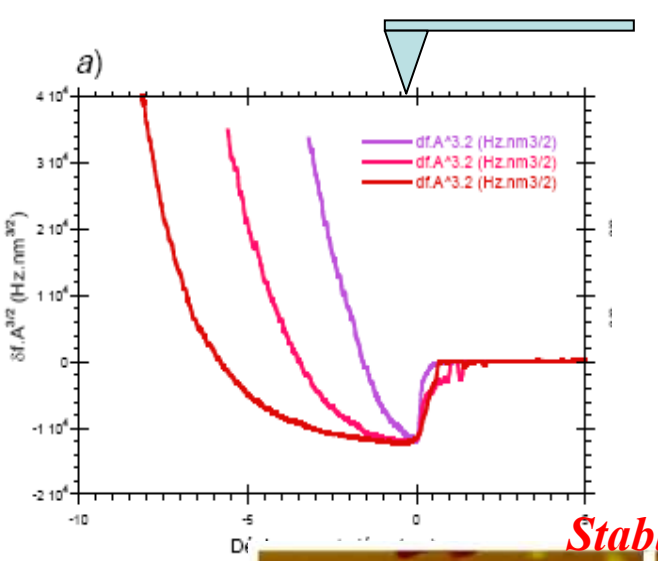




InAs Islands on GaAs

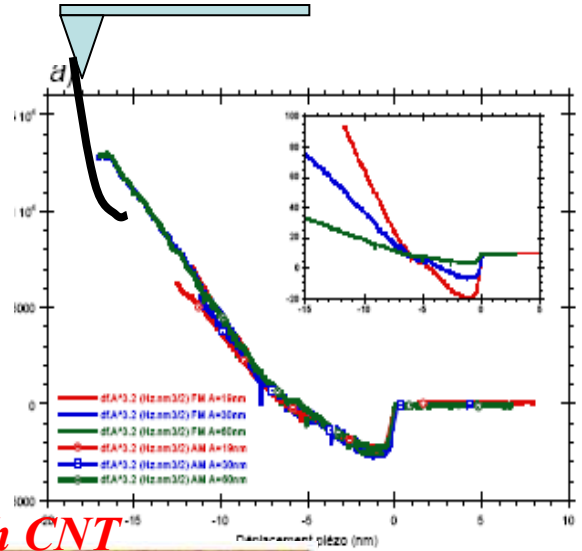


Islands become holes !

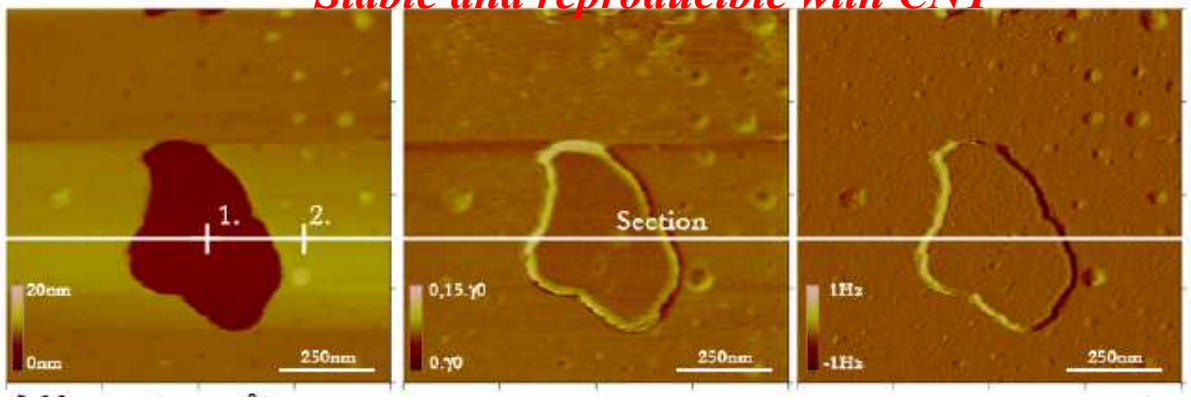


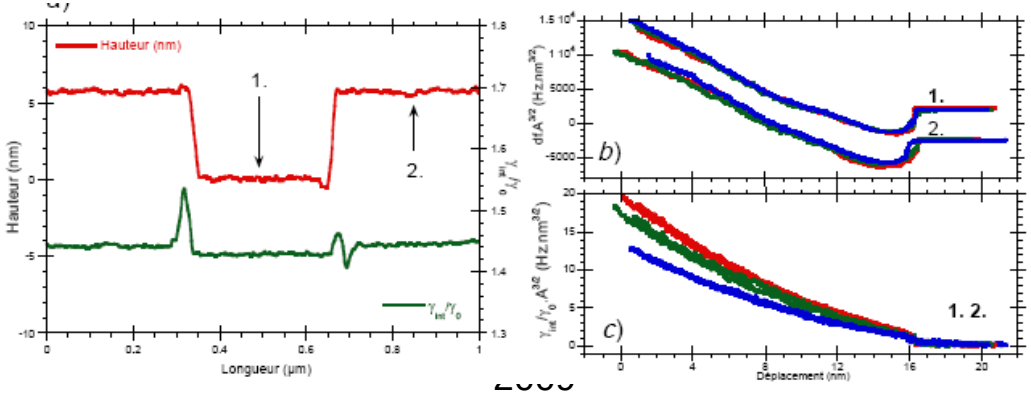
Phospholipids

FM-Force Curves



Stable and reproducible with CNT

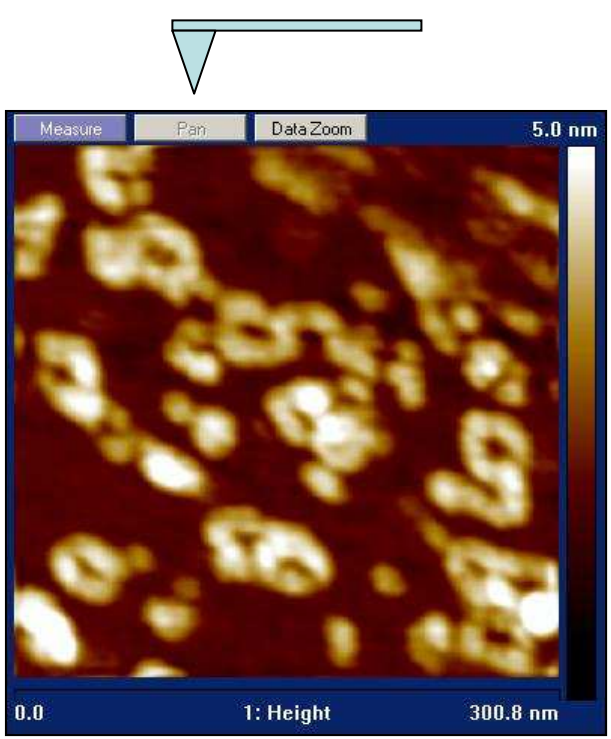


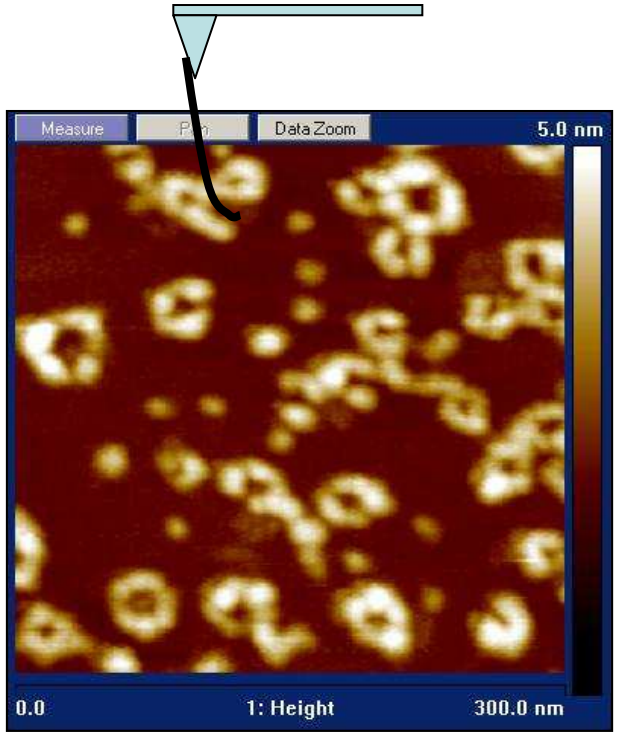


C.Jai thèse 2007

High resolution **AFM** imaging antibody
CEA Marcoule
DSV/iBEB/SBTN/LIRM
Michael Odorico ; Pierre Parot ; Jean-Luc Pellequer

Ultra sharp tip





Much better: resolution, tip stability…

Prospects
CNT a versatile AFM Tip

Electrochemical nanoreactor with position control at the nm scale.

Goal: enzymatic activity

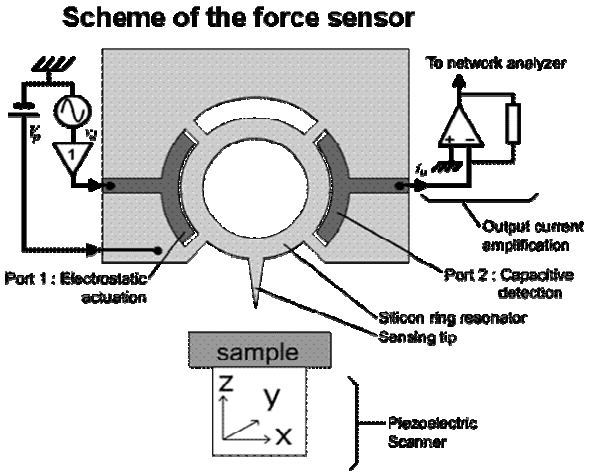
C. Demaille Univ. Paris Diderot (Head of the project)
T. Michon INRA Villenave d'Ornon.

ANR PIRIBIO

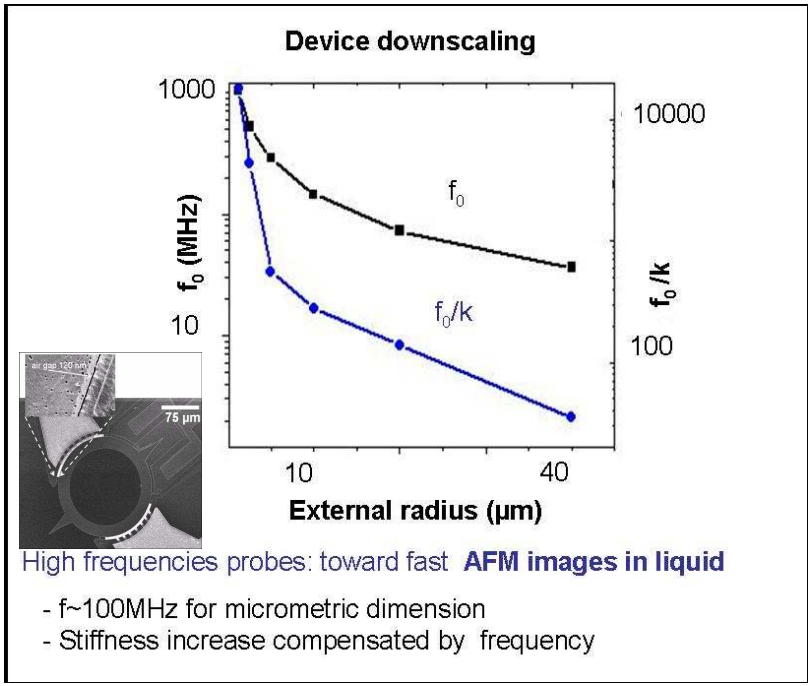
Prospects
CNT a versatile AFM Tip

High speed AFM

B. Legrand, M. Faucher, L. Buchaillot IEMN Lille,
ANR Improve LM

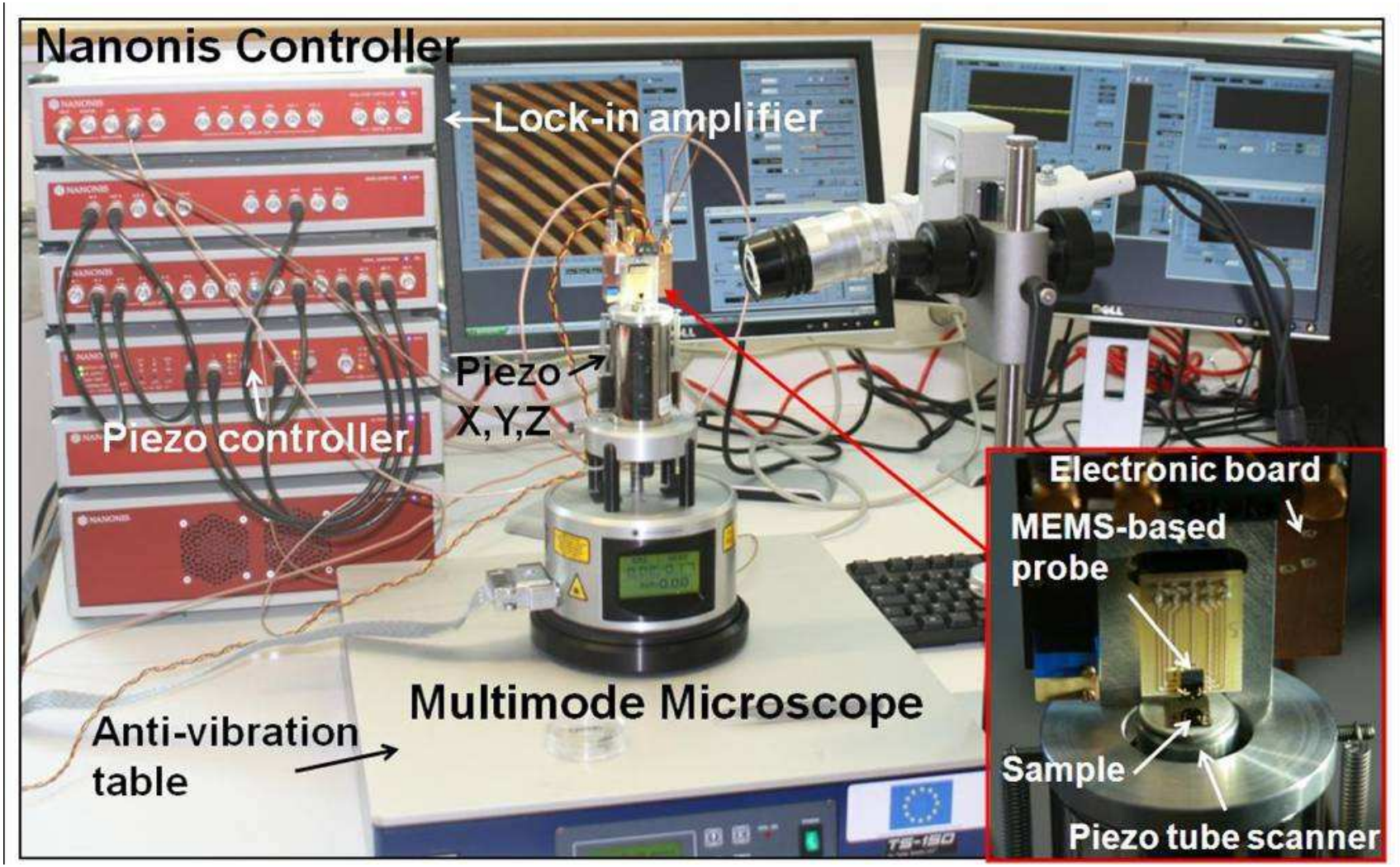


The resonator holds the active oscillating tip. The whole NEMS with its electrical connection is set at the free end of the cantilever.



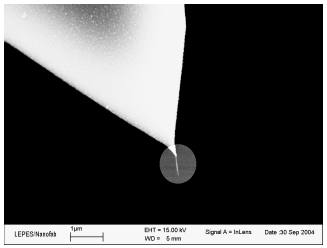
High frequencies probes: toward fast **AFM images in liquid**

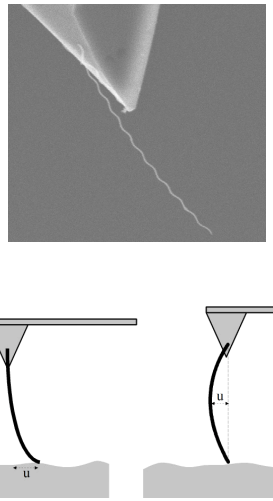
- f~100MHz for micrometric dimension
- Stiffness increase compensated by frequency

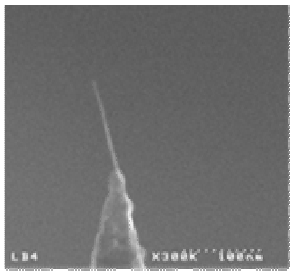

Nanonis Controller
Lock-in amplifier
Piezo
X,Y,Z
Piezo controller
Electronic board
MEMS-based
probe
Multimode Microscope
Anti-vibration
table
Sample
Piezo tube scanner

Nanoprobe CNT-Mechanical Properties

Sophie Marsaudon, Julien Buchoux,
M. Seydou,**R. Boisgard, J.P. Aimé,,** ***Université Bordeaux I.***
Anne-Marie Bonnot, ***Institut Néel, Grenoble. Cattien N'Guyen NASA Ames***
Denis Mariolle, Amal Chabli, ***CEA-LETI, MINATEC, Grenoble***
L. Buchaillot, M. Faucher, B. Legrand (IEMN-Villeneuve D'Ascq-(ACI 2005-ANR 2008)







D. Dietzel, et al ***Physical Review B*** **72, 035445 (2005),** ***Nanotechnology*** **(2005) 16, p.S73-S78,** ***JSPM*** **(2006),** ***C. Bernard et al Nanoscale Res. Let. (2007) 309-318 Nanotechnology19, 35709-35718 (2008) J. Buchoux et al (2009), M. Seydou et al Physical Review B (2009).***
S. Marsaudon et al , "Applied Scanning Probe Methods". (Springer-2009).